Review of Landslides in 2014

GEO Report No. 328

R.W.H. Lee, R.H.C. Law & D.O.K. Lo

Geotechnical Engineering Office
Civil Engineering and Development Department
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Preface

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W.K. Pun
Head, Geotechnical Engineering Office
May 2017

Foreword

This report presents the findings of a detailed diagnosis of landslides in 2014 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 further enhancing the slope engineering practice in Hong Kong.

The review was carried out by Mr R.W.H. Lee, Ms R.H.C. Law and Dr D.O.K. Lo of Landslip Preventive Measures Division 1 under the supervision of initially Mr Y. Lam and subsequently Dr D.O.K. Lo. Assistance was provided by the landslide investigation consultants engaged by the Geotechnical Engineering Office, namely Fugro AECOM Consulting Services Limited Joint Venture and Halcrow China Limited respectively. Technical support provided by Mr T.F.O. Luk, Mr L.K.W. Hui and Mr C.M. Leung is gratefully acknowledged.

H.N. Wong
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Abstract

This report presents the findings of a diagnostic review of the landslides in 2014 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 further enhancing the slope engineering practice in Hong Kong.

Altogether, 237 genuine landslides in 2014 were reported to the Government. There were 14 major landslides (viz. failure volume of 50 m^3 or more) including one occurring on an engineered man-made slope. There were also seven minor landslides (viz. failure volume of less than 50 m^3) occurring on engineered man-made slopes. The corresponding annual failure rate of engineered slopes is about 0.029% 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 2014.

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1 Introduction

This report presents the findings of a diagnostic review of the landslides in 2014 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 2014. 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 AECOM Consulting Services Limited Joint Venture (FACSLJV) and Halcrow China Limited (HCL).

2 Rainfall and Landslides in 2014

The factual information, together with the relevant statistics on rainfall and reported landslides in 2014, was documented by Chan et al (2015).

In 2014, the annual rainfall recorded at the Principal Raingauge of the Hong Kong Observatory (HKO) in Tsim Sha Tsui was 2,638.3 mm, a surplus of about 10% comparing to the mean rainfall of 2,398.5 mm between 1981 and 2010. Five Landslip Warnings were issued between 30 March and 13 August 2014. Two Black Rainstorm Warnings were issued on 30 March and 8 May 2014 respectively. Nine Red Rainstorm Warnings and 32 Amber Rainstorm Warnings were issued between 30 March and 13 August 2014, and between 29 March and 3 October 2014 respectively.

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 252 reported incidents in 2014, 237 were genuine landslides, discounting the non-landslide incidents (e.g. tree falls). There were 14 major failures, corresponding to about 6 % of the number of genuine landslides.

The distribution of landslides, as classified by the types of slope failures, 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 types of slope failures are summarised in Table 2.3. The distribution of the different facility groups affected by the major landslide is presented in Table 2.4. The distribution of the scale of failures, as classified by the types of slopes involved, is given in Table 2.5.

Table 2.1 Breakdown of Landslides by Types of Slope Failures

Types of Slope Failures		Number	Percentage (%)
Fill Slopes		11 (1)	4.6
Cut Slopes	Soil	108 (3)	45.6
	Soil/Rock	25 (1)	10.6
	Rock	11 (0)	4.6
Retaining Walls		10 (0)	4.2
Natural Hillside		63 (9)	26.6
Registered Disturbed Terrain		9 (0)	3.8
Total		237 (14)	100

Legend:

25 (1) Twenty-five landslides, one of which was a major failure

Note: Where a landslide involved more than one type of failure, the predominant type of failure has been considered in the above classification.

Table 2.2 Breakdown of Landslides by Types of Affected Facilities

Types of Affected Facilities	Hong Kong Island	Kowloon	New Territories and Outlying Islands	All
Buildings (including village houses)	4 (1)	0	20 (1)	24 (2)
Registered Squatter Dwellings	1 (0)	2 (0)	19 (0)	22 (0)
Roads	16 (3)	1 (0)	20 (1)	37 (4)
Transportation Facilities (e.g. railways, tramways, etc.)	0	0	0	0
Pedestrian Pavements/Footways	1 (0)	0	5 (0)	6 (0)
Minor Footpaths/Access Paths/ Access Roads	21 (1)	3 (0)	66 (3)	90 (4)
Construction Sites	1 (0)	0	2 (0)	3 (0)
Open Areas	6 (2)	1 (0)	15 (1)	22 (3)
Catchwaters	5 (0)	0	9 (0)	14 (0)
Others (e.g. carparks, parks, playgrounds, gardens, backyards, etc.)	2 (0)	0	19 (0)	21 (0)
Nil	5 (2)	0	7 (0)	12 (2)
Total	62 (9)	7 (0)	182 (6)	251 (15)

Legend:

16 (3) Sixteen landslides of which three were major failures

Notes:
(1) Incidents that were not genuine landslides have been excluded.
(2) A given landslide may affect more than one type of facility.
(3) Nil consequence refers to incidents where the landslide debris came to rest on the slopes, not affecting any facilities.

Table 2.3 Breakdown of Landslide Consequences by Types of Slope Failures

Types of Slope Failures		Number of Squatter Dwellings (1) Evacuated		Number of Floors, Houses or Flats Evacuated or Partially Closed	Number of Incidents Involving Closure			Deaths	Injuries Reported to GEO
		Permanent	Temporary		Roads	Pedestrian Pavements	Footpaths, Alleyways or Private Access Paths		
Fill Slopes		0	0	0	0	0	0	0	0
Cut Slopes	Soil	0	1 (1)	1(3)	12	0	6	0	0
	Soil/Rock	1 (1)	0	0	4	0	0	0	0
	Rock	1 (1)	0	0	2	0	1	0	0
Retaining Walls		0	0	0	1	0	0	0	0
Natural Hillside		0	0	0	3	2	5	0	0
Registered Disturbed Terrain		0	1 (1)	0	0	0	0	0	0
Total		2 (2)	2 (2)	1	22	2	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 registered in the 1982 Housing Department's Squatter Structure Survey (GEO, 2010).

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

(3) A cut slope failure (Incident No. 2014/03/1480) resulted in temporary closure of a kitchen on the ground floor of a village house in Fishermen New Village, Tui Min Hoi, Sai Kung.

Table 2.4 Breakdown of Facility Groups Affected by Major Landslides

Types of Major Landslides	Facility Groups Affected by Major Landslides (Group No.)						
	1a	1b	2a	2b	3	4	5
All Major Landslides	1	1	0	0	2	8	3
Major Landslides on Man-made Slopes	1	0	0	0	1	4	0
Major Landslides on Registered Disturbed Terrain	0	0	0	0	0	0	0
Major Landslides on Natural Hillside	0	1	0	0	1	4	3

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 Types of Slopes

Types of Slopes	Number of Minor Landslides (< 50 m^3)	Number of Major Landslides		Total
		(50 m^3 to < 500 m^3)	(≥ 500 m^3)	
Registered Man-made Slopes	102	4	0	106
Registered Disturbed Terrain	9	0	0	9
Unregistrable Man-made Slopes	48	1	0	49
Registrable Man-made Slopes Not Yet Registered at Time of Failure	10	0	0	10
Natural Hillside	54	9	0	63
Total	223	14	0	237

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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) (GEO, 2014a). The LPI is calculated for rainstorms that resulted in the issue of Landslip Warning and is 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 Warnings from 1984 to 2014 is presented in Figure 3.1.

In 2014, five Landslip Warnings were issued between 30 March and 13 August 2014 and the corresponding LPI was assessed to be ranging from 1 to 3. In terms of the potential to cause landslides, the rainstorms on 30 & 31 March and 11 May 2014, each having an LPI of 3, were three-tenth of the severity of the rainstorm 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 2014 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. Any unregistered man-made slopes identified during slope maintenance inspections, landslide investigations and other geotechnical inspections or studies will also be registered in the Catalogue of Slopes (GEO, 2014b) should they satisfy the slope registration criteria.

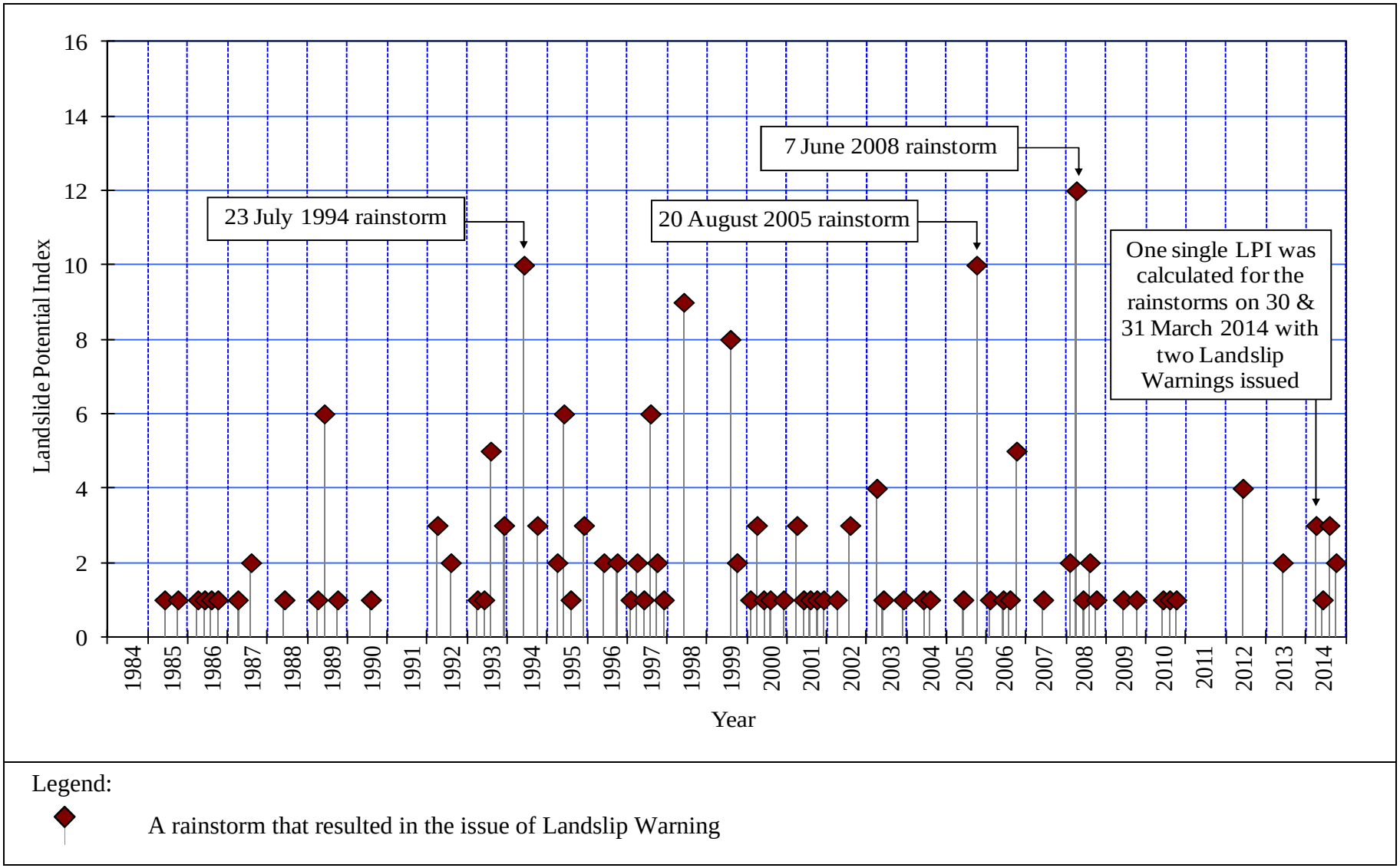


Figure 3.1 Landslide Potential Index for Rainstorms that Resulted in the Issue of Landslip Warnings from 1984 to 2014

4.2.2 Diagnosis

Of the 237 genuine landslides, 115 occurred on registered slope features (comprising 106 on registered man-made slopes and 9 on registered disturbed terrain features) and 122 occurred on slopes not registered in the Catalogue of Slopes (Table 2.5).

Among the above 122 landslides, 63 occurred on natural hillside, 49 occurred on small man-made slope features that do not meet the slope registration criteria (GEO, 2004). The remaining 10 landslides, corresponding to 4.2% of the total number of genuine landslides in 2014, involved slope features that satisfy the slope registration criteria but was not registered in the Catalogue of Slopes at the time of failures. A breakdown of these 122 landslides is given in Figure 4.1.

The 10 landslides involving registrable slopes were all minor failures with failure volume less than 30 m^3 (refer to Appendix A for details). Amongst these 10 minor failures, one resulted in temporary closure of the kitchen of a village house and three resulted in partial blockage of minor footpaths. The other incidents did not cause any significant impact on the community. Following the landslides, arrangements have been made to register the man-made slope features concerned in the Catalogue of Slopes.

Of the 49 landslides involving unregistrable man-made slope features, one involved a major failure of a fill platform at Nga Choi Hang Tsuen, Shek O. The edge of the fill platform was a 2.5 m high vertical face covered with stone facing prior to the failure. The landslide affected an open area in front of a squatter dwelling at the slope crest and did not have any consequence. The remaining 48 landslides were all minor failures with failure volume of 45 m^3 or less, of which one resulted in temporary evacuation of a squatter dwelling and one resulted in partial blockage of a minor footpath.

4.3 Performance of Registered Man-made Slopes

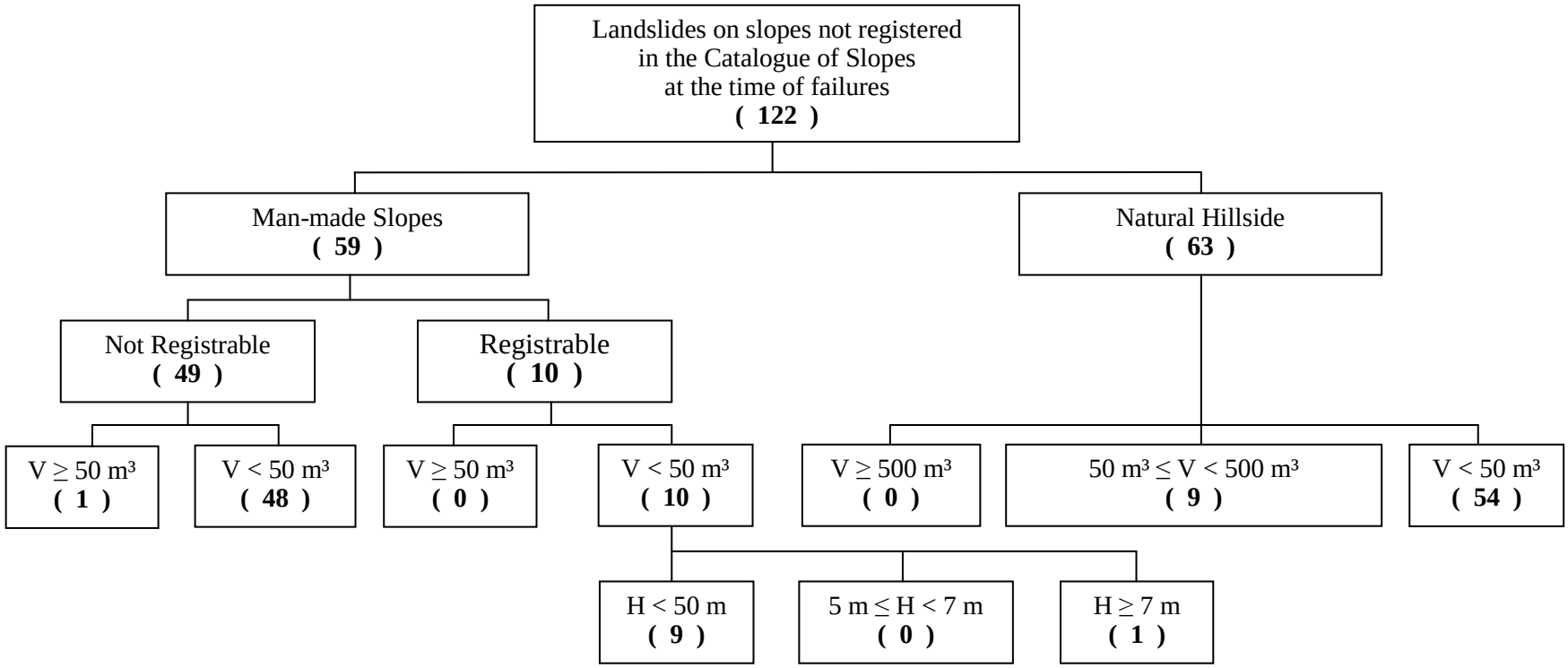
4.3.1 General

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;



Legends:

V	Failure volume
H	Height of man-made feature before failure
(48)	Number of landslide incidents = 48

Notes:
(1) 'Not Registrable' refers to case 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 registrable features in the Catalogue of Slopes.

Figure 4.1 Breakdown of Landslides on Unregistered Slopes in 2014

(c) slopes formed before 1977 that were subsequently upgraded, checked and accepted under the slope safety system as being up to the required geotechnical standards; and

(d) slopes upgraded to the required geotechnical standards using Type 3 prescriptive measures (GEO, 2009) 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 237 genuine landslides in 2014, a total of 106 landslides (about 45%) occurred on registered man-made slopes (Table 2.5). Four out of these 106 landslides (about 4%) were major failures, with failure volume ranging from 60 m^3 to 420 m^3, and the remaining 102 landslides were minor failures. Of the 106 landslides on registered man-made slopes, eight landslides (about 8%) occurred on engineered slopes and the remaining 98 landslides occurred on non-engineered slopes. Except for an incident which occurred on a non-engineered slope with a failure volume of 130 m^3 (see Section 4.3.3), there was no major landslide occurring on consequence-to-life (CTL) Category 1 slope features in 2014. A breakdown of the CTL categories of the registered man-made slopes involved in the landslides is given in Table 4.1.

Table 4.1 Breakdown of Consequence-to-life Categories of Registered Man-made Slopes Involved in the Landslides

Types of Slopes	No. of Landslides			Total
	CTL Cat. 1	CTL Cat. 2	CTL Cat. 3	
Engineered Slopes	4 (0)	3 (0)	1 (1)	8 (1)
Non-engineered Slopes	24 (1)	11 (1)	63 (1)	98 (3)

Legend:

8 (1) Eight landslides, one of which was a major failure

Discussions of the landslides on engineered and non-engineered slopes in 2014 are given in Sections 4.3.2 and 4.3.3 respectively below.

4.3.2 Landslides on Engineered Slopes

Brief descriptions of the eight landslides on engineered slopes in 2014 are given in Appendix B. A breakdown of these landslides in terms of feature type is given in Table 4.2. Among the eight landslides, five involved slopes previously upgraded under the Landslip Preventive Measures Programme (LPMP) (see Table 4.3). None of the landslides in 2014 involved slopes previously upgraded under the Landslip Prevention and Mitigation Programme (LPMitP).

Two landslides involved the failures of fill slopes (volume ≤ 10 m^3). One occurred on a recompacted fill slope underlain by a natural streamcourse with the rockhead located close to the base of fill. The failure was probably related to the transient groundwater rise above the shallow rockhead causing loss of strength of the overlying fill materials. The other one occurred on a 37° inclined soil-nailed fill slope with no grillage beams or erosion control mat provided on the slope surface. The Stage 3 Study carried out in 1997 considered that the risk of liquefaction failure was negligible based on the soil grading, topography and soil nailing works adopted. The failure involved a washout on a generally bare slope surface exposing several soil-nail heads (which remained intact) on the erosion scar.

One landslide involved the failure of a private masonry wall (volume of 16 m^3) which had been upgraded by thickening at its back by mass concrete. However, observations on the landslide scar and its vicinity revealed that there were discrepancies between the as-built records and the present wall conditions (viz. soil instead of mass concrete noted on the shallow scar and portion of wall covered only by cement mortar without masonry blocks). The stability and actual configuration of the wall would be subjected to further investigation/verification by the owners.

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 m³	0	0	0	0	0	0
50 m³ to 500 m³	0	1	0	0	0	1
> 5 m³ to < 50 m³	2 (1)	0	0	0	1	3
≤ 5 m³	0	1	1	2	0	4
Total	2 (1)	2	1	2	1	8

Legend:

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

Table 4.3 Breakdown of Landslides on Slopes Previously Treated under the LPMP

Scale of Failure (m^3)	Fill Slopes	Cut Slopes			Retaining Walls	Total
		Soil	Soil/Rock	Rock		
> 500 m³	0	0	0	0	0	0
50 m³ to 500 m³	0	0	0	0	0	0
> 5 m³ to < 50 m³	2 (1)	0	0	0	0	2
≤ 5 m³	0	1	1	1	0	3
Total	2 (1)	1	1	1	0	5

Legend:

2 (1) Of the two landslides, one occurred within the soil-nailed portion of the slopes

One landslide involved a major failure on an unsupported soil cut slope (volume of 120 m^3). No stabilization works were carried out at the moderately steep failed slope portion as the design assumed the presence of highly to moderately decomposed materials. However, a pocket of completely decomposed materials was noted at this area during construction. Yet, no design changes were made in light of this observation. Post-landslide inspection revealed that the failed portion indeed comprised even weaker completely to highly decomposed materials. The failure was probably a result of surface infiltration together with the ingress of water through cracks on the concrete paved berm immediately above the failure scarp.

The remaining four incidents involved very minor failures on cut slopes (volume ≤ 3 m^3). Three cases involved minor rockfalls (one of the cases also involved a minor erosion on the soil cut portion) and one involved the detachment of a concrete fragment from an abandoned concrete structure protruding above the slope surface. The rockfall incidents again illustrated that minor rockfalls from rock slopes are hard to assess and be prevented. The provision of surface protective measures such as rock mesh could be a pragmatic solution to deal with minor rockfalls (GEO, 2014c).

Four of the eight landslides on engineered slopes resulted in temporary closure of roads or partial blockage of a restricted access. The remaining cases did not result in any significant consequence.

4.3.3 Landslides on Non-engineered Slopes

There were 98 failures on non-engineered slopes in 2014, among which three were major and 95 were minor.

The three major landslides involved failure volume ranging from 60 m^3 to 420 m^3. Two of these landslides occurred primarily on roadside slopes of CTL Category 2 or 3 and both of them resulted in temporary closure of roads. Details of these two cases were documented in Chan et al (2015). The other major landslide occurred on a CTL Category 1 slope. The slope has a length of about 90 m and the majority of the slope portion affects an open area (previously a school campus but had been demolished) except the small distal end of the slope (with height of about 5 m) which affects a squatter dwelling at its toe. The landslide occurred at the middle portion of the slope and the debris was deposited on the open area with insignificant consequence. The critical facility (i.e. the squatter dwelling) was not affected by the landslide.

Of the 95 minor landslides, 53 of them were relatively small in scale with a failure volume less than 5 m^3. Fourteen incidents resulted in temporary closure of roads, two resulted in temporary closure of minor footpath/access road, one resulted in blockage of catchwater and two resulted in permanent evacuation of squatter dwellings at Cha Kwo Ling and Shek O respectively. The rest did not have any notable consequence.

4.3.4 Landslides Occurring in the Vicinity of Registered Squatter Structures

Twenty-two landslides occurred on slopes located in the vicinity of registered squatter structures, of which 12 occurred on registered slopes, four on unregistrable man-made slopes, four on registrable man-made slopes not yet registered at the time of failure, and two on natural hillside. All these landslides were minor, with failure volume ranging from 0.06 m^3 to 10 m^3. Those man-made slopes involved in the landslides were all non-engineered.

In 14 of the 22 landslides, squatter structures were not affected by the landslide debris as the structures were located aside/beyond the debris fronts or the crests of landslide scars. The landslide debris reached the squatter structures in the other eight landslides. In these eight cases, three cases involved Category 2 Non-development Clearance [1] (NDC) recommendation previously made on the affected squatter structures and another two cases involved the issuance of Category 1 NDC[2] recommendation on the affected squatter structures (one of which with Category 2 NDC recommendation previously served) following the 2014 incidents. No NDC recommendations were made for the remaining three cases either because the affected squatter structure is on a private lot/licensed land or the failure was of very small scale (volume of 0.06 m^3) without causing any damage to the affected squatter structure.

For the 22 landslides on slopes located in the vicinity of registered squatter structures, NDC inspections were previously conducted by the GEO on the villages concerned, except two cases for which one affected a squatter structure lying within private lot and one affected a squatter structure within a village scheduled for NDC inspection but not yet inspected at time of the failure. Following the NDC inspections, Category 2 NDC recommendations were made on eight of the cases.

[1] Category 2 Non-development Clearance (NDC) recommendations are issued to squatter structures that are considered especially vulnerable to landslides due to their close proximity to potentially unstable slopes; the clearance is through advice and persuasion.

[2] Category 1 NDC recommendations are issued to squatter structures that are in 'immediate and obvious' danger; the clearance is compulsory and will be backed up by force if necessary.

4.3.5 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.

The annual failure rates for all genuine landslides on registered man-made slopes in 2014 correspond to about 0.185% (number of landslides divided by number of registered man-made slopes), 0.0044% (total surface area of landslides divided by total surface area of registered man-made slopes), and about 1.891×10^{-6} (number of landslides divided by total surface area of registered man-made slopes in m^2) respectively. Further details are summarised in Table 4.5.

Based on the landslide data in 2014 (Table 4.5), the annual failure rates of engineered slopes are lower than that of non-engineered slopes by a factor of about 11 on a slope number basis, and about 34 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 30 times lower than that of non-engineered slopes.

In 2014, five landslides involved slopes treated under the LPMP and none involved slopes upgraded under the LPMitP. The annual failure rates of slopes previously treated under the LPMP or LPMitP correspond to 0.102% (number of landslides divided by number of registered man-made slopes treated under the LPMP or LPMitP), 0.0006% (total surface area of landslides divided by total surface area of registered man-made slopes treated under the LPMP or LPMitP), and about 6.214×10^{-7} (number of landslides divided by total surface area of registered man-made slopes treated under the LPMP or LPMitP in m^2) respectively, as summarised in Table 4.5. The annual failure rate of slopes previously treated under the LPMP or LPMitP is lower than that of non-engineered slopes by a factor ranging from about 3 to 22, comparable to that of other engineered slopes.

Table 4.4 Annual Failure Rates of Registered Man-made Slopes in 2014

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 2014	Number of Slopes	6	92	98	3	5	8
	Surface Area of Landslides (m^2)	112	2,164	2,276	44	125	169
Slopes Involved in Major Landslides in 2014	Number of Slopes	0	3	3	0	1	1
	Surface Area of Landslides (m^2)	0	666	666	0	96	96
Slopes Involved in Minor Landslides in 2014	Number of Slopes	6	89	95	3	4	7
	Surface Area of Landslides (m^2)	112	1,498	1,610	44	29	73
Total Number of Registered Slopes		11,250	18,550	29,800	12,280	15,220	27,500
Total Surface Area of Registered Slopes (m^2)		6,354,020	9,752,680	16,106,700	13,593,720	26,355,080	39,948,800
Annual Failure Rates (All Landslides)	On Slope Number Basis	0.053%	0.496%	0.329%	0.024%	0.033%	0.029%
	On Slope Surface Area Basis	0.0018%	0.0222%	0.0141%	0.0003%	0.0005%	0.0004%
	Number of Landslides Divided by Slope Surface Area (no./m^2)	9.443×10^{-7}	9.433×10^{-6}	6.084×10^{-6}	2.207×10^{-7}	1.897×10^{-7}	2.003×10^{-7}
Annual Failure Rates (Major Landslides)	On Slope Number Basis	0%	0.016%	0.010%	0%	0.007%	0.004%
	On Slope Surface Area Basis	0%	0.0068%	0.0041%	0%	0.0004%	0.0002%
	Number of Landslides Divided by Slope Surface Area (no./m^2)	0	3.076×10^{-7}	1.863×10^{-7}	0	3.794×10^{-8}	2.503×10^{-8}

Note: Landslides on registered disturbed terrain features and incidents involving fallen rock fully retained by rock mesh netting, if any, have been excluded from this calculation.

Table 4.5 Breakdown of Annual Failure Rates of Registered Man-made Slopes

Categories of Slopes		Failure Rates on Slope Number Basis (i.e. number of landslides divided by total number of slopes)	Failure Rates on Slope Surface Area Basis (i.e. surface area of landslides divided by total surface area of slopes)	Failure Rates in Terms of Number of Landslides Divided by Total Surface Area of Slopes (no./m²)
Registered Man-made Slopes	All Landslides	0.185%	0.0044%	1.891×10^{-6}
	Major Landslides	0.007%	0.0014%	7.136×10^{-8}
	Minor Landslides	0.178%	0.0030%	1.820×10^{-6}
Engineered Slopes	All Landslides	0.029% (0.102%)	0.0004% (0.0006%)	2.003×10^{-7} (6.214×10^{-7})
	Major Landslides	0.004% (0)	0.0002% (0)	2.503×10^{-8} (0)
	Minor Landslides	0.025% (0.102%)	0.0002% (0.0006%)	1.752×10^{-7} (6.214×10^{-7})
Non-engineered Slopes	All Landslides	0. 329% [11.3/3.2]	0.0141% [33.5/21.9]	6.084×10^{-6} [30.4/9.8]
	Major Landslides	0.010%	0.0041%	1.863×10^{-7}
	Minor Landslides	0.319%	0.0100%	5.898×10^{-6}

Legend:

0.029% (0.102%)	Annual failure rate of engineered slopes (considering all landslides) is 0.029% and that for slopes previously treated under the LPMP or LPMitP is 0.102%
0.329% [11.3/3.2]	Annual failure rate of non-engineered slopes (considering all landslides) is 0.329%, which is about 11.3 times and 3.2 times higher than those of engineered slopes and slopes previously treated under the LPMP or LPMitP respectively

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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 2014, the corresponding annual success rates were 99.99% 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 for the period from 1997 to 2014 is shown in Table 4.6 and Figure 4.2.

Table 4.6 Annual Success Rates of Engineered Slopes from 1997 to 2014

Year	Annual Success Rates on Slope Number Basis (i.e. number of landslides divided by total number of slopes)	
	Engineered Slopes Processed by the Slope Safety System (Scale of Failure ≥ 50 m^3)	Engineered Slopes Processed by the Slope Safety System (Scale of Failure < 50 m^3)
1997	99.97%	99.89%
1998	99.98%	99.92%
1999	99.97%	99.92%
2000	99.98%	99.91%
2001	99.98%	99.93%
2002	100%	99.95%
2003	99.99%	99.95%
2004	100%	99.97%
2005	99.98%	99.89%
2006	100%	99.95%
2007	100%	99.97%
2008	99.99%	99.89%
2009	100%	99.95%
2010	100%	99.97%
2011	100%	99.97%
2012	100%	99.95%
2013	99.99%	99.95%
2014	99.99%	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 to 2014.

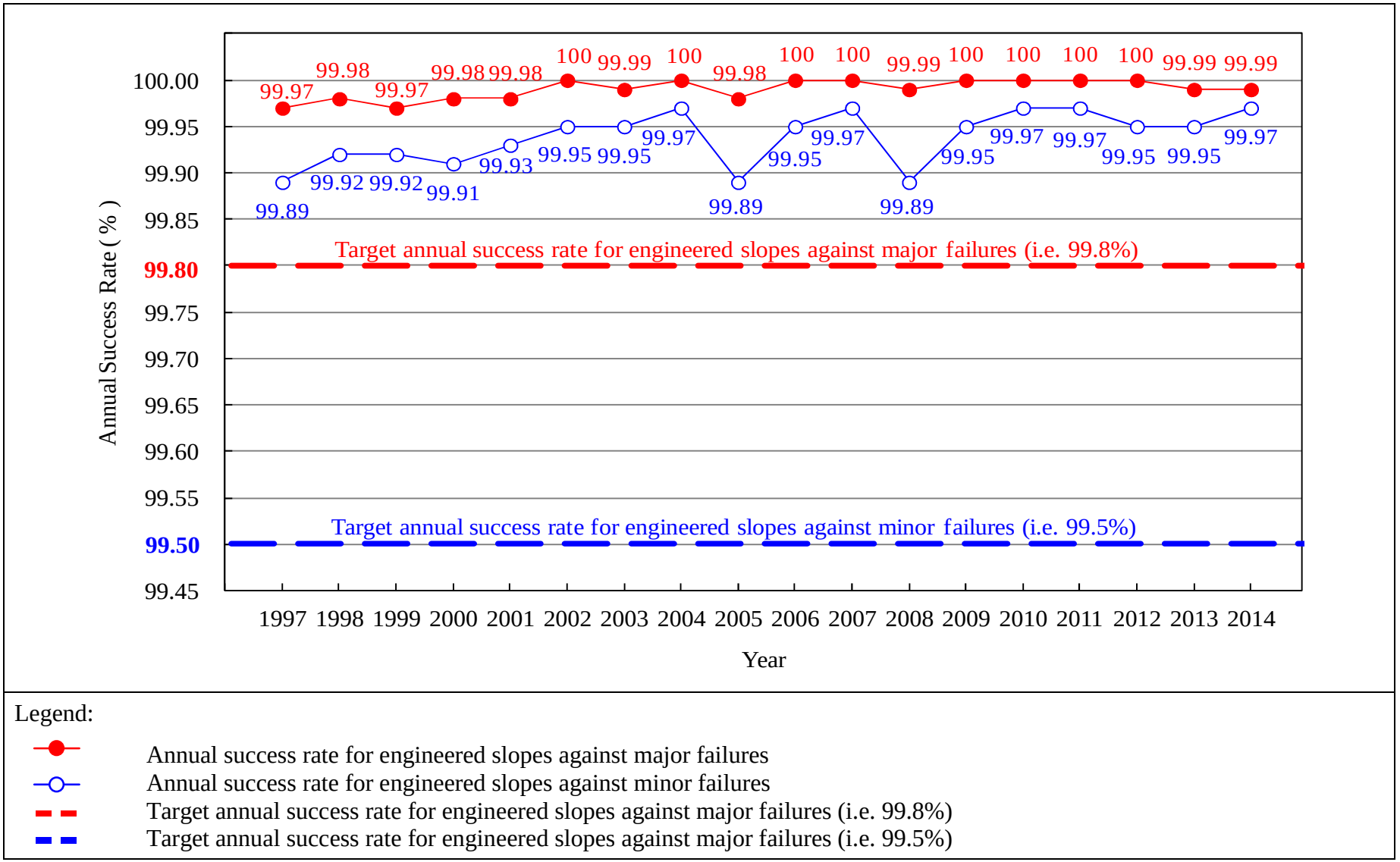

Figure 4.2 Annual Success Rates of Engineered Slopes from 1997 to 2014

4.4 Natural Terrain Landslides

A total of 63 natural terrain landslides were reported in 2014, among which 54 failures were minor and nine were major. Of the nine major incidents, one resulted in temporary closure of a road, three resulted in temporary closure of minor footpaths and the remaining five did not result in any significant consequence. The incident with the largest failure volume (200 m^3) involved an open hillside failure between Headland Road and South Bay Road (Incident No. 2014/05/1572) where the landslide debris came to rest within the hillside and did not affect any downslope facilities.

The 54 minor incidents involved mainly open hillside failures (up to about 40 m^3), boulder/rock falls (mostly less than 1 m^3 and up to 5 m^3) originating from natural hillside and some washout failures (up to about 20 m^3). Two of these incidents resulted in temporary closure of roads and four resulted in temporary closure or blockage of pedestrian pavements/minor access/hiking trail.

Among these 63 reported natural terrain landslides, six failures (comprising five landslide and one boulder fall incidents) were located within existing Historical Landslide Catchments (HLC). These incidents appear to be isolated cases which are not clustered around the previous natural terrain landslides recorded in the Enhanced Natural Terrain Landslide Inventory (ENTLI). Ten other failures were located within 50 m from the existing HLC, none of which with debris trails close to any important downslope facilities. These 16 cases were all minor failures, except one case located within an existing HLC being a major failure.

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

All the 106 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 such as blockage of surface drainage and inadequate hard surface protection was assessed to be a key contributory factor in 17 landslides, two of which were major failures. These contributed to about 16% (i.e. 17 out of 106) of the landslides on registered man-made slopes. Amongst these 17 landslides, four occurred on engineered slopes.

Of these 17 landslides involving inadequate slope maintenance, 13 affected government slopes and two affected private slopes. The remaining two incidents affected slope features of mixed government/private maintenance responsibility, where one occurred on the government portion and the other occurred on both the government and private portions of the slopes. All of the relevant maintenance parties have been informed of the incidents and advised to take appropriate follow-up action. The above diagnosis re-affirms the importance of regular slope maintenance to the performance of slopes. It also serves as a reminder that even an engineered slope is liable to failure given inadequate maintenance.

5 Conclusions

Overall, 99.97% of the engineered man-made slopes performed satisfactorily without occurrence of landslides in 2014. There was one major landslide on engineered slopes in 2014, which involved an unsupported cut slope.

The annual failure rates of major and minor landslides on engineered slopes, on a slope number basis, are 0.004% and 0.025% respectively in 2014. This corresponds to annual success rates of 99.99% and 99.97% with respect to major and minor landslides, which are above the pledged annual success rates of 99.80% and 99.50% respectively.

6 References

Chan, E.Y.M., Law, R.H.C., Lee, R.W.H. & Ting, S.M. (2015). *Factual Report on Hong Kong Rainfall and Landslides in 2014 (SPR Report No. 2/2015).* Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong 81 p.

ETWB (2005). *Prescriptive Measures for Stabilisation and Improvement of Man-made Slopes and Standardised Debris-resisting Barriers for Mitigation of Natural Terrain Landslide Hazards (Technical Circular (Works) No. 13/2005).* Environment, Transport and Works Bureau, Hong Kong, 7 p.

GEO (2004). *Registration and Upgrading of Records of Features (GEO Circular No. 15).* Geotechnical Engineering Office, Civil Engineering and Development Department, 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, Civil Engineering and Development Department, Hong Kong, 14 p.

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

GEO (2010). *Non Development Clearance (Slope Safety) of Squatters (GEO Circular No. 3).* Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong, 20 p.

GEO (2014a). *Landslide Potential Index (GEO Information Note No. 8/2014).* Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong, 5 p.

GEO (2014b). *Catalogue of Slopes (GEO Information Note No. 9/2014).* Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong, 3 p.

GEO (2014c). *Enhancement of Rock Slope Engineering Practice Based on Findings of Landslide Studies (GEO Technical Guidance Note No. 10).* Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong, 5 p.

Appendix A

List of 2014 Landslide Incidents Involving Unregistered Man-made Slopes but Registrable at the Time of Failure

Table A1 List of 2014 Landslide Incidents Involving Unregistered Man-made Slopes but Registrable at the Time of Failure (Sheet 1 of 3)

Incident No.	Location	Maximum Slope Height[(1)]	Reported		Failure			Facility Affected	Consequence
			Date	By	Date (Time)	Feature Type	Scale (m^3)		
2014/03/1480	Behind House No. 12 Fishermen New Village, Tui Min Hoi, Sai Kung	3.2 m	31/3	DLO	Unknown	Soil cut	1	Village house	The kitchen on the ground floor temporarily closed
2014/04/1490	House Nos. 13 & 14 Fishermen Village, Tui Min Hoi, Sai Kung	3.2 m	2/4	DO	Unknown	Soil cut	< 5	Nil	-
2014/04/1502	Between an LCSD's sitting-out area in Ting Kau (near Lido Beach) and DD 399 Lot No. 425	3.6 m	11/4	Public	30/3 (22:00)	Fill	28.8	Open area; Construction site	-
2014/05/1520	Near House No. 2A Tai Lam Liu Tsuen, Kwong Wing Lane, Shatin	8 m	9/5	Police	8/5 (23:00)	Fill	21	Village house; Open area	-

Table A1 List of 2014 Landslide Incidents Involving Unregistered Man-made Slopes but Registrable at the Time of Failure (Sheet 2 of 3)

Incident No.	Location	Maximum Slope Height[(1)]	Reported		Failure			Facility Affected	Consequence
			Date	By	Date (Time)	Feature Type	Scale (m^3)		
2014/05/1549	No. 9 Tai Shan Central, Lamma Island	3.1 m	13/5	DC Member	Unknown	Soil cut	0.06	Squatter structure	-
2014/05/1550	Northwest of House No. 49, Area 6, Shatin Tau New Village	3.5 m	10/5	LandsD	Unknown	Soil cut	1.5	Squatter structure	-
2014/05/1566	Footpath leading from Sai Wan Road to Sai Wan Village, Sai Kung	4 m	14/5	Public	13/5 (21:00)	Soil cut	12	Minor footpath	Footpath to Sai Wan Village partially blocked
2014/05/1569	Footpath leading from Sai Wan Road to Sai Wan Village, Sai Kung	3 m	14/5	Public	13/5 (21:00)	Soil cut	16	Minor footpath	Footpath to Sai Wan Village partially blocked

Table A1 List of 2014 Landslide Incidents Involving Unregistered Man-made Slopes but Registrable at the Time of Failure (Sheet 3 of 3)

Incident No.	Location	Maximum Slope Height[(1)]	Reported		Failure			Facility Affected	Consequence
			Date	By	Date (Time)	Feature Type	Scale (m^3)		
2014/05/1585	House No. 11 Tong Yan San Tsuen (South), Ping Shan, Yuen Long	3.1 m	16/5	DLO	30/3 (22:00)	Soil cut	0.5	Squatter structure; Minor footpath	Part of the footpath behind a squatter structure blocked
2014/11/1651	House No. 12 O Long Village, Sai Kung	3 m	5/11	ICC	Unknown	Soil cut	0.5	Squatter structure	-

Note: [(1)] The height of man-made slope before failure is referred to in determining the maximum slope height.

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Appendix B

Landslide Incidents Involving Slopes Processed under the Slope Safety System

Table B1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 1 of 6)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope Failure	Remarks
1. Slopes Upgraded Under the LPMP ($\sum$ = 5 nos.)					
2014/01/1469	6SE-D/C25	East of Garden Terrace, Tsuen Wan	0.01	Soil cut	The slope was upgraded under the LPMP in 2000. The failure involved the detachment of a concrete fragment from an abandoned concrete structure protruding above the slope surface which might be attributed to inadequate maintenance.
2014/01/1470	7NW-A/CR3	Opposite to Tai Po Tau Pumping Station and Lamp Post No. N3784, Tai Po Road – Tai Wo Section	2.5	Soil/rock cut	The slope was upgraded under the LPMP in 1999. The upgrading works comprised the installation of rock dowels and soil nails, and provision of rock mesh and erosion control mat. The incident involved rock block detachments from a steeply inclined (70°) rock cut portion and a minor surface erosion from a 35° soil cut portion, separated by a few metres. It severed the erosion control mat while the wire mesh remained intact and retained most of the landslide debris. The failure did not involve structural support.

Table B1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 2 of 6)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope Failure	Remarks
2014/01/1002HY (HyD/HK/2014/01/0001)	15NE-B/F17	Shek O Road (near Lamp Post No. 32058)	6	Fill	The slope was upgraded under the LPMP in 1998 using conventional soil nails design (nails inclined at 10° without provision of grillage beams or erosion control mat). The washout failure might be attributed to erosion on a generally bare slope surface (inclined at 37°). Several soil nail heads were exposed on the landslide scar. The installed soil nails were unaffected by the landslide.
2014/06/1061AD (ArchSD/CW/2014/06/0001)	11SE-D/F19	Cape Collinson Crematorium	10	Fill	The slope (inclined at about 40°) was underlain by a natural streamcourse with the rockhead located close to the base of fill. It was upgraded under the LPMP in 1998 by fill recompaction and the provision of a crest cut-off drain. The failure might be attributed to the transient groundwater rise above the shallow bedrock causing loss of strength of overlying fill materials.
2014/10/1070WS (WSD/2014/10/1/NTW)	11NW-A/C207	Lai Chi Kok Salt Water Service Reservoir Pumping Station	2.3 (Rockfall)	Rock cut	The slope was upgraded under the LPMP in 2001. The rock face, where the 2014 incident occurred, was stabilized by the installation of rock dowels and rock mesh. The rockfall involved the detachment of several minor rock blocks causing local damage to the rock mesh. The rock dowels in the vicinity of the rockfall source locations were unaffected by the incident.

Table B1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 3 of 6)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope Failure	Remarks
2. Slopes Assessed under the LPMP 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 (∑ = 1 no.)					
2014/05/1582	11NW-A/C259	Wah King Hill Road, Lai King	2 (Rockfall)	Rock cut	The slope was formed in 1984 under the "KCTL 369 - Tai Wo Tsuen, Reservoir Site Formation and Access Road 44/4" project with the design checked and accepted by the GEO. The incident primarily involved rockfall with the detachment of minor rock blocks from a bare rock cut face where no surface protection measures had been provided.

Table B1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 4 of 6)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope Failure	Remarks
7. <u>Slopes Upgraded By Private Owner and Checked by GEO</u> ($\sum$ = 1 no.)					
2014/05/1516	7NE-C/C228	Residence Road, The Chinese University of Hong Kong	120	Soil cut	The slope was upgraded in 2005 by the Chinese University of Hong Kong with the design checked and accepted by the GEO. The design assumed that Grade III/IV materials present at the failed portion, and no stabilization works were recommended. However, a rock discontinuity survey subsequently conducted during construction revealed the presence of Grade V materials at the failed portion. Post-landslide investigation revealed that the geology at the failed portion was considerably weaker than what was assumed in the design. In addition, surface infiltration and ingress of water through cracks on the concrete paved berm immediately above the failure scarp are also the likely contributory factors to the failure.

Table B1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 5 of 6)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope Failure	Remarks
8. Slopes Upgraded Following Service of DH Orders and Checked by GEO (∑ = 1 no.)					
2014/09/1646	15NE-A/CR160	Nos. 15-23 Stanley Village Road, Stanley	16	Retaining wall	The feature was upgraded in 2000 following a DH Order served by the BD in 1998. The upgrading works comprised thickening of the masonry toe wall (where the 2014 landslide occurred) by construction of mass concrete at its back. However, observations on the landslide scar and its vicinity revealed that there were discrepancies between the as-built records and the present wall conditions (viz. soil instead of mass concrete noted on the shallow scar and portion of wall covered only by cement mortar without masonry blocks). The stability and actual configuration of the wall would be subjected to further investigation/ verification by the owners.
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.					

Table B1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 6 of 6)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope Failure	Remarks

Legend:

Landslide occurred within the soil-nailed portion of a cut slope ($\sum$ = 1 no.)

Landslide involved unsupported cut ($\sum$ = 1 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 regarded as engineered slopes for the purpose of this report.

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

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

部份土力工程處的主要刊物目錄刊載於下頁。而詳盡及最新的土力工程處刊物目錄，則登載於土木工程拓展署的互聯網網頁 http://www.cedd.gov.hk 的"刊物"版面之內。刊物的摘要及更新刊物內容的工程技術指引，亦可在這個網址找到。

Copies of GEO publications (except geological maps and other publications which are free of charge) can be purchased either by:

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

GEOTECHNICAL MANUALS

Geotechnical Manual for Slopes, 2nd Edition (1984), 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