Review of Landslides in 2020

GEO Report No. 352

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 the landslides in 2020 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 Mr P.K.S. Chau. 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 C.M. Leung, Mr S.Y. Tse and Mr H.S. Mak is gratefully acknowledged.

Raymond W.M. Cheung
Head of the Geotechnical Engineering Office

Abstract

This report presents the findings of a diagnostic review of the landslides in 2020 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, 214 genuine landslides in 2020 were reported to the Government, of which seven were major landslides (viz. failure volume of 50 m^3 or more). There were 13 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 0.041% 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 2020.

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1 Introduction

This report presents the findings of a diagnostic review of the landslides in 2020 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 the 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 2020. 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 and Fugro (Hong Kong) Limited.

2 Rainfall and Landslides in 2020

The factual information, together with the relevant statistics on rainfall and reported landslides in 2020, was documented by Kong et al (2021).

In 2020, the annual rainfall recorded at the Principal Raingauge of the Hong Kong Observatory (HKO) in Tsim Sha Tsui was 2395.0 mm, near the mean annual rainfall of 2398.5 mm between 1981 and 2010. Two Landslip Warnings were issued respectively on 6 June and 19 August 2020. Eleven Red Rainstorm Warnings and 30 Amber Rainstorm Warnings were issued between 21 May and 5 October 2020, and between 17 February and 5 October 2020 respectively. In addition, two Black Rainstorm Warnings were issued on 6 June and 30 September 2020.

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 234 reported incidents in 2020, 214 were genuine landslides, discounting the non-landslide incidents (e.g. tree falls). There were seven major failures, corresponding to about 3.3% of the number of genuine landslides.

The distribution of landslides, as classified by the types of slope failures, is given in Table 2.1. The range of facilities affected by the landslides is summarised in Table 2.2. The consequences of the landslides in relation to the types of slope failures are summarised in Table 2.3. The distribution of the different facility groups affected by major landslides is presented in Table 2.4. The distribution of the scale of failures, as classified by the types of slopes involved, is given in Table 2.5.

Table 2.1 Breakdown of Landslides by Types of Slope Failures

Types of Slope Failures		Number	Percentage (%)
Fill Slopes		15 (0)	7.0
Cut Slopes	Soil	103 (3)	48.1
	Soil/Rock	18 (1)	8.4
	Rock	10 (0)	4.7
Retaining Walls		14 (0)	6.5
Natural Hillside		54 (3)	24.3
Total		214 (7)	100

Legend:

18 (1) Eighteen 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)	1 (0)	10 (1)	12 (1)
Registered Squatter Dwellings	0	0	15 (0)	15 (0)
Roads	15 (1)	3 (0)	29 (1)	47 (2)
Transportation Facilities (e.g. railways, tramways, etc.)	0	0	0	0
Pedestrian Pavements/Footways	1 (0)	1 (0)	4 (1)	6 (1)
Minor Footpaths/Access Paths/ Access Roads	4 (0)	4 (0)	71 (3)	79 (3)
Construction Sites	0	0	0	0
Open Areas	1 (0)	5 (0)	14 (0)	20 (0)
Catchwaters	3 (0)	0	9 (0)	12 (0)
Others (e.g. carparks, parks, playgrounds, gardens, backyards, etc.)	2 (0)	2 (0)	18 (1)	22 (1)
Nil	2 (0)	0	6 (0)	8 (0)
Total	29 (1)	16 (0)	176 (7)	221 (8)

Legend:

18 (1) Eighteen 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	1 (1)	0	0	0	1	0	0
Cut Slopes	Soil	0	0	0	10	1	1	0	0
	Soil/Rock	0	0	0	7	0	0	0	0
	Rock	0	0	0	2	0	1	0	0
Retaining Walls		0	1 (1)	0	0	0	1	0	0
Natural Hillside		0	1 (1)	0	4	0	0	0	0
Total		0	3 (3)	0	23	1	4	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.

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	5	0
Major Landslides on Man-made Slopes	0	0	0	0	1	3	0
Major Landslides on Natural Hillside	0	1	0	0	0	2	0

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 $< 500\ m^3$)	($\geq 500\ m^3$)	
Registered Man-made Slopes	102	4	0	106
Unregistrable Man-made Slopes	47	0	0	47
Registrable Man-made Slopes Not Yet Registered at Time of Failure	7	0	0	7
Natural Hillside	51	3	0	54
Total	207	7	0	214

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, 2021a). The LPI is calculated for rainstorms that prompted 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 prompted Landslip Warnings from 1985 to 2020 is presented in Figure 3.1.

In 2020, two Landslip Warnings were issued respectively on 6 June and 19 August 2020 and the corresponding LPIs were assessed as 18 and 10 respectively. In terms of the potential to cause landslides, the rainstorm of 6 June 2020 was about one-sixth 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 2020 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 inspections and other geotechnical inspections or studies will also be registered in the Catalogue of Slopes (GEO, 2021b) should they satisfy the slope registration criteria.

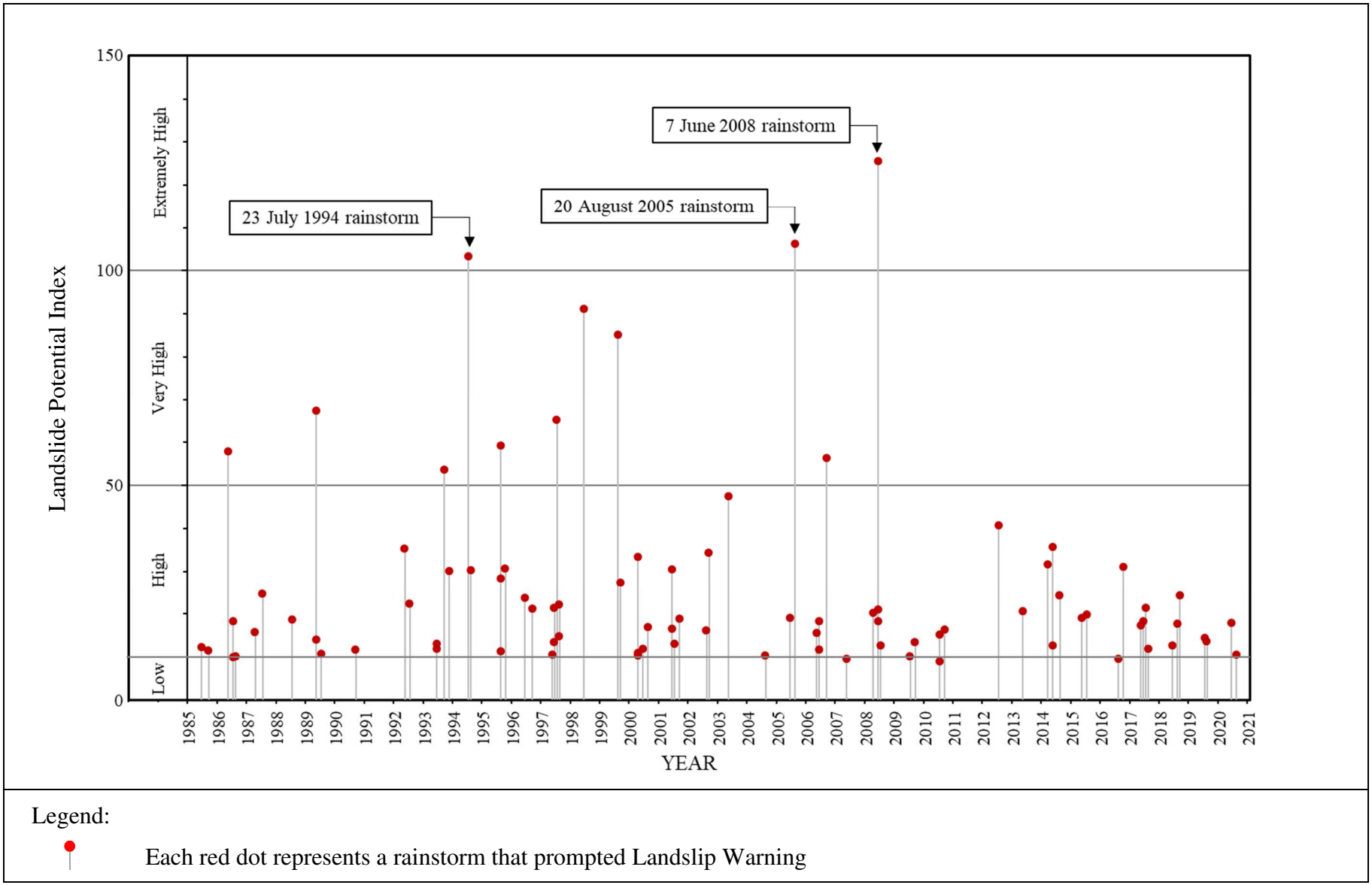


Figure 3.1 Landslide Potential Index for Rainstorms that Prompted Landslip Warning from 1985 to 2020

4.2.2 Diagnosis

Of the 214 genuine landslides, 106 occurred on registered man-made slopes and the other 108 occurred on slopes not registered in the Catalogue of Slopes (Table 2.5).

Among the above 108 landslides on slopes not registered, 54 occurred on natural hillside, 47 occurred on small man-made slope features that do not meet the slope registration criteria (DEVB, 2018). The remaining seven landslides, corresponding to 3.3% of the total number of genuine landslides in 2020, 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 108 landslides is given in Figure 4.1.

The seven landslides involving registrable slopes were all minor failures with failure volume up to about 47 m^3 (refer to Appendix A for details). Amongst these seven minor failures, one resulted in temporary evacuation of a squatter dwelling and two resulted in temporary closure of an access road and a 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 47 landslides involving unregistrable man-made slope features were all minor failures with failure volume up to about 18 m^3. Two incidents resulted in temporary road lane closure and one led to temporary closure of a footpath.

4.3 Performance of Registered Man-made Slopes

4.3.1 General

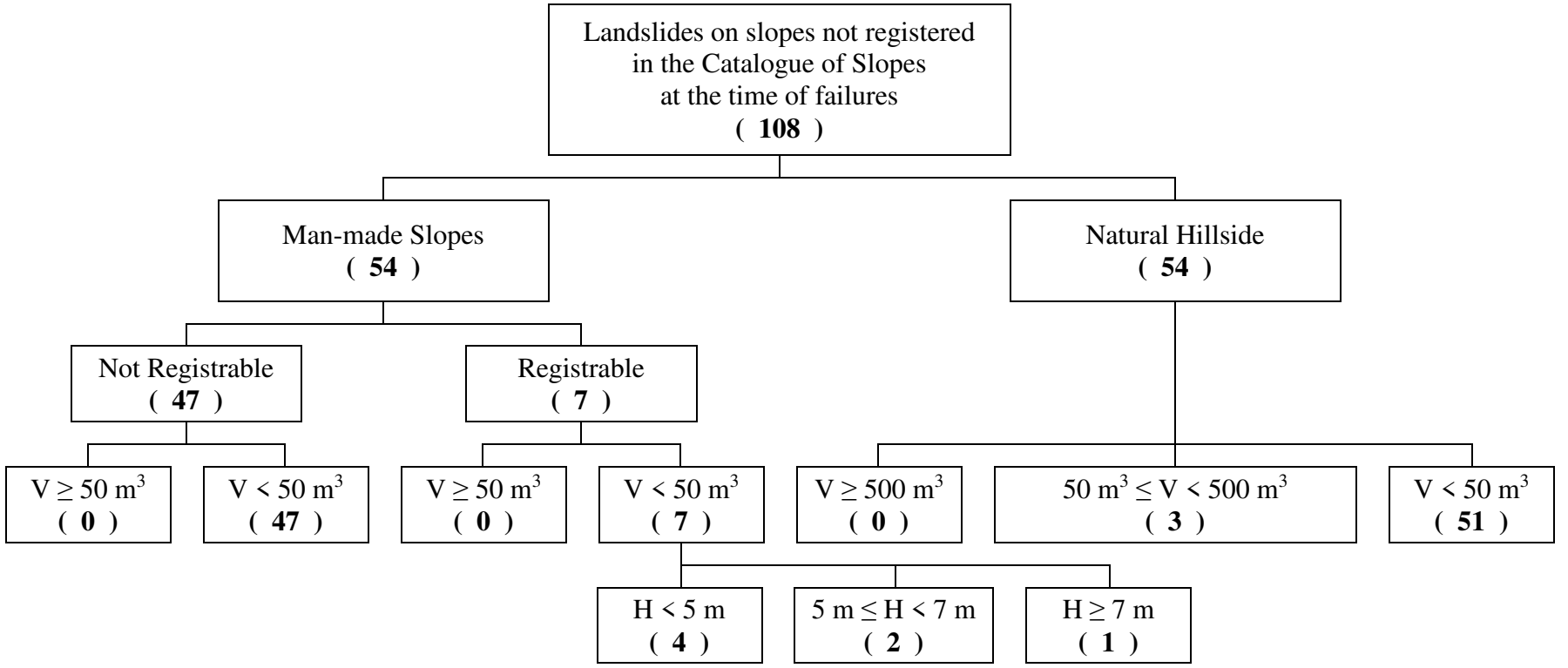
The man-made slopes registered in the Catalogue of Slopes can be broadly classified into engineered slopes and non-engineered slopes. The performance of the registered man-made slopes is reviewed in terms of their annual failure rates.

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
(54)	Number of landslide incidents = 54

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 2020

(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 214 genuine landslides in 2020, a total of 106 landslides (49.5%) occurred on registered man-made slopes (Table 2.5) and four of which were major failures. Of these 106 landslides, 13 landslides (about 12.3%) occurred on engineered slopes and the remaining 93 landslides occurred on non-engineered slopes. A breakdown of Consequence-to-life (CTL) categories of the registered man-made slopes involved in the 2020 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	11 (0)	1 (0)	1 (0)	13 (0)
Non-engineered Slopes	20 (1)	10 (1)	63 (2)	93 (4)

Legend:

20 (1) Twenty landslides, one of which was a major failure

Discussions of the landslides on engineered and non-engineered slopes in 2020 are given in Sections 4.3.2 and 4.3.3 respectively below.

4.3.2 Landslides on Engineered Slopes

Brief descriptions of the 13 landslides on engineered slopes in 2020 are given in Appendix B. A breakdown of these landslides in terms of feature type is given in Table 4.2. Among the 13 landslides, four involved slopes previously treated under the Landslip Preventive Measures Programme (LPMP) and two involved slopes previously treated under the Landslip Prevention and Mitigation Programme (LPMitP) (see Table 4.3).

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	2	0	0	0	0	2
≤ 5 m^3	1	4 (3)	3 (1)	3	0	11
Total	3	4 (3)	3 (1)	3	0	13

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/LPMitP

Scale of Failure (m^3)	Fill Slopes	Cut Slopes			Retaining Walls	Total
		Soil	Soil/Rock	Rock		
> 500 m^3	0	0	0	0	0	0
50 m^3 to 500 m^3	0	0	0	0	0	0
> 5 m^3 to < 50 m^3	0	0	0	0	0	0
≤ 5 m^3	0	2 (1)	3 (1)	1	0	6
Total	0	2 (1)	3 (1)	1	0	6

Legend:

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

One landslide involved a sliding failure on a soil/rock cut slope (volume of about 3 m^3).

Post-landslide inspection revealed that the scar was within a localized unsupported pocket of Grade IV/V materials on the cut slope. The failure was controlled by adversely orientated relict joints. Infiltration leading to the build-up of water pressure within the weathered rock mass could have caused the failure.

One landslide involved the minor detachment of Grade V materials from a small vertical chunam-covered slope face (about 2 m high by 1.5 m wide) within the soil-nailed portion of a

cut slope (volume of 0.8 m^3). The vertical slope profile with limited surface support at this locality had predisposed this small slope portion to the risk of local failure.

Five landslides involved minor washout failures. Two occurred on fill slopes (volume $\leq$ 20 m^3) and the other three are on soil-nailed cut slopes (volume $\leq$ 3 m^3). The largest washout occurred on a compacted rockfill slope below a construction site, where the temporary site drainage might have been overwhelmed under an intense rainfall which led to overflow onto the slope causing the failure. The other four were generally associated with adverse site settings, inadequate slope maintenance and/or inadequate drainage detailing.

Five landslides involved minor rockfalls (volume $\leq$ 3 m^3) primarily due to root wedging action. Post-landslide inspections revealed that two incidents involved detachment of rock blocks from bare rock cut faces. The other three originated from slopes covered with rock mesh. Fallen rock blocks were fully retained by rock mesh in one case and this incident was not regarded as a failure in accordance with GEO Technical Guidance Note No. 10 (GEO, 2020). 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, 2020).

The remaining landslide involved the distress of a compacted fill slope with soil loss of about 5 m^3. It was probably associated with leakage of collected runoff from a cracked channel on the slope.

Two of the 13 landslides on engineered slopes resulted in temporary closure of an emergency vehicular access and an exit of an MTR station. The remaining cases did not result in any significant consequence.

4.3.3 Landslides on Non-engineered Slopes

There were 93 landslides on non-engineered slopes in 2020, among which four of them were major and 89 were minor landslides.

The four major landslides involved failures volume ranged from 75 to 100 m^3. The incident on a CTL Category 2 slope at Shan Liu Ha Road resulted in damage of three parked cars and a CTL Category 3 slope at Fei Ngo Shan Road resulted in temporary road closure. The other two incidents that occurred on CTL Category 1 and 3 slopes did not have any notable consequence.

Of the 89 minor landslides, 43 of them were relatively small in scale with a failure volume less than 5 m^3. Three incidents resulted in temporary road closure. The rest did not result in any notable consequence.

4.3.4 Landslides Occurring in the Vicinity of Registered Squatter Structures

Fifteen landslides occurred on slopes located in the vicinity of registered squatter structures, of which seven occurred on registered slopes, four on unregistrable man-made slopes, two on registrable man-made slopes but not yet registered at time of failures, and two

on natural hillside. All the 15 landslides were minor in scale. For those registered man-made slopes involved in the landslides, two were engineered and five were non-engineered.

In five of the 15 landslides, the nearby squatter structures were not affected by the landslide debris as the structures were located aside/beyond the debris front. The landslide debris reached the squatter structures in the other ten landslides. In these cases, five 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 2020 incidents, no NDC recommendations were made for the remaining five cases either because the affected squatter structures were on a private lot/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.

The annual failure rates for all genuine landslides on registered man-made slopes in 2020 correspond to about 0.183% (number of landslides divided by number of registered man-made slopes), 0.0052% (total surface area of landslides divided by total surface area of registered man-made slopes), and about 1.873×10^{-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 2020 (Table 4.5), the annual failure rates of engineered slopes are lower than that of non-engineered slopes by a factor of about 8 on a slope number basis, and about 62 on a slope surface area basis. In terms of the number of landslides per total slope surface area, the corresponding failure rate of engineered slopes is about 21 times lower than that of non-engineered slopes.

[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.

Table 4.4 Annual Failure Rates of Registered Man-made Slopes in 2020

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 2020	Number of Slopes	10	83	93	3	9	12
	Surface Area of Landslides (m^2)	497	2,293	2,790	60	64	124
Slopes Involved in Major Landslides in 2020	Number of Slopes	0	4	4	0	0	0
	Surface Area of Landslides (m^2)	0	455	455	0	0	0
Slopes Involved in Minor Landslides in 2020	Number of Slopes	10	79	89	3	9	12
	Surface Area of Landslides (m^2)	497	1,838	2,335	60	64	124
Total Number of Registered Slopes		10,830	17,420	28,250	12,730	16,320	29,050
Total Surface Area of Registered Slopes (m^2)		5,946,760	9,089,170	15,035,930	13,878,060	27,141,510	41,019,570
Annual Failure Rates (All Landslides)	On Slope Number Basis	0.092%	0.476%	0.329%	0.024%	0.055%	0.041%
	On Slope Surface Area Basis	0.0084%	0.0252%	0.0186%	0.0004%	0.0002%	0.0003%
	Number of Landslides Divided by Slope Surface Area (no./m^2)	1.682×10^{-6}	9.132×10^{-6}	6.185×10^{-6}	2.162×10^{-7}	3.316×10^{-7}	2.925×10^{-7}
Annual Failure Rates (Major Landslides)	On Slope Number Basis	0%	0.023%	0.014%	0%	0%	0%
	On Slope Surface Area Basis	0%	0.0050%	0.0030%	0%	0%	0%
	Number of Landslides Divided by Slope Surface Area (no./m^2)	0	4.401×10^{-7}	2.660×10^{-7}	0	0	0

Note: One incident involving fallen rock fully retained by rock mesh netting has 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	0.183%	0.0052%	1.873×10^{-6}
	Major Landslides	0.007%	0.0008%	7.136×10^{-8}
	Minor Landslides	0.176%	0.0044%	1.802×10^{-6}
Engineered Slopes	All Landslides	0.041% (0.086%)	0.0003% (0.0006%)	2.925×10^{-7} (5.518×10^{-7})
	Major Landslides	0% (0%)	0% (0%)	0 (0)
	Minor Landslides	0.041% (0.086%)	0.0003% (0.0006%)	2.925×10^{-7} (5.518×10^{-7})
Non-engineered Slopes	All Landslides	0.329% [8/3.8]	0.0186% [62/31]	6.185×10^{-6} [21.1/11.2]
	Major Landslides	0.014%	0.0030%	2.660×10^{-7}
	Minor Landslides	0.315%	0.0155%	5.919×10^{-6}

Legend:

0.041% (0.086%)	Annual failure rate of engineered slopes (considering all landslides) is 0.041% and that for slopes previously treated under the LPMP or LPMitP is 0.086%
0.330% [8/3.8]	Annual failure rate of non-engineered slopes (considering all landslides) is 0.330%, which is about 8 times and 3.8 times higher than those of engineered slopes and slopes previously treated under the LPMP or LPMitP respectively

In 2020, four landslides involved slopes treated under the LPMP and two involved slopes treated under the LPMitP. The annual failure rates of slopes previously treated under the LPMP or LPMitP correspond to 0.086% (number of landslides divided by number of registered man-made slopes treated under the LPMP or LPMitP), 0.0006% (total surface area of landslides divided by total surface area of registered man-made slopes treated under the LPMP or LPMitP), and about 5.518×10^{-7} (number of landslides divided by total surface area of registered man-made slopes treated under the LPMP or LPMitP in m^2) respectively, as summarised in Table 4.5. The annual failure rate of slopes previously treated under the LPMP or LPMitP is lower than that of non-engineered slopes by a factor ranging from about 4 to 31, 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 2020, 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 2020 is shown in Table 4.6 and Figure 4.2.

4.4 Natural Terrain Landslides

A total of 54 natural terrain landslides were reported in 2020, among which 51 were minor and three were major in scale. The incident with the largest failure volume of about 100 m^3 involved an open hillslope failure at Tai Po where the landslide debris resulted in damage of a village house and temporary closure of a footpath (Kong et al, 2021). Another major landslide resulted in temporary road closure. No notable consequence was resulted from the remaining major landslide.

The 51 minor incidents involved open hillslope failures (up to about 44 m^3), boulder falls / rockfalls (up to 15 m^3) originating from natural hillside and washout failures or surface erosion of the hillside (up to about 40 m^3). One incident resulted in temporary evacuation of a registered squatter dwelling and another one resulted in damage of a parked car. Four incidents resulted in temporary closure of roads.

Among these 54 reported natural terrain landslides, six of which were located within existing Historical Landslide Catchments (HLC) (Ho & Roberts, 2016). 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) (Ho & Roberts, 2016). Ten other failures were located within 50 m from the existing HLC, none of which with debris trails close to any important downslope facilities. These 16 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.

Table 4.6 Annual Success Rates of Engineered Slopes from 1997 to 2020

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%
2020	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 2020.

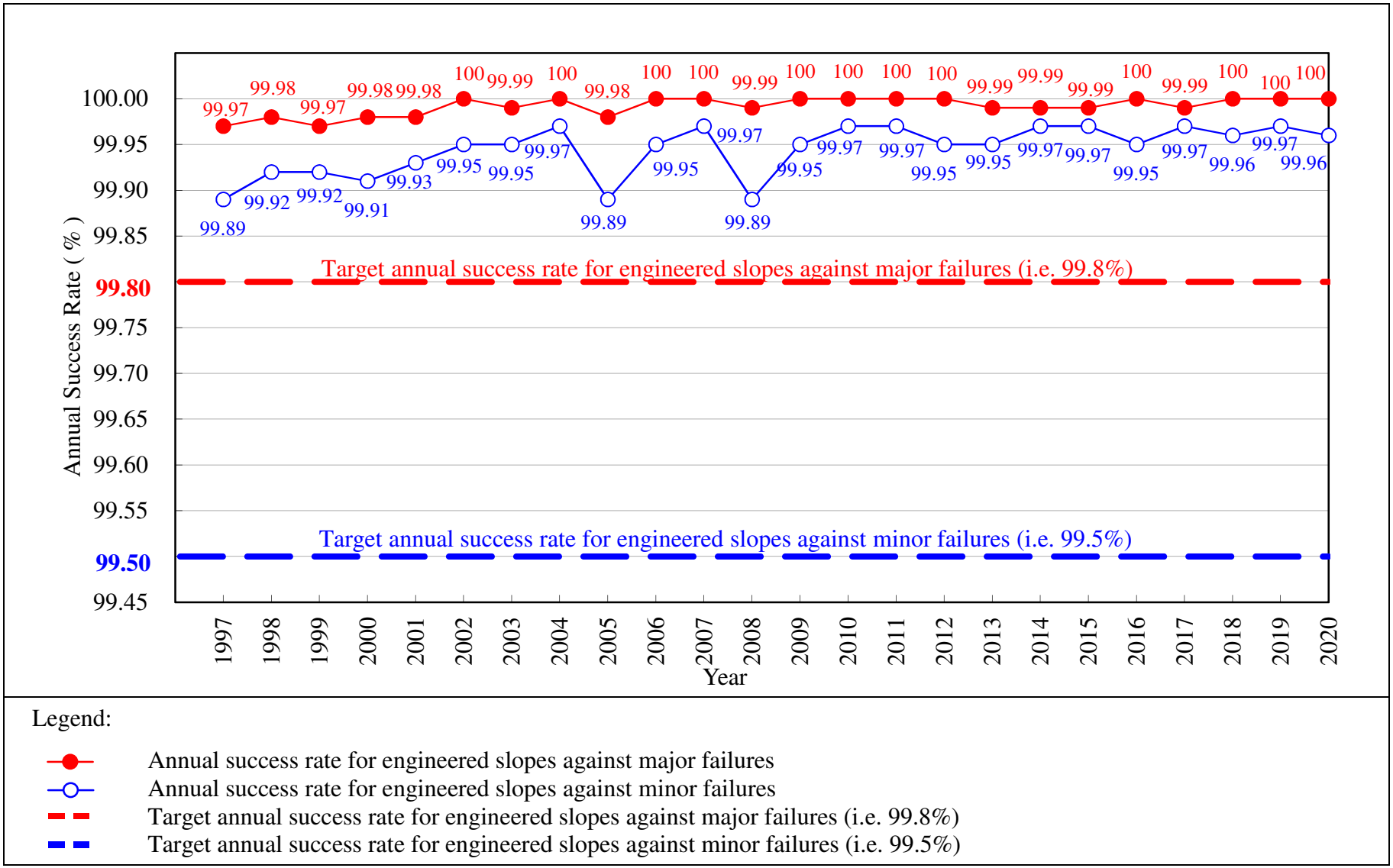


Figure 4.2 Annual Success Rates of Engineered Slopes from 1997 to 2020

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

All the 106 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 19 landslides, one of which was a major failure. These constituted about 18% (i.e. 19 out of 106) of the landslides on registered man-made slopes. Among these 19 landslides, six occurred on engineered slopes.

Of these 19 landslides involving inadequate slope maintenance, ten affected government slopes, six affected private slopes, one affected a slope with unassigned maintenance responsibility at the time of failure. Another two affected slope features of mixed government/private maintenance responsibility, of which one occurred on the government portion and the other one occurred on the private portion 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 it is not adequately maintained.

5 Improvement Initiative

Improvement initiative proposed by Kong et al (2020) following a review of landslides in 2019 and the associated progress of the follow-up actions are summarised in Appendix C.

6 Conclusions

Overall, 99.96% of the engineered man-made slopes performed satisfactorily without occurrence of landslides in 2020. There was no major landslide on engineered slopes in 2020.

The annual failure rate of minor landslides on engineered slopes, on a slope number basis, is 0.041% in 2020. This corresponds to an annual success rate of 99.96%, which is above the pledged annual success rate of 99.5%.

7 References

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Appendix A

List of 2020 Landslide Incidents Involving Unregistered Man-made Slopes but Registrable at the Time of Failure

Content

List of Table

Table A1 List of 2020 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)		
2020/06/2648	Near Feature No. 7NW-B/F145, Nam Hang Village, Tai Po	4 m	7/6	FSD	Unknown	Soil cut	8	Minor footpath	-
2020/06/2655	No. 4A & 4B, Pun Shan Chau, Tai Po	5 m	8/6	BD	8/6	Fill	47	Registered squatter dwelling	One squatter with three persons temporarily evacuated
2020/06/2657	Along access road leading to Lam Kam Road (near lamp post No. VE4256)	3.3 m	7/6	Public	Unknown	Soil cut	1	Access road	Access road temporarily closed
2020/06/2658	Next to Feature No. 11NE-D/C173, along access road leading to Po Lam Road, Tseung Kwan O	3 m	8/6	Public	6/6 (06:24)	Soil cut	5.2	Nil	-
2020/06/2671	No. 35A Ma On Shan Tsuen	5 m	8/6	DLO	27/5	Soil cut	4	Registered squatter dwelling	-

Table A1 List of 2020 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)		
2020/06/2689	Near Feature No. 3SE-C/C138, Ha Tei Ha, Tai Po	3 m	10/6	LandsD	7/6	Soil cut	7	Minor footpath	-
2020/07/2828	Above Feature No. 7SW-C/C744 near Yam Hing House of Shek Yam East Estate	10 m	30/7	HD	29/7 (22:00)	Rock cut	40	Minor footpath	Minor footpath temporarily closed

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 ($\sum$ = 6 nos.)					
2020/06/1036LD (LandsD/2020/06/0376)	6NW-C/C222	Near Nam On Temple, Fu Tai Tsuen, Lam Tei	0.8	Soil cut	The slope was upgraded under the LPMP in 2005. The incident was located on the soil-nailed portion of a cut slope with a small vertical chunam-covered slope face of about 2 m high by 1.5 m wide. The failure involved minor detachment of Grade V materials of about 0.1 m thick. The vertical slope profile with limited surface support at this locality had predisposed this small slope portion to the risk of local failure.
2020/06/1037LD (LandsD/2020/07/0400)	7NW-B/CR224	To Yuen Tung, Ma Wo Road, Tai Po	1	Soil/rock cut	The slope was upgraded under the LPMitP in 2014. The failure location, inclined at about 45º, was soil-nailed and covered with erosion control mat. The incident involved a washout failure that might be attributed to the concentrated surface water flow from a local depression at the upslope area. No soil nail heads were exposed on the erosion scar.
2020/06/1048WS (WSD/2020/6/9/NTW)	6SE-C/CR618	Ch. 2500 Tai Lam Chung Catchwater Section L, Tai Lam Chung	3 (Rockfall)	Soil/rock cut	The slope was upgraded under the LPMP in 2005. The incident involved rockfalls from a rock slope surface that was covered with rock mesh. The failure was probably caused by the build-up of cleft water pressure within the rock joints as suggested by the signs of seepage on the rock face observed during the landslide inspection. Root wedging action had played a contributory role in the rockfalls. The debris was fully retained by the rock mesh. The incident is not regarded as a failure.

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
2020/07/2717	7SE-A/C117	Southeast of Rosary Villas, Fo Tan, Sha Tin	3	Soil/rock cut	The slope was upgraded under the LPMitP in 2011. The incident involved a sliding failure on a section of slope of about 3 m high inclined at about 70º. The scar was within the "rock portion" of the slope as considered in the design. The supplementary geotechnical assessment conducted during construction identified a pocket of Grade IV/V materials which coincided with the present failure scar. Post-failure inspection revealed that the failure at this localized unsupported zone was controlled by adversely orientated relict joints. Infiltration leading to the build-up of water pressure within the weathered rock mass could have caused the failure.
2020/07/2723	11NW-B/C39	Near Shek Kip Mei MTR Station Exit B1, Shek Kip Mei	0.063 (Rockfall)	Soil/rock cut	The slope was upgraded under the LPMP in 1988. The incident involved the detachment of small rock blocks from a bare face of the lower rock batter (inclined at about 50º). Tree roots growth was noted over the rockfall location. Root-wedging action could be the principal cause of the failure. The failure resulted in temporary closure of an exit of Shek Kip Mei MTR Station.
2020/10/1065WS (WSD/2020/10/1/NTW)	11NW-A/C206	Lai Chi Kok Saltwater Pumping Station	0.76 (Rockfall)	Rock cut	The slope was upgraded under the LPMP in 2003. The incident occurred on a sub-vertical rock face near the slope toe that was covered with rock mesh. It involved the falling of rock blocks from wedging planes probably due to the development of cleft water pressure within the adversely orientated joints that might have been opened up by root wedging action. Some of the rockfall debris under-passed the rock mesh and deposited at the slope toe.

Table B1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 3 of 7)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope Failure	Remarks
2.	Slopes Assessed under the LPMP with No Upgrading Works Required ($\sum$ = 0 no.)				
	Nil.				
3.	Slopes Assessed by Studies in the late 1970's to mid-1980's with No Upgrading Works/Further Study Required ($\sum$ = 0 no.)				
	Nil.				
4.	Slopes Assessed by Government Departments and Checked by GEO with No Upgrading Works Required ($\sum$ = 0 no.)				
	Nil.				
5.	Slopes Assessed by Private Owners and Checked by GEO with No Upgrading Works Required ($\sum$ = 0 no.)				
	Nil.				

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
6.	Slopes Formed or Upgraded by Government Departments and Checked by GEO ($\sum$ = 3 nos.)				
2020/06/2644	11NE-D/F62	Above roundabout at Oi Tat House, On Tat Estate, Sau Mau Ping	20	Fill	The slope was formed under the site formation project for the development at Anderson Road in 2013 with the design checked and accepted by the GEO. The incident involved a washout failure on a compacted rockfill slope below a construction site during which construction was in progress. The eroded areas were below the low point of the site adjacent to a major outlet of the temporary site drainage system. Under the intense rainfall, the temporary site drainage might have been overwhelmed with overflow onto the slope causing the failure. The failure resulted in temporary closure of an emergency vehicular access at Oi Tat House.
2020/06/1029HY	7SW-D/CR126	Mei Tin Road near lamp post No. CE0637	3	Soil cut	The slope was modified and upgraded under a road development project at Shatin in 2005 with the design checked and accepted by the GEO. The failed portion was inclined at about 50º. It was located below the bottom row of soil nails where the slope surface was covered with erosion control mat. The incident involved a washout failure which was probably caused by overflow from partially blocked drainage with a channel bend above the failure location.

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
2020/06/1030HY	7SW-D/F576	Mei Tin Road near lamp post No. CE0637	5	Fill	The slope was formed under a road development project at Shatin in 2005 with the design checked and accepted by the GEO. The incident involved the distress of a compacted fill slope with soil loss. It was associated with leakage of collected runoff from a cracked channel at the slope mid-height.
7.	Slopes Formed or Upgraded By Private Owner and Checked by GEO ($\sum$ = 4 nos.)				
2020/05/2616	15NW-A/CR18	Lee Wing Street, Ap Lei Chau	0.03 (Rockfall)	Rock cut	The slope portion (Sub-division 1) within which the incident occurred was formed as part of the site formations works for a private development project in 1987 with the design checked and accepted by the GEO. The rockfall was originated from a bare rock cut portion at about 6 m above the slope toe. Root wedging action on the adversely orientated rock joints could be the key factor causing the failure.
2020/06/2629	11NE-B/FR284	Behind village house Nos. 131 to 133, Pik Uk Tsuen, Clear Water Bay Road, Sai Kung	6	Fill	The slope was formed during the private development for village houses in 1996. The landslide involved a washout failure on a 30º inclined fill slope. The failure location was situated below a local low point of a paved platform. Coupled with the blockage of the drainage system upslope, the failure was probably caused by water overflow.

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
2020/06/2653	10NE-A/C72	No. 46 Tin Liu Village, Ma Wan	1	Soil cut	The slope was upgraded by soil nails in a private development project for Ma Wan Park in 2008 with the design checked and accepted by the GEO. The incident involved the shallow washout failure (about 200 mm deep) at two local areas of the slope inclined at about 60º, both located between the bottom row of the soil nails and the slope toe. The failure might be attributed to concentrated surface runoff directed from the uphill sloping terrain and the paved playground at crest.
2020/08/2832	11SW-D/C253	Nos. 74-76 Peak Road, the Peak	0.1 (Rockfall)	Rock cut	The slope was upgraded as part of the site formation at No. 74-76 Peak Road around 1983 with the design checked and accepted by the GEO. The incident involved minor rockfalls sourced from about 1.5 m above slope toe and was originated from the local steep rock cut portion where rock mesh was installed. The rock mesh was severed with the fallen rock debris deposited on the carriageway. The rockfall was probably caused by the development of cleft water pressure on the adversely orientated rock joints.

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

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope Failure	Remarks
8.	Slopes Upgraded Following Service of DH Orders and Checked by GEO (∑ = 0 no.)				
	Nil.				
9.	Slopes Assessed as Not Requiring Upgrading Works But with Outstanding GEO Comments (∑ = 0 no.)				
	Nil.				
10.	Slopes Assessed as Requiring Upgrading Works But with Outstanding GEO Comments (∑ = 0 no.)				
	Nil.				

Legend:

Landslide occurred within the soil-nailed portion of a cut slope (∑ = 4 no.)
Landslide involved unsupported cut (∑ = 1 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 2019 Landslides

Content

List of Table

Table C1 Progress of Follow-up Actions on the Improvement Measure Recommended in the Review of 2019 Landslides

Recommended Improvement Measure	Progress
1. 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.	GEO Technical Guidance Note No. 10 (GEO, 2020) had been updated to highlight the good practice in design and maintenance of rock mesh on rock slopes.

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