Review of Landslides in 2019

GEO Report No. 350

V.S.F. Kong, R.C.T. Wai & R.W.H. Lee

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 2019 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 V.S.F. Kong, Mr R.C.T. Wai and Mr R.W.H Lee 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 S.Y. Tse 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 2019 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, 131 genuine landslides in 2019 were reported to the Government, of which one was a major landslide (viz. failure volume of 50 m^3 or more). There were ten 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 0.031% 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 2019.

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1 Introduction

This report presents the findings of a diagnostic review of the landslides in 2019 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 2019. 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 2019

The factual information, together with the relevant statistics on rainfall and reported landslides in 2019, was documented by Kong et al (2020).

In 2019, the annual rainfall recorded at the Principal Raingauge of the Hong Kong Observatory (HKO) in Tsim Sha Tsui was 2396.2 mm, near the mean annual rainfall of 2398.5 mm between 1981 and 2010. Two Landslip Warnings were issued respectively on 31 July and on 26 August 2019. Three Red Rainstorm Warnings and 37 Amber Rainstorm Warnings were issued between 20 April and 26 August 2019, and between 19 February and 14 October 2019 respectively. No Black Rainstorm Warning was issued in 2019.

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 157 reported incidents in 2019, 131 were genuine landslides, discounting the non-landslide incidents (e.g. tree falls). There was one major failure, corresponding to about 0.8% 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		9 (0)	6.9
Cut Slopes	Soil	61 (0)	46.5
	Soil/Rock	16 (0)	12.2
	Rock	14 (0)	10.7
Retaining Walls		15 (0)	11.5
Natural Hillside		16 (1)	12.2
Total		131 (1)	100

Legend:

16 (1) Sixteen landslides, one of which was a major failure

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

Table 2.2 Breakdown of Landslides by Types of Affected Facilities

Types of Affected Facilities	Hong Kong Island	Kowloon	New Territories and Outlying Islands	All
Buildings (including village houses)	1 (0)	0	10 (0)	11 (0)
Registered Squatter Dwellings	0	0	11 (0)	11 (0)
Roads	13 (1)	3 (0)	6 (0)	22 (1)
Transportation Facilities (e.g. railways, tramways, etc.)	0	0	0	0
Pedestrian Pavements/Footways	3 (0)	3 (0)	5 (0)	11 (0)
Minor Footpaths/Access Paths/ Access Roads	12 (1)	2 (0)	30 (0)	44 (1)
Construction Sites	1 (0)	0	0	1 (0)
Open Areas	4 (0)	0	4 (0)	8 (0)
Catchwaters	3 (0)	0	10 (0)	13 (0)
Others (e.g. carparks, parks, playgrounds, gardens, backyards, etc.)	2 (0)	0	3 (0)	5 (0)
Nil	0	0	11 (0)	11 (0)
Total	39 (2)	8 (0)	90 (0)	137 (2)

Legend:

13 (1) Thirteen landslides of which one was a major failure

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	1	0	0	0
Cut Slopes	Soil	0	0	0	1	1	1	0	0
	Soil/Rock	0	0	0	1	0	1	0	0
	Rock	0	0	0	2	1	0	0	0
Retaining Walls		0	0	0	0	0	0	0	0
Natural Hillside		0	0	0	3	0	2	0	0
Total		0	0	0	7	3	4	0	0

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.

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	0	0	2
Major Landslides on Man-made Slopes	0	0	0	0	0	0	0
Major Landslides on Natural Hillside	0	0	0	0	0	0	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 (< 50 m^3)	Number of Major Landslides		Total
		(50 m^3 to < 500 m^3)	(≥ 500 m^3)	
Registered Man-made Slopes	85	0	0	85
Unregistrable Man-made Slopes	24	0	0	24
Registrable Man-made Slopes Not Yet Registered at Time of Failure	6	0	0	6
Natural Hillside	15	1	0	16
Total	130	1	0	131

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, 2020a). 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 maximum rolling 24-hour rainfall of a rainstorm. The LPI for rainstorms that resulted in the issue of Landslip Warnings from 1985 to 2019 is presented in Figure 3.1.

In 2019, two Landslip Warnings were issued respectively on 31 July and 26 August 2019 and the corresponding LPIs were both assessed as 14. In terms of the potential to cause landslides, the rainstorm of 31 July 2019 was about one-seventh of the severity of the rainstorms of 23 July 1994 and 20 August 2005, both of which had an LPI of about 100 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 2019 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,

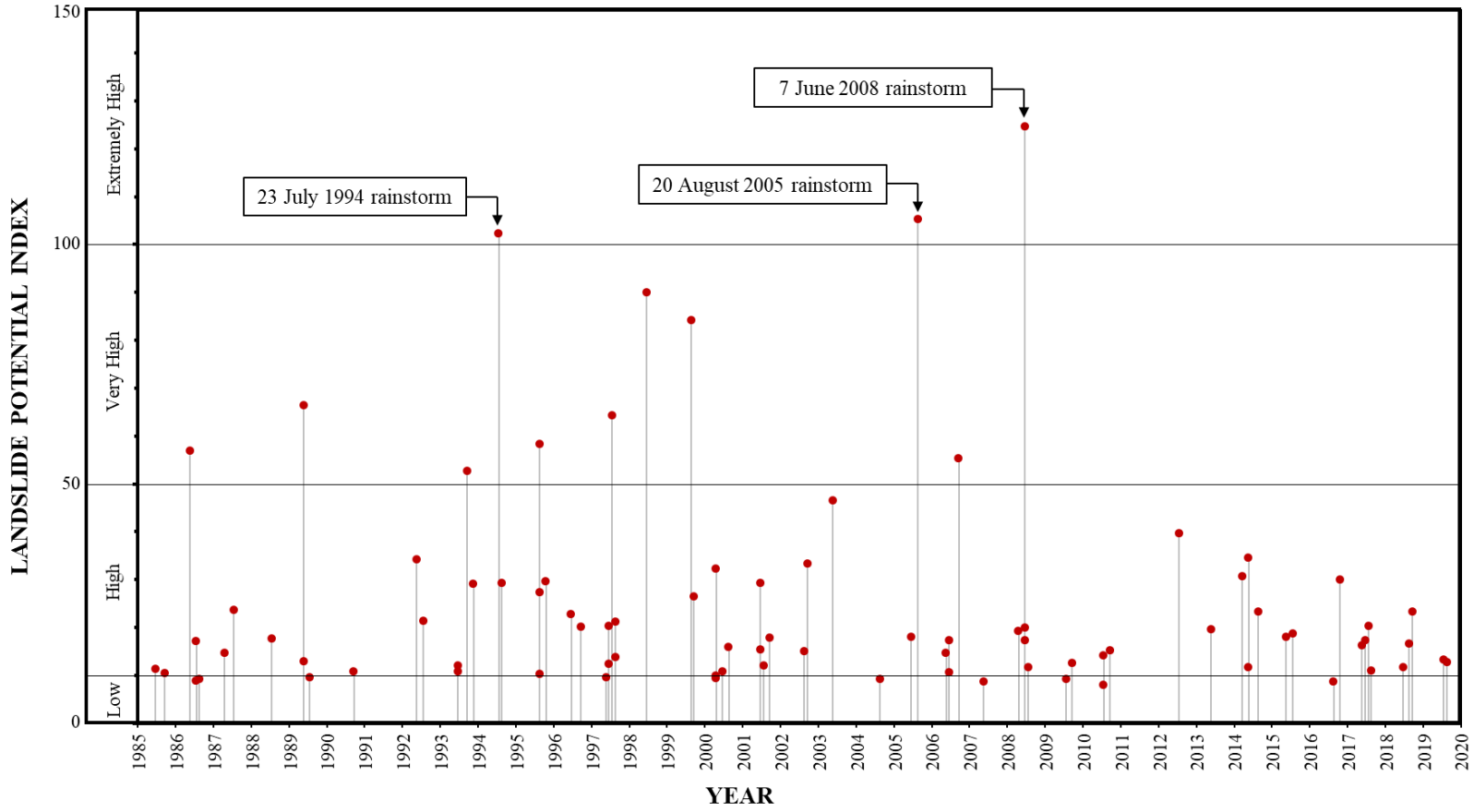
(c) observations from natural terrain landslides, and

(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, 2020b) should they satisfy the slope registration criteria.



Legend:

Each red dot represents a rainstorm that prompted Landslip Warning

Figure 3.1 Landslide Potential Index for Rainstorms that Resulted in the Issue of Landslip Warnings from 1985 to 2019

4.2.2 Diagnosis

Of the 131 genuine landslides, 85 occurred on registered man-made slopes and 46 occurred on slopes not registered in the Catalogue of Slopes (Table 2.5).

Among the above 46 landslides, 16 occurred on natural hillside, 24 occurred on small man-made slope features that do not meet the slope registration criteria (DEVB, 2018). The remaining six landslides, corresponding to 4.6% of the total number of genuine landslides in 2019, 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 46 landslides is given in Figure 4.1.

The six landslides involving registrable slopes were all minor failures with failure volume less than 12 m^3 (refer to Appendix A for details). Amongst these six minor failures, one resulted in partial collapse of the brick screen wall of a building and partial blockage of a section of an access road at Pok Fu Lam. 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 24 landslides involving unregistrable man-made slope features were all minor failures with failure volume up to about 20 m^3. One incident resulted in damage of the windows of a squatter dwelling at Sai Kung, one led to damage of a storage structure at Yuen Long, one led to local undermining of a platform at slope crest at Tai Po and one led to temporary closure of a section of an access road at Tseung Kwan O.

4.3 Performance of Registered Man-made Slopes

4.3.1 General

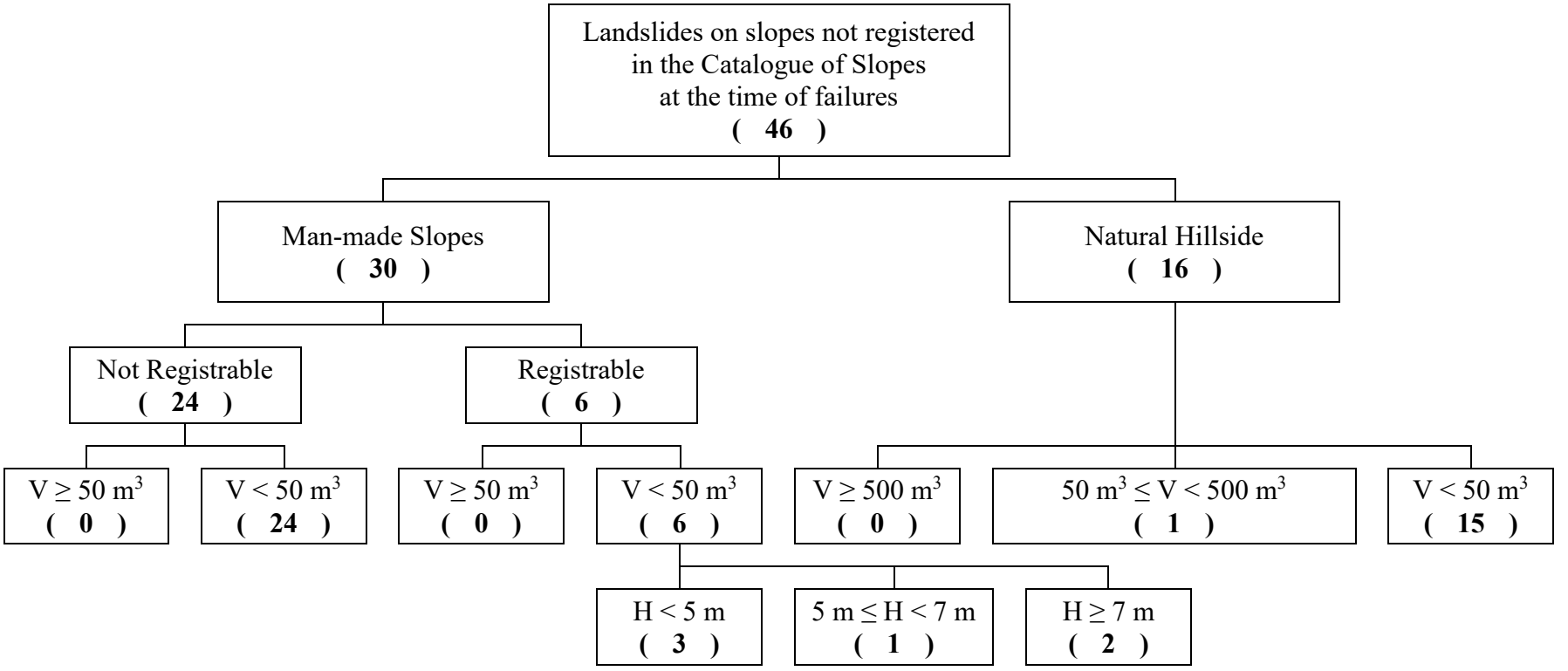
The man-made slopes registered in the Catalogue of Slopes can be broadly classified into engineered slopes and non-engineered slopes. The performance of the registered man-made slopes is reviewed in terms of their annual failure rates.

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,

(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



Legend:

V	Failure volume
H	Height of man-made feature before failure
(46)	Number of landslide incidents = 46

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 2019

(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 131 genuine landslides in 2019, a total of 85 landslides (about 65%) occurred on registered man-made slopes (Table 2.5), all of which were minor failures. Of these 85 landslides, ten landslides (about 12%) occurred on engineered slopes and the remaining 75 landslides occurred on non-engineered slopes. A breakdown of Consequence-to-life (CTL) categories of the registered man-made slopes involved in the 2019 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	8 (0)	2 (0)	0 (0)	10 (0)
Non-engineered Slopes	13 (0)	18 (0)	44 (0)	75 (0)

Legend:

8 (0) Eight landslides, none of which was a major failure

Discussions of the landslides on engineered and non-engineered slopes in 2019 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 2019 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 treated under the Landslip Preventive Measures Programme (LPMP) (see Table 4.3). None of the landslides in 2019 involved slopes previously treated under the Landslip Prevention and Mitigation Programme (LPMitP).

One landslide involved a shallow detachment on a local area of a cut slope between the bottom row of soil nails and the soil/rock interface (volume of about 0.01 m^3). The failure was probably caused by the development of transient perched water table above the soil/rock interface.

Three landslides involved minor washout failures. Two occurred on unsupported soil cut slopes (volume ≤ 20 m^3) and were generally associated with concentrated surface runoff over the failure locations due to overflow from blocked surface drainage measures or concentration of flow from a topographic depression at upslope. Another one occurred on the capping soil fill layer of the rock fill portion of a slope (volume of about 0.05 m^3) with the failure triggered by bursting of a water main.

Five landslides involved minor rockfalls (volume ≤ 1.8 m^3). Post-landslide inspections revealed that three incidents involved detachment of rock blocks from bare rock cut faces. These failures were probably caused by the development of cleft water pressure within the adversely orientated rock joints or tree root wedging action. These incidents again illustrated that minor rockfalls from rock slopes are hard to assess and be prevented. Provision of surface protection measures such as rock mesh could be a pragmatic solution to deal with minor rockfalls (GEO, 2014).

The other two minor rockfall incidents involved rock cut covered with rock mesh. One with a number of detached rock blocks fully retained by the rock mesh (Figure 4.2). The failure might be associated with the development of cleft water pressure within the adversely orientated rock joints. The bottom of the rock mesh was secured with a wire rope and remained in good contact with the slope toe. This incident was not regarded as a failure in accordance with GEO Technical Guidance Note No. 10 (GEO, 2014). Another one involved the fallen out of a detached rock block from the bottom of rock mesh (Figure 4.3). The rock block was detached years ago and trapped by the rock mesh at the slope toe. One day in 2019, the detached rock block dislodged from behind the rock mesh and deposited at the edge of the carriageway, probably caused by the deterioration of slope conditions exacerbated by root wedging action.

These two incidents reveal the difference in performance in the retaining of detached rock blocks by rock mesh. In both incidents, it is noted that the fixing details of rock mesh comply with the prevailing construction standards at the time of the slope works. The provision of a wire rope at the bottom of rock mesh was first introduced as a standard detail in 2002, giving rise to the difference in fixing of the rock meshes at the two slopes. The incidents highlight that rock blocks trapped at the slope toe are liable to fall out of rock mesh for those without a bottom wire rope. Robustness of fixing details, e.g. provision of a bottom wire rope, is important to ensure the reliability of the rock mesh protection which would contribute to guard against any possible adverse consequences from rockfall incidents.

The remaining landslide on engineered slopes involved local detachment of shotcrete slope cover of a soil cut slope (volume of about 1.5 m^3), while the groundmass underneath was not affected.

Three of the ten landslides on engineered slopes resulted in temporary closure of a section of road and sections of pedestrian pavements. The remaining cases did not result in any significant consequence.

Figure 4.2 Incident at Castle Peak Road, Sham Tseng with Rockfall Debris Fully Retained by Rock Mesh (Incident No. 2019/08/2482)

Figure 4.3 Incident at the Junction of Tai Hang Road and Mount Butler Road with a Detached Rock Block Fallen out of Rock Mesh (Incident No.2019/05/2438)

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	2	0	0	0	2
≤ 5 m^3	1	1	1 (1)	5	0	8
Total	1	3	1 (1)	5	0	10

Legend:

1 (1) Of the one landslide, 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	0	0	0	0
≤ 5 m^3	0	1	1	1	0	3
Total	0	1	1	1	0	3

Note: None of the landslides occurred within the soil-nailed portion of the slope.

4.3.3 Landslides on Non-engineered Slopes

There were 75 landslides on non-engineered slopes in 2019, all of which were minor landslides. Of these landslides, 49 of them were relatively small in scale with a failure volume less than 5 m^3. Four incidents resulted in temporary closure of sections of roads and a section of pedestrian pavement, and three led to blockage of catchwater. The rest did not have any notable consequence.

There was a rockfall incident (Incident No. 2019/06/2446) where the fallen rock was retained by the rock mesh on the slope. This incident was not regarded as a failure (GEO, 2014) 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

Eleven landslides occurred on slopes located in the vicinity of registered squatter structures, of which six occurred on registered slopes, four on unregistrable man-made slopes, and one on natural hillside. All the 11 landslides were minor, with failure volume up to about 10 m^3. Those man-made slopes involved in the landslides were non-engineered.

In one of the 11 landslides, squatter structures were not affected by the landslide debris as the structures were located beyond the debris front. The landslide debris reached squatter structures in the other ten landslides. In these ten cases, three affected squatter structures with Category 2 Non-development Clearance (NDC) [1] recommendations issued following the previous NDC inspections conducted by the GEO on the villages concerned. Following the 2019 incidents, none of the ten cases involved the issuance of Category 1 [2] or Category 2 NDC recommendations on the affected squatter structures, either because the affected squatter structures were previously served with Category 2 NDC recommendations, the structures were on licensed land or the failures were of very small scale (volume ≤ 4 m^3) without causing any damage to the affected squatter structures.

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.

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[1] 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.

[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.

The annual failure rates for all genuine landslides on registered man-made slopes in 2019 correspond to about 0.145% (number of landslides divided by number of registered man-made slopes), 0.0027% (total surface area of landslides divided by total surface area of registered man-made slopes), and about 1.481×10^{-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 2019 (Table 4.5), the annual failure rates of engineered slopes are lower than that of non-engineered slopes by a factor of about eight on a slope number basis, and about 14 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 22 times lower than that of non-engineered slopes.

In 2019, three landslides involved slopes treated under the LPMP and none involved slopes treated under the LPMitP. The annual failure rates of slopes previously treated under the LPMP or LPMitP correspond to 0.053% (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 3.433×10^{-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 5 to 42, 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 2019, the corresponding annual success rates were 100% 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 2019 is shown in Table 4.6 and Figure 4.4.

4.4 Natural Terrain Landslides

A total of 16 natural terrain landslides were reported in 2019, among which 15 were minor and one was major in scale. The major landslide involved a washout failure occurring on the natural terrain below Peel Rise, with a failure volume of about 280 m^3. It was associated with the bursting of a water main and resulted in temporary closure of a section of Peel Rise and partial undermining of a section of an access road pavement.

The 15 minor incidents involved mainly open hillslope failures (up to about 35 m^3), boulder falls (less than 2 m^3) originating from natural hillside and several washout failures (up to about 20 m^3). Two of these incidents resulted in temporary closure of sections of roads, and two resulted in temporary closure of sections of a footpath and a hiking trail.

Among these 16 reported natural terrain landslides, none of which was located within existing Historical Landslide Catchments (HLC). Two incidents, both 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 or resulted in any significant consequence.

Table 4.4 Annual Failure Rates of Registered Man-made Slopes in 2019

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 2019	Number of Slopes	9	65	74	1	8	9
	Surface Area of Landslides (m^2)	130	1,118	1,249	1	259	260
Slopes Involved in Major Landslides in 2019	Number of Slopes	0	0	0	0	0	0
	Surface Area of Landslides (m^2)	0	0	0	0	0	0
Slopes Involved in Minor Landslides in 2019	Number of Slopes	9	65	74	1	8	9
	Surface Area of Landslides (m^2)	130	1,118	1,249	1	259	260
Total Number of Registered Slopes		11,040	17,410	28,450	12,560	16,290	28,850
Total Surface Area of Registered Slopes (m^2)		6,019,950	9,108,460	15,128,410	13,837,540	27,089,550	40,927,090
Annual Failure Rates (All Landslides)	On Slope Number Basis	0.082%	0.373%	0.260%	0.008%	0.049%	0.031%
	On Slope Surface Area Basis	0.0022%	0.0123%	0.0083%	0.00001%	0.0010%	0.0006%
	Number of Landslides Divided by Slope Surface Area (no./m^2)	1.495×10^{-6}	7.136×10^{-6}	4.891×10^{-6}	7.227×10^{-8}	2.953×10^{-7}	2.199×10^{-7}
Annual Failure Rates (Major Landslides)	On Slope Number Basis	0%	0%	0%	0%	0%	0%
	On Slope Surface Area Basis	0%	0%	0%	0%	0%	0%
	Number of Landslides Divided by Slope Surface Area (no./m^2)	0	0	0	0	0	0

Note: 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	0.145%	0.0027%	1.481×10^{-6}
	Major Landslides	0%	0%	0
	Minor Landslides	0.145%	0.0027%	1.481×10^{-6}
Engineered Slopes	All Landslides	0.031% (0.053%)	0.0006% (0.0002%)	2.199×10^{-7} (3.433×10^{-7})
	Major Landslides	0% (0%)	0% (0%)	0 (0)
	Minor Landslides	0.031% (0.053%)	0.0006% (0.0002%)	2.199×10^{-7} (3.433×10^{-7})
Non-engineered Slopes	All Landslides	0.260% [8.4/4.9]	0.0083% [13.8/41.5]	4.891×10^{-6} [22.2/14.2]
	Major Landslides	0%	0%	0
	Minor Landslides	0.260%	0.0083%	4.891×10^{-6}

Legend:

0.031% (0.053%)	Annual failure rate of engineered slopes (considering all landslides) is 0.031% and that for slopes previously treated under the LPMP or LPMitP is 0.053%
0.260% [8.4/4.9]	Annual failure rate of non-engineered slopes (considering all landslides) is 0.260%, which is about 8.4 times and 4.9 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 2019

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%
2019	100%	99.97%

Note: See Figure 4.4 for a plot of annual success rates of engineered slopes against the target annual success rates from 1997 to 2019.

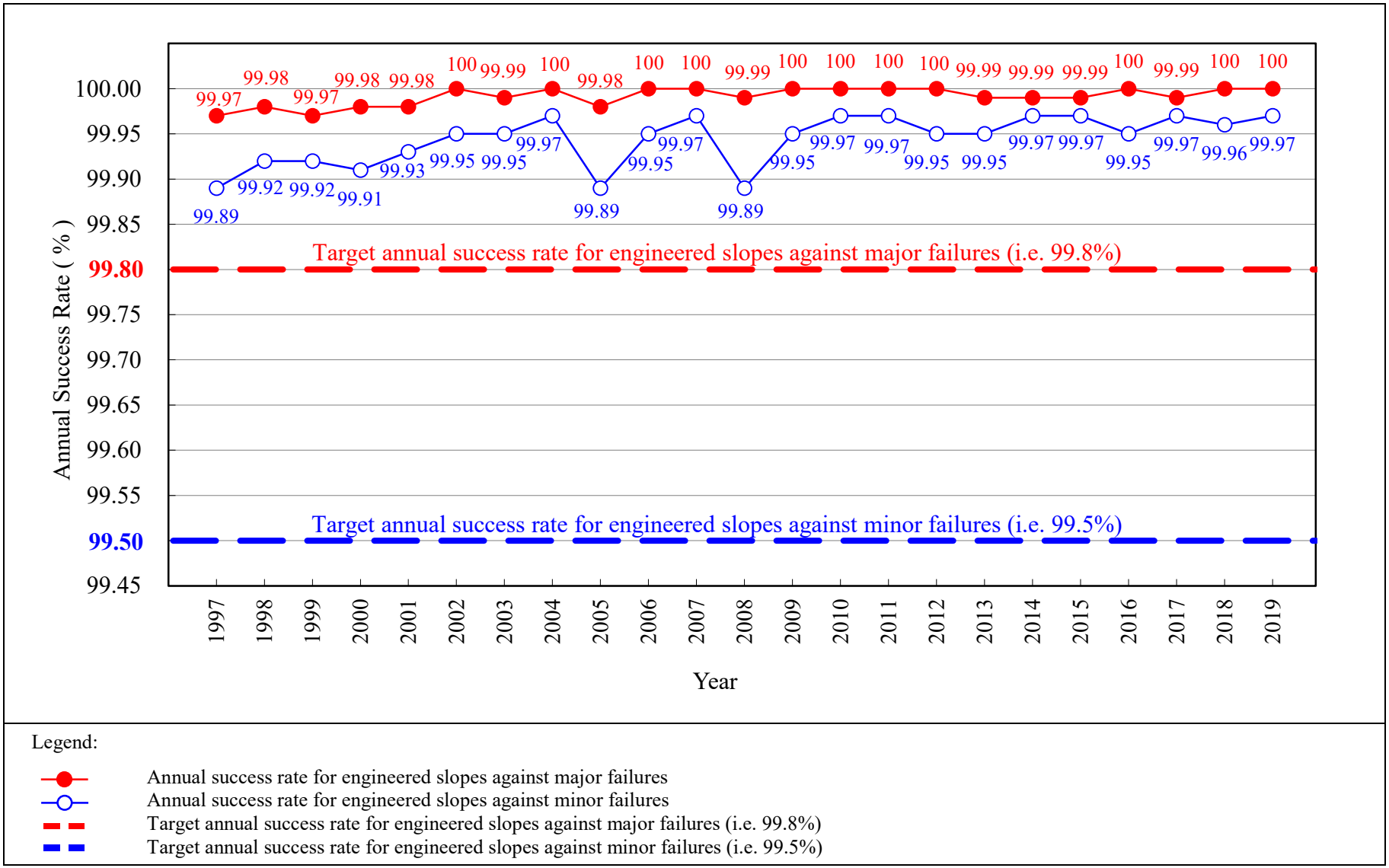

Figure 4.4 Annual Success Rates of Engineered Slopes from 1997 to 2019

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

All the 85 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 12 landslides, all of which were minor in failure scale. These constituted about 14% (i.e. 12 out of 85) of the landslides on registered man-made slopes. Among these 12 landslides, five occurred on engineered slopes.

Of these 12 landslides involving inadequate slope maintenance, eight affected government slopes, two affected private slopes and one affected a slope with unassigned maintenance responsibility at the time of failure. Another one affected a slope feature of mixed government/private maintenance responsibility, which occurred on the private portion of the slope. 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 it is not adequately maintained.

5 Proposed Improvement Initiative

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

(a) emphasise to the practitioners the good practice in inspection and maintenance of rock slopes protected with rock mesh, and to provide/adopt updated rock net details for robustness of the protection measures (Section 4.3.2).

6 Conclusions

Overall, 99.97% of the engineered man-made slopes performed satisfactorily without occurrence of landslides in 2019. There was no major landslide on engineering slopes in 2019.

The annual failure rate of minor landslides on engineered slopes, on a slope number basis, is 0.031% in 2019. This corresponds to an annual success rate of 99.97%, which is above the pledged annual success rate of 99.5%.

7 References

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Appendix A

List of 2019 Landslide Incidents Involving Unregistered Man-made Slopes but Registrable at the Time of Failure

Content

List of Table

Table A1 List of 2019 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)		
2019/04/2424	No. 1 Tai Shek Street, Sai Wan Ho	6 m	1/4	BD	Unknown	Rock cut	0.2 (Rockfall)	Minor footpath	-
2019/05/1008WS (WSD/2019/5/1/ HK&I)	Tai Tam Reservoir Road, Tai Tam	4 m	6/5	WSD	Unknown	Soil/rock cut	3 (Rockfall)	Minor footpath	-
2019/05/1009WS (WSD/2019/5/2/ HK&I)	Tai Tam Reservoir Road, Tai Tam	7 m	6/5	WSD	Unknown	Soil/rock cut	4	Access road	-
2019/06/2457	Below House No. 359, Big Wave Bay Village, Shek O	3 m	24/6	HAD	4/6	Soil cut	11.8	Minor footpath	-
2019/08/1037HY (HyD/HK/2019/ 08/0027)	Unallocated Government Land adjacent to Feature No. 11SW-B/C299, Borrett Road	4.9 m	9/8	HyD	9/8	Soil cut	0.4	Road	-

Table A1 List of 2019 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)		
2019/08/2488	No. 88A Pok Fu Lam Road	7 m	26/8	Police	26/8 (06:45)	Soil cut	10	Building; access road	Brick wall of the building partially collapsed

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 7)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope Failure	Remarks
1. Slopes Upgraded Under the LPMP/LPMitP ($\sum$ = 3 nos.)					
2019/05/2438	11SE-C/C59	Junction between Tai Hang Road and Mount Butler Road	0.1 (Rockfall)	Rock cut	The slope was upgraded under the LPMP in 2000. The incident involved the fallen out of a detached rock block years ago and at first behind the rock mesh at the slope toe. One day in 2019, the detached rock block dislodged from behind the rock mesh and deposited at the edge of the carriageway. Deterioration of slope conditions exacerbated by root wedging action probably destabilised the detached rock block rendering it to fall out from the bottom of the rock mesh.
2019/05/2440	11SW-D/CR586	Peak Road	0.01	Soil/rock cut	The slope was upgraded under the LPMP in 2000. The failure involved a shallow detachment on a local area of the slope (inclined at about 40°) between the bottom row of soil nails and the soil/rock interface. The pre-failure slope surface at this local area was sparsely vegetated. The failure was probably caused by the development of transient perched water table above the soil/rock interface as evidenced by the active seepage on the slope immediately below the scar observed during landslide inspection.

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
2019/07/2462	7SW-C/C282	Castle Peak Road, Kwai Chung	1.5 (Detachment of shotcrete cover)	Soil cut	The slope was upgraded under the LPMP in 2000. The incident involved local detachment of shotcrete cover on the slope which was probably caused by slope deterioration. Groundmass underneath the detached shotcrete cover was not affected.

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

Nil.

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

Nil.

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

Nil.

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

Nil.

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
6. <u>Slopes Formed or Upgraded by Government Departments and Checked by GEO</u> ($\sum$ = 3 nos.)					
2019/08/2482	6SE-C/C18	Near Rhine Terrace, Castle Peak Road, Sham Tseng	1.8 (Rockfall)	Rock cut	The slope was modified and upgraded under the "Improvement on Castle Peak Road" project in 2006. The incident involved rockfall from an area close to the slope toe that was covered with rock mesh. It was probably caused by the development of cleft water pressure within the adversely orientated rock joints that might have been opened up by root wedging action prior to the incident. The detached rock blocks were fully retained by the rock mesh. The bottom of the rock mesh was secured with a wire rope and remained in good contact with the slope toe. The incident is not regarded as a 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
2019/08/2490	7NE-D/C93	Ma Kam Street, Ma On Shan	20	Soil cut	The slope was formed under the project "Ma On Shan Development – Shatin New Town, Stage 2" in 1987 with the design checked and accepted by the GEO. The incident involved a washout failure at a lower portion of slope (inclined at about 30°) where the slope was densely vegetated. A stepped channel and a catchpit were severed within the erosion scar. Landslide inspection revealed that many channel sections and catchpits at upstream were subjected to varying degrees of blockage. The surface overflow onto the slope surface might have caused this washout failure. A similar washout failure was recorded in 2016 (GEO Incident No. 2016/04/1802) at the area immediately downslope of the present incident location.
2019/12/ 1050HD	11NE-A/CR115	Choi Wan (II) Estate, below Ngau Chi Wan Street	0.05	Fill	The slope was upgraded under a slope maintenance and improvement works project in 2016 with the design checked and accepted by the GEO. The incident involved a shallow washout in the approx. 200 mm thick capping soil fill at the portion of slope upgraded by fill replacement with rockfill. Above the capping soil fill, the slope portion was covered with erosion control mat and wire mesh (inclined at about 30º). The failure was probably caused by concentrated surface flow over the failure location as resulted from the bursting of a water main underneath the pedestrian pavement at slope crest.

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
7. Slopes Formed or Upgraded By Private Owner and Checked by GEO ($\sum$ = 2 nos.)					
2019/06/2450	7NW-B/C586	Behind No. 104 and 105 Château de Mansion, Ha Wong Yi Au, Tai Po	10	Soil cut	The slope was formed as part of the site formation works for the development of Château de Mansion in 1998 with the design checked and accepted by the GEO. The incident involved a shallow washout failure of the unsupported cut slope. The slope was inclined at about 30º to 45º and the slope surface was sparsely vegetated. A slight topographic depression above the slope might have directed concentrated surface runoff onto the incident location causing the failure.
2019/10/2509	11SE-A/C56	Wai Tsui Crescent, North Point	0.12 (Rockfall)	Rock cut	The slope portion on which the incident occurred was formed by cutting under a private residential development project in 1984 with the design checked and accepted by the GEO. The incident involved a wedge failure giving rise to the detachment of rock blocks from a sub-vertical bare rock cut face. The failure was probably caused by the build-up of cleft water pressure within the adversely orientated joints as suggested by the signs of seepage on the scar observed during the landslide inspection.

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
8. Slopes Upgraded Following Service of DH Orders and Checked by GEO ($\sum$ = 2 nos.)					
2019/05/2435	11NW-A/C139	Lim Cho Street, Kwai Chung	0.05 (Rockfall)	Rock cut	The slope was upgraded in 1998 following a DH Order served by the BD in 1996. The incident involved rockfall originated from a local bare rock cut portion. The rockfall was sourced from an area adjacent to a recently felled tree. The root wedging action could have opened up the adversely orientated joints causing the failure.
2019/09/2500	11SE-A/CR43	Behind Sky Scraper, Tin Hau Temple Road, North Point	0.16 (Rockfall)	Rock cut	The slope portion (Sub-division 2) on which the incident occurred was subjected to a D-Notice served by the BD in 1983. The order was discharged following the completion of slope remedial works in 1984. The incident involved rockfall originated from the bare rock cut face adjacent to two concrete buttresses. The failure was probably caused by the development of cleft water pressure within the adversely orientated joints that might have been opened up by root wedging action prior to the incident.

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
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 cut slope ($\sum$ = 1 no.)

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 post-1977 features but are not regarded as engineered slopes for the purpose of this report.

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