# Review of Landslides in 2010

## GEO Report No. 305

**A.C.O. Li, J.C.W. Leung & H.W.K. Lam**

**Geotechnical Engineering Office**
**Civil Engineering and Development Department**
**The Government of the Hong Kong**
**Special Administrative Region**

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# Preface

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

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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.

H.N. Wong
Head, Geotechnical Engineering Office
December 2014

# Foreword

This report presents the findings of a detailed diagnosis of landslides in 2010 that were reported to the Government. It serves to review the performance of the Government's slope safety system and identify areas for improvement, as well as to further enhance the slope engineering practice in Hong Kong.

The review was carried out by Dr A.C.O. Li, Mr H.W.K. Lam and Ms J.C.W. Leung of Landslip Preventive Measures Division 1 under the supervision of Mr W.K. Pun initially and later Mr Y.S. Au-Yeung. Assistance was provided by the landslide investigation consultants engaged by the Geotechnical Engineering Office, namely Fugro Scott Wilson Joint Venture and AECOM Asia Company Limited respectively. Technical support provided by Mr K.W. Cheung, Mr T.F.O. Luk and Mr K.H.K. Yiu is gratefully acknowledged.

Y.C. Chan
Head of the Geotechnical Engineering Office

## Abstract

This report presents the findings of a diagnostic review of the landslides in 2010 that were reported to the Government. The review forms part of the GEO's systematic landslide investigation programme, which is an integral component of the Government's slope safety system. The aims of this report are to review the performance of the Government's slope safety system and identify areas for improvement, as well as to further enhance the slope engineering practice in Hong Kong.

Altogether 206 genuine landslides were reported to the Government in 2010. There were 15 major landslides (viz. failure volume of 50 $m^3$ or more), and none of them involved engineered man-made slopes that have been accepted under the slope safety system. Seven minor landslides (viz. failure volume of less than 50 $m^3$) occurred on engineered man-made slopes. The corresponding annual failure rate is about 0.027% on a slope number basis (i.e. number of landslides relative to the total number of engineered slopes).

Overall, 99.97% of the engineered man-made slopes performed satisfactorily without occurrence of landslides in 2010.

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

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# 1 Introduction

This report presents the findings of a diagnostic review of the landslides in 2010 that were reported to the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department (CEDD) and other government departments. The review forms part of GEO's systematic landslide investigation (LI) programme, which is an integral component of the Government's slope safety system. 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.

The present diagnostic review considers all the available landslide data in 2010. The review has been carried out by the Landslip Preventive Measures Division 1 (LPM1) of the GEO, with assistance provided by GEO's LI consultants, namely Fugro Scott Wilson Joint Venture (FSWJV) and AECOM Asia Company Limited (AECOM).

# 2 Rainfall and Landslides in 2010

The factual information, together with the relevant statistics on rainfall and reported landslides in 2010, was documented by Leung et al (2011).

In 2010, the annual rainfall recorded at the Principal Raingauge of the Hong Kong Observatory (HKO) in Tsim Sha Tsui was 2,372 mm, close to the mean annual rainfall of 2,383 mm recorded between 1971 and 2000. Three Landslip Warnings were issued on 22 July, 28 July and 21 September 2010. Two Black Rainstorm Warnings were issued on 22 July and 28 July 2010; seven Red Rainstorm Warnings were issued between 22 July and 21 September 2010; and 17 Amber Rainstorm Warnings were issued between 7 May and 21 September 2010.

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).

In the present context, failure volume refers to the total sum 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 210 reported incidents in 2010, 206 were genuine landslides, discounting the non-landslide incidents (e.g. tree falls). There were 15 major failures, corresponding to about 7% of the number of genuine landslides.

The distribution of landslides, as classified by the type of slope failure, is given in Table 2.1. The range of facilities affected by the landslides is summarised in Table 2.2. The consequences of the landslides in relation to the type of slope failure are summarised in Table 2.3. The distribution of the different facility groups affected by major landslides is presented in Table 2.4. The distribution of the scale of failures, as classified by the type of slope involved, is given in Table 2.5.

**Table 2.1 Breakdown of Landslides by Type of Slope Failure**

| Type of Slope Failure | | Number | Percentage (%) |
|---|---|---|---|
| Fill Slopes | | 10 (2) | 4.9 |
| Cut Slopes | Soil | 103 (5) | 50.0 |
| | Soil/Rock | 23 (1) | 11.1 |
| | Rock | 4 (0) | 1.9 |
| Retaining Walls | | 15 (0) | 7.3 |
| Natural Hillside | | 41 (7) | 19.9 |
| Registered Disturbed Terrain | | 10 (0) | 4.9 |
| Total | | 206 (15) | 100 |

Legend:

23 (1) Twenty-three landslides, one of which was major failure (i.e. failure volume $\geq 50\ m^3$)

Notes:
(1) Where a landslide involved more than one type of failure, the predominant type of failure has been considered in the above classification.
(2) Incidents that were not genuine landslides have been excluded.

**Table 2.2 Breakdown of Landslides by Type of Affected Facility**

| Type of Affected Facility | Hong Kong Island | Kowloon | New Territories and Outlying Islands | All |
|---|---|---|---|---|
| Buildings (including village houses) | 3 (0) | 0 (0) | 19 (0) | 22 (0) |
| Registered Squatter Dwellings | 0 (0) | 0 (0) | 33 (2) | 33 (2) |
| Roads | 5 (0) | 1 (1) | 13 (0) | 19 (1) |
| Transportation Facilities (e.g. railways, tramways, etc.) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Pedestrian Pavements/Footways | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Minor Footpaths/Access Paths/ Access Roads | 6 (0) | 2 (1) | 68 (9) | 76 (10) |
| Construction Sites | 2 (0) | 1 (1) | 2 (0) | 5 (1) |
| Open Areas | 6 (0) | 0 (0) | 22 (1) | 28 (1) |
| Catchwaters | 0 (0) | 0 (0) | 2 (0) | 2 (0) |
| Others (e.g. carparks, parks, playgrounds, gardens, backyards, etc.) | 5 (1) | 0 (0) | 21 (1) | 26 (2) |
| Nil Consequence | 1 (0) | 0 (0) | 4 (0) | 5 (0) |
| Total | 28 (1) | 4 (3) | 184 (13) | 216 (17) |

Legend:

4 (3) Four landslides of which three were major failures (i.e. failure volume ≥ 50 $m^3$)

Notes:
(1) A given landslide may affect more than one type of facility.
(2) Incidents that were not genuine landslides have been excluded.
(3) Nil consequence refers to incidents where the landslide debris came to rest on areas with no proper access for the public (e.g. natural hillside, slope berm, disused quarry surrounded by fence, etc.).

**Table 2.3 Breakdown of Landslide Consequences by Type of Slope Failure**

| Type of Slope Failure | | Number of Squatter Dwellings [(1)] Evacuated | | Number of Floors, Houses or Flats Evacuated or Partially Closed | Number of Closure | | | Deaths | Injuries reported to GEO |
|---|---|---|---|---|---|---|---|---|---|
| | | Permanent | Temporary | | Roads | Pedestrian Pavements | Footpaths, Alleyways or Access Paths | | |
| Fill Slopes | | 0 (0) | 1 (2) | 0 | 2 | 0 | 1 | 0 | 0 |
| Cut Slopes | Soil | 1 (2) | 2 (5) | 0 | 4 | 0 | 3 | 0 | 0 |
| | Soil/Rock | 0 (0) | 0 (0) | 0 | 0 | 0 | 0 | 0 | 0 |
| | Rock | 0 (0) | 0 (0) | 0 | 0 | 0 | 0 | 0 | 0 |
| Retaining Walls | | 0 (0) | 3 (9) | 0 | 0 | 0 | 3 | 0 | 0 |
| Natural Hillside | | 0 (0) | 0 (0) | 0 | 1 | 0 | 5 | 0 | 0 |
| Registered Disturbed Terrain | | 0 (0) | 0 (0) | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | | 1 (2) | 6 (16) | 0 | 7 | 0 | 12 | 0 | 0 |

Legend:

1 (1) Number of squatter dwellings evacuated, with the number of tolerated squatter structures evacuated shown in brackets

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 purposes or non-domestic purposes and registered in 1982 Housing Department's Squatter Structure Survey (GEO, 2010b).

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

**Table 2.4 Breakdown of Facility Groups Affected by Major Landslides**

| Type of Major Landslide | Facilities Group Affected by Major Landslides (Group No.) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1a | 1b | 2a | 2b | 3 | 4 | 5 |
| All Major Landslides | 0 | 2 | 0 | 1 | 1 | 9 | 4 |
| Major Landslides on Man-made Slopes | 0 | 2 | 0 | 1 | 1 | 4 | 2 |
| Major Landslides on Registered Disturbed Terrain | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Major Landslides on Natural Hillside | 0 | 0 | 0 | 0 | 0 | 5 | 2 |

Notes: (1) Facility groups are classified in accordance with the GEO Technical Guidance Note No. 15 (GEO, 2007).
(2) A given landslide may affect more than one type of facility.

**Table 2.5 Breakdown of Scale of Failures by Type of Slope**

| Type of Slope | Number of Minor Failures | Number of Major Failures | | Total |
|---|---|---|---|---|
| | (< 50 $m^3$) | (50 $m^3$ to < 500 $m^3$) | (≥ 500 $m^3$) | |
| Registered Man-made Slopes | 108 | 8 | 0 | 116 |
| Registered Disturbed Terrain | 10 | 0 | 0 | 10 |
| Unregisterable Man-made Slopes | 34 | 0 | 0 | 34 |
| Registerable Man-made Slopes Not Yet Registered at Time of Failure | 5 | 0 | 0 | 5 |
| Natural Hillside | 34 | 7 | 0 | 41 |
| Total | 191 | 15 | 0 | 206 |

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# 3 Severity of Rainstorms as Reflected by Landslide Potential Index

Experience has shown that the annual rainfall alone 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 landslides is given by the Landslide Potential Index (LPI), as promulgated by the GEO (2009a). The LPI is calculated for rainstorms that result in the issue of Landslip Warning and used to depict the relative severity of the rainstorm with respect to its potential to cause landslides. The LPI, which is not a predictive index, is based on the 24-hour rainfall of a rainstorm. The LPI for rainstorms that resulted in the issue of Landslip Warning from 1984 to 2010 is presented in Figure 3.1.

In 2010, three Landslip Warnings were issued on 22 July, 28 July and 21 September 2010. The LPI for these rainstorm events was assessed to be 1. In terms of its potential to cause landslides, the rainstorms of 22 July, 28 July and 21 September 2010 were one-tenth of the severity of the rainstorms of 23 July 1994 and 20 August 2005, both of which had an LPI of 10 and had triggered landslides resulting in fatalities (viz. the 23 July 1994 landslide at Kwun Lung Lau and the 20 August 2005 landslide at Fu Yung Shan Tsuen).

# 4 Overall Diagnostic Review of Landslides

## 4.1 General

An overall diagnostic review of the available 2010 landslide data has been carried out to appraise the slope performance, and facilitate the identification of areas in the slope safety system for further improvement.

The diagnostic review has mainly focused on the following aspects:

(a) coverage of the Catalogue of Slopes,

(b) performance of registered man-made slopes,

(c) observations from natural terrain landslides, and

(d) other areas of technical interest.

## 4.2 Coverage of the 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) that was completed in September 1998, together with newly formed or identified slope features after 1998, are registered in the Catalogue of Slopes. Potentially registerable man-made slopes would also be identified during slope maintenance inspections, landslide investigations and other geotechnical inspections or studies (GEO, 2010a).

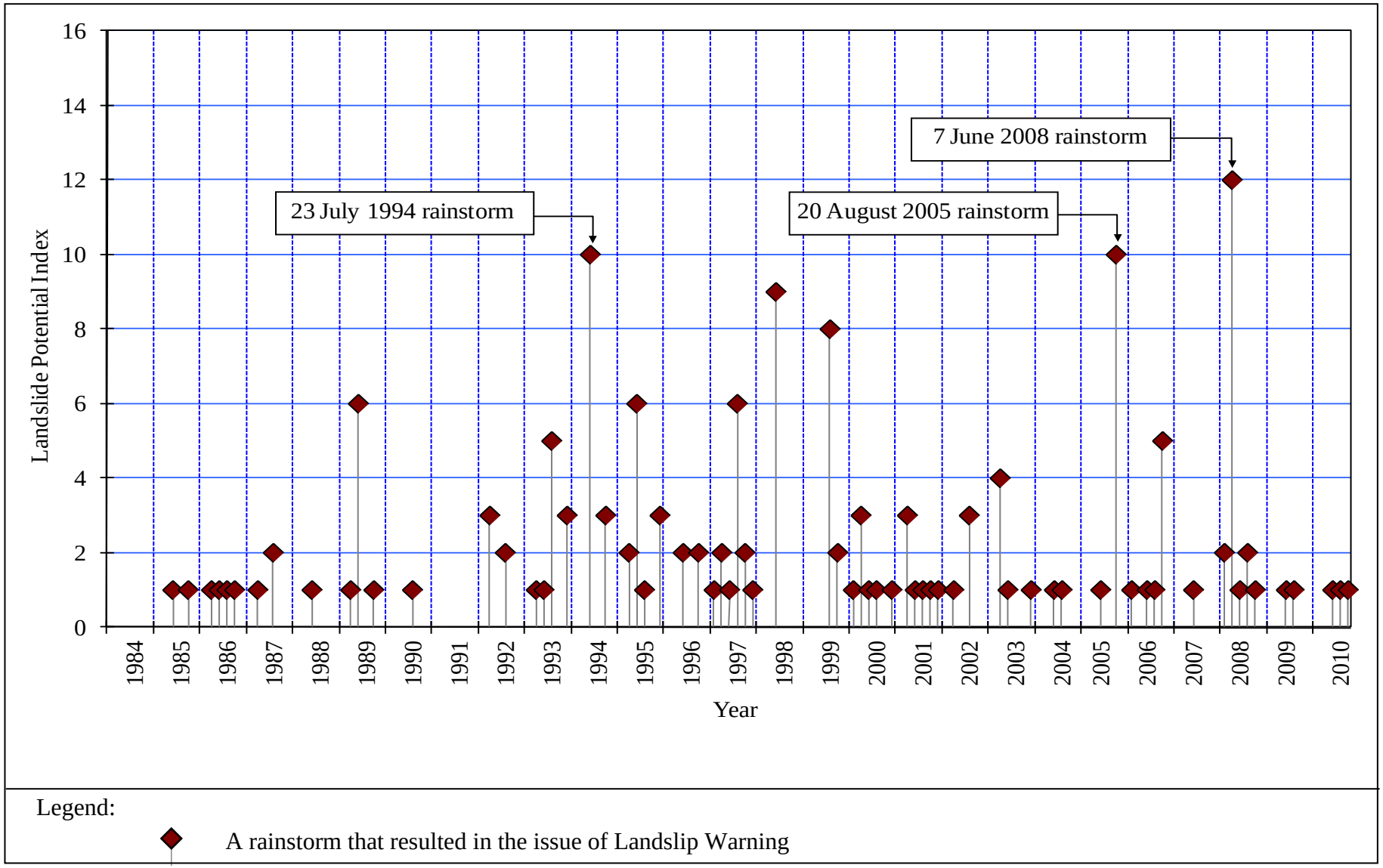


**Figure 3.1 Landslide Potential Index for Rainstorms that Resulted in the Issue of Landslip Warning from 1984 to 2010**



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### 4.2.2 Diagnosis

Of the 206 genuine landslides, 126 occurred on registered slope features (comprising 116 on registered man-made slopes and ten on registered disturbed terrain (DT) features) and 80 occurred on slopes not registered in the Catalogue of Slopes (Table 2.5).

Among the above 80 landslides, 41 occurred on natural hillside, 34 occurred on small man-made slope features that do not meet the slope registration criteria (GEO, 2004). The remaining five landslides involved slope features that satisfied the slope registration criteria but were not registered in the Catalogue of Slopes at the time of failure, which was 2.4% of the number of genuine landslides in 2010. A breakdown of these 80 landslides is given in Figure 4.1.

The landslide incidents involving the five registerable slopes were all minor failures with a failure volume $\leq 5$ m$^3$. Amongst these five failures, one resulted in temporary closure of a road and the remaining four incidents did not cause any significant impact on the community (Appendix B). Following the landslides, arrangements have been made to register the concerned man-made slope features in the Catalogue of Slopes.

The 34 landslides involving unregisterable man-made slope features were all minor failures with a failure volume d 12 m$^3$.

## 4.3 Performance of Registered Man-made Slopes

### 4.3.1 General

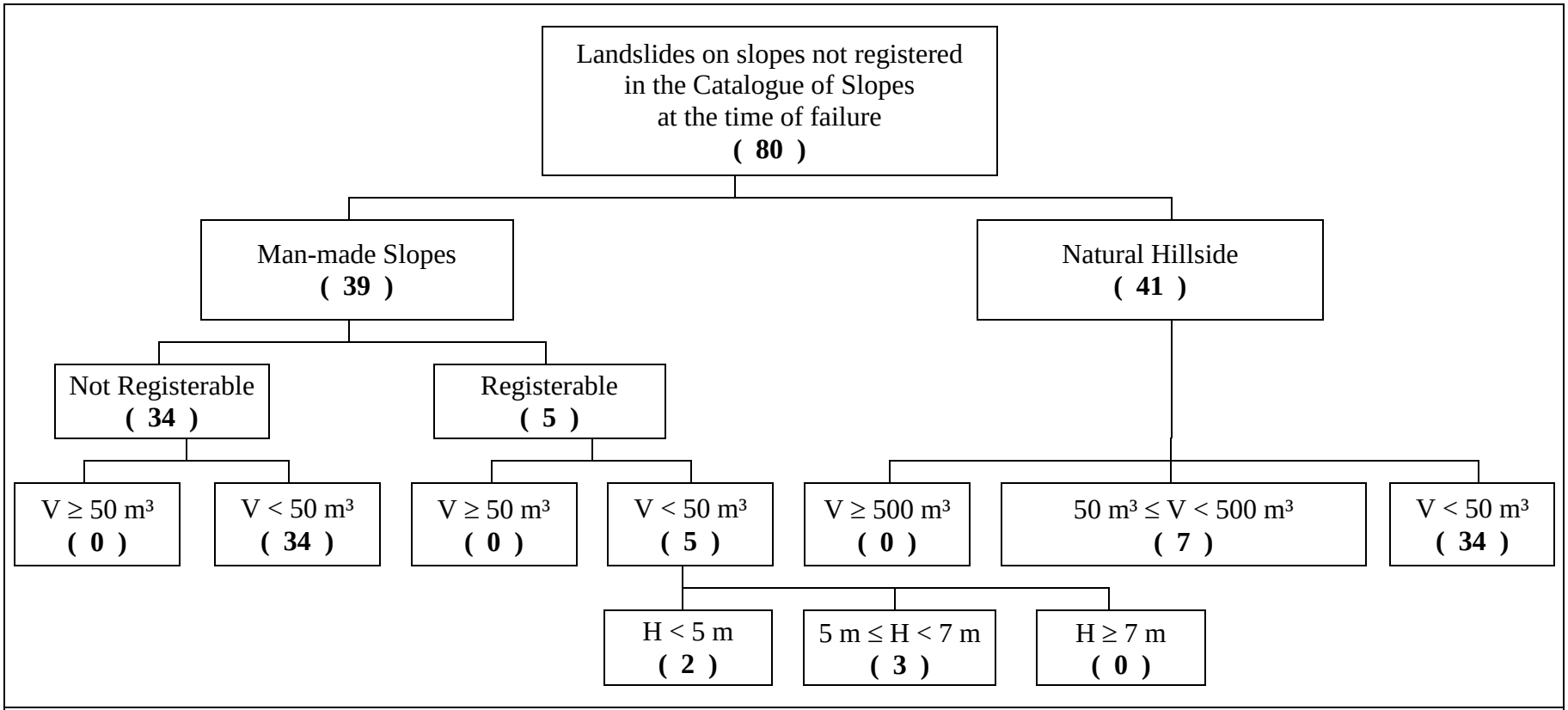
The man-made slopes registered in the Catalogue of Slopes can be broadly classified into engineered slopes and non-engineered slopes. The performance of the registered man-made slopes is reviewed in terms of their annual failure rates.

Engineered slopes include the following:

(a) slopes formed after 1977 (i.e. after the Geotechnical Control Office (renamed GEO in 1991) was established) 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




Legend:
- V Failure volume
- H Height of man-made feature before failure
- ( 80 ) Number of landslide incidents = 80

Notes:
(1) 'Not Registerable' refers to cases involving slopes that do not satisfy the feature height criteria for registration in the Catalogue of Slopes (GEO, 2004) at the time of failure.
(2) Following the landslides, arrangements have been made to register the concerned man-made slope features in the Catalogue of Slopes.

**Figure 4.1 Breakdown of Landslides on Unregistered Slopes in 2010**

(d) slopes upgraded to the required geotechnical standards using Type 3 prescriptive measures (GEO, 2009b) under an adequate quality system satisfying the requirements of Environment, Transport and Works Bureau (ETWB) Technical Circular (Works) No. 13/2005 (ETWB, 2005) whereby checking of the design by the GEO has been waived.

For the present diagnosis, 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 considered as non-engineered slopes.

Of the 206 genuine landslides in 2010, a total of 116 landslides (about 56%) occurred on registered man-made slopes (Table 2.5). Of these 116 landslides, seven (about 6%) occurred on engineered slopes, all of which were minor failures. Of the remaining 109 landslide incidents that occurred on non-engineered slopes, eight incidents were major and the remaining were minor. Further details on the landslides in 2010 involving engineered slopes are given in Appendix A. Detailed assessment of the engineered and non-engineered slopes is described in the sections below.

### 4.3.2 Landslides on Engineered Slopes

Brief description of the engineered slope failures in 2010 are given in Appendix A. A breakdown of these seven landslides in terms of feature type is given in Table 4.1.

**Table 4.1 Breakdown of Landslides on Engineered Slopes**

| Scale of Failure ($m^3$) | Fill Slopes | Cut Slopes | | | Retaining Walls | Total |
|---|---|---|---|---|---|---|
| | | Soil | Soil/Rock | Rock | | |
| > 500 $m^3$ | 0 | 0 (0) | 0 (0) | 0 | 0 | 0 |
| 50 $m^3$ to 500 $m^3$ | 0 | 0 (0) | 0 (0) | 0 | 0 | 0 |
| > 5 $m^3$ to < 50 $m^3$ | 0 | 2 (0) | 0 (0) | 0 | 0 | 2 |
| ≤ 5 $m^3$ | 0 | 2 (1) | 3 (0) | 0 | 0 | 5 |
| Total | 0 | 4 (1) | 3 (0) | 0 | 0 | 7 |

Legend:

2 (1) Of the two landslides, one occurred within or adjacent to the soil-nailed portion of the slope

Three of these seven engineered slope failures involved minor rockfalls, with a failure volume less than 0.6 $m^3$. These incidents occurred on the rock portion of soil/rock cut slopes without any surface protective measures. The incidents indicated that minor rockfalls may be difficult to guard against in the design of rock slopes. Provision of surface protective measures such as rock mesh netting could be a pragmatic solution.

One minor failure involved a soil-nailed cut slope (No. 13NE-A/C102), which was located at South Lantau Road, Lantau (Incident No. 2010/06/0942). The failure was associated with small-scale detachment (1 $m^3$) from the near-surface groundmass in between soil nail heads. This failure was shallow (~0.3 m deep) and had negligible consequence.

The other three incidents (Incident Nos. 2010/06/0947, 2010/08/1027 and 2010/05/0939) occurred on unsupported soil cut slopes. They were checked and accepted by the GEO between 1989 and 2001. The landslides involved a failure volume ranging from 2.5 $m^3$ to 40 $m^3$, with negligible consequences.

Among the seven engineered slope failures, three involved slopes that have been previously treated under the Landslip Preventive Measures (LPM) Programme (see Table 4.2).

**Table 4.2 Breakdown of Landslides on Slopes Previously Treated under the LPM Programme**

| Scale of Failure ($m^3$) | Fill Slopes | Cut Slopes | | | Retaining Walls | Total |
|---|---|---|---|---|---|---|
| | | Soil | Soil/Rock | Rock | | |
| > 500 $m^3$ | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 $m^3$ to 500 $m^3$ | 0 | 0 | 0 | 0 | 0 | 0 |
| > 5 $m^3$ to < 50 $m^3$ | 0 | 0 | 0 | 0 | 0 | 0 |
| ≤ 5 $m^3$ | 0 | 1 (1) | 2 (0) | 0 | 0 | 3 |
| Total | 0 | 1 (1) | 2 (0) | 0 | 0 | 3 |

Legend:

2 (0) Of the two landslides involved, none occurred within or adjacent to the soil-nailed portion of the slope

### 4.3.3 Landslides on Non-engineered Slopes

There were 109 failures on non-engineered slopes in 2010, among which 101 failures were minor and eight were major.

Of the eight major failures, the largest one occurred on Slope No. 11NW-B/FR5 below Pak Wan Street (150 $m^3$), which resulted in temporary closure of the road (see also Section 4.6). Two other major failures (Incident Nos. 2010/07/0976 and 2010/07/0982) affected squatter dwellings. The rest of the major landslides did not have any notable consequence.

Of the 101 minor landslides, 60 were relatively small in scale with a failure volume less than 5 $m^3$ and the rest had a failure volume ranging from 5 $m^3$ to 40 $m^3$. Four incidents resulted in temporary road closure. Another resulted in damage of a car parked at the toe of the slope that failed. The rest did not have any notable consequence.

### 4.3.4 Annual Failure Rates

The annual failure rates of registered man-made slopes under different categories are presented in Tables 4.3 and 4.4. The annual failure rates have been assessed in terms of:

(a) the number of landslides divided by the total number of slopes under a given category (e.g. slope type),

(b) the surface area of landslides divided by the total surface area of slopes under a given category, and

(c) the number of landslides divided by the total surface area of slopes under a given category.

By relating the failure rate to the surface area of slopes as in (b) above, it would have taken into account that a large slope is more susceptible to having 'defects' than a small slope. It is however noteworthy that the annual failure rates could be influenced by other factors, such as the rainfall characteristics, prevailing slope maintenance condition, etc.

The annual failure rates for all genuine landslides on registered man-made slopes in 2010 (excluding registered DT features) correspond to about 0.2% (number of landslides divided by number of registered man-made slopes), 0.005% (total surface area of landslides divided by total surface area of registered man-made slopes), and about $2 \times 10^{-6}$ (number of landslides divided by total surface area of registered man-made slopes in $m^2$) respectively. Further details are summarised in Table 4.4.

Based on the landslide data in 2010 (Table 4.4), the annual failure rates of engineered slopes are lower than that of non-engineered slopes by a factor of about 13 on a slope number basis, and about 88 on a slope surface area basis. In terms of the number of landslides per total slope surface area, the corresponding failure rate of engineered slopes is about 37 times lower than that of non-engineered slopes.

In addition, the annual failure rates of slopes previously treated under the LPM Programme correspond to 0.073% (number of landslides divided by number of registered man-made slopes treated under the LPM Programme), 0.0001% (total surface area of landslides divided by total surface area of registered man-made slopes treated under the LPM Programme), and about $4 \times 10^{-7}$ (number of landslides divided by total surface area of registered man-made slopes treated under the LPM Programme in $m^2$) respectively, as summarised in Table 4.4. The annual failure rate of slopes previously treated under the LPM Programme is lower than that of non-engineered slopes by a factor ranging from about 5 to 150, comparable to that of other engineered slopes.

GEO's target annual success rates (where success rate = 1 – failure rate) for engineered slopes are 99.8% and 99.5% against major and minor failures respectively, on the basis of the number of landslides per total number of slopes. In 2010, the corresponding annual success rates were 100% and 99.97% respectively. Hence, the targets were satisfactorily achieved. The trend of the annual success rates of engineered slopes against major and minor failures respectively for the period from 1997 to 2010 is shown in Table 4.5 and Figure 4.2.

## 4.4 Natural Terrain Landslides

A total of 41 natural terrain landslides were reported in 2010, seven of which were major failures. Three landslides resulted in temporary closure of a road, slight damage of a canopy structure of a building and flooding of a backyard and a car park of a residential building. The other natural terrain landslides did not have any notable consequence. Among these reported natural terrain landslides, seven failures (all minor) were located at or within 50 m from existing Historical Landslide Catchments.

## 4.5 Landslides with Inadequate Slope Maintenance Diagnosed as a Key Contributory Factor to Failure

All the 116 landslides on registered man-made slopes were reviewed to assess whether inadequate slope maintenance was likely to have been a key contributory factor to the failures. Reference has been made to the records of emergency inspections by the GEO or other government departments, inspections or follow-up studies by the LI consultants.

Inadequate slope maintenance was assessed to be a key contributory factor to 27 of the 116 landslides (i.e. about 23%), of which two incidents were major failures. Amongst these 27 landslides, three occurred on engineered slopes.

Of these 27 landslides involving inadequate slope maintenance, 16 affected Government slopes and five affected private slopes. The remaining six incidents affected slope features of mixed maintenance responsibility of Government/private, based on the information from the Slope Maintenance Responsibility Information System (SMRIS) maintained by the Lands Department. Of these six incidents involving slope features of mixed maintenance responsibility, four occurred on the Government portion and two were on the private portion.

**Table 4.3 Annual Failure Rates of Registered Man-made Slopes in 2010**

| Annual Failure Rates | | Non-Engineered Slopes | | | Engineered Slopes | | |
|---|---|---|---|---|---|---|---|
| | | Fill/Retaining Wall | Soil/Rock Cut | Overall | Fill/Retaining Wall | Soil/Rock Cut | Overall |
| Slopes Involved in Landslides in 2010 | Number of Slopes | 14 | 95 | 109 | 0 | 7 | 7 |
| | Surface Area of Landslides ($m^2$) | 450 | 2,082 | 2,532 | 0 | 66 | 66 |
| Slopes Involved in Major Landslides in 2010 | Number of Slopes | 2 | 6 | 8 | 0 | 0 | 0 |
| | Surface Area of Landslides ($m^2$) | 261 | 548 | 809 | 0 | 0 | 0 |
| Slopes Involved in Minor Landslides in 2010 | Number of Slopes | 12 | 89 | 101 | 0 | 7 | 7 |
| | Surface Area of Landslides ($m^2$) | 189 | 1,534 | 1,723 | 0 | 66 | 66 |
| Total Number of Registered Slopes | | 11,160 | 20,090 | 31,250 | 11,840 | 14,210 | 26,050 |
| Total Surface Area of Registered Slopes ($m^2$) | | 6,181,000 | 10,415,600 | 16,596,600 | 13,274,200 | 26,133,100 | 39,407,300 |
| Annual Failure Rates (All Landslides) | On Slope Number Basis | 0.125% | 0.473% | 0.349% | 0% | 0.049% | 0.027% |
| | On Slope Surface Area Basis | 0.007% | 0.020% | 0.015% | 0% | 0.00025% | 0.00017% |
| | Number of Landslides Divided by Slope Surface Area (no./$m^2$) | $2.265 \times 10^{-6}$ | $9.121 \times 10^{-6}$ | $6.568 \times 10^{-6}$ | 0 | $2.679 \times 10^{-7}$ | $1.776 \times 10^{-7}$ |
| Annual Failure Rates (Major Landslides) | On Slope Number Basis | 0.018% | 0.030% | 0.026% | 0% | 0% | 0% |
| | On Slope Surface Area Basis | 0.004% | 0.005% | 0.005% | 0% | 0% | 0% |
| | Number of Landslides Divided by Slope Surface Area (no./$m^2$) | $3.236 \times 10^{-7}$ | $5.761 \times 10^{-7}$ | $4.820 \times 10^{-7}$ | 0 | 0 | 0 |

Note: Landslides on registered disturbed terrain features have been excluded from this calculation.

**Table 4.4 Breakdown of Annual Failure Rates of Registered Man-made Slopes**

| Category of Slope | | Failure Rate on Slope Number Basis (i.e. number of landslides divided by total number of slopes) | Failure Rate on Slope Surface Area Basis (i.e. surface area of landslides divided by total surface area of slopes) | Failure Rate in Terms of Number of Landslides Divided by Total Surface Area of Slopes (no./m²) |
|---|---|---|---|---|
| Registered Man-made Slopes | All Landslides | 0.202% | 0.005% | $2.071 \times 10^{-6}$ |
| | Major Landslides | 0.014% | 0.001% | $1.428 \times 10^{-7}$ |
| | Minor Landslides | 0.188% | 0.003% | $1.928 \times 10^{-6}$ |
| Engineered Slopes | All Landslides | 0.027% (0.073%) | 0.00017% (0.00010%) | $1.776 \times 10^{-7}$ ($4.336 \times 10^{-7}$) |
| | Major Landslides | 0 (0) | 0 (0) | 0 (0) |
| | Minor Landslides | 0.027% (0.073%) | 0.00017 % (0.00010%) | $1.776 \times 10^{-7}$ ($4.336 \times 10^{-7}$) |
| Non-engineered Slopes | All Landslides | 0.349% [12.9/4.8] | 0.015% [88.2/150.0] | $6.568 \times 10^{-6}$ [37.0/15.1] |
| | Major Landslides | 0.026% | 0.005% | $4.820 \times 10^{-7}$ |
| | Minor Landslides | 0.323% | 0.010% | $6.086 \times 10^{-6}$ |

Legend:

| | |
|---|---|
| 0.027% (0.073%) | Annual failure rate of engineered slopes (considering all landslides) is 0.027% and that for slopes previously treated under the LPM Programme is 0.073% |
| 0.349% [12.9/4.8] | Annual failure rate of non-engineered slopes (considering all landslides) is 0.349%, which is about 12.9 times and 4.8 times higher than those of engineered slopes and slopes previously treated under the LPM Programme respectively |

**Table 4.5 Annual Success Rates of Engineered Slopes from 1997 to 2010**

| Scale of Failure | 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 | 2008 | 2009 | 2010 |
| Engineered Slopes Processed by the Slope Safety System (≥ 50 m³) | 99.97% | 99.98% | 99.97% | 99.98% | 99.98% | 100% | 99.99% | 100% | 99.98% | 100% | 100% | 99.99% | 100% | 100% |
| Engineered Slopes Processed by the Slope Safety System (< 50 m³) | 99.89% | 99.92% | 99.92% | 99.91% | 99.93% | 99.95% | 99.95% | 99.97% | 99.89% | 99.95% | 99.97% | 99.89% | 99.95% | 99.97% |

Note: See Figure 4.2 for a plot of annual success rates of engineered slopes against the target annual success rates from 1997 and 2010.

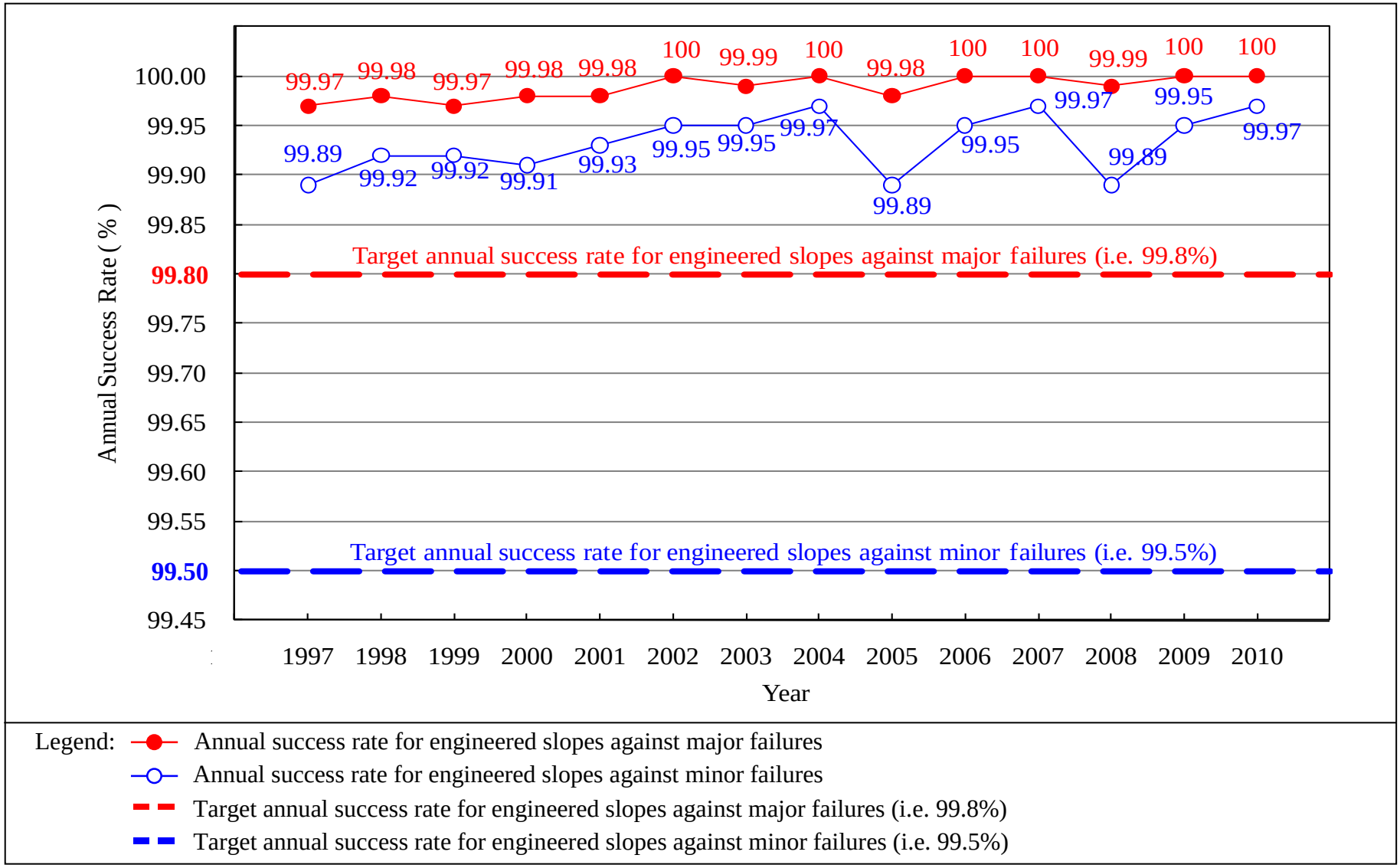



**Figure 4.2 Annual Success Rates of Engineered Slopes from 1997 to 2010**



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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 failure without adequate maintenance.

### 4.6 Major Landslides Involving Consequence-to-life Category 1 Slope Features

There were three major landslides occurring on consequence-to-life Category 1 slope features. Of these three landslides, the largest one occurred on a fill slope (No. 11NW-B/FR5) at Pak Wan Street, Shek Kip Mei on 22 July 2010 during heavy rainfall. The landslide involved a 150 $m^3$ washout failure within a construction site where preventive maintenance works to the slope were being carried out by the Highways Department. The site was located below a bend along Pak Wan Street. Overflow from a nearby drainage culvert inlet might have resulted in an overland flow along Pak Wan Street, which overspilled at the bend of Pak Wan Street, resulting in washout failure of the slope below. The incident did not cause any casualty, but it highlighted the potential landslide risk arising from overland flow.

The remaining two major landslides occurring on non-engineered slopes of consequence-to-life Category 1, affected squatter dwellings. One occurred on a 3 m high cut slope (No. 7SW-C/C990) in Shek Lei Hang Village, Kwai Chung on 22 July 2010. Another occurred on a 6 m high fill slope (No. 7SW-D/F314) in Tin Sum Pak Tin Tsuen, Shatin on 22 July 2010. The failure volumes were 80 $m^3$ and 100 $m^3$ respectively. The landslide debris damaged the squatter structures, without causing any casualty. The occupants were temporarily evacuated. The incidents indicated that some squatter dwellings could be subject to relatively high landslide risk.

## 5 Proposed Improvement Initiative

Based on the present review, the following improvement initiative is proposed:

(a) Review notable landslides incidents involving severe overland flow and identify areas in the slope surface drainage provisions for improvement (Section 4.6).

Improvement initiatives proposed by Li et al (2011) following a review of landslides in 2009 and the associated progress of the follow-up actions are summarised in Appendix C.

## 6 Conclusions

Overall, 99.97% of the engineered man-made slopes performed satisfactorily without occurrence of landslides in 2010. There was no major landslide on engineered slopes in 2010.

The annual failure rate of minor landslides on engineered slopes, on a slope number basis, was 0.027% in 2010. This corresponds to an annual success rate of 99.97%, which is well within the pledged annual success rate of 99.5%.

An initiative has 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.

## 7 References

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GEO (2004). *Registration and Upgrading of Records of Features (GEO Circular No. 15).* Geotechnical Engineering Office, Hong Kong, 20 p.

GEO (2007). *Guidelines for Classification of Consequence-to-Life Category for Slope Features (GEO Technical Guidance Note No. 15).* Geotechnical Engineering Office, Hong Kong, 14 p.

GEO (2009a). *Landslide Potential Index (GEO Information Note No. 3/2009).* Geotechnical Engineering Office, Hong Kong, 4 p.

GEO (2009b). *Prescriptive Measures for Man-made Slopes and Retaining Walls (GEO Publication No. 1/2009).* Geotechnical Engineering Office, Hong Kong, 76 p.

GEO (2010a). *Catalogue of Slopes (GEO Information Note No. 5/2010).* Geotechnical Engineering Office, Hong Kong, 3 p.

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Leung, J.C.W., Lam, H.W.K. & Chan, H.W. (2011). *Factual Report on Hong Kong Rainfall and Landslides in 2010 (SPR Report No. 3/2011).* Geotechnical Engineering Office, Hong Kong, 93 p.

Li, A.C.O., Lau, J.W.C. & Lam, C.L.H. (2011). *Review of Landslides in 2009 (LSR Report No. 1/2011).* Geotechnical Engineering Office, Hong Kong, 38 p.

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# Appendix A

## Landslide Incidents Involving Slopes Processed under the Slope Safety System

**Table A1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 1 of 4)**

| Incident No. | Slope No. | Location | Failure Volume ($m^3$) | Type of Slope | Remarks |
|---|---|---|---|---|---|
| 1. Slopes Upgraded Under the LPM Programme ($\sum$ = 3 nos.) | | | | | |
| 2010/06/0942 | 13NE-A/C102 | Along South Lantau Road, near Shek Pik Reservoir, Lantau | 1 | Soil Cut | The works, mainly comprising installation of soil nails and raking drains, and provision of vegetated cover with erosion control mat, were completed in 2005. The shallow failure (about 0.3 m deep) involved the near-surface groundmass within the soil-nailed portion of the slope. |
| 2010/06/0944 | 11SE-C/C3 | Near No. 37, Repulse Bay Road | 0.6 (rockfall) | Soil/ Rock Cut | The works, mainly comprising installation of soil nails and raking drains, rock dowels, concrete buttress, rock fall wire mesh, were completed in 2001. |
| 2010/11/1079 | 11SE-D/C49 | Near Lamp Post No. 33678 at Wan Tsui Road, Chai Wan | 0.3 (rockfall) | Soil/ Rock cut | The works, mainly comprising installation of soil nails and raking drains, and provision of typical rock slope treatment works, were completed in 1999. |

**Table A1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 2 of 4)**

| Incident No. | Slope No. | Location | Failure Volume ($m^3$) | Type of Slope | Remarks |
|---|---|---|---|---|---|
| 2. Slopes Assessed under the LPM Programme with No Upgrading Works Required (∑ = 1 no.) | | | | | |
| 2010/06/0947 | 11SE-A/CR450 | 1-10 Sai Wan Terrace, Sai Wan Ho | 40 | Soil Cut | A Stage 2 Study was completed in 2001. The report concluded that the slope met the required safety standards. |
| 3. Slopes Assessed by Studies in the Late 1970's to mid-1980's with No Upgrading Works/Further Study Required (∑ = 0 no.) | | | | | |
| Nil. | | | | | |
| 4. Slopes Assessed by Government Departments and Checked by GEO with No Upgrading Works Required (∑ = 1 no.) | | | | | |
| 2010/05/0940 | 11SW-C/C76 | Queen Mary Hospital | ~0.1 (rockfall) | Soil/ Rock Cut | A geotechnical assessment report by Arch SD was carried out in 1993, which was checked and accepted by the GEO in July 1993. By that time, no upgrading works were required in light that the slope had been treated with rock slope measures such as rock buttressing, rock dowels etc in 1983. |
| 5. Slopes Assessed by Private Owners and Checked by GEO with No Upgrading Works Required (∑ = 0 no.) | | | | | |
| Nil. | | | | | |

**Table A1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 3 of 4)**

| Incident No. | Slope No. | Location | Failure Volume ($m^3$) | Type of Slope | Remarks |
|---|---|---|---|---|---|
| 6. Slopes Formed or Upgraded by Government Departments and Checked by GEO ($\sum$ = 1 nos.) | | | | | |
| 2010/08/1027 | 7SW-C/CR457 | Natural Stream above, Wo Yi Hop Lane | 10 | Soil Cut | The geotechnical design/assessment of the slope was carried out in relation to Route 5 in Tsuen Wan Road Connections, which was checked and accepted by the GEO in 1991. |
| 7. Slopes Formed or Upgraded by Private Owners and Checked by GEO ($\sum$ = 1 no.) | | | | | |
| 2010/05/0939 | 15NE-A/CR684 | No. 45 Island Road | 2.5 | Soil Cut | The geotechnical design/assessment of the slope was carried out in relation to the site formation works under a private development project, which was checked and accepted by the GEO in 1989. |
| 8. Slopes Upgraded Following Service of DH Orders and Checked by GEO ($\sum$ = 0 no.) | | | | | |
| Nil. | | | | | |




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**Table A1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 4 of 4)**

| Incident No. | Slope No. | Location | Failure Volume ($m^3$) | Type of Slope | Remarks |
|---|---|---|---|---|---|
| 9. Slopes Assessed as Not Requiring Upgrading Works But with Outstanding GEO Comments ($\sum$ = 1 no.) | | | | | |
| ArchSD/SKW&IS-S/2010/02/0003 | 11SE-B/CR272 | Hong Kong Museum of Coastal Defence | <0.1 (rockfall) | Soil/Rock Cut | The geotechnical design/assessment of the slope was carried out in relation to the Site Formation Works for Lei Yue Mun Museum, which was checked by the GEO in 1997, with outstanding comment on slope surface protection at the slope (including the rock portion where the 2010 rockfall incident occurred). |
| 10. Slopes Assessed as Requiring Upgrading Works But with Outstanding GEO Comments ($\sum$ = 0 no.) | | | | | |
| Nil. | | | | | |

Legend:

Landslide occurred on or adjacent to the soil-nailed portion of a cut slope ($\sum$ = 1 nos.)

Landslide involved unsupported cuts ($\sum$ = 3 no.)

Notes:
(1) Slopes under Categories 1 to 8 are classified as engineered slopes.
(2) Slopes under Categories 9 and 10 are post-1977 features but are not taken as engineered slopes for the purpose of this report.
(3) Incident No. 2010/09/1050 involved a boulder fall near the crest of a cut slope No. 15NE-A/CR29 which had been processed under the slope safety system. However whether the boulder originated from the cut slope is not certain, due to lack of field evidence. This case is not covered in the slope list above.

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# Appendix B

## List of 2010 Landslide Incidents Involving Unregistered Man-made Slopes but Registerable at the Time of Failure

**Table B1 List of 2010 Landslide Incidents Involving Unregistered Man-made Slopes but Registerable at the Time of Failure**

| Incident No. | Location | Maximum Slope Height | Reported | | Failure | | | Facility Affected | Consequence |
|---|---|---|---|---|---|---|---|---|---|
| | | | Date | From | Date (Time) | Feature Type | Scale ($m^3$) | | |
| 2010/06/0949 | Opposite of lamp post N2424, Clear Water Bay Road | 5.3m | 10/6 | HyD | 10/6 | Soil Cut | 5 | Road | 1 of 2 lane of Clear Water Bay Road closed |
| 2010/06/0951 | Behind No. 49 Kam Shan Village, Tai Po | 3.3m | 8/6 | DLO | 1/1 (00:00) | Retaining wall | 0.5 | Squatter Structures | Nil |
| 2010/08/1032 | House No. 91, Fo Tan Village, Sha Tin | 5.4m | 30/7 | LandsD | 23/7 (15:15) | Soil Cut | 3 | Open Area | Nil |
| 2010/10/1071 | Near L/P No. VE4584, Tseng Tau, Sai Kung North | 5.6m | 5/10 | DLO | 1/10 (11:15) | Soil cut | 1 | Minor footpath | Nil |
| 2010/12/1086 | House No. 173, Ha Wo Che Village, Sha Tin | 4m | 16/12 | LandsD | 09/12 (14:30) | Soil Cut | 2 | Village House | Nil |

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# Appendix C

## Progress of Follow-up Actions on the Improvement Measures Recommended in the Review of 2009 Landslides

**Table C1 Progress of Follow-up Actions on the Improvement Measures Recommended in the Review of 2009 Landslides**

| Recommended Improvement Measures | Progress |
|---|---|
| 1. Develop a methodology for technical screening and review of 'signed-off' features as a safety-net measure to identify slopes requiring follow-up actions. | Trial implementation of technical screening and review of selected 'signed-off' feature has been completed. The full implementation of the technical screening and review would be carried out under GEO Strategic Goal No. 2. |
| 2. Review landslides on man-made slopes with a history of past failures and identify appropriate follow-up actions. | An initial screening has identified some man-made slopes of consequence-to-life category 1 with a history of past failures. The cases are being reviewed with respect to the actions that had been taken, so as to identify any further follow-up actions required. |

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

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## GEOTECHNICAL MANUALS

Geotechnical Manual for Slopes, 2nd Edition (1984), 302 p. (English Version), (Reprinted, 2011).

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

## GEOGUIDES

| | |
|---|---|
| Geoguide 1 | Guide to Retaining Wall Design, 2nd Edition (1993), 258 p. (Reprinted, 2007). |
| Geoguide 2 | Guide to Site Investigation (1987), 359 p. (Reprinted, 2000). |
| Geoguide 3 | Guide to Rock and Soil Descriptions (1988), 186 p. (Reprinted, 2000). |
| Geoguide 4 | Guide to Cavern Engineering (1992), 148 p. (Reprinted, 1998). |
| Geoguide 5 | Guide to Slope Maintenance, 3rd Edition (2003), 132 p. (English Version). |
| 岩土指南第五冊 | 斜坡維修指南，第三版(2003)，120頁(中文版)。 |
| Geoguide 6 | Guide to Reinforced Fill Structure and Slope Design (2002), 236 p. |
| Geoguide 7 | Guide to Soil Nail Design and Construction (2008), 97 p. |

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## GEOSPECS

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

## GEO PUBLICATIONS

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| GCO Publication No. 1/90 | Review of Design Methods for Excavations (1990), 187 p. (Reprinted, 2002). |
| GEO Publication No. 1/93 | Review of Granular and Geotextile Filters (1993), 141 p. |
| GEO Publication No. 1/2006 | Foundation Design and Construction (2006), 376 p. |
| GEO Publication No. 1/2007 | Engineering Geological Practice in Hong Kong (2007), 278 p. |
| GEO Publication No. 1/2009 | Prescriptive Measures for Man-Made Slopes and Retaining Walls (2009), 76 p. |
| GEO Publication No. 1/2011 | Technical Guidelines on Landscape Treatment for Slopes (2011), 217 p. |

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## GEOLOGICAL PUBLICATIONS

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

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

## TECHNICAL GUIDANCE NOTES

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