Review of Landslides in 2009

GEO Report No. 290

A.C.O. Li, J.W.C. Lau & C.L.H. Lam

Geotechnical Engineering Office
Civil Engineering and Development Department
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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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H.N. Wong
Head, Geotechnical Engineering Office
November 2013

Foreword

This report presents the findings of a detailed diagnosis of landslides in 2009 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 J.W.C. Lau and Ms C.L.H. Lam of Landslip Preventive Measures Division 1 under the supervision of Mr W.K. Pun. 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.

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

Abstract

This report presents the findings of a diagnostic review of the landslides in 2009 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 101 genuine landslides were reported to the Government in 2009. All the available landslide data were examined and follow-up studies on selected landslide incidents were being carried out under the systematic landslide investigation programme. These studies provided information and insights into the types, causes and mechanisms of landslides, and facilitated the identification of areas deserving attention and improvement.

Based on the landslide data in 2009, there were 2 major landslide (viz. failure volume of 50 m^3 or more), but none of them involved engineered man-made slopes that have been accepted under the slope safety system. In terms of minor landslides (viz. failure volume of less than 50 m^3) on engineered man-made slopes, the annual failure rate is about 0.047% on a slope number basis (i.e. number of landslides relative to the total number of engineered slopes).

Overall, 99.95% of the engineered man-made slopes performed satisfactorily without occurrence of landslides in 2009.

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

Contents

List of Tables

List of Figures

1 Introduction

This report presents the findings of a diagnostic review of the landslides in 2009 that were reported to the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department (CEDD). 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 2009, including the findings of individual landslide studies. 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) respectively.

2 Rainfall and Landslides in 2009

The factual information, together with the relevant statistics on rainfall and reported landslides in 2009, was documented by Lam et al (2010).

In 2009, the annual rainfall recorded at the Principal Raingauge of the Hong Kong Observatory (HKO) in Tsim Sha Tsui was 2,182 mm, which was approximately 8% below the mean annual rainfall of 2,383 mm recorded between 1971 and 2000. Two Landslip Warnings were issued on 19 July and 15 September 2009. Two Red Rainstorm Warnings were issued on 4 June and 17 July 2009; and 20 Amber Rainstorm Warnings were issued between 5 March and 30 September 2009.

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 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 102 reported incidents in 2009, 101 were genuine landslides, discounting the non-landslide incidents (e.g. tree falls). There were two major failures, corresponding to

about 2% 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 (classification given in Wong (1998)) affected by the 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		8 (0)	7.9
Cut Slopes	Soil	35 (1)	34.6
	Soil/Rock	22 (0)	21.8
	Rock	4 (0)	4.0
Retaining Walls		7 (0)	6.9
Natural Hillside		24 (1)	23.8
Registered Disturbed Terrain		1 (0)	1.0
Total		101 (2)	100.0

Legend:

35 (1) 35 landslides, one of which was major failure (i.e. failure volume ≥ 50 m³)

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	0 (0)	0 (0)	4 (0)	4 (0)
Registered Squatter Dwellings	0 (0)	0 (0)	10 (0)	10 (0)
Roads	7 (0)	1 (0)	3 (0)	11 (0)
Transportation Facilities (e.g. railways, tramways, etc.)	0 (0)	0 (0)	0 (0)	0 (0)
Pedestrian Pavements/Footways	1 (0)	0 (0)	2 (0)	3 (0)
Minor Footpaths/Access Paths	9 (0)	3 (0)	19 (2)	31 (2)
Construction Sites	0 (0)	1 (0)	0 (0)	1 (0)
Open Areas	3 (0)	1 (0)	11 (0)	15 (0)
Catchwaters	1 (0)	0 (0)	3 (0)	4 (0)
Others (e.g. carparks, parks, playgrounds, gardens, backyards, etc.)	9 (0)	1 (0)	7 (0)	17 (0)
Nil Consequence	1 (0)	1 (0)	4 (0)	6 (0)
Total	31 (0)	8 (0)	63 (2)	102 (2)

Legend:

31 (2) 31 landslides, two of which 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
		Permanent	Temporary		Roads	Pedestrian Pavements	Footpaths, Alleyways or Private Access Paths		
Fill Slopes		0 (0)	0 (0)	0	1	0	0	0	0
Cut Slopes	Soil	0 (0)	1 (1)	0	1	1	3	0	0
	Soil/Rock	0 (0)	0 (0)	0	0	0	1	0	0
	Rock	0 (0)	0 (0)	0	0	0	0	0	0
Retaining Walls		0 (0)	0 (0)	0	0	0	1	0	0
Natural Hillside		0 (0)	0 (0)	0	0	0	1	0	0
Registered Disturbed Terrain		0 (0)	0 (0)	0	0	0	0	0	0
Total		0 (0)	1 (1)	0	2	1	6	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.

(3) A minor rockfall incident (No. 2009/06/0882) behind Block A, Yen Lok Building in Chai Wan resulted in the evacuation of occupants in an unauthorised structure.

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	0	0	0	0	0	2
Major Landslides on Man-made Slopes	0	0	0	0	0	0	1
Major Landslides on Registered Disturbed Terrain	0	0	0	0	0	0	0
Major Landslides on Natural Hillsides	0	0	0	0	0	0	1

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 2.5 Breakdown of Scale of Failures by Type of Slope

Type of Slope	Number of Minor Failures (< 50 m^3)	Number of Major Failures		Total
		(50 m^3 to < 500 m^3)	(≥ 500 m^3)	
Registered Man-made Slopes	60	0	0	60
Registered Disturbed Terrain Features	1	0	0	1
Unregisterable Man-made Slopes	11	1	0	12
Registerable Man-made Slopes Not Yet Registered at Time of Failure	4	0	0	4
Natural Hillsides	23	1	0	24
Total	99	2	0	101

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. Follow-up studies on selected landslide incidents in 2009 were carried out by the LI consultants or the in-house study team of LPM1.

The individual landslide studies have provided valuable information and insights into the types, causes and mechanisms of landslides. 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 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 (GEO, 2009a), 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 2009 is presented in Figure 3.1.

In 2009, two Landslip Warnings were issued on 19 July and 15 September 2009. The LPI for these two rainstorm events was assessed to be 1. In terms of its potential to cause landslides, the rainstorms of 19 July and 15 September 2009 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 2009 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 New Catalogue of Slopes,

(b) performance of registered man-made slopes, and

(c) observations from natural terrain landslides.

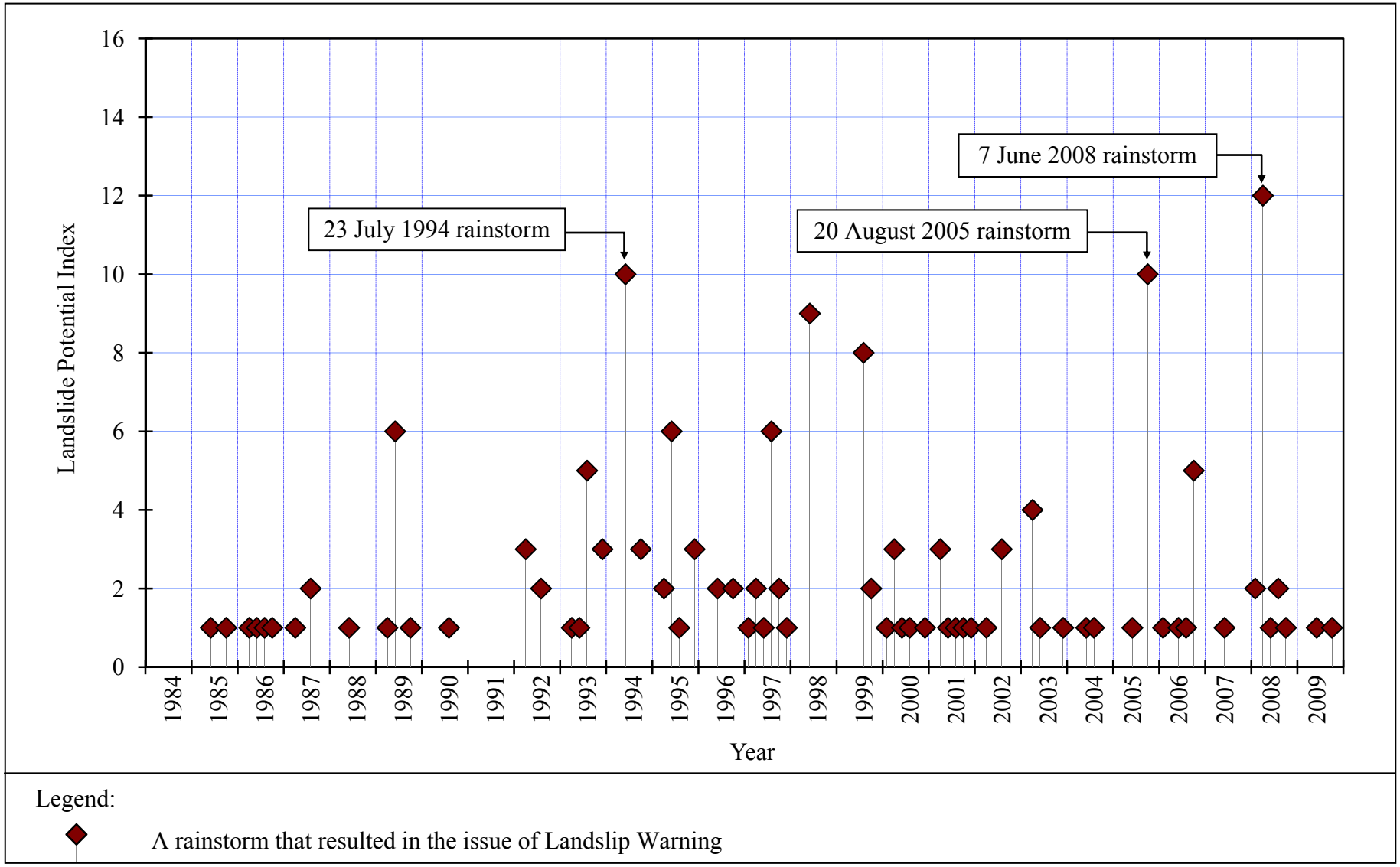


Figure 3.1 Landslide Potential Index for Rainstorms that Resulted in the Issue of Landslip Warning from 1984 to 2009

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

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) that completed in September 1998, together with newly formed or identified slope features after 1998, are registered in the New 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).

4.2.2 Diagnosis

Of the 101 genuine landslides, 61 occurred on registered slope features (comprising 60 on registered man-made slopes and one on a registered disturbed terrain (DT) feature) and 40 occurred on slopes not registered in the New Catalogue of Slopes at the time of failure (Table 2.5).

Of the above 40 landslides, 12 occurred on small man-made slope features that do not meet the slope registration criteria (GEO, 2004a) and another 24 occurred on natural hillsides. The remaining 4 landslides involved slope features that satisfied the slope registration criteria but were not registered in the New Catalogue of Slopes at the time of failure. This indicates that the number of registerable slopes that were yet to be included in the New Catalogue of Slopes at the time of failure was about 4% of the number of genuine landslides in 2009. A breakdown of these 40 landslides is given in Figure 4.1.

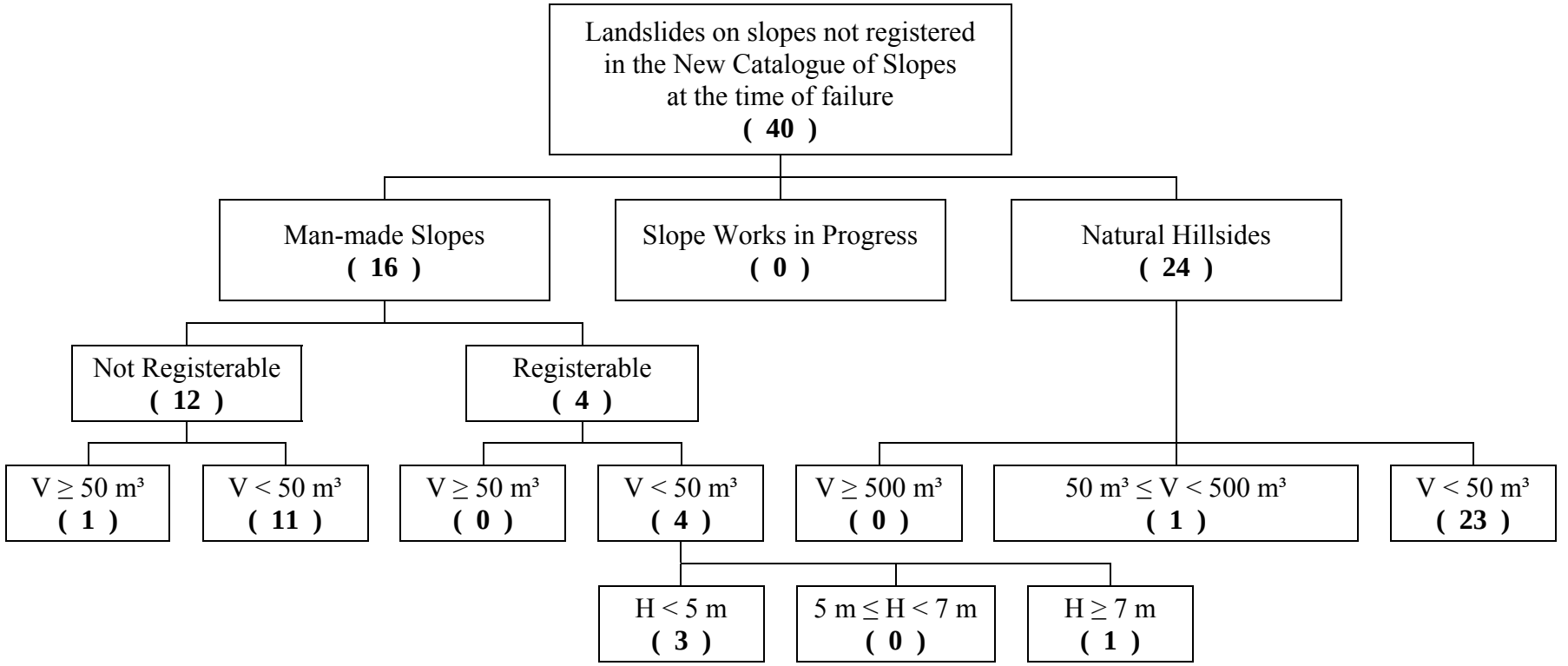
The 4 landslide incidents on registerable slopes were all minor failures with a failure volume $\leq$ 1 m³ and did not cause any significant impact on the community (Table 4.1). Following the landslides, arrangements have been made to register the concerned man-made slope features in the New Catalogue of Slopes.

Of the 12 landslides involving unregisterable man-made slope features, one was a major failure (about 60 m³ in volume) that occurred on a 3 m high soil cut slope with a masonry facing at Lin Ma Hang Road, Sha Tau Kok (Incident No. 2009/08/0898), resulting in temporary closure of a 15 m long section of Lin Ma Hang Road. The remaining 11 incidents were minor failures with a failure volume ranging from < 1 m³ to 20 m³. Amongst these 11 minor failures, one resulted in temporary road closure, one led to undermining of a section of minor footpath and the other nine incidents did not have any major consequences.

4.3 Performance of Registered Man-made Slopes

4.3.1 General

The man-made slopes registered in the New 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.



Legend:

V	Failure volume
H	Height of man-made feature before failure
(40)	Number of landslide incidents = 40

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 (GEO, 2004a) at the time of failure.

(2) Following the landslides, arrangements have been made to register the concerned man-made slope features in the New Catalogue of Slopes.

Figure 4.1 Breakdown of Landslides on Unregistered Slopes in 2009

Table 4.1 List of Landslide Incidents Involving Registerable Man-made Slopes at the Time of Failure in 2009

Incident No.	Location	Maximum Slope Height	Reported		Failure			Facility Affected	Consequence
			Date	From	Date (Time)	Feature Type	Scale (m^3)		
2009/07/0894	Behind House No.1, Nam A Village, Sai Kung	5 m	19/7	Police	19/7 (14:00)	Soil cut	< 1	Village house	Nil
2009/09/0920	Underneath the Abutment of Tolo Highway at Shek Kwu Lung Village, Tai Po	18 m	28/9	DLO	Unknown	Soil cut	1	Minor footpath	Nil
2009/12/0928	Near Slope No. 15NW-C/C162, House 29, Hung Shing Ye Wan, Lamma Island	4 m	19/11	Public	19/8	Retaining wall (Masonry)	< 1	Others (Alleyway)	Nil
WSD/ 2009/5/1/NTW	West of Slope No. 7SW-C/F514, Tsuen Wan Water Treatment Works Staff Quarters, Sheung Kwai Chung	3.5 m	18/5	WSD	Unknown	Soil cut	< 1	Squatter dwelling	Nil

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

(d) slope 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 101 genuine landslides in 2009, a total of 60 landslides (about 59%) occurred on registered man-made slopes (Table 2.5). Of these 60 landslides, 12 (about 20%) occurred on engineered slopes, all of which were minor failures. The remaining 48 landslide incidents were minor failures on non-engineered slopes. Necessary follow-up actions have been taken on these 60 landslides. Further details on the landslides in 2009 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

4.3.2.1 General

Brief descriptions of the 12 engineered slope failures in 2009 are given in Appendix A. A breakdown of these 12 landslides in terms of feature type is given in Table 4.2. Of these, 5 involved minor rockfalls with a failure volume less than 2 m^3 and 5 involved detachment of soil mass with a failure volume ranging from < 1 m^3 to about 17 m^3. The remaining 2 landslide incidents involved distressed slopes below Tai Hang Road (Incident No. 2009/05/0867) and Shek Kip Mei No. 2 Fresh Water Service Reservoir (Incident No. WSD/2009/2/2/K) respectively. The total volume of detached material and deformed material that remained on the slope was less than 50 m^3 in these 2 incidents. Four of these landslides involved slopes previously treated under the LPM Programme (Appendix A and Table 4.3).

Table 4.2 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	1	1 (1)	0 (0)	0	1	3
≤ 5 m^3	2	1 (1)	5 (0)	1	0	9
Total	3	2 (2)	5 (0)	1	1	12

Legend:

2 (2) Two landslides involved engineered cut slopes, two of which occurred within or adjacent to the soil-nailed portion of the slope

Table 4.3 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	1	1 (1)	0	0	0	2
≤ 5 m^3	1	1 (1)	0	0	0	2
Total	2	2 (2)	0	0	0	4

Legend:

2 (2) Two landslides involved engineered cut slopes, two of which occurred within or adjacent to the soil-nailed portion of the slope

Of the 12 landslides on engineered slopes in 2009, 7 are 'signed-off' features that would not normally be prioritised for action under the Landslip Prevention and Mitigation Programme (LPMitP) and Preventive Maintenance Programme (PMP). 'Signed-off' features mainly comprise the following:

(a) Government soil cut slopes that were formed or treated in or after year 2000, and processed and accepted by GEO,

(b) Government soil cut slopes that were treated with robust technology[1] (e.g. soil nailing), and processed and accepted by GEO,

(c) Government rock cut slopes, fill slopes and retaining walls that were processed and accepted by GEO, and

(d) private slopes and retaining walls that have been subjected to GEO Stage 2 Studies after 2000, checked by GEO after 2000, checked and upgraded with robust technology, or subjected to DH orders.

Of the 7 'signed-off' features that failed in 2009, 2 were treated with soil nails (i.e. robust technology). The remaining 5 involved Government rock cuts or fill slopes processed and accepted by GEO. These incidents indicate that some 'signed-off' features could fail and highlight the need for implementation of safety-net measures to arrest features with potential instability problem, particularly features that could result in severe consequence in the event of failure.

Salient observations from selected landslides involving engineered rock cut slopes, soil-nailed cut slopes and engineered fill slopes are highlighted below.

4.3.2.2 Landslides on Engineered Rock Cut Slopes

A combination of factors, including the presence of local, adversely orientated rock joints, development of localised cleft water pressure in rock joints, progressive slope deterioration and root wedging effects on rock blocks due to unplanned or undesirable vegetation, probably contributed to the 5 minor rockfall incidents on engineered slopes. Of these 5 incidents, one involved a rock cut slope (No. 11SE-A/C190) behind Tai Ming House in Quarry Bay (Incident No. 2009/11/0925) where repeated minor rockfalls ($\leq$ 1.5 m^3 in volume) had occurred in 2008 and 2009. The rock cut slope is about 12 m high and covered with rock mesh netting, which was provided as part of the rock slope treatment works under a private development project in 1996. The presence of unfavourable rock joints might have contributed to the rockfall incidents in 2008 and 2009. The minor rockfalls were successfully retained by the rock mesh netting. The incidents highlighted that minor rockfalls can be difficult to guard against in the design of rock cut slopes and that provision of rock mesh

[1] Robust technology refers to those design solutions that are not unduly sensitive to uncertainties associated with locally adverse geological and hydrogeological conditions (Cheng, 2009). For example, soil nailing is a robust technology in the case of soil cut slopes.

netting is a pragmatic and effective mitigation measure.

4.3.2.3 Landslides on Soil-nailed Cut Slopes

There were 2 minor failures on soil-nailed cut slope in 2009, which were located at Tai Lam Correctional Institution (Incident No. 2009/04/0866) and Queen's Road East (Incident No. 2009/05/0869) (Appendix A). Both of them were associated with minor surface erosion or small-scale detachment ($\leq$ 10 m³) from the near-surface groundmass. None of these failures were mobile and all had negligible consequence.

The landslide at Tai Lam Correctional Institution occurred on a soil-nailed cut slope (No. 6SW-D/C439) on 25 April 2009 and involved a shallow washout failure with an estimated failure volume of 10 m³ (Lam et al, 2010). The failed slope was upgraded in 2004 by soil nails together with the provision of prescriptive raking drains. The hard surface cover of the slope was also replaced by a vegetated cover with erosion control mat and wire mesh as part of the upgrading works. Factors probably contributing to the failure included, *inter alia*, the adverse change to the environmental conditions and overspilling of runoff from a drainage channel junction immediately above the landslide location where no catchpit or baffle wall was provided. This incident served as a reminder of the importance of proper slope surface drainage detailing (Hui et al, 2007) to the continued stability of a slope and the vulnerability of a vegetated surface cover. A review is being carried out to document the observations.

To date, no major failures involving soil-nailed slopes have occurred. This affirms that use of soil nails in slope upgrading works is robust and effective in preventing large-scale instability. However, minor failures do occur from time to time on soil-nailed slopes. The number of minor failures may be reduced by improved slope surface protection and drainage measures as recommended by Ng et al (2008).

4.3.2.4 Landslides on Engineered Fill Slopes

Of the 3 landslides on engineered fill slopes, one involved a newly formed fill slope in Hong Kong Museum of Coastal Defence (Incident No. ArchSD/SKW/2009/04/0003) and the other two involved recompacted fill slopes that were located below Tai Hang Road (Incident No. 2009/05/0867) and to the east of Beacon Hill High Level Service Reservoir (Incident No. WSD/2009/3/1/K). A follow-up review is being carried out for the Tai Hang Road incident and the salient observations are highlighted below.

The incident below Tai Hang Road involved two distressed recompacted fill slopes (Nos. 11SE-C/C70 and C89)[2]. During a follow-up inspection subsequent to the report of ground subsidence incidents at Tai Hang Road on 29 April 2009, signs of distress in the form of surface cracks up to about 200 mm deep and 10 m long were observed along the crest of the 12 m high slope No. 11SE-C/C70 (Lam et al, 2010). In addition, about 2 m³ of soil deposit and heavy but clear seepages were noted from the terraced ground in front of a

[2] The two distressed recompacted fill slope were registered as slope Nos. 11SE-C/C70 and 11SE-C/C89 at the time of the incident. Arrangement has been made to amend their feature type.

disused building of Wesley Hostel, about 50 m downslope of Tai Hang Road. Post-incident ground investigation revealed that weak areas or voids are present within the recompacted fill and in-situ groundmass up to a depth of about 11 m and that a complex network of preferential flowpaths may be present. Preliminary diagnosis of the available information suggests that the formation of weak areas or voids in the groundmass is probably a result of prolonged internal erosion due to subsurface seepage flow. A report is being prepared to document the findings of the review.

As part of the follow-up to the Tai Hang Road incident, 14 landslides on recompacted fill slopes that occurred between 1997 and 2009 were reviewed. Of these, four were major failures (i.e. failure volume ≥ 50 m³) and were mainly due to inadequate surface or subsurface drainage provisions, as well as leakage or bursting of water-carrying services. Based on the review, landslides on recompacted fill slopes were generally ductile in nature and did not involve sudden and fast-moving debris as in liquefaction failure. The review reaffirms the effectiveness of the recompaction method for upgrading of loose fill slopes. Improvement measures have been implemented in recent years with respect to the detailing of surface and subsurface drainage provisions, as well as the monitoring and maintenance of water-carrying services affecting slopes.

4.3.3 Landslides on Non-engineered Slopes

There were 48 minor failures on non-engineered slopes in 2009. Of these 48 landslides, 39 were relatively small in scale with a failure volume of ≤ 5 m³ and the remaining 9 incidents have a failure volume ranging from 6 m³ to 38 m³. Except for the incident at Ta Kwu Ling (Incident No. 2009/05/0872) that resulted in the temporary evacuation of a squatter dwelling, the other landslides on non-engineered slopes did not cause any major consequence.

4.3.4 Annual Failure Rates

The annual failure rates of registered man-made slopes under different categories are presented in Tables 4.4 and 4.5. 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.

Table 4.4 Annual Failure Rates of Registered Man-made Slopes in 2009

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 2009	Number of Slopes	7	41	48	4	8	12
	Surface Area of Landslides (m²)	125	523	648	38	97	135
Slopes Involved in Major Landslides in 2009	Number of Slopes	0	0	0	0	0	0
	Surface Area of Landslides (m²)	0	0	0	0	0	0
Slopes Involved in Minor Landslides in 2009	Number of Slopes	7	41	48	4	8	12
	Surface Area of Landslides (m²)	125	523	648	38	97	135
Total Number of Registered Slopes		11,230	20,470	31,700	11,580	14,020	25,600
Total Surface Area of Registered Slopes (m²)		6,263,400	10,675,700	16,939,100	13,278,200	26,225,600	39,503,800
Annual Failure Rates (All Landslides)	On Slope Number Basis	0.062%	0.200%	0.151%	0.035%	0.057%	0.047%
	On Slope Surface Area Basis	0.002%	0.005%	0.004%	0.0003%	0.0004%	0.0003%
	Number of Landslides Divided by Slope Surface Area (no./m²)	1.117×10^{-6}	3.840×10^{-6}	2.834×10^{-6}	3.012×10^{-7}	3.050×10^{-7}	3.038×10^{-7}
Annual Failure Rates (Major Landslides)	On Slope Number Basis	0%	0%	0%	0%	0%	0%
	On Slope Surface Area Basis	0%	0%	0%	0%	0%	0%
	Number of Landslides Divided by Slope Surface Area (no./m²)	0	0	0	0	0	0

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

Table 4.5 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	0.105%	0.001%	1.063×10^{-6}
	Major Landslides	0%	0%	0
	Minor Landslides	0.105%	0.001%	1.063×10^{-6}
Engineered Slopes	All Landslides	0.047% (0.100%)	0.0003% (0.0006%)	3.038×10^{-7} (5.928×10^{-7})
	Major Landslides	0% (0%)	0% (0%)	0 (0)
	Minor Landslides	0.047% (0.100%)	0.0003% (0.0006%)	3.038×10^{-7} (5.928×10^{-7})
Non-engineered Slopes	All Landslides	0.151% [3.2 / 1.5]	0.004% [13.3 / 6.7]	2.834×10^{-6} [9.3 / 4.8]
	Major Landslides	0%	0%	0
	Minor Landslides	0.151%	0.004%	2.834×10^{-6}

Legend:

0.047% (0.100%)	Annual failure rate of engineered slopes (considering all landslides) is 0.047% and that for slopes previously treated under the LPM Programme is 0.100%
0.151% [3.2 / 1.5]	Annual failure rate of non-engineered slopes (considering all landslides) is 0.151%, which is about 3.2 times and 1.5 times higher than those of engineered slopes and slopes previously treated under the LPM Programme respectively

The annual failure rates for all genuine landslides on registered man-made slopes in 2009 (excluding registered DT features) correspond to 0.105% (number of landslides divided by number of registered man-made slopes), 0.001% (total surface area of landslides divided by total surface area of registered man-made slopes), and 1.063×10^{-6} (number of landslides divided by total surface area of registered man-made slopes in m²) respectively. Further details are summarised in Table 4.5.

Based on the landslide data in 2009 (Table 4.5), the annual failure rates of engineered slopes are lower than that of non-engineered slopes by a factor of about 3 on a slope number basis, and about 13 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 9 times lower than that of non-engineered slopes.

In addition, the annual failure rates of slopes previously treated under the LPM Programme correspond to 0.100% (number of landslides divided by number of registered man-made slopes treated under the LPM Programme), 0.0006% (total surface area of landslides divided by total surface area of registered man-made slopes treated under the LPM Programme), and 5.928×10^{-7} (number of landslides divided by total surface area of registered man-made slopes treated under the LPM Programme in m²) respectively, as summarised in Table 4.5. The annual failure rate of slopes previously treated under the LPM Programme is lower than that of non-engineered slopes by a factor of 7 on slope surface area basis.

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 2009, the corresponding annual success rates were 100% and 99.95% 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 2009 is shown in Table 4.6 and Figure 4.2.

4.4 Natural Terrain Landslides

A total of 24 natural terrain landslides were reported in 2009, one of which was a major failure below Lin Ma Hang Road (Incident No. 2009/08/0897). Among these reported natural terrain landslides, 4 minor failures (about 17%) were at or within 50 m from the existing Historical Landslide Catchments (HLCs) and 6 minor failures (25%) occurred in hillside catchments potentially affecting urban roads or building structures. The rest occurred in hillside catchments that did not affect or were relatively far away from important facilities.

The major failure below Lin Ma Hang Road in Sha Tau Kok predominantly involved the natural hillside below a 3 m high mass concrete wall (No. 3NE-A/R10) (Lam et al, 2010). The landslide measured about 16 m wide, 11 m long and up to 5 m deep, with a failure volume of about 125 m³. The landslide occurred near the head of a natural drainage line below Lin Ma Hang Road at a location where a previous failure (Incident No. 2008/04/0097), with a failure volume of about 15 m³, was recorded. Although some landslide debris had entered the natural drainage line, the landslide did not develop into a mobile channelized debris flow probably because of the limited catchment area (about 440 m²) above the location of the failure. The landslide was probably caused by adverse groundwater condition near the natural drainage line.

Table 4.6 Annual Success Rates of Engineered Slopes from 1997 to 2009

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
Engineered Slopes Processed by the Slope Safety System ($\geq$ 50 m³)	99.97%	99.98%	99.97%	99.98%	99.98%	100%	99.99%	100%	99.98%	100%	100%	99.99%	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%

Note: See Figure 4.2 for a plot of annual success rates of engineered slopes against the target annual success rates from 1997 and 2009.

Table of Contents
Table of Contents
Table of Contents

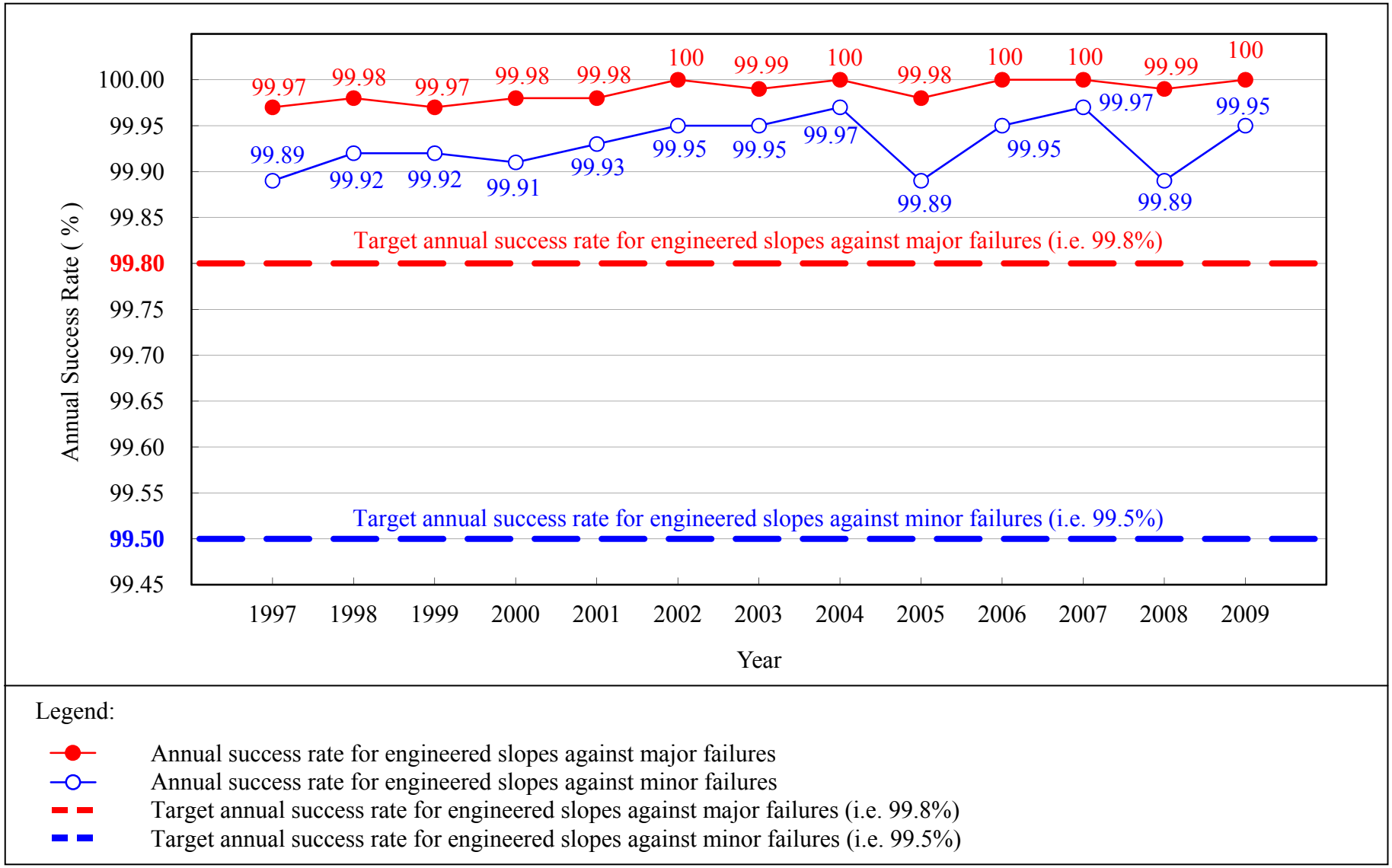


Figure 4.2 Annual Success Rates of Engineered Slopes from 1997 to 2009

4.5 Other Observations

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

Records on the history of landslides provide important information on slope performance. The failure history of registered man-made slopes with landslide reported in 2009 was examined based on the GEO's Landslide Database.

Amongst the 60 landslides on registered man-made slopes in 2009, 18 (30%) involved slopes with a history of past failures. All these 18 incidents were minor failures on cut slopes resulting in negligible consequence, and 4 of which involved engineered slopes where past failures occurred after completion of slope upgrading works. Similar incidents were also observed in the past, e.g. the 7 June 2008 landslide at Pak Fuk Road (FSWJV, 2010). These incidents serve as a reminder that slopes with a history of past failures are potentially problematic (GEO, 2004b).

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

All the 60 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 19 of the 60 landslides (i.e. about 32%), all of which were minor failures. Amongst these 19 landslides, 4 occurred on engineered slopes.

Of these 19 landslides involving inadequate slope maintenance, 9 affected Government slopes and 1 affected a private slope. The remaining 9 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 9 incidents involving slope features of mixed maintenance responsibility, 1 occurred on the Government portion, 7 were on the private portion and 1 involved both the Government and private portions of the feature.

The above diagnosis reaffirms the importance of regular slope maintenance. It also serves as a reminder that even an engineered slope is liable to fail without adequate maintenance.

5 Proposed Improvement Initiatives

Improvement initiatives were proposed by Li et al (2009) following a review of landslides in 2008. The progress of the follow-up actions is summarised in Table 5.1.

Table 5.1 Progress of Follow-up Actions on the Improvement Measures Recommended in the Review of 2008 Landslides

Recommended Improvement Measures	Progress
1. Carry out a review of landslide data to assess the performance of recompacted fill slopes and identify factors that affect their performance.	A review of landslides on recompacted fill slopes between 1997 and 2009 with detailed information was carried out. Of the 14 landslides reviewed, four were major failures with a failure volume $\geq 50\ m^3$. Landslides on recompacted fill slopes were generally ductile in nature and did not involve sudden and fast-moving debris as in liquefaction failure. The review reaffirms the effectiveness of using the recompaction approach for upgrading loose fill slopes. The prevailing practice of fill slope recompaction is considered satisfactory. Further improvement measures have been implemented in recent years, which would further enhance the robustness of recompacted fill slopes. Action completed
2. Continue to study natural terrain landslides to improve understanding of hillside failures, debris mobility and tell-tale signs of potentially active drainage lines.	Follow-up actions have been undertaken with a view to improve understanding of hillside failures based on the observations from natural terrain landslides triggered by the 7 June 2008 rainstorm. The follow-up actions included: (a) review low-level aerial photographs to identify natural terrain landslides on Lantau Island, (b) carry out detailed field mapping of selected natural terrain landslides, and (c) conduct detailed study of selected natural terrain landslides. Other relevant improvement initiatives are also being pursued under Goal 2 of the GEO Strategic Plan (2010-2015). On-going
3. Develop a methodology for the identification of sizeable fill bodies and hillside pockets in developed areas that may pose a significant landslide hazard to the community.	The methodology has been developed by Planning Division. A pilot study on the approach for dealing with the landslide hazard commenced in March 2011. Action completed

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

(a) develop a methodology for technical screening and review of 'signed-off' features as a safety-net measure to identify slopes requiring follow-up actions (Section 4.3.2.1), and

(b) review landslides on man-made slopes with a history of past failures and identify appropriate follow-up actions (Section 4.5.1).

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 0.047% respectively in 2009. The pledged annual success rates of 99.8% and 99.5% of engineered slopes in preventing major and minor landslides, respectively, were met.

(b) Overall, 99.95% of the engineered slopes performed satisfactorily without the occurrence of any landslides in 2009.

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.

7 References

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Appendix A

Landslide Incidents Involving Slopes Processed under the Slope Safety System

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

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
1. Slopes Upgraded Under the LPM Programme ($\sum$ = 4 nos.)					
2009/04/0866	6SW-D/C439#	Tai Lam Correctional Institution, Tai Lam Chung, Tuen Mun	10	Soil cut	The works, mainly comprising installation of soil nails and raking drains, and replacement of hard surface cover by vegetated cover with erosion control mat and wire mesh, were completed in 2004. The shallow failure (about 0.5 m deep) involved the near-surface groundmass within the soil-nailed portion of the slope.
2009/05/0867	11SE-C/C70# 11SE-C/C89# (see Note (3))	Below 133 Tai Hang Road	Signs of distress	Fill	The works, mainly comprising recompaction of the top 3 m of fill, construction of a mass concrete wall and provision of vegetated cover with erosion control mat, were completed in 1998.
2009/05/0869	11SW-B/C248#	Queen's Road East near Monmouth Path	2	Soil cut	The works, mainly comprising installation of soil nails and provision of vegetation cover with erosion control mat and wire mesh, were completed in 1991. The shallow failure (about 0.4 m deep) occurred near the slope crest above the soil-nailed slope portion.
WSD/ 2009/3/1/K	11NW-B/F62#	70 m East from Beacon Hill High Level Service Reservoir, Radar Station Road	17	Fill	The works, mainly comprising recompaction of the top 3 m of fill and provision of vegetated cover, were completed in 1998.

Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 2 of 5)

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 (∑ = 0 no.)					
Nil.					
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 (∑ = 0 no.)					
Nil.					
5. Slopes Assessed by Private Owners and Checked by GEO with No Upgrading Works Required (∑ = 0 no.)					
Nil.					
6. Slopes Formed or Upgraded by Government Departments and Checked by GEO (∑ = 7 nos.)					
2009/03/0855	6SW-D/C783#	Footpath at the Lay-by of Tuen Mun Road East Bound – Tai Lam Section, Tuen Mun	2 (rockfall)	Soil/rock cut	The geotechnical design/assessment of the slope was carried out in relation to the Tuen Mun Road (Tai Lam Section) Widening Project, which was checked and accepted by the GEO in 2000.

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

Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 3 of 5)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
2009/03/0860	6SE-C/C37	Tuen Mun Road near Sham Tseng Treatment Works, Tuen Mun	0.012 (rockfall)	Soil/rock cut	The geotechnical design/assessment of the slope was carried out in relation to the Water Supply to Tsing Lung Tau & Sham Tseng - Stage 1 Project, which was checked and accepted by the GEO in 1993.
2009/05/0874	15NW-B/CR131	Ap Lei Chau Bridge Road	0.5 (rockfall)	Soil/rock cut	The geotechnical design/assessment of the slope was carried out in relation to the Construction of Ap Lei Chau Bridge and Southern Approach Road Project, which was checked and accepted by the GEO in 1981. The minor rockfall occurred at the cut slope portion above the anchored caisson wall.
2009/07/0887	5SE-C/C1	Lung Mun Road, Tuen Mun	< 1 (rockfall)	Soil/rock cut	The geotechnical design/assessment of the slope was carried out in relation to the Tuen Mun Area 38 - Lung Mun Road Improvement Project, which was checked and accepted by the GEO in 1996.
ArchSD/L/ 2009/01/0001	13NE-B/FR116[#]	Cheung Sha Upper Beach, Lantau Island	10	Retaining wall	The geotechnical design/assessment of the slope was carried out in relation to the Recreational Development at Cheung Sha, Lantau Island, which was checked and accepted by the GEO in 1988. The minor failure predominantly involved a 1 m high toe retaining wall (of a recompacted fill slope) along a beach.

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

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
ArchSD/SKW/ 2009/04/0003	11SE-B/FR62#	Hong Kong Museum of Coastal Defence	< 1	Fill	The geotechnical design/assessment of the slope was carried out in relation to the Lei Yue Mun Museum Project, which was checked and accepted by the GEO in 2000. The minor washout failure occurred at the compacted soil backfill portion above the toe retaining wall.
WSD/ 2009/2/2/K	11NW-B/C582	Below Shek Kip Mei No. 2 Fresh Water Service Reservoir, Shek Kip Mei	Signs of distress	Soil/rock cut	The geotechnical design/assessment of the slope was carried out in relation to the Construction of Shek Kip Mei No. 3 Fresh Water Service Reservoir, which was checked and accepted by the GEO in 1994. The distress occurred on the unsupported soil cut portion of the slope.

7. Slopes Formed or Upgraded by Private Owners and Checked by GEO ($\sum$ = 1 no.)

2009/11/0925	11SE-A/C190	Behind Tai Ming House, Quarry Bay	1 (rockfall)	Rock cut	The geotechnical design/assessment of the slope was carried out in relation to the Site Formation for the Taikoo Primary School, which was checked and accepted by the GEO in 1993.

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

Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 5 of 5)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
8.	Slopes Upgraded Following Service of DH Orders and Checked by GEO (∑ = 0 no.)				
	Nil.				
9.	Slopes Assessed as Not Requiring Upgrading Works But with Outstanding GEO Comments (∑ = 0 no.)				
	Nil.				
10.	Slopes Assessed as Requiring Upgrading Works But with Outstanding GEO Comments (∑ = 0 no.)				
	Nil.				

Legend:

Landslide occurred on or adjacent to the soil-nailed portion of a cut slope (∑ = 2 nos.)

Landslide involved unsupported cuts (∑ = 1 no.)

Landslide involved signed-off features (∑ = 7 nos.)

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) The incident involved two distressed recompacted fill slopes below Tai Hang Road, which however were registered as cut slope features (Nos. 11SE-C/C70 and 11SE-C/C89). Arrangement has been made to amend their feature type.

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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

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

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.

GEOSPECS

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

GEO PUBLICATIONS

GCO Publication No. 1/90	Review of Design Methods for Excavations (1990), 187 p. (Reprinted, 2002).
GEO Publication No. 1/93	Review of Granular and Geotextile Filters (1993), 141 p.
GEO Publication No. 1/2006	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.

GEOLOGICAL PUBLICATIONS

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

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

TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents