Review of Landslides in 2016

GEO Report No. 341

R.C.T. Wai, R.W.H. Lee & R.H.C. Law

Geotechnical Engineering Office
Civil Engineering and Development Department
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Prepared by:

Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon,
Hong Kong.

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.

W.K. Pun
Head, Geotechnical Engineering Office
December 2018

Foreword

This report presents the findings of a detailed diagnosis of landslides in 2016 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.C.T. Wai, Mr R.W.H. Lee and Ms R.H.C. Law of Landslip Preventive Measures Division 1 under the supervision of Dr D.O.K. Lo. Assistance was provided by the landslide investigation consultants engaged by the Geotechnical Engineering Office, namely AECOM Asia Company Limited and Fugro (Hong Kong) Limited respectively. Technical support provided by Mr T.F.O. Luk, Mr L.K.W. Hui, Mr C.M. Leung and Ms M.S.M. Chan is gratefully acknowledged.

W.K. Pun
Head of the Geotechnical Engineering Office

Abstract

This report presents the findings of a diagnostic review of the landslides in 2016 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, 226 genuine landslides in 2016 were reported to the Government. There were 21 major landslides (viz. failure volume of 50 m^3 or more). There were also thirteen 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 0.046% 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 2016.

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1 Introduction

This report presents the findings of a diagnostic review of the landslides in 2016 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 2016. 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 AECOM Asia Company Limited (AECOM) and Fugro (Hong Kong) Limited (FHK).

2 Rainfall and Landslides in 2016

The factual information, together with the relevant statistics on rainfall and reported landslides in 2016, was documented by Wai et al (2017).

In 2016, the annual rainfall recorded at the Principal Raingauge of the Hong Kong Observatory (HKO) in Tsim Sha Tsui was 3026.8 mm, a surplus of 26% comparing to the mean rainfall of 2398.5 mm between 1981 and 2010. Two Landslip Warnings were issued on 2 August and 19 October 2016. One Black Rainstorm Warning was issued on 19 October 2016. Seven Red Rainstorm Warnings and 33 Amber Rainstorm Warnings were issued between 10 May and 19 October 2016, and between 5 January and 19 October 2016 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 257 reported incidents in 2016, 226 were genuine landslides, discounting

the non-landslide incidents (e.g. tree falls and flooding). There were 21 major failures, corresponding to about 9.3% 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 major landslides 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		19 (3)	8.4
Cut Slopes	Soil	101 (2)	44.7
	Soil/Rock	25 (0)	11.1
	Rock	14 (0)	6.2
Retaining Walls		12 (0)	5.3
Natural Hillside		53 (16)	23.4
Registered Disturbed Terrain		2 (0)	0.9
Total		226 (21)	100

Legend:

19 (3) Nineteen landslides, three of which were major failures

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	6 (0)	10 (1)
Registered Squatter Dwellings	0	1 (0)	10 (0)	11 (0)
Roads	20 (3)	4 (0)	25 (4)	49 (7)
Transportation Facilities (e.g. railways, tramways, etc.)	0	0	0	0
Pedestrian Pavements/Footways	1 (0)	2 (0)	4 (0)	7 (0)
Minor Footpaths/Access Paths/ Access Roads	14 (0)	4 (1)	69 (10)	87 (11)
Construction Sites	0	0	0	0
Open Areas	1 (0)	2 (0)	15 (1)	18 (1)
Catchwaters	3 (0)	0	2 (0)	5 (0)
Others (e.g. carparks, parks, playgrounds, gardens, backyards, etc.)	3 (0)	3 (0)	14 (1)	20 (1)
Nil	5 (0)	1 (0)	16 (0)	22 (0)
Total	51 (4)	17 (1)	161 (16)	229 (21)

Legend:

25 (4) Twenty-five landslides of which four 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	2	0	1	0	0
Cut Slopes	Soil	0	0	0	8	2	7	0	0
	Soil/Rock	0	0	3[(3)]	2	1	2	0	0
	Rock	0	0	0	3	0	1	0	0
Retaining Walls		0	1 (1)	0	0	0	1	0	0
Natural Hillside		0	0	0	5	0	7	0	0
Registered Disturbed Terrain		0	0	0	0	0	2	0	0
Total		0	1 (1)	3	20	3	21	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 1982 Housing Department's Squatter Structure Survey (GEO, 2010).

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

(3) A rockfall incident (Incident No. 2016/08/1896) had resulted in temporary evacuation of the lowest three floors of a residential building.

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	0	0	1	2	3	14
Major Landslides on Man-made Slopes	0	0	0	0	1	1	3
Major Landslides on Registered Disturbed Terrain	0	0	0	0	0	0	0
Major Landslides on Natural Hillside	1	0	0	1	1	2	11

Note: Facility groups are classified in accordance with the GEO Technical Guidance Note No. 15 (GEO, 2007).

Table 2.5 Breakdown of Scale of Failures by Types of Slopes

Types of Slopes	Number of Minor Landslides	Number of Major Landslides		Total
	($< 50\ m^3$)	($50\ m^3$ to $< 500\ m^3$)	($\geq 500\ m^3$)	
Registered Man-made Slopes	118	5	0	123
Registered Disturbed Terrain	2	0	0	2
Unregistrable Man-made Slopes	43	0	0	43
Registrable Man-made Slopes Not Yet Registered at Time of Failure	5	0	0	5
Natural Hillside	37	15	1	53
Total	205	20	1	226

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 1986 to 2016 is presented in Figure 3.1.

In 2016, two Landslip Warnings were issued on 2 August and 19 October 2016 and the corresponding LPI was assessed to be 1 and 3 respectively. In terms of the potential to cause landslides, the rainstorm of 19 October 2016 was 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 2016 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.

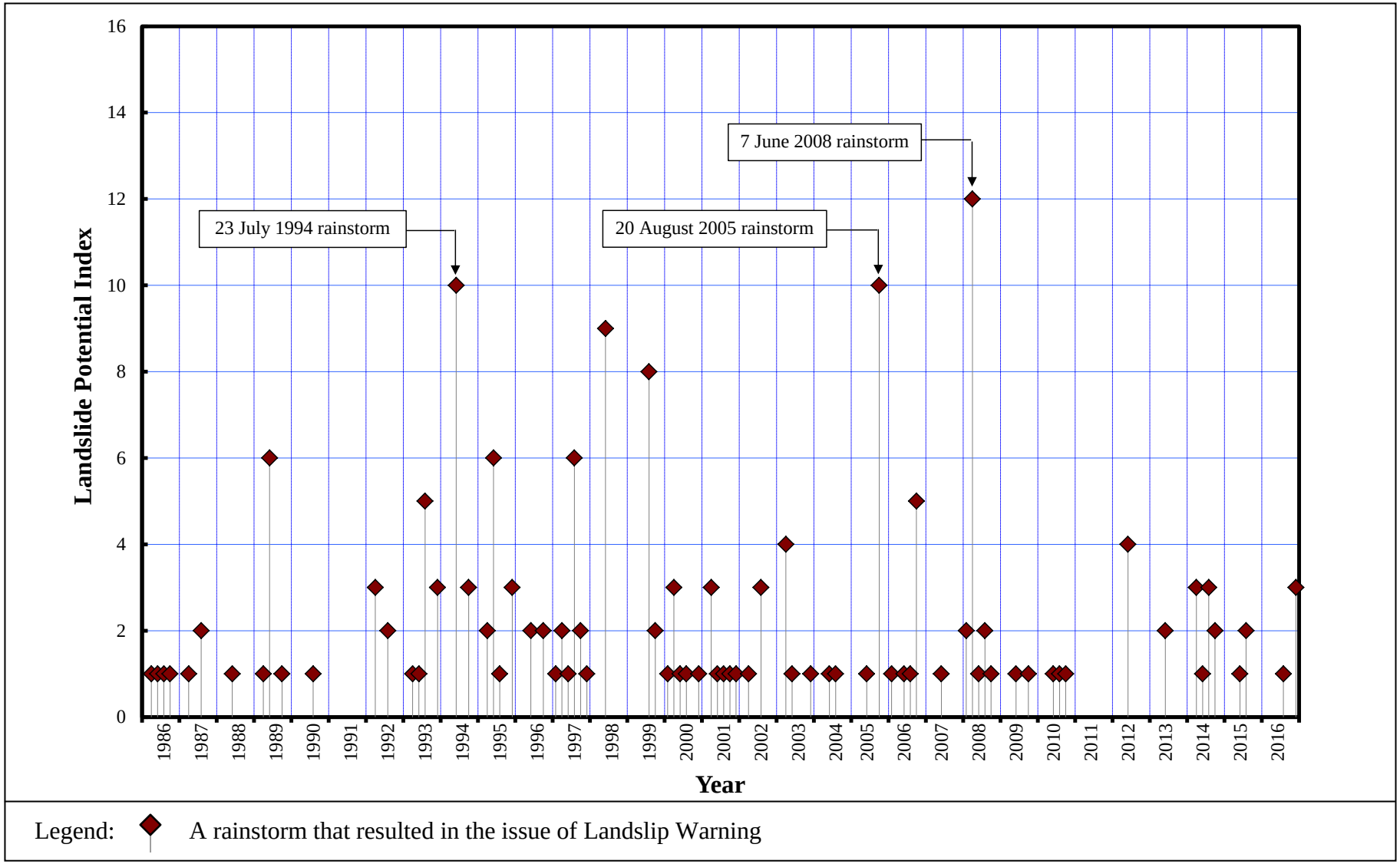


Figure 3.1 Landslide Potential Index for Rainstorms that Resulted in the Issue of Landslip Warnings from 1986 to 2016

4.2.2 Diagnosis

Of the 226 genuine landslides, 125 occurred on registered slope features (comprising 123 on registered man-made slopes and two on registered disturbed terrain features) and 101 occurred on slopes not registered in the Catalogue of Slopes (Table 2.5).

Among the above 101 landslides, 53 occurred on natural hillside, 43 occurred on small man-made slope features that do not meet the slope registration criteria (GEO, 2004). The remaining five landslides, corresponding to 2.2% of the total number of genuine landslides in 2016, involved slope features that satisfy the slope registration criteria but were not registered in the Catalogue of Slopes at the time of failures. A breakdown of these 101 landslides is given in Figure 4.1.

The five landslides involving registrable slopes were all minor failures with failure volume of 20 m^3 or less (refer to Appendix A for details). Amongst these five minor failures, one resulted in damaging of a window of a squatter structure and blockage of an alleyway. 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.

The 43 landslides involving unregistrable man-made slope features were all minor failures with failure volume less than 30 m^3. One incident resulted in damage of the ceiling and a supporting beam of a covered car park and a parked car as well as temporary evacuation of the lowest three floors of a residential building at Tai Hang, one led to temporary closure of one lane of Clear Water Bay Road, two led to temporary closure of access roads at Kwai Chung and Tai Lam and three led to temporary closure of pedestrian pavement or minor footpath at Sai Kung and Tai Po.

4.3 Performance of Registered Man-made Slopes

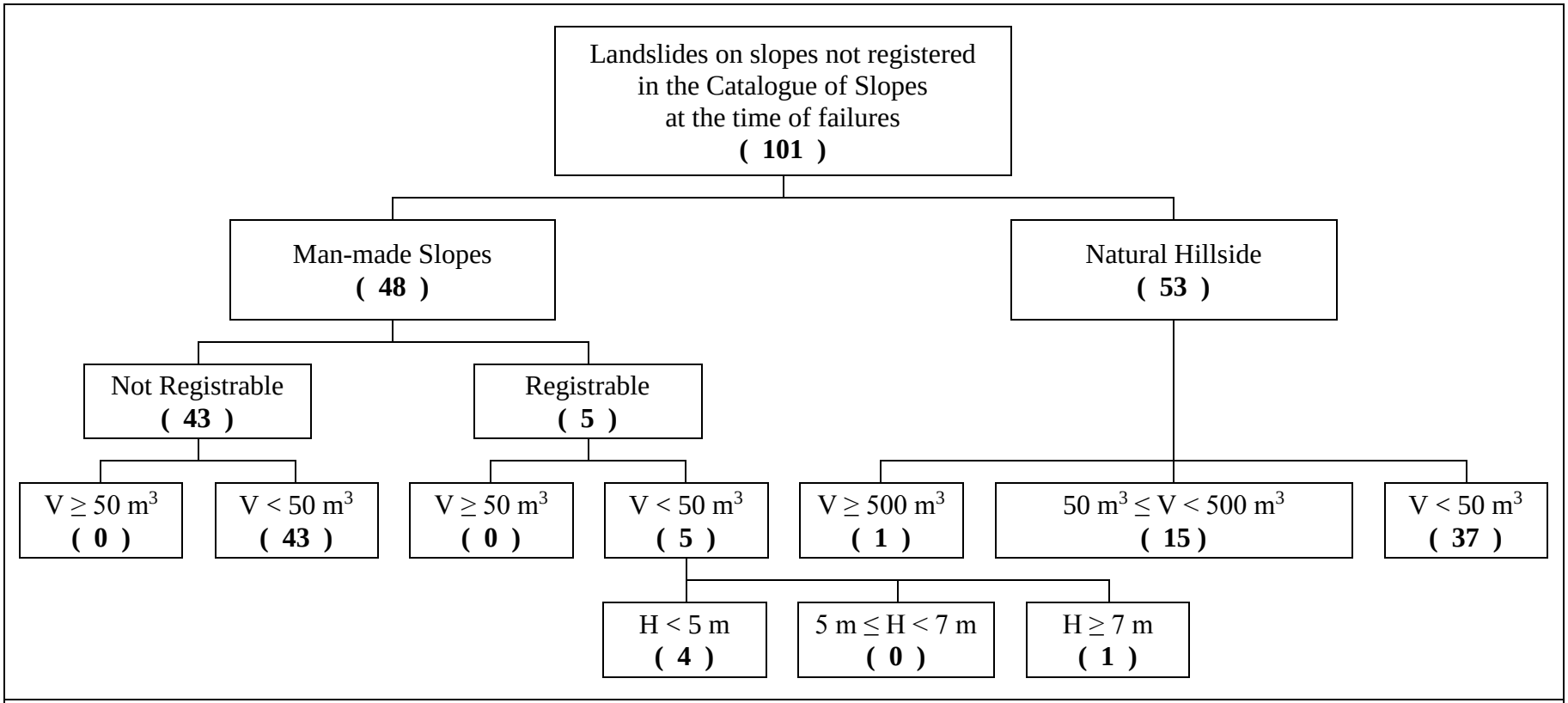
4.3.1 General

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,



Legend: V Failure volume
H Height of man-made feature before failure
(43) Number of landslide incidents = 43

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

Figure 4.1 Breakdown of Landslides on Unregistered Slopes in 2016

(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 226 genuine landslides in 2016, a total of 123 landslides (about 54%) occurred on registered man-made slopes (Table 2.5). Five out of these 123 landslides (about 4%) were major failures, with failure volume ranging from 60 m^3 to 240 m^3, and the remaining 118 landslides were minor failures. Of the 123 landslides on registered man-made slopes, 13 landslides (about 11%) occurred on engineered slopes and the remaining 110 landslides occurred on non-engineered slopes. Except for two incidents which occurred on non-engineered slopes (see Section 4.3.3), there was no major landslide occurring on consequence-to-life (CTL) Category 1 slope features in 2016. A breakdown of the CTL categories of the registered man-made slopes involved in the 2016 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	7 (0)	4 (0)	2 (0)	13 (0)
Non-engineered Slopes	22 (2)	14 (1)	74 (2)	110 (5)

Legend:

14 (1) Fourteen landslides, one of which was a major failure.

Discussions of the landslides on engineered and non-engineered slopes in 2016 are given in Sections 4.3.2 and 4.3.3 respectively below.

4.3.2 Landslides on Engineered Slopes

Brief descriptions of the 13 landslides on engineered slopes in 2016 are given in Appendix B. A breakdown of these landslides in terms of feature type is given in Table 4.2. Among the 13 landslides, four involved slopes previously upgraded under the Landslip Preventive Measures Programme (LPMP) and one involved slope previously upgraded under the Landslip Prevention and Mitigation Programme (LPMitP) (see Table 4.3). There were no retaining walls involved in the failure of engineered slopes in 2016.

Two landslides involved failures of completely to highly weathered materials above bedrock on the unsupported portions of soil-nailed cut slopes. One involved a structural-controlled failure on a soil/rock cut slope (volume of about 35 m^3). The scar was formed by two prominent joints dipping out of the slope. Post-failure investigation revealed that subsurface water flow at shallow depth as evidenced by the active seepage coming out of the slope at the locations immediately above and below the scar. The catchpit collecting water from a stepped channel as well as a berm channel immediately above the scar were completely blocked with sign of overspillage. The surface overflow might have led to enhanced infiltration over the unpaved berm and cracked chunam slope cover resulting in the development of transient perched water table above the soil/rock interface that triggered the failure. Another incident involved a minor shallow detachment on a soil/rock cut slope (volume of about 5 m^3). The slope traverses several drainage lines and active seepage was evident in close proximity to the failure scar. The failure occurred on a small local unsupported portion between the bottom row of soil nails and the soil/rock interface. Such portion was envisaged in the design to be within the rock portion inferred from rockhead levels in adjacent areas. The failure was probably caused by the development of transient perched water table above the soil/rock interface.

One landslide involved the failure on a soil-nailed cut portion of a fill slope (volume of about 25 m^3). Site formation works at the failed slope portion comprised cutting back to 35° with the removal of the existing fill materials, installation of soil nails and provision of erosion control mat. The landslide was wide but shallow without affecting the soil nails, although several intact soil nail heads were exposed on the scar. Post-failure inspection revealed the presence of loose materials within the scar suggesting that possibly the fill was not completely removed during the site formation works. The failure might be attributed to the development of a transient perched water table within a veneer of fill/colluvium overlying the insitu soil near the slope surface.

Five landslides involved minor washout failures. Three occurred on soil cut slopes (volume $\leq$ 6 m^3), one on a compacted fill slope (volume $\leq$ 2.5 m^3) and the remaining one involved washout of the compacted soil fill materials on a rock fill slope (volume $\leq$ 3.5 m^3).

The remaining five landslides involved minor rockfalls (volume $\leq$ 1 m^3). Post-landslide inspections revealed that all these five incidents occurred on bare rock faces, where no rock mesh was installed. Again these incidents 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).

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
50 m^3 to 500 m^3	0	0	0	0	0	0
> 5 m^3 to < 50 m^3	1 (1)	1	2	0	0	4
≤ 5 m^3	2	2 (1)	2	3	0	9
Total	3 (1)	3 (1)	4	3	0	13

Legend:

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

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

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

4.3.3 Landslides on Non-engineered Slopes

There were 110 landslides on non-engineered slopes in 2016, among which five were major and 105 were minor.

The five major landslides involved failure volume ranging from 60 m^3 to 240 m^3. Two of these major landslides occurred on CTL Category 1 slopes but did not affect any critical facility and both of them did not have any consequence. The other three major landslides occurred on roadside slopes of CTL Category 2 or 3 and two of the cases resulted in temporary closure of roads and the remaining one did not have any consequence. Details of the major landslide that occurred on a CTL Category 2 roadside slope resulting in temporary closure of South Lantau Road were documented in Wai et al (2017).

Of the 105 minor landslides, 85 of them were relatively small in scale with a failure volume of less than 5 m^3. Ten incidents resulted in temporary closure of roads, two resulted in temporary closure of pedestrian pavement, eight resulted in temporary closure of minor footpath/access road and one resulted in temporary evacuation of squatter dwellings at Shek Li Ka Nam. The rest did not have any notable consequence.

There were two rockfall incidents (Incident Nos. 2016/08/1895 & 2016/06/1017HY), where the fallen rock was retained by the rock mesh on the slope. These incidents were not regarded as a failure in accordance with GEO Technical Guidance Note No. 10 (GEO, 2014c) and thereby it has been discarded from the compilation of the annual failure rates presented in Section 4.3.5.

4.3.4 Landslides Occurring in the Vicinity of Registered Squatter Structures

Sixteen landslides occurred on slopes located in the vicinity of registered squatter structures, of which six occurred on registered slopes, seven on unregistrable man-made slopes, two on registrable man-made slopes not yet registered at the time of failure and one on natural hillside. All these landslides were minor, with failure volume ranging from 0.3 m^3 to 20 m^3. Those man-made slopes involved in the landslides were all non-engineered.

In five of the 16 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 11 landslides. In these cases, one involved the issuance of Category 2 Non-development Clearance[1] (NDC) recommendation on the affected squatter structure following the 2016 incident. No NDC recommendations were made for the remaining cases either because the affected squatter structure is on a private lot/licensed land or the failure was of very small scale (volume ≤ 1 m^3) without causing any damage to the affected squatter structures.

For the 16 landslides on slopes located in the vicinity of registered squatter structures, NDC inspections were previously conducted by the GEO on the villages concerned. Following the NDC inspections, Category 2 NDC recommendation was made on one 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.

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 2016 correspond to about 0.211% (number of landslides divided by number of registered man-made slopes), 0.0043% (total surface area of landslides divided by total surface area of registered man-made slopes), and about 2.159×10^{-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 2016 (Table 4.5), the annual failure rates of engineered slopes are lower than that of non-engineered slopes by a factor of about 8 on a slope number basis, and about 18 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 21 times lower than that of non-engineered slopes.

In 2016, four landslides involved slopes treated under the LPMP and one involved slope upgraded under the LPMitP. The annual failure rates of slopes previously treated under the LPMP or LPMitP correspond to 0.096% (number of landslides divided by number of registered man-made slopes treated under the LPMP or LPMitP), 0.0012% (total surface area of landslides divided by total surface area of registered man-made slopes treated under the LPMP or LPMitP), and about 5.982×10^{-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 4 to 12, comparable to that of other engineered slopes.

GEO's target annual success rates (where success rate = 1 – failure rate) for engineered slopes are 99.8% and 99.5% against major and minor failures respectively, on the basis of the number of landslides per total number of slopes. In 2016, 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 for the period from 1997 to 2016 is shown in Table 4.6 and Figure 4.2.

Table 4.4 Annual Failure Rates of Registered Man-made Slopes in 2016

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 2016	Number of Slopes	13	95	108	2	11	13
	Surface Area of Landslides (m^2)	450	1689	2139	26	271	297
Slopes Involved in Major Landslides in 2016	Number of Slopes	3	2	5	0	0	0
	Surface Area of Landslides (m^2)	395	513	908	0	0	0
Slopes Involved in Minor Landslides in 2016	Number of Slopes	10	93	103	2	11	13
	Surface Area of Landslides (m^2)	55	1176	1231	26	271	297
Total Number of Registered Slopes		11,140	18,010	29,150	12,430	15,720	28,150
Total Surface Area of Registered Slopes (m^2)		6,248,410	9,551,970	15,800,380	13,649,870	26,605,250	40,255,120
Annual Failure Rates (All Landslides)	On Slope Number Basis	0.117%	0.527%	0.370%	0.016%	0.070%	0.046%
	On Slope Surface Area Basis	0.0072%	0.0177%	0.0135%	0.0002%	0.0010%	0.0007%
	Number of Landslides Divided by Slope Surface Area (no./m^2)	2.081×10^{-6}	9.946×10^{-6}	6.835×10^{-6}	1.465×10^{-7}	4.135×10^{-7}	3.229×10^{-7}
Annual Failure Rates (Major Landslides)	On Slope Number Basis	0.027%	0.011%	0.017%	0%	0%	0%
	On Slope Surface Area Basis	0.0063%	0.0054%	0.0057%	0%	0%	0%
	Number of Landslides Divided by Slope Surface Area (no./m^2)	4.801×10^{-7}	2.094×10^{-7}	3.164×10^{-7}	0	0	0

Note: Landslides on registered disturbed terrain features and two incidents involving fallen rock fully retained by rock mesh netting 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./m^2)
Registered Man-made Slopes	All Landslides	0.211%	0.0043%	2.159×10^{-6}
	Major Landslides	0.009%	0.0016%	8.920×10^{-8}
	Minor Landslides	0.202%	0.0027%	2.069×10^{-6}
Engineered Slopes	All Landslides	0.046% (0.096%)	0.0007% (0.0012%)	3.229×10^{-7} (5.982×10^{-7})
	Major Landslides	0% (0%)	0% (0%)	0 (0)
	Minor Landslides	0.046% (0.096%)	0.0007% (0.0012%)	3.229×10^{-7} (5.982×10^{-7})
Non-engineered Slopes	All Landslides	0.37% [8/3.8]	0.0135% [18.4/11.7]	6.835×10^{-6} [21.2/11.4]
	Major Landslides	0.017%	0.0057%	3.164×10^{-7}
	Minor Landslides	0.353%	0.0077%	6.519×10^{-6}

Legend:

0.046% (0.096%)	Annual failure rate of engineered slopes (considering all landslides) is 0.046% and that for slopes previously treated under the LPMP or LPMitP is 0.096%
0.37% [8/3.8]	Annual failure rate of non-engineered slopes (considering all landslides) is 0.37%, which is about 8 times and 3.8 times higher than those of engineered slopes and slopes previously treated under the LPMP or LPMitP respectively

Table 4.6 Annual Success Rates of Engineered Slopes from 1997 to 2016

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%
2015	99.99%	99.97%
2016	100%	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 to 2016.

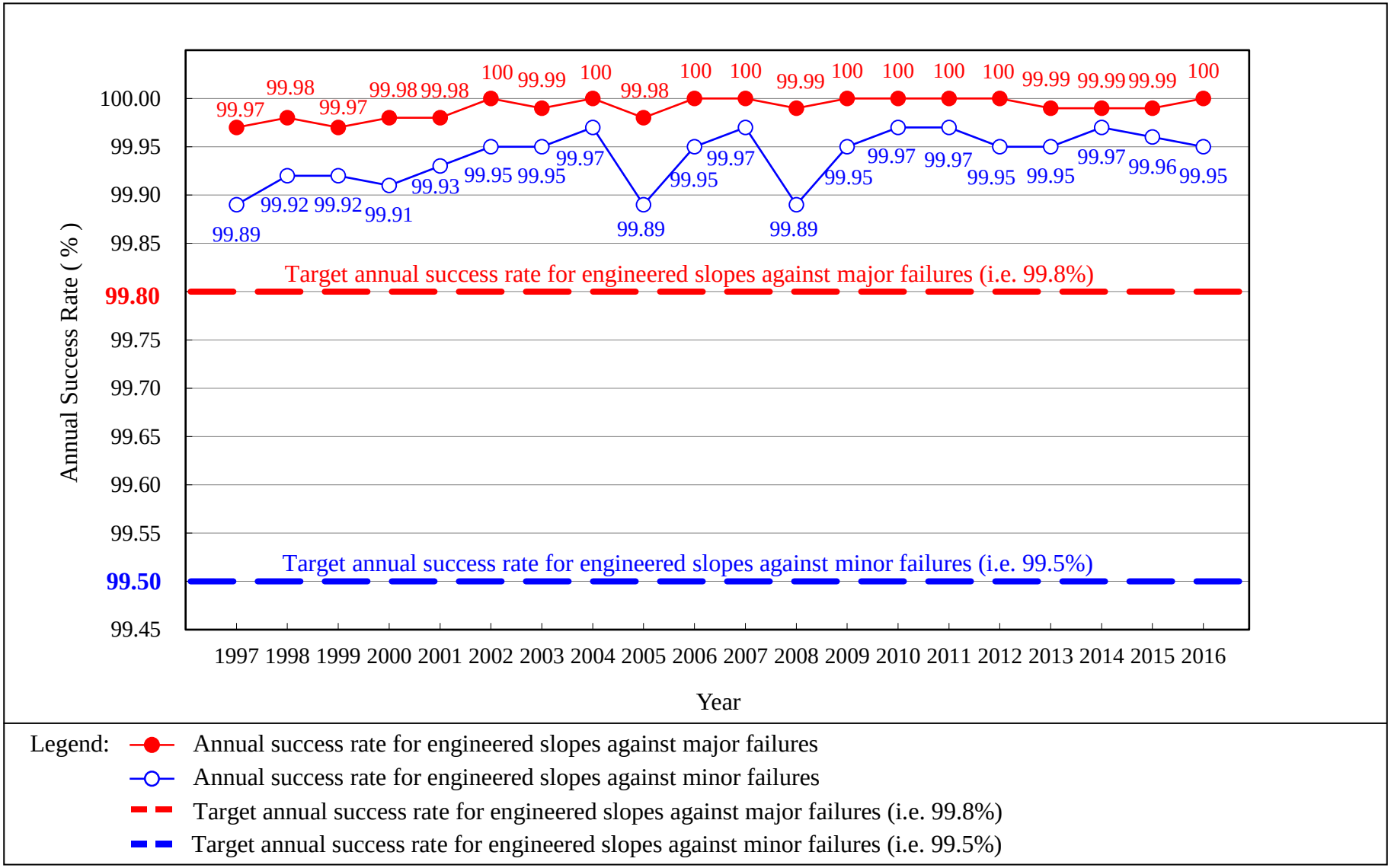


Figure 4.2 Annual Success Rates of Engineered Slopes from 1997 to 2016

4.4 Natural Terrain Landslides

A total of 53 natural terrain landslides were reported in 2016, among which 37 failures were minor and 16 were major. Of the 16 major incidents, one resulted in three parked cars partially buried by landslide debris, three resulted in temporary closure of roads, six resulted in temporary closure of minor footpaths/hiking trails and the remaining six did not result in any significant consequence. Among these major landslides, nine incidents occurred on the hillside catchments in Sai Kung East Country Park during the severe rainstorm on 21 May 2016, including the largest landslide with a failure source volume of about 2,100 m^3 (Incident No. 2016/05/1823) which involved a planar rock slide on the natural hillside above Sai Kung Sai Wan Road. It resulted in temporary closure of the road for more than three months. This incident was documented in Wai et al (2017) and a detailed landslide study was conducted (AECOM, 2017).

The 37 minor incidents involved mainly open hillside failures (up to about 35 m^3), boulder/rock falls (less than 1 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 two resulted in blockage of minor footpaths.

Among these 53 reported natural terrain landslides, four failures (comprising one landslide and three 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). Five other failures were located within 50 m from the existing HLC, none of which with debris trails close to any important downslope facilities. These nine cases were all minor failures, except one case involved a major landslide and resulted in three parked cars partially buried by landslide debris as mentioned above.

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

All the 123 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 23 landslides which were all minor in nature (failure volume up to 35 m^3). These contributed to about 19% (i.e. 23 out of 123) of the landslides on registered man-made slopes. Amongst these 23 landslides, nine occurred on engineered slopes.

Of these 23 landslides involving inadequate slope maintenance, 17 affected government slopes and one affected private slope. The remaining five incidents affected slope features of mixed government/private maintenance responsibility and all of them occurred on the 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 if not adequately maintained.

5 Proposed Improvement Initiative

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

(a) remind practitioners of the possible large variations in level of the soil/rock interface within a short distance and the importance to devise the soil nail layout judiciously to minimize the extent of local unsupported soil zone between the bottom row of soil nails and the interface of soil and rock with a view to reducing the vulnerability to failure (Section 4.3.2).

6 Conclusions

Overall, 99.95% of the engineered man-made slopes performed satisfactorily without occurrence of landslides in 2016. There was no major landslide on engineered slopes in 2016.

The annual failure rate of minor landslides on engineered slopes, on a slope number basis, is 0.046% in 2016. This corresponds to annual success rate of 99.95%, which is above the pledged annual success rate of 99.5%.

7 References

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Appendix A

List of 2016 Landslide Incidents Involving Unregistered Man-made Slopes but Registrable at the Time of Failure

Table A1 List of 2016 Landslide Incidents Involving Unregistered Man-made Slopes but Registrable at the Time of Failure

Incident No.	Location	Maximum Slope Height[(1)]	Reported		Failure			Facility Affected	Consequence
			Date	By	Date (Time)	Feature Type	Scale (m^3)		
2016/01/1790	No. 140 Middle Hill Road, Cheung Chau	4 m	18/1	Public	15/1 (18:14)	Soil cut	10	Registered squatter dwellings	A window of a registered squatter dwelling damaged. Alleyway blocked.
2016/05/1820	Kiu Tau Village, Wo Yi Hop Lane, Tusen Wan	9 m	11/5	Public	11/5 (02:00)	Fill	20	Minor footpath	-
2016/05/1835	Nam Hang Pai, Yuen Long	3.4 m	22/5	HyD	21/5	Soil cut	0.5	Minor footpath	-
2016/08/1908	Near House No. 93 Che Keng Tuk, Sai Kung	4 m	19/8	DLO	2/8	Soil cut	0.5	Village house	-
2016/09/1920	Near House No. 207 Fuk Hang Tsuen, Tuen Mun	3.1 m	29/8	DLO	Unknown	Retaining Wall (Masonry)	1.3	Open space	-

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

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 7)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope Failure	Remarks
1. <u>Slopes Upgraded Under the LPMP/LPMitP</u> ($\sum$ = 5 nos.)					
2016/06/1848	6SE-B/CR72	Tsuen Wan West Lower Level Fresh Water Service Reservoir, Tsuen Wan	35	Soil/rock cut	The slope was upgraded under the LPMP in 1993. The landslide involved failure of completely to highly weathered materials above bedrock on the unsupported portion of a soil-nailed cut slope. The scar was formed by two prominent joints dipping out of the slope. Post-failure investigation revealed that subsurface water flow at shallow depth as evidenced by the active seepage coming out of the slope at the locations immediately above and below the scar. The catchpit and the berm channel immediately above the scar were completely blocked with sign of overspillage. The surface overflow might have led to enhanced infiltration over the unpaved berm and cracked chunam slope cover resulting in the development of transient perched water table above the soil/rock interface that triggered the failure.
2016/06/1856	11SE-C/C5	Opposite No. 16 Repulse Bay Road	0.5	Soil cut	The slope was upgraded under the LPMP in 2002. The failure location, inclined at about 45°, was soil-nailed and covered with erosion control mat. The incident involved a washout failure that might be attributed to the overflow originated from a blocked surface channel at the upslope residential development. No soil nail heads were exposed on the failure scar.

Table B1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 2 of 7)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope Failure	Remarks
2016/09/1914	11SW-D/C333	Mount Nicholson Road	5.1	Soil/rock cut	The slope was upgraded under the LPMitP in 2012. The failure involved a shallow detachment on a small local unsupported portion, steeply inclined at about 70°, between the bottom row of soil nails and the soil/rock interface. Such portion was envisaged in the design to be within the rock portion. The failure was probably caused by the development of transient perched water table above the soil/rock interface.
2016/03/1006WS (WSD/2016/03/01/ HKI)	11SE-D/FR175	Opposite of Chai Wan Baptist Church, Fei Tsui Road, Chai Wan	3.5	Fill	The slope was upgraded under the LPMP in 1997. The incident involved a shallow washout failure within the 300 mm thick compacted capping soil fill over the 30° inclined rockfill slope. The erosion control mat covering the slope surface appeared to be in a poor condition prior to the failure and inadequate surface protection might have contributed to the failure.
2016/04/1009AF (AFCD/2016/04/ 0001)	7SW-C/C820	Shing Mun Country Park, Kwai Tsing	0.6 (Rockfall)	Soil/rock cut	The slope was upgraded under the LPMP in 2003. The incident involved 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 3 of 7)

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 ($\sum$ = 0 no.)					
Nil.					
3. Slopes Assessed by Studies in the late 1970's to mid-1980's with No Upgrading Works/Further Study Required ($\sum$ = 0 no.)					
Nil.					
4. Slopes Assessed by Government Departments and Checked by GEO with No Upgrading Works Required ($\sum$ = 0 no.)					
Nil.					
5. Slopes Assessed by Private Owners and Checked by GEO with No Upgrading Works Required ($\sum$ = 0 no.)					
Nil.					
6. Slopes Formed or Upgraded by Government Departments and Checked by GEO ($\sum$ = 4 nos.)					
2016/01/1789	10NE-B/C267	Tsing Yi Road, Tsing Yi	0.3 (Rockfall)	Soil/rock cut	The slope was studied and modified in mid-1980s under the "Tsuen Wan New Town – Tsing Yi Development – Slopes Above Road TY1 North of PEPCO" project with the design checked and accepted by the GEO. The incident involved rockfall with 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 7)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope Failure	Remarks
2016/02/1796	12NW-C/C210	Po Lam Road North, Tseung Kwan O	0.1 (Rockfall)	Soil/rock cut	The slope was formed under the "Junk Bay Development – Contract No. JB17/84 Hang Hau Area" project with the geotechnical submission in relation to the design of the slope checked and accepted by the GEO in 1990. The rockfall involved detachment of minor rock blocks from the bare rock cut face at the lowest batter where no surface protection measures had been provided.
2016/02/1797	11SW-D/FR654	St. Paul's Co-educational College Primary School, Nam Fung Path, Nam Fung Road	25	Fill	The slope was formed under the St. Paul's Co-educational College Primary School development in 2007 with the design checked and accepted by the GEO. The site formation works at the failed slope portion comprised cutting back to 35° with the removal of the existing fill materials, installation of soil nails and provision of erosion control mat. The landslide was wide but shallow without affecting the soil nails, although several intact soil nail heads were exposed on the scar. Post-failure inspection revealed the presence of loose materials within the scar suggesting that possibly the fill was not completely removed during the site formation works. The failure might be attributed to the development of a transient perched water table within a veneer of fill/colluvium overlying the insitu soil near the slope surface.

Table B1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 5 of 7)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope Failure	Remarks
2016/04/1802	7NE-D/C93	Ma Kam Street, Ma On Shan	6	Soil cut	The slope was formed under the project "Ma On Shan Development – Borrow Area IX including Area 103-107 Truck Road/T7 (Part), Road D16 (Part), Road P9 (Part) Area" in 1987 with the design checked and accepted by the GEO. The incident involved a minor washout at the lowest batter of the slope and a stepped channel was severed within the scar. Post-landslide investigation revealed that the catchpit collecting water from the catchment above as well as the sections of berm channel immediately above the scar were completely blocked with sign of overspillage. The surface overflow onto the bare slope surface might have caused this washout failure.
7. <u>Slopes Formed or Upgraded By Private Owner and Checked by GEO</u> ($\sum$ = 4 nos.)					
2016/06/1853	11SE-A/CR132	Behind Tsuen Wing Lau, Lai Tak Tsuen, Tai Hang	0.001 (Rockfall)	Soil/rock cut	The slope was upgraded by Hong Kong Housing Society in 1999 with the design checked and accepted by the GEO. The incident involved a rockfall originated from a bare outcrop probably due to the development cleft water pressure within the rock joints.

Table B1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 6 of 7)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope Failure	Remarks
2016/06/1867	11SE-A/C278	Behind Wah Shun Gardens, No. 898 King's Road	0.2	Soil cut	The slope was formed by Mass Transit Railway Corporation in 1984 with the design checked and accepted by the GEO. The incident involved a washout failure on the 40° inclined unsupported soil cut slope portion. The failure location was covered with chunam prior to the failure yet it appeared to be in a poor condition with cracks and growth of undesirable vegetation. The failure might be attributed to concentrated surface flow due to spillage from the partially blocked surface channels above the failure location.
2016/09/1910	15NE-A/C54	Belleview Drive	0.02 (Rockfall)	Rock cut	The slope was modified as part of the Belleview Place development in 1987 with the design checked and accepted by the GEO. The incident involved a rockfall on the bare rock face with no surface protection measures provided. Root-wedging action could be the principal cause of the failure.
2016/11/1989	11SE-A/FR197	South of Wilshire Towers, No. 200 Tin Hau Temple Road	2.4	Fill	The slope was formed under the Wilshire Towers development in 1983 with the design checked and accepted by the GEO. The incident involved a washout failure on the 35° inclined compacted fill slope portion probably due to the overflow from a blocked surface channel located immediately above the scar.

Table B1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 7 of 7)

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 (∑ = 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 within the soil-nailed portion of a cut slope (∑ = 2 nos.)

Landslide involved unsupported cut (∑ = 4 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 regarded as engineered slopes for the purpose of this report.

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