Review of Landslides in 2008

GEO Report No. 274

A.C.O. Li, J.W.C. Lau, L.L.K. Cheung & C.L.H. Lam

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

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This report was originally produced in December 2009
as GEO Landslide Study Report No. LSR 15/2009

First published, December 2012

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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.

The publications and the printed GEO Reports may be obtained from the Government's Information Services Department. Information on how to purchase these documents is given on the second last page of this report.

Y.C. Chan
Head, Geotechnical Engineering Office
December 2012

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Foreword

This report presents the findings of a detailed diagnosis of landslides in 2008 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 Dr A.C.O. Li, Mr J.W.C. Lau, Ms L.L.K. Cheung and Ms C.L.H. Lam of Landslip Preventive Measures Division 1 under the supervision of Mr W.K. Pun. Assistance was provided by the landslide investigation consultants, Fugro Scott Wilson Joint Venture and AECOM Asia Company Limited respectively, engaged by the Geotechnical Engineering Office (GEO). Technical support provided by Mr C.C. Mak, Mr T.F.O. Luk and Mr K.H.K. Yiu is gratefully acknowledged.

R.K.S. Chan
Head of the Geotechnical Engineering Office

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Abstract

This report presents the findings of a diagnostic review of the landslides in 2008 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 863 genuine landslides were reported to the Government in 2008. All the available landslide data were examined and 16 follow-up studies on selected landslide incidents were being carried out under the systematic landslide investigation programme. These studies provided information and insights into the types, causes and mechanisms of landslides, and facilitated the identification of areas deserving attention and improvement.

Based on the landslide data in 2008, two major landslides (viz. failure volume of 50 m^3 or more) occurred on engineered man-made slopes that have been accepted under the slope safety system. The corresponding annual failure rate is about 0.009% on a slope number basis (i.e. number of landslides relative to the total number of engineered slopes). In terms of minor landslides (viz. failure volume of less than 50 m^3) on engineered man-made slopes, the annual failure rate is about 0.112% on a slope number basis.

Overall, 99.88% of the engineered man-made slopes performed satisfactorily without occurrence of landslides in 2008.

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

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1 Introduction

This report presents the findings of a diagnostic review of the landslides in 2008 that were reported to the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department (CEDD). 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 2008, including the findings of the individual landslide studies. 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) respectively.

2 Rainfall and Landslides in 2008

The factual information, together with the relevant statistics on rainfall and reported landslides in 2008, was documented by Lam et al (2009).

In 2008, the annual rainfall recorded at the Principal Raingauge of the Hong Kong Observatory (HKO) in Tsim Sha Tsui was 3,066 mm, which was approximately 29% above the mean annual rainfall of 2,383 mm recorded between 1971 and 2000. Five Landslip Warnings were issued between 19 April and 10 July 2008. Two Black Rainstorm Warnings were issued on 19 April and 7 June 2008; seven Red Rainstorm Warnings were issued between 19 April and 12 July 2008; and 21 Amber Rainstorm Warnings were issued between 19 April and 5 October 2008.

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 sum total 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 868 reported landslide incidents in 2008, 863 were genuine landslides,

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discounting the non-landslide incidents (e.g. tree falls). There were 160 major failures, corresponding to about 18.5% 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 (classification given in Wong (1998)) affected by the major landslides is depicted 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		52 (9)	6.0
Cut Slopes	Soil	308 (11)	35.7
	Soil/Rock	131 (10)	15.2
	Rock	13 (1)	1.5
Retaining Walls		45 (4)	5.2
Natural Hillsides		301 (124)	34.9
Registered Disturbed Terrain		13 (1)	1.5
Total		863 (160)	100

Legend:

52 (9) 52 landslides, nine of which were major failures (i.e. failure volume $\geq 50\ m^3$).

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.

All the available data on reported landslides were examined as part of the current review. Some additional information was collated by GEO's LI consultants to assist in the selection of deserving cases for follow-up studies. A total of 16 follow-up studies on selected landslide incidents in 2008 were carried out by the LI consultants or the in-house study team of LPM1.

The individual landslide studies have provided valuable information and insights into the types, causes and mechanisms of landslides. The study reports are lodged in the Civil Engineering Library. A summary of the key findings is presented in the Hong Kong Slope Safety Website (http://hkss.cedd.gov.hk/hkss/eng/studies/lic/index.htm). Following the completion of the landslide studies, the key lessons learnt are identified and recommendations made on the necessary follow-up actions.

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Table 2.2 Breakdown of Landslides by Types of Affected Facility

Type of Affected Facility	Hong Kong Island	Kowloon	New Territories and Outlying Islands	All
Buildings	14 (8)	1 (0)	67 (13)	82 (21)
Registered Squatter Dwellings	2 (0)	3 (1)	60 (11)	65 (12)
Roads	24 (5)	5 (0)	74 (30)	103 (35)
Transportation Facilities (e.g. railways, tramways, etc.)	0 (0)	0 (0)	0 (0)	0 (0)
Pedestrian Pavements/Footways	8 (1)	2 (0)	8 (1)	18 (2)
Minor Footpaths/Access Paths	62 (6)	14 (0)	228 (41)	304 (47)
Construction Sites	2 (0)	0 (0)	3 (1)	5 (1)
Open Areas	29 (2)	16 (2)	84 (11)	129 (15)
Catchwaters	2 (0)	0 (0)	53 (7)	55 (7)
Others (e.g. carparks, parks, playgrounds, gardens, backyards, etc.)	17 (4)	11 (2)	60 (10)	88 (16)
Nil Consequence	5 (1)	5 (3)	29 (9)	39 (13)
Total	165 (27)	57 (8)	666 (134)	888 (169)

Legend:

14 (8) 14 landslides, eight of which were major failures (i.e. failure volume ≥ 50 m^3).

Notes:
(1) A given landslide may affect more than one type of facility.
(2) Incidents that were not genuine landslides have been excluded.
(3) Nil consequence refers to incidents where the landslide debris came to rest on areas with no proper access for the public (e.g. natural hillside, slope berm, disused quarry surrounded by fence, etc.).

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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
		Permanent	Temporary		Roads	Pedestrian Pavements	Footpaths, Alleyways or Private Access Paths		
Fill Slopes		0 (0)	0 (0)	1	2	0	2	0	0
Cut Slopes	Soil	7 (7)	8 (8)	0	9	1	13	0	0
	Soil/Rock	1 (1)	5 (5)	0	18	1	11	0	0
	Rock	0 (0)	0 (0)	0	0	0	3	0	0
Retaining Walls		0 (0)	4 (4)	1	0	0	6	2	0
Natural Hillsides		31 (31)	11 (11)	33	27	1	23	0	0
Registered Disturbed Terrain		0 (0)	0	1	0	0	1	0	0
Total		39 (39)	28 (28)	36	56	3	59	2	0

Legend:

8 (8) 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 1982 Housing Department's Squatter Structure Survey (GEO, 2004b).
(2) A failure may give rise to more than one type of consequence.

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Table 2.4 Breakdown of Facility Groups Affected by Major Landslides

Type of Major Landslide	Facilities Group Affected by Major Landslides (Group No.)						
	1a	1b	2a	2b	3	4	5
All Major Landslides	9	19	5	4	7	50	66
Major Landslides on Man-made Slopes	4	2	2	1	2	15	9
Major Landslides on Registered Disturbed Terrain	0	0	0	1	0	0	0
Major Landslides on Natural Hillsides	5	17	3	2	5	35	57

Notes (1) Facility groups are classified in accordance with that adopted for the New Priority Classification Systems (Wong, 1998).
(2) A given landslide may affect more than one type of facility.

Table 2.5 Breakdown of Scale of Failures by Type of Slope

Type of Slope	Number of Minor Failures	Number of Major Failures		Total
	(< 50 m^3)	(50 m^3 to < 500 m^3)	(≥ 500 m^3)	
Registered Man-made Slopes	402	30	3	435
Registered Disturbed Terrain Features	12	0	1	13
Unregisterable Man-made Slopes	77	1	0	78
Registerable Man-made Slopes Not Yet Registered at Time of Failure	35	1	0	36
Natural Hillsides	177	101	23	301
Total	703	133	27	863

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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 result in the issue of Landslip Warning and 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 (GEO, 2009a), is based on the 24-hour rainfall of a rainstorm. The LPI for rainstorms that resulted in the issue of Landslip Warning from 1984 to 2008 is presented in Figure 3.1.

In 2008, five Landslip Warnings were issued between 19 April and 10 July 2008. The LPI for the most severe rainstorm event on 7 June 2008 was 12, during which time the maximum 24-hour rolling rainfall recorded at GEO Raingauge No. N19 was 622.5 mm. As a result of the 7 June 2008 rainstorm, a total of 363 landslides were reported to the GEO, 104 of which were classified as major failures including the fatal landslide at Cafeteria Old Beach (Incident No. 2008/06/0129) (Lam et al, 2009). The 7 June 2008 rainstorm also triggered many natural terrain landslides in remote areas, which had not been reported to the Government.

In terms of its potential to cause landslides, the 7 June 2008 rainstorm was more severe than the rainstorms 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). A summary of the rainfall and landslide data for the 23 July 1994, 20 August 2005 and 7 June 2008 rainstorms is presented in Table 3.1 for comparison purposes.

4 Overall Diagnostic Review of Landslides

4.1 General

An overall diagnostic review of the available 2008 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 focused on the following aspects:

(a) coverage of the New Catalogue of Slopes,

(b) performance of registered man-made slopes, and

(c) observations from natural terrain landslides.

In addition, in response to a recommendation of the Slope Safety Technical Review Board (SSTRB, 2009), an attempt has been made to list factors that could affect the performance of man-made slopes based on a review of the landslides in 2008 and selected notable landslides in recent years. Factors that GEO can influence have been separated from those that are out of GEO's control. Other factors that may affect the performance of the slope safety system have also been identified. The key findings are summarised in Appendix A.

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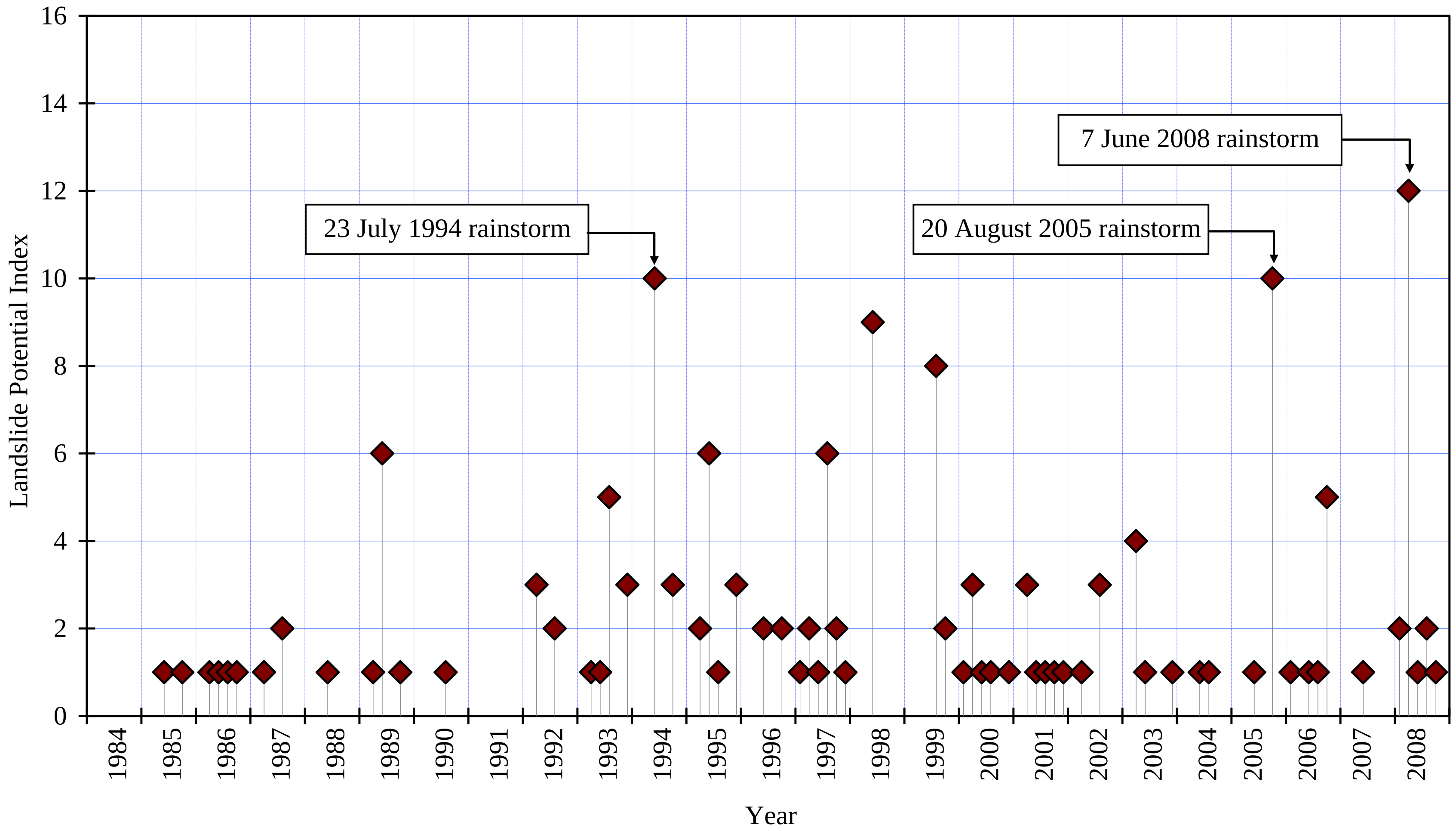

Legend:

◆ A rainstorm that resulted in the issue of Landslip Warning

Figure 3.1 Landslide Potential Index for Rainstorms that Resulted in the Issue of Landslip Warning from 1984 to 2008

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Table 3.1 Rainfall and Landslide Data for the 23 July 1994, 20 August 2005 and 7 June 2008 Rainstorms (Sheet 1 of 2)

Rainstorm			23 July 1994 Rainstorm[*]		20 August 2005 Rainstorm[*]		7 June 2008 Rainstorm[*]	
Number of reported landslides			202		229		363	
Number of major landslides	Man-made slopes		18	CTL-1 = 9[+]	50	CTL-1 = 12	20	CTL-1 = 9
				CTL-2 = 7		CTL-2 = 11		CTL-2 = 7
				CTL-3 = 2		CTL-3 = 27		CTL-3 = 4
	Natural hillsides		1	CTL-1 = 0	20	CTL-1 = 6	84	CTL-1 = 24
				CTL-2 = 0		CTL-2 = 4		CTL-2 = 10
				CTL-3 = 1		CTL-3 = 10		CTL-3 = 50
Casualty			5 fatalities and 4 injuries		1 fatality		2 fatalities	
Number of landslides affecting buildings			31		17		38	
Number of landslides affecting roads			60 (50 road sections temporarily closed)		42 (35 road sections temporarily closed)		57 (38 road sections temporarily closed)	
Maximum rolling rainfall of different durations (mm)	1-hour	HKO [§]	70.4		39.1		145.5	
		GEO [†]	211.5 (N14)		82 (N25)		153.5 (N21)	
	4-hour	HKO [§]	141.9		122.9		246.3	
		GEO [†]	365 (N14)		173.5 (N18)		384 (N19)	
	24-hour	HKO [§]	310.2		416.4		417.6	
		GEO [†]	956 (N14)		570 (N01)		622.5 (N19)	
	2-day	HKO [§]	493.9		551.9		437.9	
		GEO [†]	1215.5 (N14)		767.5 (N01)		671.5 (N19)	
	4-day	HKO [§]	677.8		640		493.6	
		GEO [†]	1449.5 (N14)		890 (N01)		767.5 (N19)	
	15-day	HKO [§]	938.1		902.5		834.8	
		GEO [†]	1860 (N14)		1279 (N38)		1161 (N40)	
	31-day	HKO [§]	1125.5		1137.6		1380.6	
		GEO [†]	2180.5 (N14)		1778.5 (N38)		1832 (N19)	

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Table 3.1 Rainfall and Landslide Data for the 23 July 1994, 20 August 2005 and 7 June 2008 Rainstorms (Sheet 2 of 2)

Rainstorm	23 July 1994 Rainstorm*	20 August 2005 Rainstorm*	7 June 2008 Rainstorm*

Legends:

* The durations of the rainstorms of 23 July 1994, 20 August 2005 and 7 June 2008 are 21-25 July 1994, 16-21 August 2005 and 6-9 June 2008 respectively.

\+ Consequence-to-life (CTL) Category

§ Maximum rolling rainfall based on rainfall data recorded at Hong Kong Observatory, Tsim Sha Tsui

† Maximum rolling rainfall amongst all GEO raingauges

Note: The locations of GEO and HKO automatic raingauges are shown in Figure 3.2.

4.2 Coverage of the New 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 completed in September 1998, together with newly formed or identified slope features after 1998, are registered in the New Catalogue of Slopes. Potentially registerable man-made slopes would also be identified during slope maintenance inspections, landslide investigations and other geotechnical inspections or studies.

4.2.2 Diagnosis

Of the 863 genuine landslides, 448 occurred on registered slope features (comprising 435 on registered man-made slopes and 13 on registered disturbed terrain (DT) features) and 415 occurred on slopes not registered in the New Catalogue of Slopes at the time of failure (Table 2.5).

Of the above 415 landslides, 78 occurred on small man-made slope features that do not meet the slope registration criteria (GEO, 2004a) and another 301 occurred on natural hillsides. The remaining 36 landslides involved slope features that satisfied the slope registration criteria but were not registered in the New Catalogue of Slopes at the time of failure. This indicates that the number of registerable slopes that were yet to be included in the New Catalogue of Slopes at the time of failure was about 4.2% of the number of genuine landslides in 2008. A breakdown of these 415 landslides is given in Figure 4.1.

Of the 36 landslides on registerable slopes, one major failure (about 75 m^3 in volume) involving a thin veneer of unknown fill material occurred on the hillside below Broadwood Road overlooking San Francisco Towers, Happy Valley (Incident No. 2008/06/0131). Debris from the landslide travelled over 60 m downhill before coming to rest at the rear of San Francisco Towers. The landslide debris also blocked the stormwater drains at the toe of

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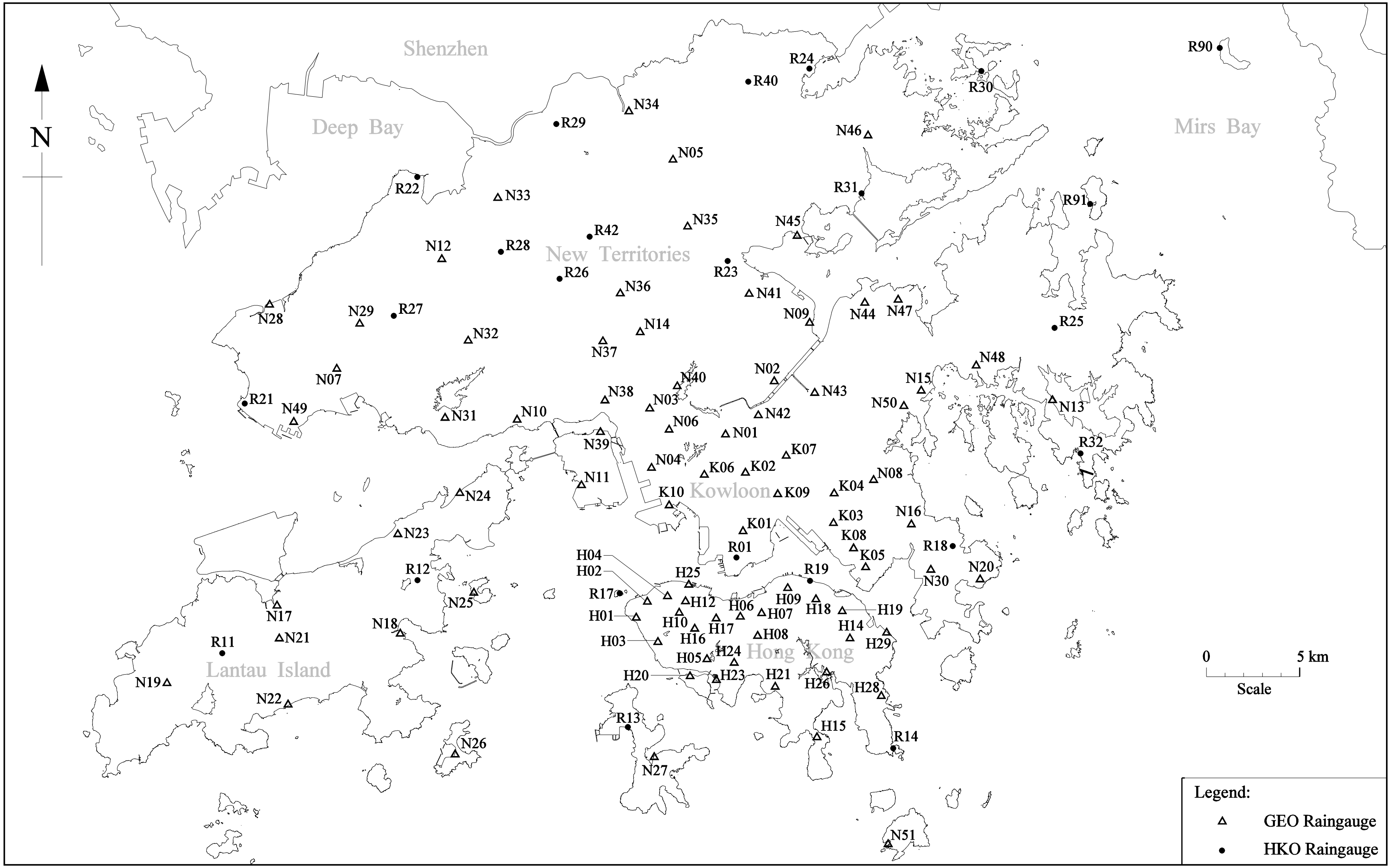

Figure 3.2 Locations of GEO and HKO Automatic Raingauges

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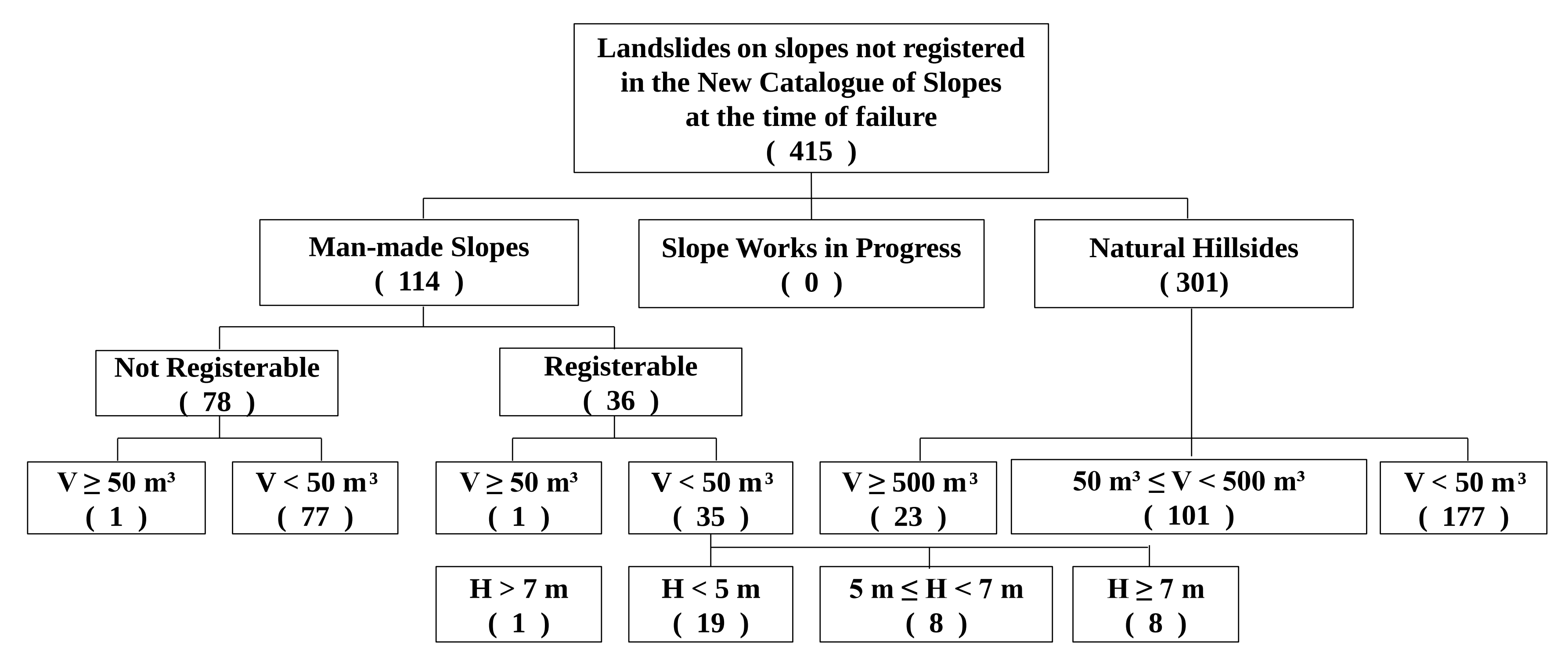

Legend:

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 New Catalogue of Slopes (GEO, 2004a) at the time of failure.
(2) Following the landslides, arrangements have been made to register the concerned man-made slope features in the New Catalogue of Slopes.

Figure 4.1 Breakdown of Landslides on Unregistered Slopes in 2008

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the hillside, contributing to the flooding of the carpark in San Francisco Towers. The landslide did not result in any casualty nor major consequences (such as evacuation of residents in the nearby buildings or closure of road). However, this incident highlighted the potential landslide hazard posed by sizeable unknown fill bodies on hillsides in urban areas. The remaining 35 landslides were minor failures; two of them resulted in the temporary evacuation of a squatter dwelling and a village house respectively, and one resulted in the permanent evacuation of a squatter dwelling. The rest of the landslides did not cause any significant impact on the community.

Following the landslides, arrangements have been made to register the concerned man-made slope features in the New Catalogue of Slopes.

Of the 13 landslides on registered DT features, one was a major failure (about 500 m^3 in volume) that occurred on slope No. 7SW-D/DT58 behind Ku Ngam Monastery, Che Kung Miu Road (Incident No. 2008/06/0319) and the remaining 12 were minor failures with a failure volume ranging from 2 m^3 to 35 m^3. Amongst these 13 landslides, one minor failure resulted in the temporary evacuation of residents in a village house in Tseng Lan Shue, Sai Kung and the other incidents did not have any major consequences.

4.3 Performance of Registered Man-made Slopes

4.3.1 General

The man-made slopes registered in the New 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) slope upgraded to the required geotechnical standards using Type 3 prescriptive measures (Wong et al, 1999) 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.

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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 863 genuine landslides in 2008, a total of 435 landslides (about 50%) occurred on registered man-made slopes (Table 2.5). Of these 435 landslides, 28 (about 6.4%) occurred on engineered slopes, comprising two major failures and 26 minor failures. The remaining 407 landslides occurred on non-engineered slopes, comprising 31 major failures and 376 minor failures. Further details on the landslides in 2008 involving engineered slopes are given in Tables 4.1 and 4.2. Detailed assessment of the engineered and non-engineered slopes is described in the sections below.

4.3.2 Landslides on Engineered Slopes

Of the 28 landslides on engineered slopes, two were major failures at Pak Fuk Road (Incident No. 2008/06/0144) and Tsing Yi Road (Incident No. 2008/06/0188) respectively. The major failure at Pak Fuk Road, with a failure volume of about 1,270 m^3, involved mainly an unsupported soil and rock cut slope (No. 11SE-A/C502), which was formed between 1976 and 1980 (generally referred to as an 'old technology' slope). Another major failure occurred on a soil and rock cut slope (No. 10NE-B/C56) at Tsing Yi Road, which involved a wedge-type failure of about 250 m^3 at the rock portion. The concerned slope had been subjected to detailed geotechnical assessments in 1980 and 1999 respectively, but no works were recommended to the portion that failed on 7 June 2008. The remaining 26 landslides were minor failures, with a failure volume ranging from less than 0.1 m^3 to 35 m^3. Of these 26 landslides, 10 involved slopes previously treated under the LPM Programme (Tables 4.1 and 4.3).

Of the 28 landslides on engineered slopes, 10 occurred on or adjacent to the soil-nailed portion of a slope (Table 4.1), six involved a rock cut or the rock portion of a cut slope, nine involved unsupported cuts (Table 4.1), two occurred on soil cut slopes with a toe retaining wall, and one occurred on a recompacted fill slope at Smithfield. The key contributory factors to the landslides on engineered, unsupported soil cuts are summarized in Table 4.4.

The fill slope failure at Smithfield (Incident No. 2008/06/0604) was a minor failure of about 25 m^3 in volume and mainly involved the top 3 m recompacted fill layer. The concerned fill slope (No. 11SW-A/FR1) was formed prior to 1976 across an old drainage line and was later upgraded under the LPM Programme in 1979 by recompacting the top 3 m of loose fill. The recompacted fill layer was underlain by loose fill of up to about 30 m in thickness. Based on the available groundwater monitoring data prior to the 2008 landslide, the groundwater regime at this site is complex with relatively significant storm response. In addition, there is prima facie evidence from the previous ground investigation in 2004 that the degree of compaction of the top 3 m recompacted fill appeared to have dropped since the recompaction works were completed in 1979. A follow-up study is being carried out to establish the probable causes and mechanisms of failure.

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Table 4.1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 1 of 11)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
1. Slopes Upgraded Under the LPM Programme (∑ = 10 nos.)					
2008/05/0122	11SW-A/C256	Kennedy Town Police Quarters, 12 Ka Wai Man Road	10	Soil cut	The works, mainly comprising cutting back of the slope and provision of a sprayed concrete cover, completed in 1990. The concerned slope is an unsupported soil cut.
2008/06/0146	11NE-D/CR467	Adjacent to House No. 100, Ma Yau Tong Village, Tseung Kwan O	< 1	Soil cut	The works, mainly comprising installation of soil nails and provision of a vegetated cover with erosion control mat and wire mesh, completed in 2005. The minor shallow failure (about 0.1 m deep) occurred near the slope toe below the lowest row of soil nails.
2008/06/0201	9SW-C/C21	Tai O Jockey Club Clinic, Tai O, Lantau Island	5	Soil/rock cut	The works, mainly comprising installation of soil nails with double corrosion protection and raking drains, and provision of a vegetated cover with erosion control mat and wire mesh, completed in 2005. The minor shallow failure (about 0.5 m deep) involved the near-surface groundmass within the soil-nailed portion of the slope.

Table 4.1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 2 of 11)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
2008/06/0275	14NW-D/C409	6E Tung Tai San Tsuen, Cheung Chau	1	Soil cut	The works, mainly comprising trimming of the slope, installation of soil nails and provision of a vegetated cover with erosion control mat, completed in 2002. The minor shallow failure (about 0.3 m deep) occurred adjacent to the soil-nailed portion of the slope.
2008/06/0285	11SW-D/CR508	Opposite Lamp Post No. 3721, 3 Severn Road, The Peak	1	Soil cut	The works, mainly comprising installation of soil nails and provision of a masonry facing near slope toe and a vegetated cover with a erosion control mat and wire mesh, completed in March 2008. The minor failure involved the detachment of masonry facing and localised soil bulging within the soil-nailed portion of the slope.
2008/06/0322	11NW-D/C45	Ko Shan Road Garden	1 (rockfall)	Soil/rock cut	The works, mainly comprising installation of soil nails at the soil portion and raking drains at the rock portion, completed in 2004. The rockfall occurred on the rock portion.
2008/06/0449	6SW-D/C7	Castle Peak Road, Tai Lam, Tuen Mun	2 (rockfall)	Rock cut	The works, mainly comprising rock slope treatment works including rock dowels and concrete buttresses, as well as provision of mesh netting to the slope surface, completed in 2002.

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Table 4.1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 3 of 11)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
2008/06/0604	11SW-A/FR1	Smithfield	25	Fill	The works, mainly comprising recompaction of the top 3 m of fill, construction of a gravity retaining wall and provision of a vegetated cover, completed in 1979. Some works were carried out at the fill slope under the Smithfield Extension Project in 1996, which did not involve any change to the slope profile.
2008/06/0638	9SW-C/C5	Hong Kong Shaolin Martial Art Centre, Lantau Island	1	Soil cut	The works, mainly comprising installation of soil nails and provision of a sprayed concrete cover to the lowest slope batter while retaining the existing chunam surface on upper slope batters, completed in 1990. The minor shallow failure (about 0.3 m deep) involved the near-surface groundmass within the soil-nailed portion of the slope, which is covered by chunam surface. The chunam surface adjacent to the failed area appeared to be poorly maintained with cracks and unplanned vegetation.
WSD/ 2008/6/20/K	11NW-B/C135	Lion Rock High Level Fresh Water No. 1 Service Reservoir	14.4	Soil cut	The works, mainly comprising cutting back of the slope and provision of a vegetated cover, completed in 1992. The concerned slope is an unsupported soil cut.

Table 4.1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 4 of 11)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
2. Slopes Assessed under the LPM Programme 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.					

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Table 4.1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 5 of 11)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
6. Slopes Formed or Upgraded by Government Departments and Checked by GEO ($\sum$ = 10 nos.)					
2008/06/0140	11NW-D/C547	Junction between Fat Kwong Street and Sheung Shing Street	10	Soil cut	The geotechnical design of the concerned slope was carried out in relation to the site formation for the Auxiliary Medical Service Training Centre, which was checked and accepted by the GEO in 1988. The concerned slope is an unsupported soil cut.
2008/06/0256	7NW-B/C493	Chainage 18.5 m, Tolo Highway (North Bound), Tai Po	30	Soil cut	The geotechnical design of the concerned slope was carried out in relation to the site formation for the New Territory Trunk Road System Project, which was checked and accepted by the GEO in 1986. The concerned slope is an unsupported soil cut.
2008/06/0320	7NE-A/C167	Ting Kok Road, Tai Po	20	Soil cut	The geotechnical design of the concerned slope was carried out in relation to the Ting Kok Road Improvement Project, which was checked and accepted by GEO in 2002. The minor shallow failure (about 0.5 m deep) involved the near-surface groundmass within the soil-nailed portion of the slope. The failure did not cause any damage to the soil nails and nail heads.

Table 4.1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 6 of 11)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
2008/06/0419	11NW-A/C196	Near Lamp Post No. E9366, Tai Po Road, Sham Shui Po	7	Soil/rock cut	The geotechnical design of the concerned slope was carried out in relation to the Tai Po Road Improvement Project (Sha Tin to Tai Wo Ping Interchange), which was checked and accepted by the GEO in 1987. The concerned slope is an unsupported soil and rock cut.
2008/06/0450	11SE-B/C594	Hong Kong Museum of Coastal Defence	20	Soil/rock cut	The geotechnical design of the concerned slope was carried out in relation to the Lei Yue Mun Museum Project, which was checked and accepted by the GEO in 2000. The minor failure occurred on the steeply inclined soil portion above the lower rock portion and did not involve the northern portion of the slope that was stabilised by soil nails.
2008/06/0467	11NW-B/C89	Beacon Hill Garden, Lung Ping Road	3	Soil cut	The concerned slope was studied under the Phase IID Landslide Studies for Lung Cheung Road Area by the GEO and modification works were recommended in 1980. The proposed works were subsequently carried out in relation to the site formation of Tai Wo Ping, which was checked and accepted by the GEO in 1982. The concerned slope is an unsupported soil cut.

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Table 4.1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 7 of 11)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
2008/06/0531	9SE-C/C22	Ngong Ping Road, Ngong Ping, Lantau Island	4	Soil/rock cut	The geotechnical design of the concerned slope was carried out in relation to the Improvement to Access Road to Ngong Ping on Lantau Island, which was checked and accepted by the GEO in 1990. The minor shallow failure (about 1.0 m deep) occurred near the slope toe below the lowest row of soil nails.
2008/07/0765	11NE-D/C73	Next to Hing Tin Street, Lam Tin	35	Soil/rock cut	The geotechnical design of the concerned slope was carried out in relation to the Lam Tin Northern Link Road Project, which was checked and accepted by the GEO in 1984. The concerned slope is an unsupported soil and rock cut.
WSD/ 2008/6/60/K	11NW-B/C582	Shek Kip Mei No. 2 Fresh Water Service Reservoir, West of Pak Tin Estate	7.5	Soil/rock cut	The geotechnical design of the concerned slope was carried out in relation to the site formation for the Shek Kip Mei No. 2 Fresh Water Service Reservoir, which was checked and accepted by the GEO in 1994. The concerned slope is an unsupported soil and rock cut.

Table 4.1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 8 of 11)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
WSD/ 2008/6/8/NTW	6SE-D/C242	Yau Kam Tau No. 2 Fresh Water Service Reservoir	6	Soil cut	The geotechnical design of the concerned slope was carried out in relation to the site formation for the Yau Kam Tau No. 2 Fresh Water Service Reservoir, which was checked and accepted by the GEO in 1994. The minor shallow failure (about 0.3 m deep) involved the near-surface groundmass within the soil-nailed portion of the slope.

7. Slopes Formed or Upgraded by Private Owners and Checked by GEO (∑ = 6 nos.)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
2008/06/0144	11SE-A/C502	Pak Fuk Road near Tin Hau Temple Road	1,270	Soil/rock cut	The site formation plans for the private development project of Bedford Gardens, including the cutting back of the concerned slope, was checked and accepted by the GCO in 1980. The slope was handed over to the Government in 1982. The concerned slope is an unsupported soil and rock cut.
2008/06/0147	11SW-D/CR141	33 Shouson Hill Road	0.5	Soil/rock cut	The geotechnical design of the concerned slope was carried out in relation to the private development project of 31-33 Shouson Hill Road, which was checked and accepted by the GEO in 1995. The minor failure occurred on a steeply inclined soil slope portion above the soil-nailed portion of the slope.

Table 4.1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 9 of 11)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
2008/06/0188	10NE-B/C56	CLP Old Power Station Storage Area, Tsing Yi Road, Tsing Yi	250	Soil/rock cut	The geotechnical assessment for the rock slope portion (i.e. failed portion) of the concerned slope was carried out in relation to a Dangerous Hillside Order on the soil slope portion, which was checked and accepted by the GEO in 1999. The failure occurred on the rock portion of the cut slope.
2008/06/0412	11SW-D/CR1576	8 Wong Nai Chung Road, Wanchai	5	Soil cut	The geotechnical design of the concerned slope was carried out in relation to the private development project of 6-10 Wong Nai Chung Gap Road, which was checked and accepted by the GEO in 1987. The failure occurred on the soil cut portion above a retaining wall.
2008/07/0689	3SW-A/CR128	Opposite to Block 2, Royal Knoll, 2 Chi Wing Close, Pak Wo Road, Fanling	3	Soil cut	The geotechnical design of the concerned slope was carried out in relation to the private development project of Royal Knoll, which was checked and accepted by the GEO in 1999. The failure occurred on the soil cut portion above a retaining wall.
2008/07/0732	7SW-C/C62	22 Kwai Hop Street, Kwai Shing	< 0.1 (rockfall)	Rock cut	The geotechnical design of the concerned slope was carried out in response to an Advisory Letter, which was checked and accepted by the GEO in 1986.

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Table 4.1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 10 of 11)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
8. Slopes Upgraded Following Service of DH Orders and Checked by GEO (∑ = 2 nos.)					
2008/06/0343	11SE-A/CR279	Above North Point Methodist Primary School, 19 Cheung Hong Street	1	Soil cut	The concerned slope was upgraded by the private owner in 2003 following the service of a DH Order in 1998. The minor shallow failure (about 0.3 m deep) involved the near-surface groundmass within the soil-nailed portion of the slope.
2008/07/0742	7SW-C/C70	Below Daughter of Mary Help of Christians Sui Ming Catholic Secondary School, Kwai Hop Street, Kwai Shing	< 1	Soil/rock cut	The concerned slope was upgraded by the private owner in 2000 following the service of a DH Order in 1998. The minor failure involved the detachment of highly weathered material on the rock portion of the slope.
9. Slopes Assessed as Not Requiring Upgrading Works But with Outstanding GEO Comments (∑ = 1 no.)					
2008/05/0121	15NW-B/C92	Near Lei Tung Estate Bus Terminus, Ap Lei Chau	0.5 (rockfall)	Soil/rock cut	The rock portion (i.e. failed portion) of the concerned slope was assessed by the Hong Kong Housing Authority (HKHA) as not requiring upgrading works in 2001 with outstanding GEO comments mainly on the geological and hydrogeological conditions of the slope. HKHA has recently provided GEO with supplementary information to address the outstanding comments.

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Table 4.1 Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 11 of 11)

Incident No.	Slope No.	Location	Failure Volume (m^3)	Type of Slope	Remarks
10. Slopes Assessed as Requiring Upgrading Works but with Outstanding GEO Comments (∑ = 0 no.)					
Nil.					

Legend:

(grey box) Landslide occurred within or adjacent to the soil-nailed portion of a cut slope (∑ = 10 nos.)

(yellow box) Landslide involved unsupported cuts (∑ = 9 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 taken as engineered slopes for the purpose of this report.

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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)	1 (0)	0	0	1
50 m^3 to 500 m^3	0	0 (0)	1 (0)	0	0	1
> 5 m^3 to < 50 m^3	1	6 (2)	4 (0)	0	0	11
≤ 5 m^3	0	8 (5)	5 (3)	2	0	15
Total	1	14 (7)	11 (3)	2	0	28

Legend:

6 (2) Six landslides involved engineered cut slopes, two of which occurred within or adjacent to the soil-nailed portion of the slope

In regard to the 10 soil-nailed slope failures, all of them were associated with minor surface erosion or small-scale detachments (≤ 20 m^3) from the near-surface groundmass. None of these failures were mobile and all had negligible consequences. Taking into account the previously recorded failures on soil-nailed cut slopes (Ng et al, 2008a), to date no major failures have occurred on soil-nailed cut slopes. In comparison, the failure volumes of those landslides on engineered unsupported cuts in 2008 were generally much larger (see Table 4.2). This affirms the robustness of soil nails for use in slope upgrading works to prevent large-scale instability. However, minor failures often occur on soil-nailed slopes. The number and size of these minor failures may be reduced by improved slope surface protection and drainage measures as recommended by Ng et al (2008a).

4.3.3 Landslides on Non-engineered Slopes

There were 31 major failures on non-engineered slopes in 2008 and two of them had a failure volume in excess of 500 m^3, which were located at Wah Yan College and Shek Tsai Po Street respectively.

The landslide at Wah Yan College (Incident No. 2008/06/0298), with a failure volume of about 550 m^3, mainly involved a natural hillside inclining at 30°, together with a 6 m high, old masonry wall (registered as feature No. 11NW-D/R87) and the associated fill platform behind at the mid-slope. The failure was probably caused by saturation of the groundmass as a result of infiltration following heavy rainfall. The presence of the masonry wall and fill platform might also have contributed to the failure.

The landslide at Shek Tsai Po Street (Incident No. 2008/06/0381), with a failure volume of about 2,000 m^3, occurred on a 55 m high soil cut slope (No. 9SW-C/C1), which was steeply inclined at 55°. The concerned slope has a history of signs of distress and instability (including a major failure of about 150 m^3 in 1986). A Dangerous Hillside (DH)

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Order was served in 2005 to the responsible private owners requiring them to carry out an investigation of the stability of the concerned slope following a safety-screening study in 2002. However, the DH Order was not yet discharged at the time of the 7 June 2008 landslide.

Table 4.3 Breakdown of Landslides on Slopes Previously Treated under the LPM Programme

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
< 50 m^3	1	6	2	1	0	10
Total	1	6	2	1	0	10

Table 4.4 Breakdown of Key Contributory Factors to Landslides on Engineered Unsupported Cut Slopes

Key Contributory Factors	All Landslides (Σ = 9 nos.)	Minor Failures (Σ = 8 nos.)	Major Failures (Σ = 1 nos.)
Direct Infiltration	4	4	0
Adverse Geological Material	1	0	1
Adverse Groundwater	2	1	1
Concentrated Surface Water Flow	2	2	0
Inadequate Geological Input	0	0	0
Inadequate Slope Maintenance	0	0	0
Inadequate Surface Drainage Provisions	0	0	0
Leakage of Water-carrying Services on Slope	1	1	0

Note: A given landslide may be associated with more than one key contributory factor to the failure.

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4.3.4 Annual Failure Rates

The annual failure rates of registered man-made slopes under different categories are presented in Tables 4.5 and 4.6. 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.

Relating the failure rate to the surface area of slopes, as in item (b) above, 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 2008 (excluding registered DT features) correspond to 435 / 55000 = 0.791% (number of landslides divided by number of registered man-made slopes), 0.031% (total surface area of landslides divided by total surface area of registered man-made slopes), and 7.955×10^{-6} (number of landslides divided by total surface area of registered man-made slopes in m^2) respectively. Further details are summarised in Table 4.6.

Based on the landslide data in 2008 (Table 4.6), the annual failure rates of engineered slopes are lower than that of non-engineered slopes by a factor of about 11 on a slope number basis, and about 22 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 32 times lower than that of non-engineered slopes.

In addition, the annual failure rates of slopes previously treated under the LPM Programme correspond to 0.270% (number of landslides divided by number of registered man-made slopes treated under the LPM Programme), 0.002% (total surface area of landslides divided by total surface area of registered man-made slopes treated under the LPM Programme), and 1.506×10^{-6} (number of landslides divided by total surface area of registered man-made slopes treated under the LPM Programme in m^2) respectively, as summarised in Table 4.6. In general, the annual failure rates of slopes previously treated under the LPM Programme is lower than that of non-engineered slopes by a factor ranging from 5 to 44, and is 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 2008, the corresponding annual success rates were 99.99% and 99.89% 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 2008 is shown in Table 4.7 and Figure 4.2.

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Table 4.5 Annual Failure Rates of Registered Man-made Slopes in 2008

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 2008	Number of Slopes	62	345	407	1	27	28
	Surface Area of Landslides (m^2)	4,092	10,755	14,847	25	1,540	1,565
Slopes Involved in Major Landslides in 2008	Number of Slopes	11	20	31	0	2	2
	Surface Area of Landslides (m^2)	2,087	3,985	6,072	0	1,062	1,062
Slopes Involved in Minor Landslides in 2008	Number of Slopes	51	325	376	1	25	26
	Surface Area of Landslides (m^2)	2,004	7,169	9,173	25	478	503
Total Number of Registered Slopes		11,300	20,500	31,800	10,450	12,750	23,200
Total Surface Area of Registered Slopes (m^2)		6,271,114	10,778,329	17,049,443	12,376,634	25,252,452	37,629,086
Annual Failure Rates (All Landslides)	On Slope Number Basis	0.549%	1.678%	1.277%	0.010%	0.212%	0.121%
	On Slope Surface Area Basis	0.065%	0.100%	0.087%	0.0002%	0.006%	0.004%
	Number of Landslides Divided by Slope Surface Area (no./m^2)	9.887×10^{-6}	3.192×10^{-5}	2.381×10^{-5}	8.080×10^{-8}	1.069×10^{-6}	7.441×10^{-7}
Annual Failure Rates (Major Landslides)	On Slope Number Basis	0.097%	0.088%	0.091%	0%	0.016%	0.009%
	On Slope Surface Area Basis	0.033%	0.033%	0.033%	0%	0.004%	0.003%
	Number of Landslides Divided by Slope Surface Area (no./m^2)	1.754×10^{-6}	1.670×10^{-6}	1.701×10^{-6}	0	7.920×10^{-8}	5.315×10^{-8}

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

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Table 4.6 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	0.791%	0.031%	7.955×10^{-6}
	Major Landslides	0.06%	0.013%	0.003×10^{-6}
	Minor Landslides	0.731%	0.018%	7.352×10^{-6}
Engineered Slopes	All Landslides	0.121% (0.270%)	0.004% (0.002%)	7.441×10^{-7} (1.506×10^{-6})
	Major Landslides	0.009% (0%)	0.003% (0%)	5.315×10^{-8} (0)
	Minor Landslides	0.112% (0.270%)	0.001% (0.002%)	6.910×10^{-7} (1.506×10^{-6})
Non-engineered Slopes	All Landslides	1.280% [11 / 5]	0.087% [22 / 44]	2.387×10^{-5} [32 / 16]
	Major Landslides	0.097%	0.033%	1.818×10^{-6}
	Minor Landslides	1.182%	0.054%	2.205×10^{-5}

Legend:

0.121% (0.270%) Annual failure rate of engineered slopes (considering all landslides) is 0.121% and that for slopes previously treated under the LPM Programme is 0.270%.

1.277% [11 / 5] Annual failure rate of non-engineered slopes (considering all landslides) is 1.277%, which is about 11 times and 5 times higher than those of engineered slopes and slopes previously treated under the LPM Programme respectively.

4.4 Key Observations

4.4.1 Severity of Rainstorms that Triggered Landslides Involving Man-made Slopes

Studies of seven landslides involving man-made slopes have been carried out and the findings provide sufficiently reliable information to assess the timing and severity of the rainstorms preceding the failures for six cases, with the exception for one where the timing of

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failure was unknown. Of these six landslide studies, the rainfall analyses show that 4 of them occurred during a rainstorm, which was virtually the most severe that the slope had experienced in the past. The remaining two landslides, one of which was the fatal landslide at Cafeteria Old Beach and the other was the major failure on the hillside below Broadwood Road overlooking San Francisco Towers (see Section 4.2.2), occurred during a rainstorm that was less severe than the previous major rainstorms. Further details on the fatal landslide at Cafeteria Old Beach are given below.

The fatal landslide at Cafeteria Old Beach (Incident No. 2008/06/0129) occurred on slope No. 6SW-C/CR797 at about 6:30 a.m. on 7 June 2008, involving the collapse of about 25 m length of an approximately 2.8 m high crest concrete retaining wall and part of the slope below. The landslide debris, with a failure volume of about 300 m^3, hit a squatter structure at the toe of the slope and resulted in two fatalities. The investigation (FSWJV, 2009) established that the landslide was principally caused by build-up of transient groundwater pressure in the groundmass following the heavy rainfall. One of the probable factors contributing to the failure was the adverse change to the site setting due to the extensive vegetation clearance on the platform at the crest of slope No. 6SW-C/CR797, about 6 to 18 months prior to the failure. This would have promoted water ingress through direct infiltration as well as local ponding on the platform, rendering the slope more susceptible to rain-induced failure.

On the basis of the observations from landslide studies, the proposition that the continued stability of an existing man-made slope may be proven by past severe rainstorms should be treated with extreme caution. Before one could confidently count on past slope performance regarding the margin of safety for long-term stability, one needs to consider factors such as potential adverse changes to the environmental conditions, adequacy of regular slope maintenance, as well as possible slope deterioration and progressive slope deformation during past rainstorms.

4.4.2 Comparison of Rainfall and Landslide History between Two Significant Rainstorms in August 2005 and June 2008

The rainstorm events of August 2005 and June 2008 had resulted in extensive landslides and a few casualties. The rainfall and landslide data for the two events, together with that for the July 1994 event, are summarised in Table 3.1. A comparison of the rainfall and landslide history of the 1994 and 2005 rainstorm events had been made in Tam et al (2008). The two rainstorm events in 2005 and 2008 are compared below.

Comparing the LPI of the two respective rainstorm events, the August 2005 rainstorm has a lower LPI of 10, compared with a LPI value of 12 for the June 2008 event (Figure 3.1). The total number of reported landslides in the June 2008 rainstorm was about 60% more than that in the August 2005 rainstorm, probably because of the more intense short-duration and 24-hour rainfall of the former. However, the number of major, man-made slope failures triggered by the August 2005 rainstorm was 50, about 2.5 times more than that triggered by the June 2008 rainstorm (Table 3.1). This may have been due to the different locations of the peak rainfalls from the respective rainstorms (Figures 4.3 and 4.4). For the August 2005 event (Figure 4.3), the peak rainfall mainly affected the urban fringe areas near Shatin and Tsuen Wan. This had resulted in a relatively high number of major landslides on man-made slopes, about half of which were of low consequence-to-life (CTL) (i.e. CTL Category 3) as many were located in urban fringe areas.

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Table 4.7 Annual Success Rates of Engineered Slopes from 1997 to 2008

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
Engineered Slopes Processed by the Slope Safety System (≥ 50 m^3)	99.97%	99.98%	99.97%	99.98%	99.98%	100%	99.99%	100%	99.98%	100%	100%	99.99%
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%

Note: See Figure 4.2 for a plot of annual success rates of engineered slopes against the target annual success rates from 1997 and 2008.

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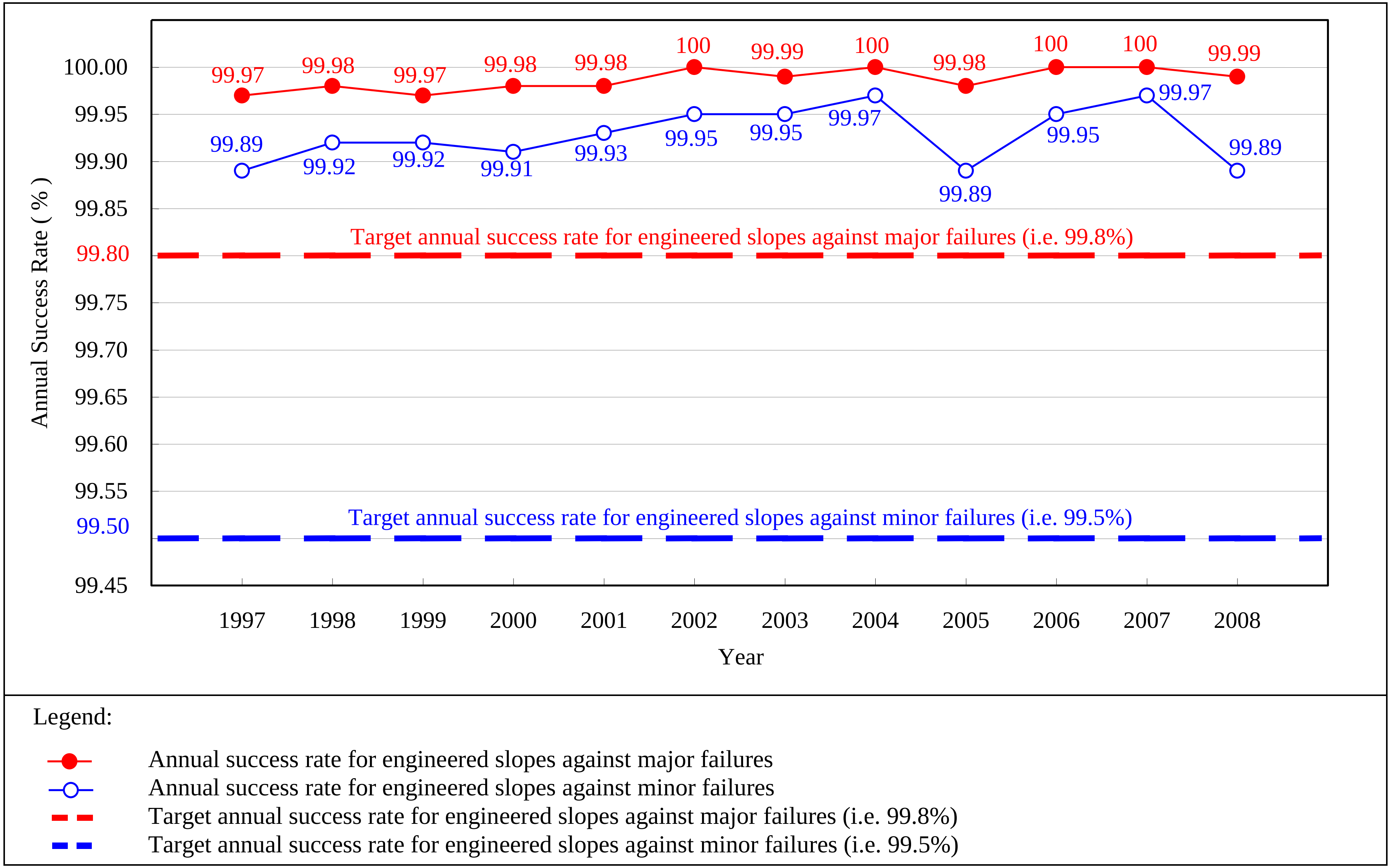

Figure 4.2 Annual Success Rates of Engineered Slopes from 1997 to 2008

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In regard to the June 2008 rainstorm, the peak rainfall occurred largely on the rural areas on western Lantau Island (Figure 4.4). Consequently, there were many more natural terrain landslides and more reported major landslides (84 nos.) involving natural hillsides than that (20 nos.) from the August 2005 rainstorm (Table 3.1). Many of them had high mobility and affected roads and developments. The relatively high debris mobility in the June 2008 landslides may have been partly caused by the intense short-duration rainfall of the June 2008 rainstorm that was more severe than that of the August 2005 event, e.g. the highest recorded 1-hour and 4-hour rolling rainfall in the June 2008 rainstorm were about twice of those in the August 2005 rainstorm (Table 3.1).

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

All the 435 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 of selected landslides by the LI consultants, together with the findings of the follow-up studies.

Inadequate slope maintenance was assessed to be a key contributory factor in 28 of the 435 landslides reviewed (i.e. about 6.4%), which comprises one major failure on an old soil cut slope at Creasy Road (Incident No. 2008/06/0151) with a failure volume of about 50 m^3 and another 27 minor failures with a failure volume ranging from less than 1 m^3 to 30 m^3. Amongst these 27 minor failures, 3 occurred on engineered slopes.

Of these 28 landslides involving inadequate slope maintenance, 16 affected Government slopes and 4 affected private slopes (of which one of them was the major failure at Creasy Road). The remaining eight affected features of mixed maintenance responsibility of Government/private, based on the information from the Slope Maintenance Responsibility Information System (SMRIS) maintained by the Lands Department. Of the eight incidents that occurred on slope features with mixed maintenance responsibility, five were on the Government portion, two were on the private portion, and one involved both the Government and private portions of the feature.

It should be noted that the number of incidents with inadequate slope maintenance is relatively small and hence they are unlikely to be of statistical significance. Nevertheless, 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 fail without adequate maintenance.

4.4.4 Landslides Affecting Squatters

In 2008, there were 65 landslide incidents, 12 of which were major failures, affecting registered squatter dwellings (i.e. those included in the 1982 Housing Department's Squatter Structure Survey (GEO, 2004b)). Of these landslides, 24 had resulted in notable consequence, including the temporary evacuation of 28 registered squatter dwellings and compulsory clearance (i.e. Category 1 Non-Development Clearance (NDC)) recommended for 39 registered squatter dwellings (Table 2.3). These landslide incidents highlighted that

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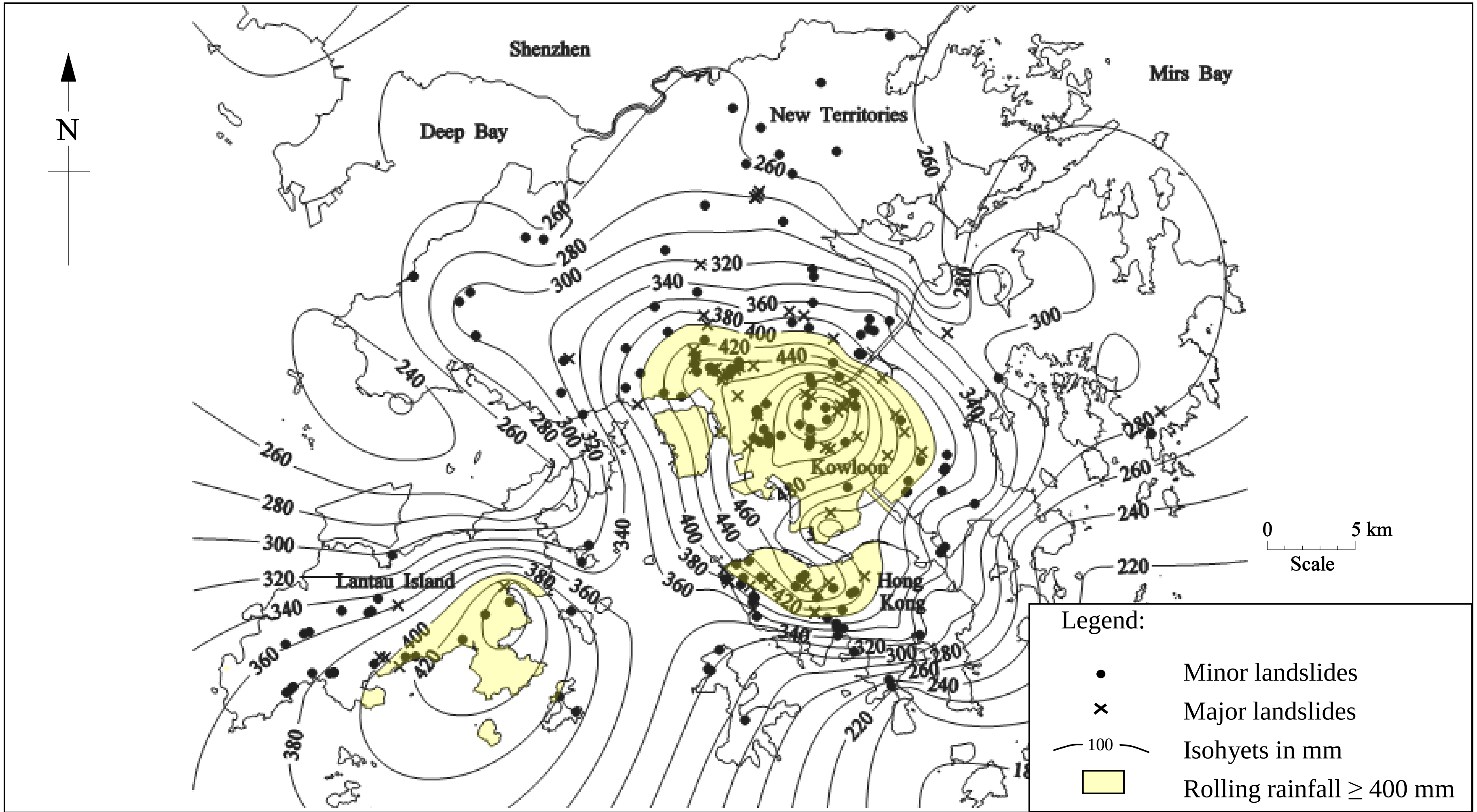

Notes: (1) The duration of the 20 August 2005 rainstorm is 16-21 August 2005.
(2) 229 genuine landslides reported to have occurred within the period between 16 and 21 August 2005.
(3) Isohyets are based on the GEO and HKO automatic raingauges (see Figure 3.2 for their locations).

Figure 4.3 Maximum Rolling 24-hour Rainfall Distribution for the 20 August 2005 Rainstorm and Locations of Landslides

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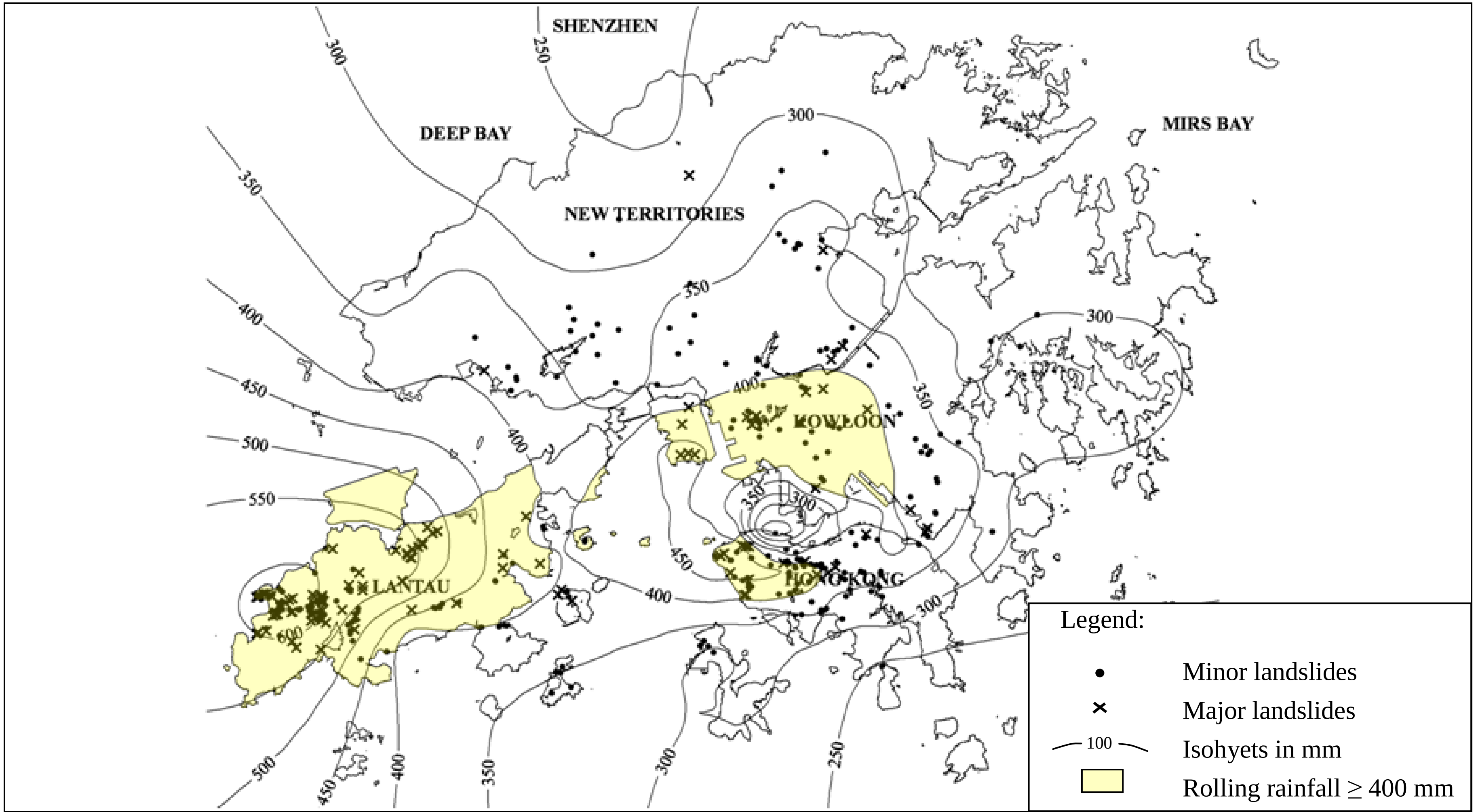

Notes: (1) The duration of the 7 June 2008 rainstorm is 6-9 June 2008.
(2) 363 genuine landslides reported to have occurred within the period between 6 and 9 June 2008.
(3) Isohyets are based on the GEO and HKO automatic raingauges (see Figure 3.2 for their locations).

Figure 4.4 Maximum Rolling 24-hour Rainfall Distribution for the 7 June 2008 Rainstorm and Locations of Landslides

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some squatter dwellings were subject to relatively high landslide risk. To address the landslide risk arising from Government man-made slopes affecting squatter dwellings, the current approach to deal with the risk by means of clearing the affected squatter dwellings has been enhanced whereby slope upgrading works would also be undertaken as part and parcel of a multi-pronged approach to manage the landslide risk.

4.4.5 Natural Terrain Landslides

4.4.5.1 Overview

The June 2008 rainstorm had triggered many sizeable natural terrain landslides. Amongst the reported landslides on natural hillsides, about 41% (124 nos.) were major failures, compared to that about 6% (35 nos.) of the reported landslides on man-made slopes were major failures.

Natural terrain landslides in 2008 had caused significant impact to the community. Many of the reported natural terrain landslides involved sizeable debris flows with a long runout distance affecting nearby facilities. In 2008, the reported natural terrain landslides accounted for about 92% of the cases involving evacuation or closure of houses or flats affected by landslides. About 63% of the number of squatter dwellings evacuated as a result of landslides were due to natural hillside failures. Moreover, about half of the number of road closures arising from landslides were due to natural hillside failures.

Many of the reported natural terrain landslides occurred on hillsides with a history of past instabilities. Some of the landslides were very sizable, involving large-scale and highly mobile debris flows with unexpected runout paths occasionally. The scale, mobility and runout characteristics of debris flows will be studied separately. The study will also cover the large number of natural terrain landslides (more than 2,000) triggered by the June 2008 rainstorm, which were not reported to the Government as they occurred in remote areas and did not affect any major facilities.

4.4.5.2 Large-scale Landslides

The 7 June 2008 rainstorm triggered many sizeable natural terrain landslides, three of which have been selected for follow-up studies. These landslides included the one that occurred on the hillside behind Hong Kong University (HKU) (Incident No. 2008/06/0193), one in catchment No. 30 above Yu Tung Road (Incident No. 2008/06/0344) and another above Shatin Pass Road (Incident No. 2008/06/0170). The failure volumes for the HKU, Yu Tung Road and Shatin Pass Road landslides were in the order of 1,700 m^3 (for the primary landslide source area), 2,400 m^3 and 3,000 m^3 respectively. In these landslides, the debris entered into a nearby drainage line and developed into a large-scale debris flow, with a runout distance up to about 600 m.

The HKU and Yu Tung Road landslides involved shallow failures of about 3 m deep, and were largely within the surface mantle of colluvium or talluvium. The shallow failures are typically triggered by slope saturation and build-up of transient water pressure as a result of infiltration and subsurface seepage flow.

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In both the HKU and Yu Tung Road landslides, the failures were spatially extensive, measuring up to about 30 m wide and 50 long, and occurring at relatively steep parts of the hillside. The HKU landslide occurred at a location where a large area of accumulation of colluvial deposits had been formed over time as a result of relatively frequent, moderate scale landslide activities in the past (Figures 4.5 and 4.6). Similarly, the Yu Tung Road landslide occurred where large areas of boulderly deposits had accumulated (Figures 4.7 and 4.8), as a result of landsliding activities, together with general mass wasting processes. In both cases, the scale of the failures appears to have been influenced by the presence and deterioration of the accumulated debris and site topography, together with the characteristics of the 7 June 2008 rainstorm.

For the landslide at Shatin Pass Road, the rupture surface was partially controlled by an adversely orientated joint within the weathered rock, with evidence of retrogressive enlargement of the main scarp after the initial failure. This has resulted in a relatively deep, up to 6 m, and sizeable failure, measuring up to about 30 m wide by 50 m long. The possible build-up of transient cleft water pressure in the rock joints as a result of infiltration may have also contributed to the failure. The mechanism of failure at Shatin Pass Road was different from that at HKU and Yu Tung Road that largely involved the surface deposits with relatively minor influence from the underlying weathered rock mass.

4.4.5.3 Presence of Recent Debris Fans

In the Yu Tung Road debris flow case, the 1945 and 1963 aerial photographs show a distinct and relatively more recent debris fan at the outlet of the main drainage line in catchment No. 30, as evidenced by the hummocky surface and different vegetation type compared with other parts of the debris fan. This more recent debris fan had possibly been formed as a result of a single large failure, with an estimated volume in the order of about 3,000 m^3, comparable with the scale of the June 2008 failure from the same catchment.

The presence of a relatively more recent debris fan could be a "tell-tale" sign of a potentially "active" drainage line with respect to channelised debris flow. However, such debris fans do not provide any indication of the likely frequency of a significant debris flow event. Moreover, the identification of such debris fans in urban areas from aerial photographs may be difficult, as the debris deposits in such areas would likely have been removed or substantially disturbed by the developments prior to any aerial photograph records. Further, the presence of debris fans may be related to fluvial deposition instead of past failures.

4.4.6 Landslides on Hillside Pockets Close to Developments in Urban Areas

In 2008, some landslides occurred on hillside pockets close to developments in urban areas, and three of them have been identified as major failures and affecting residential buildings. Amongst these three major failures, one notable landslide (Incident No. 2008/06/0156) occurred on 7 June 2008 on the hillside behind Rockwin Court, Fung Fai Terrace, Happy Valley (Figure 4.9). The estimated failure volume was 500 m^3. Some landslide debris travelled down to the rear garden of Rockwin Court and went into the flats of Rockwin Court adjacent to the toe of the hillside. Residents in nine affected flats of

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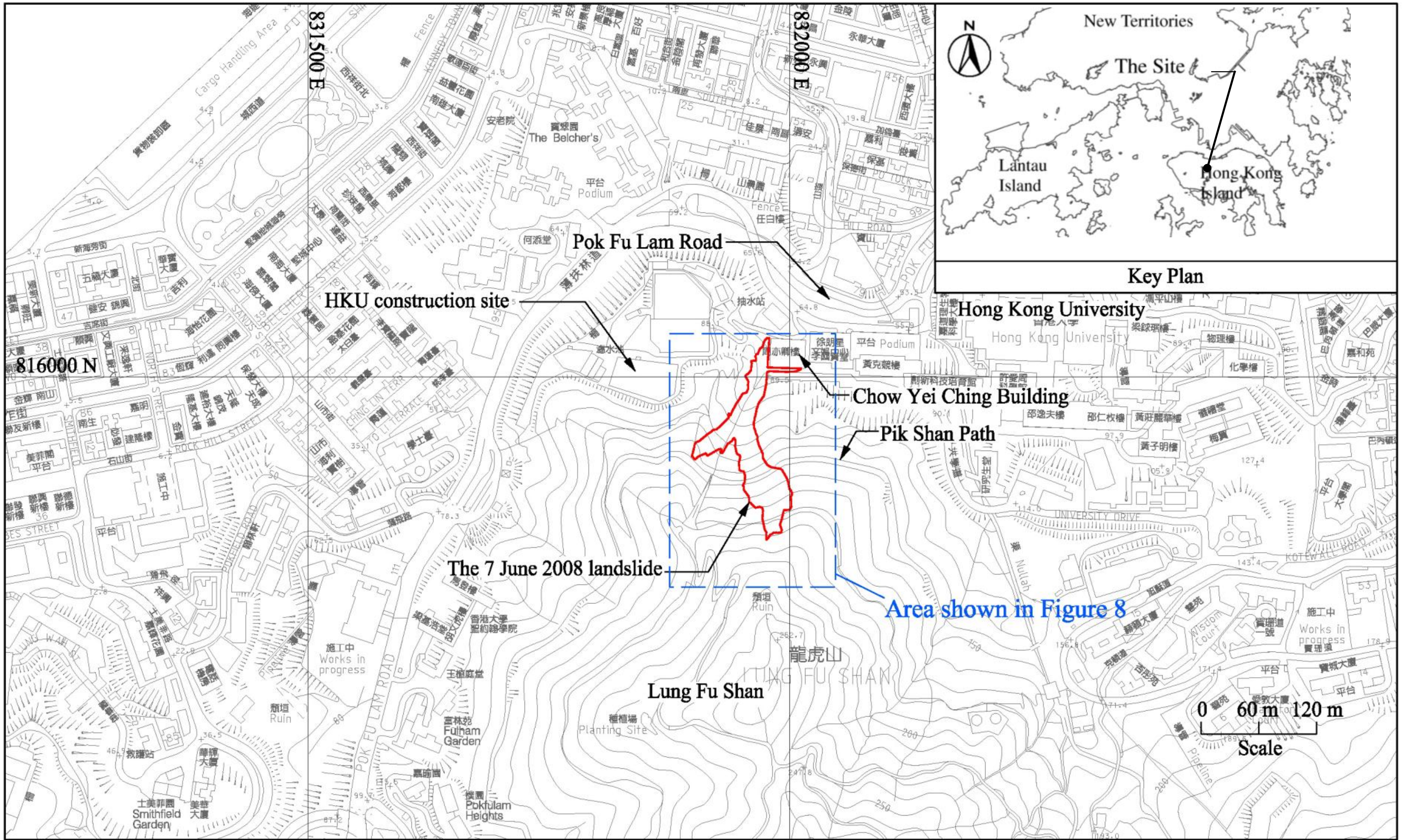

Note : Base plan is extracted from 1 : 1000 survey sheets Nos. 11SW-7C, 7D, 12A & 12B dated March 2008.

Figure 4.5 Location Plan of the 7 June 2008 Landslide on the Hillside behind HKU

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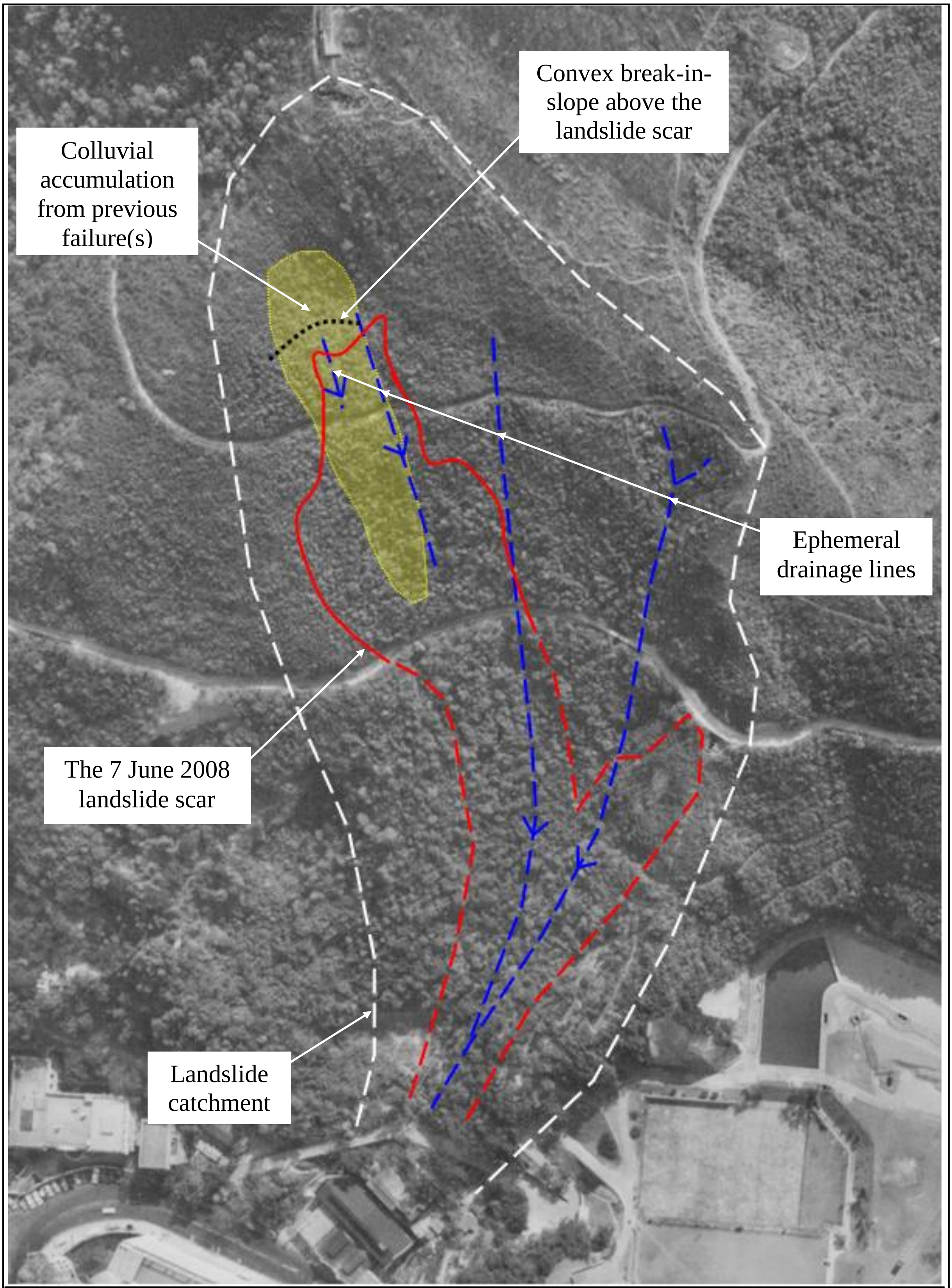

Notes: (1) The figure is based on the 1963 aerial photograph No. Y07601.
(2) See Figure 4.5 for the approximate extent of area shown in this figure.

Figure 4.6 Accumulation of Colluvial Deposits on the Hillside behind HKU

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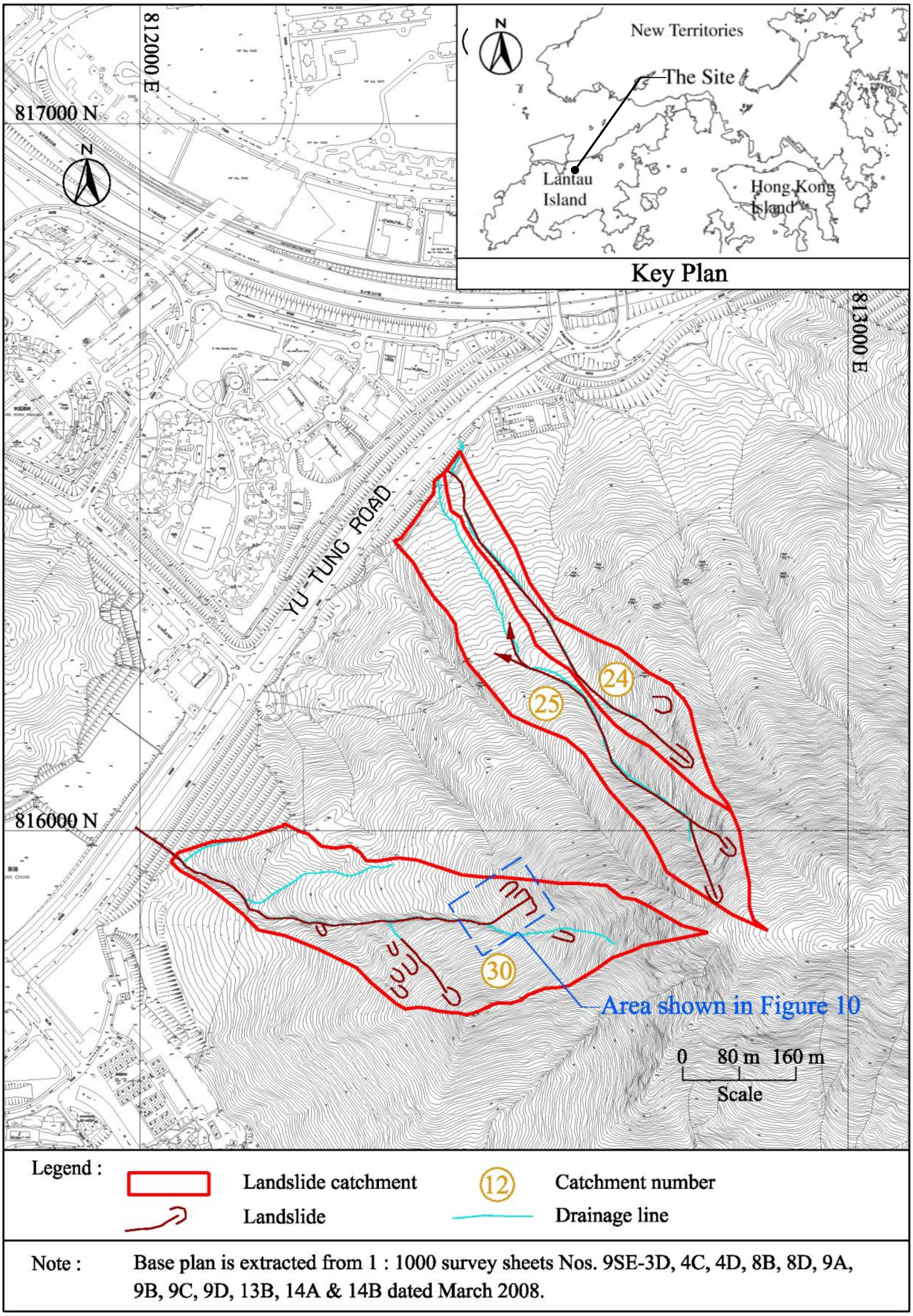

Figure 4.7 Location Plan of the 7 June 2008 Landslides on the Hillside above Yu Tung Road

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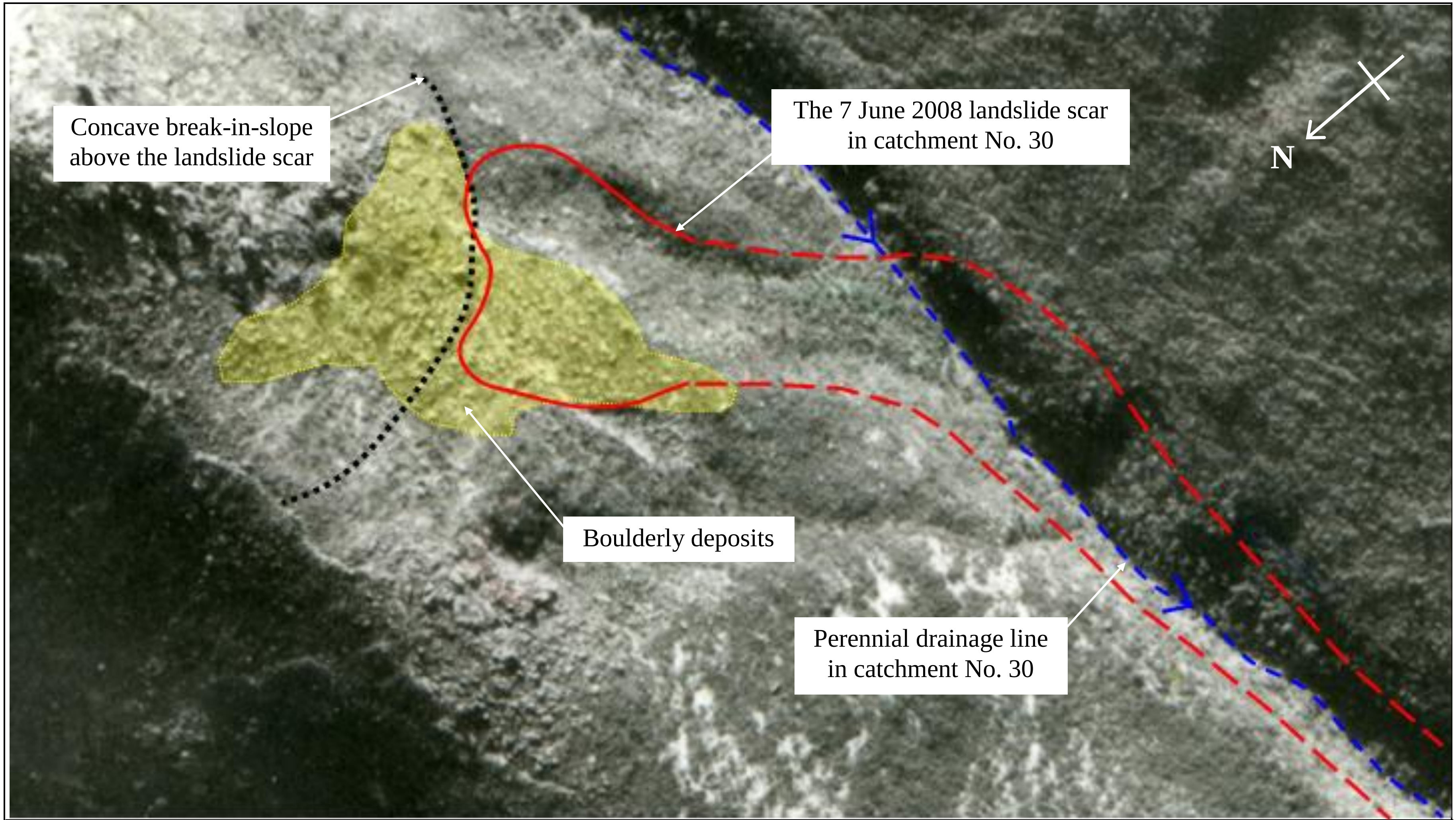

Notes: (1) The figure is based on the 1963 aerial photograph No. Y06358.
(2) See Figure 4.7 for the approximate extent of area shown in this figure.

Figure 4.8 Area of Boulderly Deposits on the Hillside above Yu Tung Road

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Rockwin Court were temporarily evacuated. The incident did not result in any casualties. The concerned hillside, which is situated below Stubbs Road overlooking Rockwin Court (Figure 4.10), is steeply inclined at about 40° and densely vegetated. The hillside catchment is a relatively small catchment with a plan area of about 1,100 m^2 and measures about 35 m wide and 30 m long. According to the GEO's Landslide Database and Enhanced Natural Terrain Landslide Inventory (ENTLI), there are no records of previous landslides on the concerned hillside.

Another major failure (Incident No. 2008/06/0159) occurred on 7 June 2008 on the hillside below Keng Hau Road, Tai Wai, involving a failure volume of about 220 m^3. The incident resulted in the temporary evacuation of the residents from three houses at the crest of the concerned hillside.

The above incidents, together with the landslide on the hillside below Broadwood Road (see Section 4.2.2), highlighted the potential landslide hazard posed by the hillsides that are close to developments in urban areas and the severe consequences in the event of a failure. By nature of their location, these hillsides may have been subjected to human disturbance and there may be a potential link between the stability of these hillsides and the surrounding man-made features (e.g. roads, surface drainage provisions, etc.).

4.4.7 Coverage of the Historical Landslide Catchment Inventory

Among the 301 reported natural terrain landslides in 2008, 175 (58%) of them occurred within 50 m of at least 1 ENTLI feature and 39 (13%) were within the existing Historical Landslide Catchments (HLCs). A total of 16 HLCs involved were ranked 300 or below, which included some of the highest ranked catchments in the HLC Inventory (HLCI). Some of the reported natural terrain landslides were not covered by the existing HLCI because the concerned hillside catchments did not affect any important facilities or the known historical landslides occurred at some distance from the facilities.

5 Proposed Improvement Initiatives

Improvement initiatives were proposed by Ng et al (2008b) following a review of the landslides that occurred in 2007. The progress of the follow-up actions is summarised in Table 5.1.

Based on the present review, the following improvement initiatives are proposed:

(a) carry out a review of landslide data to assess the performance of recompacted fill slopes and identify factors that affect their performance (Section 4.3.2),

(b) continue to study natural terrain landslides to improve understanding of hillside failures, debris mobility and tell-tale signs of potentially active drainage lines (Section 4.4.5), and

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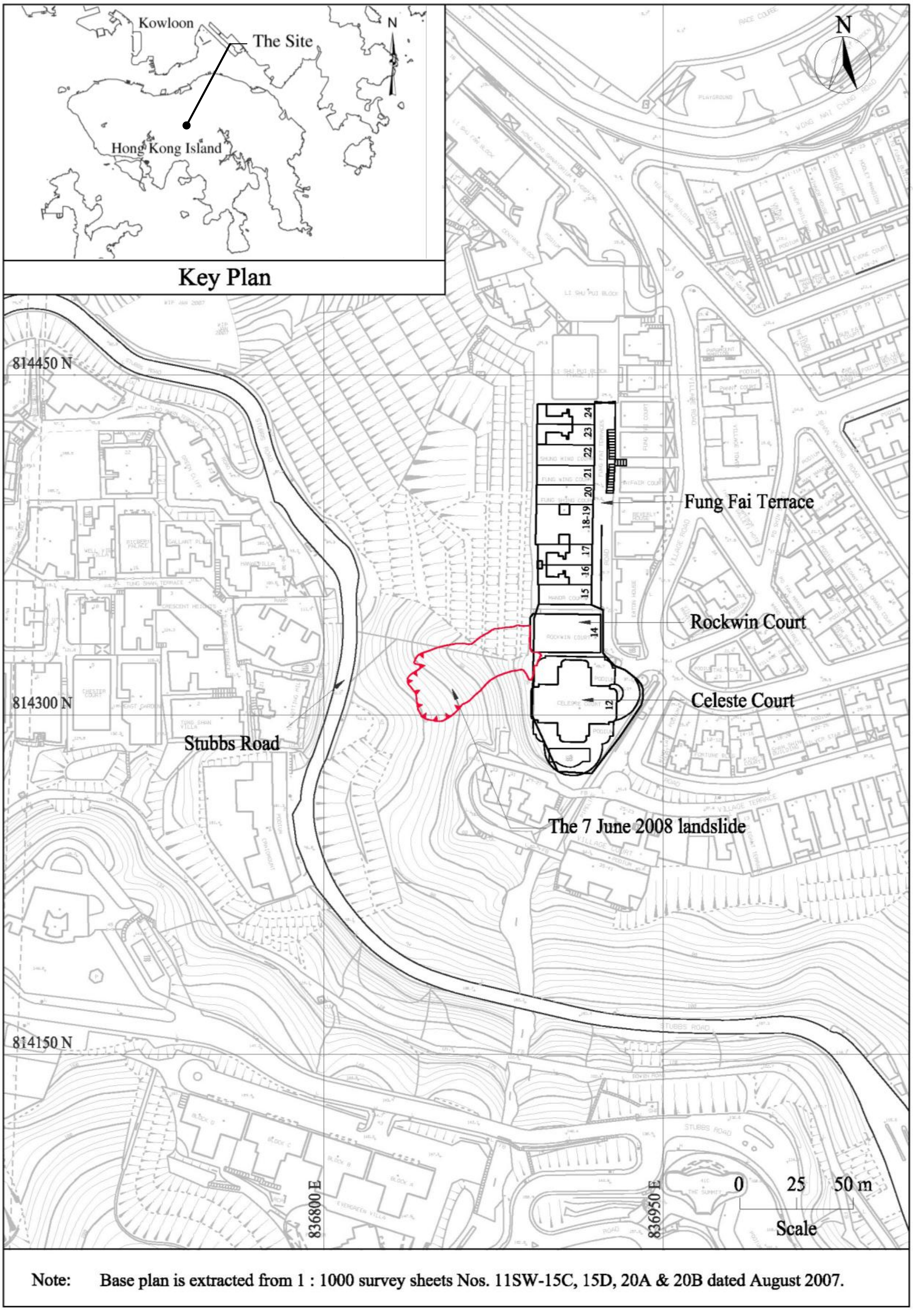

Figure 4.9 Location Plan of the 7 June 2008 Landslide behind Rockwin Court, Fung Fai Terrace

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Note: Indicative slope boundaries (yellow broken lines) are based on pre-landslide records in the GEO's Slope Information System.

Figure 4.10 Overall Setting of the Hillside behind Rockwin Court, Fung Fai Terrace

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Table 5.1 Progress of Follow-up Actions on the Improvement Measures Recommended in the Review of 2007 Landslides

Recommended Improvement Measures	Progress
1. Develop a methodology for carrying out systematic inspections of hillsides affected by major hill fires to check for possible presence of distress that may pose a threat to existing development.	The draft methodology was completed. A pilot trial is being carried out for completion by end-2009.
2. Review the landslide history and performance of private man-made slopes previously subjected to 'No Further Action (NFA)' recommendations following safety-screening studies.	A screening exercise was carried out, which identified 19 man-made slopes with occurrence of landslide after an NFA recommendation was made in safety-screening studies. Of the 19 slopes, there was only one landslide with a failure volume > 50 m^3, which occurred on slope No. 6SW-C/CR797 at Cafeteria Old Beach. The rest were generally minor failures, partly caused by inadequate slope maintenance. The necessary follow-up actions for the 19 slopes had been completed. <u>Action completed.</u>
3. Clarify the objective and nature of safety-screening studies in the relevant GEO Circular and GEO Information Notes.	The main objective of safety-screening studies is to establish whether a prima facie case exists for serving a Dangerous Hillside Order under the Buildings Ordinance requiring the responsible owners to carry out an investigation of a private slope feature. A safety-screening study, normally without ground investigation, is not a detailed investigation to confirm whether or not the slope feature meets the current safety standards. GEO Circular No. 30 (GEO, 2009b) and GEO Information Note No. 01/2009 (GEO, 2009c) have been revised by CGE/SS to provide the necessary clarification in regard to the objective and nature of safety-screening studies. <u>Action completed.</u>

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(c) develop a methodology for the identification of sizeable fill bodies and hillside pockets in developed areas that may pose a significant landslide hazard to the community (Section 4.4.6).

6 Conclusions

Based on the overall diagnostic landslide review presented in this report, the following observations are made with respect to the performance of the Government's slope safety system:

(a) The annual failure rates of major and minor landslides on engineered slopes, on a slope number basis, were 0.009% and 0.112% respectively in 2008. The pledged annual success rates of 99.8% and 99.5% of engineered slopes in preventing major and minor landslides, respectively, were met.

(b) Overall, 99.88% of the engineered slopes performed satisfactorily without the occurrence of any landslides in 2008.

A number of initiatives have been proposed, as detailed in Section 5 of this report, with a view to further improving the slope engineering practice and enhancing the slope safety system in Hong Kong.

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Appendix A

Factors Affecting the Performance of Man-made Slopes

Contents

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A.1 Introduction

A review of landslides in 2008, together with selected landslides in recent years, has been carried out to identify factors that could affect slope performance, as well as the possible enhancement measures. Factors that GEO can influence and those that are out of GEO's control have been separated to help assess the uncertainties. Other factors that may have an impact on the performance of the slope safety system are also discussed. The key findings of the review are presented below.

A.2 Factors GEO Can Influence

The factors that could affect the performance of man-made slopes and that GEO can influence are listed as follows:

(a) poor workmanship (e.g. inadequate compaction for fill slopes),

(b) inadequate site control (e.g. carrying out earthworks during wet season, inadequate temporary drainage provisions or inadequate temporary support/protection during construction),

(c) inadequate design consideration (e.g. design with low robustness, inadequate engineering geological input, poor drainage detailing),

(d) adverse change in site setting (e.g. replacement of hard surface cover on slopes by vegetated cover),

(e) adverse effects of trees or vegetation on slope stability (e.g. tree root wedging effects), and

(f) inadequate maintenance of water-carrying services (e.g. leakage or overspill).

The above factors generally involve engineering practice and standards. This calls for a need to continually review relevant technical guidelines and standards (e.g. GEO's Technical Guidance Notes) and regularly update them to promulgate the findings and lessons learnt from landslide investigations. The findings and lessons learnt should also be promulgated to the practitioners through technical workshops, seminars and publication of technical papers from time to time.

A.3 Factors Out of the Control of GEO

The factors that could affect the performance of man-made slopes and that are out of GEO's control are listed as follows:

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(a) earthquake,

(b) extreme rainfall due to climate change,

(c) slope deterioration,

(d) adverse changes to environmental condition and slope setting (e.g. illegal cultivation, illegal dumping of construction waste, unauthorised construction, uncontrolled vegetation clearance, etc.),

(e) inadequate slope maintenance, including the absence of a legal mandatory requirement for private slope maintenance,

(f) inadequate design and maintenance of drainage systems, and uncontrolled overland flow from adjacent facilities, and

(g) adverse geological and/or hydrogeological conditions.

To address the above issues, a range of public education activities have been launched to raise the community's awareness on slope safety and related safety precautionary measures. In addition, a high-level central emergency control system has recently been established to strengthen the Government's emergency management, preparedness and response in dealing with natural disasters including major landslide incidents.

A.4 Factors Affecting Slope Safety System

In addition to the factors identified above, other factors that may affect the performance of the slope safety system have been identified as follows:

(a) delay in undertaking the necessary slope upgrading or improvement works, and

(b) slope features not fully addressed in the existing slope safety system.

Based on past experience, the necessary slope upgrading or improvement works could be delayed due to objection by residents to the works or objection to the road closure required for carrying out the slope works, etc. Uncertainties in the maintenance responsibility of the slopes would also delay the works. As a result, the necessary slope upgrading or improvement works could not be carried out in a timely manner.

In 2008, a number of major failures occurred on hillside pockets close to developments in urban areas (see Section 4.4.6). These slope features are not covered under the existing slope safety system and hence would not be subject to any systematic action.

GEO PUBLICATIONS AND ORDERING INFORMATION
土力工程處刊物及訂購資料

A selected list of major GEO publications is given in the next page. An up-to-date full list of GEO publications can be found at the CEDD Website http://www.cedd.gov.hk on the Internet under "Publications". Abstracts for the documents can also be found at the same website. Technical Guidance Notes are published on the CEDD Website from time to time to provide updates to GEO publications prior to their next revision.

部份土力工程處的主要刊物目錄刊載於下頁。而詳盡及最新的土力工程處刊物目錄，則登載於土木工程拓展署的互聯網網頁 http://www.cedd.gov.hk 的"刊物"版面之內。刊物的摘要及更新刊物內容的工程技術指引，亦可在這個網址找到。

Copies of GEO publications (except geological maps and other publications which are free of charge) can be purchased either by:

Writing to
Publications Sales Section,
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Garden Road, Central, Hong Kong.
Fax: (852) 2598 7482

or
- Calling the Publications Sales Section of Information Services Department (ISD) at (852) 2537 1910
- Visiting the online Government Bookstore at http:// www.bookstore.gov.hk
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- Placing order with ISD by e-mail at puborder@isd.gov.hk

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香港中環花園道
美利大廈4樓402室
政府新聞處
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傳真: (852) 2598 7482

或
- 致電政府新聞處刊物銷售小組訂購 (電話：(852) 2537 1910)
- 進入網上「政府書店」選購，網址為 http://www.bookstore.gov.hk
- 透過政府新聞處的網站 (http://www.isd.gov.hk) 於網上遞交訂購表格，或將表格傳真至刊物銷售小組 (傳真：(852) 2523 7195)
- 以電郵方式訂購 (電郵地址：puborder@isd.gov.hk)

1:100 000, 1:20 000 and 1:5 000 geological maps can be purchased from:

Map Publications Centre/HK,
Survey & Mapping Office, Lands Department,
23th Floor, North Point Government Offices,
333 Java Road, North Point, Hong Kong.
Tel: (852) 2231 3187
Fax: (852) 2116 0774

讀者可於下列地點購買1:100 000、1:20 000及1:5 000地質圖：

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北角政府合署23樓
地政總署測繪處
電話: (852) 2231 3187
傳真: (852) 2116 0774

Requests for copies of Geological Survey Sheet Reports and other publications which are free of charge should be directed to:

For Geological Survey Sheet Reports which are free of charge:
Chief Geotechnical Engineer/Planning,
(Attn: Hong Kong Geological Survey Section)
Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon, Hong Kong.
Tel: (852) 2762 5380
Fax: (852) 2714 0247
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Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon, Hong Kong.
Tel: (852) 2762 5346
Fax: (852) 2714 0275
E-mail: florenceko@cedd.gov.hk

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免費地質調查報告:
香港九龍何文田公主道101號
土木工程拓展署大樓
土木工程拓展署
土力工程處
規劃部總土力工程師
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傳真: (852) 2714 0247
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電話: (852) 2762 5346
傳真: (852) 2714 0275
電子郵件: florenceko@cedd.gov.hk

MAJOR GEOTECHNICAL ENGINEERING OFFICE PUBLICATIONS
土力工程處之主要刊物

GEOTECHNICAL MANUALS

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

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

GEOGUIDES

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.

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.

GEO PUBLICATIONS

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.

GEOLOGICAL PUBLICATIONS

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.

TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents