Review of Landslides in 2018

GEO Report No. 348

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
Special Administrative Region

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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 2018 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 2 under the supervision of Dr H.W. Sun. 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 K.H.K. Yiu, Mr C.M. Leung and Mr C.Y. Lee 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 2018 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, 253 genuine landslides in 2018 were reported to the Government, of which 12 were major landslides (viz. failure volume of 50 m^3 or more). There were 11 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 0.038% 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 2018.

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1 Introduction

This report presents the findings of a diagnostic review of the landslides in 2018 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 2018. The review has been carried out by the Landslip Preventive Measures Division 2 (LPM2) 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 2018

The factual information, together with the relevant statistics on rainfall and reported landslides in 2018, was documented by Wai et al (2019).

In 2018, the annual rainfall recorded at the Principal Raingauge of the Hong Kong Observatory (HKO) in Tsim Sha Tsui was 2162.9 mm, a deficit of about 10% comparing to the mean annual rainfall of 2398.5 mm between 1981 and 2010. Three Landslip Warnings were issued on 7 June, 29 August and 16 September 2018. No Black Rainstorm Warning was issued in 2018 but four Red Rainstorm Warnings and 27 Amber Rainstorm Warnings were issued between 8 June and 16 September 2018, and between 6 June and 24 September 2018 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 346 reported incidents in 2018, 253 were genuine landslides, discounting

the non-landslide incidents (e.g. tree falls, flooding and waved-induced scouring damage to coastal slopes under severe typhoon). There were 12 major failures, corresponding to about 4.7% 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		14 (2)	5.5
Cut Slopes	Soil	139 (2)	55
	Soil/Rock	15 (0)	5.9
	Rock	16 (0)	6.3
Retaining Walls		9 (0)	3.6
Natural Hillside		56 (8)	22.1
Registered Disturbed Terrain		4 (0)	1.6
Total		253 (12)	100

Legend:

56 (8) Fifty-six landslides, eight 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	5 (0)	8 (0)
Registered Squatter Dwellings	0	0	17 (1)	17 (1)
Roads	21 (0)	1 (0)	18 (5)	40 (5)
Transportation Facilities (e.g. railways, tramways, etc.)	0	0	0	0
Pedestrian Pavements/Footways	4 (0)	2 (0)	3 (0)	9 (0)
Minor Footpaths/Access Paths/ Access Roads	15 (1)	2 (0)	84 (3)	101 (4)
Construction Sites	0	0	1 (0)	1 (0)
Open Areas	6 (1)	6 (1)	26 (1)	38 (3)
Catchwaters	0	0	8 (1)	8 (1)
Others (e.g. carparks, parks, playgrounds, gardens, backyards, etc.)	2 (0)	2 (0)	25 (0)	29 (0)
Nil	0	1 (0)	7 (0)	8 (0)
Total	51 (2)	14 (1)	194 (11)	259 (14)

Legend:

84 (3) Eighty-four 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' refers to incidents where the landslide debris came to rest on the slopes, not affecting any facilities.

Table 2.3 Breakdown of Landslide Consequences by Types of Slope Failures

Types of Slope Failures		Number of Squatter Dwellings (1) Evacuated		Number of Floors, Houses or Flats Evacuated or Partially Closed	Number of Incidents Involving Closure			Deaths	Injuries Reported to GEO
		Permanent	Temporary		Roads	Pedestrian Pavements	Footpaths, Alleyways or Private Access Paths		
Fill Slopes		0	0	0	0	0	1	0	0
Cut Slopes	Soil	1 (1)(3)	1 (1)	0	5	0	12	0	0
	Soil/Rock	0	0	0	0	1	0	0	0
	Rock	0	0	0	1	0	1	0	0
Retaining Walls		0	0	0	0	1	2	0	0
Natural Hillside		0	1 (1)	0	4	0	6	0	0
Registered Disturbed Terrain		0	0	0	0	0	0	0	0
Total		1 (1)	2 (2)	0	10	2	22	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, 2018).

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

(3) A cut slope failure (Incident No. 2018/09/2304) resulted in permanent evacuation of a squatter dwelling at Pai Tau Village. Details of the incident were documented in Wai et al (2019).

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	2	7	2
Major Landslides on Man-made Slopes	0	0	0	0	1	2	1
Major Landslides on Registered Disturbed Terrain	0	0	0	0	0	0	0
Major Landslides on Natural Hillside	0	1	0	0	1	5	1

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	128	4	0	132
Registered Disturbed Terrain	4	0	0	4
Unregistrable Man-made Slopes	52	0	0	52
Registrable Man-made Slopes Not Yet Registered at Time of Failure	9	0	0	9
Natural Hillside	48	6	2	56
Total	241	10	2	253

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 2018 is presented in Figure 3.1.

In 2018, three Landslip Warnings were issued on 7 June, 29 August and 16 September 2018 and the corresponding LPI was assessed to be ranging from 1 to 2. In terms of the potential to cause landslides, the rainstorm of 16 September 2018 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 2018 landslide data has been carried out to appraise the slope performance, and facilitate the identification of areas in the slope safety system for further improvement.

The diagnostic review has mainly focused on the following aspects:

(a) coverage of the Catalogue of Slopes,

(b) performance of registered man-made slopes,

(c) observations from natural terrain landslides, and

(d) other areas of technical interest.

4.2 Coverage of the Catalogue of Slopes

4.2.1 General

Sizeable man-made slopes and retaining walls, including those compiled under the GEO's project entitled "Systematic Identification and Registration of Slopes in the Territory" (SIRST) that was completed in September 1998, together with newly formed or identified slope features after 1998, are registered in the Catalogue of Slopes. Any unregistered man-made slopes identified during slope maintenance inspections, landslide investigations and other geotechnical inspections or studies will also be registered in the Catalogue of Slopes (GEO, 2014b) should they satisfy the slope registration criteria.

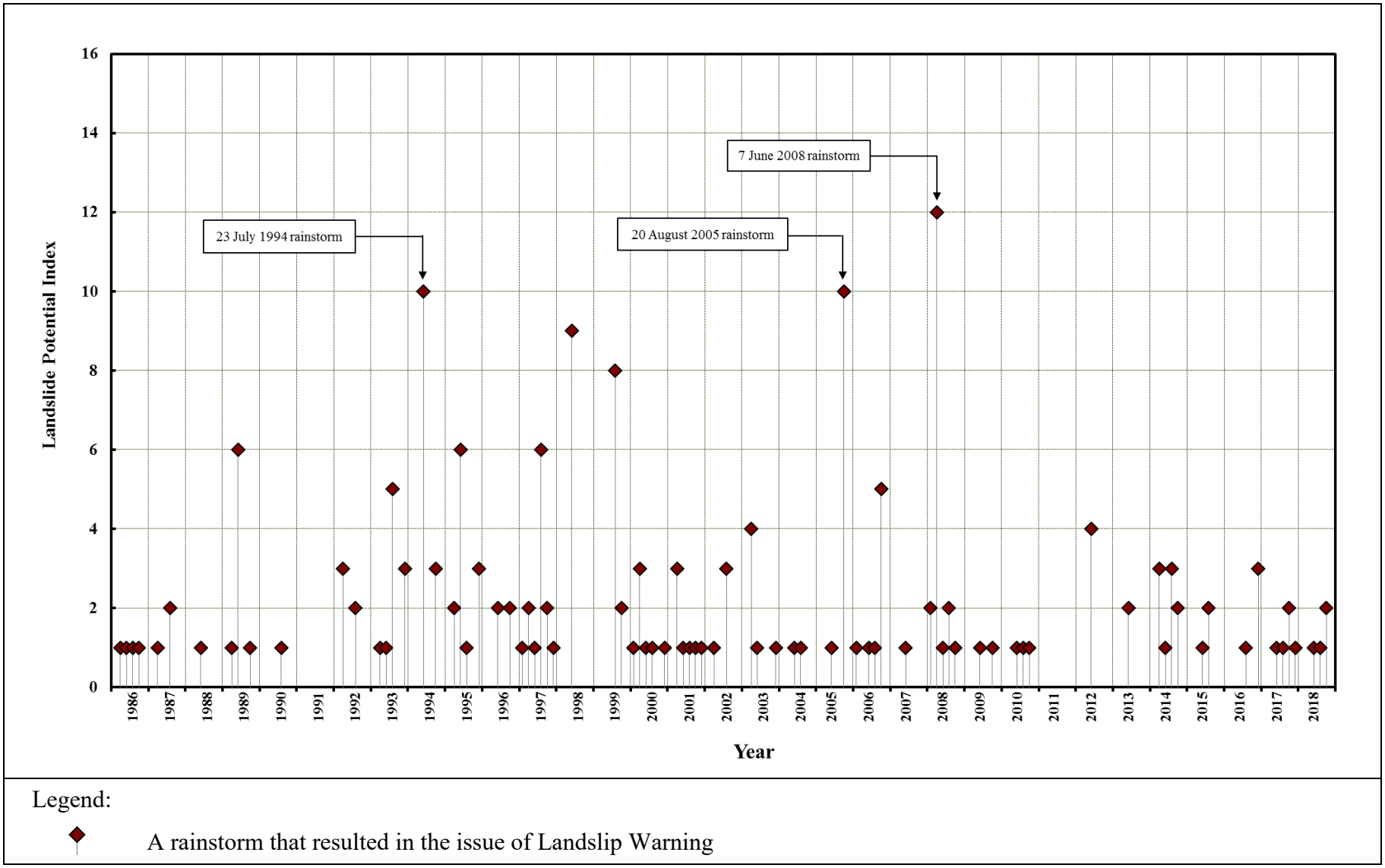


Figure 3.1 Landslide Potential Index for Rainstorms that Resulted in the Issue of Landslip Warnings from 1986 to 2018

4.2.2 Diagnosis

Of the 253 genuine landslides, 136 occurred on registered slope features (comprising 132 on registered man-made slopes and four on registered disturbed terrain features) and 117 occurred on slopes not registered in the Catalogue of Slopes (Table 2.5).

Among the above 117 landslides, 56 occurred on natural hillside, 52 occurred on small man-made slope features that do not meet the slope registration criteria (DEVB, 2018). The remaining nine landslides, corresponding to 3.6% of the total number of genuine landslides in 2018, 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 117 landslides is given in Figure 4.1.

The nine landslides involving registrable slopes were all minor failures with failure volume of 45 m^3 or less (refer to Appendix A for details). All of these nine minor failures did not result in 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 52 landslides involving unregistrable man-made slope features were all minor failures with failure volume up to about 30 m^3. One incident resulted in permanent evacuation of a squatter dwelling at Pai Tau Village, Shatin and three led to temporary closure of minor footpaths at Tai Po, Pat Heung and Tuen Mun.

4.3 Performance of Registered Man-made Slopes

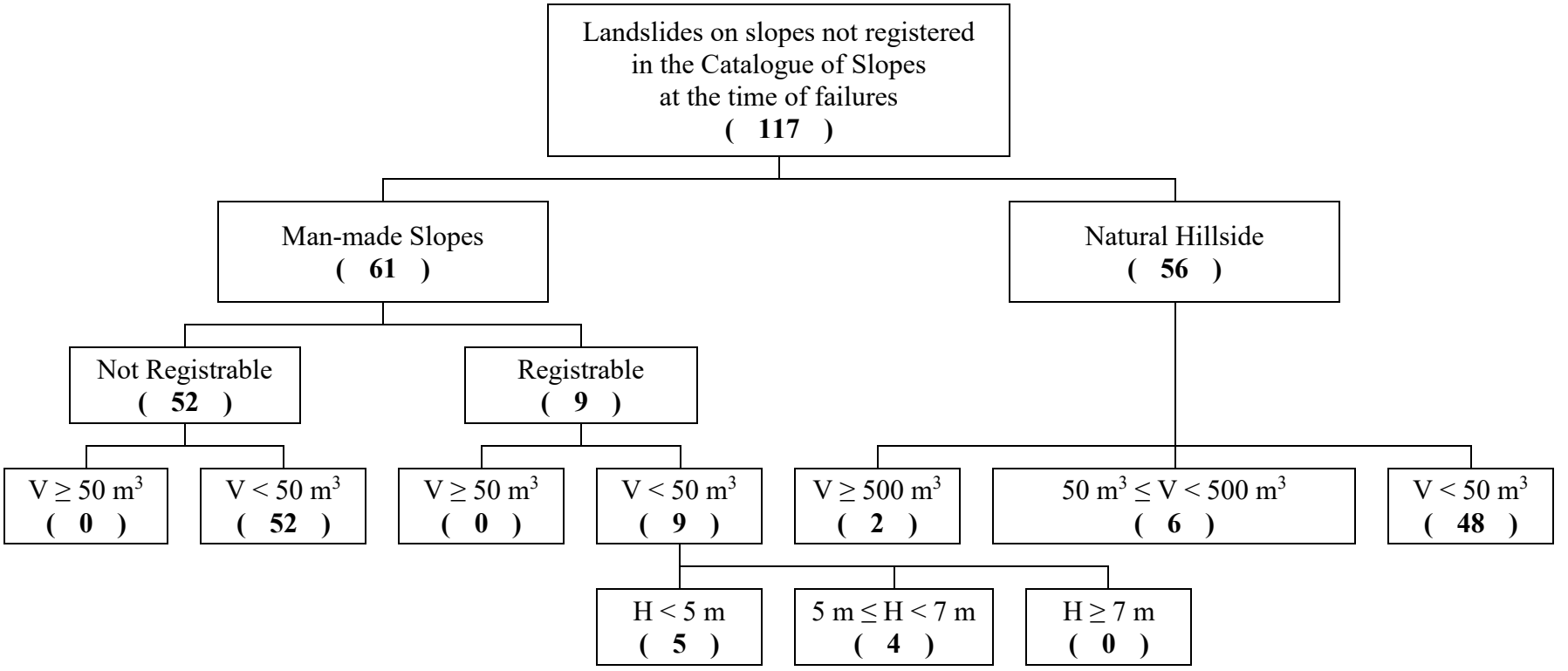
4.3.1 General

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
(52)	Number of landslide incidents = 52

Notes:

(1) 'Not Registrable' refers to cases involving slopes that do not satisfy the feature height criteria for registration in the Catalogue of Slopes (DEVB, 2018) 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 2018

(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 253 genuine landslides in 2018, a total of 132 landslides (about 52%) occurred on registered man-made slopes (Table 2.5). Four out of these 132 landslides (about 3%) were major failures with failure volume ranging from 70 m^3 to 190 m^3 and the remaining 128 landslides were minor failures. Of the 132 landslides on registered man-made slopes, 11 landslides (about 8%) occurred on engineered slopes and the remaining 121 landslides occurred on non-engineered slopes. No major landslide occurred on consequence-to-life (CTL) Category 1 slope features in 2018. A breakdown of the CTL categories of the registered man-made slopes involved in the 2018 landslides is given in Table 4.1.

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

Types of Slopes	No. of Landslides			Total
	CTL Cat.1	CTL Cat.2	CTL Cat.3	
Engineered Slopes	7 (0)	3 (0)	1 (0)	11 (0)
Non-engineered Slopes	27 (0)	17 (1)	77 (3)	121 (4)

Legend:

17 (1) Seventeen landslides, one of which was a major failure

Discussions of the landslides on engineered and non-engineered slopes in 2018 are given in Sections 4.3.2 and 4.3.3 respectively below.

4.3.2 Landslides on Engineered Slopes

Brief descriptions of the 11 landslides on engineered slopes in 2018 are given in Appendix B. A breakdown of these landslides in terms of feature type is given in Table 4.2. Among the 11 landslides, four involved slopes previously upgraded under the Landslip Preventive Measures Programme (LPMP) (see Table 4.3). None of the landslides in 2018 involved slope previously upgraded under the Landslip Prevention and Mitigation Programme (LPMitP).

Six landslides involved minor washout failures (volume ≤ 3 m^3). Four occurred on soil-nailed cut slopes and two occurred on unsupported cut slopes. These failures were generally associated with overflow from blocked surface channels or abrupt change in channel alignment above the failure locations. Inadequately maintained hard surface cover or lack of surface protection on steep slope portions had rendered the slopes vulnerable to surface erosion.

Four landslides involved minor rockfalls/boulder fall (volume ≤ 5 m^3). Two involved detachment of rock blocks from the slope faces covered with old chunam. Another two involved detachment from bare rock faces. These failures were probably related to the deterioration of the hard surface cover and/or exacerbated by tree root wedging action. They 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).

The remaining landslide involved local spalling of shotcrete slope cover (volume of about 0.02 m^3) while the groundmass underneath was not affected.

One of the 11 landslides on engineered slopes resulted in temporary closure of a pedestrian pavement. The remaining cases did not result in any significant consequence.

Table 4.2 Breakdown of Landslides on Engineered Slopes

Scale of Failure (m^3)	Fill Slopes	Cut Slopes			Retaining Walls	Total
		Soil	Soil/Rock	Rock		
> 500 m^3	0	0	0	0	0	0
50 m^3 to 500 m^3	0	0	0	0	0	0
> 5 m^3 to < 50 m^3	0	0	0	0	0	0
≤ 5 m^3	0	7 (4)	2	2	0	11
Total	0	7 (4)	2	2	0	11

Legend:

7 (4) Of the seven landslides, four 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	0	0	0	0
≤ 5 m^3	0	1	1	2	0	4
Total	0	1	1	2	0	4

4.3.3 Landslides on Non-engineered Slopes

There were 121 landslides on non-engineered slopes in 2018, among which four were major and 117 were minor landslides.

The four major landslides involved failures volume ranging from 70 m^3 to 190 m^3. The incidents on a CTL Category 2 slope at Fan Kam Road and a CTL Category 3 slope at Tai Lam Country Park resulted in temporary road closure. The other two incidents that occurred on CTL Category 3 slopes did not have any notable consequence.

Of the 117 minor landslides, 65 of them were relatively small in scale with a failure volume less than 5 m^3. Two incidents resulted in temporary closure of roads, five resulted in temporary closure of minor footpath/access road/alleyway and one resulted in temporary evacuation of a squatter dwelling at Wo Hop Shek Village. The rest did not have any notable consequence.

4.3.4 Landslides Occurring in the Vicinity of Registered Squatter Structures

Twenty-five landslides occurred on slopes located in the vicinity of registered squatter structures, of which nine occurred on registered slopes, 12 on unregistrable man-made slopes, two on registrable man-made slopes not yet registered at the time of failure and two on natural hillside. Of these 25 landslides, one occurring on natural hillside was a major landslide with an estimated total source volume about 900 m^3, and the remaining landslides were all minor, with failure volume up to 13 m^3. In terms of the engineering status of those man-made slopes involved in the landslides, one was engineered and the rest were non-engineered.

In eight of the 25 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 17 landslides. Among these

cases, one involved the issuance of Category 1 Non-development Clearance (NDC) [1] recommendation on the affected squatter structure (with Category 2 NDC[2] recommendation previously served) following the 2018 incident. No NDC recommendations were made following the incidents for the remaining 16 cases because the affected squatter structure is on a private lot/licensed land or the failure was of very small scale (volume ≤ 1.5 m^3) without causing any damage to the affected squatter structure.

For the 17 landslides with landslide debris reached the squatter structures, NDC inspections were previously conducted by the GEO on the villages concerned. Following the NDC inspection, Category 2 NDC recommendation was made on a squatter structure involved in one of the landslides.

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 2018 correspond to about 0.23% (number of landslides divided by number of registered man-made slopes), 0.005% (total surface area of landslides divided by total surface area of registered man-made slopes), and about 2.355×10^{-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 2018 (Table 4.5), the annual failure rates of engineered slopes are lower than that of non-engineered slopes by a factor of about 11 on a slope number basis, and about 77 on a slope surface area basis. In terms of the number of landslides per total slope surface area, the corresponding failure rate of engineered slopes is about 30 times lower than that of non-engineered slopes.

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[1] Category 1 Non-development Clearance (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.

[2] Category 2 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.

Table 4.4 Annual Failure Rates of Registered Man-made Slopes in 2018

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 2018	Number of Slopes	16	105	121	0	11	11
	Surface Area of Landslides (m^2)	388	2361	2749	0	96	96
Slopes Involved in Major Landslides in 2018	Number of Slopes	2	2	4	0	0	0
	Surface Area of Landslides (m^2)	199	210	409	0	0	0
Slopes Involved in Minor Landslides in 2018	Number of Slopes	14	103	117	0	11	11
	Surface Area of Landslides (m^2)	189	2151	2340	0	96	96
Total Number of Registered Slopes		10,930	17,720	28,650	12,550	16,100	28,650
Total Surface Area of Registered Slopes (m^2)		6,026,850	9,147,740	15,174,590	13,879,894	27,001,016	40,880,910
Annual Failure Rates (All Landslides)	On Slope Number Basis	0.146%	0.593%	0.422%	0%	0.068%	0.038%
	On Slope Surface Area Basis	0.0064%	0.0258%	0.0181%	0%	0.0004%	0.0002%
	Number of Landslides Divided by Slope Surface Area (no./m^2)	2.655×10^{-6}	1.148×10^{-5}	7.974×10^{-6}	0	4.074×10^{-7}	2.691×10^{-7}
Annual Failure Rates (Major Landslides)	On Slope Number Basis	0.018%	0.011%	0.014%	0%	0%	0%
	On Slope Surface Area Basis	0.0033%	0.0023%	0.0027%	0%	0%	0%
	Number of Landslides Divided by Slope Surface Area (no./m^2)	3.318×10^{-7}	2.186×10^{-7}	2.636×10^{-7}	0	0	0

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

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

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	0.230%	0.0050%	2.355×10^{-6}
	Major Landslides	0.007%	0.0007%	7.136×10^{-8}
	Minor Landslides	0.223%	0.0043%	2.283×10^{-6}
Engineered Slopes	All Landslides	0.038% (0.073%)	0.0002% (0.0002%)	2.691×10^{-7} (4.654×10^{-7})
	Major Landslides	0% (0%)	0% (0%)	0 (0)
	Minor Landslides	0.038% (0.073%)	0.0002% (0.0002%)	2.691×10^{-7} (4.654×10^{-7})
Non-engineered Slopes	All Landslides	0.422% [11/5.8]	0.0180% [76.8/79.1]	7.974×10^{-6} [29.6/17.1]
	Major Landslides	0.014%	0.0027%	2.636×10^{-7}
	Minor Landslides	0.408%	0.0154%	7.71×10^{-6}

Legend:

0.038% (0.073%)	Annual failure rate of engineered slopes (considering all landslides) is 0.038% and that for slopes previously treated under the LPMP or LPMitP is 0.073%
0.422% [11/5.8]	Annual failure rate of non-engineered slopes (considering all landslides) is 0.422%, which is about 11 times and 5.8 times higher than those of engineered slopes and slopes previously treated under the LPMP or LPMitP respectively

In 2018, four landslides involved slopes treated under the LPMP and none involved slopes upgraded under the LPMitP. The annual failure rates of slopes previously treated under the LPMP or LPMitP correspond to 0.073% (number of landslides divided by number of registered man-made slopes treated under the LPMP or LPMitP), 0.0002% (total surface area of landslides divided by total surface area of registered man-made slopes treated under the LPMP or LPMitP), and about 4.654×10^{-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 6 to 79, 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 2018, the corresponding annual success rates were 100% and 99.96% 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 2018 is shown in Table 4.6 and Figure 4.2.

4.4 Natural Terrain Landslides

A total of 56 natural terrain landslides were reported in 2018, among which 48 were minor and eight were major in scale. Of the eight major landslides, one resulted in damage of a storage structure, a container and several vehicles as well as temporary closure of a road, two led to temporary closure of roads, one resulted in damage of a vehicle and temporary closure of an access road, one resulted in blockage of catchwater and the remaining three did not result in any notable consequence. Among these major landslides, five occurred on the hillside catchments in Lam Tsuen Country Park under the severe rainstorm on 29 August 2018, including the largest two landslides developed into three distinct landslide clusters with total source volume ranging from 200 m^3 to 800 m^3 (Incident Nos. 2018/08/2228 & 2018/08/2229) which involved open hillslope failures from multiple source areas on the natural hillside, a number of which with debris converged into drainage lines and turned into channelized debris flows descending towards Fan Kam Road. Other factual information pertaining to these two incidents were documented in Wai et al (2019).

The 48 minor incidents involved mainly open hillslope failures (up to about 47 m^3), boulder/rock falls (less than 4 m^3) originating from natural hillside and some washout failures (up to about 20 m^3). One led to a temporary evacuation of a squatter dwelling, two resulted in temporary closure of roads and two resulted in blockage of minor footpaths.

Among these 56 reported natural terrain landslides, eight incidents (comprising six slope failures and two rockfall/boulder fall incidents) were located within existing Historical Landslide Catchments (HLC). Except the largest two incidents as mentioned above, these incidents (i.e. the other six incidents; all being minor in scale) appeared 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 incidents, all being minor in scale, were located within 50 m from the existing HLC, none of which with debris trails close to any important downslope facilities. Of the said 13 minor failures within or in the vicinity of the existing HLC, two resulted in damage of vehicles, another two resulted in damage of steel chain link fences of the premises and the rest did not result in any significant consequence.

Table 4.6 Annual Success Rates of Engineered Slopes from 1997 to 2018

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%
2018	100%	99.96%

Note: See Figure 4.2 for a plot of annual success rates of engineered slopes against the target annual success rates from 1997 to 2018.

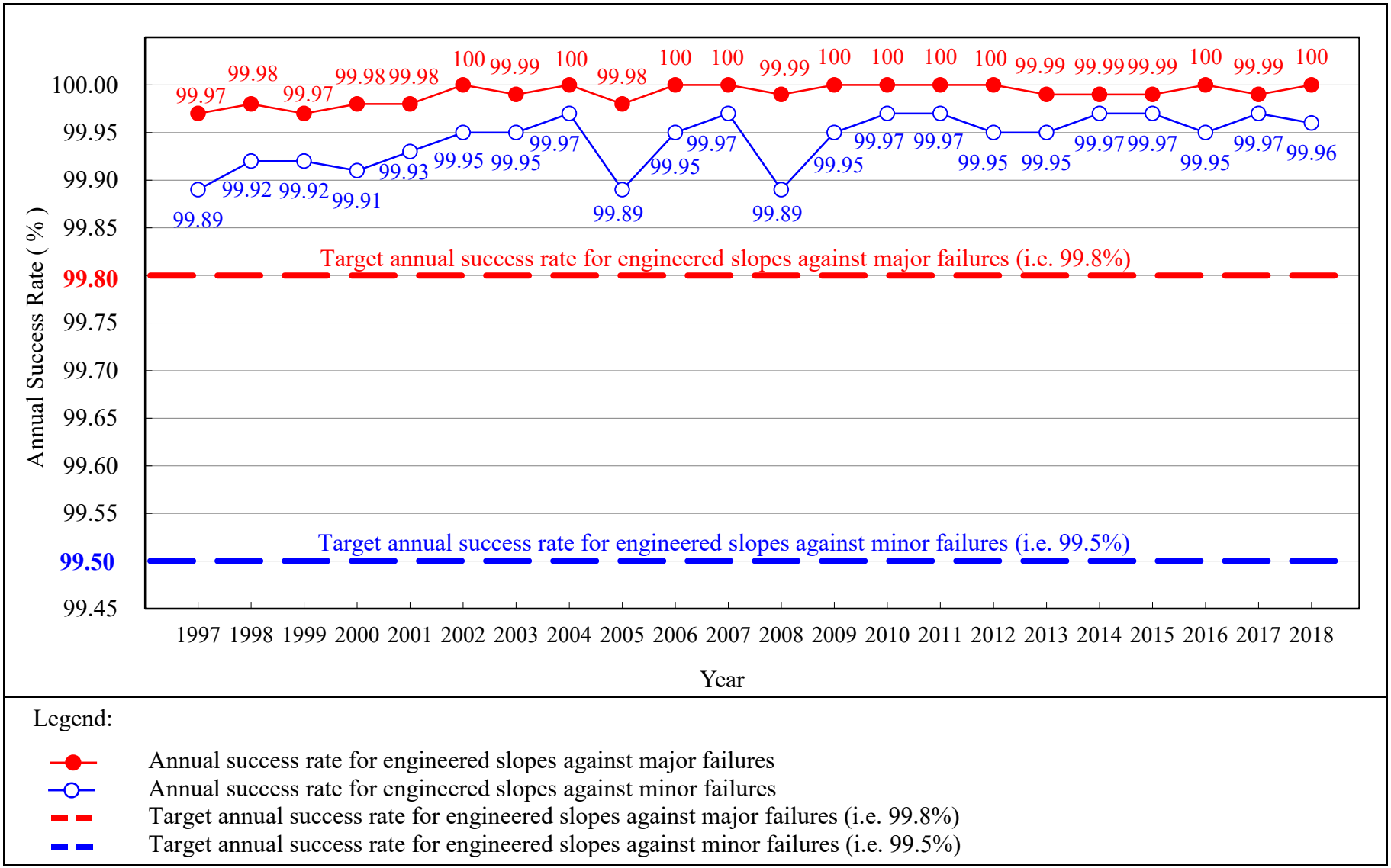

Figure 4.2 Annual Success Rates of Engineered Slopes from 1997 to 2018

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

All the 132 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 29 landslides, all of which were minor in failure scale. These constituted about 22% (i.e. 29 out of 132) of the landslides on registered man-made slopes. Among these 29 landslides, seven occurred on engineered slopes.

Of these 29 landslides involving inadequate slope maintenance, 16 affected government slopes, five affected private slopes and one affected a slope with unassigned maintenance responsibility at the time of failure. Another seven affected slope features of mixed government/private maintenance responsibility, of which two occurred on the government portions and five occurred on the private portions of the slopes. The relevant maintenance parties have been informed of the incidents and advised to take appropriate follow-up action. The above diagnosis reiterates 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 Conclusions

Overall, 99.96% of the engineered man-made slopes performed satisfactorily without occurrence of landslides in 2018. There was no major landslide on engineering slopes in 2018.

The annual failure rate of minor landslides on engineered slopes, on a slope number basis, is 0.038% in 2018. This corresponds to annual success rates of 99.96%, which is above the pledged annual success rates of 99.50%.

6 References

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Appendix A

List of 2018 Landslide Incidents Involving Unregistered Man-made Slopes but Registrable at the Time of Failure

Content

List of Table

Table A1 List of 2018 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)		
2018/06/2177	Yue Kok Village, Lai Chi Shan, Tai Po	6 m	13/6	Public	7/6	Soil cut	45	Open area	-
2018/06/2179	Below Feature No. 7NW-D/C96, San Uk Ka, Tai Po	3 m	13/6	LandsD	8/6	Soil cut	2	Registered squatter dwelling; minor footpath	-
2018/08/2235	Adjacent to Feature No. 3SW-C/C559, Tai Lung Village, Sheung Shui	3.5 m	29/8	Public	29/8	Soil cut	0.5	Road	-
2018/08/2260	Near Feature No. 3SW-C/CR610, Ying Pun, Fanling	4 m	30/8	Public	29/8 (18:00)	Soil cut	3	Other (watermain)	-
2018/09/2274	Near Lamp Post No. VD7562, Ying Pun, Fanling	5.5 m	6/9	Public	30/8	Soil cut	10	Registered squatter dwelling	-

Table A1 List of 2018 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)		
2018/09/2280	Near Lamp Post No. VD0028, Fan Kam Road, Sheung Shui	6 m	8/9	Public	Unknown	Soil cut	0.8	Minor footpath	-
2018/09/2286	Near Lamp Post No. BD4034, So Kwun Wat, Tuen Mun	5 m	12/9	Public	30/8	Soil cut	2	Access road	-
2018/09/2308	Near Feature No. 7SW-B/CR514, Pak Tin Tsuen, Shatin	4 m	17/9	Public	16/9	Soil cut	1.5	Minor footpath	-
2018/10/2365	Near Feature No. 3SW-C/C266, Tai Lung, Sheung Shui	5 m	7/9	LandsD	Unknown	Soil cut	9.4	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

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.)					
2018/02/2149	11NE-C/C62	Hong Ning Road	0.02 (Spalling of shotcrete cover)	Soil/rock cut	The slope was upgraded under the LPMP in 1999. The incident involved local spalling of shotcrete cover on the slope which was probably caused by slope deterioration. Groundmass underneath the detached shotcrete cover was not affected.
2018/04/2162	11SE-C/C54	Tai Hang Road	0.03 (Rockfall)	Rock cut	The slope was upgraded under the LPMP in 2001. The incident occurred on a scaled rock face near the slope toe and no surface protection measures had been provided. It involved the wedge failure of a rock block probably caused by the build-up of cleft water pressure within the adversely orientated joints that might have been opened up by root wedging action.
2018/06/2174	9SW-C/C5	Hong Kong Shaolin Wushu Culture Centre, Tai O	1.6	Soil cut	The slope was upgraded under the LPMP in 1990. The portion of slope involved in the present failure (under the maintenance responsibility of private since 2017) was steeply-inclined at about 60°. It was installed with soil nails and covered with chunam. Substantial blockage of surface channels above the failure location and dilapidation of chunam were evidenced suggesting a poor state of slope maintenance. The overflow from the blocked channels might have caused the washout failure. While the installed soil nails appeared to remain intact, several soil nail heads were exposed with some being partially undermined on the erosion scar.

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
2018/09/2337	11SE-C/C166	Opposite to French International School, Price Road	1	Soil cut	The slope was upgraded under the LPMP in 1999. The failure occurred over a thin mantle of soil underlain by rock at the soil/rock interface near the slope toe. The failed portion was inclined at about 40°. It was located below the bottom row of soil nails and no surface protection measures had been provided. The incident involved a washout failure which was probably caused by overflow from the blockage of surface channels associated with inadequate maintenance.

2. Slopes Assessed under the LPMP/LPMitP with No Upgrading Works Required ($\sum$ = 0 no.)

   Nil.

3. Slopes Assessed by Studies in the late 1970's to mid-1980's with No Upgrading Works/Further Study Required ($\sum$ = 0 no.)

   Nil.

4. Slopes Assessed by Government Departments and Checked by GEO with No Upgrading Works Required ($\sum$ = 0 no.)

   Nil.

5. Slopes Assessed by Private Owners and Checked by GEO with No Upgrading Works Required ($\sum$ = 0 no.)

   Nil.

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
6. Slopes Formed or Upgraded by Government Departments and Checked by GEO ($\sum$ = 2 nos.)					
2018/08/1024AD (ArchSD/F/2018/08/0004)	3SW-C/C412	Kiu Tau Road	2.5	Soil cut	The slope was formed between 1976 and 1978 and subsequently modified under a redevelopment project for Wo Hop Shek Cemetery in 2013 with the design checked and accepted by the GEO. The incident involved a washout failure on a 55° inclined unsupported cut slope covered by vegetation with erosion control mat and wire mesh. The failure might be attributed to an adverse site setting leading to overflow from the platform above the failure location. Most of the debris was retained by the wire mesh.
2018/03/2155	5SE-C/C1	Lung Mun Road	5 (Rockfall)	Soil / rock cut	The slope was formed in 1984 in association with the construction of Lung Mun Road and Castle Peak Power Station at Tap Shek Kok, Tuen Mun with the design checked and accepted by the GEO. The incident involved rockfall originated from a bare outcrop probably due to the development of cleft water pressure within the adversely orientated joints that might have been opened up by root wedging action prior to the failure.

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

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope Failure	Remarks
7. Slopes Formed or Upgraded By Private Owner and Checked by GEO (∑ = 1 no.)					
2018/06/2188	6SE-C/C533	Castle Peak Road, Tsing Lung Tau	0.13	Soil cut	The slope portion (Sub-division 2) on which the incident occurred was modified by cutting and installation of soil nails during the redevelopment of the village house at toe in 1994 with the design checked and accepted by the GEO. The incident involved a washout failure on the sparsely vegetation slope portion (inclined at about 65°) near the slope crest, above the uppermost row of soil nails. The failure was probably caused by overflow from the surface channel section, involving an abrupt change in channel alignment, above it.
8. Slopes Upgraded Following Service of (Dangerous Hillside) DH Orders and Checked by GEO (∑ = 4 nos.)					
2018/09/2285	11SW-B/C65	Northeast of Pine Court, near Canossa Hospital, Robinson Road	3	Soil cut	The slope portion (Sub-division 3) on which the incident occurred was upgraded by soil nails in 2003 following a DH Order served by the BD in 2001. The incident involved a washout failure on a local steep slope portion (inclined at about 60°) near the slope crest, right above the uppermost row of soil nails. The pre-failure slope surface at this local area was sparsely vegetated which might have rendered it susceptible to erosion.

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
2019/01/2411	11SW-B/CR398	Confucius Hall Secondary School, 77 Caroline Hill Road	2	Soil cut	The slope portion (Sub-division 2) on which the incident occurred was subjected to a DH Order served by the BD in 1992. The order was discharged following the completion of slope remedial works in 1993. The incident involved a washout failure resulting in two erosion scars on the local steep areas (inclined at about 65°) covered with sparse vegetation. Although the failed areas fall within the extent of DH Order served in 1992, they are outside the area with the remedial works completed. Following the incident, another DH Order was served by the BD requesting the owners to investigate the stability of the failed areas and the other adjoining untreated areas.
2018/06/2189 2018/08/2217	11SW-A/C329	Behind 96D Pok Fu Lam Road	0.3 (Rockfall) 0.05 (Boulder fall)	Rock cut Soil cut	The slope portion (Sub-division 1) on which the incidents occurred was upgraded in 1991 following a DH Order served by the BD in 1988. Incident No. 2018/06/2189 involved rockfall originated from the unsupported lowest chunam-covered slope batter (inclined at about 75°). A tree was growing over the failure location and extensive network of tree roots was observed on the scar surface. It is evident that root wedging action had played a key contributory role in this failure. Incident No. 2018/08/2217 involved boulder fall with detachment of some chunam slope cover originated from the steeply inclined unsupported portion of the slope (inclined at about 75°) near the slope crest. The inadequately maintained chunam cover and tree root effect could have contributed to the failure.

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
9.	Slopes Assessed as Not Requiring Upgrading Works But with Outstanding GEO Comments ($\sum$ = 0 no.)				
	Nil.				
10.	Slopes Assessed as Requiring Upgrading Works But with Outstanding GEO Comments ($\sum$ = 0 no.)				
	Nil.				

Legend:

Landslide occurred within the soil-nailed portion of a slope ($\sum$ = 4 nos.)

Landslide involved unsupported cut ($\sum$ = 2 nos.)

Notes: (1) Slopes under Categories 1 to 8 are classified as engineered slopes.
(2) Slopes under Categories 9 and 10 are not regarded as engineered slopes for the purpose of this report.

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