REVIEW OF LANDSLIDES IN 2006

GEO REPORT No. 237

S.M. Tam & T.M.F. Lau

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

REVIEW OF LANDSLIDES IN 2006

GEO REPORT No. 237

S.M. Tam & T.M.F. Lau

This report is largely based on GEO Landslide Study Report No. LSR 12/2007 produced in December 2007

First published, November 2008

Prepared by:

Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon,
Hong Kong.

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.

The Geotechnical Engineering Office also produces documents specifically for publication. These include guidance documents and results of comprehensive reviews. These publications and the printed GEO Reports may be obtained from the Government's Information Services Department. Information on how to purchase these documents is given on the second last page of this report.

R.K.S. Chan
Head, Geotechnical Engineering Office
November 2008

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

FOREWORD

This report presents the findings of a detailed diagnosis of the landslides in 2006 that were reported to the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department. It serves to review the performance of the Government's slope safety system and identify areas for improvement in order to further enhance the slope engineering practice in Hong Kong.

The review was carried out by Messrs S.M. Tam and T.M.F. Lau of Landslip Preventive Measures Division 1 under the supervision of Mr K.K.S. Ho. Assistance was provided by the GEO's landslide investigation consultants, Fugro Scott Wilson Joint Venture and Maunsell Geotechnical Services Limited respectively.

R.K.S. Chan
Head of the Geotechnical Engineering Office

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

ABSTRACT

This report presents the findings of a diagnostic review of the landslides in 2006 that were reported to the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department. The review forms part of the GEO's systematic landslide investigation programme, which was introduced following the 23 July 1994 Kwun Lung Lau landslide. The aims of this report are to review the performance of the Government's slope safety system and identify areas for improvement in order to further enhance the slope engineering practice in Hong Kong.

Altogether 193 genuine landslides were reported to the Government in 2006. All the available landslide data were examined and seven landslide incidents were selected for follow-up studies under the systematic landslide investigation programme. These studies provided information and insight into the types and mechanisms of slope failures, and facilitated the identification of areas deserving attention and improvement.

Based on the landslide data in 2006, no major landslide (viz. failure volume of 50 m^3 or more) occurred on engineered man-made slopes that have been accepted under the slope safety system. In terms of minor landslides (viz. failure volume less than 50 m^3) on engineered man-made slopes, the annual failure rate is about 0.05% on a slope number basis.

Overall, about 99.95% of the engineered man-made slopes performed satisfactorily without occurrence of landslides in 2006.

Recommendations for further improvement of the slope safety system and the slope engineering practice in Hong Kong are given in this report.

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

CONTENTS

1. INTRODUCTION

This report presents the findings of a diagnostic review of the landslides that were reported to the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department (CEDD) in 2006. The review forms part of GEO's systematic landslide investigation (LI) programme, which was introduced following the 23 July 1994 Kwun Lung Lau landslide. The LI programme has the following two principal objectives.

(a) to identify, through studies of landslides, slopes that are affected by inherent instability problems so that appropriate follow-up actions can be taken for integrated slope assessment and upgrading works, and

(b) to review the performance of Government's slope safety system and identify areas for improvement in slope engineering practice.

Selected significant landslides were identified for in-depth studies to identify lessons learnt and the necessary follow-up actions. The findings of the studies are presented in a series of Landslide Study Reports. The present diagnostic review considers all the available landslide data in 2006, including the findings of the individual landslide studies, in order to examine the performance of Government's slope safety system and identify areas that deserve attention or improvement. The review has been carried out by the Landslip Preventive Measures Division 1 of the GEO, with assistance provided by GEO's LI consultants, namely Fugro Scott Wilson Joint Venture (FSWJV) and Maunsell Geotechnical Services Limited (MGSL) respectively.

Based on the review, some improvement measures are proposed to further enhance the Government's slope safety system and the slope engineering practice in Hong Kong.

2. RAINFALL AND LANDSLIDES IN 2006

The factual information, together with the relevant statistics on rainfall and reported landslides in 2006, was documented by Kong & Tam (2007).

In 2006, the annual rainfall recorded at the Hong Kong Observatory (HKO)'s Principal Raingauge in Tsim Sha Tsui was 2,628 mm. This was approximately 19% higher than the mean annual rainfall of 2,214 mm between the years of 1961 and 1990. Four Landslip Warnings were issued on 3 May 2006, 2 June 2006, 9 June 2006 and 13 September 2006 respectively.

Out of the total of 198 reported landslide incidents in 2006, 193 were genuine landslides, discounting those non-landslide incidents such as tree falls. There were altogether five major failures (viz. failure volume $\geq 50\ m^3$), corresponding to some 2.6% of the number of genuine landslides.

The distribution of landslides as classified by the type of failure is given in Table 1. The range of facilities affected by the landslides is summarised in Table 2. The consequences of the landslides in relation to the type of failure are summarised in Table 3. The distribution of the different facility groups (as classified in accordance with Wong (1998)) affected by the major landslides is depicted in Table 4.

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

The information of all the reported landslides has been uploaded to GEO's computerised Slope Information System (SIS), which is accessible by the general public through computer terminals in the GEO. All the available data on reported landslides were examined as part of the current review. Some additional information was collated by GEO's LI consultants to assist in the selection of deserving cases for follow-up studies. A total of seven incidents were selected for follow-up studies by the LI consultants in 2006.

The individual landslide studies have provided valuable information and insights into the types and mechanisms of slope failures. The study reports are lodged in the Civil Engineering Library. A summary of the key findings is presented in the Hong Kong Slope Safety Website (http://hkss.cedd.gov.hk/hkss/eng/studies/lic/index.htm). Following completion of the landslide studies, the key lessons learnt are identified and recommendations made on the necessary follow-up actions.

3. SEVERITY OF RAINSTORMS AS REFLECTED BY LANDSLIDE POTENTIAL INDEX

Although the annual rainfall in 2006 as recorded at HKO's Principal Raingauge in Tsim Sha Tsui was some 19% above average, experience has shown that the annual rainfall is not a good measure of the severity of the individual rainstorms in terms of their potential to trigger landslides. A more direct measure of the severity of the individual rainstorms in the context of slope failures is given by the Landslide Potential Index (LPI), as promulgated by GEO (2005).

The LPI for the most severe rainstorm of 13 September 2006 was 5, during which time the maximum rolling 24-hour rainfall (as used in the correlation for calculating the LPI) was 391 mm. In terms of its potential to cause landsides, this particular rainstorm was about half as severe as that which triggered the fatal landslide at Kwun Lung Lau on 23 July 1994 (corresponding to an LPI of 10), in accordance with the definition of LPI.

During the 13 September 2006 rainstorm, a total of 25 landslide incidents were reported to the GEO.

4. OVERALL DIAGNOSTIC REVIEW OF LANDSLIDES

4.1 Scope of the Review

An overall diagnostic review of all the available landslide data in 2006 has provided a more global picture of the performance of the different types of slopes in Hong Kong. They in turn have facilitated the identification of specific areas that deserve attention.

The review has focused on the following aspects:

(a) coverage of the New Catalogue of Slopes,

(b) annual failure rates of different types of registered slopes, and

(c) diagnosis of landslides on slopes with geotechnical engineering input and, where relevant, geotechnical submissions that have been accepted under the slope safety system (hereinafter referred to as engineered slopes).

4.2 Coverage of the New Catalogue of Slopes

4.2.1 General

Sizeable man-made slopes and retaining walls, including those compiled under a GEO's project entitled "Systematic Identification and Registration of Slopes in the Territory" (SIRST) and completed in September 1998, together with features newly formed or identified after 1998, are registered in the New Catalogue of Slopes. The methodology adopted in the identification of potentially registerable features under the SIRST project (which was done primarily based on Aerial Photograph Interpretation (API) and a review of existing topographic plans), along with the criteria for slope registration, is given in GEO Circular No. 15 (GEO, 2004b).

4.2.2 Diagnosis

Of the 193 genuine landslides, 126 occurred on registered slope features (including 122 on registered man-made slopes and four on registered Disturbed Terrain (DT) features) (Table 5). A breakdown of the other 67 incidents is given in Figure 1.

Of the above 67 incidents, one involved a man-made slope which was being modified under a private redevelopment project at the time of the 2006 incident, 20 involved small man-made slope features that do not meet the slope registration criteria and 37 involved natural hillside failures. The remaining 9 incidents involved features that satisfied the slope registration criteria but were not registered in the New Catalogue of Slopes at the time of the landslides (Table 5 and Figure 1).

4.2.3 Discussion

The above diagnosis indicates that the number of registerable slopes that were yet to be included in the New Catalogue of Slopes at the time of failure was about 4.7% of the number of genuine landslides in 2006. Of the above nine landslides, eight of them did not result in significant consequence to the public, whilst the remaining case resulted in temporary closure of a road in the urban area (viz. Deep Water Bay Road). Also, none of the nine incidents involved a major failure, and more than half of them comprised relatively small slopes, i.e. <5 m high.

Eight of the nine slope features have been duly registered in the New Catalogue of Slopes following the landslide incidents. Registration of the other feature is in progress at the time of preparing this report.

4.3 Annual Failure Rates of Registered Slopes

4.3.1 General

Based on the landslide data and a review of the slope status, the average failure rate of registered slopes can be assessed in terms of the different types of slopes that are of different

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

ages, i.e. pre-1977 (viz. old slopes formed or substantially modified before 1977 when the Geotechnical Control Office (renamed GEO in 1991) was established), or post-1977 (viz. formed or substantially modified after 1977).

The status of a slope can be distinguished in terms of whether or not it has been engineered in the past (i.e. with geotechnical engineering input). Engineered slopes include the following:

(a) slopes formed after 1977 that were designed, checked and accepted under the slope safety system as being up to the required geotechnical standards;

(b) slopes formed before 1977 that were subsequently assessed, checked and accepted under the slope safety system as being up to the required geotechnical standards;

(c) slopes formed before 1977 that were subsequently upgraded, checked and accepted under the slope safety system as being up to the required geotechnical standards; and

(d) slopes with Type 3 prescriptive measures (Wong et al, 1999) carried out under a quality assurance system that satisfies the requirements of ETWB TCW No. 13/2005 (whereby checking of the design of Type 3 prescriptive measures by the GEO has been waived).

The types of slope features considered in the present diagnosis include soil cuts, rock cuts, fill slopes and retaining walls.

Landslides are classified as follows:

(a) minor failure (i.e. failure volume $<50\ m^3$), and

(b) major failure (i.e. failure volume $\geq 50\ m^3$ or where a fatality has occurred).

In the present context, the failure volume refers to the sum total of the volume of detached material and the volume of any deformed material that remains on the slope (which may, or may not, have displaced significantly).

The distribution of the scale of the genuine landslides for the different types of slopes is summarised in Table 5.

4.3.2 Diagnosis

Of the 193 genuine landslides reported in 2006, a total of 126 landslides (about 65.3%) affected 124 registered slopes (including four registered Disturbed Terrain features), i.e. two slopes had multiple failures in 2006. Of these 126 landslide incidents, three were major failures.

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

The approximate number of engineered and non-engineered slope features has been estimated on the basis of the classification assigned under the "Systematic Identification of Features in the Territory" (SIFT) project, together with desk study findings, taking into consideration whether the slope features have gone through the slope safety system. The estimates based on reference to SIFT information are subject to uncertainty because the SIFT class of a slope is assessed using API. Further discussion on the scope of the SIFT project is given by Wong & Ho (1999).

Twelve of the 193 genuine landslides (about 6.2%) affected engineered slopes, none of which were major failures.

Based on the 2006 landslide data and a detailed review of the slope status, the annual failure rates of the different types of registered slopes are shown in Table 6. These calculated failure rates are not particularly sensitive to the assumptions made regarding the total number of the different types of slopes, bearing in mind the likely order of uncertainty involved. The calculated failure rates do not reflect the long-term average values because of the limited observation period. Notwithstanding this, annual failure rates derived from a systematic review of all the landslide data over the year can provide useful insights into the performance of the slope safety system.

4.3.3 Discussion

The failure rates of engineered and non-engineered slopes have been calculated using three approaches as explained below.

The first approach involves assessing the failure rates in terms of the number of landslides divided by the total number of slopes of a certain status (viz. a given slope type, such as cut slopes, that is either engineered or not engineered). In this regard, the failure rates of different slope categories and the performance of the slope safety system are related to the slope population as registered in the Slope Catalogue.

The second approach involves assessing the failure rates in terms of the surface area of landslides divided by the total surface area of all slopes of the corresponding status.

The third approach involves assessing the failure rates in terms of the number of landslides divided by the total surface area of slopes of the corresponding status. Relating the failure rate to the surface area of slopes, as opposed to just the number of slopes, would take into consideration the fact that a large slope is more susceptible to 'defects' than a small slope.

Based on the data in 2006, the annual failure rates for all reported landslides on registered man-made slopes correspond to 2.2×10^{-3} (number of landslides/number of registered slopes), 0.05×10^{-3} (total surface area of landslides/total surface area of registered slopes), and 2.3×10^{-6} (number of landslides/total surface area of registered slopes in m^2) respectively, using the three different approaches as described above.

Comparisons of the annual failure rates of engineered slopes with those of non-engineered slopes are given in Section 4.4.2 below. It should be noted that the calculated annual failure rates could be affected by factors such as the rainfall characteristics, prevailing slope maintenance condition, etc.

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

4.4 Diagnosis of Landslides on Engineered Slopes

4.4.1 General

A review of the 2006 landslides indicates that some of the incidents involved failure of engineered slopes. A meaningful diagnosis of landslides on engineered slopes requires detailed information about the nature and probable causes of the failures, together with the status and development history of the slopes of concern. The present assessment is based on the detailed information obtained from follow-up landslide studies and examination.

Of the 12 landslides that affected engineered slopes, one of them was formed in the 1980s or before, five were formed in the 1990s, and six were formed after 2000 (see Table 7). For the present purposes, slopes that were not accepted under the slope safety system (e.g. no geotechnical submissions made to the GEO for checking, or submissions with outstanding GEO comments) are not considered to be engineered slopes.

Engineered slopes with geotechnical submissions accepted under the slope safety system are classified in accordance with the following:

(a) whether the slope was formed after 1977, or whether it was an existing feature previously subjected to upgrading works or demonstrated by stability assessment as being up to the required geotechnical standards,

(b) the mechanism under which stability assessments or slope upgrading works were carried out (e.g. the Landslip Preventive Measures (LPM) Programme, private or Government development projects, works by private owners or default works by Government following the issue of Dangerous Hillside Orders),

(c) whether detailed geotechnical design calculations were undertaken,

(d) whether site-specific ground investigation and laboratory testing were carried out for slope stability assessment and design of slope upgrading works,

(e) whether the slope stability assessment or design of slope upgrading works was checked and accepted by the GEO, and

(f) whether the slope was upgraded to meet current standards using prescriptive measures under an adequate quality system satisfying the requirements of ETWB TCW No. 13/2005 (viz. with the checking by the GEO waived).

4.4.2 Overall Diagnosis

A breakdown of the 12 landslides that occurred on engineered slopes in 2006 with respect to slope type and scale of failure is shown in Table 8. Five of them involved soil cuts,

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

one involved a rock cut, four involved recompacted fill slopes and two involved masonry walls. All of them only involved minor failures (failure volumes ranging from 0.2 m^3 to 20 m^3). The maintenance responsibility for the failed portions of eight of the slopes rests with Government whilst the other four rests with private owners.

The annual failure rates for the 2006 landslide data are summarised in Table 9 for the different categories of engineered slopes.

On a slope number basis, the failure rate of engineered slopes is about seven times less than that of non-engineered slopes, whereas on a unit area basis, the failure rate of engineered slopes is some 41 times less than that of non-engineered slopes. In terms of the number of landslides as divided by the total slope surface area, the corresponding failure rate of engineered slopes is about 18 times less than that of non-engineered slopes.

Of the 12 engineered slopes that failed in 2006, two were previously included in the LPM Programme (see Table 10). The corresponding annual failure rates for LPM slopes are summarised in Table 11.

It may be noted from the above diagnosis that the annual failure rate of LPM slopes for all landslides in 2006 was apparently higher than the corresponding figure for engineered slopes (both on a slope number basis and in terms of the number of landslide per unit slope area). On a unit area basis, however, the failure rate of LPM slope was lower than that of engineered slopes. This observation could be partly due to the fact that the slopes upgraded under the LPM Programme, which focuses on those slopes that pose a threat to public safety, are generally more difficult with complex ground conditions. Caution needs to be exercised, however, because the numbers being compared are relatively small and hence they may not be statistically significant. In view of the above, the diagnosis should be taken as indicative only.

Of the five incidents on engineered cuts, three (0.2 m^3 to 4 m^3) affected soil-nailed cut slopes and two affected an unsupported cut. A detailed review of these, together with other recorded failures of soil-nailed cut slopes, was undertaken by Ng et al (2007). It was established that none of the failures were mobile and all had negligible consequences. The majority of these failures were associated with minor surface erosion or small-scale detachments (<5 m^3) from the near-surface materials in between, or adjacent to, soil nail heads (reinforced concrete pads). There are about 4,000 soil cut slopes treated with soil nails, starting from the late 1980s. To date, no landslides have been reported on soil nailed cut slopes with a hard surface cover and no major failures have occurred. This reflects a very good performance record for cut slopes treated with soil nails in terms of prevention of large-scale slope instability.

The target annual success rates (where success rate = 1 - failure rate) for engineered slopes pledged by the GEO are 99.8% and 99.5% against major failures and minor failures respectively, as defined in terms of slope number. In 2006, the actual annual success rates were 100% and 99.95% respectively. Hence, the pledged targets were satisfactorily achieved.

The trend of the annual success rates of engineered slopes against major and minor failures respectively, for the period of 1997 to 2006, is shown in Table 12.

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

4.5 Key Observations

4.5.1 Severity of Rainstorms that Triggered Landslides

Based on those rain-induced landslides with sufficiently reliable information to assess the timing and severity of the rainstorms preceding the failures, none of them involved rainstorms that were more severe than those experienced in the past. As such, deterioration of the slope condition may have played a role in the incidents, except for one case whereby there was likely to have been some adverse changes in environmental conditions following the slope upgrading works.

On the basis of the above, the proposition that the continued stability of an existing slope may be proven by past severe rainstorms should be treated with extreme caution. Before one could confidently count on past slope performance regarding the margin of safety for long-term stability, one needs to consider factors such as possible slope deterioration, progressive slope deformation during past rainstorms and potential adverse changes in environmental conditions.

4.5.2 Landslides on Natural Hillsides and Disturbed Terrain

In 2006, a total of 41 reported landslides occurred on hillsides, including registered Disturbed Terrain (DT) features (i.e. about 21% of the genuine landslides). One of these involved a major failure (viz. the significant distress observed at Kwun Yam Shan (MGSL, 2007). Three of these landslides occurred within three separate Historical Landslide Catchments (HLC) (definition of HLC is given in the report by Wong & Ko, 2006). Aerial photographs have been taken in 2006 and the Enhanced Natural Terrain Landslide Inventory (ENTLI) is being updated based on the information from the aerial photographs.

The nature of the 41 incidents has been assessed based on the available information (see the classification shown in Figure 2). Thirty-four are classified as natural hillside failures (i.e. the failures affected hillsides that have not been modified by human activities, such as cutting, filling, etc.). The other seven (which included four registered DT features) involved hillsides that have been locally modified or disturbed by human activities but the man-made elements did not play a significant contributory role in the failures.

The major natural hillside failure that was reported in March 2006 involved significant signs of distress over a large area (plan area of about 3,000 m^2), in the form of an extensive system of tension cracks (local maximum down throws of more than 1 m), on the hillside some 50 m upslope of the source area of the August 2005 major landslide (total volume of about 2,350 m^3) that occurred on the same hillside (MGSL, 2007). The distressed hillside was identified by the LI consultant during a subsequent site inspection as part of the follow-up study of the August 2005 landslide. The possibility that the extensive tension cracking was already present on the hillside at the time of the August 2005 landslide cannot be precluded, although it could have suffered further movement subsequent to the above landslide. Natural hillsides with extensive signs of distress can be especially vulnerable to the effect of direct infiltration and possible build-up of cleft water pressure. The slope condition is liable to deteriorate rapidly as the ground progressively opens up more and more, which may mean that failures in the form of slope detachments could occur at moderate rainfall.

The above incident serves as a reminder that a sufficiently detailed inspection of the ground adjoining and above the failed area should be carried out promptly in follow-up

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

inspections by the inspection officer as judged necessary, when safe inspections are permitted by the site and weather conditions. It is of essence to check carefully for any signs of slope movement or distress that could be more extensive than that suggested by the slope detachment and extend beyond the area of slope detachment by quite a significant distance (e.g. the 1997 Lai Ping Road landslide and the 1997 Ching Cheung Road landslide), as highlighted by Wong & Ho (2001).

4.5.3 Landslides with Inadequate Maintenance Diagnosed as a Key Contributory Factor to Failure

All the 126 reported landslide incidents involving registered slope features were reviewed to assess whether inadequate maintenance was likely to have been a key contributory factor in the failures. Reference has been made to the records of emergency inspections by the GEO or other Government departments, inspections of selected landslides by the LI consultants, together with the findings of the follow-up landslide studies.

Inadequate slope maintenance was assessed to be a major contributory factor in 28 (all minor landslides) out of 126 reported incidents (i.e. 22%). Amongst them, three incidents occurred on engineered slopes, including one rock cut (viz. unplanned vegetation on a private feature), one fill slope and one unsupported soil cut (both involving blocked surface drainage channels on private features).

Of the 28 incidents, 12 affected Government slopes and 16 affected private slopes based on the information in the Slope Maintenance Responsibility Information System (SMRIS) managed by the Lands Department (Lands D). It is noted that one of the 16 private features was actually under a Short Term Tenancy (STT) up until January 2006 when the STT was terminated by the Lands D at the request of the tenant and hence technically the feature was not under private maintenance responsibility at the time of the landslide which occurred in July 2006 notwithstanding the information given in SMRIS. The request was made by the tenant in October 2005 following the receipt of a Warning Letter in January 2005 issued by Lands D. The Warning Letter was recommended by the GEO based on the findings of a Stage 2 Study under the LPM Programme, which established prima facie evidence that the slope was liable to become dangerous. The subject slope was subsequently re-assigned to Lands D for maintenance in January 2007. The slope was not subject to regular maintenance when it was under the STT and during the period when the maintenance responsibility was yet to be re-assigned (i.e. between January 2006 and January 2007).

4.5.4 Landslides on Man-made Slopes with a History of Past Failures

A preliminary review by the Standards and Testing (S&T) Division of the GEO in July 2007 indicated that, based on the records of reported landslides and the SIRST field sheets, about 12% (i.e. around 900 nos.) of the 'old technology' slopes[1] and about 17% (i.e. around 1,100 nos.) of the old man-made slopes (i.e. formed before 1977) of moderate risk have a history of past (reported or inferred) instabilities. The above review did not consider whether

[1] 'Old technology' slopes were formed or treated from 1977 to the late 1980s based on the knowledge and technology at the time. These typically comprise slopes trimmed back to a less steep gradient without the provision of reinforcement or structural support. These slopes are more prone to degradation and less robust than those treated with modern technology (e.g. reinforced with soil nails).

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

the past failures occurred before or after completion of slope upgrading/improvement works, if any.

The present review has examined the failure history of those registered man-made slopes with landslides reported in 2006, based on reference to the GEO's landslide database. The breakdown is shown in Figure 3.

Amongst the 122 genuine landslides that occurred on registered man-made slopes in 2006, 29 (i.e. about 24%) took place on slopes with a history of reported landslides (see Figure 3). Of these 29 slopes, 12 are of Consequence-to-life (C-T-L) Category 1.

As shown in Figure 3, of the 93 landslides that occurred on slopes with no past reported landslides, 30 of the corresponding slopes had inferred past instability according to site observations made during the slope registration exercise (i.e. the SIRST project which was undertaken by the GEO from 1994 to 1998). Information on the inferred past instabilities is scant and the degree of confidence of the assessment is uncertain.

Records on the history of landslides provide important information on slope performance. These, together with the observations of signs of distress during slope inspections (e.g. under the slope maintenance programmes of the designated government departments), constitute key sources of information for consideration of the necessary follow-up actions. The GEO is currently updating the priority ranking system for man-made slopes for the post-2010 Landslip Prevention and Mitigation Programme (LPMitP) and will take due cognizance of slope performance, together with other key parameters such as potential consequences in the event of failure, in the revised priority ranking system. The latter will also consider the landslide history, if any, after slope upgrading works or formation of new slopes after 1977 (i.e. after the establishment of the GEO).

4.5.5 Landslides on Slopes Not Fully Processed by the Slope Safety System

The review has examined landslides on man-made slopes that had not been fully processed by the slope safety system (i.e. part of the slope was not engineered). Two minor landslides occurred on the unengineered portions of otherwise engineered slopes. One of the incidents involved a slope that was partly modified under a Government project in 1986. The remaining portion of the slope, where the minor landslide occurred in 2006, was not engineered.

The other incident involved a slope of mixed maintenance responsibility. The Government portion of the feature was upgraded under the LPM Programme in 2001 whereas the private portion was subjected to two Advisory Letters issued by the Buildings Department following the minor landslides that occurred within the private portion in 2005 and 2006 respectively. The portion of the slope under private ownership was subsequently injected into the LPM Programme for safety-screening study.

4.5.6 Use of LPI to Reflect Severity of Rainstorms in terms of Potential for Triggering Landslides

The LPI for the most severe rainstorm of 13 September 2006 was 5, during which time

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

25 landslides were reported to the GEO (see Section 3). In terms of its potential to cause landsides, this particular rainstorm was about half as severe as that which triggered the fatal landslide at Kwun Lung Lau on 23 July 1994 (corresponding to an LPI of 10), considering the rolling 24-hour rainfall intensity as assumed in the calculation of LPI. The 25 reported landslides comprised 2 major failures, 6 minor failures and 17 very minor failures (Kong & Tam, 2007).

Based on the assumptions made in the LPI, which considers the maximum 24-hour rolling rainfall, an LPI of 5 would correspond to about 150 landslides. The same rainfall-landslide correlation model as that used for calculating LPI has been adopted for the operation of the Landslip Warning System (Yu et al, 2003).

In contrast, for the most severe rainstorm of 16-21 August 2005 which had an LPI of 10, the corresponding number of landslides based on the current rainfall-landslide model would be 293, which is of a similar order to the actual number of reported landslides (viz. 229). It is noted that both the 23 July 1994 and the 16-21 August 2005 rainstorms had high antecedent rainfalls whereas the 13 September 2006 rainstorm had relatively low antecedent rainfall.

Figure 4 plots the number of reported landslides and the LPI values for the past rainstorms. The scatter is fairly considerable, which reflects the uncertainties involved. It can be seen that for certain rainstorms with a high LPI (e.g. the 8-9 June 1998 with an LPI of 9), the number of reported landslides was only 96. On the other hand, certain rainstorms with a low LPI (e.g. the 15-16 June 1993 rainstorm with an LPI of 1) had resulted in 123 landslides.

The LPI algorithm only considers the 24-hour rolling maximum rainfall and not the rainfall intensities for other durations. It also does not consider antecedent rainfall. This is a simplification. Rainfall and landslide occurrence in Hong Kong are highly variable and landslides can occur under small rainfall albeit with a low probability. Given the simplifying assumptions made and the uncertainties involved, caution should be exercised to ensure that the use of LPI to reflect the severity of rainstorms and any observations that might be made in comparing relative slope performance under different rainstorms should be done in the right context. Further study on the effect of antecedent rainfall on landslide occurrence on man-made slopes is being carried out by the S&T Division with a view to improving the rainfall-landslide correlation.

Apart from the calculation of LPI, the rainfall-landslide correlation model has also been applied to the operation of the Landslip Warning System. The S&T Division of the GEO has completed an interim review of the rainfall-landslide correlation model in May 2007. It is expected that the correlation model will be improved further in due course by the GEO given additional data.

5. PROPOSED IMPROVEMENT INITIATIVES

Improvement initiatives were proposed by Tam et al (2006) following the diagnostic review of the landslides that occurred in 2005. The progress of the follow-up actions is summarised in Table 13.

Based on the present review, the following improvement initiatives are proposed:

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

(a) Review the unengineered portions of slopes that had not been fully processed by the slope safety system, together with the corresponding landslide history, to identify the necessary follow-up actions (see Section 4.5.5); and

(b) review the feasibility of an alert system for prompt review of priority slopes (e.g. private slopes subjected to undischarged DH Orders/Warning Letters) in the event of changes in slope ownership or maintenance responsibility (see Section 4.5.3).

6. CONCLUSIONS

Based on the overall diagnostic landslide review presented in this report, the following observations are made with respect to the performance of the Government's slope safety system:

(a) The annual failure rates of major and minor landslides on engineered slopes, on a slope number basis, were 0% and 0.05% respectively in 2006. The pledged annual success rates of 99.8% and 99.5% of engineered slopes in preventing major and minor landslides, respectively, were met.

(b) Overall, about 99.95% of the engineered slopes performed satisfactorily without the occurrence of any landslides in 2006.

The landslide risk from man-made slopes is still significant and the ongoing LPM effort should be sustained in the interest of public safety. Also, the need to attend to natural terrain landslide hazards is illustrated.

A number of initiatives have been proposed, as detailed in Section 5 of the report, with a view to further improving the slope engineering practice and enhancing the slope safety system in Hong Kong.

7. REFERENCES

Geotechnical Engineering Office (2004a). Non Development Clearance (Slope Safety) of Squatters (GEO Circular No. 3). Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong SAR Government, 16 p.

Geotechnical Engineering Office (2004b). Registration and Upgrading of Records of Features (GEO Circular No. 15). Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong SAR Government, 20 p.

Geotechnical Engineering Office (2005). Landslide Potential Index (GEO Information Note 3/2005). Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong SAR Government, 4 p.

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

Kong, H.S.W. & Tam, S.M. (2007). Factual Report on Hong Kong Rainfall and Landslides in 2006 (Special Project Report No. SPR 4/2007). Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong SAR Government, 90 p.

Maunsell Geotechnical Services Limited (2007). Detailed Study of the 22 August 2005 Landslide and Distress on the Natural Hillside at Kwun Yam Shan, below Tate's Ridge (Landslide Study Report No. LSR 5/2007). Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong SAR Government, 135 p. + 2 drawings.

Ng, A.F.H., Lau, M.F., Shum, K.W., Cheung, W.M. (2007). Review of Selected Landslides Involving Soil-nailed Slopes (Landslide Study Report No. LSR 8/2007). Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong SAR Government, 96 p.

Tam, S.M., Lau, T.M.F., Ng, A.F.H. & Kong, H.S.W. (2006). Review of Landslides in 2005 (Landslide Study Report No. LSR 15/2006). Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong SAR Government, 51 p.

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

Wong, H.N. & Ho, K.K.S. (1999). Review of 1997 and 1998 Landslides (GEO Report No. 107). Geotechnical Engineering Office, Civil Engineering Department, Hong Kong SAR Government, 53 p.

Wong, H.N. & Ho, Ken (2001). Characterisation of Slope Movements in Hong Kong. Proceedings of the 20th Annual Seminar of the HKIE Geotechnical Division: Geotechnical Deformations and Movements, Hong Kong, pp. 133-143.

Wong, H.N. & Ko, F.W.Y. (2006). Landslide Risk Assessment - Application and Practice (GEO Report No. 195). Geotechnical Engineering Office, Civil Engineering Department, Hong Kong SAR Government, 280 p.

Wong, H.N., Pang, L.S., Wong, A.C.W., Pun, W.K. & Yu, Y.F. (1999). Application of Prescriptive Measures to Slopes and Retaining Wall (2nd Edition) (GEO Report No. 56). Geotechnical Engineering Office, Civil Engineering Department, Hong Kong SAR Government, 73 p.

Yu, Y.F., Lam, J.S. & Siu, C.K. (2003). Interim Report on Review of Landslip Warning Criteria (Special Project Report No. SPR 4/2003). Geotechnical Engineering Office, Civil Engineering Department, Hong Kong SAR Government, 19 p.

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 - Distribution of Landslides as Classified by Type of Slope Failure

Type of Failure		No. of Landslide	Percentage (%)
Fill Slope		16 (2)	8.3
Cut Slope	Soil	68 (0)	35.2
	Soil/Rock	45 (2)	23.3
	Rock	11 (0)	5.7
Retaining Wall		12 (0)	6.2
Natural Hillside		37 (1)	19.2
Registered Disturbed Terrain		4 (0)	2.1
Total		193 (5)	100

Legend:
16 (2) Sixteen landslides of which two were major failure.

Notes: (1) Where a landslide involved more than one type of failure, the predominant type of failure has been assumed in the above classification.

(2) Reported incidents that were not genuine landslides have been excluded.

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

Table 2 - Number of Landslides Affecting Different Facilities

Affected Facility	Hong Kong Island	Kowloon	New Territories and Outlying Islands	All
Squatter Dwellings	1 (0)	0 (0)	11 (0)	12 (0)
Buildings	0 (0)	0 (0)	12 (1)	12 (1)
Roads	16 (0)	4 (0)	13 (3)	33 (3)
Transportation Facilities (railways, tramways, LRT, etc.)	0 (0)	0 (0)	0 (0)	0 (0)
Pedestrian Pavements/Footways	9 (0)	1 (0)	2 (0)	12 (0)
Minor Footpaths/Access	5 (0)	2 (0)	33 (0)	40 (0)
Construction Sites	1 (1)	0 (0)	0 (0)	1 (1)
Open Areas	13 (0)	2 (0)	29 (0)	44 (0)
Catchwaters	1 (0)	0 (0)	7* (0)	8 (0)
Others (e.g. carparks, parks, playgrounds, gardens, backyards, etc.)	10 (0)	3 (0)	19 (1)	32 (1)

Legend:
13 (3) Thirteen landslides, three of which were major failures.
* One of the incidents affected the area below a catchwater overflow weir.

Notes: (1) One of the incidents, which was a major landslide, affected two key types of facility.
(2) Reported incidents that were not genuine landslides have been excluded.

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

Table 3 - Landslide Consequence as Related to Type of Slope Failure

Type of Failure		No. of Squatter Dwellings Evacuated		No. of Blocks, Houses or Flats Evacuated or Partially Closed	No. of Closure			Deaths	Injuries
		Permanent	Temporary		Roads	Pedestrian Pavements	Footpaths, Back Lanes, Private Access		
Fill Slope		0	0	0	2	1	0	0	0
Cut Slope	Soil	0	6 (10)	1	3	0	1	0	0
	Soil/Rock	0	0	0	11	0	0	0	0
	Rock	0	0	0	0	0	0	0	0
Retaining Wall		0	1 (2)	0	1	1	1	0	0
Natural Hillside		1 (2)	0	0	1	3	3	0	0
Registered Disturbed Terrain		0	0	0	0	1	1	0	0

Legend:

6 (10) Number of squatter dwellings evacuated with the number of tolerated squatter structures evacuated shown in bracket.

Notes:

(1) A squatter dwelling is defined as a place of residence that contains one or more 'tolerated squatter structures', i.e. structures built for domestic purpose or non-domestic purpose and registered in the 1982 Housing Department's Squatter Structure Survey (GEO, 2004a).

(2) A failure may give rise to more than one key type of consequence.

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

Table 4 - Distribution of Facility Groups Affected by Major Landslides

	Types of Facilities Affected or Potentially Affected by Major Landslides (Group No.)						
	1a	1b	2a	2b	3	4	5
All Major Landslides	1	0	0	1	2	2	0
Major Landslides on Man-made Slopes	0	0	0	1	2	1	0
Major Landslides on Natural Hillsides	1	0	0	0	0	1	0

Notes: (1) Facility groups are classified in accordance with that adopted for the New Priority Classification Systems (Wong, 1998).

(2) A given landslide may affect more than one type of facility.

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

Table 5 - Breakdown of Scale of Failures for Different Types of Slopes

	Number of Minor Failures (<50 m³)	Number of Major Failures		
		(50 m³ to 500 m³)	(>500 m³)	
Registered Man-made Slopes	119	3	0	Σ = 122
Registered Disturbed Terrain Features	4	0	0	Σ = 4
Unregisterable Man-made Slopes	20	1	0	Σ = 21
Registerable Man-made Slopes Not Yet Registered at Time of Failure	9	0	0	Σ = 9
Natural Hillsides	36	0	1	Σ = 37
	Σ = 188	Σ = 4	Σ = 1	Σ = 193

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

Table 6 - Annual Failure Rates of Registered Man-made Slope Features Based on Landslides Reported in 2006

		Non-Engineered Slopes			Engineered Slopes		
		Fill/Retaining Wall	Soil/Rock Cut	Overall(1)	Fill/Retaining Wall	Soil/Rock Cut	Overall
Slopes Involved in Landslides in 2006	Number of Slopes	17	93	110	6	6	12
	Surface Area of Landslides (m^2)	443	2131	2574	92	30	122
Slopes Involved in Major Landslides in 2006	Number of Slopes	1	2	3	0	0	0
	Surface Area of Landslides (m^2)	212	190	402	0	0	0
Slopes Involved in Minor Landslides in 2006	Number of Slopes	16	91	107	6	6	12
	Surface Area of Landslides (m^2)	231	1941	2172	92	30	122
Total Number of Registered Slopes		11,480	21,220	32,700	10,220	12,080	22,300
Total Surface Area of Registered Slopes (m^2)		6,446,000	11,629,000	18,075,000	11,863,000	23,669,000	35,532,000
Annual Failure Rates (All Landslides Considered)	On a Slope Number Basis	0.15 %	0.44 %	0.34 %	0.06 %	0.05 %	0.05 %
	On a Unit Slope Surface Area Basis	0.007 %	0.018 %	0.014 %	0.78×10^{-3} %	0.13×10^{-3} %	0.34×10^{-3} %
	Number of Landslides Divided by Slope Surface Area (no./m^2)	2.64×10^{-6}	8.00×10^{-6}	6.09×10^{-6}	5.05×10^{-7}	2.53×10^{-7}	3.37×10^{-7}
Annual Failure Rates (Major Landslides Only)	On a Slope Number Basis	0.009 %	0.009 %	0.009 %	0 %	0 %	0 %
	On a Unit Slope Surface Area Basis	0.003 %	0.002 %	0.002 %	0 %	0 %	0 %
	Number of Landslides Divided by Slope Surface Area (no./m^2)	1.55×10^{-7}	1.71×10^{-7}	1.65×10^{-7}	0	0	0

Note: (1) Registered Disturbed Terrain features are excluded from this calculation.

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

Table 7 - Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 1 of 6)

1. Slopes Upgraded Under the LPM Programme

Slope No.	Incident No.	Location	Volume (m^3)	Type of Slope	Remarks
3SE-D/C61	ArchSD/NT/ 2006/04/0001	Tai Mei Tuk Management Centre, Tai Po	4	Soil cut (with soil nails)	LPM works completed in 2003.
11SW-B/CR384	2006/09/0731	6 Leighton Lane, Causeway Bay	3	Soil/Rock cut	The slope was previously known as feature No. 11SW-B/CR265, which was upgraded under the LPM Programme in 1990.

2. Slopes Assessed under the LPM Programme with No Upgrading Works Required

Nil.

3. Slopes Assessed by Studies in the late 1970's to mid-1980's with No Upgrading Works/Further Study Required

Nil.

4. Slopes Assessed by Government Departments and Checked by GEO with No Upgrading Works Required

Nil.

Table 7 - Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 2 of 6)

5. Slopes Assessed by Private Owners and Checked by GEO with No Upgrading Works Required

Slope No.	Incident No.	Location	Volume (m³)	Type of Slope	Remarks
11SW-D/R206	2006/04/0592	North-east of Sheffield Garden, 5 Shiu Fai Terrace	1	Retaining wall	The stability analyses of the wall, prepared under the redevelopment of Nos. 3-4 Shiu Fai Terrace in 1979/80, were checked and accepted by the GCB.

6. Slopes Formed or Upgraded by Government Departments and Checked by GEO

Slope No.	Incident No.	Location	Volume (m³)	Type of Slope	Remarks
11NW-B/FR60	ArchSD/PM2/ 2006/06/0001	Slope behind Phoenix House, Lung Cheung Road	4	Fill	Slope upgrading works were designed by Ho Tin & Associates Consulting Engineers Limited under Arch SD's Minor Works Term Consultancy No. CAA L015. Geotechnical design of the subject slope was checked and accepted by the GEO in the 2004.
11SW-C/F419	2006/05/0601	Victoria Road, Pok Fu Lam	3	Fill	The geotechnical design of the slope, as part of the Victoria Road Improvement Stage II Project, was checked and accepted by the GEO in 2001.

Table 7 - Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 3 of 6)

6. Slopes Formed or Upgraded by Government Departments and Checked by GEO (Cont'd)

Slope No.	Incident No.	Location	Volume (m^3)	Type of Slope	Remarks
6SE-D/FR105	WSD2006/6/7/ NTW	Tai Lam Chung Catchwater Section M near Ting Kau	10	Fill	Slope upgrading works were designed by High-Point Rendel (HK) Limited under Agreement No. CE 18/97. Geotechnical design of the subject slope was checked and accepted by the GEO in the 2001.
7NW-D/C397	2006/06/0615	Tai Po Country Trail, Lo Lau Uk	5	Soil cut	The geotechnical design of the slope was checked and accepted by the GEO in 1995.

7. Slopes Formed or Upgraded by Private Owners and Checked by GEO

Slope No.	Incident No.	Location	Volume (m^3)	Type of Slope	Remarks
11SW-C/C681	2006/07/0660	48 Mount Kellett Road, The Peak	0.2	Soil/Rock cut (with soil nails)	The geotechnical design of the slope, as part of the redevelopment of the building lot, was accepted by the GEO in 1994.
11SW-C/FR319	2006/08/0694	Ebenezer School and Home for the Visually Impaired, 131 Pok Fu Lam Road, Pok Fu Lam	4	Retaining wall and fill	The geotechnical design of the slope, as part of the redevelopment of Ebenezer School, was accepted by the GEO in 1993.

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

Table 7 - Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 4 of 6)

7. Slopes Formed or Upgraded by Private Owners and Checked by GEO (Cont'd)

Slope No.	Incident No.	Location	Volume (m^3)	Type of Slope	Remarks
11SW-C/FR61	2006/04/0589	Information Crescent, Cyberport, Pok Fu Lam	20	Fill	• The geotechnical design of the slope, as part of the development of the Cyberport, was checked and accepted by the GEO under a private development project in 2000. • The maintenance responsibility of slope was subsequently taken up by HyD and the owner(s) of Lot No. IL8834 RP. • The landslide occurred on the Government portion of the slope.
11SW-C/C87	2006/08/0695	Ebenezer School and Home for the Visually Impaired, 131 Pok Fu Lam Road, Pok Fu Lam	0.5 (rockfall)	Rock cut	The north-western portion of the slope, where the 2006 rockfall incident occurred, was upgraded in association with the redevelopment of the Ebenezer School in 1995. The remaining portion of the slope was upgraded under the LPM Programme in 1999.
11SW-C/C383	2006/09/0709	Victoria Road below Caritas Wo Cheng Chung Secondary School	0.5 (washout at soil cut portion)	Soil/Rock cut (with soil nails)	The geotechnical design of the slope, as part of the redevelopment of Wo Cheng Chung Secondary School, was accepted by the GEO in 2003.

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

Table 7 - Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 5 of 6)

8. Slopes Upgraded Following Service of DH Orders and Checked by GEO

Nil.

9. Slopes Assessed as Not Requiring Upgrading Works but with Outstanding GEO Comments

Nil.

Table of Contents
Table of Contents
Table of Contents

Table 7 - Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 6 of 6)

10. Slopes Assessed as Requiring Upgrading Works but with Outstanding GEO Comments

Slope No.	Incident No.	Location	Volume (m³)	Type of Slope	Remarks
11SE-D/C417	2006/11/0746	West of Wo Hing House, Hing Wah Estate, Chai Wan	2 (washout)	Soil/Rock cut	According to the incident report prepared by the Island Division of the GEO, the incident was caused by overflow from the Sai Wan Service Reservoir, and that the washout occurred at slope No. 11SE-D/C417 although there was no observable scar. While the exact location of the source of the washout debris could not be ascertained, there is the possibility that part of the washout debris might have been come from slope No. 11SE-D/C47, which is located further upslope of slope No. 11SE-D/C417. The submission of a preliminary report for the proposed rock slope treatment works as part of the slope upgrading works carried out under HKHA's LPM Programme LPM 2/86 in 1987/88 has not yet been received from the HKHA.

Notes: (1) Slopes under Categories 1 to 8 are classified as engineered slopes.

(2) Slopes under Categories 9 and 10 are post-1978 features but are not taken as engineered slopes for the purpose of this report.

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

Table 8 - Breakdown of Landslides on Engineered Slopes

	Soil Cut	Rock Cut	Fill Slope	Retaining Wall	
All Landslides	5	1	4	2	$\sum$ = 12 (100%)
>500 m³	0	0	0	0	$\sum$ = 0 (0%)
50 m³ to 500 m³	0	0	0	0	$\sum$ = 0 (0%)
<50 m³	5	1	4	2	$\sum$ = 12 (100%)

Table 9 - Breakdown of Annual Failure Rates on Engineered and Non-Engineered Slopes

	Failure Rate on a Slope Number Basis (Number of Landslides Divided by Total Number of Slopes)	Failure Rate on a Unit Area Basis (Surface Area of Landslides Divided by Total Slope Surface Area)	Failure Rate in Terms of Number of Landslides Divided by Total Slope Surface Area (no./m^2)
Registered Slopes with No Geotechnical Input (All Landslides Considered)	0.34%	0.014%	6.09×10^{-6}
Engineered Slopes Processed by the Slope Safety System (All Landslides Considered)	0.05%	0.34×10^{-3}%	3.37×10^{-7}
Registered Slopes with No Geotechnical Input (Major Landslides Only)	0.009%	0.002%	1.65×10^{-7}
Engineered Slopes Processed by the Slope Safety System (Major Landslides Only)	0%	0%	0
Registered Slopes with No Geotechnical Input (Minor Landslides Only)	0.33%	0.012%	5.92×10^{-6}
Engineered Slopes Processed by the Slope Safety System (Minor Landslides Only)	0.05%	0.34×10^{-3}%	3.37×10^{-7}

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

Table 10 - Breakdown of Landslides on Slopes Previously Treated under the LPM Programme

	Soil Cut	Rock Cut	Fill Slope	Retaining Wall	
All Landslides	2	0	0	0	$\sum = 2$
>500 m^3	0	0	0	0	$\sum = 0$
50 m^3 to 500 m^3	0	0	0	0	$\sum = 0$
<50 m^3	2	0	0	0	$\sum = 2$

Table 11 - Breakdown of Annual Failure Rates on Slopes Previously Treated under the LPM Programme

	Failure Rate on a Slope Number Basis (Number of Landslides Divided by Total Number of Slopes)	Failure Rate on a Unit Area Basis (Surface Area of Landslides Divided by Total Slope Surface Area)	Failure Rate in Terms of Number of Landslides Divided by Total Slope Surface Area (no./m^2)
Slopes Treated under LPM Programme (All Landslides Considered)	0.06%	0.1×10^{-3}%	3.81×10^{-7}
Slopes Treated under LPM Programme (Major Landslides Only)	0%	0%	0
Slopes Treated under LPM Programme (Minor Landslides Only)	0.06%	0.1×10^{-3}%	3.81×10^{-7}

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

Table 12 - Annual Success Rate of Engineered Slopes from 1997 to 2006

	Annual Success Rate on a Slope Number Basis, % (Number of Landslides Divided by Total Number of Slopes)									
	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Engineered Slopes Processed by the Slope Safety System (≥50 m^3)	99.97	99.98	99.97	99.98	99.98	100	99.99	100	99.98	100
Engineered Slopes Processed by the Slope Safety System (<50 m^3)	99.89	99.92	99.92	99.91	99.93	99.95	99.95	99.97	99.89	99.95

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

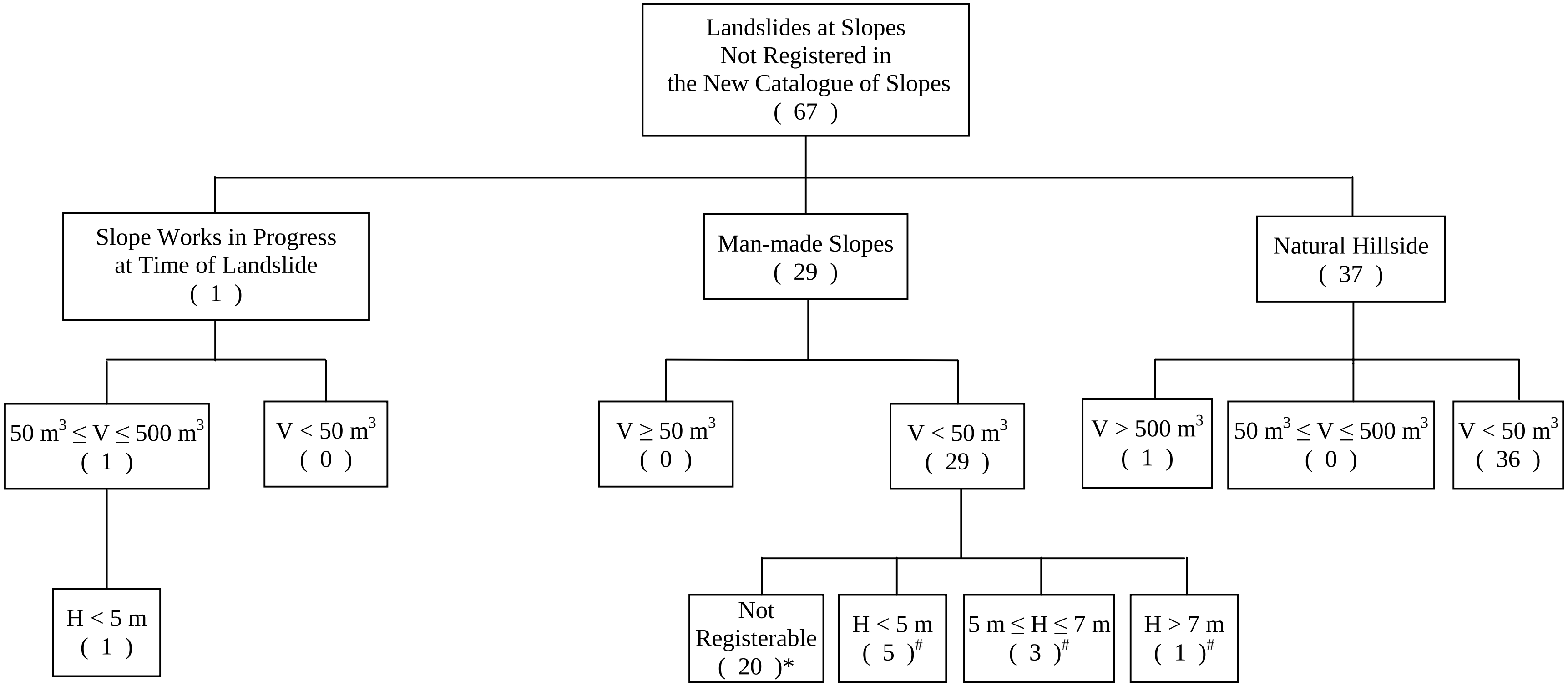
Table 13 - Progress of Follow-up Actions on the Improvement Measures Recommended in the Review of 2005 Landslides

Recommended Improvement Measures	Progress
1. Continue to study notable natural terrain landslides to improve the understanding of hillside failures and the assessment of hillside susceptibility.	One significant natural terrain landslide has been selected for detailed study by the landslide investigation consultants (MGSL, 2007).
2. Review the strategy for managing the risk of landslides affecting catchwaters.	The report on the preliminary strategic review completed by GEO/WSD/DSD was submitted to the then ETWB in 2006. WSD commenced a consultancy agreement on 1 February 2007 to develop a strategy and methodology for managing the hazards of catchwaters and carry out a pilot study for the improvement of 4 major catchwaters (viz. Shing Mun, Beacon Hill, Golden Hill and Tai Lam Chung Catchwaters).
3. Expand the review of landslides involving soil nailed slopes and propose suitable improvement measures.	Review completed by LPM1 and S&T Divisions. Findings are documented in LSR No. 8/2007 (Ng et al, 2007).
4. Review slopes with reported major failures after completion of works to establish the need for follow-up actions.	Review of 255 cases completed. A total of 23 slopes have been recommended for injection into the LPM Programme.

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

LIST OF FIGURES

Table of Contents
Table of Contents
Table of Contents

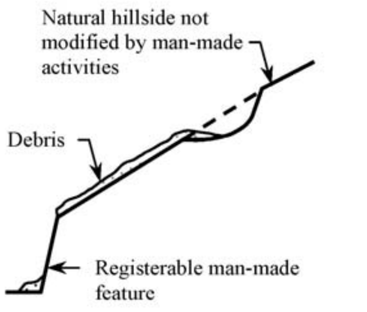
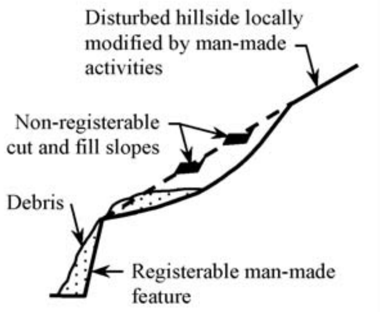
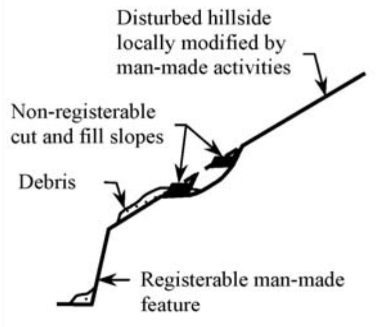
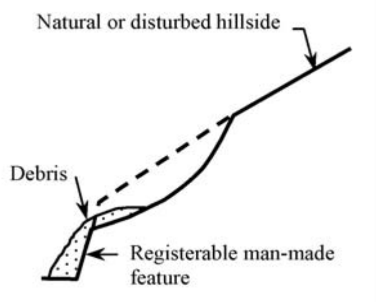


Legend : V - Failure volume
H - Slope height in metre
(67) Number of cases = 67

Notes : (*) 'Not Registerable' refers to cases involving slopes that do not satisfy the feature height criteria for registration in the New Catalogue of Slopes.
(#) Eight out of the nine registerable slope features have been registered in the New Catalogue of Slopes following the failures.

Figure 1 - Breakdown of Landslides on Unregistered Slopes in 2006

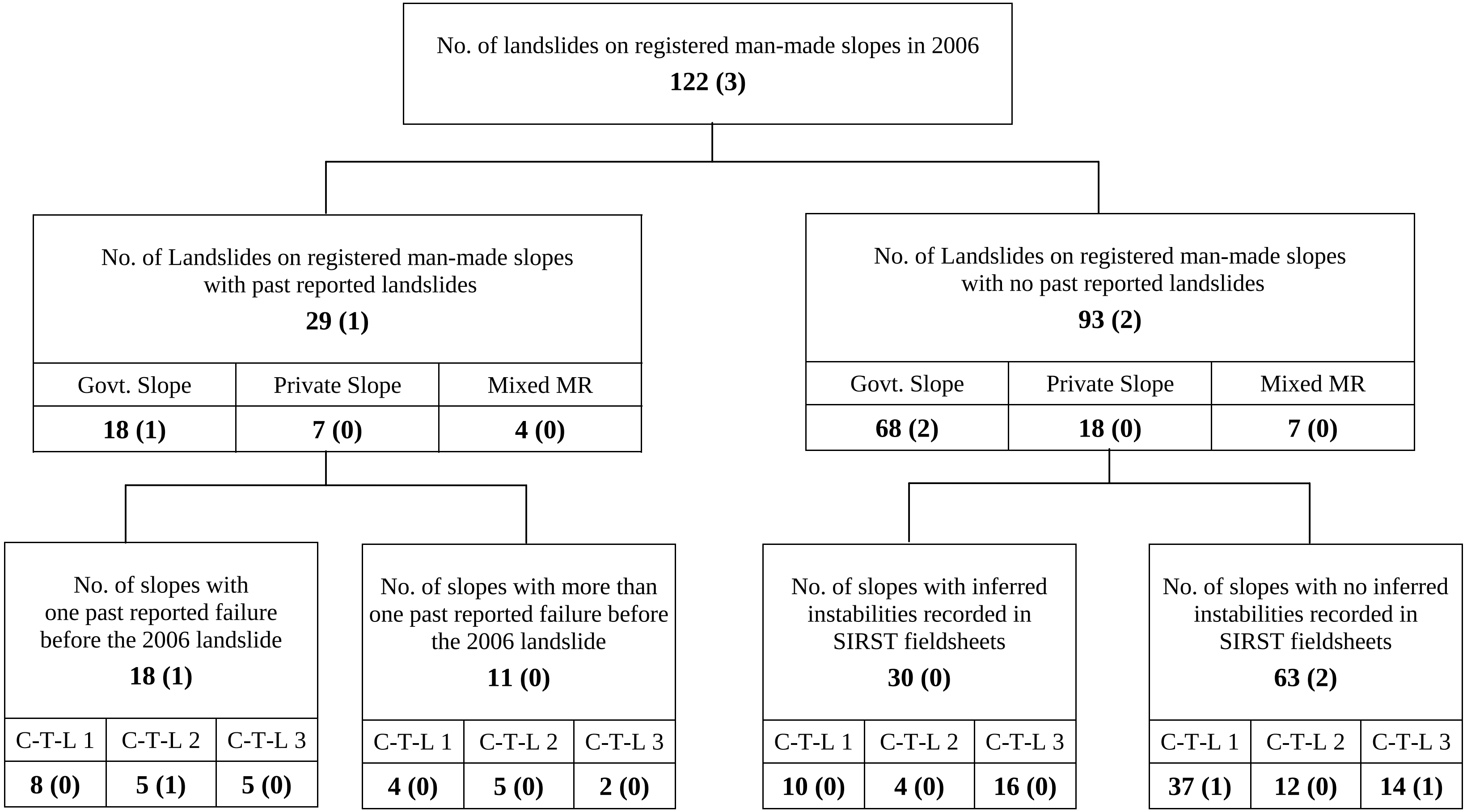
Table of Contents
Table of Contents
Table of Contents
Table of Contents

	Natural hillside failure	Disturbed-hillside failure		Hillside failure involving registerable man-made features
		Type A	Type B	
Classification				
Example				
	1990 Tsing Shan debris flow (SPR6/96) 1997 Wonderland Villas (#88) 1998 Pak Sha Wan (#108) 1998 Outward Bound School (#108) 1999 Sham Tseng San Tsuen (#169)	1993 Lantau Trail (#61) 1997 Lido Beach (#89) 1997 Ka Tin Court (#91)	1997 To Fung Shan Cemetery (#89) 1997 Shatin Heights Road (#88)	1995 Shum Wan Road (#178) 1997 Ma On Shan (#90) 1997 Kau Wah Keng (#76)

Remark: # GEO Report No.

Figure 2 - General Classification of Hillside Failures

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



Note :
122 (3) 122 landslides of which three were major failures.

Figure 3 - Breakdown of Landslides Involving Registered Man-made Slopes with Past Instabilities in 2006

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

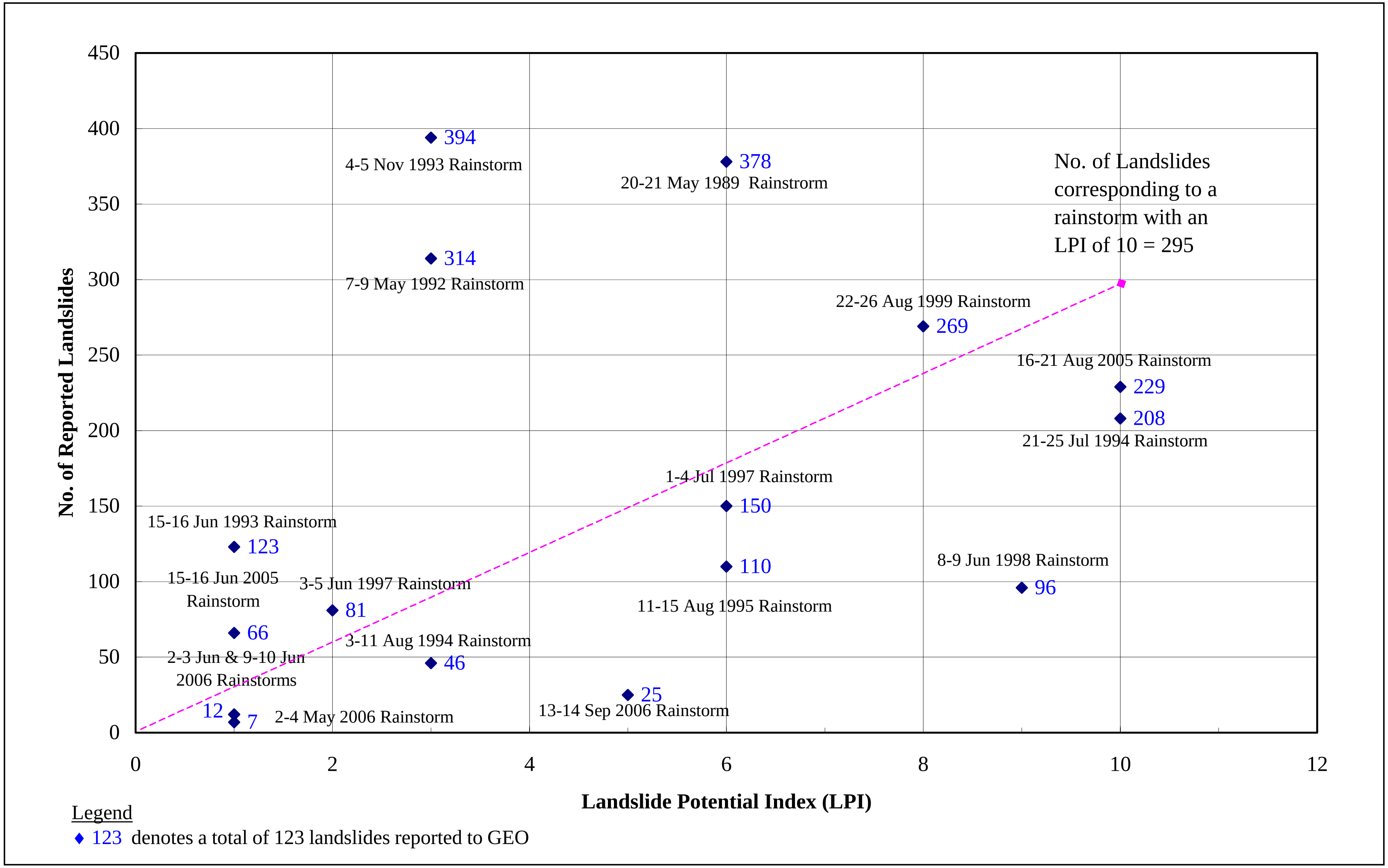


Figure 4 - A Plot of Number of Reported Landslides in Past Major Rainstorms against Landslide Potential Index

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.

部份土力工程處的主要刊物目錄刊載於下頁。而詳盡及最新的土力工程處刊物目錄，則登載於土木工程拓展署的互聯網網頁http://www.cedd.gov.hk 的"刊物"版面之內。刊物的摘要及更新刊物內容的工程技術指引，亦可在這個網址找到。

Copies of GEO publications (except maps and other publications which are free of charge) can be purchased either by:

writing to
Publications Sales Section,
Information Services Department,
Room 402, 4th Floor, Murray Building,
Garden Road, Central, Hong Kong.
Fax: (852) 2598 7482

or

- Calling the Publications Sales Section of Information Services Department (ISD) at (852) 2537 1910
- Visiting the online Government Bookstore at http:// www.bookstore.gov.hk
- Downloading the order form from the ISD website at http://www.isd.gov.hk and submit the order online or by fax to (852) 2523 7195
- Placing order with ISD by e-mail at puborder@isd.gov.hk

讀者可採用以下方法購買土力工程處刊物(地質圖及免費刊物除外):

書面訂購
香港中環花園道
美利大廈4樓402室
政府新聞處
刊物銷售組
傳真: (852) 2598 7482

或

- 致電政府新聞處刊物銷售小組訂購 (電話：(852) 2537 1910)
- 進入網上「政府書店」選購，網址爲 http://www.bookstore.gov.hk
- 透過政府新聞處的網站 (http://www.isd.gov.hk) 於網上遞交訂購表格，或將表格傳真至刊物銷售小組 (傳真：(852) 2523 7195)
- 以電郵方式訂購 (電郵地址：puborder@isd.gov.hk)

1:100 000, 1:20 000 and 1:5 000 maps can be purchased from:

Map Publications Centre/HK,
Survey & Mapping Office, Lands Department,
23th Floor, North Point Government Offices,
333 Java Road, North Point, Hong Kong.
Tel: 2231 3187
Fax: (852) 2116 0774

讀者可於下列地點購買1:100 000，1:20 000及1:5 000地質圖：

香港北角渣華道333號
北角政府合署23樓
地政總署測繪處
電話: 2231 3187
傳真: (852) 2116 0774

Requests for copies of Geological Survey Sheet Reports, publications and maps which are free of charge should be sent to:

For Geological Survey Sheet Reports and maps which are free of charge:
Chief Geotechnical Engineer/Planning,
(Attn: Hong Kong Geological Survey Section)
Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon, Hong Kong.
Tel: (852) 2762 5380
Fax: (852) 2714 0247
E-mail: jsewell@cedd.gov.hk

For other publications which are free of charge:
Chief Geotechnical Engineer/Standards and Testing,
Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon, Hong Kong.
Tel: (852) 2762 5346
Fax: (852) 2714 0275
E-mail: wmcheung@cedd.gov.hk

如欲索取地質調查報告、其他免費刊物及地質圖，請致函：

地質調查報告及地質圖:
香港九龍何文田公主道101號
土木工程拓展署大樓
土木工程拓展署
土力工程處
規劃部總土力工程師
(請交:香港地質調查組)
電話: (852) 2762 5380
傳真: (852) 2714 0247
電子郵件: jsewell@cedd.gov.hk

其他免費刊物:
香港九龍何文田公主道101號
土木工程拓展署大樓
土木工程拓展署
土力工程處
標準及測試部總土力工程師
電話: (852) 2762 5346
傳真: (852) 2714 0275
電子郵件: wmcheung@cedd.gov.hk

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, 2007).
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.
Geoguide 7	Guide to Soil Nail Design and Construction (2008), 97 p.

GEOSPECS

Geospec 1	Model Specification for Prestressed Ground Anchors, 2nd Edition (1989), 164 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. 1/2000	Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls (2000), 146 p.
GEO Publication No. 1/2006	Foundation Design and Construction (2006), 376 p.
GEO Publication No. 1/2007	Engineering Geological Practice in Hong Kong (2007), 278 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