AN UPDATED ASSESSMENT OF LANDSLIDE RISK POSED BY MAN-MADE SLOPES AND NATURAL HILLSIDES IN HONG KONG

GEO REPORT No. 252

P.F.K. Cheng & F.W.Y. Ko

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. These include guidance documents and results of comprehensive reviews. These 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.

R.K.S. Chan
Head, Geotechnical Engineering Office
July 2010

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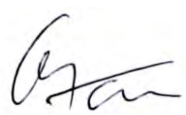
FOREWORD

This report presents the findings of an updated assessment of the landslide risks posed by man-made slopes registered in the Catalogue of Slopes and natural hillsides. The update was carried out in 2007, based on information up to the end of 2006.

For man-made slopes, the failure frequency models were refined based on updated slope information and landslide records. These updated slope information and landslide records were extracted from various databases for the assessment of the landslide risk. The assessment was carried out by Ms P.F.K. Cheng of the Standards & Testing Division (S&T) under the supervision of Dr D.O.K. Lo (formerly of S&T Division), with much of the data collection and analyses performed by the technical staff of the Slope 1 Section, S&T Division.

For natural hillsides, the failure frequency models were enhanced with the latest information from the Enhanced Natural Terrain Landslide Inventory and the Historical Landslide Catchment Inventory. The assessment was carried out by Ms F.W.Y. Ko of the Planning Division under the supervision of Mr H.N. Wong, with the assistance of the technical staff of the Engineering Geology Section, Planning Division.

Valuable assistance was provided by the database controllers of the Landslip Preventive Measures Division 1, the Slope Safety Division and the Districts Divisions. All contributions are gratefully acknowledged.



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ABSTRACT

Landslide risk arising from man-made slopes registered in the Catalogue of Slopes and natural hillsides has been assessed by quantitative risk assessment (QRA). The objective of the current study is to update the landslide risk estimation for the year 2010 in order to facilitate the formulation of future landslide prevention and mitigation programme. This study deals with risk to life only, other types of risk such as economic risk and social impact have not been considered.

The update of the landslide risk for man-made slopes is based on the slope information and landslide records upto the end of 2006. The assessment follows the QRA study carried out in 2004, which includes the determination of the failure frequency models of different groups of slopes and the analysis of the corresponding potential consequences in terms of fatalities. The results indicate that the risk level due to man-made slopes for the year 2010 is similar to that estimated in the 2004 study. The latest estimate also shows that by 2010, a major portion of landslide risk arising from man-made slopes will be from old technology slopes and sub-standard slopes of moderate risk.

The update of the landslide risk for natural hillsides involves mainly an enhancement of the failure frequency models using the latest information from the Enhanced Natural Terrain Landslide Inventory and the Historical Landslide Catchment Inventory. The QRA framework and approach adopted in the 2004 assessment were largely followed to assess the landslide risk of natural hillsides. The results indicate that the risk level due to natural hillsides in 2010 is comparable to that obtained in the 2004 assessment, despite some changes to the overall landslide risk distributions given the additional information available.

Further development on the QRA models and the ranking methodology for man-made slopes and natural hillsides respectively would be addressed in separate documentations.

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1. INTRODUCTION

Landslide risk of man-made slopes registered in the Catalogue of Slopes and natural hillsides were assessed by quantitative risk assessment (QRA) in 2004. The details of the QRA models and findings are documented in following reports:

(a) GEO Report No. 177 - Assessment of Landslide Risk of Man-made Slopes in Hong Kong (Lo & Cheung, 2005).

(b) GEO Report No. 191 - Assessment of Landslide Risk of Natural Hillsides in Hong Kong (Wong et al, 2006).

Between 2005 and 2006, additional information on man-made slopes and natural hillside catchments with known historical landslides close to existing developments (i.e. Historical Landslide Catchments, HLC) were collated from the Feature Status Review (FSR) and the Enhanced Natural Terrain Landslide Inventory (ENTLI) projects respectively.

These additional information were considered in the QRA updates for man-made slopes and natural hillsides in 2007, following the QRA frameworks and approaches adopted in the 2004 assessments but with refinements made to cater for changes and improved models based on the additional data available.

This report highlights the key refinements to the QRA models, and presents the findings of the assessments of the landslide risk posed by man-made slopes and natural hillsides in Hong Kong. The assessments on man-made slopes and natural hillsides are presented in Appendix A and B respectively.

2. KEY REFINEMENTS

The key refinements to the QRA models adopted for assessing landslide risk arising from registered man-made slopes and natural hillsides are highlighted below:

(a) For the QRA on registered man-made slopes:

(i) The estimated number of man-made slopes under different groups was updated upto the end of 2006 based on information from Slope Information System and FSR.

(ii) The failure frequency models of each group of slopes were refined on the basis of the GEO landslide records upto the end of 2006.

(iii) Based on the results of the FSR, the number of old technology slopes was updated. Separate failure frequency models were derived for the old technology slopes.

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(b) For the QRA on natural hillsides:

(i) All historical failures on natural hillsides in Hong Kong for the observation period between 1924 and 2003 were considered in the selection of HLC for assessment in the QRA update, without the consideration of the Year 2000 Development Lines (c.f. Wong et al, 2006).

(ii) About 300+ HLC affect only demolished/ruined structures or have a catchment area less than 200 m^2. Their landslide risk was not assessed in the QRA update and therefore have calculated PLL = 0. The revised number of HLC considered in the QRA update is 2428. The 300+ HLC would be replaced by new HLC generated from natural terrain landslides that have occurred on or after 2004 and the additional landslide risk was estimated from the average landslide risk per HLC.

(iii) The failure frequency model was refined by taking into consideration the degree of certainty of relict landslides as identified in the ENTLI project. In addition, allowance has been made for the improved recognition of historical landslides due to the use of low-flight aerial photographs, which affects the years of observation of relict landslides and landslide frequency-magnitude relationships.

(iv) The landslide risk of natural hillsides does not include any projection for extreme rainfall scenarios so as to maintain consistency with the assessment made on the landslide risk of registered man-made slopes.

3. KEY FINDINGS

The key findings of the QRA updates for registered man-made slopes and natural hillsides are summarised below:

(a) For the QRA on registered man-made slopes:

(i) The calculated landslide risk of all the registered man-made slopes is about 5 PLL per year in the year 2010.

(ii) The proportion of risk of each group of man-made slopes is comparable to the 2004 study.

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(iii) The failure frequency of the old technology slopes in this study has been derived on the basis of updated slope information and landslide records. In general, the failure frequency of the old technology slopes is lower than the sub-standard slopes, but still higher than the slopes treated by robust technology. The updated landslide risk of the old technology slopes is comparable to that estimated in 2004.

(b) For the QRA on natural hillsides:

(i) An inventory of 2,428 HLC was compiled, which comprises 1839 HLC affecting 4525 existing buildings, 237 HLC affecting 369 dilapidated or demolished buildings, and 447 HLC affecting 467 important transport corridors.

(ii) Based on the 'Best-estimate' model with Half-Bayesian update (Wong et al, 2006), the calculated landslide risk of the 2,428 HLC is 2.2 PLL per year. When the additional landslide risk of the new HLC generated from natural terrain landslides that have occurred on or after 2004 is taken into account, the estimated landslide risk of the 2,700 HLC is about 2.5 PLL per year. The other hillside catchments (i.e. those without known historical landslides close to developments) have a total risk comparable to that of the HLC. This means that the 2,700 HLC constitute about 50% of the risk of natural terrain landslides on existing developments in Hong Kong.

(iii) The average risk-per-catchment for the 2,428 HLC is about 9.4×10^{-4} PLL per year. This risk figure is comparable to that obtained in the 2004 assessment. Landslide risk is unevenly distributed among the HLC. 87% of the landslide risk of natural hillsides comes from the HLC where channelized debris flow could develop. Among these, about 30% of the landslide risk comes from those HLC affecting multi-storey buildings (i.e. buildings of four storeys or above). They may deserve priority attention for follow-actions, which may include undertaking natural terrain hazard study and implementing hazard mitigation measures if found necessary.

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(iv) The best-estimated risk of natural terrain landslides on existing developments in Hong Kong is 5 PLL per year. This calculated risk to life is of comparable order to that of the remaining registered man-made slopes by the year 2010.

4. CONCLUSIONS

The global QRA for registered man-made slopes and natural hillsides in Hong Kong were updated in 2007, which formed the basis for formulating the post-2010 landslide risk management strategies. The landslide risk figures assessed for registered man-made slopes and natural hillsides are comparable to those in the 2004 assessments, despite the changes in the failure frequency models arising from the additional information collated. Further development on the QRA models and the ranking methodology for man-made slopes and natural hillsides respectively would be carried out and reported in separate documentations.

5. REFERENCES

Lo, D.O.K. & Cheung, W.M. (2005). Assessment of Landslide Risk of Man-made Slopes in Hong Kong (GEO Report No.177). Geotechnical Engineering Office, Hong Kong, 84 p.

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APPENDIX A

ASSESSMENT OF LANDSLIDE RISK ON MAN-MADE SLOPES IN HONG KONG

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A1. BACKGROUND

In 2004, the Geotechnical Engineering Office (GEO) carried out a quantitative risk assessment (QRA) on registered man-made slopes affecting developments and squatters to examine the progress made in respect of the landslide risk reduction target through the Landslip Preventive Measures (LPM) Programme and the Enhanced Maintenance Programme (EMP), and to facilitate the formulation of future landslide prevention and mitigation programme. Details of the results and findings of the QRA study carried out in 2004 are documented in Lo & Cheung (2005).

In the present study, the failure frequency models for man-made slopes have been refined on the basis of the information from the FSR, the Slope Information System and the landslide records upto the end of 2006.

At the time of the 2004 study, it was estimated that there were about 7,500 old technology slopes[1]. Since then, Districts Divisions of the GEO had carried out a Feature Status Review (FSR), in which a detailed review of post-1977 slopes was conducted. The FSR has identified about 8,800 old technology slopes in the Catalogue of Slopes. The present study updates the information of old technology slopes and refines the failure frequency models based on the actual landslide records of the old technology slopes.

Following the same methodology of the 2004 assessment, the landslide risk results presented in this report focus only on risk to life, which is expressed in terms of Potential Loss of Life (PLL). Other types of risk such as economic risk and social impact have not been considered.

A2. SOURCES OF INFORMATION USED IN THE LANDSLIDE RISK ASSESSMENT

Information from the following sources has been extracted for the present study:

(a) Slope Information System (SIS);

(b) Landslip Preventive Measures Information System (LPMIS);

(c) EMP database;

(d) Dangerous Hillside Orders and Advisory Letters Database System (DADS);

(e) District Works Information System (DWIS);

(f) Feature Status Review (FSR) database;

(g) Slope Checking Status Information System (SCSIS);

(h) GEO Landslide Database;

[1] Slopes formed or treated based on knowledge and technology from 1977 to the late 1980's typically comprise slopes trimmed back to less steep gradient without the provision of reinforcement or structural support.

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(i) Systematic Identification and Registration of Slope in the Territory (SIRST) database;

(j) Report on QRA of landslides affecting squatters (Fugro, 2004); and

(k) List of slopes affecting registered squatter structures[2].

A3. ASSUMPTIONS MADE IN THE LANDSLIDE RISK ASSESSMENT

The following assumptions have been made in the landslide risk assessment:

(a) The number of sub-standard slopes and robust technology slopes is estimated on the basis of the classification established through the "Systematic Identification of Features in the Territory (SIFT)" project. In the SIFT project, registered man-made slopes assigned with SIFT Classes A, B1 or C1 correspond to sub-standard slopes. Slopes with SIFT Classes B2 or C2 as well as those that have been indicated by LPMIS or DADS to be either upgraded under the LPM Programme or works completed by private owners to discharge Dangerous Hillside Order (DHO) served on them correspond to robust technology slopes.

(b) The number of old technology slopes is based on the findings of the FSR.

(c) The use of soil nails for retrofitting slopes has gained popularity since 1990. The number of soil-nailed slopes is estimated based on information from LPMIS, EMP database, DWIS and SCSIS. The failure frequency of soil-nailed slopes is derived from past landslide records as summarised by Ng et al (2007). While the failures of soil-nailed slopes so far are all minor (i.e. failure volume less than 50 m^3), the failure frequency model for soil-nailed slopes was modified to accommodate the possibility of a major failure (failure volume greater than 50 m^3) over a 14-year period.

(d) There are about 56,400 man-made slopes registered in the Catalogue of Slopes at the end of 2006. Apart from the 3,200 slopes affecting registered squatter structures, there are 53,200 slopes affecting developments. Among which 26,500 are sub-standard slopes[3], 17,900 are robust technology slopes[4] and 8,800 are old technology slopes.

[2] Structures covered by the Housing Department's Squatter Control Survey conducted in 1982.
[3] Sub-standard slopes are referred as "Old slopes" in the 2004 study (Lo & Cheung, 2005).
[4] Robust technology slopes are referred as "New slopes" in the 2004 study (Lo & Cheung, 2005).

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There are about 3,200 slopes affecting squatters. A breakdown of these slopes as of the end of 2006 is given in Figure A1.

(e) By 2010, 2,500 sub-standard government slopes will be upgraded and 3,000 sub-standard private slopes will be subjected to safety-screening under the 10-year Extended LPM Project. Over the same period, the stability of the remaining high-priority (Consequence-to-life (CTL) Category 1) sub-standard government slopes will be improved through the use of prescriptive measures under the EMP.

(f) Sub-standard government slopes to be selected for LPM action will be those in CTL Categories 1 or 2 with Combined New Priority Classification System (CNPCS) score equal to or exceeding 8.

(g) Sub-standard private slopes to be selected for safety-screening will be those in CTL Category 1 with CNPCS score equal to or exceeding 3. For the purpose of risk assessment, it is assumed that all safety-screened sub-standard private slopes will be dealt with by year 2010. The failure frequency for new slopes has been adopted for these slopes.

(h) Sub-standard government slopes of CTL Category 1 that have not been selected for LPM action will be improved using prescriptive measures[5], e.g. Type 3 (structural support) or equivalent, except for those small slopes with height less than 8 m and CNPCS score of less than 3 where only Types 1 & 2 works (surface protection and subsurface drainage) have been assumed.

(i) The failure frequency models are refined on the basis of the landslide records from 1984 to 2006. Modification has been made to account for unreported landslide incidents and severe rainstorm prior to the landslide records.

(j) The failure frequency model for sub-standard slopes implemented with Type 3 prescriptive measures or equivalent is assumed to be same as that of robust technology slopes.

(k) Based on the study by Wong & Ho (1995), it is assumed that the probability of failure of a sub-standard slope will be halved after the implementation of Types 1 or 2 prescriptive measures. In reporting the QRA results in the following

[5] Types of prescriptive measures are described in GEO Report No. 56 (Wong et al, 1999).

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sections, the CTL Cat 1 sub-standard slopes treated with Types 1 or 2 prescriptive measures together with the CTL Cat 2 sub-standard slopes will be collectively grouped as sub-standard slopes with moderate risk.

(l) All sub-standard soil cut slopes selected for action in the 10-year Extended LPM Project will be stabilised using soil nails.

(m) The consequences of failure of the sub-standard and robust technology slopes in 2010 remain broadly similar to those in 2006.

A4. METHODOLOGY

A4.1 Failure Frequency Model

The failure frequency model adopted in this study follows that in the 2004 study (Lo & Cheung, 2005). Specific failure frequency models were derived from landslide records for each group of slopes (viz. sub-standard slopes, robust technology slopes and old technology slopes affecting developments, and slopes affecting registered squatter structures). Each group of slopes is further subdivided in respect of their feature types, i.e. soil cut slopes, rock cut slopes, retaining walls and fill slopes. Landslide incident records between 1984 and 2006 were used to formulate the failure frequency model for each type of slopes. Separate failure frequency model has been developed for those slopes treated with soil nails in light of their performance history as summarised by Ng et al (2007). The updated failure frequencies for different slope categories are given in Tables A1 to A4. Similar to the 2004 study, these failure frequency models are used as a basis to generate the corresponding ones for year 2010 according to the surface area of slopes.

A review of SIRST database revealed that the site inspection carried out during the SIRST study has identified more slopes that have past instability than that suggested by the landslide incidents reported to the GEO. This could be due to the fact that not all the landslides were reported to the GEO, particularly in the 1980s. Consequently the likelihood of landsliding of man-made slopes may have been underestimated if the failure frequency model is solely based on reported landslide incidents. Moreover, the available landslide records commencing from the year 1984 may not have included the more severe rainstorms experienced in Hong Kong, e.g. the ones in 1982. In light of the foregoing, the failure frequencies adopted in the current study are assumed to be 25% higher that the ones derived from reported landslide records.

A4.2 Consequence Model

The landslide consequence model adopted in this study follows that in the 2004 study, which is based on the one proposed by Wong et al (1997). In this model, consideration has been given to the consequence of a reference landslide of a prescribed size directly affecting a given type of facility located at the worst possible spot assuming occupation of the facility under average conditions. The consequence is then scaled with respect to the size of the

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actual failure relative to that of the reference landslide and the vulnerability of the facility given its actual location relative to the zone of the landslide. A reference landslide is defined as a 10-m wide failure with a volume of 50 m^3. The expected number of fatalities for different types of facilities has been determined from past statistics, observation and judgement. For the vulnerability of different facilities, a vulnerability factor, which is defined as the probability of loss of life, has been determined with due consideration of (i) the nature, proximity and spatial distribution of the facilities, (ii) mobility of debris and likely extent of the upslope influence zone, (iii) scale of failure, and (iv) degree of protection offered to persons by the facility.

Details of the consequence model including the expected number of fatalities of a reference landslide, distribution of landslide debris volume, the values of vulnerability factor for different types of facilities, and the distribution of width of landslides are described in Appendix H of Lo & Cheung (2005).

A4.3 Estimation of Landslide Risk

The global landslide risk for man-made slopes is determined by the summation of products of failure frequency and the respective consequences for all classes of slope features. A worked example demonstrating the method for calculating the landslide risk for an old soil cut slope is given in Appendix I of Lo & Cheung (2005).

A5. ANALYSIS AND RESULTS

A5.1 Landslide Risk in 2010

Upon completion of the 10-year Extended LPM Project and the EMP in 2010, it is anticipated that the number of sub-standard slopes affecting developments will be reduced to about 23,500. The number of robust technology slopes affecting developments will correspondingly be increased to about 20,900. Amongst the robust technology slopes, 5,500 slopes were assumed treated by the LPM Project and about 2,800 slopes were assumed treated by Type 3 prescriptive measures or equivalent through EMP. The number of old technology slopes affecting developments and man-made slopes affecting registered squatter structures will remain as about 8,800 and 3,200 respectively. The results of the assessment are as follows:

(a) The landslide risk (PLL per year) attributed to old technology slopes affecting developments will be about 2.0.

(b) The landslide risk (PLL per year) attributed to robust technology slopes affecting developments will be about 0.4.

(c) The landslide risk (PLL per year) attributed to sub-standard slopes affecting developments will be about 1.4, among which 93% comes from slopes with moderate risk (i.e. not CTL Cat 3 slopes).

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(d) The landslide risk (PLL per year) attributed to slopes affecting registered squatter structures will be about 1.3.

The total landslide risk (PLL per year) attributed to all categories of man-made slopes will be about 5.1 (i.e. 2.0 + 1.4 + 0.4 + 1.3). These risk figures represented in terms of proportion of total landslide risk is shown in Table A5.

A5.2 Discussion

The risk assessment conducted in this study indicated that upon completion of the 10-year Extended LPM Project and the EMP in 2010, the landslide risk (PLL per year) arising from sub-standard slopes affecting developments will be reduced to about 1.4. Comparing to the landslide risk due to sub-standard slopes of 7.9 (PLL per year) in 2000 (Lo & Cheung, 2005), it is anticipated that the Slope Safety Pledge made in respect of landslide risk reduction can be met.

The risk assessment in this study involves a number of uncertainties. Although many of these uncertainties cannot be measured or quantified, they should be borne in mind when interpreting the estimated risk figures. The uncertainties are as follows:

(a) The categorisation of slopes (viz. sub-standard slopes, robust technology slopes, old technology slopes and soil-nailed slopes) is based on information contained in various databases mentioned in Section 2. The results of the study depend on the accuracy of the information provided by these sources.

(b) Due to the lack of performance data of slopes treated by Type 1 or 2 prescriptive measures, the respective failure frequency model has to be established by judgement.

(c) Similar to the 2004 study, the failure frequency model adopted relates the likelihood of failure to the slope surface area. The assumption that the failure probability is linearly proportional to the slope surface area may introduce uncertainty to the risk assessment.

(d) The estimated risk level in 2010 depends on the progress of the 10-year Extended LPM Project and the EMP in the coming years including the discharge of Dangerous Hillside Orders served on private slopes.

A6. CONCLUSIONS

An update of the landslide risk due to man-made slopes was carried out using the latest slope information and landslide records. The results indicate that the risk level due to man-made slopes in 2010 is similar to that estimated in the 2004 study. The latest estimate

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shows that, upon completion of the current 10-year Extended LPM Project in 2010, the landslide risk attributed to sub-standard slopes will be reduced to below 25% of the level in 1977. By 2010, a major portion of landslide risk arising from man-made slopes will be from old technology slopes and sub-standard slopes with moderate risk.

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Table A1 - Average Annual Landslide Frequency for Sub-standard Slopes Affecting Developments

(a) Soil Cut Slopes

Slope Height, H (m)	No. of Slopes	Average No. of Failures Per Year	Total Slope Area ($\times 10^3 m^2$)	Average Annual Failure Frequency ($\times 10^{-6}$/year/m^2)
H ≤ 10	13,184	67.4	4,409	15.3
10 < H ≤ 20	1,075	21.6	1,460	14.8
20 < H	210	8.5	893	9.5
Total	14,469	97.5	6,762	14.4

(b) Rock Cut Slopes

Slope Height, H (m)	No. of Slopes	Average No. of Failures Per Year	Total Slope Area ($\times 10^3 m^2$)	Average Annual Failure Frequency ($\times 10^{-6}$/year/m^2)
H ≤ 10	1,226	6	560	10.7
10 < H ≤ 20	307	5.3	438	12.1
20 < H	91	3	450	6.8
Total	1,624	14.3	1,448	9.9

(c) Retaining Walls

Slope Height, H (m)	No. of Slopes	Average No. of Failures Per Year	Total Slope Area ($\times 10^3 m^2$)	Average Annual Failure Frequency ($\times 10^{-6}$/year/m^2)
H ≤ 5	4,428	4.7	731	6.4
5 < H ≤ 10	1,089	1.4	372	3.9
10 < H	53	0.2	70	2.5
Total	5,570	6.3	1,173	5.4

(d) Fill Slopes

Slope Height, H (m)	No. of Slopes	Average No. of Failures Per Year	Total Slope Area ($\times 10^3 m^2$)	Average Annual Failure Frequency ($\times 10^{-6}$/year/m^2)
H ≤ 10	3,531	5.8	2,513	2.3
10 < H ≤ 20	1,006	3.4	1,239	2.8
20 < H	324	0.9	739	1.2
Total	4,861	10.1	4,490	2.2

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Table A2 - Average Annual Landslide Frequency for Robust Technology Slopes Affecting Developments (Sheet 1 of 2)

(a) Soil Cut Slopes[6]

Slope Height, H (m)	No. of Slopes	Average No. of Failures Per Year	Total Slope Area ($\times 10^3 m^2$)	Average Annual Failure Frequency ($\times 10^{-6}$/year/m^2)
H ≤ 10	3,207	2.8	1,890	1.5
10 < H ≤ 20	912	1.7	1,820	0.9
20 < H	585	1.8	5,104	0.4
Total	4,704	6.3	8,814	0.7

(b) Soil-Nailed Cut Slopes

Slope Height, H (m)	No. of Slopes	Average No. of Failures Per Year	Total Slope Area ($\times 10^3 m^2$)	Average Annual Failure Frequency ($\times 10^{-6}$/year/m^2)
H ≤ 10	2,148	0.4	1,005	0.4
10 < H ≤ 20	962	1.1	1,593	0.7
20 < H	622	0.3	3,609	0.1
Total	3,732	1.8	6,208	0.3

(c) Rock Cut Slopes

Slope Height, H (m)	No. of Slopes	Average No. of Failures Per Year	Total Slope Area ($\times 10^3 m^2$)	Average Annual Failure Frequency ($\times 10^{-6}$/year/m^2)
H ≤ 10	215	0.3	144	2.1
10 < H ≤ 20	122	0.3	256	1.2
20 < H	77	0.6	511	1.2
Total	414	1.2	910	1.3

(d) Retaining Walls

Slope Height, H (m)	No. of Slopes	Average No. of Failures Per Year	Total Slope Area ($\times 10^3 m^2$)	Average Annual Failure Frequency ($\times 10^{-6}$/year/m^2)
H ≤ 5	2,957	0.1	657	0.2
5 < H ≤ 10	1,671	0.1	877	0.1
10 < H	246	0.1	375	0.3
Total	4,874	0.3	1,909	0.2

[6] Unsupported cut slopes formed or treated after 1990 and without structural reinforcements.

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Table A2 - Average Annual Landslide Frequency for Robust Technology Slopes Affecting Developments (Sheet 2 of 2)

(e) Fill Slopes

Slope Height, H (m)	No. of Slopes	Average No. of Failures Per Year	Total Slope Area ($\times 10^3 m^2$)	Average Annual Failure Frequency ($\times 10^{-6}$/year/m^2)
$H \leq 10$	2,901	0.8	3,650	0.2
$10 < H \leq 20$	874	1	2,470	0.4
$20 < H$	334	0.4	2,429	0.2
Total	4,109	2.2	8,549	0.3

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Table A3 - Average Annual Landslide Frequency Old Technology Slopes Affecting Developments

(a) Soil Cut Slopes

Slope Height, H (m)	No. of Slopes	Average No. of Failures Per Year	Total Slope Area ($\times 10^3 m^2$)	Average Annual Failure Frequency ($\times 10^{-6}$/year/m^2)
$H \leq 10$	3,775	10.8	2,673	4.0
$10 < H \leq 20$	922	4.5	2,187	2.1
$20 < H$	606	6.8	5,231	1.3
Total	5,303	22.1	10,092	2.2

(b) Rock Cut Slopes

Slope Height, H (m)	No. of Slopes	Average No. of Failures Per Year	Total Slope Area ($\times 10^3 m^2$)	Average Annual Failure Frequency ($\times 10^{-6}$/year/m^2)
$H \leq 10$	106	0.1	80	1.3
$10 < H \leq 20$	34	0.1	64	1.6
$20 < H$	30	0.1	247	0.4
Total	170	0.3	391	0.8

(c) Retaining Walls

Slope Height, H (m)	No. of Slopes	Average No. of Failures Per Year	Total Slope Area ($\times 10^3 m^2$)	Average Annual Failure Frequency ($\times 10^{-6}$/year/m^2)
$H \leq 5$	904	0.4	230	1.7
$5 < H \leq 10$	240	0.2	133	1.5
$10 < H$	14	0.1	16	6.3
Total	1,158	0.7	380	1.8

(d) Fill Slopes

Slope Height, H (m)	No. of Slopes	Average No. of Failures Per Year	Total Slope Area ($\times 10^3 m^2$)	Average Annual Failure Frequency ($\times 10^{-6}$/year/m^2)
$H \leq 10$	1,784	1.9	2,110	0.9
$10 < H \leq 20$	298	1.8	514	3.5
$20 < H$	117	0.7	401	1.7
Total	2,199	4.4	3,025	1.5

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Table A4 - Average Annual Landslide Frequency of Slopes Affecting Registered Squatter Structures

(a) Soil Cut Slopes

Slope Height, H (m)	No. of Slopes	Average No. of Failures Per Year	Total Slope Area ($\times 10^3 m^2$)	Average Annual Failure Frequency ($\times 10^{-6}$/year/m^2)
H ≤ 10	1,903	12.5	497	25.1
10 < H ≤ 20	62	1.2	111	10.4
20 < H	17	0.7	101	6.4
Total	1,982	14.4	709	20.3

(b) Rock Cut Slopes

Slope Height, H (m)	No. of Slopes	Average No. of Failures Per Year	Total Slope Area ($\times 10^3 m^2$)	Average Annual Failure Frequency ($\times 10^{-6}$/year/m^2)
H ≤ 10	34	0.3	9	27.8
10 < H ≤ 20	2	0.1	3	16.7
20 < H	2	0.4	22	18.1
Total	38	0.8	34	23.5

(c) Retaining Walls

Slope Height, H (m)	No. of Slopes	Average No. of Failures Per Year	Total Slope Area ($\times 10^3 m^2$)	Average Annual Failure Frequency ($\times 10^{-6}$/year/m^2)
H ≤ 5	822	1.5	100	15.0
5 < H ≤ 10	90	0.2	24	8.3
10 < H	7	0.1	5	10.0
Total	919	1.8	129	14.0

(d) Fill Slopes

Slope Height, H (m)	No. of Slopes	Average No. of Failures Per Year	Total Slope Area ($\times 10^3 m^2$)	Average Annual Failure Frequency ($\times 10^{-6}$/year/m^2)
H ≤ 10	203	0.4	182	2.2
10 < H ≤ 20	24	0.2	54	2.8
20 < H	3	0.1	5	20.0
Total	230	0.7	242	2.9

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Table A5 - Risk Profile for All Man-made Slopes in 2010

Slope Category		Proportion of Total Risk of Man-made Slopes (%)
Old technology slopes affecting developments		20
Robust technology slopes affecting developments		4
Sub-standard slopes affecting developments	CTL Category 1 and 2	14
	CTL Category 3	< 1
Slopes affecting registered squatter structures		12
Note: Natural hillsides (including natural terrain catchments, boulder fall hazards and disturbed terrain features) contribute the remaining of the total landslide risk.		

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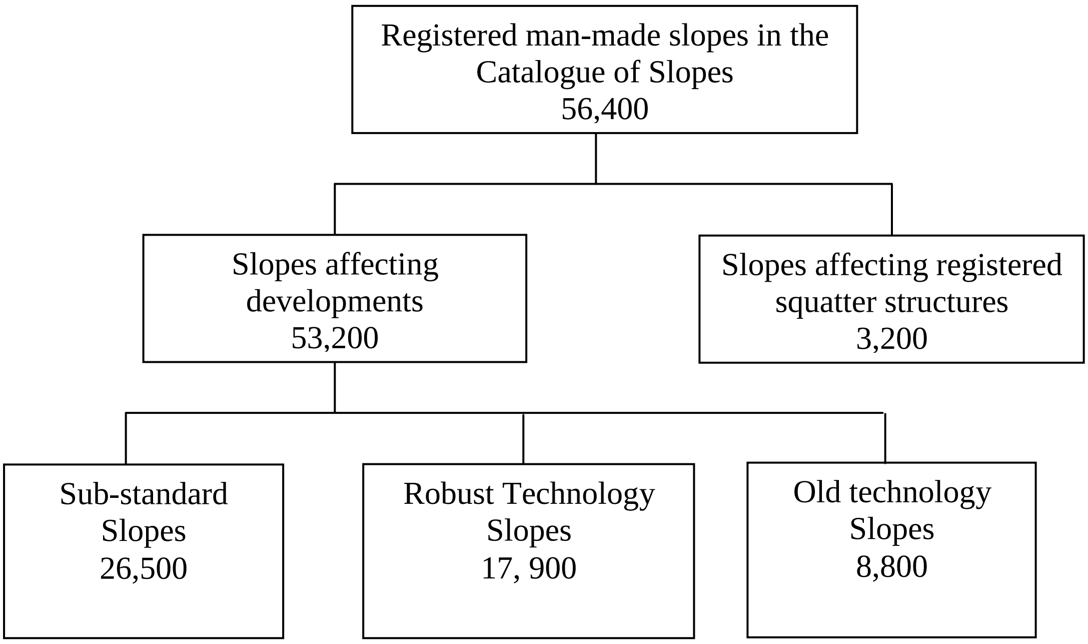

Figure A1 - Number of Man-made Slopes in the Catalogue of Slopes as in 2006

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APPENDIX B

ASSESSMENT OF LANDSLIDE RISK ON NATURAL HILLSIDES IN HONG KONG

CONTENTS

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B1. BACKGROUND

In 2004, the Geotechnical Engineering Office (GEO) carried out a global quantitative risk assessment (QRA) on natural hillsides to facilitate the formulation of the post-2010 landslip prevention and mitigation programme. Details of the QRA and its findings are documented in Wong et al (2006).

About 450 nos. of natural hillside catchments with known historical natural terrain landslides close the existing developments were assessed in the 2004 QRA. The natural terrain landslides contained in the Natural Terrain Landslide Inventory (NTLI) were used as the basis for selection and compilation of the inventory of the natural hillside catchments.

The NTLI was compiled in the mid-1990s based on aerial photograph interpretation (API) using the available high-flight aerial photographs (i.e. over 8,000 feet) (King, 1999). It contains about 30,000 landslide features of which about 12,000 and 18,000 are recent and relict landslide features respectively. It has been noted that the API based on high-flight aerial photographs has a limited resolution, at which natural terrain landslides that are of smaller size or that had occurred some time before the aerial photographs were taken cannot be recognised. Owing to this, the GEO commissioned in 2005 a two-year assignment (Maunsell-Fugro Joint Venture, 2007a & 2007b) to review and update the NTLI, which aims to identify historical natural terrain landslides using low-flight aerial photographs to compile the Enhanced Natural Terrain Landslide Inventory (ENTLI), and with the landslide data in the ENTLI, to identify natural hillside catchments with known historical landslides close to existing developments (i.e. Historical Landslide Catchments, HLC).

With this enhancement, the number of identified historical natural terrain landslides increased from 30,000 to over 100,000 for the observation period between 1924 and 2003. Many of the newly identified landslides are relict landslide features. Correspondingly, the number of HLC increased from about 450 to about 2,700. Furthermore, additional data to better reflect the nature and characteristics of the landslide features and HLC identified were collated in the ENTLI project.

Following the ENTLI project, the landslide risk of the 2,700 HLC was assessed in the QRA update in 2007. While the QRA framework and approach adopted in the 2004 assessment were largely followed, the existing QRA models were reviewed and improved to take into account the additional data with respect to the landslide features and the HLC available.

This Appendix presents the details and findings of the QRA update for assessing the landslide risk to the community posed by natural hillsides in Hong Kong.

B2. KEY REFINEMENTS

The QRA framework and approach adopted in the 2004 assessment (Wong et al, 2006) were largely followed in this QRA update, with refinements made to cater for changes and improved models based on the additional data. The key refinements that have been made include:

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(a) All historical hillside failures on natural hillsides in Hong Kong for the observation period between 1924 and 2003 were considered in the selection of HLC for assessment in the QRA update, without the consideration of the Year 2000 Development Lines (c.f. Wong et al, 2006).

(b) About 300+ HLC affect only demolished/ruined structures or have a catchment area less than 200 m^2. Their landslide risk was not assessed in the QRA update and therefore have calculated PLL = 0. The revised number of HLC considered in the QRA update is 2428. The 300+ HLC would be replaced by new HLC generated from natural terrain landslides that have occurred on or after 2004 and the additional landslide risk was estimated from the average landslide risk per HLC.

(c) The failure frequency model was refined by taking into consideration the degree of certainty of relict landslides as identified in the ENTLI project. In addition, allowance has been made for the improved recognition of historical landslides due to the use of low-flight aerial photographs, which affects the years of observation of relict landslides and landslide frequency-magnitude relationships.

(d) The landslide risk of natural hillsides does not include any projection for extreme rainfall scenarios so as to maintain consistency with the assessment made on the landslide risk of registered man-made slopes.

B2.1 Failure Frequency Model

B2.1.1 Recognition Factors

The improved recognition of historical landslides due to the use of low-flight aerial photographs coupled with that of high-flight aerial photographs in the ENTLI project was reflected in the recognition factors (Table B1). At this level of resolution, landslides with a notional volume of 500 m^3 (i.e. Hazard H2, with volumes typically ranging from 200 m^3 to 2,000 m^3) or above were believed to have been confidently identified. The ability to recognise landslides of smaller sizes (i.e. Hazard H1) was slightly improved as well.

B2.1.2 Number of Relict Landslides

In connection with the above, the number of landslide features identified in the ENTLI increased by more than three-fold. Many of the newly identified landslides are relict landslide features and about 85% of the landslide features in the ENTLI are relict.

Noting the uncertainty that might inevitably be involved in identifying relict landslide features by API, an additional data to describe the degree of certainty of each of the relict

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landslide features identified was included in the ENTLI to improve the overall credibility and resolution of the landslide dataset. This is represented by a new classification for relict landslide features (Table B2) (Maunsell-Fugro Joint Venture, 2007a). The new information was incorporated in the failure frequency model to explicitly accout for the uncertainty associated with the number of relict landslides considered. For example, if a HLC has three relict landslide features of Classes A, B and C respectively, the number of relict landslide features considered in the frequency model of the 2004 assessment would be simply three. But in the enhanced frequency model adopted in the QRA update, it would be $1 \times 0.8 + 1 \times 0.5 + 1 \times 0.1$, which is 1.4.

B2.1.3 Observation Periods

The observation periods that were used to assess the actual landslide failure frequency of each HLC were previously determined based on the period of time within which features could be interpreted from the available high-flight aerial photographs. With the use of low-flight aerial photographs, the improved recognition of historical landslides, especially for those that had occurred some time before the aerial photographs were taken, affected the years of observation that had been adopted, in particular for relict landslide features. Based on an analysis of the ENTLI, it was taken that on average relict landslide features came from an observation period of 150 years. The observation period of recent landslide features adopted in the 2004 assessment was still valid.

B2.1.4 Frequency-magnitude Relationships

With an improved recognition of historical landslides and an increase in the number of landslide features in the ENTLI, the frequency-magnitude relationships for different hazard scenarios adopted in the failure frequency model of the 2004 assessment was reviewed and adjusted to reflect the overall landslide distribution depicted in the ENTLI (Table B3).

B2.2 Consequence Model

There were no modifications made to the consequence model adopted in the 2004 assessment and the same was applied in the QRA update. Despite this, it is considered useful to supplement further details on the application of the multipliers to modify the population at risk (Pn) as presented in Section C2 of Wong et al (2006). Four types of building usage are considered for each building structure:

Usage	Legend
Residential, Industrial, Commercial	A
Lobby	B
Car Park	C
Stores, Playground, Sitting-out Area, Open Space	D

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There are indeed a pair of multipliers each for buildings 'with protection' and 'without protection':

(a) For buildings 'without protection':

(i) If a building is one-storey, the population at risk is modified by a multiplier, M_1, as given below:

$$M_1 = A + \frac{B}{5} + \frac{C}{10} + \frac{D}{60}$$

(ii) If a building is two-storey or above, the population at risk is modified by a multiplier, M_2, as given below:

$$M_2 = \frac{3}{4}\left(A + \frac{B}{5} + \frac{C}{10} + \frac{D}{60}\right) + \frac{1}{4}$$

(b) For buildings 'with protection':

(i) If a building is one-storey, the population at risk is modified by a multiplier, M_3, as given below:

$$M_3 = A + \frac{B}{5} + \frac{C}{10} \times 2 + \frac{D}{60} \times 2$$

(ii) If a building is two-storey or above, the population at risk is modified by a multiplier, M_4, as given below:

$$M_4 = \frac{3}{4}\left(A + \frac{B}{5} + \frac{C}{10} \times 2 + \frac{D}{60} \times 2\right) + \frac{1}{4}$$

B3. QUANTIFICATION OF NATURAL TERRAN LANDSLIDE RISK

The natural terrain landslide risk arising from the 2,428 HLC was assessed, based on the information on the catchments and the facilities at risk collated in the inventory of HLC and application of the QRA models in the QRA update. The risk to life is quantified in terms of annual potential loss of life (PLL).

Based on the 'Best-estimate' model with Half-Bayesian update (Wong et al, 2006), the calculated landslide risk of the 2,428 HLC is 2.2 PLL per year (Figure B1). When the additional landslide risk of the new HLC generated from natural terrain landslides that have occurred since 2004 is taken into account, the estimated landslide risk of the 2,700 HLC is about 2.5 PLL per year. The other hillside catchments (i.e. those without known historical landslides close to developments) have a total risk comparable to that of the HLC. This means that the 2,700 HLC constitute about 50% of the risk of natural terrain landslides on existing developments in Hong Kong.

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Breakdowns of the QRA results are given in Figure B1. The average risk per catchment is about 9.4 × 10^{-4} PLL per year. The average risk of catchment affecting buildings (9.4 × 10^{-4} PLL per year) is higher than that affecting important transport corridors (4.2 × 10^{-4} PLL per year). As each of the catchments affecting building structures has an average of 2.6 buildings at risk, the average risk on each building is 3.6 × 10^{-4} PLL per year.

The 2,428 HLC comprise 1,839 HLC affecting 4,525 existing buildings, 237 HLC affecting 369 dilapidated or demolished structures, and 447 HLC affecting 467 important transport corridors. The dilapidated or demolished buildings were taken as of negligible risk (i.e. PLL = 0) in the QRA update, i.e. assuming that the structures would neither be re-occupied nor re-built in the short term. However, they would be kept under regular review for the possibility of any re-development proposals. By excluding these dilapidated or demolished buildings, each of the catchments affecting building structures has an average of 2.5 buildings at risk, the average risk on each building is 3.8 × 10^{-4} PLL per year.

B4. EVALUATION OF HAZARD AND RISK

The analysis of hazard and risk distribution given in Section 5.3 of Wong et al (2006) was updated to reflect the latest diagnosis of the landslide risk assessment. Natural terrain landslide hazards are classified by a combination of the scale of landslide and mechanism of debris movement:

(a) Scale of landslide

(i) H1 = 50 m^3 notional (20 m^3 to 200 m^3)
(ii) H2 = 500 m^3 notional (200 m^3 to 2,000 m^3)
(iii) H3 = 5,000 m^3 notional (2,000 m^3 to 20, 000 m^3)
(iv) H4 = 20,000+ m^3 notional (>20,00 m^3)

(b) Mechanism of debris movement

(i) C = channelied debris flow
(ii) T = mixed debris flow/avalanche along topographic depression
(iii) S = open slope debris slide/avalanche

Key figures are included below:

(a) Scale of Hazard

The distribution of risk according to different scales of hazards is presented in Figure B2. Hazard H2 is the most significant hazard, which constitutes about 75% of the total risk.

Hazard H2 (notional 500 m^3, typically ranging from 200 m^3 to 2,000 m^3) and Hazard H3 (notional 5,000 m^3, typically ranging from 2,000 m^3 to 20,000 m^3) have the largest share of risk in respect of building collapse.

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(b) Type of Catchment

The distribution of risk for different types of catchments is shown in Figure B3. For risk on buildings, about 87% of the risk comes from HLC where channelised debris flows could develop. The risk proportion of open slope landslides on important transport corridors is much higher than that on buildings.

(c) Type of Facility

The distribution of risk according to facility types is given in Figure B4. About 70% of the risk on buildings comes from houses up to 3-storey, whereas the other 30% from multi-storey buildings.

(d) Proximity of Facility to Catchment

For the 4525 buildings that had been inspected and classified in the inventory of HLC, their proximity to the HLC concerned and the risk distribution are shown in Figure B5. Most of the buildings in the inventory are located within Proximity Zones 3 to 4.

B5. CONCLUSIONS

The QRA update on the risk of natural terrain landslides has the following key conclusions:

(a) Based on the 'Best-estimate' model with Half-Bayesian update (Wong et al, 2006), the calculated landslide risk of the 2,428 HLC is 2.2 PLL per year. When the additional landslide risk of the new HLC generated from natural terrain landslides that have occurred on or after 2004 is taken into account, the estimated landslide risk of the 2,700 HLC is about 2.5 PLL per year. The other hillside catchments (i.e. those without known historical landslides close to developments) have a total risk comparable to that of the HLC. This means that the 2,700 HLC constitute about 50% of the risk of natural terrain landslides on existing developments in Hong Kong.

(b) The average risk-per-catchment for the 2,428 HLC is about 9.4×10^{-4} PLL per year. This risk figure is comparable to that obtained in the 2004 assessment. Landslide risk is unevenly distributed among the HLC. The landslide risk distribution according to the classification of HLC is shown in Figure B3. 87% of the landslide risk comes from the

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HLC where channelized debris flow could develop. Among these, about 30% of the landslide risk comes from those HLC affecting multi-storey buildings (i.e. buildings of four storeys or above). They may deserve priority attention for follow-actions, which may include natural terrain hazard study and implementation of hazard mitigation measures if found necessary.

(c) The best-estimated risk of natural terrain landslides on existing developments in Hong Kong is 5 PLL per year. This calculated risk to life is of comparable order to that of the remaining registered man-made slopes by the year 2010.

B6. REFERENCES

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Table B1 - Recognition Factors

Landslide Hazard[1]	Recognition Factor
(C/T/S)H1	55%
(C/T/S)H2	100%
(C/T/S)H3	100%
(C/T/S)H4	100%

Table B2 - Classification for Relict Landslide Features in ENTLI

Class for Relict Landslide Features[2]	Degree of Certainty
A	80%
B	50%
C	10%

[1] As defined in Wong et al, 2006 (GEO Report No. 191)

Scale of landslide
(i) H1 = 50 m^3 notional (20 m^3 to 200 m^3)
(ii) H2 = 500 m^3 notional (200 m^3 to 2,000 m^3)
(iii) H3 = 5,000 m^3 notional (2,000 m^3 to 20, 000 m^3)
(iv) H4 = 20, 000 + m^3 notional (>20,00 m^3)

Mechanism of debris movement
(i) C = channelied debris flow
(ii) T = mixed debris flow/avalanche along topographic depression
(iii) S = open slope debris slide/avalanche

[2] As defined in Maunsell-Fugro Joint Venture, 2007a

Class A - relicts have identifiable characteristics that provide a high degree of confidence, e.g. debris clearly related to the source area, or scarp predominantly sharp
Class B - relicts have characteristics that allow the features to be interpreted as a landslide with a reasonable degree of confidence, e.g. scarp predominantly rounded, or scarp with rock outcrop resulting in a limited degree of sharp scarp
Class C - features which may have involved landsliding in their formation, but the evidence is limited, e.g. depression related to drainage line, or broad depression outside the drainage lines

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Table B3 - Magnitude-Frequency Distributions for HLC

(a) For channelised debris flow and topographic depression catchments

Magnitude-Frequency Distribution Group	Total Debris Volume			
	H1	H2	H3	H4
(C/T)1	89.06%	12.57%	-	-
(C/T)2	78.38%	20.95%	0.15%	-
(C/T)3	72.19%	25.15%	0.75%	0.08%
(C/T)4	64.96%	29.34%	1.51%	0.75%

(b) For open slope debris slide or avalanche catchments

Magnitude-Frequency Distribution Group[3]	Total Debris Volume			
	H1	H2	H3	H4
S1	96.57%	4.19%	-	-
S2	91.47%	8.38%	0.02%	-
S3	86.18%	12.57%	0.15%	0.02%
S4	80.20%	16.76%	0.75%	0.08%

[3] Magnitude-frequency Group for Open Slope Debris Slide or Avalanche Catchments (extracted from Wong et al, 2006 - Table B11(b))

Rainfall Scenario	Catchment Size			
	S	M	L	VL
A	S1	S1	S1	S1
B	S1	S1	S1	S2
C	S1	S2	S3	S4
D	S1	S2	S3	S4

where Rainfall Scenario is defined as (extracted from Wong et al, 2006 - Table B3)

Rainfall Scenario	Normalized 24-hour Rainfall	Mean Annual Frequency of Occurrence	NTLI Landslide Density (No./km^2)
A	≤0.10	F_a = 1/1.23 = 0.8130	D_a = 0.0593
B	>0.10 - 0.20	F_b = 1/2.09 = 0.4785	D_b = 0.4387
C	>0.20 - 0.30	F_c = 1/16.46 = 0.0608	D_c = 2.3354
D	>0.30 - 0.35	F_d = 1/281.81 = 0.0035	D_d = 10.6811

and Catchment size is defined as (extracted from Wong et al, 2006 - Table B9)

Catchment Size	Plan Area of the Portion of Catchment ≥15° Gradient	Adjustment
S	≤3,000 m^2	Where applicable, the catchment size is upgraded or downgraded based on consideration of Table B9 (b) and Table B9 (c). Note that 'S' is the lowest category and 'VL' is the highest category.
M	3,000 m^2 - 10,000 m^2	
L	>10,000 m^2	
VL		

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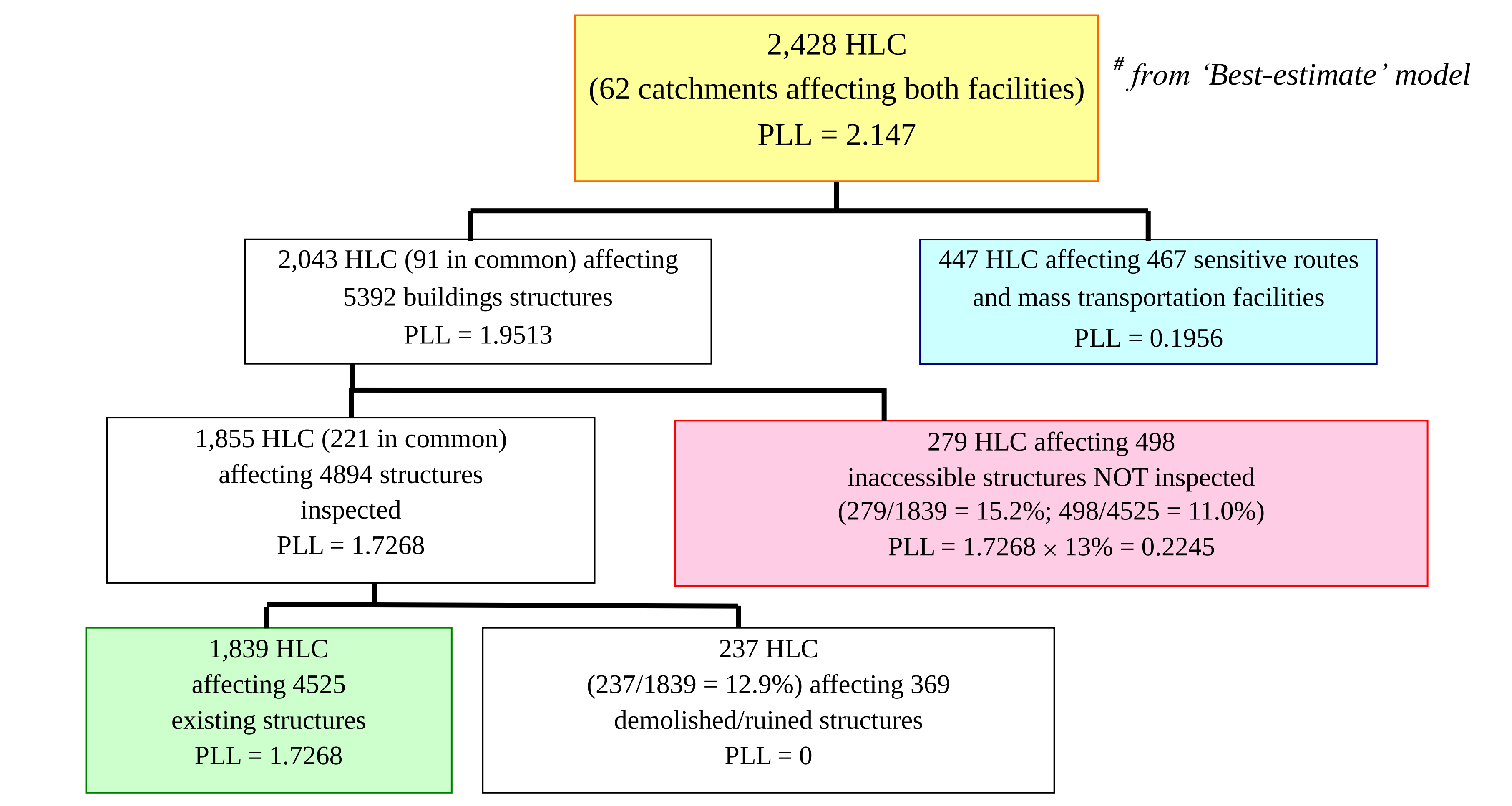

Note: About 300+ HLC affect only demolished/ruined structures or have a catchment area less than 200 m^2. They are not assessed in the QRA update and have calculated PLL = 0. They are therefore not included in the above summary. They would be replaced by new HLC generated from natural terrain landslides that have occurred on or after 2004 and the additional landslide risk is estimated to be about 0.282 (300 ÷ 1,839 × 1.7268). The estimated landslide risk of the 2,700 HLC is about 2.5 PLL per year.

Figure B1 - QRA Results on 2,700 Historical Landslide Catchments

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	Percentage of Total Risk Value			
	H1	H2	H3	H4
Sensitive Routes and Mass Transportation Facilities	23.4%	71.8%	3.2%	1.6%
Building Structures including Collapse	15.4%	75.6%	6.6%	2.4%
Collapse of Building Structures Only	0.0%	4.1%	3.5%	1.1%
Total Risk	16.2%	75.2%	6.2%	2.4%

Notes: (1) Total risk of the 2,428 HLC is 2.147 PLL/year.
(2) Definitions of H1, H2, H3 and H4 as in Wong et al, 2006
(i) H1 = 50 m^3 notional (20 m^3 to 200 m^3)
(ii) H2 = 500 m^3 notional (200 m^3 to 2,000 m^3)
(iii) H3 = 5,000 m^3 notional (2,000 m^3 to 20, 000 m^3)
(iv) H4 = 20, 000+ m^3 notional (>20,00 m^3)

Figure B2 - Distribution of Risk among Different Types of Hazards

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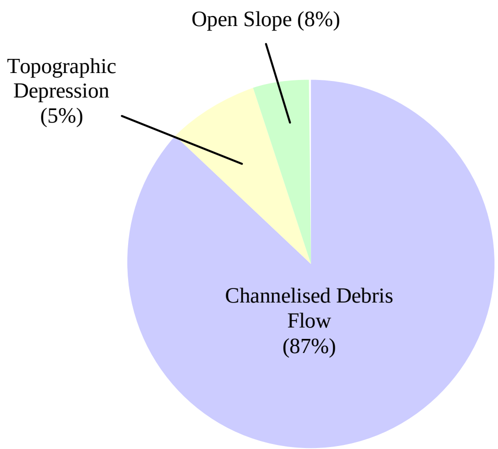
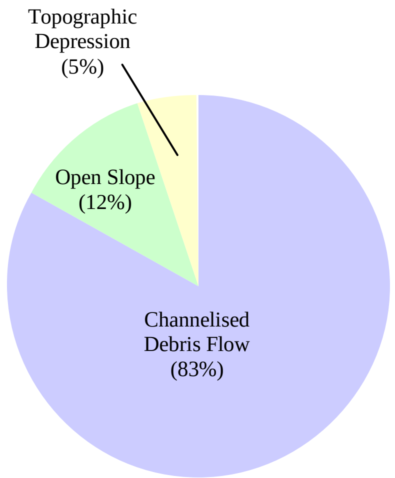
		Channelised Debris Flow	Topographic Depression	Open Slope
Building Structures	Risk of All 2,428 HLC including Building Collapse	1.5081	0.0842	0.1345
	Building Collapse Only	0.1244	0.0078	0.0178
Sensitive Routes and Mass Transportation Facilities		0.1116	0.0147	0.0694

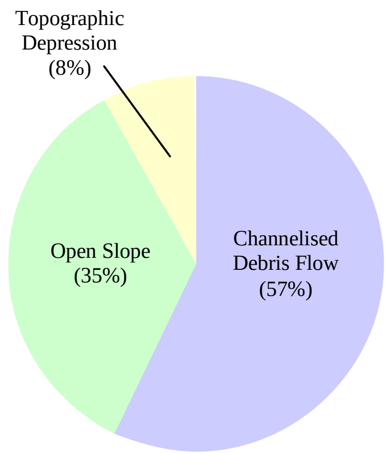
Risk Proportion according to Type of Catchment:



Overall Risk on Building Structures, including Collapse



Risk on Building Collapse



Risk on Sensitive Routes and Mass Transportation Facilities

Figure B3 - Distribution of Risk among Different Types of Catchments

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	Building Structures[1]							Sensitive Routes and Mass Transportation Facilities
	B1 (a)	B1 (b)	B2	B3	B4	B5	B6	
Risk of All 2,428 HLC	0.6407 (37.1%)	0.0492 (2.8%)	0.4812 (28.0%)	0.3340 (19.3%)	0.0746 (4.3%)	0.1436 (8.3%)	0.0035 (0.2%)	0.1956 (100%)
No. of Catchments	1450	212	487	134	50	45	17	447
No. of Facilities	2864 (63.3%)	345 (7.6%)	980 (21.7%)	188 (4.2%)	58 (1.3%)	66 (1.4%)	24 (0.5%)	467 (100%)
Types of Facility	Isolated houses up to 2-storey	Isolated houses of 3-storey	Cluster of houses up to 3-storey	Multi-storey Buildings				Sensitive Routes and Mass Transportation Facilities
Average Risk per Facility (PLL/year)	2.1×10^{-4}		4.9×10^{-4}	1.7×10^{-3}				4.2×10^{-4}

[1.] As in Wong et al, 2006: B1 = Individual houses or structures of one to three storeys
B2 = Cluster of houses or structures of one to three storeys
B3 = Buildings of four to ten storeys, including podium and similar area
B4 = Multi-storey buildings of 11 to 20 storeys, including podium and similar area
B5 = High-rise buildings of more than 20 storeys, including podium and similar area
B6 = Sensitive structures that may involve severe consequence, including PHI, tunnel portal, petrol stations, railway platform, MTR exit

Figure B4 - Distribution of Risk among Different Types of Facilities

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Proximity Zone (Refer to Wong et al (2006) for Figure C1 in Definitions)	No. of Building Structures	Total Risk in the Zone (PLL/year)	Proportion of Risk of All 2,428 HLC	Risk/Building Structures (PLL/year)
1	125 (2.8%)	0.1008	5.8%	8.1×10^{-4}
2	271 (6.0%)	0.2316	13.5%	8.5×10^{-4}
3	681 (15.0%)	0.6300	36.5%	9.3×10^{-4}
4	1359 (30.0%)	0.5425	31.4%	4.0×10^{-4}
5	1324 (29.3%)	0.2080	12.0%	1.6×10^{-4}
6	583 (12.9%)	0.0137	0.8%	2.4×10^{-5}
7	169 (3.7%)	0.0002	0.01%	1.1×10^{-6}
8	13 (0.3%)	0.0000	0%	0
Sum	4525	1.7268	Average risk per building structures = 3.8×10^{-4}	

Note: Average risk of a HLC affecting building structures = 9.4×10^{-4}.

Figure B5 - Distribution of Risk among Facilities in Different Proximity Zones

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GEOTECHNICAL MANUALS

Geotechnical Manual for Slopes, 2nd Edition (1984), 300 p. (English Version), (Reprinted, 2000).

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.

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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)。
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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.

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

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