Review of Landslides in 2012

GEO Report No. 312

R.W.H. Lee, J.C.W. Leung & D.O.K. Lo

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. Printed copies are also available for some GEO Reports. For printed copies, a charge is made to cover the cost of printing.

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H.N. Wong
Head, Geotechnical Engineering Office
July 2015

Foreword

This report presents the findings of a detailed diagnosis of landslides in 2012 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 to further enhance the slope engineering practice in Hong Kong.

The review was carried out by Mr R.W.H. Lee and Ms J.C.W. Leung and Dr D.O.K. Lo of Landslip Preventive Measures Division 1 under the supervision of initially Dr A.C.O. Li up to September 2013 and subsequently Mr Y. Lam. Assistance was provided by the landslide investigation consultants engaged by the Geotechnical Engineering Office, namely Fugro Scott Wilson Joint Venture and AECOM Asia Company Limited respectively. Technical support provided by Mr K.W. Cheung, Mr L.K.W. Hui and Mr C.M. Leung is gratefully acknowledged.

H.N. Wong
Head of the Geotechnical Engineering Office

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Abstract

This report presents the findings of a diagnostic review of the landslides in 2012 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 to further enhance the slope engineering practice in Hong Kong.

Altogether, 163 genuine landslides were reported to the Government in 2012. There were eight major landslides (viz. failure volume of 50 m^3 or more) and fourteen landslides (viz. failure volume of less than 50 m^3) occurred on engineered man-made slopes. The corresponding annual failure rate of engineered slopes is about 0.048% on a slope number basis (i.e. number of landslides relative to the total number of engineered slopes).

Overall, 99.95% of the engineered man-made slopes performed satisfactorily without occurrence of landslides in 2012.

Recommendations for further improvement of the slope safety system and slope engineering practice in Hong Kong are also given in this report.

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1 Introduction

This report presents the findings of a diagnostic review of the landslides in 2012 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 2012. The review has been carried out by the Landslip Preventive Measures Division 1 (LPM1) of the GEO, with assistance provided by GEO's LI consultants, namely Fugro Scott Wilson Joint Venture (FSWJV) and AECOM Asia Company Limited (AECOM).

2 Rainfall and Landslides in 2012

The factual information, together with the relevant statistics on rainfall and reported landslides in 2012, was documented by Leung et al (2013).

In 2012, the annual rainfall recorded at the Principal Raingauge of the Hong Kong Observatory (HKO) in Tsim Sha Tsui was 1,924.7 mm which is about 20 % below the annual average of 2,398.5 mm recorded between 1981 and 2010. One Landslip Warning was issued on 24 July 2012. No Black Rainstorm Warning was issued in 2012 but two Red Rainstorm Warnings were issued on 29 April and 24 September 2012 and 19 Amber Rainstorm Warnings were issued between 16 April and 24 September 2012.

Reported landslides are classified as follows:

(a) minor failure (i.e. failure volume < 50 m^3), and

(b) major failure (i.e. failure volume e 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 169 reported incidents in 2012, 163 were genuine landslides, discounting the non-landslide incidents (e.g. tree falls). There were eight major failures, corresponding to

about 5% of the number of genuine landslides.

The distribution of landslides, as classified by the type of slope failure, 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 type of slope failure are summarised in Table 2.3. The distribution of the different facility groups affected by the major landslide is presented in Table 2.4. The distribution of the scale of failures, as classified by the type of slope involved, is given in Table 2.5.

Table 2.1 Breakdown of Landslides by Type of Slope Failure

Type of Slope Failure		Number	Percentage (%)
Fill Slopes		7 (0)	4.3
Cut Slopes	Soil	63 (0)	38.7
	Soil/Rock	28 (0)	17.2
	Rock	9 (0)	5.5
Retaining Walls		9 (0)	5.5
Natural Hillsides		44 (8)	27.0
Registered Disturbed Terrain		3 (0)	1.8
Total		163 (8)	100.0

Legend:

44 (8) Forty-four landslides, eight of which were major failures

Notes:
(1) Where a landslide involved more than one type of failure, the predominant type of failure has been considered in the above classification.
(2) Incidents that were not genuine landslides have been excluded.

Table 2.2 Breakdown of Landslides by Type of Affected Facility

Type of Affected Facility	Hong Kong Island	Kowloon	New Territories and Outlying Islands	All
Buildings (including village houses)	0	0	6 (0)	6 (0)
Registered Squatter Dwellings	0	0	19 (0)	19 (0)
Roads	11 (0)	0	8 (1)	19 (1)
Transportation Facilities (e.g. railways, tramways, etc.)	0	0	0	0
Pedestrian Pavements/Footways	1 (0)	1 (0)	1 (0)	3 (0)
Minor Footpaths/Access Paths/ Access Roads	11 (0)	6 (0)	50 (4)	67 (4)
Construction Sites	2 (0)	0	0	2 (0)
Open Areas	3 (0)	1 (1)	17 (0)	21 (1)
Catchwaters	0	0	5 (0)	5 (0)
Others (e.g. carparks, parks, playgrounds, gardens, backyards, etc.)	5 (0)	1 (0)	15 (3)	21 (3)
Nil	2(0)	0	7 (0)	9 (0)
Total	35 (0)	9 (1)	128 (8)	172 (9)

Legend:

8 (1) Eight landslides of which one was 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 consequence refers to incidents where the landslide debris came to rest on the slopes, not affecting any facilities.

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Table 2.3 Breakdown of Landslide Consequences by Type of Slope Failure

Type of Slope Failure		Number of Squatter Dwellings (1) Evacuated		Number of Floors, Houses or Flats Evacuated or Partially Closed	Number of Closure			Deaths	Injuries reported to GEO
		Permanent	Temporary		Roads	Pedestrian Pavements	Footpaths, Alleyways or Access Paths		
Fill Slopes		0	0	0	0	0	0	0	0
Cut Slopes	Soil	2(2)	0	0	2	0	5	0	0
	Soil/Rock	0	0	0	2	0	1	0	0
	Rock	0	0	0	0	0	1	0	0
Retaining Walls		0	0	3(3)	0	0	0	0	0
Natural Hillsides		0	0	0	7	0	7	0	0
Registered Disturbed Terrain		0	0	0	0	0	0	0	0
Total		2(2)	0	3	11	0	14	0	0

Legend:

2(2) 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. structures built for domestic purposes or non-domestic purposes and registered in the 1982 Housing Department's Squatter Structure Survey (GEO, 2010a).

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

(3) A retaining wall failure (Incident No. 2012/05/1180) resulted in the temporary evacuation of 30 residents from 3 village houses at Yat Wing Garden, Tai Po.

Table 2.4 Breakdown of Facility Groups Affected by Major Landslides

Type of Major Landslide	Facility Group Affected by Major Landslides (Group No.)						
	1a	1b	2a	2b	3	4	5
All Major Landslides	0	0	0	0	0	3	6
Major Landslides on Man-made Slopes	0	0	0	0	0	0	0
Major Landslides on Registered Disturbed Terrain	0	0	0	0	0	0	0
Major Landslides on Natural Hillsides	0	0	0	0	0	3	6

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 Type of Slope

Type of Slope	Number of Minor Landslides (< 50 m³)	Number of Major Landslides		Total
		(50 m³ to < 500 m³)	(e 500 m³)	
Registered Man-made Slopes	72	0	0	72
Registered Disturbed Terrain Features	3	0	0	3
Unregistrable Man-made Slopes	35	0	0	35
Registrable Man-made Slopes Not Yet Registered at Time of Failure	9	0	0	9
Natural Hillsides	36	8	0	44
Total	155	8	0	163

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), as promulgated by the GEO (2009a). The LPI is calculated for rainstorms that resulted in the issue of Landslip Warning and is used to depict the relative severity of the rainstorm with respect to its potential to cause landslides. The LPI, which is not a predictive index, is based on the 24-hour rainfall of a rainstorm. The LPI for rainstorms that resulted in the issue of Landslip Warnings from 1984 to 2012 is presented in Figure 3.1.

In 2012, one Landslip Warning was issued on 24 July 2012 and its corresponding LPI was assessed to be 4. In terms of its potential to cause landslides, the rainstorm of 24 July 2012 was two-fifths 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 2012 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. Potentially registrable man-made slopes would also be identified during slope maintenance inspections, landslide investigations and other geotechnical inspections or studies (GEO, 2010b).

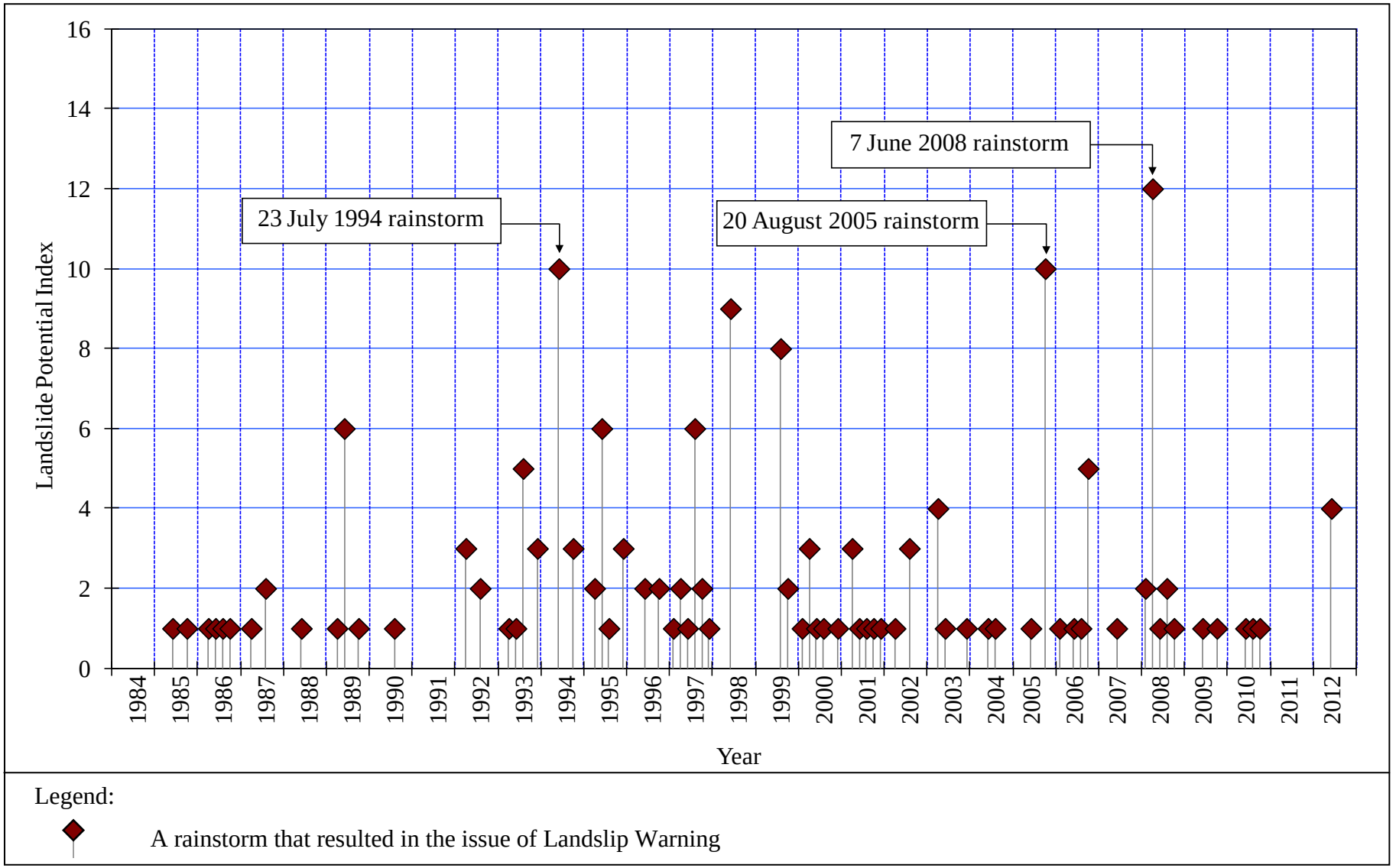

Figure 3.1 Landslide Potential Index for Rainstorms that Resulted in the Issue of Landslip Warnings from 1984 to 2012

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4.2.2 Diagnosis

Of the 163 genuine landslides, 75 occurred on registered slope features (comprising 72 on registered man-made slopes and 3 on a registered disturbed terrain features) and 88 occurred on slopes not registered in the Catalogue of Slopes (Table 2.5).

Among the above 88 landslides, 44 occurred on natural hillsides, 35 occurred on small man-made slope features that do not meet the slope registration criteria (GEO, 2004). The remaining 9 landslides, corresponding to 5.5% of the total number of genuine landslides in 2012, involved slope features that satisfy the slope registration criteria but was not registered in the Catalogue of Slopes at the time of failure. A breakdown of these 88 landslides is given in Figure 4.1.

The 9 landslide incidents involving registrable slopes were all minor failures with failure volume equal to or less than 40 m^3. Amongst these 9 minor failures, one resulted in permanent evacuation of two residents from two squatter structures at the north of Ham Tin Tsuen. The other incidents did not cause any significant impact on the community (Appendix A). Following the landslides, arrangements have been made to register the man-made slope features concerned in the Catalogue of Slopes.

The 35 landslides involving unregistrable man-made slope features were all minor failures with failure volume equal to or less than 40 m^3. One incident resulted in the temporary evacuation of 30 residents from 3 village houses at Yat Wing Garden, Tai Po.

4.3 Performance of Registered Man-made Slopes

4.3.1 General

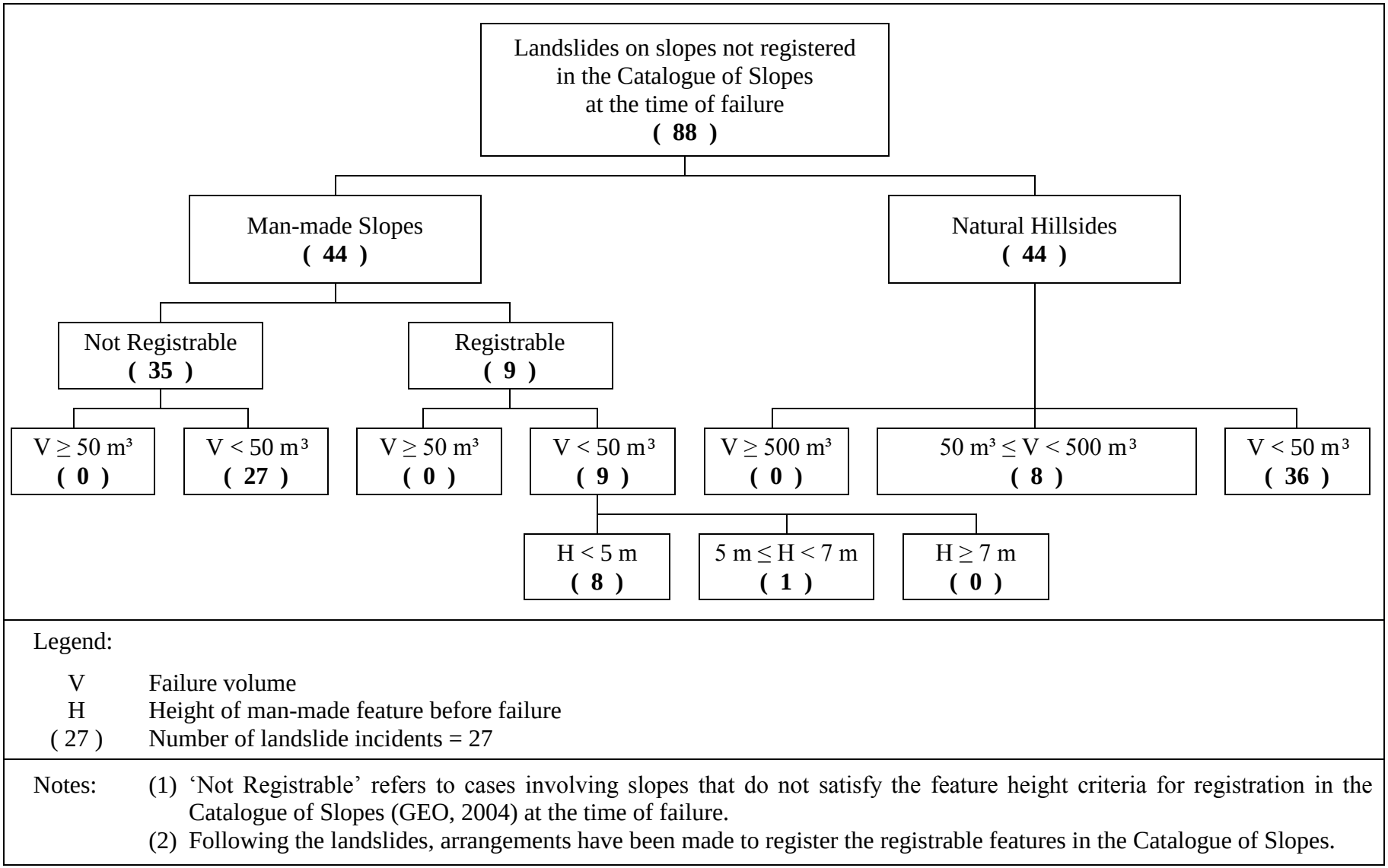
The man-made slopes registered in the Catalogue of Slopes can be broadly classified into engineered slopes and non-engineered slopes. The performance of the registered man-made slopes is reviewed in terms of their annual failure rates.

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
(27)	Number of landslide incidents = 27

Notes:

(1) 'Not Registrable' refers to cases involving slopes that do not satisfy the feature height criteria for registration in the Catalogue of Slopes (GEO, 2004) at the time of failure.

(2) Following the landslides, arrangements have been made to register the registrable features in the Catalogue of Slopes.

Figure 4.1 Breakdown of Landslides on Unregistered Slopes in 2012

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(d) slopes upgraded to the required geotechnical standards using Type 3 prescriptive measures (GEO, 2009b) 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 163 genuine landslides in 2012, a total of 72 landslides (about 44%) occurred on registered man-made slopes (Table 2.5). Of these 72 landslides, 14 (about 19%) occurred on engineered slopes, all of which were minor landslides. All of the remaining 58 landslide incidents that occurred on non-engineered slopes were minor failures. There was no major landslide occurring on consequence-to-life (CTL) Category 1 slope features in 2012. A breakdown of the CTL categories of the registered man-made slopes involved in the landslides is given in Table 4.1.

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

Type of Slope	No. of Landslides			Total
	CTL Cat.1	CTL Cat.2	CTL Cat.3	
Engineered Slopes	10 (0)	2 (0)	2 (0)	14 (0)
Non-engineered Slopes	16 (0)	4 (0)	38 (0)	58 (0)

Legend:

10 (0) Ten landslides, none of which was major failure

Further details of the landslides in 2012 involving engineered slopes are given in Appendix B. Detailed assessment of the engineered and non-engineered slopes is described in the sections below.

4.3.2 Landslides on Engineered Slopes

Brief descriptions of the 14 landslides on engineered slopes in 2012 are given in

Appendix B. A breakdown of these landslides in terms of feature type is given in Table 4.2. Among the 14 landslides, six involved slopes that have been previously upgraded under the Landslip Preventive Measures Programme (LPMP) (see Table 4.3).

Seven landslides involved minor rockfalls. One of the incidents involved a debris volume of 3 m^3 on Slope No. 7NW-D/C240 (Incident No. 2012/05/1011AD), where the debris was successfully retained by the rock mesh. The slope was upgraded in 2003. This incident was not regarded as an engineered slope failure in accordance with GEO Technical Guidance Note No. 10 (GEO, 2009c). On the other hand, Incident No. 2012/07/1200 occurred at a slope with rock mesh netting, but at the rockfall location the rock mesh was detached from the slope surface and hence unable to retain the dislodged rock blocks. It was observed that the rock surface was rugged and the rock mesh did not follow closely the profile of the rock cut surface. In addition, the designed spacing of the fixing points (i.e. 3 m c/c) for the rock mesh at the rockfall location was not met and no fixing points could be found at the bottom part of the mesh (Figure 4.2).

For the remaining rockfall incidents (Incident Nos. 2012/03/1152, 2012/06/1185, 2012/10/1241, 2012/10/1245 and 2012/10/1050WS), the fallen rock blocks/rockfall debris were deposited on the toe facilities, except for one case with the debris trapped by a chain-link fence at the slope toe.

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	1(1)	0	0	3
≤ 5 m^3	0	1	6(1)	4	0	11
Total	0	3	7(2)	4	0	14

Legend:

7(2) Of the seven landslides, two occurred within the soil-nailed portion of the slopes

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 m³	0	0	0	0	0	0
50 m³ to 500 m³	0	0	0	0	0	0
> 5 m³ to < 50 m³	0	1	1(1)	0	0	2
≤ 5 m³	0	0	3(1)	1	0	4
Total	0	1	4(2)	1	0	6

Legend:

4(2) Of the four landslides involved, two occurred within the soil-nailed portion of the slopes

Although these rockfall incidents were all minor in nature, they had caused a certain extent of public nuisance. Again, these incidents illustrated that minor rockfalls from rock slopes are hard to assess and be prevented, but the provision of surface protective measures such as rock mesh netting could be a pragmatic solution to deal with minor rockfalls. The rockfall incident No. 2012/07/1200 also illustrated that the importance of paying attention to the detailing of the rock mesh netting to ensure that it functions properly over time, in order to safeguard the public from even minor rockfalls.

Two incidents (Incident Nos. 2012/04/1164 and 2012/02/1149) involved minor detachment of old chunam surface on the slope portion maintained by private owners. Both of the incidents involved slopes which had been processed by the Buildings Department (BD) in the early 1980's. The incidents were probably related to the deterioration of the old chunam coupled with tree root wedging action locally on the slopes. The corresponding private owners of the slope portion had been requested to repair or replace the cracked or detached hard surface cover following the incidents.

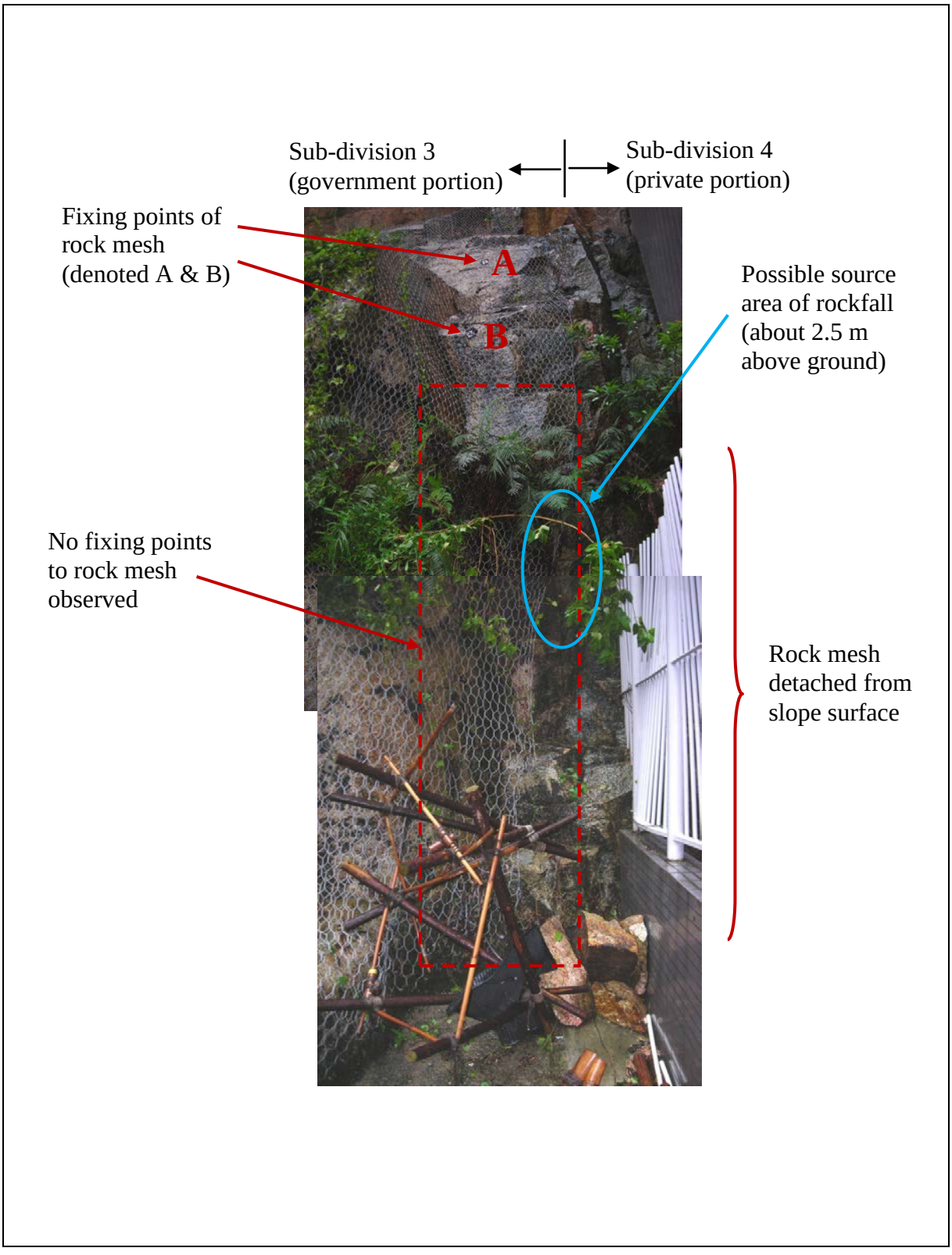

Figure 4.2 Detached Rock Mesh Netting at Slope No. 11SE-A/C84 near Mansion Street, Quarry Bay (Incident No. 2012/07/1200)

Two incidents (Incident Nos. 2012/07/1215 and 2012/03/1004AF) involved shallow washout failures on the soil-nailed portions of soil/rock cuts. The features involved were upgraded by means of soil nails under the LPMP in 2003/2004. Incident No. 2012/07/1215 involved a minor washout of the near-surface groundmass (landslide volume of 15 m^3) around the soil nail heads, and the presence of adversely orientated relict joints with weak infilling materials was noted on the failure scar. Incident No. 2012/03/1004AF involved a washout failure (landslide volume of 5 m^3) on a steeply inclined slope (about 70º) with the installed soil nails spaced widely apart (at 3 m c/c and 2 m c/c horizontal and vertical spacing respectively). The failure debris was fully retained by the existing wire mesh and erosion control mat. Both landslides did not affect the soil nails, and demonstrated the effectiveness of soil nails in preventing large-scale failures. The incidents resulted in negligible consequence.

The remaining three incidents (Incident Nos. 2012/07/1214, 2012/08/1043WS, and 2012/05/1013HY) occurred on unsupported soil cuts with landslide volume ranging from 5 m^3 to 35 m^3. Incident Nos. 2012/07/1214 and 2012/08/1043WS involved washout failures probably caused by overspilling of runoff water at the stepped channel outlets adjoining the crest of the failure scars. Incident No. 2012/05/1013HY involved a minor landslide on a steep unsupported cut portion of a partially soil-nailed slope probably triggered by direct infiltration. The footpath/access road at the slope toe were affected in these cases.

4.3.3 Landslides on Non-engineered Slopes

There were 58 failures on non-engineered slopes in 2012, among all were minor.

Of the 58 minor landslides, 37 were relatively small in scale with a failure volume less than 5 m^3 and the rest had a failure volume ranging from 5 m^3 to 45 m^3. Eight incidents resulted in temporary closure of roads, pedestrian pavements or minor footpaths. The rest did not have any notable consequence.

4.3.4 Landslides Occurred in the Vicinity of Registered Squatter Structures

Nineteen 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, four on registrable man-made slopes not yet registered at the time of failure, and the remaining five on natural slopes. All were minor, with failure volume ranging from 0.5 m^3 to 30 m^3. Those man-made slopes involved in the landslides were all non-engineered.

The landslide debris reached the squatter structures in 12 of the 19 failures. Squatter structures were not affected by the debris in the other seven cases (either due to the small scale of failures or the squatter structures located aside the toes of the landslide scars). In four of these 12 cases, Category 2 Non-development Clearance[1] (NDC) recommendations had previously been made on the affected squatter structures. Among these cases, Category 1

[1] Category 2 Non-development Clearance (NDC) recommendations are issued to squatter structures that are considered especially vulnerable to landslides due to their close proximity to potentially unstable slopes; the clearance is through advice and persuasion.

NDC [2] recommendations were made on the two affected squatter structures (with the occupants stayed put since the previous Category 2 NDC recommendations) following Incident No. 2012/09/1239. No NDC recommendation was made for the remaining eight cases as no damage was induced on the affected squatter structures (except Incident No. 2012/05/1170 where a brick wall suffered minor surface damage) and the failures were of very small scale (with landslide volume less than 3 m^3).

4.3.5 Annual Failure Rates

The annual failure rates of registered man-made slopes under different categories are presented in Tables 4.3 and 4.4. 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 2012 correspond to about 0.124% (number of landslides divided by number of registered man-made slopes), 0.0026% (total surface area of landslides divided by total surface area of registered man-made slopes), and about 1×10^{-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 2012 (Table 4.5), the annual failure rates of engineered slopes are lower than that of non-engineered slopes by a factor of about 4 on a slope number basis, and about 21 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 11 times lower than that of non-engineered slopes.

[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.

Table 4.4 Annual Failure Rates of Registered Man-made Slopes in 2012

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 2012	Number of Slopes	3	55	58	0	13	13
	Surface Area of Landslides (m^2)	39.04	1276.5	1315.54	0	152	152
Slopes Involved in Major Landslides in 2012	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 2012	Number of Slopes	3	55	58	0	13	13
	Surface Area of Landslides (m^2)	39.04	1276.5	1315.54	0	152	152
Total Number of Registered Slopes		10,890	19,460	30,350	12,160	14,790	26,950
Total Surface Area of Registered Slopes (m^2)		6,151,220	10,231,400	16,382,620	13,476,980	26,195,900	39,672,880
Annual Failure Rates (All Landslides)	On Slope Number Basis	0.028%	0.283%	0.191%	0%	0.088%	0.048%
	On Slope Surface Area Basis	0.001%	0.012%	0.008%	0%	0.0006%	0.0004%
	Number of Landslides Divided by Slope Surface Area (no./m^2)	4.877×10^{-7}	5.376×10^{-6}	3.540×10^{-6}	0	4.963×10^{-7}	3.277×10^{-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: Landslides on registered disturbed terrain features and the incident (see Section 4.3.2) involving landslide debris retained by rock mesh netting have been excluded from this calculation.

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

Category of Slope		Failure Rate on Slope Number Basis (i.e. number of landslides divided by total number of slopes)	Failure Rate on Slope Surface Area Basis (i.e. surface area of landslides divided by total surface area of slopes)	Failure Rate in Terms of Number of Landslides Divided by Total Surface Area of Slopes (no./m²)
Registered Man-made Slopes	All Landslides	0.124%	0.0026%	1.267×10^{-6}
	Major Landslides	0	0	0
	Minor Landslides	0.124%	0.0026%	1.267×10^{-6}
Engineered Slopes	All Landslides	0.048% (0.136%)	0.0004% (0.0016%)	3.277×10^{-7} (7.949×10^{-7})
	Major Landslides	0 (0)	0 (0)	0 (0)
	Minor Landslides	0.048% (0.136%)	0.0004% (0.0016%)	3.277×10^{-7} (7.949×10^{-7})
Non-engineered Slopes	All Landslides	0.191% [4.0/1.4]	0.0080% [21.0/4.9]	3.540×10^{-6} [10.8/4.5]
	Major Landslides	0	0	0
	Minor Landslides	0.191%	0.0080%	3.540×10^{-6}

Legend:

0.048% (0.136%)	Annual failure rate of engineered slopes (considering all landslides) is 0.048% and that for slopes previously treated under the LPMP or LPMitP is 0.136%
0.191% [4.0/1.4]	Annual failure rate of non-engineered slopes (considering all landslides) is 0.191%, which is about 4.0 times and 1.4 times higher than those of engineered slopes and slopes previously treated under the LPMP or LPMitP respectively

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In 2012, six landslides involved slopes treated under the LPMP and none involved slopes upgraded under the Landslip Prevention and Mitigation Programme (LPMitP). The annual failure rates of slopes previously treated under the LPMP or LPMitP correspond to 0.136% (number of landslides divided by number of registered man-made slopes treated under the LPMP or LPMitP), 0.0016% (total surface area of landslides divided by total surface area of registered man-made slopes treated under the LPMP or LPMitP), and about 7.9×10^{-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 1.4 to 5, 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 2012, the corresponding annual success rates were 100% and 99.95% respectively. Hence, the targets were satisfactorily achieved. The trend of the annual success rates of engineered slopes against major and minor failures respectively for the period from 1997 to 2012 is shown in Table 4.6 and Figure 4.3.

4.4 Natural Terrain Landslides

A total of 44 natural terrain landslides were reported in 2012, among which 36 failures were minor and eight were major. All the eight major incidents did not cause any major consequence. The incident (Incident No. 2012/12/1260) with the largest failure volume (200 m^3) involved an open hillside failure occurred at the natural hillside above Fung Hang Family Walk which resulted in temporary closure of part of a footpath.

The 36 minor incidents involved mainly boulder/rock falls (mostly less than 1 m^3 with maximum up to 12 m^3) originating from natural hillsides and washout failures (up to 12 m^3). However, four of these incidents (Incident Nos. 2012/04/1156, 2012/04/1157, 2012/07/1193 and 2012/07/1196) resulted in temporary closure of roads/pedestrian pavements or minor access/footpaths. One incident (Incident No. 2012/08/1226) resulted in minor damage of a passing-by vehicle. Two of these incidents (Incident Nos. 2012/07/1196 and 2012/08/1226) occurred at the same hillside catchment while LPM works were in progress in the man-made rock cut slope below. Natural terrain hazard study for the subject hillside catchment under LPMitP was being scheduled for commencement at time of the incidents.

Among these 44 reported natural terrain landslides, two failures (all involving boulder/rock falls) were located at the existing Historical Landslide Catchments (HLC). These incidents appear to be isolated cases which are not clustered around the previous natural terrain landslides recorded in the Enhanced Natural Terrain Landslide Inventory (ENTLI). Five other failures were located within 50 m from the existing HLC. In all these seven cases, the landslide trails were not close to any important facilities, except in one case where the landslide debris was deposited close to a squatter structure.

Table 4.6 Annual Success Rates of Engineered Slopes from 1997 to 2012

Year	Annual Success Failure Rate 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%

Note: See Figure 4.3 for a plot of annual success rates of engineered slopes against the target annual success rates from 1997 to 2012.

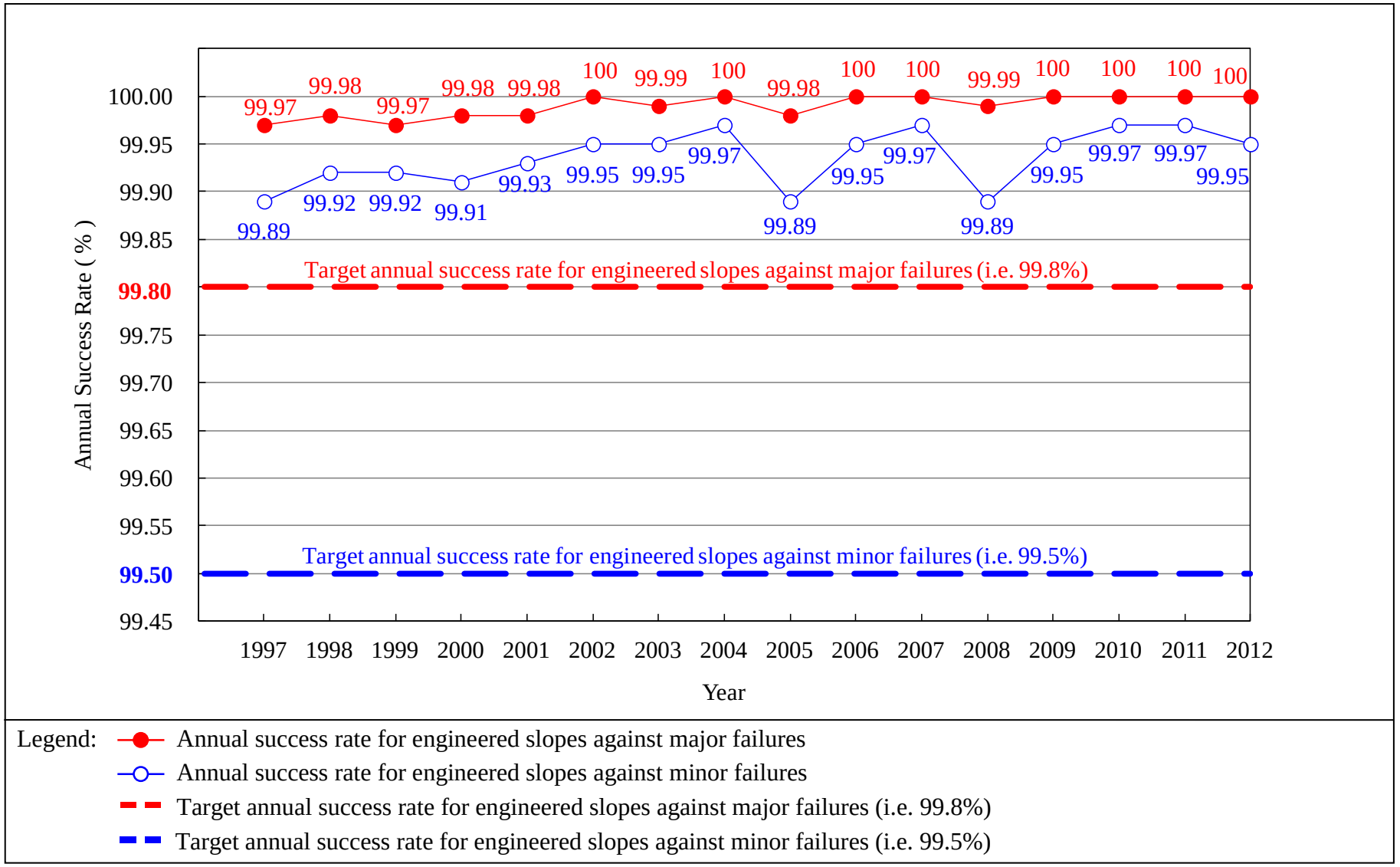

Figure 4.3 Annual Success Rates of Engineered Slopes from 1997 to 2012

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

All the 72 landslides on registered man-made slopes were reviewed to assess whether inadequate slope maintenance was likely to have been a key contributory factor to the failures. Reference has been made to the records of emergency inspections by the GEO or other Government departments, inspections or follow-up studies by the LI consultants.

Inadequate slope maintenance such as blockage of surface drainage and inadequate hard surface protection was assessed to be a key contributory factor in 21 landslides, which contributed to 29% (i.e. 21 out of 72) of the landslides on registered man-made slopes. All the 21 landslides were minor failures, of which seven occurred on engineered slopes.

Of these 21 landslides involving inadequate slope maintenance, 12 affected Government slopes and 5 affected private slopes. The remaining 4 incidents affected a slope feature of mixed maintenance responsibility of Government/private, where two occurred on the private portion and the other two occurred on the Government portion of the slopes. All of the relevant maintenance parties have been informed of the incidents and advised to take appropriate follow-up action. The above diagnosis re-affirms the importance of regular slope maintenance to the performance of slopes. It also serves as a reminder that even an engineered slope is liable to failure given inadequate maintenance.

5 Proposed Improvement Initiative

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

(a) Review of the fixing of rock mesh netting to rock face, in particular for rugged slope surface (Section 4.3.2).

6 Conclusions

Overall, 99.95% of the engineered man-made slopes performed satisfactorily without occurrence of landslides in 2012. There was no major landslide on engineered slopes in 2012.

The annual failure rate of minor landslides on engineered slopes, on a slope number basis, was 0.048% in 2012. This corresponds to an annual success rate of 99.95%, which is above the pledged annual success rate of 99.5%.

One improvement initiative has been proposed, as detailed in Section 5 of this report, with a view to further enhancing the slope engineering practice and the slope safety system in Hong Kong.

7 References

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GEO (2009c). *Enhancement of Rock Slope Engineering Practice Based on Findings of Landslide Studies (GEO Technical Guidance Note No. 10).* Geotechnical Engineering Office, Hong Kong, 5 p.

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Appendix A

List of 2012 Landslide Incidents Involving Unregistered Man-made Slopes but Registrable at the Time of Failure

Table A1 List of 2012 Landslide Incidents Involving Unregistered Man-made Slopes but Registrable at the Time of Failure (Sheet 1 of 3)

Incident No.	Location	Maximum Slope Height	Reported		Failure			Facility Affected	Consequence
			Date	By	Date (Time)	Feature Type	Scale (m^3)		
2012/03/1154	Near House No. 99, Nam Shan Lane, Sai Kung	4 m	26/3	Public	Unknown	Retaining wall (masonry wall)	8	Others (planting area)	Nil
2012/05/1176	Kingsway Industrial Building, 13-17 Cheung Wing Road and 167-175 Wo Yi Hop Road, Kwai Chung	4 m	10/5	BD	29/4	Soil cut	3	Buildings (storage area)	Nil
2012/08/1223	House No. 32, Po Lin Monastery, Ngong Ping, Lantau	3 m	31/7	Public	Unknown	Soil Cut	1	Others (alleyway)	Nil
2012/08/1224	Behind House No. 45 Sun On Village, Sai Kung	4 m	3/8	Public	Unknown	Soil Cut	5	Open area	Nil

Table A1 List of 2012 Landslide Incidents Involving Unregistered Man-made Slopes but Registrable at the Time of Failure (Sheet 2 of 3)

Incident No.	Location	Maximum Slope Height	Reported		Failure			Facility Affected	Consequence
			Date	By	Date (Time)	Feature Type	Scale (m^3)		
2012/08/1225	East of No. 55 Luk Mei Tsuen, Sai Kung	4 m	3/8	Public	24/7 (8:00)	Retaining wall (masonry wall)	2	Open area	Nil
2012/09/1239	Behind squatter structures at the platform above Feature No. 7SW-C/C880, North of Ham Tin Tsuen	4 m	25/9	Public	Around end of July 2012	Soil cut	6	Squatter structure	One squatter structure was damaged by landslide debris; Cat 1 NDC issued for 2 structures and 2 persons permanently evacuated
2012/05/1014HY (HyD/NTW/2012/05/0015)	Castle Peak Road - Lingnan	4 m	5/7	HyD	17/5	Soil cut	2.82	Squatter structure	Nil

Table A1 List of 2012 Landslide Incidents Involving Unregistered Man-made Slopes but Registrable at the Time of Failure (Sheet 3 of 3)

Incident No.	Location	Maximum Slope Height	Reported		Failure			Facility Affected	Consequence
			Date	By	Date (Time)	Feature Type	Scale (m^3)		
2012/07/1020AF (AFCD/2012/08/0002)	Shing Mun Jogging Trail	5 m	20/8	AFCD	24/7	Soil cut	40	Access road	Part of footpath closed
2012/08/1041AF (AFCD/2012/08/0017)	Tai Lam Forest Track - Tin Fu Tsai Section	4.8 m	20/8	AFCD	8/8	Soil cut	1	Access road	Part of access road closed

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Appendix B

Landslide Incidents Involving Slopes Processed under the Slope Safety System

Table B1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 1 of 8)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
1. <u>Slopes Upgraded Under the LPMP</u> ($\sum$ = 6 nos.)					
2012/03/1152	11SW-D/C91	Behind L'Hotel (Island South), Tong Bin Lane, Wong Chuk Hang	0.06 (rockfall)	Rock cut	Slope upgrading works under the LPMP were completed on the rock cut portion (i.e. lower part of western portion) in 1986 and the soil cut portion (i.e. upper part of western portion and the eastern portion) in 2003. The upgrading works on the rock cut portion mainly comprised installation of rock dowels and prescriptive raking drains, construction of concrete buttresses and provision of rock mesh, while the soil cut portion was nailed. The minor rockfall occurred at the interface of the soil and rock portion where damaged shotcrete cover was noted.
2012/07/1200	11SE-A/C84 (sub-division 3)	Mansion Street, Quarry Bay	0.07 (rockfall)	Soil/rock cut	The south-eastern portion of the slope (sub-division 3) was upgraded under the LPMP in 2002 with typical rock slope treatment works to the rock portion, where the rockfall occurred. The rock mesh was detached from the slope surface, hence unable to retain the dislodged rock blocks. The rock surface was rugged and the rock mesh did not follow closely the profile of the rock cut surface. Besides, the designed spacing of the fixing points at the rockfall location was not met and no fixing points could be found at the bottom part of the mesh.

Table B1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 2 of 8)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
2012/07/1215	2SE-C/C199	Adjoining access road to DD104 Lot 4666, Ngau Tam Mei	15	Soil/rock cut	The slope was upgraded under LPMP in 2004. The upgrading works mainly comprised cut back, installation of soil nails and raking drains, provision of vegetation cover, erosion control mat and local wire mesh. The incident involved a shallow washout failure (about 0.5 m deep) around the soil nail heads on the portion of slope (standing at about 48º) where no wire mesh is installed.
2012/10/1050WS (WSD/2012/10/1/HK)	11SW-A/C297	Above Mount Davis Service Reservoir	0.5 (rockfall)	Soil/rock cut	The slope was upgraded under LPMP in 2003 by installation of soil nails to the upper soil portion, provision of typical rock slope treatment works (viz. scaling, buttressing, rock dowel installation and rock mesh) to the rock portion, provision of hydroseeded surface cover and installation of prescriptive raking drains at areas with drainage concentration. The probable rockfall source area was at the lowest slope batter of the rock cut portion which was likely bare without any rock mesh protection at the time of failure.

Table B1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 3 of 8)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
2012/03/1004AF (AFCD/2012/03/0001)	7SW-C/C820	Shing Mun Country Park, Tsuen Wan	5	Soil/rock cut	The slope was upgraded under LPMP in 2003. The upgrading works comprised cut back, installation of soil nails and raking drains, typical rock slope treatment, provision of vegetation cover, erosion control mat and local wire mesh. The incident involved a shallow washout failure (about 0.5 m deep) at the lowest slope batter (standing at about 70º) with soil nails. The landslide debris was fully retained by the existing wire mesh and erosion control mat.
2012/05/1013HY (HyD/NTE/2012/05/0013)	7SE-A/C155	San Chuk Street, Fo Tan	35	Soil cut	The slope was upgraded under LPMP in 2004. The upgrading works comprised cut back, installation of soil nails and raking drains, typical rock slope treatment, provision of hard and vegetation cover. The failure, resulting in two scars, occurred on the cut back portion of slope (standing at about 38º) without soil nails.

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

   Nil.

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

   Nil.

Table B1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 4 of 8)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
4. <u>Slopes Assessed by Government Departments and Checked by GEO with No Upgrading Works Required</u> ($\sum$ = 0 no.)					
Nil.					
5. <u>Slopes Assessed by Private Owners and Checked by GEO with No Upgrading Works Required</u> ($\sum$ = 1 no.)					
2012/04/1164	11SW-D/C556	No. 19 Middle Gap Road, Hong Kong	0.01 (detached chunam)	Soil/rock cut	The slope was included into the development project of the premises in 1982 and was checked up to the current standard. Slope improvement works by means of provision of rock mesh to the lower rock portion and the upper soil portion (covered by chunam surface) was made to the slope in 2005 during the remedial works on the adjacent slopes within the premises in response to a DH Order. The detached chunam surface was retained by the rock mesh.

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Table B1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 5 of 8)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
6. <u>Slopes Formed or Upgraded by Government Departments and Checked by GEO</u> ($\sum$ = 4 nos.)					
2012/07/1214	6SW-A/C87	Caritas Li Ka Shing Care & Attention Home, Wah Fat Street, Tuen Mun	5	Soil cut	The slope was formed by cutting without structural support in 1980s under the development of Tuen Mun New Town Area S39. The geotechnical design of the slope works was checked and accepted by the GEO in 1983, and the formation of the slope was completed in 1987. The incident involved a washout failure at the steeper (about 42° at failure location) southern end portion of the slope where no erosion control mat was installed.
2012/10/1245	7SW-C/CR457	Above access road to Wo Yi Hop Village, Kwai Chung	0.1 (rockfall)	Rock cut	The slope was formed by cutting under the project "Tsuen Wan Development – Route 5 TDD Contract TW41/85, Route 5 Tsuen Wan Connections" in 1990. The geotechnical design of the slope was checked and accepted by the GEO in 1990. No design or as-built drawings could be located but stabilization works such as buttresses were observed on the rock slope portion. The incident involved rockfall from bare rock cut surface where no rock mesh was installed.

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Table B1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 6 of 8)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
2012/05/1011AD[(1)] (ArchSD/TP/2012/05/0001)	7NW-D/C240	Along Tai Po Kau Track, Tai Po Kau Forest Office	3 (rockfall)	Soil/rock cut	Upgrading and preventive maintenance works were carried out in 2003 under Agreement No. CE43/99 and GEO had accepted the geotechnical deign of the works. The proposed works included cut back, installation of soil nails, removal of loose boulder, construction of boulder buttress, provision of vegetation cover and erosion control mat. The as-built records could not be located (whether or not soil nails were installed cannot be ascertained) but stabilization works such as rock mesh and masonry buttresses were observed on the rock slope portion. The incident involved detachment of rock fragments on the rock portion which were fully retained by the rock mesh.
2012/08/1043WS (WSD/2012/8/1/NTW)	2SE-D/CR437	Access road to Ngau Tam Mei Water Treatment Works	15	Soil cut	The slope comprised a retaining wall and a slope formed by cutting as part of the site formation works for the Additional Treatment and Water Transfer Facilities under Agreement No. CE 45/95. The geotechnical design of the site formation works was checked and accepted by GEO in 2002. The incident involved a washout failure on the cut slope (standing at about 30º) near the eastern end of the feature without the retaining wall.

Table B1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 7 of 8)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
7. <u>Slopes Formed or Upgraded by Private Owners and Checked by GEO</u> ($\sum$ = 1 no.)					
2012/02/1149	11SE-D/C20 (sub-division 2)	Caritas Chai Wan Marden Foundation Secondary School, Chai Wan	0.01 (detached chunam)	Rock cut	The subject slope portion (sub-division 2) was formed as part of the site formation works for the secondary school with the corresponding site formation plans approved by BD in 1980. The incident involved detachment of the broken chunam surface probably due to root wedging action by a nearby tree and poor maintenance of the hard surface cover.
8. <u>Slopes Upgraded Following Service of DH Orders and Checked by GEO</u> ($\sum$ = 2 nos.)					
2012/06/1185	15NE-A/C74	No. 115 Repulse Bay Road	0.1 (rockfall)	Rock cut	The northern-western slope portion, where the rockfall occurred, was upgraded by the corresponding private owners in 2004 following the service of a DH Order in 1998. The upgrading works comprised mainly installation of rock bolts with extruded concrete block and tie beams, construction of no-fines concrete buttress, installation of soil nails to the upper soil slope portion and provision of shotcrete surface, hydroseeding surface and rock mesh at various locations. The probable rockfall source area was covered by thin vegetation without any rock mesh protection at the time of failure.

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Table B1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 8 of 8)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
2012/10/1241	11SE-A/CR85	Behind The Hong Kong Federation of Youth Groups Building, No. 204 Tsat Tsz Mui Road, Quarry Bay	1 (rockfall)	Soil/ rock cut	The eastern slope portion, where the rockfall occurred, was upgraded by the corresponding private owners in 1994 following the service of a 'D' Notice in 1983. The upgrading works included provision of localized concrete buttresses. No rock mesh had been provided to the rock portion where the rockfall occurred.

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 ($\sum$ = 2 nos.)

Landslide involved unsupported cuts ($\sum$ = 3 nos.)

Notes:
(1) Slopes under Categories 1 to 8 are classified as engineered slopes. Incident No. 2012/05/1011AD involving minor rockfall with the landslide debris retained by the rock mesh netting on the slope is not regarded as a failure (GEO, 2009c).
(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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TECHNICAL GUIDANCE NOTES

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