Review of Landslides in 2011

GEO Report No. 306

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

Geotechnical Engineering Office
Civil Engineering and Development Department
The Government of the Hong Kong
Special Administrative Region

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Preface

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. The GEO Reports can be downloaded from the website of the Civil Engineering and Development Department (http://www.cedd.gov.hk) on the Internet. Printed copies are also available for some GEO Reports. For printed copies, a charge is made to cover the cost of printing.

The Geotechnical Engineering Office also produces documents specifically for publication in print. These include guidance documents and results of comprehensive reviews. They can also be downloaded from the above website.

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H.N. Wong
Head, Geotechnical Engineering Office
December 2014

Foreword

This report presents the findings of a detailed diagnosis of landslides in 2011 that were reported to the Government. It serves to review the performance of the Government's slope safety system and identify areas for improvement.

The review was carried out by Mr H.W.K. Lam, Ms J.C.W. Leung and Dr D.O.K. Lo, of Landslip Preventive Measures Division 1 under the supervision of Dr A.C.O. Li. 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 K.H.K. Yiu is gratefully acknowledged.

Y.C. Chan
Head of the Geotechnical Engineering Office

Abstract

This report presents the findings of a diagnostic review of the landslides in 2011 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.

Altogether, 77 genuine landslides were reported to the Government in 2011. There was one major landslide (viz. failure volume of 50 m^3 or more), involving a consequence-to-life Category 3 soil cut slope. Six minor landslides (viz. failure volume of less than 50 m^3) occurred on engineered man-made slopes. The corresponding annual failure rate is about 0.019% on a slope number basis (i.e. number of landslides relative to the total number of engineered slopes).

Overall, 99.98% of the engineered man-made slopes performed satisfactorily without occurrence of landslides in 2011.

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1 Introduction

This report presents the findings of a diagnostic review of the landslides in 2011 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 2011. 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 2011

The factual information, together with the relevant statistics on rainfall and reported landslides in 2011, was documented by Leung et al (2012).

In 2011, the annual rainfall recorded at the Principal Raingauge of the Hong Kong Observatory (HKO) in Tsim Sha Tsui was 1,476.7 mm, about 38.5% below the annual average of 2,402.1 mm recorded between 1981 and 2010. No Landslip Warning or Black Rainstorm Warning was issued in 2011. Two Red Rainstorm Warnings were issued on 22 May 2011 and 14 Amber Rainstorm Warnings were issued between 17 April and 19 September 2011.

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 83 reported incidents in 2011, 77 were genuine landslides, discounting the non-landslide incidents (e.g. flooding). There was one major failure, corresponding to about

1.3% 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 major landslides 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)	9.1
Cut Slopes	Soil	32 (1)	41.5
	Soil/Rock	12 (0)	15.6
	Rock	4 (0)	5.2
Retaining Walls		8 (0)	10.4
Natural Hillside		13 (0)	16.9
Registered Disturbed Terrain		1 (0)	1.3
Total		77 (1)	100.0

Legend:

32 (1) Thirty-two landslides, one of which was major failure (i.e. failure volume ≥ 50 m^3)

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)	3 (0)	1 (0)	5 (0)	9 (0)
Registered Squatter Dwellings	0 (0)	0 (0)	4 (0)	4 (0)
Roads	2 (0)	0 (0)	6 (0)	8 (0)
Transportation Facilities (e.g. railways, tramways, etc.)	0 (0)	0 (0)	0 (0)	0 (0)
Pedestrian Pavements/Footways	0 (0)	0 (0)	6 (0)	6 (0)
Minor Footpaths/Access Paths/ Access Roads	3 (0)	2 (0)	13 (0)	18 (0)
Construction Sites	0 (0)	0 (0)	0 (0)	0 (0)
Open Areas	1 (0)	2 (0)	5 (0)	8 (0)
Catchwaters	0 (0)	0 (0)	0 (0)	0 (0)
Others (e.g. carparks, parks, playgrounds, gardens, backyards, etc.)	2 (0)	2 (0)	16 (1)	20 (1)
Nil	0 (0)	2 (0)	2 (0)	4 (0)
Total	11 (0)	9 (0)	57 (1)	77 (1)

Legend:

16 (1) Sixteen landslides of which one was major failure (i.e. failure volume ≥ 50 m^3)

Notes:
(1) Incidents that were not genuine landslides have been excluded.
(2) Nil consequence refers to incidents where the landslide debris came to rest on the slopes, not affecting any facilities.

Table 2.3 Breakdown of Landslide Consequences by 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	1	1	2	0	0
Cut Slopes	Soil	0	0	0	0	0	1	0	0
	Soil/Rock	0	0	0	1	0	1	0	0
	Rock	0	0	0	1	0	0	0	0
Retaining Walls		0	0	0	0	0	1	0	0
Natural Hillside		0	0	0	2	0	1	0	0
Registered Disturbed Terrain		0	0	0	0	0	0	0	0
Total		0	0	0	5	1	6	0	0

Note: (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 1982 Housing Department's Squatter Structure Survey (GEO, 2010b).

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

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	Number of Major Landslides		Total
	(< 50 m^3)	(50 m^3 to < 500 m^3)	(≥ 500 m^3)	
Registered Man-made Slopes	46	1	0	47
Registered Disturbed Terrain	1	0	0	1
Unregisterable Man-made Slopes	15	0	0	15
Registerable Man-made Slopes Not Yet Registered at Time of Failure	1	0	0	1
Natural Hillside	13	0	0	13
Total	76	1	0	77

3 Overall Diagnostic Review of Landslides

3.1 General

An overall diagnostic review of the available 2011 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.

3.2 Coverage of the Catalogue of Slopes

3.2.1 General

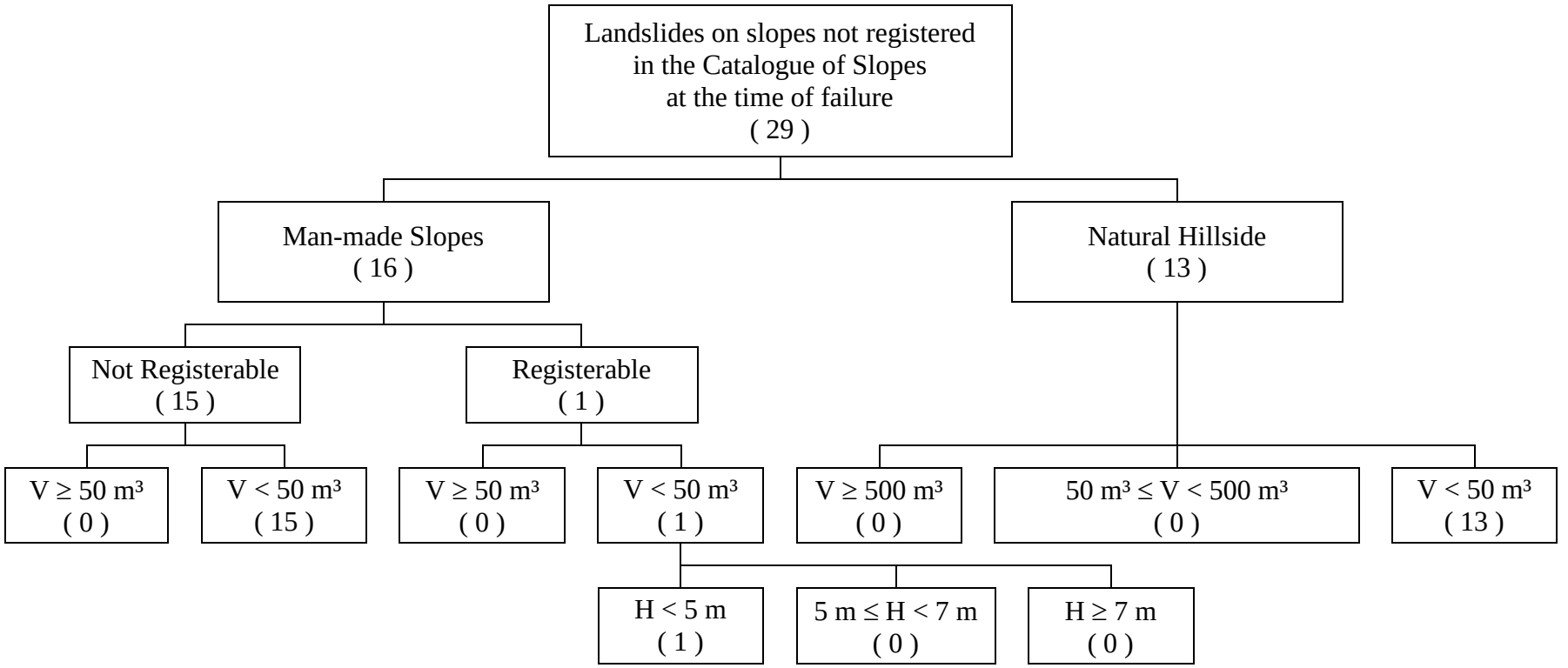
Sizeable man-made slopes and retaining walls, including those compiled under the GEO's project entitled "Systematic Identification and Registration of Slopes in the Territory" (SIRST) that was completed in September 1998, together with newly formed or identified slope features after 1998, are registered in the Catalogue of Slopes. Potentially registerable man-made slopes would also be identified during slope maintenance inspections, landslide investigations and other geotechnical inspections or studies (GEO, 2010a).

3.2.2 Diagnosis

Of the 77 genuine landslides, 48 occurred on registered slope features (comprising 47 on registered man-made slopes and one on a registered disturbed terrain feature) and 29 occurred on slopes not registered in the Catalogue of Slopes (Table 2.5).

Among the above 29 landslides, 13 occurred on natural hillside, 15 occurred on small man-made slope features that do not meet the slope registration criteria (GEO, 2004). The remaining one landslide, corresponding to 1.3% of the total number of genuine landslides in 2011, involved a slope feature that satisfies the slope registration criteria but was not registered in the Catalogue of Slopes at the time of failure. A breakdown of these 29 landslides is given in Figure 3.1.

The landslide incident involving a registerable but not yet registered slope was a minor failure with a failure volume < 5 m^3. The landslide affected a rural access road and did not cause any significant impact on the community (Appendix A). Following the landslide, arrangements have been made to register the man-made slope feature concerned as part of the adjacent registered feature in the Catalogue of Slopes.



Legend:

V	Failure volume
H	Height of man-made feature before failure
(29)	Number of landslide incidents = 29

Notes:

(1) 'Not Registerable' 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 landslide, arrangements have been made to register the registrable feature as part of the adjacent registered feature in the Catalogue of Slopes.

Figure 3.1 Breakdown of Landslides on Unregistered Slopes in 2011

The 15 landslides involving unregisterable man-made slope features were all minor failures with a failure volume less than 40 m^3.

3.3 Performance of Registered Man-made Slopes

3.3.1 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

(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 77 genuine landslides in 2011, a total of 47 landslides (about 61%) occurred on registered man-made slopes (Table 2.5). Of these 47 landslides, six (about 13%) occurred on engineered slopes, all of which were minor failures. Of the remaining 41 landslide incidents that occurred on non-engineered slopes, one incident was major involving a 15 m high consequence-to-life Category 3 soil cut in Sha Tau Kok and the remaining were minor. There was no major landslide occurring on consequence-to-life Category 1 slope features in 2011.

Further details of the landslides in 2011 involving engineered slopes are given in Appendix B. Detailed assessment of the engineered and non-engineered slopes is described in the sections below.

3.3.2 Landslides on Engineered Slopes

Brief descriptions of the six landslides on engineered slopes in 2011 are given in Appendix B. A breakdown of these landslides in terms of feature type is given in Table 3.1. Among the six landslides, two involved slopes that have been previously upgraded under the Landslip Preventive Measures Programme (LPMP) (see Table 3.2).

Three of these six landslides involved minor rock slide or rockfalls. The rock slide incident involved a failure volume of 8 m^3 on Slope No. 3SE-B/C131 (Incident No. 2011/06/1114), where the debris was successfully retained by the rock mesh netting. The slope was upgraded under the LPMP in 2006. This incident was not regarded as a failure in accordance with the GEO Technical Guidance Note No. 10 (GEO, 2009a). The other two incidents (at Slope Nos. 11SE-C/C123 and 11SE-A/C10, and reported under Incident Nos. 2011/05/1102 and 2011/07/1123 respectively) occurred on private slopes involving rockfalls with a failure volume of about 1 m^3. No surface protective measures were provided at the failed rock slope portions. 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 netting could be a pragmatic solution to deal with minor rockfalls or rock slides.

Table 3.1 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	1	0	1	0	0	2
≤ 5 m^3	1	0	3 (1)	0	0	4
Total	2	0	4 (1)	0	0	6

Legend:

5 (1) Of the five landslides, one occurred within or adjacent to the soil-nailed portion of the slope

Table 3.2 Breakdown of Landslides on Slopes Previously Treated under the LPMP

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

Legend:

2 (1) Of the two landslides involved, one occurred within or adjacent to the soil-nailed portion of the slopes

Two landslides (Incident Nos. ArchSD/TW/2011/12/0001 and 2011/06/1113) occurred on fill slopes Nos. 7SW-C/F503 and 7SW-D/F550 respectively. The former was probably associated with bursting of water-carrying services near the crest of the slope, and the latter was probably due to overflow from a blocked catchpit. The failure volume of these landslides was 20 m^3 and 2.5 m^3 respectively. The landslide at Slope No. 7SW-C/F503 resulted in temporary closure of a road, and the other had negligible consequence.

The remaining incident involved minor surface erosion on a soil cut (Slope No. 11NW-B/C37 under Incident No. 2011/10/1130) which was upgraded by means of soil nails under the LPMP in 2002. The failure volume was about 0.3 m^3. The vegetation cover on some parts of the slope was not well established exposing the soil, which would have become more susceptible to surface erosion. The landslide did not affect the soil nails, and demonstrated the effectiveness of soil nails in preventing large-scale failure. The incident resulted in negligible consequence.

3.3.3 Landslides on Non-engineered Slopes

There were 41 failures on non-engineered slopes in 2011, among which 40 failures were minor and one major.

The major failure occurred on a consequence-to-life Category 3 slope (No. 3NW-D/C41) behind a construction depot adjacent to Loi Tung Village, Sha Tau Kok. The failure volume was about 150 m^3. The incident did not result in any notable consequence.

Of the 40 minor landslides, 29 were relatively small in scale with a failure volume less

than 5 m^3 and the rest had a failure volume ranging from 6 m^3 to 30 m^3. There was a rockfall incident (at Slope No. 11NE-A/C284), where the fallen rock was retained by the rock mesh on slope, and this incident was not considered as a failure. Four incidents resulted in temporary closure of the road/pedestrian pavement or minor footpath. The rest did not have any notable consequence.

There were four landslides occurring on slopes located in the vicinity of registered squatter structures. Two landslides occurred on registered slopes, one on an unregistered man-made slope and the remaining one on a natural slope. All were very minor, with a failure volume of less than 3 m^3. In three of the four failures the landslide debris affected squatter structures. Among these three cases, Non Development Clearance (NDC) Category 2 recommendation had previously been made for the affected squatter structures in two of the failures and no NDC recommendation was made in the other case in view of preventive maintenance works being planned for the slope at the time.

3.3.4 Annual Failure Rates

The annual failure rates of registered man-made slopes under different categories are presented in Tables 3.3 and 3.4. 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 2011 correspond to about 0.079% (number of landslides divided by number of registered man-made slopes), 0.001% (total surface area of landslides divided by total surface area of registered man-made slopes), and about 8×10^{-7} (number of landslides divided by total surface area of registered man-made slopes in m^2) respectively. Further details are summarised in Table 3.4.

Based on the landslide data in 2011 (Table 3.4), the annual failure rates of engineered slopes are lower than that of non-engineered slopes by a factor of about 7 on a slope number basis, and about 39 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 19 times lower than that of non-engineered slopes.

In 2011, two landslides involved slopes treated under the LPMP and none involved

Table 3.3 Annual Failure Rates of Registered Man-made Slopes in 2011

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 2011	Number of Slopes	4	36	40	2	3	5
	Surface Area of Landslides (m^2)	67.00	525.85	592.85	29.60	6.31	35.91
Slopes Involved in Major Landslides in 2011	Number of Slopes	0	1	1	0	0	0
	Surface Area of Landslides (m^2)	0	153.00	153.00	0	0	0
Slopes Involved in Minor Landslides in 2011	Number of Slopes	4	35	39	2	3	5
	Surface Area of Landslides (m^2)	67.00	372.85	439.85	29.60	6.31	35.91
Total Number of Registered Slopes		11,010	19,740	30,750	12,040	14,510	26,550
Total Surface Area of Registered Slopes (m^2)		6,233,300	10,403,600	16,636,900	13,394,900	26,023,700	39,418,600
Annual Failure Rates (All Landslides)	On Slope Number Basis	0.036%	0.182%	0.130%	0.017%	0.021%	0.019%
	On Slope Surface Area Basis	0.001%	0.005%	0.004%	0.0002%	0.00002%	0.0001%
	Number of Landslides Divided by Slope Surface Area (no./m^2)	6.394×10^{-7}	3.443×10^{-6}	2.394×10^{-6}	1.498×10^{-7}	1.156×10^{-7}	1.272×10^{-7}
Annual Failure Rates (Major Landslides)	On Slope Number Basis	0%	0.005%	0.003%	0%	0%	0%
	On Slope Surface Area Basis	0%	0.001%	0.001%	0%	0%	0%
	Number of Landslides Divided by Slope Surface Area (no./m^2)	0	9.564×10^{-8}	5.984×10^{-8}	0	0	0

Note: Landslides on registered disturbed terrain features and the two incidents (see Sections 3.3.2 and 3.3.3) involving landslide debris retained by rock mesh netting have been excluded from this calculation.

Table 3.4 Breakdown of Annual Failure Rates of Registered Man-made Slopes

Category of Slopes		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	0.079%	0.0011%	8.035×10^{-7}
	Major Landslides	0.002%	0.0003%	1.785×10^{-8}
	Minor Landslides	0.077%	0.0008%	7.856×10^{-7}
Engineered Slopes	All Landslides	0.019% (0.024%)	0.00009% (0.00004%)	1.272×10^{-7} (1.405×10^{-7})
	Major Landslides	0 (0)	0 (0)	0 (0)
	Minor Landslides	0.019% (0.024%)	0.00009% (0.00004%)	1.272×10^{-7} (1.405×10^{-7})
Non-engineered Slopes	All Landslides	0.129% [6.9/5.5]	0.0035% [38.8/84.2]	2.394×10^{-6} [18.8/17.0]
	Major Landslides	0.003%	0.0009%	5.984×10^{-8}
	Minor Landslides	0.126%	0.0026%	2.334×10^{-6}

Legend:

0.019% (0.024%)	Annual failure rate of engineered slopes (considering all landslides) is 0.019% and that for slopes previously treated under the LPMP or LPMitP is 0.024%
0.130% [6.9/5.5]	Annual failure rate of non-engineered slopes (considering all landslides) is 0.130%, which is about 6.9 times and 5.5 times higher than those of engineered slopes and slopes previously treated under the LPMP or LPMitP respectively

slopes upgraded under Landslip Prevention and Mitigation Programme (LPMitP). The annual failure rates of slopes previously treated under the LPMP or LPMitP correspond to 0.024% (number of landslides divided by the total number of man-made slopes treated under the LPMP or LPMitP), 0.00004% (total surface area of landslides divided by total surface area of registered man-made slopes treated under the LPMP or LPMitP), and about 1.4×10^{-7} (number of landslides divided by total surface area of man-made slopes treated under the LPMP or LPMitP in m^2) respectively, as summarised in Table 3.4. The annual failure rate of slopes previously treated under the LPMP or LPMitP is lower than that of non-engineered slopes by a factor ranging from about 6 to 84, 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 2011, the corresponding annual success rates were 100% and 99.98% 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 2011 is shown in Table 3.5 and Figure 3.2.

3.4 Natural Terrain Landslides

A total of 13 natural terrain landslides were reported in 2011 and all were minor failures. The incident (Incident No. 2011/06/1110) with the largest failure volume (30 m^3) occurred at a natural hillside below Stubbs Road. The failure was probably triggered by uncontrolled surface runoff from a blocked surface channel and catchpit, resulting in landslide debris inundating a residential area below the hillside and blocking an alleyway.

The remaining 12 incidents involved mainly minor washout failure (all less than 10 m^3) or boulder/rock falls originating from natural hillsides. Among these 12 incidents, two landslides (Incident Nos. 2011/07/1121 and 2011/12/1145) resulted in temporary closure of Tai Hang Road. One incident (Incident No. 2011/04/1098) involved a boulder fall, resulting in damage to an external wall within a bus terminus. The boulder could have been disturbed by construction activities nearby. The remaining nine incidents did not cause any notable consequence.

Among the 13 natural terrain landslides, three (all involving boulder/rock falls) were located at or close to (within 50 m) existing Historical Landslide Catchments.

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

All the 47 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.

Table 3.5 Annual Success Rates of Engineered Slopes from 1997 to 2011

Scale of Failure	Annual Success Rate on Slope Number Basis (i.e. number of landslides divided by total number of slopes)														
	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Engineered Slopes Processed by the Slope Safety System ($\geq$ 50 m^3)	99.97%	99.98%	99.97%	99.98%	99.98%	100%	99.99%	100%	99.98%	100%	100%	99.99%	100%	100%	100%
Engineered Slopes Processed by the Slope Safety System ($<$ 50 m^3)	99.89%	99.92%	99.92%	99.91%	99.93%	99.95%	99.95%	99.97%	99.89%	99.95%	99.97%	99.89%	99.95%	99.97%	99.98%

Note: See Figure 3.2 for a plot of annual success rates of engineered slopes against the target annual success rates from 1997 and 2011.

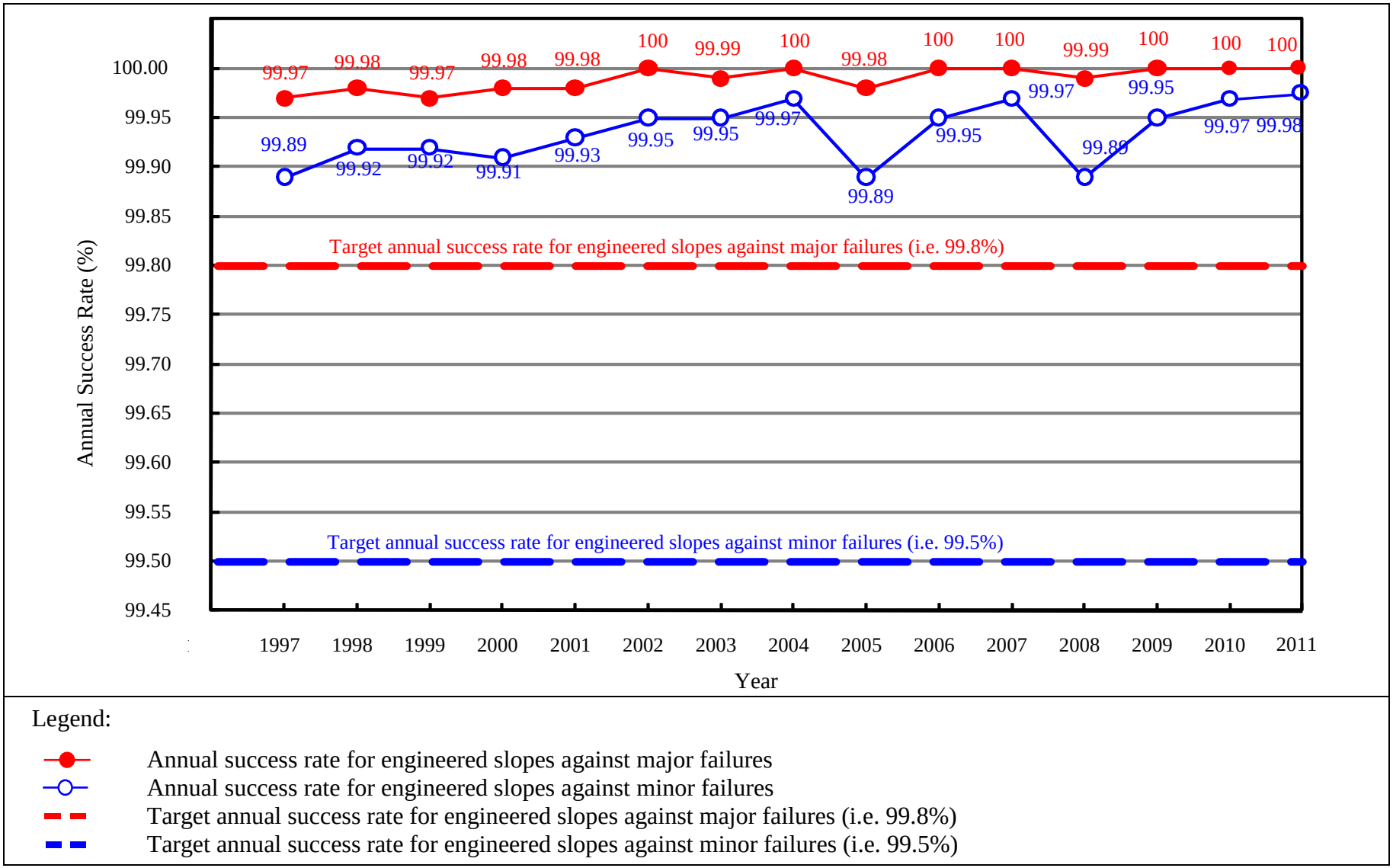
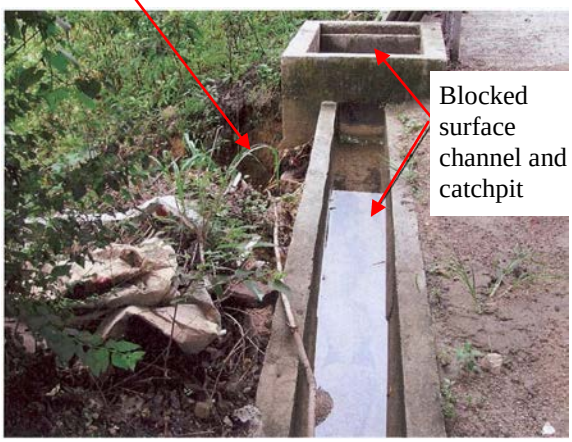


Figure 3.2 Annual Success Rates of Engineered Slopes from 1997 to 2011

Inadequate slope maintenance such as blockage of surface drainage and inadequate hard surface protection (see examples in Figure 3.3) was assessed to be a key contributory factor in 11 landslides. It contributed to about 23% (i.e. 11 out of 47) of the landslides on registered man-made slopes. This annual percentage remains on a high side in recent years (from 23% to 32% between 2009 and 2010), compared with the annual average of about 13% in the mid-2000s. All the 11 landslides were minor failures, of which three occurred on engineered slopes (i.e. Slope Nos. 11NW-B/C37, 7SW-D/F550 and 11SE-A/C10). Of these 11 landslides, seven occurred on government slopes and two on private slopes. The remaining two incidents occurred on slope features with mixed maintenance responsibility of government/private, where one occurred on the private portion and the other occurred on the government 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 re-affirms the importance of regular slope maintenance. It also serves as a reminder that even an engineered slope is liable to failure without adequate maintenance.



Blocked surface channel and catchpit observed at Feature No. 7SW-D/F550 (Incident No. 2011/06/1113)

Dilapidated hard surfacing observed at Feature No. 8SW-C/C62 (Incident No. 2011/01/1088)

Figure 3.3 Examples of Inadequate Slope Maintenance

4 Conclusions

Overall, 99.98% of the engineered man-made slopes performed satisfactorily without occurrence of landslides in 2011. There was no major landslide on engineered slopes in 2011.

The annual failure rate of minor landslides on engineered slopes, on a slope number basis, was 0.019% in 2011. This corresponds to an annual success rate of 99.98%, which is above the pledged annual success rate of 99.5%.

The present review indicates that the percentage of failures due to inadequate slope maintenance has remained on the high side. Although all these failures are minor in scale, they re-affirm the importance of regular maintenance and serve as a reminder that even an engineered slope is liable to failure without adequate maintenance.

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Appendix A

List of 2011 Landslide Incidents Involving Unregistered Man-made Slopes but Registerable at the Time of Failure

Table A1 List of 2011 Landslide Incidents Involving Unregistered Man-made Slopes but Registerable at the Time of Failure

Incident No.	Location	Maximum Slope Height	Reported		Failure			Facility Affected	Consequence
			Date	From	Date (Time)	Feature Type	Scale (m^3)		
2011/05/1103	Sheung Kok Shan Road	4 m	25/5	FEHD	Unknown	Soil Cut	2	Road	Nil

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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 4)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
1. Slopes Upgraded Under the LPMP ($\sum$ = 2 nos.)					
2011/06/1114[(1)]	3SE-B/C131	Bride's Pool Road	8 (Rock slide)	Soil/rock cut	The slope was upgraded under LPMP in 2006. The upgrading works mainly comprised installation of soil nails and raking drains, rock slope treatment works such as rock mesh netting and buttress etc. The incident occurred on the rock slope portion and was structurally-controlled. The landslide debris was successfully retained by existing rock mesh netting.
2011/10/1130	11NW-B/C37 (sub-division 1)	Behind United Christian College, Tai Hang Tung	0.3	Soil/rock cut	The subject slope portion was upgraded under LPMP in 2002, where soil nails, raking drains, surface drainage measures and vegetation cover with erosion control mat were installed. The incident involved minor surface erosion. The vegetation on some part of the slope was not well established exposing bare soil surface which was susceptible to surface erosion.

Table B1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 2 of 4)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
2. Slopes Assessed under the LPMP with No Upgrading Works Required (∑ = 0 no.) Nil.					
3. Slopes Assessed by Studies in the late 1970's to mid-1980's with No Upgrading Works/Further Study Required (∑ = 0 no.) Nil.					
4. Slopes Assessed by Government Departments and Checked by GEO with No Upgrading Works Required (∑ = 0 no.) Nil.					
5. Slopes Assessed by Private Owners and Checked by GEO with No Upgrading Works Required (∑ = 0 no.) Nil.					
6. Slopes Formed or Upgraded by Government Departments and Checked by GEO (∑ = 1 no.)					
2011/12/1025AD (ArchSD/TW/2011/12/0001)	7SW-C/F503	Kwok Shui Road Park, Tsuen Wan	20	Fill	The slope was formed in 1980s under the Park and Playground Project at Tsuen Wan Area 6, Site 115. The geotechnical design of the site formation works was checked and accepted by the GCO in 1984. The incident was probably triggered by the bursting of a buried watermain in Kwok Shui Road near the slope crest.

Table B1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 3 of 4)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
7. Slopes Formed or Upgraded by Private Owners and Checked by GEO ($\sum$ = 1 no.)					
2011/06/1113	7SW-D/F550	Mei Tin Road, Tai Wai	2.5	Fill	The slope was formed in around 2008 in association with the site formation works for a private development project. The site formation plans were checked and accepted by the GEO in 2005. The incident was a washout failure, probably due to overflow from a blocked catchpit.
8. Slopes Upgraded Following Service of DH Orders and Checked by GEO ($\sum$ = 2 nos.)					
2011/05/1102	11SE-C/C123	14 Wilson Road, Jardines Lookout	0.5 (Rockfall)	Soil/rock cut	The slope was upgraded by the owner of the slope in 2005 following the service of a DH Order in 1999. The upgrading works included installation of soil nails, rock dowels and raking drains, as well as concrete buttress. No rock mesh was provided at the rock portion that failed in 2011.
2011/07/1123	11SE-A/C10	46 Tin Hau Temple Road	1 (Rockfall)	Soil/rock cut	The slope was upgraded by the Buildings Department in 2001 as default works following the service of a DH Order in 1992. The upgrading works included installation of soil nails, raking drains, and rock dowels as well as concrete buttress. No rock mesh was provided at the rock portion that failed in 2011.

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

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
9. Slopes Assessed as Not Requiring Upgrading Works But with Outstanding GEO Comments ($\sum$ = 0 no.)					
Nil.					
10. Slopes Assessed as Requiring Upgrading Works But with Outstanding GEO Comments ($\sum$ = 1 no.)					
2011/09/1126	15NW-B/C92	Bus Terminal at Lei Tung Estate, Ap Lei Chau	< 0.1 (Rockfall)	Soil/rock cut	The geotechnical design of the slope upgrading works was carried out by the Housing Authority, and was checked by the GEO in 2001, with outstanding comments on the groundwater level for the soil portion of the slope. GEO had no adverse comment on the rock portion where no stabilization measures were considered necessary. The upgrading works were completed in August 2002. No rock mesh was provided at the rock portion that failed in 2011.

Legend:

Landslide occurred on or adjacent to the soil-nailed portion of a cut slope ($\sum$ = 1 no.)

Notes:
(1) Slopes under Categories 1 to 8 are classified as engineered slopes. Incident No. 2011/06/1114 involving rock slide debris retained by the rock mesh netting on the slope is not taken as a failure (GEO, 2009a).
(2) Slopes under Categories 9 and 10 are post-1977 features but are not taken as engineered slopes for the purpose of this report.

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Geotechnical Manual for Slopes, 2nd Edition (1984), 302 p. (English Version), (Reprinted, 2011).

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Highway Slope Manual (2000), 114 p.

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Geoguide 1	Guide to Retaining Wall Design, 2nd Edition (1993), 258 p. (Reprinted, 2007).
Geoguide 2	Guide to Site Investigation (1987), 359 p. (Reprinted, 2000).
Geoguide 3	Guide to Rock and Soil Descriptions (1988), 186 p. (Reprinted, 2000).
Geoguide 4	Guide to Cavern Engineering (1992), 148 p. (Reprinted, 1998).
Geoguide 5	Guide to Slope Maintenance, 3rd Edition (2003), 132 p. (English Version).
岩土指南第五冊	斜坡維修指南，第三版(2003)，120頁(中文版)。
Geoguide 6	Guide to Reinforced Fill Structure and Slope Design (2002), 236 p.
Geoguide 7	Guide to Soil Nail Design and Construction (2008), 97 p.

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GEOSPECS

Geospec 1	Model Specification for Prestressed Ground Anchors, 2nd Edition (1989), 164 p. (Reprinted, 1997).
Geospec 3	Model Specification for Soil Testing (2001), 340 p.

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GCO Publication No. 1/90	Review of Design Methods for Excavations (1990), 187 p. (Reprinted, 2002).
GEO Publication No. 1/93	Review of Granular and Geotextile Filters (1993), 141 p.
GEO Publication No. 1/2006	Foundation Design and Construction (2006), 376 p.
GEO Publication No. 1/2007	Engineering Geological Practice in Hong Kong (2007), 278 p.
GEO Publication No. 1/2009	Prescriptive Measures for Man-Made Slopes and Retaining Walls (2009), 76 p.
GEO Publication No. 1/2011	Technical Guidelines on Landscape Treatment for Slopes (2011), 217 p.

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The Quaternary Geology of Hong Kong, by J.A. Fyfe, R. Shaw, S.D.G. Campbell, K.W. Lai & P.A. Kirk (2000), 210 p. plus 6 maps.

The Pre-Quaternary Geology of Hong Kong, by R.J. Sewell, S.D.G. Campbell, C.J.N. Fletcher, K.W. Lai & P.A. Kirk (2000), 181 p. plus 4 maps.

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