Review of Landslides in 2017

GEO Report No. 346

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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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.

Raymond WM Cheung
Head, Geotechnical Engineering Office
March 2022

Foreword

This report presents the findings of a detailed diagnosis of landslides in 2017 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 C.M. Leung, Mr D.P.Y. Lee 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 2017 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, 152 genuine landslides in 2017 were reported to the Government. There were eight 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 0.032% on a slope number basis (i.e. number of landslides relative to the total number of engineered slopes).

Overall, 99.97% of the engineered man-made slopes performed satisfactorily without occurrence of landslides in 2017.

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1 Introduction

This report presents the findings of a diagnostic review of the landslides in 2017 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 2017. 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 2017

The factual information, together with the relevant statistics on rainfall and reported landslides in 2017, was documented by Wai et al (2018).

In 2017, the annual rainfall recorded at the Principal Raingauge of the Hong Kong Observatory (HKO) in Tsim Sha Tsui was 2572.1 mm, a surplus of seven percent comparing to the mean rainfall of 2398.5 mm between 1981 and 2010. Four Landslip Warnings were issued on 24 May, 13 June, 17 July and 27 August 2017. One Black Rainstorm Warning was issued on 24 May 2017. Five Red Rainstorm Warnings and 24 Amber Rainstorm Warnings were issued between 24 May and 3 August 2017, and between 21 April and 17 October 2017 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 188 reported incidents in 2017, 152 were genuine landslides, discounting the non-landslide incidents (e.g. tree falls and flooding). There were eight major failures, corresponding to about 5.2 % 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		12 (0)	7.9
Cut Slopes	Soil	57 (2)	37.5
	Soil/Rock	13 (2)	8.5
	Rock	10 (2)	6.6
Retaining Walls		12 (0)	7.9
Natural Hillside		45 (2)	29.6
Registered Disturbed Terrain		3 (0)	2.0
Total		152 (8)	100

Legend:

13 (2) Thirteen 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)	3 (0)	0	2 (0)	5 (0)
Registered Squatter Dwellings	0	1 (1)	9 (0)	10 (1)
Roads	19 (1)	1 (0)	14 (1)	34 (2)
Transportation Facilities (e.g. railways, tramways, etc.)	0	0	0	0
Pedestrian Pavements/Footways	6 (0)	2 (0)	3 (0)	11 (0)
Minor Footpaths/Access Paths/ Access Roads	10 (1)	4 (1)	34 (0)	48 (2)
Construction Sites	2 (0)	0	1 (0)	3 (0)
Open Areas	4 (0)	2 (0)	13 (1)	19 (1)
Catchwaters	4 (0)	0	2 (1)	6 (1)
Others (e.g. carparks, parks, playgrounds, gardens, backyards, etc.)	1 (0)	0	6 (1)	7 (1)
Nil	4 (0)	2 (0)	4 (0)	10 (0)
Total	53 (2)	12 (2)	88 (4)	153 (8)

Legend:

53 (2) Fifty-three landslides of which two 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	1 (1)	0	3	1	1	0	0
	Soil/Rock	0	5 (5)[3]	0	1	0	0	0	0
	Rock	0	0	0	0	1	0	0	0
Retaining Walls		0	1 (2)	0	0	0	1	0	1
Natural Hillside		0	0	0	0	0	4	0	0
Registered Disturbed Terrain		0	0	0	0	0	0	0	0
Total		0	7 (8)	0	5	2	6	0	1

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) Temporary evacuation of five squatter dwellings was resulted from a single incident No. 2017/06/2052. Details of the incident were documented in Wai et al (2018).

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

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)	(≥ 500 m^3)	
Registered Man-made Slopes	66	5	1	72
Registered Disturbed Terrain	3	0	0	3
Unregistrable Man-made Slopes	25	0	0	25
Registrable Man-made Slopes Not Yet Registered at Time of Failure	7	0	0	7
Natural Hillside	43	2	0	45
Total	144	7	1	152

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 2017 is presented in Figure 3.1.

In 2017, four Landslip Warnings were issued on 24 May, 13 June, 17 July and 27 August 2017 and the corresponding LPI was assessed to be ranging from 1 to 2. In terms of the potential to cause landslides, the rainstorm of 17 July 2017 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 2017 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,

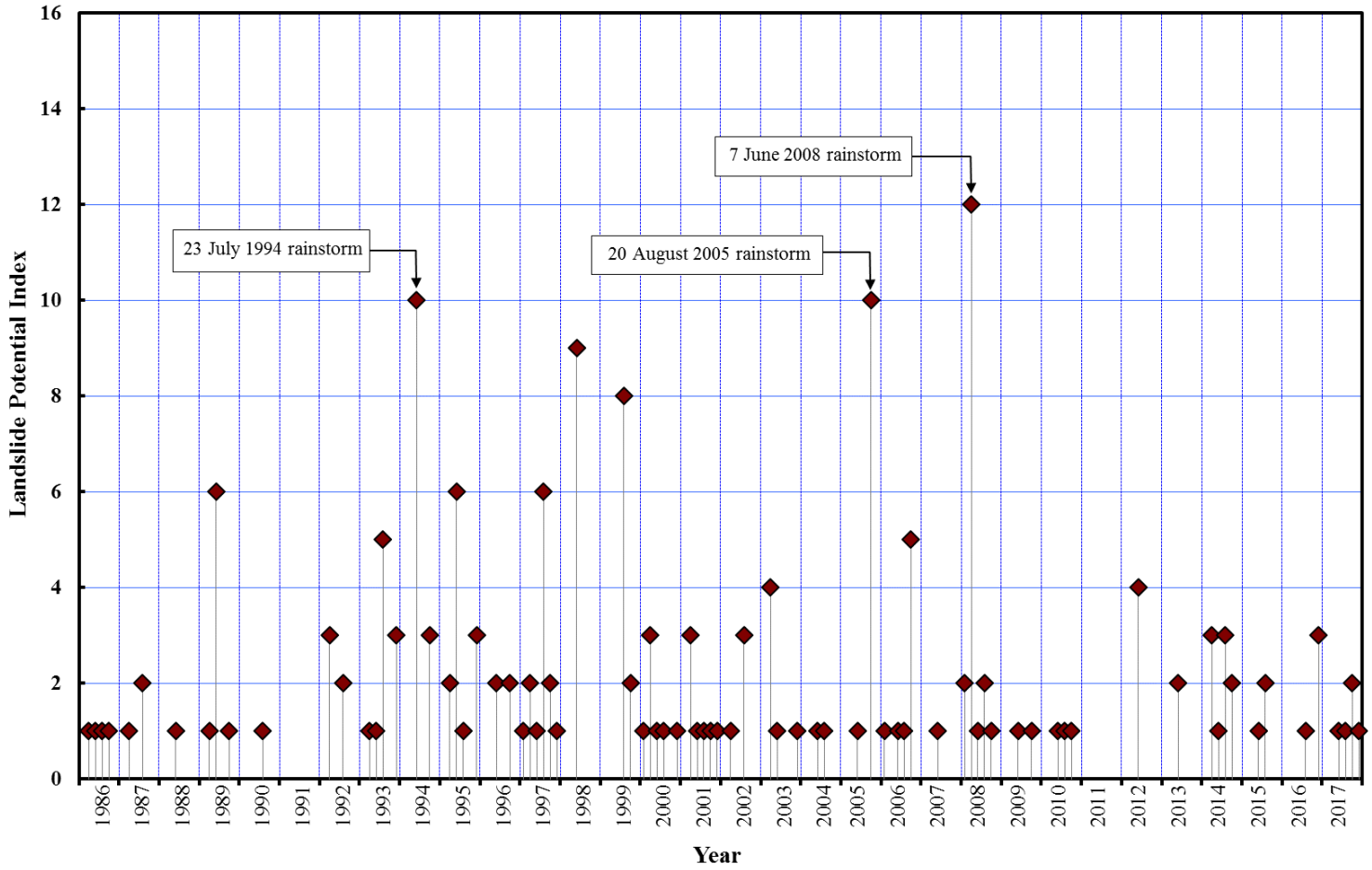
(c) observations from natural terrain landslides, and

(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 1986 to 2017

4.2.2 Diagnosis

Of the 152 genuine landslides, 75 occurred on registered slope features (comprising 72 on registered man-made slopes and three on registered disturbed terrain features) and 77 occurred on slopes not registered in the Catalogue of Slopes (Table 2.5).

Among the above 77 landslides, 45 occurred on natural hillside, 25 occurred on small man-made slope features that do not meet the slope registration criteria (GEO, 2004). The remaining seven landslides, corresponding to 4.6% of the total number of genuine landslides in 2017, 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 77 landslides is given in Figure 4.1.

The seven landslides involving registrable slopes were all minor failures with failure volume of 8 m^3 or less (refer to Appendix A for details). Amongst these seven minor failures, one resulted in temporary closure of minor footpath. 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 25 landslides involving unregistrable man-made slope features were all minor failures with failure volume less than 17 m^3. One incident resulted in minor injury of a villager due to fallen bricks and temporary evacuation of a squatter swelling. Another incident led to temporary closure of one lane of Bride's Pool Road.

4.3 Performance of Registered Man-made Slopes

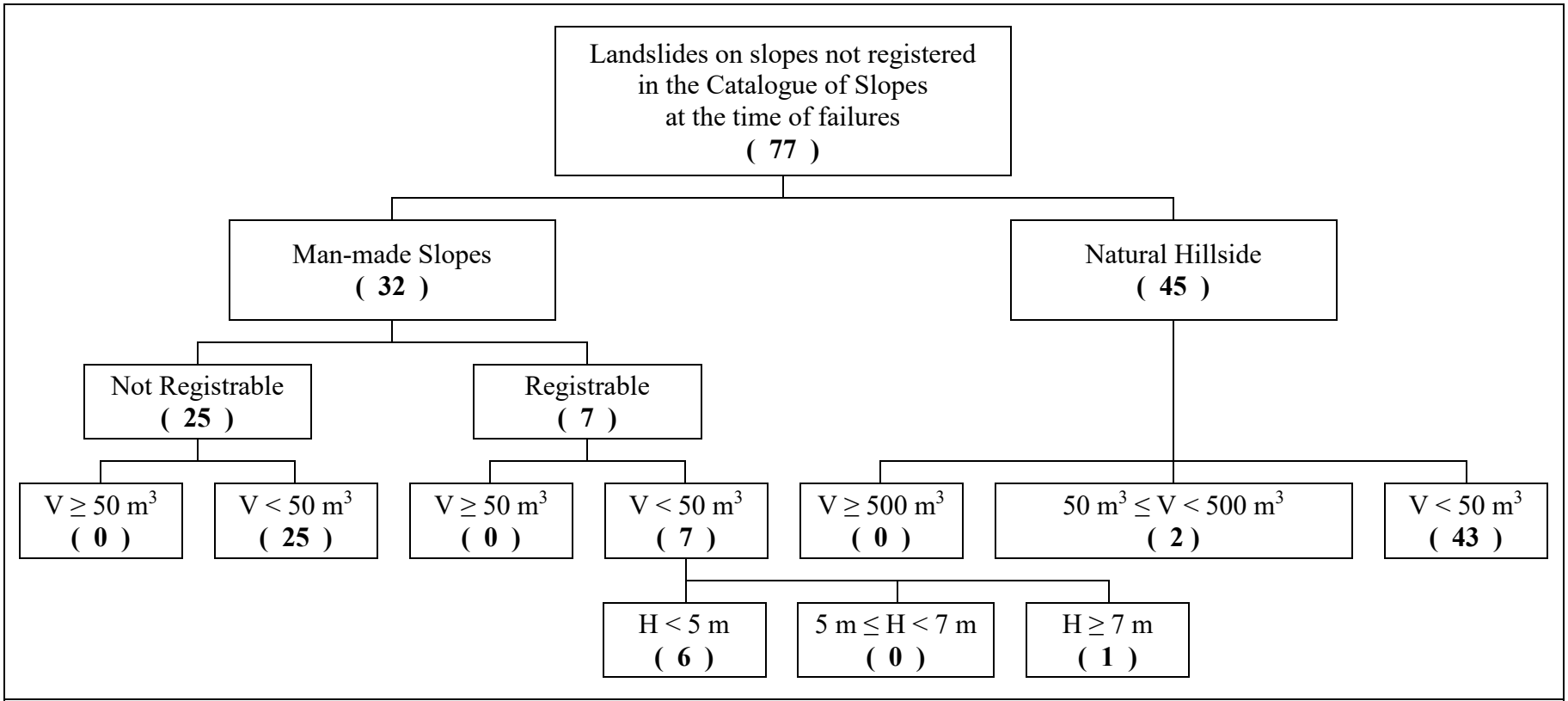
4.3.1 General

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
(32)	Number of landslide incidents = 32

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 2017

(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 152 genuine landslides in 2017, a total of 72 landslides (about 47%) occurred on registered man-made slopes (Table 2.5). Six out of these 72 landslides (about 8%) were major failures, of which five with failure volume ranging from 50 m^3 to 130 m^3 and one with failure volume of 1300 m^3, and the remaining 66 landslides were minor failures. Of the 72 landslides on registered man-made slopes, ten landslides (about 14%) occurred on engineered slopes and the remaining 62 landslides occurred on non-engineered slopes. Except for an incident 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 2017. A breakdown of the CTL categories of the registered man-made slopes involved in the 2017 landslides is given in Table 4.1.

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

Types of Slopes	No. of Landslides			Total
	CTL Cat.1	CTL Cat.2	CTL Cat.3	
Engineered Slopes	4 (0)	3 (1)	3 (0)	10 (1)
Non-engineered Slopes	14 (1)	6 (1)	42 (3)	62 (5)

Legend:

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

Discussions of the landslides on engineered and non-engineered slopes in 2017 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 2017 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, four involved slopes previously upgraded under the Landslip Preventive Measures Programme (LPMP) (see Table 4.3). None of the landslides in 2017 involved slope previously upgraded under the Landslip Prevention and Mitigation Programme (LPMitP). There were no retaining walls involved in the failure of engineered slopes in 2017.

One landslide involved a sizeable rock slope failure (volume of about 1,300 m^3). It was a translational rockslide characterized by three sets of adversely-orientated joints. The failure was likely caused by the development of cleft water pressure in the jointed rock mass attributable to the ingress of surface water into the rock joints and subsurface flow. The crown and west flank of the scar were delineated by dense vegetation which have been exhibiting substantial growth over the past decade. The penetration of roots to considerable depth into the joint apertures, as evidenced on the scar, could have progressively wedged open the rock joints resulting in enhanced water ingress and deterioration of the slope. Subsurface flow was also evidenced and some of which was observed through the lenses of highly fractured and completely decomposed granite within the scar. Moreover, the additional surface runoff due to the blockage of upslope channels might have some contribution to the rockslide. Other factual information pertaining to the case was documented in Wai et al (2018).

One landslide involved a failure (volume of about 3 m^3) on a 55° inclined soil-nailed cut slope within the soil-nailed zone with scar depth of about 0.5 m and without affecting the soil nails. The local shallow detachment was probably due to infiltration primarily through the vegetated area at the slope crest. The debris was fully retained by the wire mesh installed on the slope surface and no soil nail heads were exposed on the scar.

Five landslides involved minor washout failures. Four occurred on unsupported cut slopes (volume $\leq$ 8 m^3) and the other one occurred on a fill slope with the failure location covered by a thin layer of compacted rockfill (volume of about 16 m^3).

The remaining three landslides involved minor rockfalls (volume $\leq$ 3 m^3). One involved detachment of rock blocks from the slope face covered with deteriorated chunam. The other two involved detachment from rock cut faces covered with rock mesh, one of which with debris fully retained by the rock mesh (Incident No. 2017/07/2085) where this incident was 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. 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	1	0	1
50 m^3 to 500 m^3	0	0	0	0	0	0
> 5 m^3 to < 50 m^3	1	1	0	0	0	2
≤ 5 m^3	0	3 (1)	2	2	0	7
Total	1	4 (1)	2	3	0	10

Legend:

4 (1) Of the four 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	1	0	0	0	0	1
≤ 5 m^3	0	1	1	1	0	3
Total	1	1	1	1	0	4

4.3.3 Landslides on Non-engineered Slopes

There were 62 landslides on non-engineered slopes in 2017, among which five were major and 57 were minor.

The five major landslides involved failure volume ranging from 50 m^3 to 130 m^3. The incidents on a CTL Category 1 slope at Sam Ka Tsuen and a CTL Category 2 at Tai Tam Road resulted in temporary evacuation of squatter dwellings and temporary road closure respectively (Wai et al, 2018). The slopes were being scheduled for LPMit action at the time of failure. Another three incidents occurred on CTL Category 2 or 3 slopes that resulted in blockage of

catchwater and temporary closure of a carpark or road.

Of the 57 minor landslides, 36 of them were relatively small in scale with a failure volume of less than 5 m^3. Two incidents resulted in temporary closure of roads, one resulted in temporary closure of pedestrian pavement, one resulted in temporary closure of access road, one resulted in damage of a temporary storage structure and one resulted in temporary evacuation of a squatter dwelling at Kau Wah Keng San Tsuen. The rest did not have any notable consequence.

There was a minor rockfall incident, where the fallen rock was retained by the rock mesh on the slope (Incident No. 2017/07/2064). This incident was 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 nine occurred on registered slopes, six on unregistrable man-made slopes, and one on natural hillside. Of these sixteen landslides, one was major with failure volume of 90 m^3, and the remaining landslides were all minor, with failure volume ranging from 0.05 m^3 to 40 m^3. Those man-made slopes involved in the landslides were all non-engineered.

In six 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 ten landslides. In these cases, four involved Category 2 Non-development Clearance[1] (NDC) recommendation previously made on the affected squatter structures. No NDC recommendations were made for the remaining six cases following the 2017 incidents either because the affected squatter structure is on a private lot/licensed land or the failure was of very small scale (volume $\leq$ 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 recommendations were made on five 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 2017 correspond to about 0.122% (number of landslides divided by number of registered man-made slopes), 0.0026% (total surface area of landslides divided by total surface area of registered man-made slopes), and about 1.249×10^{-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 2017 (Table 4.5), the annual failure rates of engineered slopes are lower than that of non-engineered slopes by a factor of about 6.7 on a slope number basis, and about 8.6 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 17.8 times lower than that of non-engineered slopes.

In 2017, four 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 0.076% (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 4.716×10^{-7} (number of landslides divided by total surface area of registered man-made slopes treated under the LPMP or LPMitP in m^2) respectively, as summarised in Table 4.5. The annual failure rate of slopes previously treated under the LPMP or LPMitP is lower than that of non-engineered slopes by a factor ranging from about 3 to 16, 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 2017, 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 2017 is shown in Table 4.6 and Figure 4.2.

Table 4.4 Annual Failure Rates of Registered Man-made Slopes in 2017

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 2017	Number of Slopes	8	53	61	1	8	9
	Surface Area of Landslides (m^2)	196	900	1096	13	323	336
Slopes Involved in Major Landslides in 2017	Number of Slopes	0	5	5	0	1	1
	Surface Area of Landslides (m^2)	0	394	394	0	251	251
Slopes Involved in Minor Landslides in 2017	Number of Slopes	8	48	56	1	7	8
	Surface Area of Landslides (m^2)	196	506	702	13	72	85
Total Number of Registered Slopes		11,060	17,790	28,850	12,510	15,940	28,450
Total Surface Area of Registered Slopes (m^2)		6,141,150	9,290,160	15,431,310	13,748,930	26,875,260	40,624,190
Annual Failure Rates (All Landslides)	On Slope Number Basis	0.072%	0.298%	0.211%	0.008%	0.05%	0.032%
	On Slope Surface Area Basis	0.0032%	0.0097%	0.0071%	0.0001%	0.0012%	0.0008%
	Number of Landslides Divided by Slope Surface Area (no./m^2)	1.303×10^{-6}	5.705×10^{-6}	3.953×10^{-6}	7.273×10^{-8}	2.977×10^{-7}	2.215×10^{-7}
Annual Failure Rates (Major Landslides)	On Slope Number Basis	0%	0.028%	0.017%	0%	0.006%	0.004%
	On Slope Surface Area Basis	0%	0.0042%	0.0026%	0%	0.0009%	0.0006%
	Number of Landslides Divided by Slope Surface Area (no./m^2)	0	5.382×10^{-7}	3.24×10^{-7}	0	3.721×10^{-8}	2.462×10^{-8}

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	0.122%	0.0026%	1.249×10^{-6}
	Major Landslides	0.01%	0.0012%	1.07×10^{-7}
	Minor Landslides	0.112%	0.0014%	1.14×10^{-6}
Engineered Slopes	All Landslides	0.032% (0.076%)	0.0008% (0.0004%)	2.215×10^{-7} (4.716×10^{-7})
	Major Landslides	0.004% (0%)	0.0006% (0%)	2.462×10^{-8} (0)
	Minor Landslides	0.028% (0.076%)	0.0002% (0.0004%)	1.969×10^{-7} (4.716×10^{-7})
Non-engineered Slopes	All Landslides	0.211% [6.7/2.8]	0.0071% [8.6/16.3]	3.953×10^{-6} [17.8/8.4]
	Major Landslides	0.017%	0.0026%	3.24×10^{-7}
	Minor Landslides	0.194%	0.0045%	3.629×10^{-6}

Legend:

0.032% (0.076%)	Annual failure rate of engineered slopes (considering all landslides) is 0.032% and that for slopes previously treated under the LPMP or LPMitP is 0.076%.
0.211% [6.7/2.8]	Annual failure rate of non-engineered slopes (considering all landslides) is 0.211%, which is about 6.7 times and 2.8 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 2017

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%
2017	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 2017.

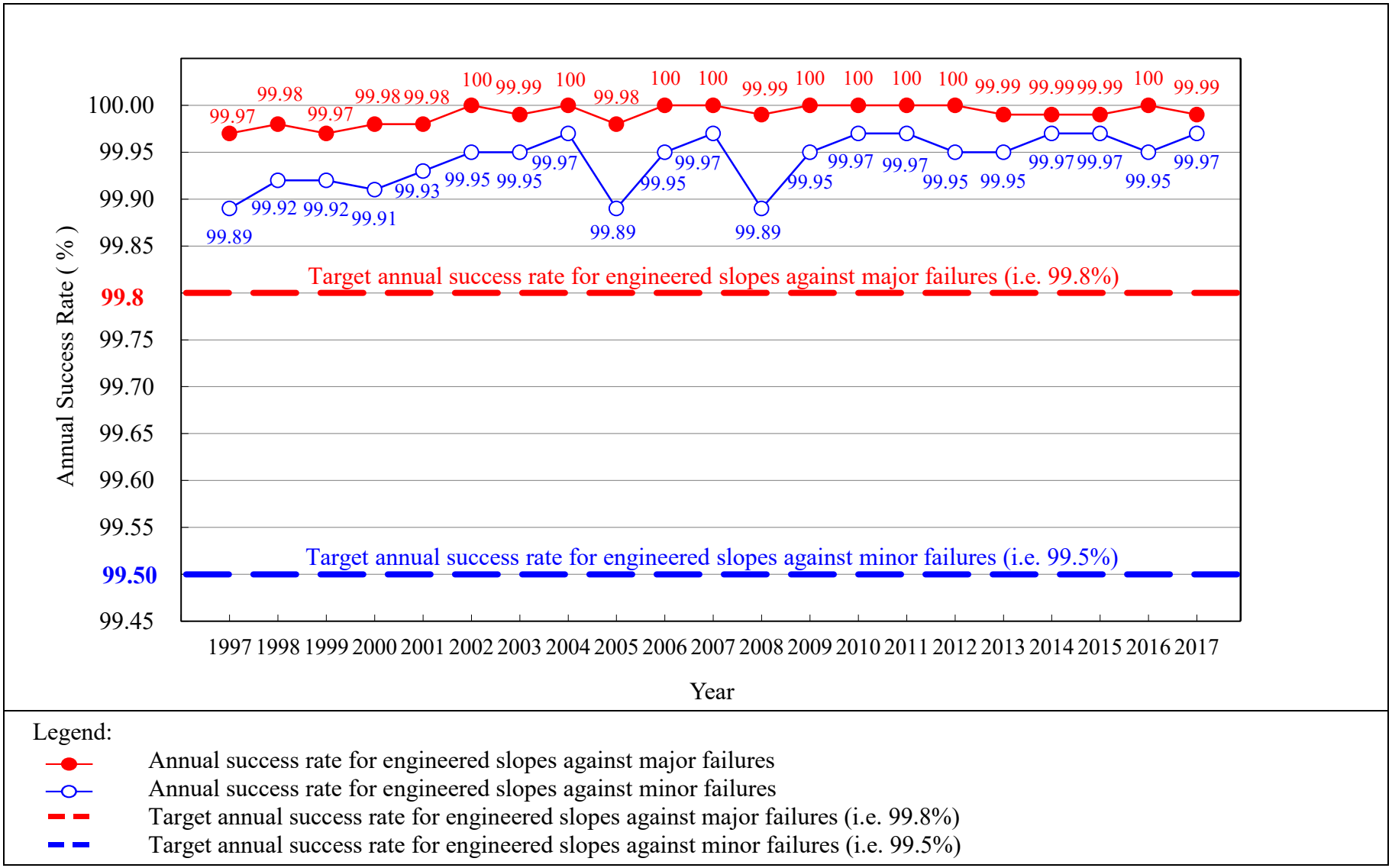


Figure 4.2 Annual Success Rates of Engineered Slopes from 1997 to 2017

4.4 Natural Terrain Landslides

A total of 45 natural terrain landslides were reported in 2017, among which 43 failures were minor and two were major. The two major incidents did not result in any significant consequence. The incident with the largest failure volume of about 55 m^3 involved a washout failure above the University of Hong Kong (Incident No. 2017/04/2003) where the landslide debris came to rest within the hillside resulting in temporary closure of the hiking trail.

The 43 minor incidents involved mainly open hillside failures (up to about 42 m^3), boulder/rock falls (less than 5 m^3) originating from natural hillside and some washout failures (up to about 25 m^3). Three of these incidents resulted in temporary closure of minor footpath/access road/hiking trail.

Among these 45 reported natural terrain landslides, ten failures (comprising seven landslides 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). Seven other failures were located within 50 m from the existing HLC, none of which with debris trails close to any important downslope facilities. These 17 cases were all minor failures, except one case located within an existing HLC being a major failure which did not result in any significant consequence.

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

All the 72 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 16 landslides, one of which was a major failure. These contributed to about 22% (i.e. 16 out of 72) of the landslides on registered man-made slopes. Amongst these 16 landslides, seven occurred on engineered slopes.

Of these 16 landslides involving inadequate slope maintenance, ten affected government slopes and three affected private slope. The remaining three incidents affected slope features of mixed government/private maintenance responsibility, where one occurred on the government portion and the other two 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

Improvement initiative proposed by Wai et al (2017) following a review of landslides in 2016 and the associated progress of the follow-up actions are summarised in Appendix C.

6 Conclusions

Overall, 99.97% of the engineered man-made slopes performed satisfactorily without occurrence of landslides in 2017. There was one major rockslide on an engineered slope in 2017.

The annual failure rate of major and minor landslides on engineered slopes, on a slope number basis, are 0.004% and 0.028% respectively in 2017. 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.

7 References

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Appendix A

List of 2017 Landslide Incidents Involving Unregistered Man-made Slopes but Registrable at the Time of Failure

Content

List of Table

Table A1 List of 2017 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)		
2017/02/2002	Behind Housed No. 7, Tui Min Hoi, Sai Kung	3.5 m	9/2	DLO	Unknown	Soil cut	3.5	Village house	-
2017/05/2018	No. 24 Man Kung Uk, Sai Kung (near Lamp Post No. VE2354)	3 m	24/5	FSD	24/5 (11:30)	Retaining wall (Masonry)	5	Minor footpath	Minor footpath temporarily closed
2017/06/2025	Near Feature No. 6SW-C/CR149, So Kwun Wat, Tuen Mun	3.2 m	31/5	LandsD	Unknown	Soil cut	3	Open area	-
2017/07/2062	North of DD130 Lot 871 RP, Lo Fu Hang, Lam Tei, Tuen Mun	4 m	3/7	Public	Unknown	Retaining wall (Masonry)	3	Open area	-
2017/07/2086	Hang Hau Wing Lung Road, Sai Kung	4.5 m	20/7	LandsD	Unknown	Soil cut	8	Road	-

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

Table A1 List of 2017 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)		
2017/10/2133	South of Feature No. 11NW-A/CR28, Butterfly Valley Road, Lai Chi Kok	3.5 m	29/9	CSD	Unknown	Rock cut	0.4	Open area	-
2017/12/2142	Between Feature Nos. 11SW-D/R141 and 11SW-D/C737, Stubbs Road	8 m	19/12	HyD	Unknown	Soil cut	0.1	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

Content

List of Table

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

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope Failure	Remarks
1. Slopes Upgraded Under the LPMP/LPMitP ($\sum$ = 4 nos.)					
2017/05/2016	15NE-B/FR20	Shek O Road	16	Fill	The slope was upgraded under the LPMP in 1999. The failure location, inclined at about 35°, was immediately below the slope crest where the compacted rockfill provided as part of the upgrading works over the existing soil fill had thinned out. The incident involved a washout failure that might be attributed to splashing of ponding water from carriageway low point at crest by passing-by vehicles, over the deteriorated slope surface.
2017/06/2044	15NE-A/C48	Junction of Belleview Drive and Repulse Bay Road	2.6 (Rockfall)	Rock cut	The slope was upgraded under the LPMP in 2010. The incident primarily involved minor rockfall from a highly fractured rock slope surface that was covered with rock mesh. The failure might have been caused by root wedging and spillage from a blocked U-channel above the failure location. Most of the debris was retained by the rock mesh.

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

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope Failure	Remarks
2017/07/2065	11SW-A/CR81	Near No. 80 Robinson Road	1	Soil cut	The slope was upgraded under the LPMP in 1989 and 2013. The incident occurred at the boundary of the unsupported portion of the slope involving washout of a local strip of concrete apron and the sidewall of a down-the-slope U-channel together with the underlying soil. Above the failure location, the abrupt change in channel gradient could have rendered overshooting of the high-velocity channel flow resulting in erosion at the failure location with deteriorated hard cover.
2017/10/2136	11NE-C/CR63	Junction of Hong Ning Road and Chun Wah Road, Kwun Tong	0.3	Soil/ rock cut	The slope was upgraded under the LPMP in 1999. The incident involved a washout failure on the unsupported portion of the slope standing at about 38° where no surface protection measures were provided. The failure might be attributed to erosion of surface materials on a generally bare slope surface.
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 6)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope Failure	Remarks
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 ($\sum$ = 3 nos.)				
2017/06/2060	11NW-B/CR109	Lung Ping Road, Tai Wo Ping	8	Soil cut	The slope was formed before 1977 and subsequently modified under the "Infrastructure Works for Housing Sites adjacent to Lung Ping Road at Tai Wo Ping" project with the design checked and accepted by the GEO in 2016. The incident involved a washout failure on a vegetated slope surface (inclined at about 35°) with scar depth of about 0.5 m. Several erosion gullies were observed at the upper portion of the scar. The failure might be attributed to concentrated surface water flow due to spillage from a partially blocked crest surface channel above the failure location.

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

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope Failure	Remarks
2017/05/1006AD (ArchSD/F/2017/05/0001)	3SW-C/CR406	Wo Hop Shek Cemetery, Fanling	3	Soil cut	The slope was formed between 1976 and 1978 and subsequently modified under a redevelopment project for Wo Hop Shek Cemetery in the late 2000s with the design checked and accepted by the GEO. The incident involved a failure on a 55° inclined soil-nailed cut slope within the soil-nailed zone with scar depth of about 0.5 m and without affecting the soil nails. The local shallow detachment was probably due to infiltration primarily through the vegetated area at the slope crest. The debris was fully retained by the wire mesh installed on the slope surface and no soil nail heads were exposed on the scar.
2017/07/2085	15NE-A/C138	Stanley Gap Road	0.5 (Rockfall)	Rock cut	The incident occurred shortly after the substantial completion of upgrading works on the slope under the Preventive Maintenance Programme of Highways Department with the design checked and accepted by the GEO. The incident involved minor rockfall probably due to the development cleft water pressure within rock joints. The debris was fully retained by the rock mesh.

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

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope Failure	Remarks
7. Slopes Formed or Upgraded By Private Owner and Checked by GEO ($\sum$ = 2 nos.)					
2017/04/2007	11SE-D/C1329	Adjacent to staircase linking Deep water Bay Drive and South Island School	2.5	Soil cut	The slope was formed by cutting back during the site formation works for development of residential building and government accommodation at R.B.L 1056 Shouson Hill Road in 1987 under BD submission. The incident involving a washout failure on a soil cut slope resulting in two scars, was probably caused by overflown of drainage runoff from blocked surface channels associated with lack of maintenance.
2017/05/2017	10NE-B/C57	Tsing Yi Road, Tsing Yi	1300	Rock cut	The slope was formed between 1963 and 1968 in relation to the site formation works under a private development. Geotechnical assessments were subsequently conducted by the lot owners in 1981 and 2000. The incident involved a sizeable rock slope failure (volume of about 1,300 m^3). It was a translational rockslide characterized by three sets of adversely-orientated joints. The failure was likely caused by the development of cleft water pressure in the jointed rock mass attributable to the ingress of surface water into the rock joints and subsurface flow. The crown and west flank of the scar were delineated by dense vegetation which have been exhibiting substantial growth over the past decade. The penetration of roots to considerable depth into the joint apertures, as evidenced on the scar, could have progressively wedged open the rock joints resulting in enhanced water ingress and deterioration of the slope. Subsurface flow was also evidenced and some of which was observed through the lenses of highly fractured and completely decomposed granite within the scar. Moreover, the additional surface runoff due to the blockage of upslope channels might have some contribution to the rockslide.

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

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope Failure	Remarks
8. Slopes Upgraded Following Service of DH Orders and Checked by GEO (∑ = 1 no.)					
2017/06/2050	11NW-D/C355	West of the Methodist College, Gascoigne Road, Yau Ma Tei	0.07 (Rockfall)	Soil/ rock cut	The slope was upgraded in 1985 following a DH Order served by the BD in 1983. The incident involved minor rockfall on a rock face that was covered with the deteriorated chunam. Tree roots growth was noted over the rockfall location. Root-wedging action could be the principal cause of the failure.
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 (∑ = 1 no.)

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.

Appendix C

Progress of Follow-up Actions on the Improvement Measure Recommended in the Review of 2016 Landslides

Contents

List of Table

Table C1 Progress of Follow-up Actions on the Improvement Measure Recommended in the Review of 2016 Landslides

Recommended Improvement Measure	Progress
1. 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.	GEO Technical Guidance Note No. 11 (GEO, 2018) had been updated to highlight the importance of devising the soil nail layout near the soil and rock interface in a judicious manner to minimize the extent of local unsupported soil zone between the bottom row of soil nails and the interface.

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