REVIEW OF LANDSLIDES IN 2005

GEO REPORT No. 220

S.M. Tam, T.M.F. Lau, A.F.H. Ng & H.S.W. Kong

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

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

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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
January 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 2005 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, T.M.F. Lau, A.F.H. Ng and H.S.W. Kong 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 2005 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 fatal 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 481 genuine landslides were reported to the Government in 2005. All the available landslide data were examined and 18 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 2005, four major landslides (viz. failure volume of 50 m^3 or more) occurred on engineered man-made slopes that have been accepted under the slope safety system. The corresponding annual failure rate is about 0.02% on a slope number basis (i.e. number of landslides relative to the total number of slopes of such category). In terms of minor landslides (viz. failure volume of less than 50 m^3) on engineered man-made slopes, the annual failure rate is about 0.11% on a slope number basis.

Overall, about 99.87% of the engineered man-made slopes performed satisfactorily without occurrence of landslides in 2005.

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

Page No.

Table of Contents
Table of Contents
Table of Contents

1. INTRODUCTION

This report presents the findings of a diagnostic review of the landslides in 2005 that were reported to the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department (CEDD). The review forms part of the GEO's systematic landslide investigation (LI) programme, which was introduced following the 23 July 1994 Kwun Lung Lau fatal 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 the Government's slope safety system and identify areas for improvement in respect of the slope engineering practice.

Selected significant landslides were identified for in-depth studies to identify lessons learnt together with the necessary follow-up actions. The findings of the studies are presented separately in a series of Landslide Study Reports. The present diagnostic review considers all the available landslide data in 2005, including the findings of the individual landslide studies, in order to examine the performance of the Government's slope safety system and identify areas that deserve attention and improvement. The 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 (FSWJV) and Maunsell Geotechnical Services Limited (MGSL) respectively.

Based on the review, 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 2005

The factual information and the relevant statistics on the rainfall and reported landslides in 2005 were documented by Kong & Ng (2006).

In 2005, the annual rainfall recorded at the Hong Kong Observatory (HKO)'s Principal Raingauge at Tsim Sha Tsui was 3,215 mm. This was some 45% higher than the mean annual rainfall of 2,214 mm recorded between 1961 and 1990. It was also the third wettest year in Hong Kong since records began in 1884. The months of June and August 2005 were the fourth wettest June and the second wettest August on record respectively. The total amount of rainfall in these two months alone (viz. 1,865.2 mm) was about 84% of the mean annual rainfall. Two Landslip Warnings were issued on 24 June 2005 and 19 August 2005 respectively.

Out of a total of 487 reported landslides in 2005, 481 were genuine landslides, discounting those non-landslide incidents such as tree falls. There were altogether 82 major failures (i.e. failure volume $\geq 50\ m^3$), which amounted to some 17% of the number of genuine landslides.

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

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 major landslides is depicted 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 available data on reported landslides were examined as part of the current study. Additional information was collated by GEO's LI consultants to assist in the selection of deserving cases for follow-up studies. Eighteen incidents were selected for follow-up studies in 2005.

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

The annual rainfall in 2005 was well above average. A more direct measure of the severity of the individual rainstorms in the present context is the number of landslides it could cause. This is given by the Landslide Potential Index (LPI), which is promulgated by the GEO (2005). The LPI reflects the relative severity of a specific rainstorm as compared with the most severe rainstorm in the past 20 years in terms of the number of landslides that the rainstorm could trigger, taking due consideration of the characteristics of the rainstorms (viz. the maximum rolling 24-hour rainfall intensity based on the local automatic raingauges), and the spatial distribution of rainstorms relative to the disposition of the registered man-made slopes. The number of landslides on man-made slopes is predicted on the basis of statistical correlations between rainfall intensity and landslide frequency established for the different types of registered man-made slopes developed by Yu (2004) based on reference to landslide and rainfall data for the period of 1984 to 2000. Under the rainfall-landslide correlation model adopted for the operation of the present Landslip Warning System in Hong Kong, the predicted number of landslides on natural terrain and unregistered man-made slopes is taken to be the same as the total number of landslides on registered man-made slopes in the areas affected by the rainfall (Yu et al, 2003).

The LPI for the most severe rainstorm in August 2005, which resulted in a fatality at Fu Yung Shan Tsuen, was 10. This is the same as the LPI associated with the July 1994 rainstorm which resulted in the fatal Kwun Lung Lau landslide.

3. OVERALL DIAGNOSTIC REVIEW OF LANDSLIDES

3.1 Scope of the Review

An overall diagnostic review of all the available landslide data in 2005 has 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.

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

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).

3.2 Coverage of the New Catalogue of Slopes

3.2.1 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 review of existing topographic plans), along with the criteria for slope registration in the New Catalogue of Slopes, is given in GEO Circular No. 15 (GEO, 2004b).

3.2.2 Diagnosis

Of the 481 genuine landslides, 293 occurred on registered slope features (including 288 on registered man-made slopes and five on registered Disturbed Terrain (DT) features). A breakdown of the other 188 incidents is given in Figure 1.

Of the above 188 incidents, 51 involved small man-made slope features and 114 involved natural hillsides, all of which do not satisfy the criteria for registration in the New Catalogue of Slopes. The remaining 23 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 (Figure 1).

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 4.8% of the number of genuine landslides in 2005. Of the 23 landslides, 18 incidents caused no significant consequences to the public, three landslides resulted in permanent evacuation of squatter dwellings and the remaining two involved temporary closure of roads. None of the 23 incidents involved a major failure.

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

Eighteen of the above 23 slope features, about half of which comprised relatively small slopes (i.e. less than 5 m high), have been duly registered in the New Catalogue of Slopes following failure. Registration of the remaining five features was in progress at the time of writing this report.

3.3 Annual Failure Rates of Registered Slopes

3.3.1 General

Based on the landslide data and a review of slope status, the average failure rate of registered slopes can be assessed in terms of the different types of slopes of different 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 carried out under a quality assurance system that satisfies the requirements of ETWB TCW No. 13/2005 (whereby checking by the GEO of the design of 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 a landslide is classified as follows:

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

(b) major failure (i.e. failure volume ≥50 m3).

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

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

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

3.3.2 Diagnosis

Of the 481 genuine landslides reported in 2005, a total of 293 landslide incidents (about 61%) affected 286 registered slopes (i.e. seven slopes had multiple landslide incidents). Of these 293 landslide incidents, 56 were major failures.

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).

Twenty-nine of the 481 genuine landslides (about 6%) affected engineered slopes, four of which being major failures.

Based on the 2005 landslide data and a detailed review of the status of the failed slopes, the annual failure rates of the different types of registered slopes have been calculated (Table 6). These calculated failure rates are not particularly sensitive to the assumptions 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 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 will provide useful insights 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 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.

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

Based on the data in 2005, the annual failure rates for all reported landslides on registered man-made slopes correspond to 5.2×10^{-3} (number of landslides/number of registered slopes), 0.35×10^{-3} (total surface area of landslides/total surface area of registered slopes), and 5.4×10^{-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 3.4.2 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.

3.4 Diagnosis of Landslides on Engineered Slopes

3.4.1 General

A review of the 2005 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.

Of the 29 landslides that affected engineered slopes, eleven of them (three of which were major failures) were formed in the 1980's or before, five (none of which involved a major failure) were formed in the 1990's, and thirteen (one of which was a major failure) 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.

One of the minor failures in 2005 (30 m^3 in volume) involved a slope with outstanding GEO comments on the geotechnical submission made in 2003. Accordingly, this was not taken to be an incident involving engineered slope failure.

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. 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),

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

(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).

3.4.2 Overall Diagnosis

A breakdown of the 29 landslides that occurred on engineered slopes in 2005 with respect to slope type and scale of failure is shown in Table 9. Four of them involved major failures whereas the remainder involved minor failures (failure volumes ranging from 0.03 m^3 to 40 m^3).

The annual failure rates for the 2005 landslide data are summarised in Table 10 for the different categories of engineered slopes.

On a slope number basis, the failure rate of engineered slopes is about six times less than that of non-engineered slopes, whereas on a unit area basis, the failure rate of engineered slopes is some 20 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 17 times less than that of non-engineered slopes.

Of the 29 engineered slopes that failed in 2005, 11 (all of which were minor failures) were previously included in the LPM Programme (see Table 11). The corresponding annual failure rates for LPM slopes are summarised in Table 12.

Based on the above diagnosis, the annual failure rate of LPM slopes for all landslides in 2005 was apparently higher than that for all engineered slopes, but it was lower than that for non-engineered slopes. This observation could be partly due to the fact that the LPM Programme is targeting those difficult and sizeable slopes 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.

It is noteworthy that a notable proportion of failures of engineered slopes affected features formed before 1990. Of the corresponding 11 incidents, three were major failures (which affected one soil cut, the rock portion of a soil/rock cut, and one fill slope respectively), and eight were minor failures (affecting five soil cuts and three rock cuts respectively).

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

A notable proportion of the failures of engineered slopes in 2005 affected features formed after 2000. One of them, which affected a compacted fill slope, was a major failure (100 m^3). The other 12 minor incidents affected an unsupported soil cut, nine soil cuts with soil nails, the unreinforced portion of a soil/rock cut, together with a fill slope. A relatively high proportion of the 2005 landslides that affected engineered slopes formed after 2000 may be attributed to the more extensive use of vegetation in lieu of hard covers in recent years. It should be noted that many of the failures of the post-2000 engineered slopes were of a small scale and hence the corresponding risk was relatively low.

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 number of slopes. In 2005, the actual annual success rates were 99.98% and 99.89% 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 2005, is summarised in Table 13.

3.5 Key Observations

3.5.1 Severity of Rainstorms that Triggered Landslides

Of the 29 landslides that affected engineered slopes, 26 are considered as rain-induced. Amongst these 26 incidents, 20 had sufficiently reliable information to assess the timing and severity of the rainstorms preceding the failures. Fourteen (i.e. 70%) of the 20 cases involved rainstorms which were more severe than those experienced in the past based on data from automatic raingauges installed in the vicinity of the subject slopes in the mid-1980's.

With regard to the other six incidents which failed during less severe rainfall than that experienced in the past, deterioration of the slope condition may have played a role in cases with no obvious changes in environmental factors and where contribution from inadequate slope maintenance was judged to be probably minimal. Another possible reason could be slope deformation caused by previous severe rainstorms which could have resulted in cracking and opening up of the ground, with subsequent failures occurring under less severe rainstorms.

The above diagnosis suggests that the proposition that the continued stability of an existing slope may be proven by having been tested by past rainstorms should be treated with extreme caution. Before one could confidently count on past performance regarding the margin of safety for long-term stability, there is a need to consider factors such as slope deterioration, deformation and possible changes in environmental factors.

3.5.2 Rainfall Forecasting and Landslip Warning

Two Landslip Warnings were issued in 2005, i.e. between 10:15 a.m. on 24 June and 7:45 a.m. on 25 June, and between 9:00 p.m. on 19 August and 6:15 a.m. on 22 August.

The current Landslip Warning is operated by reference to the actual rainfall in the past

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

21 hours together with a 3-hour rainfall forecast made by the HKO. The rainfall forecasting is done using the nowcasting system named SWIRLS (Short-range Warning of Intense Rainstorms in Localized Systems), under which radar signal power is converted into rainfall intensity using a dynamic correlation function, calibrated in real-time based on raingauge data. Details are given by Wong et al (2006).

The August 2005 rainstorm has highlighted the resolution and limitations of the SWIRLS system in rainfall forecasting. This is illustrated by the 3-hour rainfall forecast made at 5:00 p.m. on 19 August 2005 (see Figure 2) as compared with the actual rainfall intensity from 5:00 p.m. to 8:00 p.m. (see Figure 3). It can be seen from Figures 2 and 3 that the forecast was out by a significant margin in this instance. In the event, the landslip alert level was established by the SWIRLS system at 8:06 p.m., whereas the Landslip Warning criteria were reached at 8:15 p.m..

According to Cheung et al (2006), the above discrepancy was allegedly due to the rain bands affecting Hong Kong intensified rapidly during the latter half of the 3-hour forecast period, whereas the SWIRLS system, as it stood then, assumed that both the rainfall intensity and the echo motions of the radar signals would persist during the forecast period. This emphasizes the uncertainties involved in rainfall nowcasting, particularly for severe rainstorms.

To address the above observations, HKO has recently implemented two major enhancements to the SWIRLS system. The enhanced system would need to be tested against real rainstorms.

3.5.3 Comparison of Rainfall and Landslide History between the Two Significant Rainstorms in July 1994 and August 2005

The LPI values for both the rainstorm events during 21-25 July 1994 and 16-21 August 2005 have been assessed to be 10, based on the methodology outlined in Section 2. This would tend to suggest that the above two rainstorms were comparable in terms of their potential in causing landslides. However, it should be remembered that the above calculations are based on the consideration of the 24-hour rainfall only. As the two rainstorms had both caused extensive landslides and casualties, they have been compared in more detail to examine any key observations that can be made.

Table 14 presents a summary of the rainfall and landslide data for the two respective rainstorms. It can be seen from Table 14 that the July 1994 rainstorm was more severe in terms of short-duration rainfall, whereas the August 2005 rainstorm was more severe in terms of medium- to long-duration rainfall.

A total of 202 landslides (of which 19 were major failures) were reported as a result of the July 1994 rainstorm. A total of 229 landslides (of which 70 were major failures) were reported as a result of the August 2005 rainstorm. There is the possibility that the landslides might have been under-reported in 1994, as public awareness of landslide problems was not as high then as compared to the present day due to the considerable public education efforts in this regard by the GEO after 1994. However, it is considered unlikely that the major landslides would have suffered significant under-reporting in 1994 where they affect public

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

facilities. There would be landslides in remote areas on natural hillsides that do not affect the general public and hence would not get reported (these will be picked up by aerial photographs as part of the updating of the Natural Terrain Landslide Inventory).

Another factor which could have affected the number of landslides in August 2005 would be the slope maintenance works undertaken by the slope maintenance departments for all the 39,000 registered government slopes under the routine and enhanced maintenance programmes, together with the efforts of the LPM Programme, all of which have been substantially stepped up since 1995. The routine maintenance works, in particular, are expected to be fairly effective in limiting the number of minor failures for a given rainstorm.

The actual consequences of the two respective landslides may be reflected by the casualties and the degree of social disruption (e.g. number of buildings affected and number of road closure). It can be seen from Table 14 that the actual consequences in 1994 appeared to be more severe than that in 2005. However, it should be cautioned that the actual consequences, especially in terms of casualties, do not take account of 'near-miss' events. As such, the potential consequences of the August 2005 landslides may not necessarily be less severe than that of July 1994 landslides.

The potential consequences of landslides may be reflected, to a certain extent, by the number of major failures affecting different facilities. The August 2005 rainstorm has triggered a lot more major landslides as compared with that of the July 1994 rainstorm. This is possibly a result of the differing characteristics of the respective rainfall events, in particular the higher long-duration (or antecedent rainfall) associated with the August 2005 rainstorm. A breakdown of the major landslides for the July 1994 and August 2005 rainstorms is shown in Table 14. The influence of the 15-day and 31-day antecedent rainfall on the number and size of landslides was previously studied by Pun et al (1999). The study concluded that higher antecedent rainfall could affect the size and proportion of major landslides in a rainstorm, but not necessarily result in more landslides. It is apparent that such observations are generally in line with the outcome associated with the above two rainstorm events.

It can be seen from Table 14 that a notable proportion of the major landslides arising from the August 2005 affected slopes of consequence-to-life category 3 (i.e. affecting lightly used facilities). In terms of landslides on man-made slopes of consequence-to-life categories 1 and 2, the number of major landslides were 16 in July 1994 and 23 in August 2005. The corresponding figures for reported major landslides on natural hillsides were zero and 10 respectively.

The LPI has been developed to provide a means to describe the severity of a rainstorm in the context of its potential to cause landslides (i.e. total number of landslides). It is not intended to quantify the consequence or size of the landslides, although as more landslides occur, there is a higher chance that some of them are of major size and have more severe consequences. The total number of landslides caused by the two rainstorm events, both with an LPI of 10, are comparable. It would appear that the LPI gives a reasonable quantification of the severity of a rainstorm within its context.

It should be noted that the rainfall/landslide correlation models as adopted for the LPI calculations were derived basically from historical data for registered man-made features only.

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

The LPI does not reflect the severity of the rainstorm in terms of consequences or number of major incidents. The rainfall data used in the development of the frequency model were based on the maximum rolling 24-hour rainfall only; the effects of antecedent rainfall were not considered in the development of the correlation models.

Given the scatter of the data, there are significant uncertainties involved in the correlation model as adopted for the calculation of the LPI value. Also, the potential influence of high antecedent rainfall is not accounted for in the present methodology for LPI calculations. Although the calculated LPI values for the two severe rainstorms in July 1994 and August 2005 are the same, given the uncertainties involved in the statistical correlations for the derivation of LPI, caution should be exercised in making any definitive conclusions regarding slope performance based on a comparison of the actual consequences of these two rainstorms alone.

3.5.4 Landslides on Engineered Slopes

3.5.4.1 General

In 2005, 29 landslides occurred on engineered slopes involving 20 soil cuts, four rock cuts and five fill slopes. The maintenance responsibility for the failed portions of 23 slopes rests with Government, whereas the other six are under private ownership.

3.5.4.2 Soil Cuts

One of the 20 landslides that affected engineered soil cuts involved was a major failure.

Sixteen of minor failures occurred on vegetated slopes, one on a slope with bare surface and the other three (one of which was major) affected slopes with hard surface cover. The distribution of the corresponding slopes processed by the slope safety system was 7 nos. in the 1980's , 2 nos. in the 1990's and 11 nos. after 2000.

Of the 20 landslides, nine occurred on soil cuts with soil nails. The majority of these involved very minor detachments from the near-surface material in between the soil nail heads (i.e. within the active zone of the soil nails) of the vegetated slopes (Table 7). Similar failures had occurred in the past with other vegetated slopes with soil nails, as noted and discussed by Ng et al (2005). Two other 2005 incidents on soil-nailed cuts involved more sizeable failures (of 20 m^3 and 35 m^3 respectively) affecting a larger zone.

Ng et al (op cit) had recommended that a review of failures of soil-nailed slopes be undertaken to examine if there is a need for improved detailing against the occurrence of shallow failures within the active zone of the soil nails. The cases in 2005 have greatly enriched the database of such failures for a more comprehensive review.

Eleven of the 20 landslides (i.e. 55%) involving soil cuts occurred on unsupported cuts. Amongst the 11 cases, seven were formed in the 1980's, two in the 1990's and the other two after 2000. One of the 11 landslides was a major failure (800 m^3) on an unsupported cut, which was formed in the early 1980's, and had a past major landslide in 1993.

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

The key contributory factors to the failures of engineered unsupported cuts are summarized in Table 15. Of the 11 landslides, six (including the major failure) involved failures that were controlled mainly by geological and groundwater conditions that were more adverse than previously anticipated, whilst the other five incidents were due to lack of maintenance (3 nos.), inadequate surface drainage provisions (1 no.), and concentrated surface water flow following uncontrolled discharge from the uphill catchment (1 no.).

3.5.4.3 Rock Cuts

Amongst the four rockfall incidents that affected engineered rock cuts, one was processed by the slope safety system in the late 1970's, two in the 1980's and the other in early 1990's.

A combination of local adverse joints, water ingress through enhanced surface infiltration (as a result of replacement of hard cover to vegetated cover for the upper soil portion), and progressive deterioration of the slope condition (resulting in the progressive opening up of the rock joints), probably played a key role in the failures. Unplanned and undesirable vegetation due to inadequate maintenance, probably leading to root jacking action on adversely orientated rock blocks, was also an important contributory factor to one of the failures.

One of the four incidents was a major failure on the rock portion of a sizeable (maximum 47 m high) soil/rock slope, which involved the detachment and displacement of rock mass of more than 150 m^3 in volume. The slope was previously processed by the slope safety system in the late 1970's.

The rock portion was fully covered by shotcrete, which prevented a detailed assessment of the slope condition during Engineer Inspections carried out in 1999 and 2003 respectively. The slope was included in the Enhanced Maintenance Programme (EMP) in 2001 and prescriptive soil nails together with raking drains were installed to improve the stability of the soil portion. At that time, there were no records of past instability of the rock portion, and no works were undertaken under the EMP to improve the rock portion. Details of the study were given in Lau & Ho (2006).

The other three rockfall incidents on engineered rock cuts involved very minor detachments (maximum 0.2 m^3). None of these three subject rock cuts had a rock mesh netting.

3.5.4.4 Fill Slopes

With regard to the five incidents on engineered fill slopes, one of the affected slopes was processed by the slope safety system in the 1980's, one in the 1990's and three after 2000.

Of the five incidents, two were major landslides, both with a failure volume of 100 m^3. One of these occurred on a private fill slope, which was formed in association with a private redevelopment project in the early 1980's. The landslide debris, which comprised soil and

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

broken pieces of a parapet wall, was deposited on the road below and the road was temporarily closed.

The other major landslide involved a compacted fill slope that was formed in 2003 in a construction site of a housing estate redevelopment. The landslide was a fairly extensive but shallow failure, with a scar that measured less than 1 m in depth and about 18 m in width. The Housing Department engaged a consultant to undertake an investigation of the failure. The study noted that the compacted fill contained some foreign materials locally in the area which was formed in two different construction stages, and that the degree of compaction at the time of failure appeared to be less than the stipulated requirement in some areas.

The remaining three incidents on engineered fill slopes were minor failures, involving inadequate maintenance and surface drainage provisions.

3.5.5 Landslides on Natural Hillsides and Disturbed Terrain

A total of 119 landslides on hillsides (including disturbed terrain) were reported in 2005 (i.e. about 25% of the genuine landslides), 28 of which involved major failures.

The nature of the 119 incidents has been diagnosed based on the available information. Sixty-five are classified as natural hillside failures (i.e. the failures affected natural hillsides which have not been modified by human activities, such as cutting, filling, cultivation, etc.). The other 54 (including five 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.

Some of the hillside failures resulted in notable consequences, including one fatality in a squatter village (Fu Yung Shan landslide incident, see also Section 3.5.8), temporary evacuation of part of a staff quarter in a hospital complex (Queen Mary Hospital landslide incident), together with temporary closure of a primary school (Bowen Road landslide incident) as well as roads in the urban areas (e.g. Lai King Hill Road landslide incident) and sole accesses (e.g. Fei Ngo Shan landslide incident).

The 2005 landslides have highlighted the diverse range of hillside failures, including slow-moving shallow instability (e.g. Queen Mary Hospital landslide incident) and fast-moving debris, either in the form of open hillslope failure or channelised debris flow (e.g. Kwan Yam Shan landslide incident), landslides carrying sizeable boulders (e.g. Tai Hang Road boulder fall incident), knock-on effects from one landslide to another (e.g. Bowen Road landslide incident), etc. Apart from large stretches of natural hillsides, including local disturbed terrain, above developments, relatively small hillside pockets within developed areas are also liable to pose a significant hazard, especially when it is subjected to disturbance (e.g. de-vegetation) or adverse influence from developments above (e.g. uncontrolled discharge onto the hillside, leakage of services, uncontrolled surface water flow due to inadequate surface drainage provisions or inadequate maintenance, etc.).

Most of the hillside failures were shallow (less than 3 m) involving a shallow mantle of colluvium or the near-surface material, but some involved deep failures in the saprolites. The causes of hillside failures can also be diverse. The majority of the landslides are

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

triggered by heavy rainfall but some were due to uncontrolled surface water flow or leakage of water-carrying services (e.g. Lai King Hill Road landslide incident). Past disturbance of the hillsides, such as the presence of wartime relics of military trenches (e.g. Kwum Yam Shan incident), old disused drainage ditches with no maintenance (e.g. Ma On Shan incident), de-vegetation (e.g. Tai Hang Road incident), local dumping of fill (Bowen Road incident), illegal cultivation (e.g. Fu Yung Shan incident), deposition of trash which could lead to an unfavourable hydraulic boundary condition (e.g. Fu Yung Shan incident), presence of topsoil with a high organic content due to past land-use (e.g. Victoria Road incident below the Vocational Training Council Training Centre Complex), may be contributory factors in the failures.

Apart from the above adverse anthropogenic influences, the hillside failures, especially the sizeable landslides, have also shown that the hillsides may exhibit intermittent movement over a long period and progressive deterioration for a considerable period of time before detachment of debris. The prolonged movement may be manifested by open cracks, which may or may not be infilled with foreign materials, making the slope more vulnerable to progressive deterioration and therefore liable to fail in a sudden manner when subjected to intense rainfall.

Apart from being a potential contributory factor to hillside failure through leakage, water-carrying services are also liable to escalate the landslide consequence should the pipelines become ruptured by slope movement or failure. In the case of the Queen Mary Hospital landslide incident, the extensive distress on the hillside was discovered because a pressurized water supply pipeline, which had been constructed directly across terrain with pre-existing slope instability, was fractured when the heavy rainfall in August 2005 triggered further slope movement. Loss of water pressure was reported, and this led eventually to the recognition of the problem. The potential consequences could have been much more severe if the sudden fracture of a pressurized water main by slope movement were to result in the release of a considerable amount of free water, which in turn might lead to a mobile and massive landslide. Facilities that are liable to exacerbate the likelihood and/or the consequence of slope movement or instability (e.g. pressurised mains, gas pipes, etc.), especially where they are to be unavoidably cited on terrain with a history of instability, would warrant attention.

It is noteworthy that some of the hillside failures in 2005 have occurred in terrain with no apparent past instability based on aerial photographs and field mapping, whereas other failures have occurred in areas with a history of past instability. Even in cases involving possible re-activation of past failures or retrogressive failures in areas with past failures, the previous landslides in recent times (i.e. excluding the possible relict landslides) were of a smaller scale than that in 2005 in some instances. This may be a function of the rainfall characteristics in 2005 (i.e. high antecedent rainfall) and progressive deterioration of the hillsides.

As regards debris mobility, the hillside failures in 2005 also highlighted the complexity in respect of the actual debris runout, both in terms of the runout paths and distances. Debris entering a natural streamcourse may not necessarily fully follow the alignment of the drainage line as the debris is liable to overshoot at bends, depending on factors such as volume of failure, degree of entrainment, debris movement mechanisms, changes in streamcourse directions, etc.. The 2005 landslides have also highlighted the

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

importance of subtle local depressions on a hillside in controlling the debris flowpath, but these depressions are not discernable especially in a heavily vegetated hillside from the available topographic maps.

The diverse range of hillside landslides in 2005 served as an important reminder of the complexities and uncertainties involved in the assessment of hillside susceptibility, evaluation of landslide consequences and quantification of landslide risk.

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

All the 293 reported landslide incidents involving registered slope features were reviewed to assess whether inadequate maintenance was likely to have been a major 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 48 out of the 293 incidents (i.e. 16%). Amongst them, four incidents occurred on engineered slopes (three on soil cuts and one on a fill slope).

Of the 48 incidents, 29 affected Government slopes, 16 affected private slopes and one affected both the Government and private portions of a mixed maintenance (MR) responsibility slope feature. Based on the information in the Slope Maintenance Responsibility Information System (SMRIS) managed by the Lands Department, the MR of the slopes involved in the remaining two incidents is yet to be determined as at the end of November 2006.

The above re-affirms the importance of regular slope maintenance. It also serves as a reminder that even an engineered slope is liable to fail because of inadequate maintenance.

3.5.7 Landslides Affecting Catchwaters

Amongst the 481 genuine landslides in 2005, 39 (i.e. 8%) occurred on slopes affecting catchwaters, 12 of which were major failures. One of the minor landslides affected an engineered soil cut.

Selected past landslides affecting catchwater slopes leading to havoc on the downhill developments (e.g. the 5 November 1993 Tong Fok incident, the 5 November 1993 Alpine Garden incident and the 2 July 1997 Tuen Mun Highway incident) have illustrated the potential hazard of the knock-on effects following blockage of the catchwater channels by landslide debris. This was illustrated again by the debris flood incident at Lo Wai in Tsuen Wan on 20 August 2005 (MGSL, 2006). Debris from the failure of a man-made slope on the uphill side of a catchwater blocked the catchwater channel and caused the water flow to back up and hence discharge via overflow weirs into a natural streamcourse. The large discharge down the streamcourse caused entrainment and collapse of the stream banks and developed into a debris flood. A number of registered squatter structures alongside the streamcourse

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

were affected, and one of the piers of a footbridge across the streamcourse was destroyed. The debris flood caused serious flooding in Lo Wai Village and necessitated large-scale temporary evacuation. The site setting was adverse in that landslides occurring some 800 m above Lo Wai Village, through a serious of knock-on effects, led to major havoc and significant social consequences to the developed area downhill.

A similar incident involving a landslide causing blockage of the catchwater channel above Kong Pan Tin Tsuen in Tsuen Wan, and leading to large discharge via overflow weir into a natural streamcourse. In the process, a squatter structure alongside the streamcourse was undermined and the debris laden surface runoff traversed overland across Route Twisk at the toe of the hillside and caused the failure of an old fill slope on the downhill side of the road and temporary road closure.

The indirect risk posed to the developed areas and any squatters by blockages of catchwaters was underlined by the above incidents. Provision of overflow weirs has helped to preserve the integrity of the catchwater channel but there would appear to be insufficient attention paid to assessing, and catering for, the consequential flows down the natural streamcourses. The more vulnerable streamcourses were inadequate to carry the debris-laden flood water, putting any developed areas and squatter dwellings close to, or at the mouths of, streamcourses at high risk of being carried away by the debris flood or debris flow. Although the ensuing evacuations and road closures following the 2005 catchwater incidents caused some disruption, the consequences could have been more severe. The incidents emphasize the need to adopt a more holistic approach in respect of the planning, design, inspection, maintenance and rehabilitation of catchwaters/streamcourses across the various responsible departments whose work impacts on landslip mitigation and flood routing.

3.5.8 Landslides Affecting Squatters

In 2005, 40 landslides (i.e. 8% of the total reported genuine landslides) affected registered squatter dwellings, of which eight were major failures. Amongst the 40 landslides, 25 occurred on registered man-made slopes, six on unregistered, but registerable, man-made slopes, one on a registered DT feature, five on hillsides and three on small man-made slope that do not satisfy the slope registration criteria (i.e. slope height <3 m).

The 40 landslides collectively resulted in one fatality, together with recommendations for the permanent evacuation of 34 registered squatter dwellings and the temporary evacuation of 8 registered squatter dwellings[1].

Amongst the 34 registered squatter dwellings that were recommended for permanent evacuation after the 2005 landslides, 18 were subject to outstanding Category 2 Non-development Clearance (NDC) recommendations arising from previous NDC inspections (GEO, 2004a).

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[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.

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

The landslide related fatality at Fu Yung Shan Tsuen involved the collapse of a disturbed hillside pocket within a squatter area, during which time the Landslip Warning was in force. The deceased, who was not a resident in the Fu Yung Shan squatter area, was probably on a footpath affected by the landslide.

The fatal incident at Fu Yung Shan Tsuen has highlighted the following:

(a) The NDC policy although had been effective to mitigate the landslide risk to vulnerable squatter dwellings by clearance before the mid-1990's has become ineffective since then, as the policy to clear those vulnerable squatters with forced eviction as the last resort has, in effect, been dropped (i.e. clearance has become voluntary). Squatter settlements on steep hilly terrain, including dwellings, access paths and open spaces, continue to be susceptible to landslide hazards.

(b) Vulnerable hillsides and substandard man-made slopes within squatter areas are susceptible to landslides during heavy rainfall, and slope failures are liable to occur without prior observable warning. The landslide risk posed to the public will be accentuated when the Landslip Warnings are not heeded by squatter residents or visitors to squatter areas.

(c) Human disturbances to hillsides and man-made slopes, such as uncontrolled dumping of refuse and illegal earthworks, are liable to adversely affect the infiltration characteristics of the ground. This in turn could render the slopes more susceptible to landslides. The landslide risk may increase with time due to inadequate land management control and progressive slope deterioration.

A Quantitative Risk Assessment (QRA) of the landslide hazards arising from man-made slopes and hillsides (including natural terrain and disturbed terrain) was subsequently completed by the GEO for the squatter area at Fu Yung Shan (Wong & Ko, 2006). With regard to the risk to structures, hillsides account for 65% of the risk and man-made slopes contribute the other 35%. More than 85% of the risk to structures from hillsides is associated with disturbed hillsides. The study concluded that the NDC recommendations made previously by the GEO on the basis of engineering judgement were consistent with the QRA findings in that the vast majority of the existing squatter structures with outstanding NDC recommendations are exposed to an unacceptably high landslide risk. Also, the NDC recommendations were found to be not unduly conservative by reference to the risk criteria.

The QRA further noted that the landslide risk of the footpath network at Fu Yung Shan is much lower than that of the squatter structures. The August 2005 landslide, which resulted in one fatality, was an improbable and unfortunate event, and should not be taken as indicating that the footpath network in Fu Yung Shan Tsuen is of high risk.

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

The incidents at Lo Wai Village and Kong Pan Tin Tsuen have highlighted that squatter dwellings located along or close to streamcourses located downstream of catchwater overflow weirs can be hazardous in the event of significant discharge from the catchwater above. Significant discharge can take place when the design capacity of the catchwater channel is exceeded under intense rainfall. The situation would be exacerbated if the catchwater channel were to be significantly blocked by landslide debris. At the time of writing this report, clearance actions on NDC recommendations made by the GEO on about 500 such squatter dwellings based on previous NDC inspections remain outstanding.

4. PROPOSED IMPROVEMENT INITIATIVES

Improvement initiatives were proposed by Ng et al (2005) following the diagnostic review of the landslides that occurred in 2004. The progress of the follow-up actions is summarised in Table 16.

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

(a) continue to study notable natural terrain landslides to improve the understanding of hillside failures and the assessment of hillside susceptibility (see Section 3.5.5);

(b) review the strategy for managing the risk of landslides affecting catchwaters (see Section 3.5.7);

(c) expand the review of landslides involving soil-nailed slopes and propose suitable improvement measures (see Section 3.5.4.2); and

(d) review slopes with reported major failures after completion of works to establish the need for follow-up actions (see Section 3.5.4.2).

The 2005 landslides have shown that the NDC policy, although had been effective to mitigate the landslide risk to vulnerable squatter dwellings by clearance before the mid-1990's, has become ineffective, as clearance of the concerned squatters has become voluntary since the mid-1990's. A more effective means to reduce landslide risk associated with government slopes that threaten registered squatter dwellings, including consideration of land management issues, is being formulated by the relevant bureaux. In view of this, no further improvement initiatives are proposed in this regard.

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 and minor landslides on

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

engineered slopes, on a slope number basis, were 0.02% and 0.11% respectively in 2005. The pledged annual success rates of 99.8% and 99.5% of engineered slopes in preventing major and minor landslides, respectively, were met.

(b) More than 99.85% of the engineered slopes performed satisfactorily without the occurrence of any landslides in 2005.

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 4 of the report, with a view to further improving the slope engineering practice and enhancing the slope safety system in Hong Kong.

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

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

LIST OF TABLES

Table of Contents
Table of Contents
Table of Contents

Table 1 - Distribution of Landslides as Classified by Type of Slope Failure

Type of Failure		No. of Landslide	Percentage (%)
Fill Slope		35 (8)	7.3
Cut Slope	Soil	219 (36)	45.5
	Soil/Rock	86 (10)	17.9
	Rock	10 (0)	2.1
Retaining Wall		12 (0)	2.5
Natural Hillsides		114 (26)	23.7
Registered Disturbed Terrain		5 (2)	1.0
Total		481 (82)	100

Legend:
35 (8) Thirty-five landslides of which eight 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) Incidents which 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	0 (0)	0 (0)	40 (8)	40 (8)
Buildings	8 (5)	2 (1)	20 (3)	30 (9)
Roads	38 (7)	6 (2)	48 (13)	92 (22)
Transportation Facilities (railways, tramways, LRT, etc.)	0 (0)	0 (0)	0 (0)	0 (0)
Pedestrian Pavements/Footways	12 (1)	4 (0)	6 (0)	22 (1)
Minor Footpaths/Access	28 (1)	6 (1)	71 (12)	105 (14)
Construction Sites	0 (0)	0 (0)	3 (0)	3 (0)
Open Areas	33 (3)	14 (4)	52 (7)	99 (14)
Catchwaters	5 (2)	0 (0)	34 (10)	39 (12)
Others (e.g. carparks, parks, playgrounds, gardens, backyards, etc.)	23 (2)	4 (1)	35 (6)	62 (9)

Legend:
8 (5) Eight landslides of which five were 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 3 - 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		6 (7)	2 (2)	0	5	0	0	0	0
Cut Slope	Soil	16 (60)	6 (21)	5	21	8	13	0	0
	Soil/Rock	0	0	1	16	2	3	0	0
	Rock	0	0	0	3	1	1	0	0
Retaining Wall		1 (5)	0	1	0	0	4	0	0
Natural Hillsides		9 (10)	0	5	17	2	11	1	0
Registered Disturbed Terrain		2 (4)	0	0	0	0	1	0	0

Legend:

16 (60) 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.

(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

	Facility Group Affected by Major Landslides (Group No.)						
	1a	1b	2a	2b	3	4	5
All Major Landslides	9	9	0	1	10	23	30
Major Landslides on Man-made Slopes	6	6	0	1	6	17	18
Major Landslides on Registered Disturbed Terrain Features	0	0	0	0	0	2	0
Major Landslides on Natural Hillsides	3	3	0	0	4	4	12

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 5 - Breakdown of Scale of Failures for Different Classes of Slopes

	Number of Minor Failures (<50 m³)	Number of Major Failures		
		(50 m³ to 500 m³)	(>500 m³)	
Registered Man-made Slopes	234	46	8	Σ = 288
Registered Disturbed Terrain Features	3	1	1	Σ = 5
Small Unregisterable Man-made Slopes	51	0	0	Σ = 51
Registerable Man-made Slopes Not Yet Registered at Time of Failure	23	0	0	Σ = 23
Natural Hillsides	88	18	8	Σ = 114
	Σ = 399	Σ = 65	Σ = 17	Σ = 481

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 2005

		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 2005	Number of Slopes	26	233	259	5	24	29
	Surface Area of Landslides (m^2)	2243	14750	16993	319	1317	1636
Slopes Involved in Major Landslides in 2005	Number of Slopes	6	44	50	2	2	4
	Surface Area of Landslides (m^2)	1708	10477	12185	262	743	1005
Slopes Involved in Minor Landslides in 2005	Number of Slopes	20	189	209	3	22	25
	Surface Area of Landslides (m^2)	535	4273	4808	57	574	631
Total Number of Registered Slopes		11,600	21,550	33,150	10,100	11,750	21,850
Total Surface Area of Registered Slopes (m^2)		6,493,000	11,831,000	18,324,000	11,984,000	23,472,000	35,456,000
Annual Failure Rates (All Landslides Considered)	On a Slope Number Basis	0.22 %	1.08 %	0.78 %	0.05 %	0.20 %	0.13 %
	On a Unit Slope Surface Area Basis	0.035 %	0.12 %	0.093 %	2.66×10^{-3} %	5.61×10^{-3} %	4.61×10^{-3} %
	Number of Landslides Divided by Slope Surface Area (no./m^2)	4.00×10^{-6}	1.97×10^{-5}	1.41×10^{-5}	4.17×10^{-7}	1.02×10^{-6}	8.18×10^{-7}
Annual Failure Rates (Major Landslides Only)	On a Slope Number Basis	0.05 %	0.20 %	0.15 %	0.02 %	0.017 %	0.018 %
	On a Unit Slope Surface Area Basis	0.026 %	0.088 %	0.066 %	2.19×10^{-3} %	3.17×10^{-3} %	2.83×10^{-3} %
	Number of Landslides Divided by Slope Surface Area (no./m^2)	9.2×10^{-7}	3.72×10^{-6}	2.73×10^{-6}	1.67×10^{-7}	8.52×10^{-8}	1.13×10^{-7}

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 9)

1. Slopes Upgraded Under the LPM Programme

Slope No.	Incident No.	Location	Volume (m^3)	Type of Slope	Remarks
11NE-C/C13	2005/05/0112	Shum Wan Shan Fresh Water Pumping Station, near Jordan Valley Playground	0.2 (rockfall)	Soil/rock cut	LPM works (cut back with shotcrete cover and rock slope treatment works) completed in 1988.
11SE-D/C57	2005/05/0125	Sai Wan Service Reservoir, Tai Tam Road, Chai Wan	5	Soil/rock cut	LPM works (soil nails and rock slope treatment works) completed in 2004.
11SW-B/CR5	2005/06/0205	Hong Kong Zoological & Botanical Gardens, Upper Albert Road	2	Soil cut and retaining wall	LPM works (soil nails, raking drains and vegetated cover with erosion control mat) completed in 2005.
6SE-C/CR323	2005/07/0255	Shu On Terrace, Sham Hong Road, Sham Tseng	1.2	Soil cut	LPM works (soil nail, raking drains and vegetated cover) completed in 2003.
11SW-A/C102	2005/08/0306	Junction of Victoria Road and Sai See Street, Kennedy Town	3	Soil cut	LPM works (soil nails and vegetated cover with erosion control mat) completed in 2004.

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 9)

1. Slopes Upgraded Under the LPM Programme (Cont'd)

Slope No.	Incident No.	Location	Volume (m^3)	Type of Slope	Remarks
13NE-A/C100	2005/08/0313a	Near Shek Pik Reservoir, South Lantau Road	5	Soil/rock cut	LPM works (soil nails, raking drains, rock dowels and vegetated cover with erosion control mat) completed in 2004.
13NE-A/C102	2005/08/0313b	Near Shek Pik Reservoir, South Lantau Road	5	Soil cut	LPM works (soil nails and vegetated cover with erosion control mat) completed in 2005.
13NE-A/C108	2005/08/0313c	Near Shek Pik Reservoir, South Lantau Road	2	Soil/rock cut (mainly soil)	LPM works (soil nails, raking drains, skin walls and vegetated cover with erosion control mat) completed in 2004.
7SW-C/CR1045	2005/08/0451	Lei Pui Street near junction of Shek Pai Street, Kwai Chung	3	Soil/rock cut	LPM works (soil nails, raking drains, vegetated cover on soil portion and rock slope treatment works) completed in 2002.
15NE-A/C152	2005/08/0493	Ma Hang Prison behind a vacant quarter	35	Soil/rock cut	LPM works (soil nails and of vegetated cover) completed in 2001.
6SE-D/CR437	2005/08/0504	Tai Lam Chung Catchwater Section M, Ch 5000	20	Soil/rock cut	LPM works (soil nails, raking drains, vegetated cover on soil portion and rock slope treatment works) completed in 2002.

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 9)

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.

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

Slope No.	Incident No.	Location	Volume (m^3)	Type of Slope	Remarks
11SW-A/C1183	2005/06/0162	Lung Wah Street opposite Mount Davis Ambulance Depot	2	Soil cut	The geotechnical design of the subject slope was checked and accepted by the GEO in 2001 in association with a site formation project at Lung Wah Street.

Table 7 - Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 4 of 9)

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
11SE-B/C50	2005/06/0163	Sze Shan Street, Yau Tong	3	Soil cut	The geotechnical design of the subject slope was checked and accepted by the GEO in 1992.
11SW-A/CR146	2005/06/0237	Pokfulam Road	10 (2 scars, each of 5 m^3)	Soil cut and retaining wall	The geotechnical design of the subject slope was checked and accepted by the GCO in 1982.
15NE-C/FR128	2005/08/0287	Carmel Road, Stanley	0.03 (washout)	Fill and retaining wall	The geotechnical design of the subject slope was checked and accepted by the GEO in 1996 in association with the site formation works under the Ma Hang Development Phases 2 & 3.
15NW-B/C313	2005/08/0295	Island Road	20	Soil/Rock cut	The geotechnical design of the subject slope was checked and accepted by the GCO in 1983.
3SW-C/C234	2005/08/0396	Police Tactical Unit, Fanling	40	Soil cut	The geotechnical design of the subject slope was checked and accepted by the GCO in 1989.
11NE-D/C871	2005/10/0558	Anderson Road Quarry	Signs of distress	Soil cut	The geotechnical design of the subject slope was checked and accepted by the GEO in 1998.

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 9)

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
11NE-D/C44	2005/11/0561	Above Tennis Court of Hiu Ming Street Playground, Kwun Tong	0.125 (rockfall)	Rock cut	The geotechnical design of rock slope stabilisation works at eastern portion, where the landslide incident occurred, was checked and accepted by the GCO in 1981. The western portion was upgraded under LPM Contract No. 5/GCO/83 and completed in 1986.
7SW-C/FR10	HD/NT/2005/12/0001	Between toe retaining wall and lowest berm, Tai Ha Street, Kwai Chung	100	Fill	The geotechnical design of the subject slope was checked and accepted by the GEO in 2003 under a Housing Re-development project.
7SW-C/FR311	ArchSD/TW/2005/10/0001	Shing Mun Valley Swimming Pool	10	Fill	The geotechnical design on the subject slope was checked and accepted by the GEO in 1992.

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 6 of 9)

7. <u>Slopes Formed or Upgraded by Private Owners and Checked by GEO</u>

Slope No.	Incident No.	Location	Volume (m³)	Type of Slope	Remarks
7NW-B/FR254	2005/06/0174b	Hong Chi Pinehill No. 3 School, Chung Nga Road, Nam Hang, Tai Po	2	Fill	The geotechnical design of the subject slope was checked and accepted by the GEO in 2002.
11NE-A/C153	2005/08/0299	Ping Ting Road (opposite to Hung Sin Chau Memorial School)	170 (rockfall + rock wedge displacement)	Soil/Rock cut	The geotechnical design of the failed portion (at northern part of the slope) was approved by BD in 1979. The designs of central and southern part of the slope were checked and accepted by GCO in 1984 and 1987 respectively.
11SW-C/FR126	2005/08/0308	57 Mount Davis Road, Honeyville Canossian Retreat House	100	Fill and retaining wall	The subject slope was modified in association with the site formation works for the redevelopment of Honeyville Canossian Retreat House between 1980 and 1984. The slope works design was checked and accepted by the Geotechnical Control Branch of the Buildings Ordinance Office in 1983.

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 7 of 9)

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
11SE-A/C285	2005/08/0364	Tai Hang Drive (opposite to Ronsdale Garden)	800	Soil cut	The slope was formed between 1981 and 1982 in conjunction with the construction of part of Tai Hang Drive extension, under Phase 1 site formation for the residential development of Ronsdale Garden. The slope works design was checked and accepted by the GCO in 1981.
7SW-C/C1072	2005/08/0378	Greenknoll Court, No. 382 Castle Peak Road, Kwai Chung	15	Soil cut	The geotechnical design of the subject slope was checked and accepted by the GCO in 1989.
11SW-C/C185	2005/08/0475	Chinese Christian Cemetery, Junction of Victoria Road and Consort Rise, Pok Fu Lam	40	Soil cut	The stability of the subject slope was assessed by the private owner upon a request made by BDD in their letter dated 22 December 1982. The slope was subsequently modified and the geotechnical design was checked and accepted by the GCO in 1986.

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 8 of 9)

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

Slope No.	Incident No.	Location	Volume (m^3)	Type of Slope	Remarks
11NW-B/CR54	2005/06/0182	Chi Yun College, 19 Kwong Lei Road, Sham Shiu Po	1	Soil cut	Slope upgraded under default works in 1983 by BD following service of a DH Order in 1982.
11NW-A/C120	2005/08/0434	Behind No. 23 Chung Shan Terrace, Kwai Chung	0.1 (rockfall)	Rock cut	Slope upgraded (by BOO in default) in 1992 following service of a DH Order in 1988.

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

Nil.

Table 7 - Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 9 of 9)

10. <u>Slopes Assessed as Requiring Upgrading Works but with Outstanding GEO Comments</u>

Slope No.	Incident No.	Location	Volume (m^3)	Type of Slope	Remarks
11SW-C/C933	2005/08/0412	Victoria Road (LMP 47546) near Wah Chui Street, Pok Fu Lam	30	Soil and rock cut	The subject slope was formed/modified under the Victoria Road Improvement - Stage 2. GEO’s comments in 2003, such as issues on verification of design groundwater level and outstanding geotechnical submission on the rock slope portion, have not yet been addressed.

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 8 - Classification of Engineered Slopes

Feature Type	Classification
Post-1978 Features (i.e. formed or upgraded after 1978)	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-1978 Features (i.e. formed before 1978 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 - Breakdown of Landslides on Engineered Slopes

	Soil Cut	Rock Cut	Fill Slope	Retaining Wall	
All Landslides	20	4	5	0	Σ = 29 (100%)
>500 m^3	1	0	0	0	Σ = 1 (3.4%)
50 m^3 to 500 m^3	0	1	2	0	Σ = 3 (10.3%)
<50 m^3	19	3	3	0	Σ = 25 (86.3%)

Table 10 - 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)	0.78 %	0.093 %	1.41×10^{-5}
Engineered Slopes Processed by the Slope Safety System (All Landslides Considered)	0.13%	4.61×10^{-3} %	8.18×10^{-7}
Registered Slopes with No Geotechnical Input (Major Landslides Only)	0.15 %	0.066 %	2.73×10^{-6}
Engineered Slopes Processed by the Slope Safety System (Major Landslides Only)	0.02 %	2.83×10^{-3} %	1.13×10^{-7}
Registered Slopes with No Geotechnical Input (Minor Landslides Only)	0.63 %	0.026 %	1.14×10^{-5}
Engineered Slopes Processed by the Slope Safety System (Minor Landslides Only)	0.11 %	1.78×10^{-3} %	7.05×10^{-7}

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

Table 11 - Breakdown of Landslides on Slopes Previously Treated under the LPM Programme

	Soil Cut	Rock Cut	Fill Slope	Retaining Wall	
All Landslides	10	1	0	0	$\sum = 11$
>500 m³	0	0	0	0	$\sum = 0$
50 m³ to 500 m³	0	0	0	0	$\sum = 0$
<50 m³	10	1	0	0	$\sum = 11$

Table 12 -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)	0.379 %	3.60×10^{-3} %	2.30×10^{-6}
Slopes Treated under LPM Programme (Major Landslides Only)	0 %	0 %	0
Slopes Treated under LPM Programme (Minor Landslides Only)	0.379 %	3.60×10^{-3} %	2.30×10^{-6}

Table of Contents

Table of Contents

Table of Contents

Table of Contents

Table 13 - Annual Success Rate of Engineered Slopes from 1997 to 2005

	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
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
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

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

Table 14 - Comparison between 21-25 July 1994 and 16-21 August 2005 Rainstorms

		21-25 July 1994 Rainstorm		16-21 August 2005 Rainstorm	
Number of Landslides		202		229	
Number of major landslides	Man-made slopes	18	CTL-1[^] = 9	50	CTL-1 = 12
			CTL-2 = 7		CTL-2 = 11
			CTL-3 = 2		CTL-3 = 27
	Natural hillsides	1	CTL-1 = 0	20	CTL-1 = 6
			CTL-2 = 0		CTL-2 = 4
			CTL-3 = 1		CTL-3 = 10
Casualty		5 fatalities & 4 injuries		1 fatality	
Number of landslides affecting buildings		31		17	
Number of landslides affecting roads		60 (50 road sections temporarily closed)		42 (35 road sections temporarily closed)	
Maximum Rolling Rainfall of Different Durations					
1-hour		62.5 mm (HKO)[*]		41.5 mm (HKO)	
		101 mm (H02)[#]		47 mm (N38)[%]	
24-hour		290 mm (HKO)		385.5 mm (HKO)	
		362 mm (H02)		449 mm (N38)	
2-day		458.5 mm (HKO)		507 mm (HKO)	
		544 mm (H02)		597.5 mm (N38)	
4- day		639.5 mm (HKO)		592 mm (HKO)	
		586 mm (H02)		715 mm (N38)	
15- day		891.5 mm (HKO)		840 mm (HKO)	
		791 mm (H02)		1194.5 mm (N38)	
31-day		1061.5 mm (HKO)		1069.5 mm (HKO)	
		941 mm (H02)		1727 mm (N38)	

<u>Remarks</u>

[^] Consequence-to-life Category
[*] (HKO) - Based on rainfall data recorded at Raingauge No. R01 at the Hong Kong Observatory
[#] (H02) - Based on rainfall data recorded at Raingauge No. H02, which corresponds to the July 1994 Kwun Lung Lau fatal landslide
[%] (N38) - Based on rainfall data recorded at Raingauge No. N38, which corresponds to the August 2005 Fu Yung Shan Tsuen fatal landslide

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

Table 15 - Breakdown of Key Contributory Factors in Landslides on Engineered Unsupported Soil Cut Slopes

	All Landslides (∑ = 11 No.)	Local Minor Failures (∑ = 10 No.)	Major Failures (∑ = 1 No.)
Adverse Groundwater	3 (27.3%)	3 (30%)	0 (0%)
Adverse Geological Material	3 (27.3%)	2 (20%)	1 (100%)
Inadequate Slope Maintenance	3 (27.3%)	3 (30%)	0 (0%)
Inadequate Surface Drainage Provisions	1 (9.1%)	1 (10%)	0 (0%)
Concentrated Surface Water Flow	1 (9.1%)	1 (10%)	0 (0%)

Note: A given landslide may be associated with more than one key contributory factor to the failure.

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

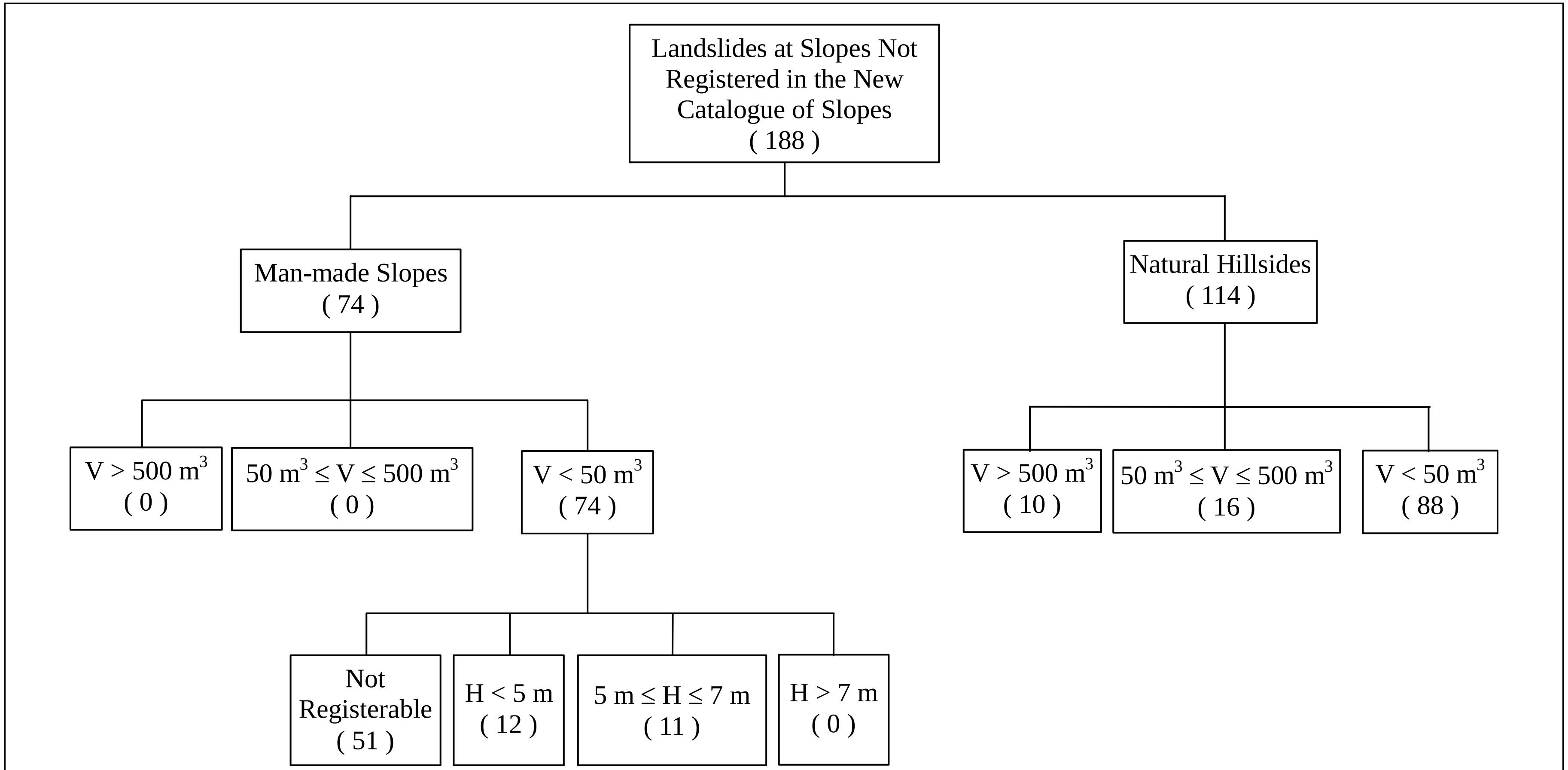
Table 16 - Progress of Follow-up Actions on the Improvement Measures Recommended in the Review of 2004 Landslides

Recommended Improvement Measures	Progress
1. Carry out a review of reported landslides on soil-nailed slopes to examine if there is a need for improved detailing against shallow failures.	Relevant landslide data have been reviewed and documentation of the relevant cases in a report is in progress.
2. Carry out a review of the need for improved subsurface drainage provisions in compacted fill slopes, especially for sites with an adverse hydrogeological setting.	Relevant landslide incidents have been reviewed. A draft report, documenting the findings and suggestions for improvement, is being prepared.
3. Identify historical landslides that occurred on hillsides within or near the 'development lines'.	Interpretation of low-flight aerial photographs is in progress under the Enhanced Natural Terrain Landslide Inventory (ENTLI) project. The scope of work includes identification of historical hillside failures within development lines. The possibility of identifying historical hillside failures by reviewing records of reported landslide incidents as part of the ENTLI work is being examined.

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

LIST OF FIGURES

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



Legend:

V	Failure volume	H	Slope height in metre	(188)	Number of cases = 188

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 have been registered in the New Catalogue of Slopes following the failures.

Figure 1 - Breakdown of Landslides on Unregistered Slopes in 2005

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

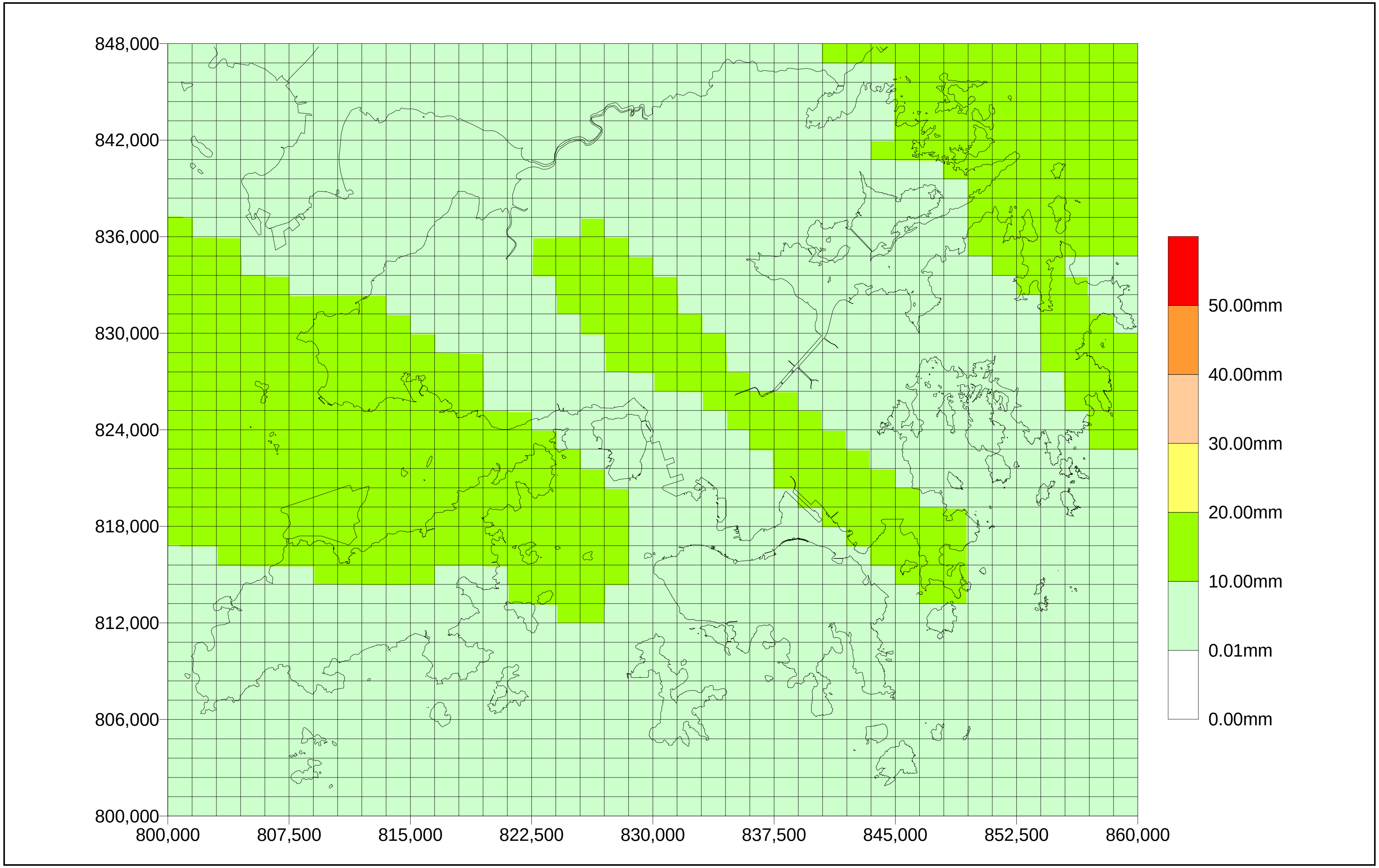


Figure 2 - 3-Hour Forecast Rainfall between 5:00 p.m. and 8:00 p.m. on 19 August 200

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

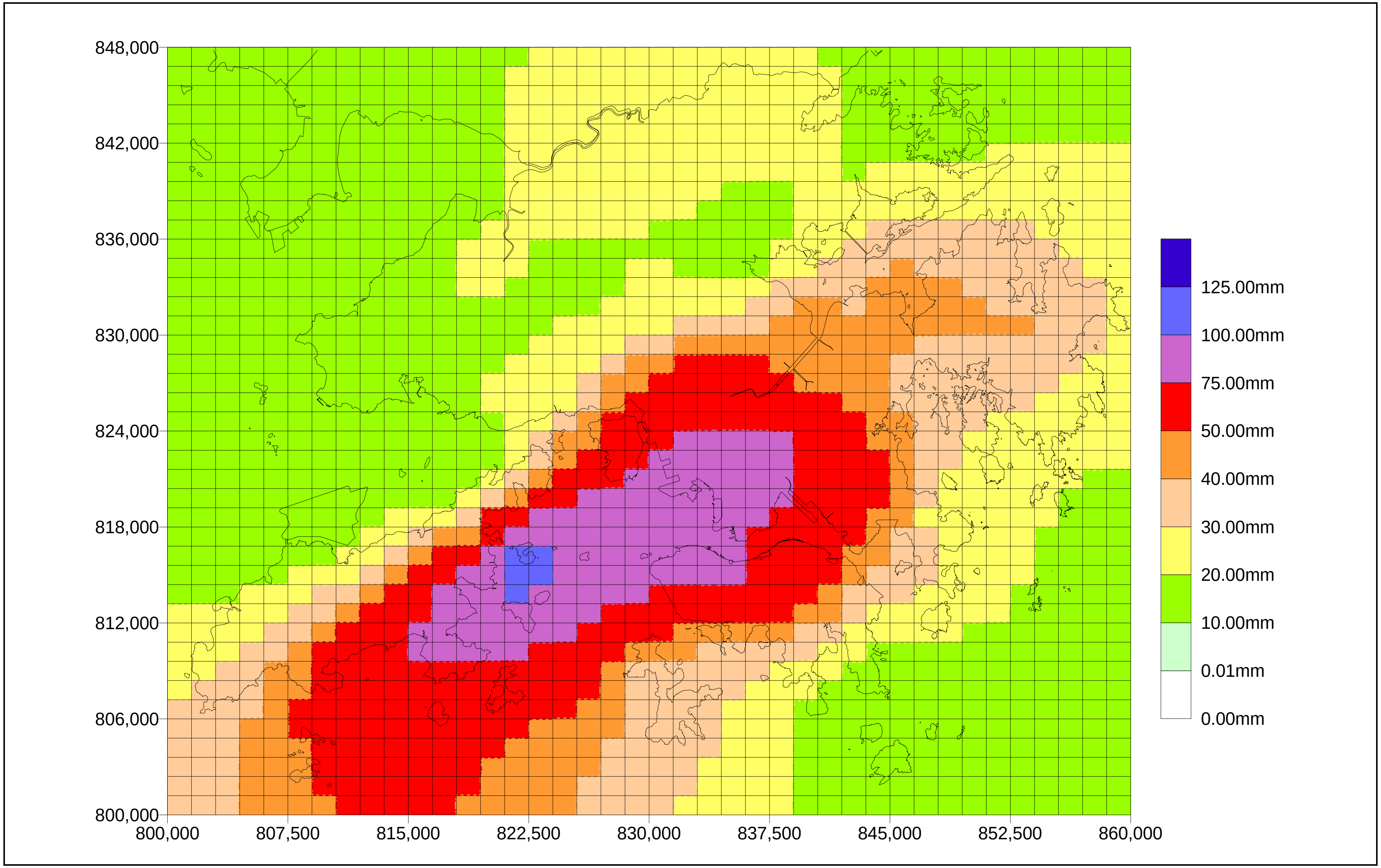


Figure 3 - 3-Hour Recorded Rainfall between 5:00 p.m. and 8:00 p.m. on 19 August 2005

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

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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.

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.

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GEO Publication No. 1/93	Review of Granular and Geotextile Filters (1993), 141 p.
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TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents