Review of Landslides in 2015

GEO Report No. 335

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

Geotechnical Engineering Office
Civil Engineering and Development Department
The Government of the Hong Kong
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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
March 2018

Foreword

This report presents the findings of a detailed diagnosis of landslides in 2015 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 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
Head of the Geotechnical Engineering Office

Abstract

This report presents the findings of a diagnostic review of the landslides in 2015 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, 161 genuine landslides in 2015 were reported to the Government. There were ten major landslides (viz. failure volume of 50 m^3 or more) including one occurring on an engineered man-made slope. There were also nine 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 0.036% on a slope number basis (i.e. number of landslides relative to the total number of engineered slopes).

Overall, 99.96% of the engineered man-made slopes performed satisfactorily without occurrence of landslides in 2015.

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1 Introduction

This report presents the findings of a diagnostic review of the landslides in 2015 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 2015. 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 2015

The factual information, together with the relevant statistics on rainfall and reported landslides in 2015, was documented by Wai et al (2016).

In 2015, the annual rainfall recorded at the Principal Raingauge of the Hong Kong Observatory (HKO) in Tsim Sha Tsui was 1,874.5 mm, a deficit of about 22% comparing to the mean rainfall of 2,398.5 mm between 1981 and 2010. Two Landslip Warnings were issued on 20 May and 22 July 2015. One Black Rainstorm Warning was issued on 26 May 2015. Four Red Rainstorm Warnings and 21 Amber Rainstorm Warnings were issued between 20 May and 15 August 2015, and between 11 May and 4 October 2015 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 $\geq 50\ m^3$ 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 182 reported incidents in 2015, 161 were genuine landslides, discounting the non-landslide incidents (e.g. tree falls). There were ten 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 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		11 (2)	6.8
Cut Slopes	Soil	78 (2)	48.5
	Soil / Rock	14 (0)	8.7
	Rock	14 (2)	8.7
Retaining Walls		8 (0)	5.0
Natural Hillside		30 (4)	18.6
Registered Disturbed Terrain		6 (0)	3.7
Total		161 (10)	100

Legend:

14 (2) Fourteen landslides, two 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)	2 (0)	0	10 (0)	12 (0)
Registered Squatter Dwellings	0	0	18 (0)	18 (0)
Roads	8 (0)	2 (0)	15 (2)	25 (2)
Transportation Facilities (e.g. railways, tramways, etc.)	0	0	0	0
Pedestrian Pavements / Footways	2 (0)	1 (0)	1 (0)	4 (0)
Minor Footpaths / Access Paths / Access Roads	8 (0)	0	43 (3)	51 (3)
Construction Sites	0	0	1 (0)	1 (0)
Open Areas	1 (0)	1 (0)	23 (3)	25 (3)
Catchwaters	2 (0)	0	5 (1)	7 (1)
Others (e.g. carparks, parks, playgrounds, gardens, backyards,etc.)	3 (0)	0	11 (0)	14 (0)
Nil	1 (0)	3 (0)	9 (1)	13 (1)
Total	27 (0)	7 (0)	136 (10)	170 (10)

Legend:

23 (3) Twenty-three 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	1	0	0	0	0
Cut Slopes	Soil	0	0	0	1	0	2	0	0
	Soil / Rock	0	0	0	3	0	0	0	0
	Rock	0	0	0	3	1	0	0	4(3)
Retaining Walls		0	0	0	0	0	2	0	0
Natural Hillside		0	0	0	2	0	1	0	0
Registered Disturbed Terrain		1 (1)	0	0	0	0	0	0	0
Total		1 (1)	0	0	10	1	5	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. all 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) Four injuries were resulted from a single rockfall incident No. 2015/02/1659.

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	0	0	0	0	1	6	3
Major Landslides on Man-made Slopes	0	0	0	0	1	4	1
Major Landslides on Registered Disturbed Terrain	0	0	0	0	0	0	0
Major Landslides on Natural Hillside	0	0	0	0	0	2	2

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

Table 2.5 Breakdown of Scale of Failures by 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)	(≥ 500 m^3)	
Registered Man-made Slopes	80	6	0	86
Registered Disturbed Terrain	5	0	0	5
Unregistrable Man-made Slopes	33	0	0	33
Registrable Man-made Slopes Not Yet Registered at Time of Failure	7	0	0	7
Natural Hillside	26	4	0	30
Total	151	10	0	161

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 2015 is presented in Figure 3.1.

In 2015, two Landslip Warnings were issued on 20 May and 22 July 2015 and the corresponding LPI was assessed to be 1 and 2. In terms of the potential to cause landslides, the rainstorm of 22 July 2015 was one-fifth 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 2015 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,

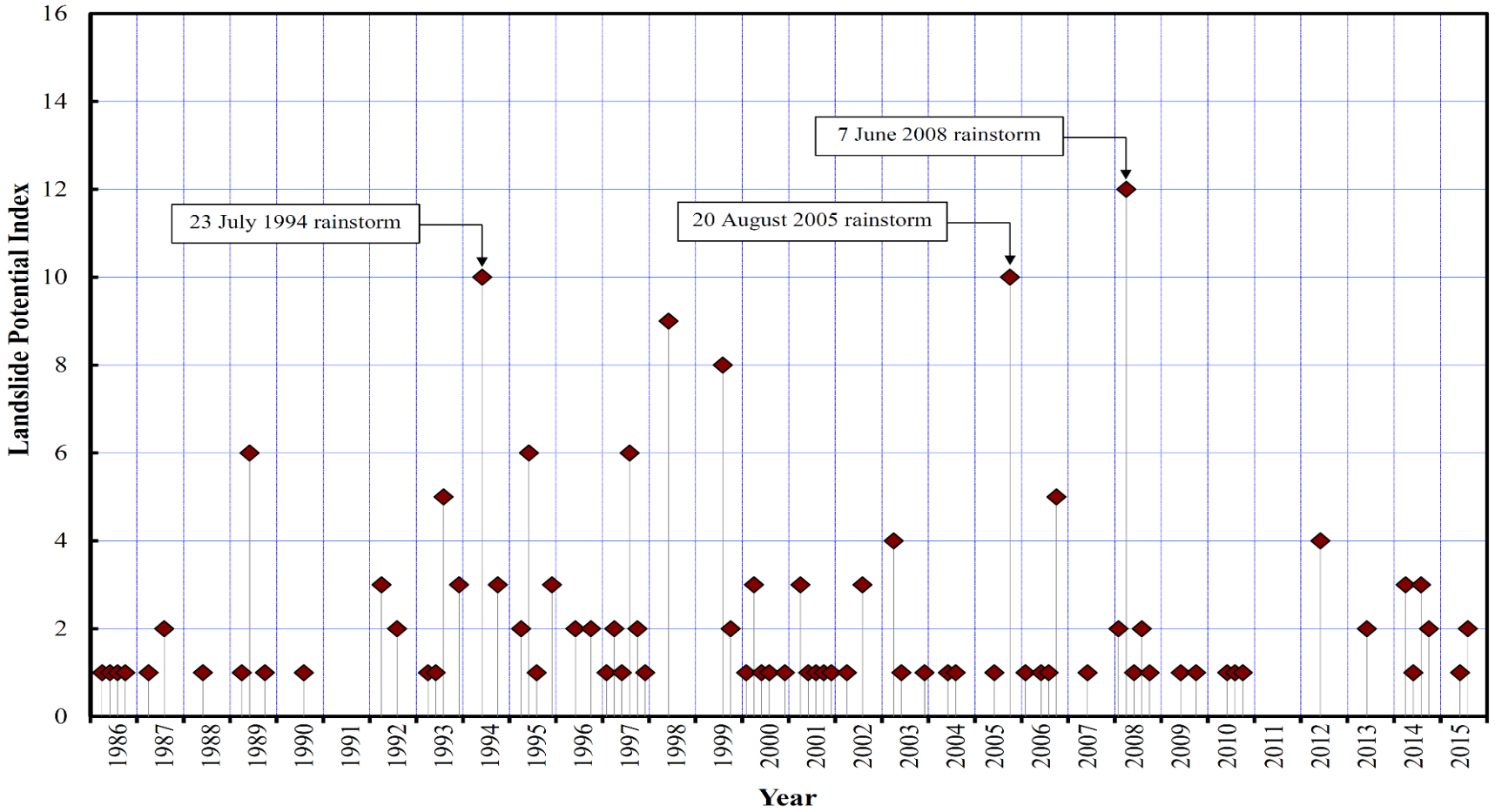
(c) observations from natural terrain landslides, and

(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.



Legend:

A rainstorm that resulted in the issue of Landslip Warning

Figure 3.1 Landslide Potential Index for Rainstorms that Resulted in the Issue of Landslip Warnings from 1984 to 2015

4.2.2 Diagnosis

Of the 161 genuine landslides, 91 occurred on registered slope features (comprising 86 on registered man-made slopes and five on registered disturbed terrain features) and 70 occurred on slopes not registered in the Catalogue of Slopes (Table 2.5).

Among the above 70 landslides, 30 occurred on natural hillside, 33 occurred on small man-made slope features that do not meet the slope registration criteria (GEO, 2004). The remaining seven landslides, corresponding to 4.3% of the total number of genuine landslides in 2015, 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 70 landslides is given in Figure 4.1.

The seven landslides involving registrable slopes were all minor failures with failure volume less than 25 m^3 (refer to Appendix A for details). Amongst these seven minor failures, one resulted in permanent evacuation of a squatter dwelling at Pai Tau Village, Shatin. 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 33 landslides involving unregistrable man-made slope features were all minor failures with failure volume of 33 m^3 or less. One incident resulted in damage to a squatter dwelling at Tsing Chuen Wai, Tuen Mun and three led to temporary closure of minor footpaths at Wo Liu Hang Road, Sui Wo Road and Ma On Shan Tsuen respectively.

4.3 Performance of Registered Man-made Slopes

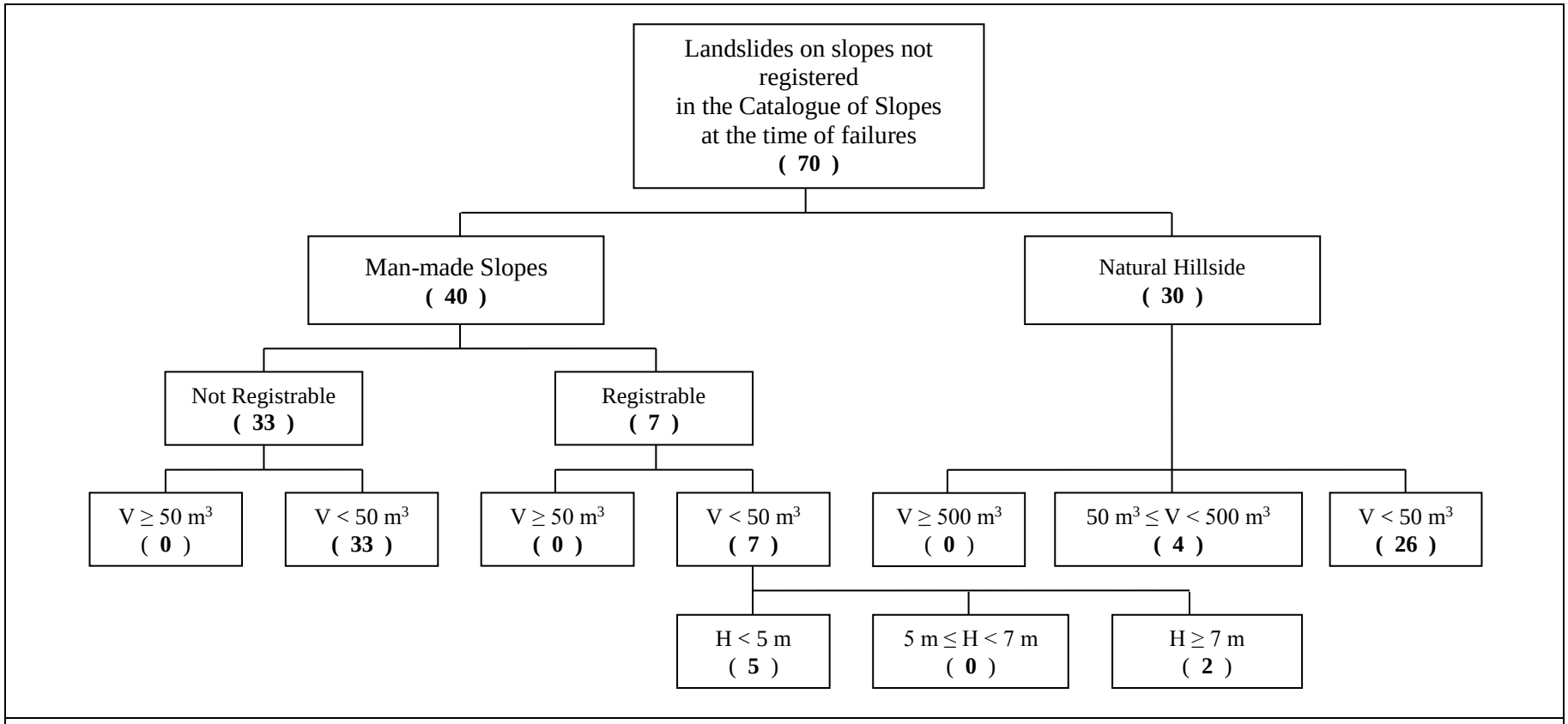
4.3.1 General

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
(40)	Number of landslide incidents = 40

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 2015

(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 161 genuine landslides in 2015, a total of 86 landslides (about 53%) occurred on registered man-made slopes (Table 2.5). Six out of these 86 landslides (about 7%) were major failures, with failure volume ranging from 55 m^3 to 350 m^3, and the remaining 80 landslides were minor failures. Of the 86 landslides on registered man-made slopes, ten landslides (about 12%) occurred on engineered slopes and the remaining 76 landslides occurred on non-engineered slopes. Except for an incident which occurred on an engineered slope with a failure volume of 150 m^3 (see Section 4.3.2), there was no major landslide occurring on consequence-to-life (CTL) Category 1 slope features in 2015. 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	5 (1)	3 (0)	2 (0)	10 (1)
Non-engineered Slopes	19 (0)	12 (0)	45 (5)	76 (5)

Legend:

5 (1) Five landslides, one of which was a major failure

Discussions of the landslides on engineered and non-engineered slopes in 2015 are given in Sections 4.3.2 and 4.3.3 respectively below.

4.3.2 Landslides on Engineered Slopes

Brief descriptions of the ten landslides on engineered slopes in 2015 are given in Appendix B. A breakdown of these landslides in terms of feature type is given in Table 4.2. Among the ten landslides, three involved slopes previously upgraded under the Landslip Preventive Measures Programme (LPMP) (see Table 4.3). None of the landslides in 2015 involved slopes previously upgraded under the Landslip Prevention and Mitigation Programme (LPMitP). There were no retaining walls involved in the failure of engineered slopes in 2015.

One landslide involved a major rock slide of about 150 m^3 in volume that occurred on the lowest batter of a 180 m high soil and rock cut slope in a rehabilitated quarry. The upper half of the landslide scar lies within a shear zone which extended beyond and above the scar. Post-failure investigation revealed that the drainage capacity of the stepped channel was unable to accommodate the surface runoff on the slope at the time of failure, leading to overspillage and ponding at the area above the failure scar. Sections of the berm channels conveying runoff to the stepped channel were also noted to be blocked causing further ponding in the area. Ponding allowed continued infiltration directly into the shear zone exposed on the unpaved berm elevating the water pressures within the highly permeable fractured rock mass and resulting in the failure.

One landslide involved minor rockfalls (volume $\leq$ 8 m^3) from a rock outcrop with the lower portion of the failure scar encroaching into the soil portion of the slope where soil nails were installed. The rockfalls were controlled by adversely orientated joints which formed the upper release plane. The failed rock portion, with no structural support, was subject to severe deterioration, e.g. joints were typically opened up by tree root action. The failure was probably caused by the building up of cleft water pressure along the opened rock joints, and the associated sliding failure at the soil portion was shallow with no soil nails exposed.

Three landslides involved minor washout failures. One was a minor washout failure (volume $\leq$ 3 m^3) on a soil-nailed slope within the soil-nailed zone with scar depth less than 0.5 m and without affecting the soil nails. The remaining two involved minor washout failures on a compacted fill slope and an unsupported cut slope (volume $\leq$ 6 m^3 and $\leq$ 2 m^3 respectively).

The remaining five incidents involved very minor failures on cut slopes. One involved a boulder fall (volume $\leq$ 0.02 m^3) from the bare slope surface near the edge of the boundary of slope. Four involved minor rockfalls (volume $\leq$ 1 m^3) from rock slopes. 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).

4.3.3 Landslides on Non -engineered Slopes

There were 76 failures on non-engineered slopes in 2015, among which five were major and 71 were minor.

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	1	0	1
> 5 m^3 to < 50 m^3	1	0	1	0	0	2
≤ 5 m^3	0	3 (1)	0	4	0	7
Total	1	3 (1)	1	5	0	10

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

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	1	0	0	1
≤ 5 m^3	0	1	0	1	0	2
Total	0	1	1	1	0	3

The five major landslides involved failure volume ranging from 55 m^3 to 350 m^3. All of these landslides occurred on roadside slopes or catchwater slope of CTL Category 3, of which two cases resulted in temporary closure of road/access road and three cases did not have any consequence. Details of the major landslide that resulted in temporary closure of road were documented in Wai et al (2016).

Of the 71 minor landslides, 51 of them were relatively small in scale with a failure volume of less than 5 m^3. One incident involved a minor rockfall (volume $\leq$ 0.05 m^3) from a bare rock cut slope with a fallen rock block punching through the window of a tour bus travelling along the road and resulted in four persons injured by the broken glass fragments. Details of this incident were documented in Wai et al (2016). In addition, five incidents resulted in temporary closure of roads and one resulted in temporary closure of pedestrian pavement. The rest did not have any notable consequence.

4.3.4 Landslides Occurring in the Vicinity of Registered Squatter Structures

Eighteen landslides occurred on slopes located in the vicinity of registered squatter structures, of which nine occurred on registered slopes, eight on unregistrable man-made slopes and one on natural hillside. All these landslides were minor, with failure volume ranging from 0.1 m^3 to 10 m^3. Those man-made slopes involved in the landslides were all non-engineered.

In two of the 18 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 16 landslides. In these cases, three involved Category 2 Non-development Clearance[1] (NDC) recommendation previously made on the affected squatter structures, one involved the issuance of Category 2 NDC recommendation on the affected squatter structure following the 2015 incident and one involved the issuance of Category 1 NDC[2] recommendation on the affected squatter structures (with Category 2 NDC recommendation previously served) following the 2015 incident. No NDC recommendations were made for the remaining 11 cases because the affected squatter structure is on a private lot / licensed land or the failure was of very small scale (volume $\leq$ 1.5 m^3) without causing any damage to the affected squatter structure or the slope affecting the squatter structure had been included into the LPMitP.

For the 18 landslides on slopes located in the vicinity of registered squatter structures, NDC inspections were previously conducted by the GEO on the villages concerned, except four cases with the affected squatter structures lying within licensed land. Following the NDC inspections, Category 2 NDC recommendations were made on four of the cases.

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[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 2015 correspond to about 0.141% (number of landslides divided by number of registered man-made slopes), 0.0025% (total surface area of landslides divided by total surface area of registered man-made slopes), and about 1.445×10^{-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 2015 (Table 4.5), the annual failure rates of engineered slopes are lower than that of non-engineered slopes by a factor of about 7 on a slope number basis, and about 12 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 18 times lower than that of non-engineered slopes.

In 2015, three landslides involved slopes treated under the LPMP and none involved slope upgraded under the LPMitP. The annual failure rates of slopes previously treated under the LPMP or LPMitP correspond to 0.059% (number of landslides divided by number of registered man-made slopes treated under the LPMP or LPMitP), 0.0004% (total surface area of landslides divided by total surface area of registered man-made slopes treated under the LPMP or LPMitP), and about 3.657×10^{-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 21, comparable to that of other engineered slopes.

Table 4.4 Annual Failure Rates of Registered Man-made Slopes in 2015

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 2015	Number of Slopes	7	64	71	0	10	10
	Surface Area of Landslides (m^2)	290	891	1181	0	238	238
Slopes Involved in Major Landslides in 2015	Number of Slopes	2	3	5	0	1	1
	Surface Area of Landslides (m^2)	261	329	590	0	160	160
Slopes Involved in Minor Landslides in 2015	Number of Slopes	5	61	66	0	9	9
	Surface Area of Landslides (m^2)	29	562	591	0	78	78
Total Number of Registered Slopes		11,210	18,290	29,500	12,320	15,480	27,800
Total Surface Area of Registered Slopes (m^2)		6,279,180	9,596,090	15,875,270	13,579,560	26,600,670	40,180,230
Annual Failure Rates (All Landslides)	On Slope Number Basis	0.062%	0.350%	0.241%	0%	0.065%	0.036%
	On Slope Surface Area Basis	0.0046%	0.0093%	0.0074%	0%	0.0009%	0.0006%
	Number of Landslides Divided by Slope Surface Area (no./m^2)	1.115×10^{-6}	6.669×10^{-6}	4.472×10^{-6}	0	3.759×10^{-7}	2.489×10^{-7}
Annual Failure Rates (Major Landslides)	On Slope Number Basis	0.018%	0.016%	0.017%	0%	0.006%	0.004%
	On Slope Surface Area Basis	0.0042%	0.0034%	0.0037%	0%	0.0006%	0.0004%
	Number of Landslides Divided by Slope Surface Area (no./m^2)	3.185×10^{-7}	3.126×10^{-7}	3.150×10^{-7}	0	3.759×10^{-8}	2.489×10^{-8}

Note: Landslides on registered disturbed terrain features and five 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	0.141%	0.0025%	1.445×10^{-6}
	Major Landslides	0.010%	0.0013%	1.070×10^{-8}
	Minor Landslides	0.131%	0.0012%	1.338×10^{-6}
Engineered Slopes	All Landslides	0.036% (0.059%)	0.0006% (0.0004%)	2.489×10^{-7} (3.657×10^{-7})
	Major Landslides	0.004% (0)	0.0004% (0)	2.488×10^{-8} (0)
	Minor Landslides	0.032% (0.059%)	0.0002% (0.0004%)	2.240×10^{-7} (3.657×10^{-7})
Non-engineered Slopes	All Landslides	0.241% [6.7/4.1]	0.0074% [12.6/20.5]	4.472×10^{-6} [18/12.2]
	Major Landslides	0.017%	0.0037%	3.150×10^{-7}
	Minor Landslides	0.224%	0.0037%	4.157×10^{-6}

Legend:

0.036% Annual failure rate of engineered slopes (considering all landslides) is (0.059%)0.035% and that for slopes previously treated under the LPMP or LPMitP is 0.059%

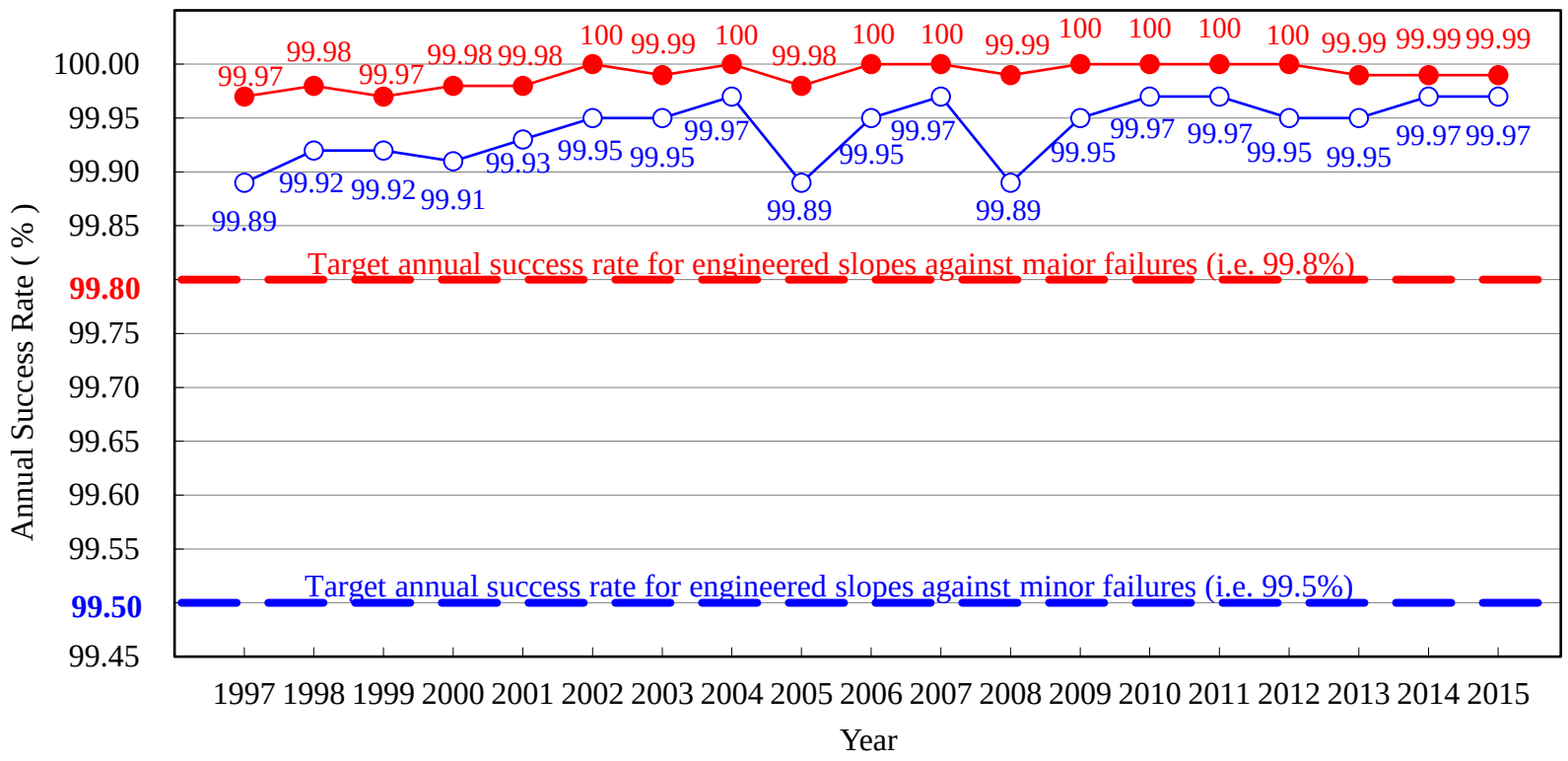
0.241% Annual failure rate of non-engineered slopes (considering all landslides) is [6.7/4.1]0.241%, which is about 6.7 times and 4.1 times higher than those of engineered slopes and slopes previously treated under the LPMP or LPMitP respectively

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 2015, 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 2015 is shown in Table 4.6 and Figure 4.2.

Table 4.6 Annual Success Rates of Engineered Slopes from 1997 to 2015

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%

Note: See Figure 4.2 for a plot of annual success rates of engineered slopes against the target annual success rates from 1997 to 2015.



Legend:

- Annual success rate for engineered slopes against major failures
- Annual success rate for engineered slopes against minor failures
- Target annual success rate for engineered slopes against major failures (i.e. 99.8%)
- Target annual success rate for engineered slopes against minor failures (i.e. 99.5%)

Figure 4.2 Annual Success Rates of Engineered Slopes from 1997 to 2015

4.4 Natural Terrain Landslides

A total of 30 natural terrain landslides were reported in 2015, among which 26 failures were minor and four were major. All of the four major incidents did not result in any significant consequence. The two incidents with the largest failure volume of 100 m^3 involved open hillside failures. The one occurring at Hei Ling Chau (Incident No. 2015/07/1719) affected a district open space. The other one occurring above MacLehose Trail Section 2 in Chek Keng, Sai Kung (Incident No. 2015/08/1731) did not affect any facility.

The 26 minor incidents involved mainly open hillside failures (up to about 45 m^3), boulder/rock falls (mostly less than 1 m^3 and up to 3 m^3) originating from natural hillside and some washout failures (up to about 27 m^3). Two of these incidents resulted in temporary closure of roads and one resulted in partially blockage of a restricted road within country park.

None of these 30 reported natural terrain landslides was located within existing Historical Landslide Catchments (HLC). Nevertheless, nine failures were located within 50 m from the existing HLCs, none of which with debris trails close to any important downslope facilities. All the nine cases were minor failures.

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

All the 86 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 20 landslides, one of which was major failure. These contributed to about 23% (i.e. 20 out of 86) of the landslides on registered man-made slopes. Amongst these 20 landslides, five occurred on engineered slopes.

Of these 20 landslides involving inadequate slope maintenance, 11 affected government slopes and four affected private slopes. The remaining five incidents affected slope features of mixed government/private maintenance responsibility, where one occurred on the government portion and the other four 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 given inadequate maintenance.

5 Conclusions

Overall, 99.96% of the engineered man-made slopes performed satisfactorily without occurrence of landslides in 2015. There was one major rockslide on an engineered slope in 2015.

The annual failure rates of major and minor landslides on engineered slopes, on a slope number basis, are 0.004% and 0.032% respectively in 2015. 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

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Appendix A

List of 2015 Landslide Incidents Involving Unregistered Man-made Slopes but Registrable at the Time of Failure

Table A1 List of 2015 Landslide Incidents Involving Unregistered Man-made Slopes but Registrable at the Time of Failure (Sheet 1 of 2)

Incident No.	Location	Maximum Slope Height(1)	Reported		Failure			Facility Affected	Consequence
			Date	By	Date (Time)	Feature Type	Scale (m^3)		
2015/01/1653	Behind House No. 18 Cho Ma Wu, Nam Hang, Tai Po	4 m	9/1	Public	Unknown	Soil cut	0.26	Registered squatter dwelling	-
2015/05/1680	Pat Tsz Wo Village, Fo Tan	10 m	22/5	DO	Unknown	Soil cut	3	Open area	-
2015/05/1690	East of D.D. 225 Lot 621 S.B, access road linking Ha Yeung Village and Sheung Sze Wan, Sai Kung	4 m	28/5	DO	27/5	Soil cut	25	Access road	-
2015/08/1733	Below 350 Pai Tau Village next to Feature No. 7SW-D/CR157, Shatin	9 m	15/8	Police	Unknown	Disturbed terrain	6	Registered squatter dwelling and minor footpath	Category 1 NDC Recommendation on a squatter structure made to LandsD
2015/08/1747	50 m east of Feature No. 15NE-A/R342, Tai Tam Tuk Reservoir	3.5 m	17/8	WSD	12/8 (16:00)	Soil cut	1	Road verge	-

Table A1 List of 2015 Landslide Incidents Involving Unregistered Man-made Slopes but Registrable at the Time of Failure (Sheet 2 of 2)

Incident No.	Location	Maximum Slope Height(1)	Reported		Failure			Facility Affected	Consequence
			Date	By	Date (Time)	Feature Type	Scale (m^3)		
2015/09/1763	North of Feature No. 6NW-C/R22, San Hing Tsuen, Tuen Mun	6 m	24/9	LandsD	Unknown	Soil cut	1.4	Storage house	-
2015/08/1022 AF (AFCD/2015/ 08/0001)	Beside Feature No. 7SW-C/C1025, Kam Shan Country Park, Shatin	3 m	19/8	AFCD	Unknown	Soil cut	4	Access road	-

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. Slopes Upgraded Under the LPMP (∑ = 3 nos.)					
2015/07/1709	13NE-B/C165	South Lantau Road, Lantau	8	Soil/rock cut	The slope was upgraded under the LPMP in 2003. The upgrading works comprised the installation of soil nails and raking drains, typical rock slope treatment works and provision of vegetation cover with erosion control mat and wire mesh. The failure primarily involved rockfall from a rock outcrop with the lower part of the landslide scar encroaching into the soil portion where soil nails were installed. The failed rock portion, with no structural support, was subjected to severe deterioration (e.g. typically opened up by tree root action). A number of unplanned trees and extensive vegetation were growing on the rock outcrop. The failure was probably caused by the building up of cleft water pressure along the opened rock joints. The associated sliding failure at the soil portion was shallow with no soil nails exposed.

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
2015/07/1712	11SE-C/C54	Tai Hang Road	0.02 (Boulder fall)	Soil cut	The slope was upgraded under the LPMP in 2001. The upgrading works comprised the installation of soil nails and raking drains, typical rock slope treatment works, and provision of vegetation cover with erosion control mat and shotcrete cover. The fallen boulder was originated from the bare slope surface near the edge of the southern slope boundary.
2015/10/1777	11NE-D/C520	Po Lam Road North, Sai Kung	0.1 (Rockfall)	Rock cut	The slope was previously registered as No. 12NW-C/C75. The slope was upgraded under the LPMP in 2005. The upgrading works comprised the installation of soil nails and raking drains, typical rock slope treatment works, and provision of vegetation cover with erosion control mat and shotcrete cover. The incident primarily involved rockfall with the detachment of minor rock blocks from a bare rock cut face.
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.					

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
4. <u>Slopes Assessed by Government Departments and Checked by GEO with No Upgrading Works Required</u> (∑ = 0 no.) Nil.					
5. Slopes Assessed by Private Owners and Checked by GEO with No Upgrading Works Required (∑ = 0 no.) Nil.					
6. <u>Slopes Formed or Upgraded by Government Departments and Checked by GEO</u> (∑ = 4 nos.)					
2015/02/1658	11NE-D/C141	Opposite of Serenity Place, To Lok Road, Tsueng Kwan O	0.3 (Rockfall)	Rock cut	The slope was formed in the early 1980s under the Junk Bay Development. The incident primarily involved rockfall with the detachment of minor rock blocks from a bare rock cut face.
2015/08/1727	2SE-B/C258	Along access road to Kwu Tung Fresh Water Service Reservoir, Sheung Shui	2.6	Soil cut	The slope supported with soil nails was formed by the WSD in 1996. It is a washout failure on a vegetated slope surface with scar depth less than 0.5 m. Although the failure occurred within the soil-nail zone with recessed soil nail head, no soil nail head was exposed on the scar. The crest surface channel and catchpit were observed to be blocked, which may have resulted in surface water overflow on to the slope and contributed to the failure.

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
2015/08/1744	7SE-A/C506	Adjacent to Ex-Turret Hill Quarry, North of Tai Shek Kwu, Shatin	150	Rock cut	The slope was formed in connection with a quarry excavation from 1964 to 1984. Rock slope treatment works including removal of loose rock blocks and provision of wire mesh netting were implemented between 1989 and 1994 under a quarry rehabilitation project. The design and the stability assessment was checked and accepted by the GEO in 1994. The rock slide occurred on the lowest batter of a 180 m high soil and rock cut slope in the rehabilitated quarry. The upper half of the landslide scar lies within a shear zone which extended beyond and above the scar. Post-failure investigation revealed that the drainage capacity of the stepped channel was unable to accommodate the surface runoff on the slope at the time of failure, leading to overspillage and ponding at the area above the failure scar. Sections of the berm channels conveying runoff to the stepped channel were also noted to be blocked causing further ponding in the area. Ponding allowed continued infiltration directly into the shear zone exposed on the unpaved berm elevating the water pressures within the highly permeable fractured rock mass and resulting in the failure.

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
2015/08/1023HY (HyD/NTE/2015 /08/0021)	7NE-D/F153	Ma On Shan Bypass near Lamp Post No. BE1431, Ma On Shan, Shatin	6	Soil cut	The slope was formed between 2001 and 2004 in association with the construction of Trunk Road T7 with the design checked and accepted by the GEO. The incident involved a minor washout failure on a compacted fill slope. Post-landslide investigation revealed that the drainage capacity of the crest surface channel was unable to accommodate the surface runoff at the time of failure, leading to water overflow onto the slope and causing the failure.
7. <u>Slopes Upgraded By Private Owner and Checked by GEO</u> ($\sum$ = 2 nos.)					
2015/09/1755	7SE-A/C107	Nos. 21-29 Sui Wo Road, Sha Tin Sui Wo Road, Shatin	0.1 (Rockfall)	Rock cut	Slope No. 7SE-A/C107 with mixed government/private maintenance responsibility was formed before 1977 under a public development project covering the construction of Sui Wo Road. The slope was further modified under a private development at the crest platform in 1981 and the relevant design submission was checked and accepted by the GEO. The rockfall involved the detachment of minor rock blocks from the bare rock cut within the private portion of the slope.

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
2015/08/1736	8NW-C/C54	No. 50 Kei Ling Ha Lo Wa, Sai Sha Road, Sai Kung	2	Soil cut	The failure occurred at the private portion of the slope which was formed in association with the development of a private lot at slope toe in the late 1980s and the design was checked and accepted by the GEO. The crest surface channel was observed to be blocked, resulting in surface water overflow onto the slope and causing the failure.
8. Slopes Upgraded Following Service of DH Orders and Checked by GEO (∑ = 1 no.)					
2015/04/1662	11NW-A/C120	Behind Chung Shan Terrace No.23 Castle Peak Road, Kwai Chung	1 (Rockfall)	Rock cut	This is a rockfall failure that occurred on a rock cut slope. The failed rock slope portion was served with a Dangerous Hillside Order in 1991. The Dangerous Hillside Order was discharged in 1992 after the completion of typical rock slope stabilization works including rock scaling, dentition, rock bolts and concrete buttress. The rockfall involved the detachment of a rock block from the bare rock surface, causing local damage to a corrugated roof cladding over the alleyway.
9. Slopes Assessed as Not Requiring Upgrading Works But with Outstanding GEO Comments (∑ = 0 no.)					
Nil.					

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
10. <u>Slopes Assessed as Requiring Upgrading Works But with Outstanding GEO Comments</u> (∑ = 0 no.)					
Nil.					

Legend:

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

Landslide involved unsupported cut (∑ = 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.

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