REVIEW OF LANDSLIDES IN 2007

GEO REPORT No. 253

A.F.H. Ng, J.W.C. Lau & T.M.F. Lau

GEOTECHNICAL ENGINEERING OFFICE

CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT

THE GOVERNMENT OF THE HONG KONG SPECIAL ADMINISTRATIVE REGION

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

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

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
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July 2010

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

FOREWORD

This report presents the findings of a detailed diagnosis of landslides in 2007 that were reported to the Government. 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 A.F.H. Ng, J.W.C. Lau and T.M.F. Lau of Landslip Preventive Measures Division 1 under the supervision of Mr K.K.S. Ho. Assistance was provided by the landslide investigation consultants, Fugro Scott Wilson Joint Venture and Halcrow China Limited respectively, engaged by the Geotechnical Engineering Office (GEO).

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

Table of Contents

Table of Contents

Table of Contents

Table of Contents

ABSTRACT

This report presents the findings of a diagnostic review of the landslides in 2007 that were reported to the Government. The review forms part of the GEO's systematic landslide investigation programme, which was introduced following the 23 July 1994 Kwun Lung Lau landslide. The aims of this report are to review the performance of the Government's slope safety system and identify areas for improvement in order to further enhance the slope engineering practice in Hong Kong.

Altogether 83 genuine landslides were reported to the Government in 2007. All the available landslide data were examined and ten 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 2007, no major landslide (i.e. failure volume of 50 m^3 or more) occurred on engineered man-made slopes that have been accepted under the slope safety system. For minor landslides (i.e. failure volume less than 50 m^3) on engineered man-made slopes, the annual failure rate is about 0.03% in terms of the number of landslides divided by the total number of engineered slopes.

Overall, about 99.97% of the engineered man-made slopes performed satisfactorily without occurrence of landslides in 2007.

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

CONTENTS

1. INTRODUCTION

This report presents the findings of a diagnostic review of the landslides that were reported to the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department (CEDD) in 2007. The review forms part of GEO's systematic landslide investigation (LI) programme, which was introduced following the 23 July 1994 Kwun Lung Lau landslide. The LI programme has the following two principal objectives:

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

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

Selected significant landslides were identified for in-depth studies to identify lessons learnt and the necessary follow-up actions. The findings of the studies are presented in a series of Landslide Study Reports. The present diagnostic review considers all the available landslide data in 2007, including the findings of the individual landslide studies, in order to examine the performance of Government's slope safety system and identify areas that deserve attention or improvement. The review has been carried out by the Landslip Preventive Measures Division 1 of the GEO, with assistance provided by GEO's LI consultants, namely Fugro Scott Wilson Joint Venture (FSWJV) and Halcrow China Limited (HCL) respectively.

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

2. RAINFALL AND LANDSLIDES IN 2007

The factual information, together with the relevant statistics on rainfall and reported landslides in 2007, was documented by Lau & Chan (2008).

In 2007, the annual rainfall recorded at the Hong Kong Observatory (HKO)'s Principal Raingauge in Tsim Sha Tsui was 1,707 mm. This was approximately 28% below the mean annual rainfall of 2,383 mm recorded between 1971 and 2000. One Landslip Warning was issued on 20 May 2007. Two Red Rainstorm Warnings were issued between 24 April and 10 June 2007, and 12 Amber Rainstorm Warnings were issued between 24 April and 22 August 2007.

Reported landslides are classified as follows:

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

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

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

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

Of a total of 86 reported landslide incidents in 2007, 83 were genuine landslides, discounting those non-landslide incidents such as tree falls. There were only 2 major failures, corresponding to some 2.4% of the number of genuine landslides.

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

The information of all the reported landslides has been uploaded to GEO's Slope Information System (SIS), which is accessible by the general public through computer terminals in the GEO. All the available data on reported landslides were examined as part of the current review. Some additional information was collated by GEO's LI consultants to assist in the selection of deserving cases for follow-up studies. A total of 10 incidents in 2007 were selected for follow-up studies by the LI consultants.

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

3. SEVERITY OF RAINSTORMS AS REFLECTED BY LANDSLIDE POTENTIAL INDEX

Experience has shown that the annual rainfall is not a good measure of the severity of the individual rainstorms in terms of their potential to trigger landslides. A more direct measure of the severity of the individual rainstorms in the context of slope failures is given by the Landslide Potential Index (LPI), as promulgated by the GEO (2005). The LPI is calculated for rainstorms that result in the issue of Landslip Warning. The LPI is used to depict the relative severity of the rainstorm with respect to its potential to cause landslides.

In 2007, one Landslip Warning was issued on 20 May 2007, during which time the maximum rolling 24-hour rolling rainfall from the GEO Raingauges was 229 mm. The LPI corresponding to this rainstorm event was assessed to be 1. In terms of its potential to cause landslides, this rainstorm was one-tenth of the severity of the 23 July 1994 rainstorm that triggered the fatal landslide at Kwun Lung Lau (which has an LPI of 10). The calculated LPI of 1 shows that the 20 May 2007 rainstorm was not severe.

As a result of the 20 May 2007 rainstorm, a total of 7 minor landslide incidents (involving a failure volume of < 50 m^3) were reported to the GEO, 2 of which were reported during the operation of the GEO's Emergency Control Centre on 20 May 2007.

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

4. OVERALL DIAGNOSTIC REVIEW OF LANDSLIDES

4.1 Scope of the Review

An overall diagnostic review of all the available landslide data in 2007 has provided a more global picture of the performance of the different types of slopes in Hong Kong. They in turn have facilitated the identification of specific areas that deserve attention.

The review has focused on the following aspects:

(a) coverage of the New Catalogue of Slopes,

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

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

4.2 Coverage of the New Catalogue of Slopes

4.2.1 General

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

The above is the only practical and cost-effective means for the enormous task as many old man-made slopes do not have documentary records and are difficult to identify from field inspections. The method has worked well for large slopes in built-up areas. However, there are technical constraints associated with the approach, e.g. slopes shadowed or concealed by clouds, dense vegetation or buildings, or by incomplete aerial photographic survey coverage at low altitude. Several attempts have been made by the GEO over the years to identify potentially 'missed' man-made slopes and have them registered as appropriate. However, there is likely to be a small residual number of registerable man-made slopes that have not been identified for registration through the above exercises.

4.2.2 Diagnosis

Of the 83 genuine landslides, 54 occurred on registered slope features (including 52 on registered man-made slopes and two on registered Disturbed Terrain (DT) features) (Table 5). A breakdown of the other 29 incidents is given in Figure 1.

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

Of the above 29 incidents, 1 involved a temporary soil cut slope during construction under a government project at the time of the 2007 incident, 13 involved small man-made slope features that do not meet the slope registration criteria and 11 involved natural hillside failures. The remaining 4 landslides, all of which were minor failures, involved features that satisfied the slope registration criteria but were not registered in the New Catalogue of Slopes at the time of the landslides (Table 5 and Figure 1).

4.2.3 Discussion

The above diagnosis indicates that the number of registerable slopes that were yet to be included in the New Catalogue of Slopes at the time of failure was less than 5% of the number of genuine landslides in 2007. Of the above four minor landslides involving registerable slopes as noted in Section 4.2.2, two resulted in temporary closure of roads in urban areas (i.e. Po Shan Road and Peak Road), and one resulted in the permanent evacuation of a squatter dwelling. The remaining incident did not result in any significant consequences to the community.

Following the landslides, the above 4 man-made slope features have been registered in the New Catalogue of Slopes.

4.3 Annual Failure Rates of Registered Slopes

4.3.1 General

Based on the landslide data and a review of the slope status, the average failure rate of registered slopes can be assessed in terms of the different types of slopes that are of different ages, i.e. pre-1977 (i.e. old slopes formed or substantially modified before 1977 when the Geotechnical Control Office (renamed GEO in 1991) was established), or post-1977 (i.e. 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

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

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

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

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

4.3.2 Diagnosis

Of the 83 genuine landslides reported in 2007, a total of 54 landslides (about 65%) affected registered slopes (including two registered Disturbed Terrain features). Of these 54 landslide incidents, two 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).

Seven of the 83 genuine landslides (about 8.4%) affected engineered slopes, none of which were major failures.

Based on the 2007 landslide data and a detailed review of the slope status, the annual failure rates of the different types of registered slopes are shown in Table 6. These calculated failure rates are not particularly sensitive to the assumptions made regarding the total number of the different types of slopes, bearing in mind the likely order of uncertainty involved. The calculated failure rates do not reflect the long-term average values because of the limited observation period. Notwithstanding this, annual failure rates derived from a systematic review of all the landslide data over the year can provide some insights into the performance of the slope safety system.

4.3.3 Discussion

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

The first approach involves assessing the failure rates in terms of the number of landslides divided by the total number of slopes of a certain status (i.e. of a given slope type, such as cut slopes, comprising either engineered slopes or non-engineered slopes). 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.

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

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 same 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 same status. Relating the failure rate to the surface area of slopes, as opposed to just the number of slopes, would take into account the fact that a large slope is more susceptible to having 'defects' than a small slope.

Based on the data in 2007, the annual failure rates for all reported landslides on registered man-made slopes correspond to 9.5×10^{-4} (number of landslides/number of registered slopes), 0.2×10^{-4} (total surface area of landslides/total surface area of registered slopes), and 9.6×10^{-7} (number of landslides/total surface area of registered slopes in m^2) respectively, using the three different approaches as described above.

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

4.4 Diagnosis of Landslides on Engineered Slopes

4.4.1 General

A review of the 2007 landslides indicates that some of the incidents involved failure of engineered slopes. A meaningful diagnosis of landslides on engineered slopes requires detailed information about the nature and probable causes of the failures, together with the status and development history of the slopes of concern. The present assessment is based on the detailed information obtained from follow-up landslide studies and examination.

Of the 7 incidents that affected engineered slopes, 4 of them was formed in the 1980s or before, 2 were formed in the 1990s, and 1 was formed after 2000 (see Table 7). Six of them were landslide incidents and the remaining one involved loss of ground behind a retaining wall. For the present purposes, slopes that were not accepted under the slope safety system (e.g. no geotechnical submissions made to the GEO for checking, or submissions with outstanding GEO comments) are not considered to be engineered slopes.

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

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

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

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

Dangerous Hillside Orders),

(c) whether detailed geotechnical design calculations were undertaken,

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

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

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

4.4.2 Overall Diagnosis

A breakdown of the 7 landslide incidents that occurred on engineered slopes in 2007 with respect to slope type and scale of failure is shown in Table 8. Of these, 3 involved soil cuts, 2 involved rock cuts, 1 involved a compacted fill slope and 1 involved a retaining wall. All of these comprised minor failures, 6 of which involved failure volumes less than 5 m^3 and 1 involved a failure volume of 16 m^3.

The maintenance responsibility for the failed portions of 5 of the slopes rests with Government, whilst that for the other 2 rests with private owners.

The annual failure rates for the 2007 landslide data are summarised in Table 9 for the different categories of engineered slopes.

On a slope number basis, the annual failure rate of engineered slopes is about 5 times less than that of non-engineered slopes, whereas on a unit area basis, the annual failure rate of engineered slopes is some 13 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 14 times less than that of non-engineered slopes.

Of the 7 engineered slopes that failed in 2007, 3 were previously included in the LPM Programme (see Table 10). The corresponding annual failure rates for LPM slopes are summarised in Table 11.

It may be noted from the above diagnosis that the annual failure rates of LPM slopes for all landslides in 2007 were apparently higher than the corresponding figures for engineered slopes by about 3 to 5 times (under all 3 approaches described in Section 4.3.3). This observation could be partly due to the fact that the slopes upgraded under the LPM Programme, which focuses on those slopes that pose a threat to public safety, are generally more difficult with complex ground conditions. Caution needs to be exercised, however, because the numbers being compared are relatively small and hence they may not be

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

statistically significant. In view of the above, the diagnosis should be taken as indicative only.

Of the 7 landslide incidents on engineered slopes, 1 involved ground loss behind a retaining wall amounting to about 16 m^3 in volume probably as a result of internal erosion caused by leakage from the surface drainage system on the slope above over a prolonged period, as a result of inadequate maintenance by the private owners.

Another minor landslide incident (2 m^3) occurred on a fill slope that was formed under a public housing development project in 2004.

The remaining 5 minor incidents occurred on 2 soil/rock cuts (involving rockfalls of 0.03 m^3 and 0.04 m^3 in volume), and 3 unsupported soil cuts (failure volumes ranging from 1 m^3 to 4 m^3). The key contributory factors to the failures of engineered unsupported soil cuts are summarised in Table 12.

No failures occurred on soil-nailed slopes in 2007.

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 2007, the actual annual success rates were 100% and 99.97% 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 2007, is shown in Table 13.

4.5 Key Observations

4.5.1 Severity of Rainstorms that Triggered Landslides

Of the 83 genuine landslides reported in 2007, 10 were selected for follow-up study. These studies provided sufficiently reliable information to assess the timing and severity of the rainstorms preceding the failures. Analyses show that none of the 10 cases involved rainstorms that were more severe than that experienced in the past. As such, deterioration of the slope condition may have played a role in the incidents as there were no obvious changes in environmental conditions of the slopes, except the one which was likely caused by the rupture of a water main mounted on a retaining wall.

Out of the above 10 incidents, 3 involved engineered slopes, viz. 2 rock cuts and 1 retaining wall. Minor rock falls from the rock cuts took place probably in the form of progressive opening up of the adversely orientated joints due to root action of the unplanned vegetation, resulting in deterioration of the slope condition. Lack of maintenance was likely for the incident involving significant ground loss behind the retaining wall due to the leakage from a dilapidated slope drainage system.

On the basis of the above, the proposition that the continued stability of an existing slope may be proven by past severe rainstorms should be treated with extreme caution. Before one could confidently count on past slope performance regarding the margin of safety

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

for long-term stability, one needs to consider factors such as possible slope deterioration, progressive slope deformation during past rainstorms, potential adverse changes in environmental conditions and adequacy of regular slope maintenance.

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

All the 54 reported landslide incidents involving registered slope features were reviewed to assess whether inadequate maintenance was likely to have been a key contributory factor in the failures. Reference has been made to the records of emergency inspections by the GEO or other Government departments, inspections of selected landslides by the LI consultants, together with the findings of the follow-up landslide studies.

Inadequate slope maintenance was assessed to be a key contributory factor in 7, all of which were minor landslides, out of 54 reported incidents (i.e. 13%). Amongst them, only 1 incident occurred on an engineered slope, which involved ground loss behind a concrete retaining wall.

Of the 7 landslide incidents, 3 affected Government slopes, 2 affected private slopes and 2 affected features of mixed maintenance responsibility (MR) of Government/private based on the information given in the Lands Department's Slope Maintenance Responsibility Information System (SMRIS). Of the 2 incidents that occurred on slope features with mixed MR, one was on the private portion while the other was on the government portion.

It should be noted that the number of incidents with inadequate maintenance is small and hence they are unlikely to be of statistical significance. Nevertheless, the above diagnosis 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.

4.5.3 Follow-up on Distressed Hillsides after Hill Fire

Major tension cracks were identified by a consultant working on a nearby development site after the dense vegetation on the north-facing and south-facing hillsides was removed by a hill fire in April 2007. A cluster of occupied squatter dwellings is located at the toe of the south-facing hillside (which is a historical landslide catchment (HLC)), whilst an abandoned farmland is located at the toe of the north-facing hillside.

The tension cracks were up to about 35 m long, 0.8 m deep with a horizontal separation of about 0.3 m. Field evidence suggests that the cracks have probably existed for quite some time before they were exposed following the hill fire. It is noteworthy that the distress on the south-facing hillside was located above a number of relict landslide scars.

Five relict landslides on the south-facing hillside are included in GEO's Enhanced Natural Terrain Landslide Inventory (ENTLI). The tension cracks are near 4 of these relict scars. Nine occupied squatter dwellings located at the toe were subjected to previous inspections by the GEO under the Non Development Clearance (NDC) Programme, 4 of which were subjected to Category 2 NDC recommendations in 1993. In light of the distress observed on the hillside, the remaining 5 squatter dwellings at the toe, together with 3 other

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

squatter dwellings in the vicinity of a drainage line that were similarly subjected to previous NDC inspections (also with no NDC recommendations), were recommended for Category 2 clearance in late 2007. At the recommendation of the GEO, the tension cracks were sealed up by the Highways Department as emergency works.

Natural hillsides are liable to suffer from progressive deterioration given repeated rainstorms, with possible development of distress such as tension cracks. The presence of tension cracks would promote enhanced water ingress and exacerbate hillside degradation, which could lead to sizeable, mobile landslides. Such signs of distress, which may or may not be associated with relict landslides, may be concealed by heavy vegetation and are not amenable to direct observation through aerial photographs. As illustrated in Plates 1 and 2, the presence of tension cracks could be easily missed even where the vegetation has been largely removed by a hill fire, especially where the distress is not known or suspected, unless the distress is very severe and extensive and where a detailed API is undertaken by experienced personnel, coupled with ground truthing.

Airborne LiDAR (Light Detection and Ranging) technology with virtual deforestation capability has the potential for identifying ground features below the vegetation canopy, such as relict landslides and terrain morphology. However, based on the pilot trial recently commissioned by the GEO (Ng & Chiu, 2008), remote detection of tension cracks on hillsides appeared not practical by means of airborne LiDAR survey of heavily vegetated hillsides, given its current state of development.

When major hill fires have affected HLCs resulting in vegetation removal exposing large areas of bare ground, consideration should be given to developing a methodology for systematic follow-up inspections of the hillsides to check for possible presence of significant distress. When the practicality of the methodology is tried and tested, it may be extended to cover non-HLC areas, especially where there are building clusters or important transport corridors close by.

4.5.4 Landslides on Man-made Slopes with Safety-screening Studies that Recommended 'No Further Action'

In 2007, a minor rockfall (< 1 m^3) occurred on a portion of a privately owned soil/rock cut, which was previously assessed by a safety-screening study in 1998 under the LPM Programme (denoted as Stage 2 Study) as requiring 'No further action' (NFA). DH Orders were recommended on the remaining slope portions following the study, where a small landslide (6 m^3) occurred in 2004 before the DH Order was discharged.

Based on a preliminary review of GEO's landslide database, in the period of 1992 to 2007, 17 landslides were reported on 15 man-made slopes (comprising 8 wholly private slopes and 7 slopes of mixed private/government maintenance responsibility) subjected to NFA recommendations by safety-screening studies (i.e. LPM Stage 2 Studies). These included 1 major failure (50 m^3) on a fill slope. The other failures were generally of small scale, ranging from less than 1 m^3 to about 15 m^3 in volume.

In light of the above, it would be useful to conduct a review of the landslide history and performance of slopes that have been subjected to NFA recommendations following a Stage 2 Study based on the current methodology that has been adopted since the early 1990s.

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

The key objective of the safety-screening study is to establish whether there is any prima facie evidence at the time of the study for serving a DH Order under the Buildings Ordinance. Given the constraints that typically no ground investigation or detailed topographic survey is carried out as part of the Stage 2 Study, these studies are subject to some uncertainties and much engineering judgement is called for.

In order to avoid potential misconceptions by the private owners and other parties, it is of the essence to spell out clearly in the relevant documents (e.g. GEO Circular No. 30 on "Stage 1 and Stage 2 Geotechnical Studies of Slopes and Retaining Walls", and GEO Information Notes 04/2008 and 05/2008 on "The Landslip Preventive Measures (LPM) Programme" and "The Landslip Prevention and Mitigation Programme (LPMitP)" respectively), that a safety-screening study does not comprise a Stability Assessment to confirm whether or not the slope meets the required safety standards.

5. PROPOSED IMPROVEMENT INITIATIVES

Improvement initiatives were proposed by Tam & Lau (2007) following a review of the landslides that occurred in 2006. The progress of the follow-up actions is summarised in Table 14.

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

(a) develop a methodology for carrying out systematic inspections of hillsides affected by major hill fires to check for possible presence of distress that may pose a threat to existing development (Section 4.5.3),

(b) review the landslide history and performance of private man-made slopes previously subjected to 'No Further Action' recommendations following safety-screening studies (Section 4.5.4), and

(c) clarify the objective and nature of safety-screening studies in the relevant GEO Circular and GEO Information Notes (Section 4.5.4).

6. CONCLUSIONS

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

(a) The annual failure rates of major and minor landslides on engineered slopes, on a slope number basis, were 0% and 0.03% respectively in 2007. The pledged annual success rates of 99.8% and 99.5% of engineered slopes in preventing major and minor landslides, respectively, were met.

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

(b) Overall, about 99.97% of the engineered slopes performed satisfactorily without the occurrence of any landslides in 2007.

A number of initiatives have been proposed, as detailed in Section 5 of this 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

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		5 (0)	6.0
Cut Slope	Soil	35 (1)	42.2
	Soil/Rock	12 (0)	14.4
	Rock	7 (0)	8.4
Retaining Wall		11 (1)	13.3
Natural Hillside		11 (0)	13.3
Registered Disturbed Terrain		2 (0)	2.4
Total		83 (2)	100

Legend:
35 (1) Thirty 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) Reported incidents that were not genuine landslides have been excluded.

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

Table 2 - Number of Landslides Affecting Different Facilities

Affected Facility	Hong Kong Island	Kowloon	New Territories and Outlying Islands	All
Squatter Dwellings	0 (0)	0 (0)	8 (0)	8 (0)
Buildings	0 (0)	0 (0)	8 (0)	8 (0)
Roads	5 (1)	2 (0)	8 (0)	15 (1)
Transportation Facilities (railways, tramways, LRT, etc.)	0 (0)	0 (0)	0 (0)	0 (0)
Pedestrian Pavements/Footways	2 (0)	2 (0)	0 (0)	4 (0)
Minor Footpaths/Access	6 (0)	0 (0)	12 (0)	18 (0)
Construction Sites	0 (0)	0 (0)	2 (0)	2 (0)
Open Areas	0 (0)	2 (0)	11 (0)	13 (0)
Catchwaters	1 (0)	0 (0)	3 (1)	4 (1)
Others (e.g. carparks, parks, playgrounds, gardens, backyards, etc.)	2 (0)	1 (0)	11 (0)	14 (0)

Legend:
15 (1) Fifteen landslides of which one was major failure.

Notes:
(1) There are a total of 3 incidents (i.e. Incident Nos. LI2007/04/2002, LI2007/04/2003 and WSD/2007/7/1/HKI), each of which affected two types of facilities.
(2) Reported incidents that are not genuine landslides have been excluded.

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

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

Type of Failure		No. of Squatter Dwellings Evacuated		No. of Blocks, Houses or Flats Evacuated or Partially Closed	No. of Closure			Deaths	Injuries
		Permanent	Temporary		Roads	Pedestrian Pavements	Footpaths, Back Lanes, Private Access		
Fill Slope		0	0	0	1	0	1	0	0
Cut Slope	Soil	1 (1)	0	0	0	0	0	0	0
Cut Slope	Soil/Rock	0	2 (2)	0	2	1	0	0	0
Cut Slope	Rock	0	0	0	0	0	0	0	0
Retaining Wall		1 (1)	0	0	2	0	0	0	0
Natural Hillside		0	0	0	0	0	4	0	0
Registered Disturbed Terrain		0	0	0	0	0	0	0	0

Legend:
2 (2) Number of squatter dwellings evacuated with the number of tolerated squatter structures evacuated shown in bracket.

Notes:
(1) A squatter dwelling is defined as a place of residence that contains one or more 'tolerated squatter structures', i.e. structures built for domestic purpose or non-domestic purpose and registered in the 1982 Housing Department's Squatter Structure Survey (GEO, 2004a).
(2) A failure may give rise to more than one key type of consequence.

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

Table 4 - Distribution of Facility Groups Affected by Major Landslides

	Facilities Groups Affected by Major Landslides						
	1a	1b	2a	2b	3	4	5
All Major Landslides	0	0	0	0	1	0	1
Major Landslides on Man-made Slopes	0	0	0	0	1	0	1
Major Landslides on Registered Disturbed Terrain Features	0	0	0	0	0	0	0
Major Landslides on Natural Hillsides	0	0	0	0	0	0	0

Notes: (1) Facility groups are classified in accordance with that adopted for the New Priority Classification Systems (Wong, 1998).
(2) A given landslide may affect more than one type of facility.

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

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

	Number of Minor Failures (< 50 m^3)	Number of Major Failures		
		(50 m^3 to 500 m^3)	(> 500 m^3)	
Registered Man-made Slopes	50	1	1	Σ = 52
Registered Disturbed Terrain Features	2	0	0	Σ = 2
Unregisterable Man-made Slopes	13	0	0	Σ = 13
Registerable Man-made Slopes Not Yet Registered at Time of Failure	4	0	0	Σ = 4
Slope Works in Progress at Time of Failure	1	0	0	Σ = 1
Natural Hillsides	11	0	0	Σ = 11
	Σ = 81	Σ = 1	Σ = 1	Σ = 83

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 2007

		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 2007	Number of Slopes	5	40	45	2	5	7
	Surface Area of Landslides (m^2)	222	707	929	21	116	137
Slopes Involved in Major Landslides in 2007	Number of Slopes	1	1	2	0	0	0
	Surface Area of Landslides (m^2)	200	240	440	0	0	0
Slopes Involved in Minor Landslides in 2007	Number of Slopes	4	39	43	2	5	7
	Surface Area of Landslides (m^2)	22	467	489	21	116	137
Total Number of Registered Slopes		11,350	20,900	32,250	10,420	12,330	22,750
Total Surface Area of Registered Slopes (m^2)		6,307,522	10,974,365	17,281,887	12,212,102	24,466,957	36,679,059
Annual Failure Rates (All Landslides Considered)	On a Slope Number Basis	0.04%	0.19%	0.14%	0.02%	0.04%	0.03%
	On a Unit Slope Surface Area Basis	0.004%	0.006%	0.005%	0.0002%	0.0005%	0.0004%
	Number of Landslides Divided by Slope Surface Area (no./m^2)	0.79×10^{-6}	3.64×10^{-6}	2.6×10^{-6}	1.64×10^{-7}	2.04×10^{-7}	1.91×10^{-7}
Annual Failure Rates (Major Landslides Only)	On a Slope Number Basis	0.009%	0.005%	0.006%	0%	0%	0%
	On a Unit Slope Surface Area Basis	0.003%	0.002%	0.003%	0%	0%	0%
	Number of Landslides Divided by Slope Surface Area (no./m^2)	1.59×10^{-7}	0.91×10^{-7}	1.16×10^{-7}	0	0	0

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

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

Table 7 - Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 1 of 5)

1. Slopes Upgraded Under the LPM Programme

Slope No.	Incident No.	Location	Volume (m^3)	Type of Slope	Remarks
11NE-C/C62	2007/05/0008	Hong Ning Road, Sau Mau Ping, Kowloon (opposite to Sau Mau Ping Police Station)	0.03 (rockfall)	Soil/rock cut	LPM works were completed in 1999. The works on the rock cut portion comprised rock dowels, raking drains, concrete buttress, scaling and trimming works, and sprayed concrete. The source area and its vicinity (which measures about 5 m by 6 m) comprised a bare rock face that was covered with tree roots, with no sprayed concrete or wire mesh netting.
3SE-C/C23	LandsD/TP/ 2008/01/0002	Behind House Nos. 26 & 27, Shuen Wan Chim Uk, Tai Po	1	Soil cut	LPM works were completed in 1991. The slope is up to about 16 m high and inclined at about 45°. The slope has a vegetated surface without erosion control mat or wire mesh. The northern portion of the slope (about 100 m long) was upgraded by trimming and soil nailing, whereas the southern portion of 75 m long was upgraded by cutting back to a gentle gradient only. The shallow (less than 0.5 m deep) small detachment occurred on the unsupported cut portion.
7SW-C/C871	WSD/2007/11/ 1/NTW	Adjoining Tsuen Wan Freshwater Service Reservoir	4	Soil cut	The slope was upgraded under the LPM Programme in 1978. The upgrading works comprised trimming back. The upgraded slope is up to 35 m high and inclined at about 35°. According to WSD, leakage occurred from a buried water pipe in the slope, which was probably the cause of the landslide.

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 5)

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

Slope No.	Incident No.	Location	Volume (m^3)	Type of Slope	Remarks
14NW-D/C267	2007/06/0039	Cheung Chau Playground	3	Soil cut	The chunamed cut slope was assessed under the Cheung Chau Recreation Ground Stage II (Modification) Programme No. 37 project in 1979 and considered to meet the required geotechnical standard. The stability assessment was accepted by the checking authority. The landslide comprised a rain-induced small detachment from the unsupported cut.

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 5)

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

Slope No.	Incident No.	Location	Volume (m^3)	Type of Slope	Remarks
11NE-A/F444	2007/11/0070 (see Plate 3)	Pui Man Street, Kowloon	2 (erosion)	Fill	Geotechnical design, undertaken by the Housing Department, was checked and accepted by the GEO in 1999. The failure was possibly associated with uncontrolled overflow of surface water from blocked drains (severe blockage of drain, together with erosion damage to the crest platform cover, was observed in March 2007 by the maintenance department). For the incident that was reported in November 2007, uncontrolled concentrated surface water flow probably eroded part of the crest platform at a low point (at about the same location of the damaged area observed in March 2007), leading to the formation of erosion gullies on the fill slope below.

Table 7 - Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 4 of 5)

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

Slope No.	Incident No.	Location	Volume (m^3)	Type of Slope	Remarks
11SE-A/CR152	2007/04/0002	Behind Wun Sha Tower, 33 Wun Sha Street, Tai Hang	16 (ground loss at wall crest)	Soil cut and retaining wall	The lower portion of the slope at which the 2007 failure occurred was modified during the redevelopment of Wun Sha Tower in 1979/80. The site formation submission was checked and accepted by GCB of BOO in 1978.
11SW-B/C85	2007/09/0067	42 MacDonnell Road, Hong Kong	0.04 (rock fall)	Soil and rock cut	The eastern portion of the slope at which the 2007 rock fall incident occurred was modified during the redevelopment of 48 - 48C MacDonnell Road. The slope stabilisation works design was checked and accepted by GCO in 1985.

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 5)

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

Nil.

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

Nil.

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-1978 features but are not taken as engineered slopes for the purpose of this report.

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

Table 8 - Breakdown of Landslides on Engineered Slopes

	Soil Cut	Rock Cut	Fill Slope	Retaining Wall
All Landslides	3	2	1	1
> 500 m^3	0	0	0	0
50 m^3 to 500 m^3	0	0	0	0
< 50 m^3	3	2	1	1

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

	Failure Rate on a Slope Number Basis (number of landslides divided by total number of slopes)	Failure Rate on a Unit Area Basis (surface area of landslides divided by total slope surface area)	Failure Rate in Terms of Number of Landslides Divided by Total Slope Surface Area (no./m^2)
Registered Slopes with No Geotechnical Input (all landslides considered)	0.14%	0.005%	2.60×10^{-6}
Engineered Slopes Processed by the Slope Safety System (all landslides considered)	0.03%	0.0004 %	1.91×10^{-7}
Registered Slopes with No Geotechnical Input (major landslides only)	0.006%	0.003%	1.16×10^{-7}
Engineered Slopes Processed by the Slope Safety System (major landslides only)	0%	0%	0
Registered Slopes with No Geotechnical Input (minor landslides only)	0.13%	0.003%	2.49×10^{-6}
Engineered Slopes Processed by the Slope Safety System (minor landslides only)	0.03%	0.0004 %	1.91×10^{-7}

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

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

	Soil Cut	Rock Cut	Fill Slope	Retaining Wall
All Landslides	2	1	0	0
> 500 m^3	0	0	0	0
50 m^3 to 500 m^3	0	0	0	0
< 50 m^3	2	1	0	0

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

	Failure Rate on a Slope Number Basis (number of landslides divided by total number of slopes)	Failure Rate on a Unit Area Basis (surface area of landslides divided by total slope surface area)	Failure Rate in Terms of Number of Landslides Divided by Total Slope Surface Area (no./m^2)
Slopes Treated under LPM Programme (all landslides considered)	0.09%	0.0019%	5.18×10^{-7}
Slopes Treated under LPM Programme (major landslides only)	0%	0%	0
Slopes Treated under LPM Programme (minor landslides only)	0.09%	0.0019%	5.18×10^{-7}

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

Table 12 - Breakdown of Key Contributory Factors in Landslides on Engineered Unsupported Soil Cut Slopes

	All Landslides ($\sum = 3$ No.)	Local Minor Failures ($\sum = 3$ No.)	Major Failures ($\sum = 0$ No.)
Adverse Groundwater	1	1	0
Adverse Geological Material	0	0	0
Inadequate Geological Input	0	0	0
Inadequate Slope Maintenance	0	0	0
Direct Infiltration	1	1	0
Leakage of water carrying services on slope	1	1	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 13 - Annual Success Rate of Engineered Slopes from 1997 to 2007

	Annual Success Rate on Slope Number Basis (i.e. number of landslides divided by total number of slopes)										
	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Engineered Slopes Processed by the Slope Safety System ($\geq 50\ m^3$)	99.97%	99.98%	99.97%	99.98%	99.98%	100%	99.99%	100%	99.98%	100%	100%
Engineered Slopes Processed by the Slope Safety System ($< 50\ m^3$)	99.89%	99.92%	99.92%	99.91%	99.93%	99.95%	99.95%	99.97%	99.89%	99.95%	99.97%

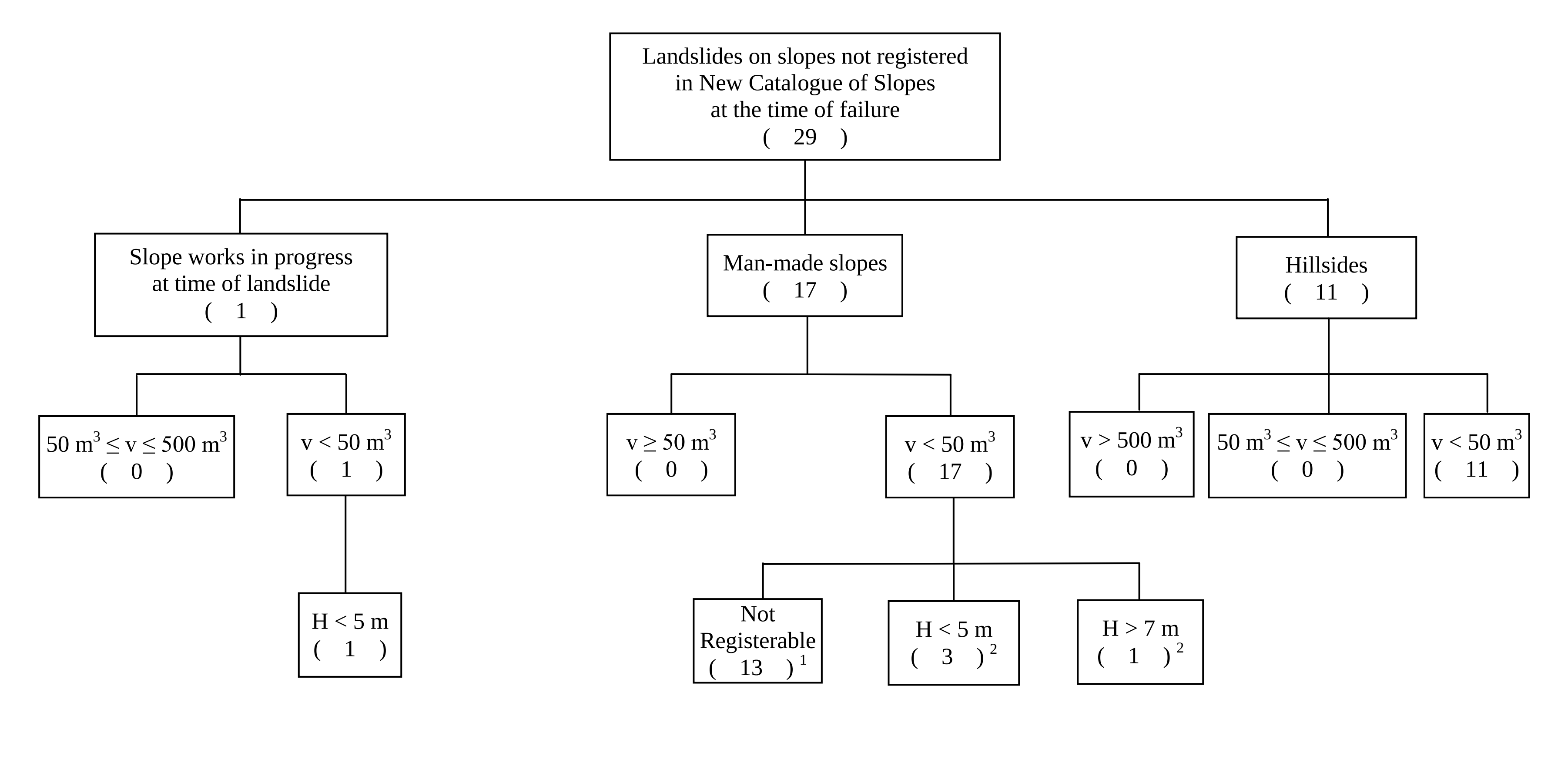
Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 14 - Progress of Follow-up Actions on the Improvement Measures Recommended in the Review of 2006 Landslides

Recommended Improvement Measures	Progress
1. Review the un-engineered portion of slopes that had not been fully processed by the slope safety system, together with the corresponding landslide history, to identify the necessary follow-up actions.	About 200 post-GEO features with slope portions not checked by the GEO have been identified and reviewed. No major landslides have occurred on such slope portions since formation. Deserving slopes will be followed up under the LPM/LPMitP or EMP, as appropriate. <u>Action completed</u>.
2. Review and improve the effectiveness of the existing alert systems in respect of changes in slope ownership, maintenance responsibility or termination of tenancy agreements or Government Land Licences for slopes with un-discharged DH Orders or Warning Letters, for initiating prompt follow-up actions as necessary.	The alert systems have been reviewed by CGE/SS and LandsD. CGE/SS has improved the existing system by putting in place a mechanism to vet the monthly SIMAR disclosure to check for any MR changes involving features that have been subjected to un-discharged DH Orders or un-discharged Warning Letters. LPM Branch will be alerted promptly as appropriate for necessary follow-up action under the LPM/LPMit Programme. LandsD has undertaken to promptly inform GEO of any changes in MR of features with outstanding Warning Letters and update the SIMAR records accordingly. <u>Action completed</u>.

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

LIST OF FIGURES



Legend :

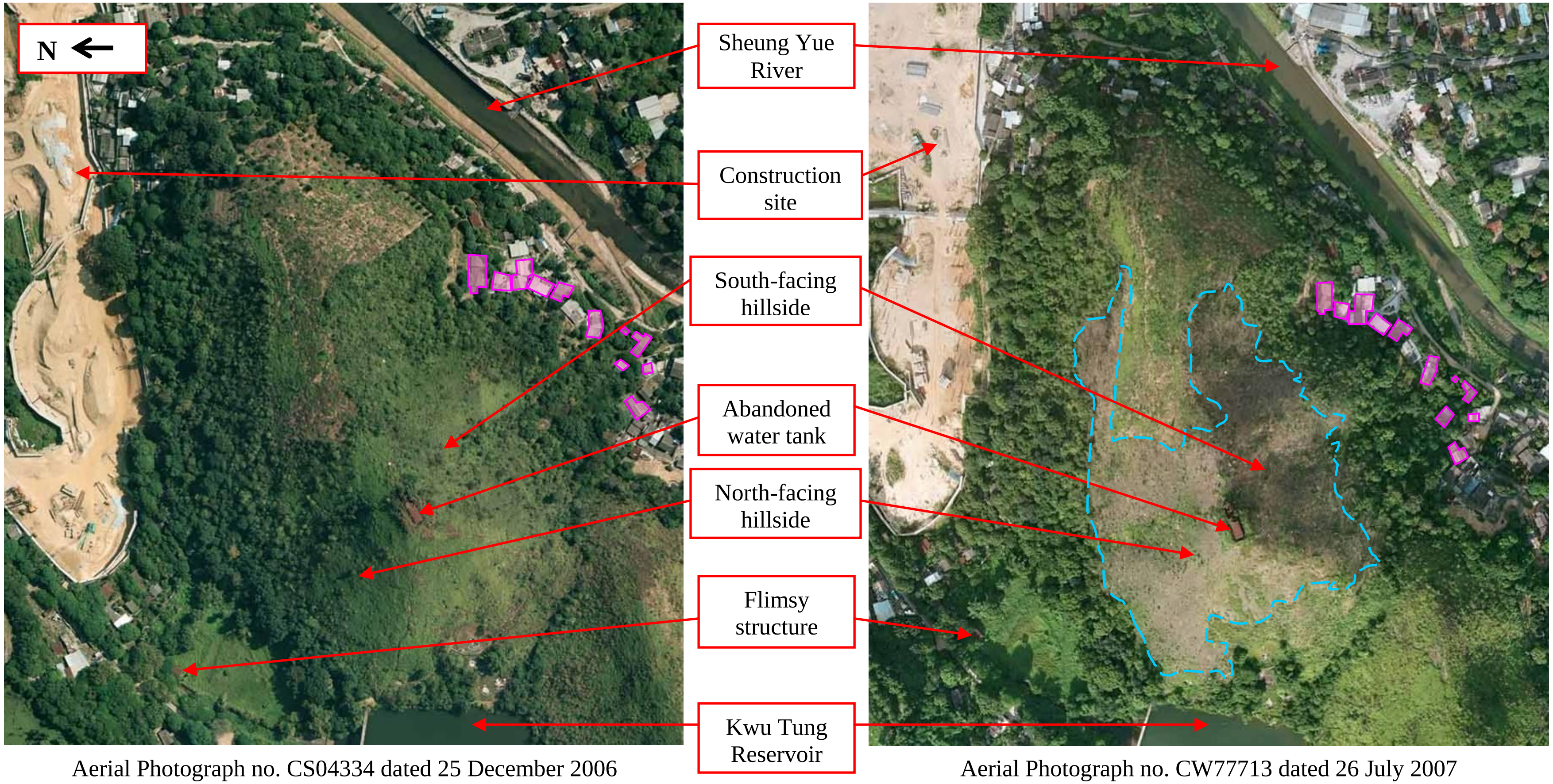
v	Failure volume
H	Height of man-made feature before failure
(29)	Number of cases = 29

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 at the time of failure.
(2) Registerable slope features have been registered in the New Catalogue of Slopes following the failures.

Figure 1 - Breakdown of Landslides on Unregistered Slopes in 2007

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

LIST OF PLATES



Aerial Photograph no. CS04334 dated 25 December 2006
before the hill fire on 1 April 2007

Aerial Photograph no. CW77713 dated 26 July 2007
after the hill fire on 1 April 2007

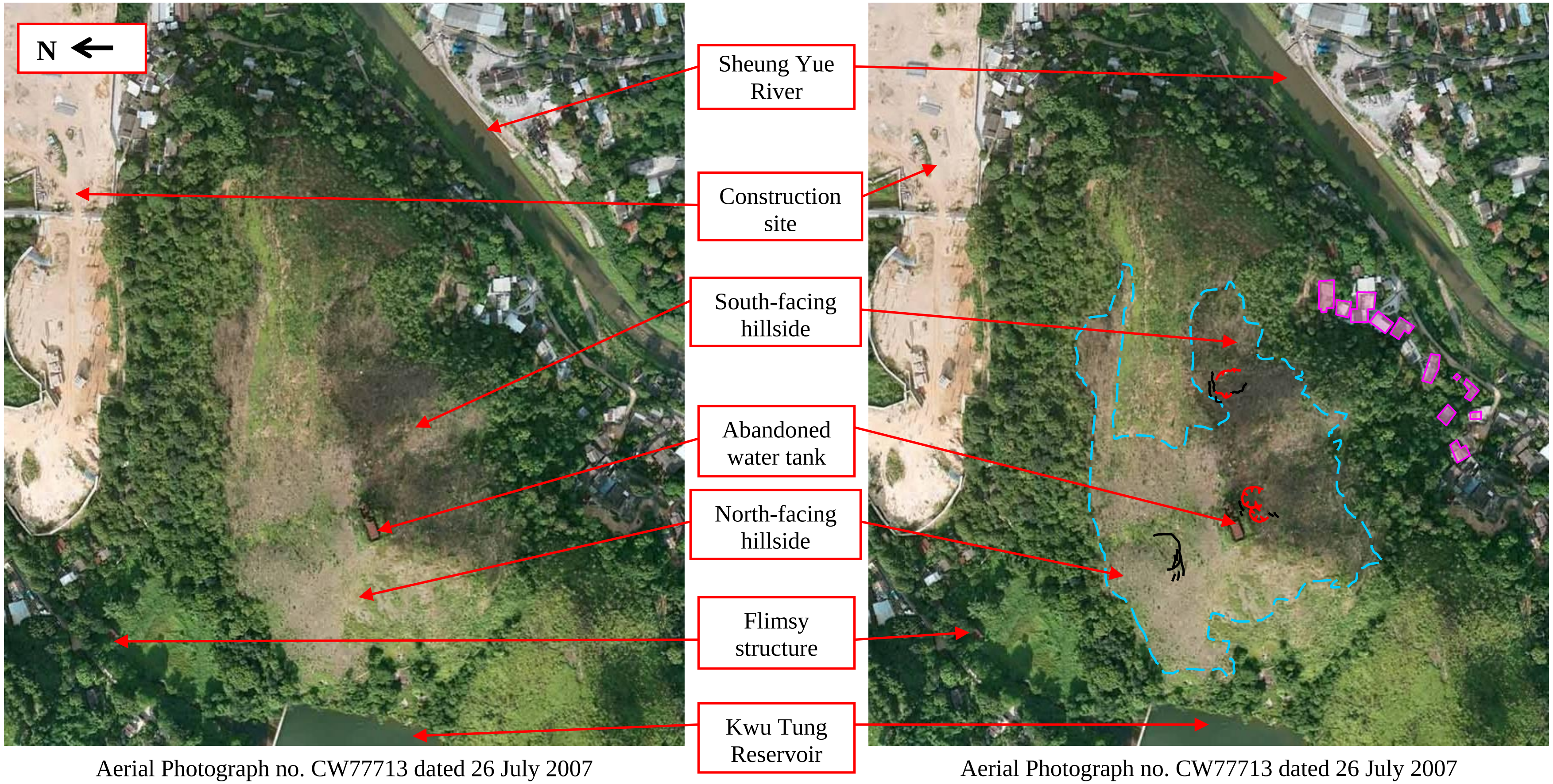
Plate 1 - Aerial View of the Distressed Natural Hillsides at East of Kwu Tung Reservoir

Legend:

Approximate extent of hill fire occurred on 1 April 2007

Squatter dwellings

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



Aerial Photograph no. CW77713 dated 26 July 2007
after the hill fire on 1 April 2007

Aerial Photograph no. CW77713 dated 26 July 2007
after the hill fire on 1 April 2007 with tension cracks marked

Plate 2 - Aerial View of the Distressed Hillsides at East of Kwu Tung Reservoir with Tension Cracks Marked

Legend:

Approximate extent of hill fire occurred on 1 April 2007

Squatter dwellings with Category 2 Non-Development Clearance recommended

Tension crack

Landslide scar

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

Plate 3 - The 14 November 2007 Landslide Incident at Pui Man Street

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

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

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

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

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

GEOTECHNICAL MANUALS

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

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

GEOGUIDES

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TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents

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