REVIEW OF LANDSLIDES IN 2003

GEO REPORT No. 184

T.H.H. Hui, A.F.H. Ng & H.W. Sun

GEOTECHNICAL ENGINEERING OFFICE

CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT

THE GOVERNMENT OF THE HONG KONG

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

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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 last page of this report.

R.K.S. Chan
Head, Geotechnical Engineering Office
August 2006

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

FOREWORD

This report presents the findings of a detailed diagnosis of landslides that occurred in 2003 and 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 to further enhance the slope engineering practice in Hong Kong.

The review was carried out by Mr T.H.H. Hui, Mr A.F.H. Ng and Dr H.W. Sun of the 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.

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

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

Table of Contents

ABSTRACT

This report presents the findings of a detailed diagnostic review of landslides in 2003 that were reported to the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department. The diagnosis forms part of 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 201 genuine landslides were reported to the Government in 2003. All the available landslide data were examined and 21 landslide incidents were selected for follow-up study under the landslide investigation programme. These studies provided information and insight into the types and mechanisms of landslides and facilitated the identification of areas deserving attention and improvement.

Based on the landslide data in 2003, the annual failure rate in terms of major landslides (viz. failure volume of 50 m^3 or above) on engineered man-made slopes that have been accepted under the slope safety system is about 0.005% on a slope number basis (i.e. the number of landslides relative to the total number of slopes of this category). The corresponding annual failure rate in terms of minor landslides (viz. failure volume of less than 50 m^3) on engineered man-made slopes is about 0.048% on a slope number basis.

Overall, about 99.95% of the engineered man-made slopes performed satisfactorily without occurrence of any reported landslides in 2003.

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

CONTENTS

Page No.

Table of Contents
Table of Contents
Table of Contents

1. INTRODUCTION

This report presents the findings of an overall diagnostic review of landslides that occurred in 2003 and were reported to the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department (CEDD). The diagnostic review forms part of the GEO's systematic landslide investigation (LI) programme, which was introduced following the 23 July 1994 Kwun Lung Lau landslide. The LI programme has two principal objectives, as follows:

(a) 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) review the performance of Government's slope safety system and identify improvement to the slope engineering practice.

Individual landslides were selected for in-depth studies to identify lessons that can be learnt together with the necessary follow-up actions. The findings of the studies are presented in a series of Landslide Study Reports. The present diagnostic review examines all the available landslide data, including the findings of the individual landslide studies, in order to assess the performance of the Government's slope safety system and to identify areas that deserve attention and improvement. The diagnostic review has been carried out by the Landslip Preventive Measures Division 1 of the GEO, with assistance provided by the GEO's LI consultants, Fugro Scott Wilson Joint Venture and Maunsell Geotechnical Services Limited.

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

2. RAINFALL AND LANDSLIDES IN 2003

The factual information and the relevant statistics on rainfall and the reported landslides in 2003 were documented by Hui & Ng (2004). In 2003, the annual rainfall recorded at the Hong Kong Observatory (HKO)'s principal raingauge at Tsim Sha Tsui was 1,942 mm, which is about 12% lower than the mean rainfall of 2,214 mm recorded between 1961 and 1990. One Landslip Warning was issued on 5 May 2003.

Altogether 201 genuine landslides, discounting non-landslide incidents such as tree falls, were identified to have occurred in 2003 out of a total of 224 reported incidents. The total number of major failures (i.e. failure volume of $\geq 50\ m^3$) was eleven, which amounts to about 5.5% of the number of genuine landslides.

The range of different facilities affected by the landslides is summarised in Table 1. The consequences of the landslides, which have been classified in accordance with the type of failure, are summarised in Table 2. Table 3 shows the distribution of the different facility groups that were affected by the major landslides. The distribution of landslides as classified

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

by the type of failure is given in Table 4.

The information of all the reported landslides has been uploaded to the GEO's computerised Slope Information System (SIS), which is accessible by the general public through computer terminals in the GEO. All the data on reported landslides were examined and additional information was collated by the LI consultants to assist in the selection of deserving incidents for follow-up studies. In 2003, twenty one landslide incidents were selected for follow-up studies.

The individual landslide studies provided valuable information and insight into the types and mechanisms of landslides, which was essential for deriving the necessary follow-up actions. The findings of the landslide studies have been documented and the reports are lodged in the Civil Engineering Library. A summary of the findings of the investigations of significant landslides is presented in the Hong Kong Slope Safety Website (http://hkss.cedd.gov.hk/hkss/eng/studies/lic/index.htm). Following each of the landslide studies, the key lessons learnt are identified and recommendations are made separately on the necessary site-specific or more general follow-up actions.

Selected notable landslide incidents in 2003 are described in the report by Hui & Ng (2004).

3. OVERALL DIAGNOSTIC REVIEW OF LANDSLIDES

3.1 Scope of the Review

The overall diagnostic review of all the available landslide data in 2003 provided a global picture of the performance of the different types of slopes in Hong Kong and 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).

Where appropriate, the review has also taken cognizance of selected categories of landslide problems whereby collective information obtained over the past few years has highlighted the need for attention.

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

3.2 Coverage of the New Catalogue of Slopes

3.2.1 General

Sizeable man-made slopes and retaining walls, including those compiled under the GEO's project entitled 'Systematic Identification and Registration of Slopes in the Territory' (SIRST) which was 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 review of existing topographic plans), together with the criteria for registration of sizeable man-made slope features in the New Catalogue of Slopes, is given in GEO Circular No. 15.

A further slope registration exercise was carried out by the GEO in 2002-2003, following which approximately 4,000 additional man-made slope features were included in the New Catalogue of Slopes.

3.2.2 Diagnosis

Of the 201 genuine landslides, 108 occurred on registered slope features. A breakdown of the other 93 incidents is given in Figure 1.

Of these 93 incidents, 53 involved small man-made slope features and 32 involved natural hillsides, all of which do not satisfy the criteria for registration in the New Catalogue of Slopes. One of the other incidents involved a slope where works were in progress at the time of failure and hence it was not yet ready for registration.

The remaining seven incidents involved features that satisfy the slope registration criteria but were not registered in the New Catalogue of Slopes at the time of the failure (see Figure 1 for details).

3.2.3 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 3% of the number of genuine landslides in 2003. None of the seven landslide incidents involved a major failure or any notable consequences, such as building evacuation or road closure.

All the seven slope features of concern were registered in the New Catalogue of Slopes following the landslides.

3.3 Annual Failure Rates of Registered Slopes

3.3.1 General

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

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

slopes of different ages, i.e. pre-1977 (viz. formed or substantially modified before 1977), 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. 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 carried out under a quality assurance system that satisfies the requirements of WBTC No. 11/2000 (whereby the checking by the GEO of the design of the Type 3 prescriptive measures is waived).

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

The scale of failure is classified as follows:

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

(b) major failure (i.e. failure volume of $\geq 50\ m^3$).

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

The distribution of the failure volume of the genuine landslides is summarised in Table 5.

3.3.2 <u>Diagnosis</u>

Of the 201 genuine landslides reported in 2003, a total of 108 landslide incidents (about 59%) affected 97 registered slopes (i.e. eleven of the slopes had multiple landslide incidents). Of these 108 landslide incidents, eight (about 7.4%) were major failures.

Approximate estimates of the number of engineered and non-engineered slope features have been made by reference to the classification assigned under the 'Systematic Identification of Features in the Territory' (SIFT) project and desk study findings on whether

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

the slope features have been through the slope safety system.

The estimates of the number of engineered and non-engineered slopes based on reference to SIFT data are subject to some uncertainty as the SIFT class of a slope is assessed primarily using aerial photograph interpretation. Further information on the scope and limitations of the SIFT project is given by Wong & Ho (1999).

Eleven of the 201 genuine landslides (about 5%) affected engineered slopes, one of which was a major failure.

Based on the 2003 landslide data and a detailed review of the status of the slopes involved in the landslides, the annual failure rates of the different types of registered slopes have been calculated (see Table 6). These calculated failure rates are not particularly sensitive to the assumptions made about the total numbers of different types of slopes given the likely order of uncertainty involved. It should be noted that the calculated failure rates do not necessarily correspond to long-term average values because of the limited observation period. Notwithstanding this, these annual failure rates derived from a systematic review of all the landslide data will provide useful insight into the performance of the slope safety system.

3.3.3 Discussion

The failure rates of engineered and non-engineered slopes have been calculated using three approaches. The first approach involves assessing the failure rate on a slope number basis, i.e. the failure frequency is taken to correspond to the number of landslides divided by the total number of slopes of a certain status. This is relevant in relating the failure rate of different slope categories and the performance of the slope safety system to the slope population as registered in the Slope Catalogue. The second approach involves assessing the landslide rate in terms of the surface area of landslides divided by the total surface area of slopes of the corresponding status (e.g. engineered slopes and non-engineered slopes). The third approach involves assessing the landslide rate 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 area of slopes rather the number of slopes takes into account the fact that large slopes are generally more susceptible to ‘defects’ than small slopes. As there can be a marked difference between the surface areas of slopes of different status, it would be relevant to relate the failure rate to the slope surface area also.

Based on the reported landslides on registered man-made slopes in 2003, the annual failure rates for all reported landslides correspond to 1.75×10^{-3} (number of landslides/number of registered slopes), 33.3×10^{-6} (total surface area of landslides/total surface area of registered slopes) and 1.78×10^{-6} (number of landslides/total surface area of registered slopes) respectively using the three different approaches as described above.

Comparisons of the annual failure rates of engineered slopes with that of non-engineered slopes are given in Section 3.4.2 below. It should be noted that the calculated failure rates for the different types of registered slopes based on the 2003 landslide data could be affected by factors such as the actual rainfall characteristics and the prevailing slope maintenance condition.

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

3.4 Diagnosis of Landslides on Engineered Slopes

3.4.1 General

A review of the 2003 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 detailed information obtained from the follow-up landslide studies.

In 2003, eleven landslides occurred on ten engineered slopes (two of which were upgraded in the 1980's, four in the 1990's and four since 2000, see Table 7). For the present purposes, slope features 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. In 2003, none of the landslides involved slope features with outstanding GEO comments on the geotechnical submissions or slope features without evidence of a geotechnical submission being made to the GEO for checking where this was required.

Engineered slopes with geotechnical submissions accepted under the slope safety system are classified in accordance with the following (see Table 8):

(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. 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 carried out,

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

(e) whether the stability assessment or the design of slope upgrading works was checked and accepted by the GEO, or whether there were any outstanding GEO comments on the geotechnical submissions that were not satisfactorily resolved by the concerned party, and

(f) whether the slope was upgraded to meet current standards using prescriptive measures under an adequate quality system satisfying the requirements of WBTC No. 11/2000

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

with the checking by the GEO waived.

A summary of the pertinent findings of the follow-up landslide studies is given in Table 9.

3.4.2 General Diagnosis

The breakdown of the eleven failures that affected engineered slopes in 2003 with respect to slope type and scale of failure is shown in Table 10. One of these involved a major failure whereas the remaining cases involved minor failures.

The annual failure rates for the 2003 landslide data on a slope number basis, unit slope surface area basis and the number of landslides per slope surface area basis respectively are summarised in Table 11 for different categories of slopes.

On a slope number basis, the likelihood of failure of engineered slopes is about five times less than that of non-engineered slopes while on a unit area basis, the likelihood of failure of engineered slopes is about 14 times less than that of non-engineered slopes. In terms of the number of landslides divided by the slope surface area, the likelihood of failure of engineered slopes is also about 14 times less than that of non-engineered slopes.

It may be noted from the above diagnosis that for the year 2003, the annual failure rate of LPM slopes for all landslides was apparently higher than the corresponding figure for engineered slopes and was close to that for non-engineered slopes. This could be related partly to the fact that the LPM Programme tends to tackle more difficult sites usually with complex ground conditions. The fact that the rainstorms in 2003 were not severe could also have been a contributory factor in the relative annual failure rates for the different slope categories. Caution needs to be exercised because the numbers being compared are small and may not be statistically significant. Hence, the diagnosis should be taken as indicative only.

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 2003, the actual annual success rates were 99.99% and 99.95% for major failures and minor failures respectively. The pledged targets were therefore achieved.

Of the ten engineered slopes that failed in 2003, six were previously included in the LPM Programme (see Table 12). For 2003, the annual failure rates for slopes that were dealt with under the LPM Programme are summarised in Table 13. Further discussion on pertinent observations on failures of engineered slopes is given in Section 3.5.2.

3.5 Key Observations

3.5.1 Severity of Rainstorms that Triggered Landslides

Of the eleven failures that affected engineered slopes, eight (one of which was a major failure) were triggered by rainfall where there was sufficiently reliable information to assess

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

the timing and severity of the rainstorms preceding the landslides (Table 9). Five (all were minor) of the eight incidents involved rainstorms which were less severe than those experienced in the past based on data from automatic raingauges installed in the mid-1980's.

For the above five failures with respect to the severity of rainstorms in 2003, progressive deterioration of the slope condition probably played a key role in those cases where contribution from inadequate slope maintenance was judged to be significant and where there were no obvious changes in environmental factors. Slope deterioration could take the form of intermittent slope deformation caused by previous successive severe rainstorms resulting in progressive opening up of the ground. It is conceivable that gradual deterioration of the slope condition could also take place without obvious deformation, e.g. changes in near-surface hydrogeology related to formation, collapse or blockage of erosion pipes. As a result, subsequent failures could occur during, or soon after, rainstorms that are not particularly severe.

The relative severity of specific rainstorms in triggering landslides is reflected by the Landslide Potential Index, LPI (GEO, 2004a), which takes account of key factors such as intensity, duration, areal extent and spatial location of the rainstorm relative to the locations of vulnerable slopes. The calculated LPI is about 8% for the 4 to 6 May 2003 rainstorm and about 2% for the 7 to 12 June 2003 rainstorm, which were the two worst rainstorms in 2003. These confirm that the 2003 rainstorms was much less severe (in terms of the potential to trigger landslides) than those in the 1990's. For example, the highest LPI for rainstorms in 2003 was less than half of that triggered the July 1994 Kung Lung Lau Landslide. This indicates that the rainstorms in 2003 were not particularly severe in terms of their potential in triggering landslides, which is one of the reasons for the fairly insignificant and small number of landslides in 2003.

3.5.2 Landslides on Engineered Slopes

3.5.2.1 General

In 2003, eleven landslides occurred on ten engineered slopes (Table 9), comprising three soil cuts, four rock cuts and three fill slopes (two involved compacted soil fill within the top 3 m and one involved compacted rockfill). The maintenance responsibility for nine of these slopes rested with Government whereas the other one was under private ownership.

3.5.2.2 Soil Cuts

A total of four minor landslides occurred on three soil nailed cut slopes with vegetated covers (two of which had a hard cover prior to the upgrading works).

Two of the slopes were upgraded in 2000 and 2003 respectively whereas the other one was upgraded in the early 1990's. In one of the recently upgraded slopes, more critical slip surfaces were not analysed in the design which resulted in soil nails being designed to cover the lower portion of the cut slope only. The 20 m^3 failure occurred within the upper portion of the unsupported cut face involving shallow colluvium. About a month after the above failure, small detachments of soil (about 3 m^3) also occurred from the local steep cut faces in between the soil nail heads within the lower portion of the same slope. Similar problems of

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

shallow detachments of soils between soil nail heads occurred on the other recently upgraded cut slopes. In both cases, wire mesh protection was not provided for the vegetated surface between the soil nail heads and locally oversteep profiles or local breaks in slope were not trimmed during construction.

In the other cut slope engineered in the early 1990's, inadequate maintenance was a major contributory factor in causing the local shallow failure below a blocked surface drain.

3.5.2.3 Rock Cuts

The four rockfall incidents affected engineered rock cuts that were accepted under the slope safety system in the early 1980's (2 nos.) and mid-1990's (2 nos.) respectively. A combination of local adverse joints and unfavourable groundwater regimes, together with progressive deterioration of the slope condition, probably played a key role in the incidents. In addition, inadequate attention to dealing with unplanned/undesirable vegetation was a key contributory factor for three of the cases.

Key lessons learnt from landslide studies and suggested good practice for rock cut slopes are summarised in GEO Technical Guidance Note (TGN) No. 10 on 'Enhancement of Rock Slope Engineering Practice Based on Findings of Landslide Studies', which was promulgated in 2002. The failures of engineered rock cuts in recent years have reinforced the importance of direct assessment of possible failure modes based on detailed field inspections, with due regard to local adverse joints together with all variations in azimuth and slope angle as well as the potential block size, instead of placing undue reliance on conventional stereoplot analyses alone.

There have also been a number of rockfalls from engineered rock cuts whereby tree root action played a key contributory role in the failure. Tree root growth can result in progressive deterioration of the slope condition, which makes it more vulnerable to water ingress. Care is needed in assessing the kinematic feasibility of rock blocks, with due regard of possible forces arising from the jacking action of tree roots. As noted in GEO TGN No. 10, specialist advice by suitable tree experts on the treatment of trees and special maintenance requirements should be considered, as appropriate, for an integrated assessment of the necessary slope works.

Notwithstanding the above, some of the reported failures were due to local steepening of the dip angle of adverse rock joints behind the slope face, which could not be easily identified during the design or construction stage. Also, the assessment of rock cuts with extensive tree growth in a heavily jointed rock mass is fraught with uncertainty. In view of the inherent uncertainties, suitable wire mesh netting should be used more extensively as prescriptive measures to mitigate the effects of possible local detachments, as promulgated in GEO TGN No. 10.

3.5.2.4 Fill Slopes

With regard to the three incidents on engineered fill slopes, the affected features were accepted under the slope safety system in the mid-1980's, late 1990's and 2002 respectively.

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

The most notable case involved a recently upgraded fill slope whereby major washout (see Wong et al (1997) for classification of landslides in Hong Kong) occurred during the first significant rainstorm after the upgrading works (volume of failure about 150 m^3). The slope is located below a sharp bend as well as a local low point of a rural road. The site setting has a sizeable catchment and partial blockage of the road drainage system led to concentrated surface water flow over the fill slope causing severe erosion. In this incident, inadequate attention to the assessment and detailing of slope drainage, together with poor connection details of the cross-road drain, probably played a key role in the failure. The second incident affected a fill slope engineered in the late 1990's and similarly involved inadequate assessment and detailing of surface drainage provisions.

Overall, there appears to be merit in undertaking an integrated review of recent landslides involving surface drainage problems in order to identify areas deserving attention.

In the other incident involving an engineered fill slope upgraded in the mid-1980's, the failure was caused by the bursting of a buried water pipe above the slope crest. In the past few years, there have been more than ten notable landslides triggered by bursting or leakage of water-carrying services. It would be instructive to conduct an integrated review of all the related landslide incidents to facilitate revision of the 'Code of Practice on Inspection & Maintenance of Water Carrying Services Affecting Slopes' (Works Branch, 1996), as appropriate.

3.5.3 Landslides on Natural Hillsides and Registered Disturbed Terrain Features

A total of 36 failures on hillsides (including disturbed terrain) was reported in 2003, five of which involved major failures.

Of these 36 cases, 25 (i.e. 69%) were classified as natural hillside failures, i.e. the failure affected natural hillsides which have not been modified by man-made activities, such as cutting, filling, cultivation, etc. The other eleven failures involved hillsides locally modified or disturbed by man-made activities (four of which were registered Disturbed Terrain (DT) features). However, the man-made elements of the disturbed terrain did not play a significant contributory role in the above failures as such.

One of the major failures involved a channelised debris flow developed whereby the debris damaged a brick boundary wall at the back of a village house and some of the outwash material entered the inhabited building. As a result, the village house was closed temporarily for about five months. Although there was no record of historical landslides in the vicinity of the 2003 failure according to GEO's Natural Terrain Landslide Inventory (NTLI) and Large Landslides Database, interpretation of the available low-level aerial photographs (nominally 4,000 feet) as part of the detailed landslide study revealed that the hillside of concern has a history of retrogressive failures. This highlights the potential natural terrain landslide hazards from catchments with a history of failures, that apparently has no record of any past instability according to the NTLI. The NTLI was compiled largely based on the use of high-level aerial photographs (viz. 8,000 to 20,000 feet), which was a cost-effective and efficient methodology for the purposes of setting up a general landslide inventory given the immense scale of the task. However, this is subject to the limitation that the high-level aerial photographs are not of a sufficient resolution to identify all the past

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

hillside failures.

There is merit to carry out aerial photograph interpretation (API) using low-level aerial photographs (say, for selected hillsides affecting the urban areas) to progressively enhance the NTLI and assist in the identification of potentially hazardous catchments affecting developments. This exercise would also help to eliminate those non-genuine landslides that may have been included in the NLTI due to the relatively low resolution of the high-level aerial photographs. The enhanced quality of the landslide inventory will also contribute to improving the rainfall-landslide correlations and quantification of risk in respect of natural terrain landslides.

3.5.4 Assessment of Signs of Distress and Necessary Follow-up

Some of the notable landslides in 2003 and the past few years (e.g. the 11 June 2003 Rehab Path incident on a mixed maintenance responsibility (MR) slope (Incident No. 2003/6/0111), the 22 May 2002 Shatin Pass incident on a government slope (Incident No. 2002/5/0030) and the 9 June 2001 Castle Peak Road incident on a private slope (Incident No. MW2001/6/7)) have revealed that the above slopes exhibited signs of distress (viz. loose rock blocks, corestones or boulders) that were observed some time before the subsequent final detachments.

Slopes with signs of distress may be identified during slope maintenance inspections (routine maintenance inspections or Engineer Inspections), inspections of landslides and the adjacent areas, slope studies, etc. Appropriate actions or precautionary measures implemented in a timely manner to deal with the observed distress can enhance public safety.

For government slopes being studied by consultants under the LPM Programme, the consultants are required to alert the project engineer of any need for non-routine maintenance works prior to completion of the study/investigation or commencement of upgrading works.

For mixed MR slopes, WBTC No. 26/99 states that ‘it is good practice and conducive to public safety for the department responsible for the government portion to inspect the entire slope as far as reasonable and practicable, and to notify the GEO and BD immediately for further action if any signs of instability or distress or other serious problems on the private portion are discovered during its inspections’. Following the 11 June 2003 Rehab Path incident, the GEO has provided additional guidance to all the slope maintenance departments in the form of typical scenarios that warrant referral to the GEO for follow-up actions on the private slope portions.

Where signs of distress are judged to be posing an immediate and obvious danger, the term contractors of the Buildings Department (BD) in the case of private slopes or the responsible government departments in the case of government slopes may be mobilised to carry out the necessary urgent precautionary or mitigation works. This arrangement has worked well.

However, there could be cases whereby the signs of distress are not posing an immediate and obvious danger (e.g. local loose rock blocks) but that non-routine maintenance or precautionary works are judged necessary to prevent deterioration to a condition that is of

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

stability concern. For government slopes, the slope maintenance departments may be requested to carry out the necessary works on an out-of-turn basis. For private slopes, the situation may be more complicated. GEO Circular No. 24 on ‘Dangerous Hillside Orders and Advisory Letters’ dated 1 July 2004 states that if there is ‘sufficient concern over the condition of a feature to require action to be taken to discharge a duty of care, the GEO should initiate the issue of an Advisory Letter to the owner’. If the slope is already being studied or has been included in the Landslip Preventive Measures (LPM) Stage 2 Study Programme, the above GEO Circular notes that action may be taken to ‘inform the owners in the Advisory Letter that geotechnical studies are being carried out by GEO on that feature and also any other features for which the owners are responsible and advise them that further Advisory Letters or DH Orders may be served on them in due course’. This seems to be an expedient means of informing the owners of the specific concerns and the necessary precautionary measures. There is also a provision in the GEO Circular No. 24 for the inclusion of special conditions in the recommendation of DH Orders by the GEO. In this connection, the GEO Circular No. 24 states that ‘Special conditions may be included to require the owners to take particular action in addition to the DH Order. Examples are precautionary measures or temporary works to be taken prior to the completion of the remedial/preventive works, checking and repair of buried services in the vicinity’.

Concerns have been expressed with regard to the practicality and possible complications of the above actions in GEO Circular No. 24. There is merit to carry out a review of the current procedure and guidance in respect of follow-up actions on private slopes when signs of distress are observed.

3.5.5 Landslides with Inadequate Maintenance Diagnosed as a Key Contributory Factor to Failures

All the 108 reported landslide incidents involving registered man-made slope features were reviewed to assess whether inadequate maintenance was likely to have been a major contributory factor in the failure. 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 findings of the follow-up landslide studies as appropriate. Inadequate slope maintenance was assessed as a major contributory factor in 16 of the 108 incidents (i.e. 15%).

Of these 16 incidents, eleven affected Government slopes (none of which was engineered features) and five affected private slopes (one of which was an engineered feature). The landslide frequency involving failures with inadequate maintenance as a key contributory factor is slightly lower for Government slopes compared with that for private slopes (with a ratio of about 0.9). However, caution needs to be exercised because the numbers involved are relatively small and they may not be statistically significant. The above diagnosis should therefore be taken as indicative only.

3.5.6 Application of New Landslide Investigation Tools

Recent developments in the 3-S technology (viz. Geographic Information System, GIS, Remote Sensing, RS, and Global Positioning System, GPS) have been applied extensively in

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

slope engineering practice. Much of the necessary development work in adapting the above technologies to geotechnical engineering applications is pioneered by the GEO, a summary of which is given by Wong (2004). Efforts have been made under the landslide study programme to capitalise, as far as possible, on the latest developments in site characterisation and landslide investigation tools to enhance the quality of the investigation. For example, since the acquisition of a land-based laser scanner by the CEDD in 2002, it has been used frequently to map and monitor landslide scars, which has proved useful particularly where physical access to the landslide site is difficult or potentially dangerous.

A mini-CCTV camera has been developed by the LPM Division 1 for inspection of underground cavities and buried services in landslide studies and slope investigations. The CCTV camera has also proved useful for inspection of soil nail drillholes, especially where difficulties were encountered in drilling or grouting. Real-time monitoring of groundwater pressure, including suction, is routinely carried out for landslide studies. Trial use of the thermo infra-red image and seismic sympathetic vibration techniques developed in Japan (Nakamura, 2004) for detection of possible voids beneath hard surface covers to slopes has been carried out in Hong Kong under the direction of the LPM Division 1.

It would be useful to continue to apply the new investigation tools to the landslide studies, where practicable, with a view to enhancing the quality of the investigation and gaining experience of use and insight on their applicability to local conditions. The above should include trial application of various slope movement monitoring techniques.

4. PROPOSED IMPROVEMENT INITIATIVES

Improvement initiatives were proposed by Hui et al. (2003) following the diagnostic review of the reported landslides in 2002. The progress of the follow-up actions is summarised in Table 15.

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

(a) carry out an overall review of recent landslides where inadequate surface drainage provisions were key contributory factors to the failures to identify areas for improvement (see Section 3.5.2),

(b) carry out an overall review of recent landslides associated with bursting or leakage of water-carrying services to identify areas for improvement (see Section 3.5.2),

(c) carry out API using low-level aerial photographs covering selected hillsides affecting the urban areas of Hong Kong to enhance the Natural Terrain Landslide Inventory (see Section 3.5.3), and

(d) review the current procedure and guidance in respect of follow-up actions on private slopes with signs of distress to identify areas for improvement (see Section 3.5.4).

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

5. 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 landslides and minor landslides on engineered slope, on a slope number basis, were 0.005% and 0.048% respectively for the year 2003. Thus, the pledged annual success rates of 99.8% and 99.5% of engineered slopes in preventing major and minor landslides respectively have been met.

(b) More than 99.95% of the engineered slopes performed satisfactorily without the occurrence of any landslides reported in 2003.

A number of initiatives is proposed with a view to further improving the slope engineering practice and enhancing the slope safety system in Hong Kong, as detailed in Section 4 of this report.

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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 - Number of Landslides Affecting Different Facilities

Affected Facility	Hong Kong Island	Kowloon	New Territories and Outlying Islands	All
Squatter Dwellings	0 (0)	0 (0)	10 (0)	10 (0)
Buildings	2 (0)	1 (0)	12 (1)	15 (1)
Roads	9 (0)	1 (0)	17 (0)	27 (0)
Transportation Facilities (railways, tramways, LRT, etc.)	0 (0)	0 (0)	0 (0)	0 (0)
Pedestrian Pavements/Footways	0 (0)	2 (0)	3 (0)	5 (0)
Minor Footpaths/Access	4 (0)	2 (0)	60 (3)	66 (3)
Construction Sites	0 (0)	1 (1)	2 (0)	3 (1)
Open Areas	8 (1)	1 (0)	28 (1)	37 (2)
Catchwaters	0 (0)	0 (0)	7 (0)	7 (0)
Others (e.g. carparks, parks, playgrounds, gardens, backyards, etc.)	4 (0)	1 (0)	30 (4)	35 (4)

Legend:

3 (1) Three landslides of which one was major failure.

Notes: (1) A given landslide may affect more than one key type of facility.
(2) Incidents which were not genuine landslides have been excluded.

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

Table 2 - Landslide Consequence 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	2	0	1	1	0	0	0
Cut Slope	Soil	0	0	0	3	0	7	0	0
	Soil/Rock	0	0	1	2	0	1	0	0
	Rock	0	0	0	2	1	0	0	0
Retaining Wall		0	1	0	0	0	1	0	0
Natural Hillside		0	0	1	1	0	3	0	0
Disturbed Terrain		0	0	0	0	0	1	0	0

Note: 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 3 - Distribution of Facility Groups Affected by Major Landslides

	Facility Group Affected by Major Landslides						
	1a	1b	2a	2b	3	4	5
All Major Landslides	1	0	0	1	0	5	4
Major Landslides on Man-made Slope	0	0	0	1	0	1	4
Major Landslides on Natural Hillside	1	0	0	0	0	4	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 key type of facility.

Table 4 - Number of Landslides as Classified by Type of Slope Failure

Type of Failure		No.	Percentage (%)
Fill Slope		16 (3)	8.0
Cut Slope	Soil	105 (2)	52.2
	Soil/Rock	25 (1)	12.4
	Rock	7 (0)	3.5
Retaining Wall		12 (0)	6.0
Natural Hillside		32 (3)	15.9
Registered Disturbed Terrain Features		4 (2)	2.0
Total		201 (11)	100

Legend:

5 (1) Five landslides of which one was 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) Incidents which were not genuine landslides have been excluded.

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

Table 5 - Breakdown of Scale of Failure for Different Classes of Slopes

	Number of Minor Failure (< 50 m^3)	Number of Major Failure		
		(50 to 500 m^3)	(> 500 m^3)	
Registered Man-made Slopes	100	8	0	Σ = 108
Small Unregisterable Man-made Slopes	53	0	0	Σ = 53
Registerable Man-made Slopes Not Registered at Time of Failure	8(1)	0	0	Σ = 8
Natural Hillside	29	3	0	Σ = 32
	Σ = 190	Σ = 11	Σ = 0	Σ = 201

Note: One minor failure occurred on a man-made slope within an active construction site, which was yet to be registered at the time of failure.

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

Table 6 - Annual Failure Rates of Registered Slope Features Based on Landslides Reported in 2003

		No. of Failures on Non-Engineered Slopes			No. of Failures on Engineered Slopes		
		Fill/Retaining Wall	Soil/Rock Cut	Overall[(1)]	Fill/Retaining Wall	Soil/Rock Cut	Overall
Slopes with Landslides in 2003	Number	6	79	85	3	8	11
	Surface Area of Landslides (m^2)	374	1,213	1,587	126	76	202
Slopes with Major Landslides in 2003	Number	2	3	5	1	0	1
	Surface Area of Landslides (m^2)	344	149	493	109	0	109
Slopes with Minor Landslides in 2003	Number	4	76	80	2	8	10
	Surface Area of Landslides (m^2)	30	1,064	1,094	17	76	93
Total Number of Registered Slopes		11,820	22,480	34,300	9,730	10,970	20,700
Total Surface Area of Registered Slopes (m^2)		6,683,000	12,801,000	19,484,000	11,762,000	22,541,000	34,303,000
Annual Failure Rates (All Landslides Considered)	On a Slope Number Basis	0.05 %	0.35 %	0.25 %	0.03 %	0.07 %	0.05 %
	On a Unit Slope Surface Area Basis	5.60 x 10^{-3} %	9.48 x 10^{-3} %	8.15 x 10^{-3} %	1.07 x 10^{-3} %	0.34 x 10^{-3} %	0.59 x 10^{-3} %
	Number of Landslides Divided by Slope Surface Area (no./m^2)	0.90 x 10^{-6}	6.17 x 10^{-6}	4.36 x 10^{-6}	0.26 x 10^{-6}	0.35 x 10^{-6}	0.32 x 10^{-6}
Annual Failure Rates (Major Landslides Only)	On a Slope Number Basis	0.02 %	0.01 %	0.01 %	0.01 %	0 %	4.83 x 10^{-3} %
	On a Unit Slope Surface Area Basis	5.15 x 10^{-3} %	1.16 x 10^{-3} %	2.53 x 10^{-3} %	0.93 x 10^{-3} %	0 %	0.32 x 10^{-3} %
	Number of Landslides Divided by Slope Surface Area (no./m^2)	0.30 x 10^{-6}	0.23 x 10^{-6}	0.26 x 10^{-6}	0.09 x 10^{-6}	0	0.03 x 10^{-6}

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 4)

1. Slopes Upgraded Under the LPM Programme

Slope No.	Incident No.	Location	Volume (m^3)	Type of Slope	Remarks
11SE-A/FR48	2003/09/0194	Adjacent to St. Michael's Primary School, Fortress Hill Road, North Point	2 (washout)	Fill	LPM works completed in 1987.
15NE-B/FR31	2003/11/0201	Below Shek O Road, Shek O	Sign of distress	Fill	LPM works completed in 1999.
6NE-B/C8	2003/05/0009a	Fan Kam Road, Pat Heung	20	Soil cut	LPM works completed in 2000.
	2003/06/0126		3		
11SE-C/C531	ArchSD/E/ 2003/05/0001	Mount Parker Road, Quarry Bay	1 (rockfall)	Soil/rock cut	LPM works completed in 2000.
10SW-C/FR11	2003/05/0052	Opposite Lai Chi Yuen, South Lantau Road, Lantau Island	150 (washout)	Fill	LPM works completed in 2002.
7SW-C/C820	AFCD/NT/2003 /09/0001	Near Shing Mun Road, Shing Mun Country Park, Kwai Chung	3	Soil/rock cut	LPM works completed 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 2 of 4)

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.

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

Nil.

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 3 of 4)

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

Slope No.	Incident No.	Location	Volume (m^3)	Type of Slope	Remarks
7SW-C/C362	2003/08/0170	Above Route Twisk and Ma Sim Pai Road, Tsuen Wan	16 (rockfall)	Rock cut	Geotechnical design on the subject slope prepared by PWD's consultant was checked by GCO in 1981.
11NE-D/CR764	HD/03/03	On Tin Street, Lam Tin	0.015 (rockfall)	Soil/rock cut	Geotechnical design on the subject slope prepared by Housing Department was checked by GEO in 1996.
11SE-D/CR22	2003/11/0200	Near No. 396, Chai Wan Road, Chai Wan	1 (washout)	Soil cut	Geotechnical design of the slope upgrading works prepared by the Advisory Division of the GEO for Highways Department was checked by GEO in 1993.

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

Nil.

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 4)

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

Slope No.	Incident No.	Location	Volume (m^3)	Type of Slope	Remarks
11SW-C/C169	2003/05/0047	No. 23 Bisney Road, Pokfulam	< 0.1 (rockfall)	Soil/rock cut	Geotechnical submission was checked by GCO in 1980. Slope upgrading works were completed in 1982.

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

Nil.

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

Nil.

Notes: (1) Slopes under Categories 1 to 8 are classified as engineered slopes.
(2) Slopes under Categories 9 and 10 are post-1977 features but are not taken as engineered slopes.

Table 8 - Classification of Engineered Slopes

Feature Type	Classification
Post-1977 Features (i.e. formed or upgraded after 1977)	1
Newly Formed	1N
Upgraded by LPM	1A
Upgraded by Other Government Departments	1B
Upgraded by Private Owners	1C
Upgraded following issue of DH Orders	1D
Pre-1977 Features (i.e. formed before 1977 and subsequently assessed under the slope safety system)	2
Assessed by LPM Stage 2 or Stage 3 Studies	2A
Assessed by Other Government Departments	2B
Assessed by Private Owners	2C
Assessed by Old Studies (e.g. Planning Division Stage 1 Study, Binnie & Partners Phase II Study, Existing Slopes Division Stage 1 Study)	2D

Note: The classification may be extended where possible by adding S, T, U, Y or N which are defined as follows:
S = detailed design calculations based on site-specific ground investigation and laboratory testing
T = detailed design calculations without site-specific ground investigation and laboratory testing
U = no detailed design calculations
Y = upgrading works/assessments were audited and accepted by the GEO
N = no evidence that the works/assessments were audited and accepted by the GEO

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

Table 9 - Summary of Key Findings of Follow-up Landslide Studies (Sheet 1 of 7)

Landslide	Slope Status (classification)*	Worst Rain	Deterioration	Massive Relict Failure		Previous Failure/ Distress after Slope Assessed or Modified to Current Standards		Deficiency in Design/Assessment			Deficiency in Upgrading Works	Poor Condition of Maintenance	GEO Checking		Unauthorized Construction	Volume of Failure (m³)		Remarks
				Recorded	More from API	Recorded	More from API	G/W	Materials strength	Others #			Submitted to GEO for checking	Outstanding GEO comment not resolved		Detached	Deformed	
5.5.2003 South Lantau Road (opposite Lai Chi Yuen) (10SW-C/FR11) (DS)	Engineered (Slope upgraded under LPM Programme in 2002) (1ASY)	The first rainstorm after completion of slope upgrading works	N	N	Not done	N	Not done	N	N	Y	Sig	N	Y	N	N	150 (two scars)	0	Two major washout failures occurred on a 10 m high fill slope during heavy rainfall. The failures were located below low points along a rural road. The failures were probably caused by overtopping of concentrated surface runoff from the road above the fill slope. Inadequate drainage detailing and partially blockage of road drainage system were also key contributory factors.
5.5.2003 and 13.6.2003 Fan Kam Road, Pat Heung (6NE-B/C8) (DS)	Engineered (Slope upgraded under LPM Programme in 2000) (1ASY)	Highest recorded rainfall for duration up to 4 hours since 1983	N	N	N	Y	N	N	N	Y	N	N	Y	N	N	20	0	The 5 May 2003 landslide, which involved the surface mantle of colluvium, occurred on a 7 m high unsupported steep (40°) slope portion of a soil-nailed cut slope. The minor failure was probably caused by the direct infiltration leading to loss of suction and/or the local build-up of transient perched water pressure above the colluvium/saprolite interface during heavy rainfall. The more critical slip surface involving shallow failure within the colluvium was not considered in the stability analysis in the detailed design.
		N	N	N	N	Y	N	N	N	Po	Po	N	Y	N	N	3	0	The 13 June 2003 minor landslide involved a shallow detachment of saprolite in between the soil nail heads on a locally over-steep (50° to 55°) portion of a soil cut slope. The presence of minor scars on the over-steep slope portion would lead to local enhanced infiltration into the slope. The local failure of the over-steep portion was probably caused by concentrated direct infiltration.

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

Table 9 - Summary of Key Findings of Follow-up Landslide Studies (Sheet 2 of 7)

Landslide	Slope Status (classification)*	Worst Rain	Deterioration	Massive Relict Failure		Previous Failure/ Distress after Slope Assessed or Modified to Current Standards		Deficiency in Design/Assessment			Deficiency in Upgrading Works	Poor Condition of Maintenance	GEO Checking		Unauthorized Construction	Volume of Failure (m³)		Remarks
				Recorded	More from API	Recorded	More from API	G/W	Materials strength	Others #			Submitted to GEO for checking	Outstanding GEO comment not resolved		Detached	Deformed	
Time unknown Shek O Road, (15NE-B/FR31) (DS)	Engineered (Slope upgraded under LPM Programme in 1999) (1ASY)	Not assessed	Y	N	N	Y	N	N	N	Y	Mod	N	Y	N	N	0	With signs of distress	Signs of slope movement in the form of cracking and dislocation of drainage channel, cracks along the verge above slope crest and deformation of concrete maintenance stairway were observed on the slope. Some of the cracks appeared fresh while others were old, which suggest possible prolonged and progressive development of slope movements. The continuous movement of the slope was probably caused by settlement of the ground. Leakage of a 600 mm diameter cross-road drain at the slope crest and poor detailing of the surface drainage provisions were key contributory factors.
11.6.2003 Below Margaret Trench Medical Rehabilitation Centre, Rehab Path, Lam Tin (11NE-D/C373) (LR)	Not engineered	N	Y	N	N	N/A	N/A	N/A	N/A	N/A	N/A	Sig	N/A	N/A	N	15	0	A minor rockfall occurred on the private portion of a mixed old soil/rock cut slope which has a history of instability. An unauthorised and unoccupied flimsy structure at the slope toe was destroyed in the incident. Dilated rock joints, some partly in filled, were exposed, which would have allowed rapid water ingress. The growth of unplanned/undesirable vegetation along the dilated joints might have resulted in jacking action on the rock blocks Progressive deterioration of the slope condition associated with lack of maintenance of the private slope portion probably played a key role in the rockfall.

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

Table 9 - Summary of Key Findings of Follow-up Landslide Studies (Sheet 3 of 7)

Landslide	Slope Status (classification)*	Worst Rain	Deterioration	Massive Relict Failure		Previous Failure/ Distress after Slope Assessed or Modified to Current Standards		Deficiency in Design/Assessment			Deficiency in Upgrading Works	Poor Condition of Maintenance	GEO Checking		Unauthorized Construction	Volume of Failure (m³)		Remarks
				Recorded	More from API	Recorded	More from API	G/W	Materials strength	Others #			Submitted to GEO for checking	Outstanding GEO comment not resolved		Detached	Deformed	
6.6.2003 and 25.8.2003 Tung Kin Road, A Kung Ngam (11SE-B/C101) (LR)	Not engineered	N	Y	N	N	N/A	N/A	N/A	N/A	N/A	N/A	Y	N/A	N/A	N	70	0	The major rockfall occurred on a 50 m to 60 m high old soil/rock cut slope, which has a history of instability. The rockfall was structurally controlled and was likely triggered by rainfall. Slope deterioration and tree root action were probably the key contributory factors to the rockfall. The Short Term Tenancies at the slope toe were granted with a condition that a 20 m buffer zone in front of the slope should be maintained, based on slope safety consideration. However, unauthorised structures were erected within the buffer zone. These structures were cleared in 2000 following repeated warnings by the GEO and the collaborations by different Government departments.
		N	Y	N	N	N/A	N/A	N/A	N/A	N/A	N/A	Y	N/A	N/A	N	0.6	0	The minor rockfall occurred at the northern end of the slope. Some of the rockfall debris affected an industrial building at the slope toe. The rockfall was probably triggered by rainfall, with slope deterioration and tree root action as key contributory factors.
6.6.2003 Below St. Catharine's School for Girls, Kung Lok Road, Kwun Tong (11NE-C/C71) (LR)	Not engineered	N	Y	N	N	N/A	N/A	N/A	N/A	N/A	N/A	Mod	N/A	N/A	N	1	0	The minor rockfall occurred on an old rock/soil cut slope which has a history of instability. The detachment was rain-induced and was probably caused by water ingress into dilated sub-vertical rock joints, resulting in possible build-up of local cleft water pressure. Progressive deterioration of the rock slope and tree root jacking action of unplanned/undesirable mature trees were the probable key contributing factors to the rockfall.

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

Table 9 - Summary of Key Findings of Follow-up Landslide Studies (Sheet 4 of 7)

Landslide	Slope Status (classification)*	Worst Rain	Deterioration	Massive Relict Failure		Previous Failure/ Distress after Slope Assessed or Modified to Current Standards		Deficiency in Design/Assessment			Deficiency in Upgrading Works	Poor Condition of Maintenance	GEO Checking		Unauthorized Construction	Volume of Failure (m^3)		Remarks
				Recorded	More from API	Recorded	More from API	G/W	Materials strength	Others #			Submitted to GEO for checking	Outstanding GEO comment not resolved		Detached	Deformed	
5.5.2003 Hillside above village house No. 51, Wong Chuk Yuen Upper Village, Pat Heung (LR)	Not engineered	Highest recorded rainfall for duration up to 4 hours since 1983	Y	N	Y	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	160	0	The major landslide occurred on the natural hillside and the debris entered and channelised along an existing steep-sided gully immediately below the landslide source. The debris demolished a brick wall at the back of village house No. 51 at the toe of the hillside. The failure was probably caused by development of transient water pressures within the surface mantle of colluvium. Possible human influence such as unauthorized cultivation which could have given rise to enhanced infiltration into the ground mass may have played a role in the landslide.
2.9.2003 Lai Sing Court, Tai Hang Road (11SE-A/R51) (LR)	Not engineered	N	Y	N	Not done	N	Not done	N/A	N/A	N/A	N/A	Mod	N/A	N/A	N/A	1	0	The minor failure involved the detachment of several stone-pitching blocks from a 5.5 m high registered feature. The material exposed at the failure scar indicated that the feature was likely to be a cut slope with a thin masonry facing. The failure was probably caused by root action of unplanned/undesirable vegetation.
14.9.2003 Below Hiu Kwong Street, Sau Mau Ping (within active construction site) (11NE-D/F10) (LR)	Not engineered (LPM slope upgrading works in progress at the time of failure)	N	N	N	Not done	N/A	N/A	N	N	Y	Po	N	N/A	N/A	N	200	0	A major landslide occurred on a 12 m high 55^{o} steep temporary cut (formed 3 days before failure) in loose fill within an active construction site during moderate rainfall. The failure was probably caused by the direct infiltration leading to loss of suction and inadequate surface protection provisions.

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

Table 9 - Summary of Key Findings of Follow-up Landslide Studies (Sheet 5 of 7)

Landslide	Slope Status (classification)*	Worst Rain	Deterioration	Massive Relict Failure		Previous Failure/ Distress after Slope Assessed or Modified to Current Standards		Deficiency in Design/Assessment			Deficiency in Upgrading Works	Poor Condition of Maintenance	GEO Checking		Unauthorized Construction	Volume of Failure (m³)		Remarks
				Recorded	More from API	Recorded	More from API	G/W	Materials strength	Others #			Submitted to GEO for checking	Outstanding GEO comment not resolved		Detached	Deformed	
5.5.2003 Hillside at Kau Lung Hang Shan, Tai Po (LR)	Not engineered	Highest recorded rainfall for duration up to 2 hours since 1990	Y	N	Y	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N	200	0	The major landslide occurred on the natural hillside and became channelised after entering a drainage line. The failure was probably triggered by rainfall. The adverse structural combination of the bedding and sheeting joint orientations, together with possibly high sub-surface groundwater conditions, were the probable key contributory factors to the landslide. The travel angle and travel distance of the debris were about 22° and 165 m respectively.
25.8.2003 Above Route Twisk and Ma Sim Pai Road, Tsuen Wan (7SW-C/C362) (LR)	Engineered (Geotechnical submission checked by GEO in 1981) (1BY)	N	Y	N	Not done	N	Not done	N	N	Mod	N	Min	Y	N	N	8	8	The minor rockfall involved planar sliding of sizeable rock blocks along a local adversely orientated steeply inclined basal release surface at a height of about 10 m. The failure may have been the result of progressive deterioration of the rock slope. Root action associated with unplanned/undesirable vegetation was probably a contributory factor to the rockfall.
8.9.2003 Near Shing Mun Road, Shing Mun Country Park, Kwai Chung (7SW-C/C820) (LR)	Engineered (Slope upgraded under LPM Programme in 2003) (1AT)	The first rainstorm after completion of slope upgrading works	N	N	Not done	N	Not done	N	N	Po	N	N	Y	N	N	3	0	The minor landslide involved shallow failure of saprolite in between soil nail heads at a newly upgraded soil cut slope during moderate rainfall. The failure was probably caused by direct infiltration and local concentrated surface runoff towards the crest of the failure scar.
12.6.2003 On Tin Street, Lam Tin (11NE-D/C764) (LR)	Engineered (Geotechnical submission checked by GEO in 1995) (1BY)	N	Y	N	Not done	N	Not done	N	N	N	N	Lit	Y	N	N	0.01	0	The minor rockfall occurred on a steep (60°) bare rock cut slope during moderate rainfall. The detachment may have been the result of progressive deterioration of the rock slope.

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

Table 9 - Summary of Key Findings of Follow-up Landslide Studies (Sheet 6 of 7)

Landslide	Slope Status (classification)*	Worst Rain	Deterioration	Massive Relict Failure		Previous Failure/ Distress after Slope Assessed or Modified to Current Standards		Deficiency in Design/Assessment			Deficiency in Upgrading Works	Poor Condition of Maintenance	GEO Checking		Unauthorized Construction	Volume of Failure (m³)		Remarks
				Recorded	More from API	Recorded	More from API	G/W	Materials strength	Others #			Submitted to GEO for checking	Outstanding GEO comment not resolved		Detached	Deformed	
8.11.2003 Below Chai Wan Swimming Pool, Chai Wan Road (11SE-D/CR22) (LR)	Engineered (Slope portion concerned upgraded by Highways Department in 1994/95) (1BSY)	N	Y	N	Not done	N	Not done	N	N	N	N	Sig.	Y	N	N	1	0	The minor landslide occurred on a 6 m high soil cut slope during moderate rainfall. The catchpit and surface drainage channels immediately above the failure were found to have been blocked with debris arising from vegetation clearance. The slope upgrading works comprising installation of soil nails at the soil portion and construction of buttress walls at the rock portion of the slope were undertaken by the Highways Department. The landslide was probably caused by overspilling of water from the crest channels, resulting in enhanced infiltration into the slope.
Time unkown Mount Parker Road, Quarry Bay (11SE-C/C531) (LR)	Engineered (Slope upgraded under LPM in 2000) (1ASY)	Not assessed	Y	N	Not done	N	Not done	N	N	N	Po	N	Y	N	N	1	0	The minor rockfall involved the detachment of a boulder sized rock block near the crest of a soil/rock cut slope. The rockfall was probably caused by progressive deterioration and the local build-up of cleft water pressure behind rock block, with tree root action as a contributory factor.
6.5.2003 23 Bisney Road, Pokfulam (11SW-C/C169) (LR)	Engineered (Slope upgraded following services of DH Orders in 1979 and 1990) (1DSY)	N	Y	N	Not done	N	Not done	N	N	N	N	Sig	Y	N	N	0.1	0	The minor rockfall occurred on a soil/rock cut slope. The rockfall was probably associated with uprooting of a tree on the slope. Inadequate slope maintenance was a key contributory factor to the failure.
21.9.2003 North-west of St. Michael's Primary School, Fortress Hill Road (11SE-A/FR48) (LR)	Engineered (Slope upgraded under LPM Programme in 1987) (1ASY)	Not assessed	N	N	Not done	N	Not done	N	N	N	N	N	Y	N	N	2	0	The minor washout failure occurred at the upper portion of a 18 m high fill slope. The washout was probably caused by the bursting of a buried 80 mm diameter UPVC salt water pipe at the slope crest.

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

Table 9 - Summary of Key Findings of Follow-up Landslide Studies (Sheet 7 of 7)

Landslide	Slope Status (classification)*	Worst Rain	Deterioration	Massive Relict Failure		Previous Failure/ Distress after Slope Assessed or Modified to Current Standards		Deficiency in Design/Assessment			Deficiency in Upgrading Works	Poor Condition of Maintenance	GEO Checking		Unauthorized Construction	Volume of Failure (m^3)		Remarks
				Recorded	More from API	Recorded	More from API	G/W	Materials strength	Others #			Submitted to GEO for checking	Outstanding GEO comment not resolved		Detached	Deformed	
11.6.2003 Ngau Kwo Tin, Lantau (within active construction site) (13NW-B/C173) (LR)	Not engineered (Slope upgrading works in progress at the time of failure)	N	N	N	N	N/A	N/A	N	N	N	Lit	N	Y	N	N	3	0	The minor landslide involved shallow failure of saprolite in between soil nail heads on a locally over-steep portion of a cut slope. The failure was probably triggered by rainfall, with local concentrated surface runoff as a key contributory factor.
5.5.2003 Near No. 31 Peacock Road, Ming Yuen Mansions (11SE-A/CR169) (LR)	Not engineered	N	Y	N	Not Done	N	Not Done	N/A	N/A	N/A	N/A	Min	Y	N	N	<0.01	0	The minor rockfall incident occurred on a 27 m high rock cut slope and damaged a car parked at the slope toe. The rockfall was probably caused by slope deterioration and tree root action.

Legend:

Y = Yes N = No Po = Possible
Sig = Significant contribution Mod = Moderate contribution Min = Minor contribution Lit = Little contribution
(DS) = Detailed Study (LR) = Landslide Review (FN) = File Note

Notes:
(1) Massive failure denotes incident with failure volume (detached + deformed volume) > 500 m^3.
Major failure denotes incident with failure volume between 50 m^3 and 500 m^3.
Minor failure denotes incident with failure volume < 50 m^3.
(2) * denotes classification of slope status in accordance with Table 8 of this report.
(3) # denotes other deficiency in design/assessment, including poor detailing, inappropriate geological model, incorrect slope stability analysis, inadequate drainage provisions, etc.

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

Table 10 - Breakdown of Landslides on Engineered Slopes

		Soil Cut Slope	Rock Cut Slope	Fill Slope	Retaining Wall	
All Landslides		4	4	3	0	∑ = 11
Major Failure	(> 500 m³)	0	0	0	0	∑ = 0 (0 %)
	(50 to 500 m³)	0	0	1	0	∑ = 1 (9 %)
Minor Failure (< 50 m³)		4	4	2	0	∑ = 10 (91 %)

Table 11 - Annual Failure Rates on Engineered and Non-Engineered Slopes

	Failure Rate on Slope Number Basis (Number of Landslides Divided by Number of Slopes)	Failure Rate on Unit Slope Surface Area Basis (Surface Area of Landslides Divided by Surface Area of Slopes)	Failure Rate in Terms of Number of Landslides Divided by the Slope Surface Area (no./m^2)
Registered Slopes with No Geotechnical Input (All Landslides Considered)	0.25 %	8.15×10^{-3} %	4.36×10^{-6}
Engineered Slopes Processed by the Slope Safety System (All Landslides Considered)	0.05 %	0.59×10^{-3} %	0.32×10^{-6}
Registered Slopes with No Geotechnical Input (Major Landslides Only)	0.01 %	2.53×10^{-3} %	0.26×10^{-6}
Engineered Slopes Processed by the Slope Safety System (Major Landslides Only)	4.83×10^{-3} %	0.32×10^{-3} %	0.03×10^{-6}
Registered Slopes with No Geotechnical Input (Minor Landslides Only)	0.23 %	5.61×10^{-3} %	4.11×10^{-6}
Engineered Slopes Processed by the Slope Safety System (Minor Landslides Only)	0.048 %	0.27×10^{-3} %	0.29×10^{-6}

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

Table 12 - Breakdown of Landslides on Slopes Previously Treated under the LPM Programme

		Soil Cut Slope	Rock Cut Slope	Fill Slope	Retaining Wall	
All Landslides		3	1	3	0	∑ = 7
Major Failure	(> 500 m^3)	0	0	0	0	∑ = 0
	(50 to 500 m^3)	0	0	1	0	∑ = 1
Minor Failure (< 50 m^3)		3	1	2	0	∑ = 6

Table 13 - Breakdown of Annual Failure Rates on Slopes Previously Treated under the LPM Programme

	Failure Rate on Slope Number Basis (Number of Landslides Divided by Number of Slopes)	Failure Rate on Unit Slope Surface Area Basis (Surface Area of Landslides Divided by Surface Area of Slopes)	Failure Rate in Terms of Number of Landslides Divided by the Slope Surface Area (no./m^2)
All Landslides Considered	0.271 %	4.82×10^{-3} %	1.95×10^{-6}
Major Landslides Only	0.038 %	3.05×10^{-3} %	0.28×10^{-6}
Minor Landslide Only	0.232 %	1.77×10^{-3} %	1.67×10^{-6}

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

Table 14 - Breakdown of Key Contributory Factors in Landslides on Engineered Unsupported Soil Cut Slopes

	All Landslides ($\sum$ = 1 No.)	Local Minor Failures ($\sum$ = 1 No.)	Major Failures ($\sum$ = 0 No.)
Adverse Groundwater	0 (0%)	0 (0%)	0 (0%)
Adverse Geological Material	1 (100%)	1 (100%)	0 (0%)
Inadequate Slope Maintenance	0 (0%)	0 (0%)	0 (0%)
Note: A given landslide may be associated with more than one key contributory factors to the failure.			

Table of Contents

Table of Contents

Table of Contents

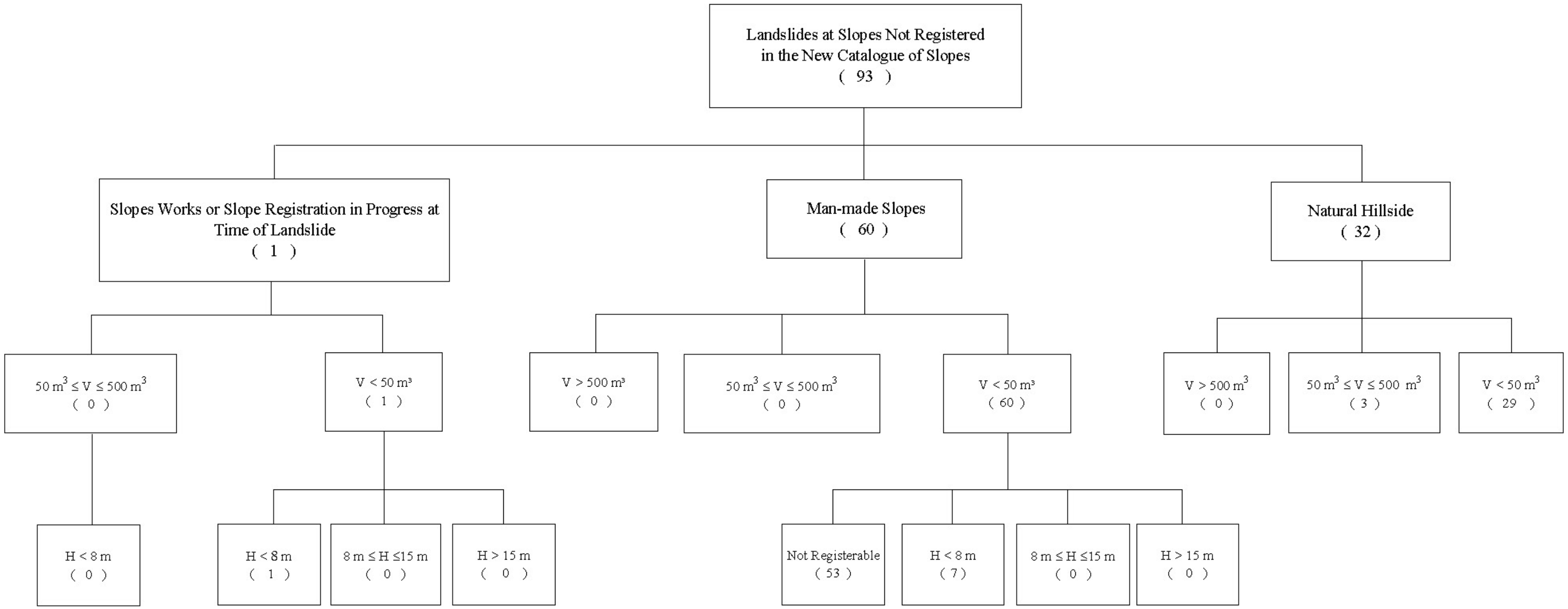
Table of Contents

Table 15 - Progress of Follow-up Actions on the Improvement Measures Recommended in the Review of 2002 Landslides

Recommended Improvement Initiatives	Progress
1. Examine the feasibility of establishing a suitable annual index to serve as an indicator of the performance trend of the slope safety system with respect to rain-induced failures.	A methodology involving the use of the Landslide Potential Index to reflect the performance trend of soil cut slopes has been developed and is being tested.
2. Carry out a review of landslides affecting squatter structures.	Review has been completed and documentation of the findings is in progress.
3. Provide guidelines for proper calculation of CNPCS scores for newly registered features or re-evaluation of CNPCS scores during Engineer Inspections for maintenance.	Guidelines have been prepared and GCC endorsement is being sought.
4. Review the need to provide further guidance on good practice for EI based on observations from landslide studies.	Suitable guidance is given in the Third Edition of Geoguide 5 which was promulgated in December 2003.
5. Promulgate guidance on technical audits of EI by the maintenance departments and recommend that the seriousness of non-compliance identified by the audits should be duly reflected in the consultant's performance appraisal reports.	Guidance notes on technical audits of EI have been promulgated to departments responsible for slope maintenance in August 2004.
6. Review the practicality of stepping up independent detailed technical audits of selected EI by the GEO to provide a supporting service to the maintenance departments and the resource requirements.	Crucial areas of improvement of EI quality have been identified and guidance notes on technical audits of EI have been promulgated to departments responsible for slope maintenance in August 2004.

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

LIST OF FIGURES



Legend:

V Failure volume H Slope height in m (2) Number of cases = 2

Notes: (1) "Not Registerable" refers to cases involving slopes that do not satisfy the feature height criteria for registration in the New Catalogue of Slopes
(2) All Registerable slope features were registered in the New Catalogue of Slopes following the failures.

Figure 1 - Breakdown of Landslides at Unregistered Slopes in 2003

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

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 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.

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