REVIEW OF LANDSLIDES IN 2001

GEO REPORT No. 155

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GEOTECHNICAL ENGINEERING OFFICE

CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT

THE GOVERNMENT OF THE HONG KONG

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PREFACE

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

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 last page of this report.

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FOREWORD

This report presents the findings of a detailed diagnosis of landslides in the year 2001 that were reported to the GEO. It serves to review the performance of Government's slope safety system and identify areas for improvement in order to further enhance slope engineering practice in Hong Kong.

The review was carried out by the Landslip Investigation Division of the Geotechnical Engineering Office (GEO), with assistance provided by GEO's landslide investigation consultants, Fugro Maunsell Scott Wilson Joint Venture and Maunsell Geotechnical Services Limited.

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ABSTRACT

The aims of this report are to review the performance of Government's slope safety system and identify areas for improvement to further enhance slope engineering practice through a systematic diagnosis of landslides in the year 2001 that were reported to the Geotechnical Engineering Office (GEO). The review forms part of GEO's landslide investigation programme which was introduced following the 23 July 1994 Kwun Lung Lau landslide.

A total of 214 genuine landslides were reported to the GEO in 2001. All the landslide data were examined and a total of 25 landslide incidents was selected for follow-up study under the landslide investigation programme. These studies provided information and insight on the types and mechanisms of landslides in Hong Kong and facilitated the identification of areas deserving attention.

Based on the landslide data in 2001, the annual failure rate in terms of sizeable landslides (i.e. a failure volume of 50 m^3 or above) on engineered man-made slopes that have been through the slope safety system is about 0.02%. The corresponding annual failure rate in terms of minor landslides (i.e. a failure volume of less than 50 m^3) on engineered man-made slopes that have been through the slope safety system is about 0.07%.

Overall, more than 99.9% of the engineered slopes performed satisfactorily without occurrence of any landslides reported in 2001.

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 detailed diagnostic review of landslides reported to the GEO in 2001. The review forms part of the Geotechnical Engineering Office (GEO)'s landslide investigation (LI) programme which was introduced following the 23 July 1994 Kwun Lung Lau landslide. This 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 improvement to current slope engineering practice.

Individual landslides were selected for in-depth studies to identify lessons learnt and the necessary follow-up actions. This diagnostic review examines all the available landslide data, together with the findings of the individual landslide studies, in order to assess the performance of Government's slope safety system and identify areas deserving attention. The review has been carried out by the Landslip Investigation Division of the GEO, with assistance provided by GEO's LI consultants, Fugro Maunsell Scott Wilson Joint Venture and Maunsell Geotechnical Services Limited.

Based on this review, technical and administrative improvement measures are proposed to further enhance the slope safety system and slope engineering practice in Hong Kong.

2. STUDIES OF INDIVIDUAL LANDSLIDES

The factual information and the relevant statistics on rainfall and landslides reported to the GEO in 2001 were documented by Lam (2002). The annual rainfall recorded at the Hong Kong Observatory (HKO)'s principal raingauge at Tsim Sha Tsui was 3091.8 mm, which is about 40% higher than the average annual rainfall of about 2200 mm. A total of eight Landslip Warnings was issued between 6 June 2001 and 8 September 2001.

Altogether 214 genuine landslides (i.e. discounting non-landslide incidents such as tree falls, flooding, very minor washout, etc.) were identified to have occurred in 2001 out of a total of 227 incidents reported to the GEO. The total number of sizeable failures, i.e. with failure volume $\geq 50\ m^3$, was 16 (viz. about 8% of the reported genuine landslides). Of these 16 major landslides, eight were failures on natural hillside.

The range of different facilities affected by the landslides is summarised in Table 1. The consequences of the landslides, as classified in accordance with the type of failure, is summarised in Table 2. Table 3 shows the distribution of the different facility groups affected by the sizeable landslides. The distribution of landslides as classified by the type of failure is given in Table 4.

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Information on all the landslide incidents reported to the GEO has been uploaded to the computerised Slope Information System of the GEO which is accessible by the general public through computer terminals in the GEO. All the data on the reported landslides were examined and additional information was collated by the LI consultants to identify those incidents that warrant follow-up study. Altogether 25 landslide incidents were selected for follow-up study. Three types of landslide studies were conducted, namely:

(a) forensic study of a serious landslide (i.e. a study with the highest rigour of proof that can be presented as expert evidence in legal proceedings),

(b) detailed study of a significant landslide (i.e. an in-depth study, usually involving detailed aerial photograph interpretation and ground investigation, of the history of the slope and probable causes of the failure), and

(c) review of a notable landslide (i.e. a study that focuses on selected key aspects of an incident without the need for a comprehensive overall investigation).

The individual landslide studies provided valuable information and insight into the types and mechanisms of landslides in Hong Kong, together with the necessary follow-up actions in respect of the landslide incidents. The findings of the landslide studies are documented in a series of reports which are lodged in the Civil Engineering Library. Summaries of significant landslides are included in the Hong Kong Slope Safety Website (http://hkss.ced.gov.hk/hkss/eng/whatsnew/lic/index.htm). Following each landslide study, the key lessons learnt are identified and recommendations are made on site-specific or more general follow-up actions, together with action parties as agreed with GEO's senior management for implementing the recommendations. The progress of the follow-up actions in the implementation of the recommendations is subsequently monitored by the LI Division on a regular basis.

Some of the notable landslides reported to the GEO in 2001 are described in the factual report on rainfall and landslides for the year 2001 (Lam, 2002).

3. OVERALL LANDSLIDE REVIEW

3.1 Scope of the Review

The review of the overall landslide data in 2001 provided a global picture of the performance of the different types of slopes in Hong Kong. This facilitated a diagnosis of the specific areas that deserve attention.

The overall review has focused on the following key aspects:

(a) coverage of the Slope Catalogue,

(b) failure rates of different types of registered slopes, and

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(c) diagnosis of landslides on engineered slopes with geotechnical engineering input and submissions that have been through the slope safety system (hereinafter referred to as engineered slopes).

3.2 Coverage of the Slope Catalogue

3.2.1 General

All sizeable man-made slopes and retaining walls, including those complied under the project entitled 'Systematic Identification and Registration of Slopes in the Territory' (SIRST) which was completed in September 1998 together with features newly formed or identified after 1998, are registered in the New Catalogue of Slopes. The criteria for registration of man-made slope features in the Government's Slope Catalogue are given in GEO Circular No. 15.

3.2.2 Diagnosis

A total of 113 out of the 214 genuine landslides occurred on slope features that were unregistered at the time of failure. A breakdown of these 113 incidents is given in Figure 1.

Of the 113 incidents, 39 (i.e. 35%) involved small man-made features that do not satisfy the slope registration criteria and 61 (i.e. 54 %) involved natural hillsides which would not have been registered because they are not man-made slope features. Two of the incidents involved features where slope works were in progress.

The remaining eleven features (i.e. 113 - 39 - 61 - 2) are registerable (i.e. they satisfy the registration criteria) but had not been registered at the time of the landslide.

Of the above eleven features, three involved sizeable failures (i.e. failure volume $\geq 50\ m^3$). Two of the three failures resulted in permanent evacuation of squatter structures. Seven (i.e. 64%) of the eleven features were less than 7 m in height, one of which only marginally met the registration criteria (viz. a 3 m high retaining wall).

3.2.3 Discussion

The above diagnosis indicates that the number of registerable slopes not yet included in the Slope Catalogue at the time of landslides was about 5.1% (i.e. 11 out of 214) of the total number of genuine landslides reported in 2001. Three of the landslides on the eleven unregistered slope features resulted in permanent evacuation of squatters. All the eleven slope features concerned have been registered following the landslides. Action is in progress by the GEO to identify similar slope features as far as practicable for registration in the Slope Catalogue.

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3.3 Failure Rates of Registered Slopes

3.3.1 General

Based on the overall landslide data, the average failure rates of registered slopes can be assessed in terms of the different types of slopes of different ages, i.e. pre-1977 (viz. formed or substantially modified before 1977), or post-1977 (viz. formed or substantially modified after 1977).

The status of a slope has been distinguished in terms of whether or not it has been engineered in the past. Engineered slopes include the following:

(a) slopes formed after 1977 with geotechnical engineering input and with design submissions having been through the slope safety system (i.e. audited as being acceptable) as necessary,

(b) slopes formed before 1977 that were subsequently upgraded, with geotechnical design submissions having been through the slope safety system as necessary,

(c) slopes formed before 1977 that were subsequently subjected to a stability assessment with geotechnical submissions having been through the slope safety system as necessary, including Government slopes that were assessed as being up to the required geotechnical standards, and

(d) slopes upgraded using prescriptive measures under an adequate quality assurance system that satisfies the requirements of WBTC No. 11/2000 (i.e. GEO checking on the design of the prescriptive measures has been waived).

The types of slope features considered in the present diagnosis are soil cuts, rock cuts, fill slopes and retaining walls.

For the purposes of the present diagnosis, the classification of the scale of failure is as follows:

(a) minor failure (i.e. failure volume of $< 50\ m^3$),

(b) major failure (i.e. failure volume between $50\ m^3$ and $500\ m^3$), and

(c) massive failure (i.e. failure volume of $> 500\ m^3$).

In the context of this diagnosis, 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 and may or may not have displaced significantly.

The distribution of failure volumes for the landslides reported in 2001 is summarised

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in Table 5.

3.3.2 Diagnosis

Of the 214 genuine landslides reported to the GEO in 2001, a total of 101 incidents (about 47%) affected 99 registered slopes (i.e. two of the slopes had multiple landslide incidents). Of these 101 landslide incidents, three (about 3%) were sizeable failures.

Of the 101 landslide incidents on registered slopes, a total of 17 engineered slopes was affected. Approximate estimates of the numbers of engineered and non-engineered slope features in the Slope Catalogue have been made by reference to the project entitled 'Systematic Identification of Features in the Territory' (SIFT) (i.e. SIFT Classes A, B1 and C1 correspond to pre-GCO (Geotechnical Control Office, renamed GEO in 1991) fill or cut slopes and SIFT Classes B2 and C2 correspond to post-GCO slopes), together with slopes whose status in terms of compliance with the required geotechnical standards has changed following actions under the Landslip Preventive Measures (LPM) Programme, re-development projects, etc. Further information about the SIFT project, including its scope and limitations, is given by Wong & Ho (2000).

Based on the landslide data in 2001, the calculated annual failure rates for the different types of registered slopes are summarised in Table 6. These calculated failure rates are not particularly sensitive to the assumptions made about the numbers of different types of slopes given the likely order of uncertainty involved. It should be noted that the calculated failure rates do not necessarily correspond to long-term values because of the limited observation period. Notwithstanding this, the calculated annual failure rates from a systematic review of landslide data will provide useful insight into the performance of the slope safety system.

3.3.3 Discussion

Overall, the total number of landslides reported to the GEO in 2001 on registered slopes corresponds to an annual failure rate of about 0.18% (i.e. 99/54,000) of all the features registered in the Slope Catalogue.

The calculated failure rates for the different types of registered slopes could be affected by the actual rainfall characteristics, including the spatial distribution, intensity and duration of rainfall, together with the maintenance condition of slopes and the performance of any slope upgrading works. As noted by Lam (2002), the year 2001 was wetter than an average year in terms of the annual rainfall as recorded at the HKO's principal raingauge at Tsim Sha Tsui.

3.4 Diagnosis of Landslides on Engineered Slopes

3.4.1 General

A review of the landslides reported in 2001 indicates that some of the incidents involved failure of engineered slopes. A meaningful diagnosis of failures of engineered slopes requires detailed information on the nature and probable causes of the landslides,

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together with the status and development history of the slopes concerned. The present assessment is based on the detailed information obtained from the follow-up landslide studies.

Landslides occurred on 17 engineered slopes in 2001 (see Table 7). It should be noted that, for the present purposes, features that did not get through the slope safety system (e.g. no submissions made to the GEO for checking or submissions made by parties outside the GEO with outstanding comments) are not considered to be engineered slopes.

In 2001, none of the landslides involved any slope features with outstanding GEO comments on geotechnical submissions or features with no evidence of a geotechnical submission for GEO checking where this was required.

Engineered slopes with geotechnical submission having been through the slope safety system had sufficient information to allow a diagnosis of the causes of failures. These slopes have been classified in accordance with the system shown in Table 8, under which the following aspects are considered:

(a) whether the slope was formed after 1977 or an existing feature which was previously subjected to upgrading works or stability assessment,

(b) the mechanism under which stability assessments or slope upgrading works were carried out (e.g. under the LPM Programme, under private or Government development projects, works by private owners or default works by Government following the issue of DH Orders),

(c) whether detailed geotechnical design calculations were carried out,

(d) whether site-specific ground investigation and laboratory testing were carried out,

(e) whether the stability assessment or design of slope upgrading works was audited and accepted by the GEO, or whether there were any outstanding GEO's comments on the submissions that were not satisfactorily addressed by the designers, and

(f) whether the slope was upgraded to meet current standards using prescriptive measures under an adequate quality system satisfying the requirements of WBTC No. 11/2000 with GEO checking on the design of upgrading works waived.

A summary of the pertinent findings of the follow-up landslide studies is given in Table 9.

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3.4.2 Diagnosis

The breakdown of the 17 engineered slopes with respect to the type of slopes and scale of failure is shown in Table 10. It can be seen from Table 10 that 82% of these cases (i.e. 14 slopes) involved minor failures whereas 18% (i.e. three slopes) involved sizeable failures.

Based on the 2001 landslide data, the annual failure rates for the different classes of slopes can be evaluated, as summarised below (Table 6):

(a) registered slopes with no geotechnical input = 0.23% (for all landslides),

(b) engineered slopes processed by the slope safety system = 0.09% (for all landslides),

(c) registered slopes with no geotechnical input = nil (for sizeable landslides),

(d) engineered slopes processed by the slope safety system = 0.02% (for sizeable landslides),

(e) registered slopes with no geotechnical input = 0.23% (for minor landslides), and

(f) engineered slopes processed by the slope safety system = 0.07% (for minor landslides).

Of the 17 engineered slope features, six were previously included in the LPM Programme (none of which involved a sizeable failure, see Table 11). As far as slopes dealt with under the LPM Programme are concerned, the annual failure rates based on the 2001 landslide data are as follows:

(a) Slopes treated under LPM Programme (for all landslides) = 0.26%, and

(b) slopes treated under LPM Programme (for sizeable landslides) = nil.

It may be noted from the above diagnosis that for the year 2001, the annual failure rate of LPM slopes for all landslides was apparently higher than the corresponding figure for all engineered slopes. This could be partly related to the fact that the LPM Programme tends to tackle more difficult sites involving large slopes, usually with complex ground conditions. However, caution needs to be exercised because the numbers being compared are small and may not be statistically significant. Hence, the diagnosis should be taken as indicative only.

Of the 17 engineered slopes that failed in 2001, poor slope maintenance condition was diagnosed as a key factor in the failure of eight slope features (seven of which involved minor failures and one involved a major failure). Most of the cases mentioned above are minor

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rockfall incidents. This highlights the need to further improve the slope maintenance practice in rock slopes. Further discussions are given in Sections 3.5.4 and 3.5.6.

Design issues (e.g. inadequate ground investigation, under-prediction of transient groundwater pressure, inadequate consideration of adverse geological materials and poor detailing of surface drainage provisions) played a key role in eight of the failures involving engineered slopes. This highlights the need to improve slope engineering practice in order to further reduce the failure rate of engineered slopes.

3.5 Technical Assessment

3.5.1 Slope Deformation without Full Detachment of Debris

The majority of the landslides in Hong Kong involve shallow failures that reportedly occur with little or no prior warning at or around peak rainfall intensity. As with landslides that occurred between 1997 and 2000, the 2001 landslide data have provided further evidence that the instability could involve slope deformation (as evidenced by signs of distress such as extensive tension cracks) without complete detachment of the displaced mass from the slip surface. The important practical implications of the above findings were discussed by Wong & Ho (2001) and Ho et al (2001).

One of the failures on engineered soil cut slopes in 2001 involving significant slope deformation without complete detachment of the unstable ground mass from the slip surface. In this case, there was evidence of progressive slope deformation over several years. Significant rise of the base groundwater table following heavy rainfall was one of the key contributory factors in the failure.

3.5.2 Severity of Rainstorms that Triggered Landslides

Of the 17 failures that affected engineered slopes, 15 incidents were triggered by rainfall where there was sufficiently reliable information to assess the timing and severity of the rainstorms preceding the landslides (Table 9). Five of the 15 incidents occurred during unprecedented rainstorms since slope formation or modification, whilst the remaining ten incidents involved rainstorms which were less severe than those experienced in the past based on data from automatic raingauges installed in the mid-1980's.

For the above ten 'surprise' failures with respect to severity of rainstorms, deterioration of the slope condition probably played a key role in those cases where contribution from inadequate slope maintenance was judged to be significant and where there were no obvious changes in environmental factors. Slope deterioration could take the form of intermittent slope deformation caused by previous successive severe rainstorms resulting in progressive opening up of the ground. It is conceivable that gradual deterioration of the slope condition could also take place without obvious deformation, e.g. changes in near-surface hydrogeology related to evolution of erosion pipes, washout or re-deposition of joint infill, etc. As a result, subsequent failures may occur under rainstorms that are not particularly severe.

The significance of the above findings with respect to the severity of rainstorm triggering landslides was discussed by Ho et al (2001).

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3.5.3 Landslides on Engineered Soil Cut Slopes

In 2001, landslides (one massive failure and two minor failures) occurred on three unsupported soil cut slopes with heights up to 53 m. These slopes were attended to in the 1990's and in 2000. All three slopes have been studied in sufficient detail to enable a diagnosis of the failures.

The massive failure involved more adverse groundwater conditions and more adverse geological material than those assumed in the design whilst the two minor landslides involved inadequate slope maintenance.

A breakdown of the key contributory factors together with the scale of failure is shown in Table 12.

The massive failure involved significant deformation and distress of the cut-back slope without complete detachment of the unstable ground mass. This case was mainly associated with complex and adverse geological and hydrogeological conditions which were not fully appreciated during the design stage. This highlights the need for improved geological input in the assessment of the ground conditions.

Since the introduction of soil nails for upgrading soil cut slopes in Hong Kong in the late 1980's, there is as yet no record of any failure of permanent soil-nailed slopes. On the other hand, there have been notable failures of high unsupported cuts which have been designed based on theoretical slope stability analyses. The stability of high unsupported cuts can be vulnerable to variations in ground conditions and possible undetected adverse ground and groundwater conditions. More robust schemes, such as soil nails or hybrid schemes involving cutting back and soil nails, are generally preferred to simply cutting back, especially where high unsupported cuts are being considered because the performance of the latter is more vulnerable to undetected adverse ground and groundwater conditions.

There have been some reported cases of problems encountered with soil nail construction and instability of soil nailed slopes during the construction stage. It would be useful to review all known cases involving problems in connection with the construction and performance of soil nailed slopes and identify areas for attention for further reference.

3.5.4 Landslides on Engineered Rock Cut Slopes

In 2001, minor failures occurred on seven engineered rock cut slopes (six of which were attended to in the 1980's and one in the 1990's). All had a failure volume of less than 1 m^3, except for one incident with a failure volume of about 15 m^3. Such small detachments of less than 1 m^3 only have a very small chance of direct spatial impact. However, in the event of direct impact, the consequence could be quite severe because of the nature of the material.

In five of the seven incidents, poor maintenance conditions involving unplanned vegetation was diagnosed as a key contributory factor in the failure. Rock slopes can be prone to local deterioration given that most of the rock slopes in Hong Kong are not provided with a surface cover. The other two failures were caused by local adverse groundwater

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conditions and involved local adverse jointing in the rock mass, which had not been adequately addressed in the slope design. The occurrence of such minor detachments can be very difficult to confidently guard against in design assessments.

One of the failures involving detachment of small rock blocks from a rock face that was in a poor maintenance condition resulted in two injuries in a van passing along a busy road below the slope. The slope concerned was privately owned and a Dangerous Hillside (DH) Order was previously served by the Government but action has yet to be taken by the private owners on the substandard slope at the time of the landslide some two years after the issue of the DH Order. The incident served as a reminder that inaction by private owners in dealing with substandard slopes, especially where they are in a poor maintenance condition, could pose a threat to public safety.

Another notable failure involved detachment from a rock cut slope above a busy road. The detached rock block was probably destabilised by progressive tree root growth associated with unplanned vegetation penetrating into adversely orientated joint apertures and wedging the joints open. The local build-up of cleft water pressure behind the rock block due to surface infiltration into the open joint probably played a key role in triggering the detachment. The unplanned tree was previously identified for removal during slope maintenance inspections and it was subsequently cut back to the main stump. However, the unplanned tree regenerated fairly quickly within a period of several months. This highlights the importance of paying due attention to effective means of removing unplanned trees that are adversely affecting slope stability.

3.5.5 Failures on Engineered Fill Slopes

A total of three failures occurred on engineered fill slopes in 2001. These comprised two major failures on slopes (formed in the early 1980's and early 1990's respectively) and one minor failure on a slope upgraded in the early 1990's. For the two major failures, one involved defective water-carrying services which contributed to the build-up of groundwater pressure within the near-surface material whilst the other incident involved a blocked catchpit leading to uncontrolled surface water flow.

The minor failure involved formation of an erosion hole of about 6 m^3 in volume as a result of prolonged internal erosion of a fill slope that was previously upgraded by recompacting the upper 3 m. The failure was due to concentrated subsurface water flow, which was exacerbated by poor detailing of subsurface drainage and filter provisions in a slope that straddles a major drainage line. There was evidence of significant loss of fines from the fill slope over the years but this was not highlighted in the past routine maintenance inspections or Engineer Inspection.

3.5.6 Landslides with Poor Slope Maintenance Condition Diagnosed as a Key Contributory Factor to Failure

All the reported landslide incidents on man-made slopes have been reviewed to assess whether poor slope maintenance condition was likely to have been a major contributory factor in the failure.

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In 2001, there was a total of 152 landslide incidents involving man-made slopes. Of these 152 incidents, two affected slope features under construction, 34 affected slope features that are not registerable and 15 affected slope features that are registerable but were not registered at the time of failure.

An assessment of the remaining 101 (i.e. 152 - 2 - 34 - 15) incidents has been made to examine whether poor slope maintenance condition was one of the major contributory factors to the failures. Reference has been made to the records of emergency inspections by the GEO, inspections of selected landslides by the LI consultants and the findings of the follow-up landslide studies, where appropriate, for the assessment. Poor slope maintenance condition was assessed as a major contributory factor in 38 (i.e. 38%) of the 101 incidents.

Of the 38 incidents with inadequate maintenance being a key contributory factor, 34 affected government slope features and four affected private slope features.

As noted in Section 3.4.2, of the 17 engineered slopes that failed in 2001, poor slope maintenance condition was diagnosed as a key contributory factor in the failure of eight cases (seven of which were minor and one was major). Of these eight incidents, five affected Government slope features and three affected private slope features.

Apart from inadequate slope maintenance, the follow-up landslide studies have also highlighted that there is room for improvement in the EI's and the implementation of some EI recommendations. Areas requiring attention as identified in the review of some of the past EI's included failure to detect problems such as prolonged erosion, adverse effects of unplanned vegetation on rock faces and leakage from buried water-carrying services, inadequate follow-up to past recommendations made after maintenance inspections not identified, removal of loose blocks on rock cut slopes not clearly identified in the recommendations (e.g. in plan and on photographs with marked-up overlays) and no involvement of the engineer making the recommendations in the subsequent implementation of the works or in carrying out a post-implementation inspection for such cases.

The above observations reinforce the need to ensure that the EI's are carried out in a rigorous manner by complying with the good practice promulgated by the GEO. To check the quality of the EI on government slopes, maintenance departments should set up suitable procedures to step up the independent technical audit of the submitted EI reports, as previously recommended in the supplementary guidance notes on slope maintenance that were issued by the GEO in April 2000. Also, the need for a follow-up EI to verify the adequacy of the follow-up actions taken in discharging the EI recommendations (e.g. scaling of loose blocks from a rock slope) should be considered by the slope owners or maintenance agents on a case-by-case basis.

Apart from the need to enhance slope maintenance practice, it would also be useful to adopt more robust design or improvement schemes and to improve slope detailing (e.g. by providing improved slope protection and drainage provisions) so that the slope would be less vulnerable to inadequate maintenance. Types 1 and 2 prescriptive measures, in accordance with GEO Report No. 56, should be implemented on as many of the slopes as possible where appropriate. For those old slopes where the existing slope drainage provisions and surface protection are inadequate or are absent, routine maintenance will do very little to arrest slope deterioration and minimise the chance of slope detachments. In such cases, enhanced

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maintenance using at least Type 1 and/or Type 2 prescriptive measures in accordance with GEO Report No. 56 should be carried out as far as possible.

3.5.7 Landslides on Natural Hillsides

A total of 61 hillside failures was reported to the GEO in 2001, eight of which (i.e. 13%) were sizeable failures.

Of the 61 hillside failures, 44 (i.e. 72%) were classified as natural hillside failures (four of which were sizeable), i.e. the failure affected natural hillsides which had not been modified by man-made activities such as cutting, filling, cultivation and mining (Ho et al, 2001). Fifteen (i.e. 25%) of the hillside failures (three of which were sizeable) involved failure of disturbed hillsides which were locally modified by man-made activities. The remaining two landslides (one of which was sizeable) occurred predominantly on natural hillsides but the failures also partly involved registerable man-made features.

The most significant hillside failure in 2001 involved a massive debris flow (780 m^3) above Lei Pui Street, Kwai Chung. The debris flow affected an active construction site at the toe of the hillside as well as Lei Pui Street below. Two squatter structures were demolished by the landslide and casualties were only narrowly avoided. The affected squatter structures were previously recommended for clearance by the GEO in 1992 on slope safety grounds under the Non-Development Clearance Programme. However, the residents of the two squatter structures refused to be re-housed. There was no indication of an incipient natural hillside failure prior to the occurrence of the debris flow above Lei Pui Street. This incident highlighted the need to continue to study major landslides on natural hillsides under the LI programme to improve the understanding of the diverse range of hillside instability problems in Hong Kong.

3.5.8 Updating of CNPCS Scores of Slope Features Following Landslide Incidents

Potentially substandard slopes are selected for action under the Landslip Preventive Measures (LPM) Programme in accordance with a risk-based priority ranking system. Combined New Priority Classification System (CNPCS) scores, which take into consideration the likelihood of failure and the severity of the consequence in the event of failure, reflect the relative risk posed by the different slope features in respect to potential loss of life. The CNPCS scores are also referred to by the maintenance departments in prioritising actions under the slope maintenance programmes.

The CNPCS score reflects the contribution of a number of key factors, including past failure, that affect the risk-to-life posed by the feature. The CNPCS scores for old registered man-made slopes were obtained under the Systematic Identification and Registration of Slopes in the Territory (SIRST) project which was completed in 1998. The scores are updated from time to time to take account of the prevailing situation (e.g. following Engineer Inspections).

A review was carried out on the 381 pre-1977 slopes with both CNPCS scores and landslides reported to the GEO between 1999 and 2001. It transpires that many of these

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slopes (> 80%) were recorded as having no past instability. Prompt updating of the CNPCS scores to take account of known landslides will facilitate future selection of slopes for priority action under the LPM Programme.

4. PROPOSED IMPROVEMENT MEASURES

4.1 General

Technical and administrative improvement measures were proposed by Ho et al (2001) following the review of the reported landslides in 2000. The progress of the follow-up actions taken is summarised in Table 13.

A number of technical and administrative improvement measures have been recommended following the study of the reliability and robustness of engineered slopes. Other proposed improvement measures, following the review of the reported landslides reported in 2001, are given in the sections below.

4.2 Technical Improvement Measures

As noted in Section 3.5.3, there have been reported cases of problems associated with soil nail construction and instability of temporary soil nailed slopes. It is proposed that a review be carried out to document the problematic cases. This will assist in highlighting areas that warrant attention in the design and construction of soil nails.

4.3 Administrative Improvement Measures

The following administrative improvement measures are proposed:

(a) Review data on landslides that occurred prior to the engagement of an Authorised Person or default works following the service of a Dangerous Hillside Order and examine if there are any areas that warrant improvement (see Section 3.5.4).

(b) Formalise a procedure to promptly re-calculate and update the CNPCS scores of slopes to take account of landslide occurrence to facilitate future selection of slopes for priority action under the LPM Programme (see Section 3.5.8).

5. CONCLUSIONS

Based on a detailed review of landslides reported in 2001 that were reported to the GEO, the following observations are made with respect to the performance of the Government's slope safety system:

(a) The annual failure rates of sizeable landslides and minor

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landslides on engineered slopes were about 0.02% and 0.07% respectively for the year 2001.

(b) More than 99.9% of the engineered slopes performed satisfactorily without the occurrence of any landslides reported in 2001.

A number of technical and administrative improvement measures have been proposed to further enhance the slope safety system and slope engineering practice in Hong Kong as detailed in Section 4 of this report.

6. REFERENCES

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Table 1 - Number of Landslides Affecting Different Facilities

Affected Facility	Hong Kong Island	Kowloon	New Territories and Outlying Islands	All
Squatters	0 (0)	0 (0)	32 (5)	32 (5)
Buildings	0 (0)	0 (0)	6 (0)	6 (0)
Roads	10 (0)	1 (0)	37 (4)	48 (4)
Transportation Facilities (railways, tramways, LRT, etc.)	0 (0)	0 (0)	0 (0)	0 (0)
Pedestrian Pavements/ Footways	6 (1)	2 (0)	5 (0)	13 (1)
Minor Footpaths/Access	3 (0)	1 (0)	33 (3)	37 (3)
Construction Sites	1 (0)	0 (0)	4 (2)	5 (2)
Open Areas	6 (1)	7 (0)	37 (2)	50 (3)
Catchwaters	0 (0)	0 (0)	0 (0)	0 (0)
Others (e.g. carparks, parks, playgrounds, gardens, backyards, etc.)	3 (0)	0 (0)	32 (2)	35 (2)

Legend:

32 (5) Thirty-two landslides of which five were major failures (i.e. failure volume ≥ 50 m^3).

Notes: (1) A given landslide may affect more than one key type of facility.
(2) The types of facility affected by landslide incidents are generally classified based on information given in GEO Incident Reports.

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Table 2 - Landslide Consequence Related to Type of Slope Failure

Type of Failure		No. of Squatter Huts Evacuated		No. of Blocks, Houses or Flats Evacuated or Partially Closed	No. of Landslides Closure			Deaths	Injuries
		Permanent	Temporary		Roads	Pedestrian Pavements	Footpaths, Back Lanes, Private Access		
Fill Slope		1	2	-	-	2	-	-	-
Cut Slope	Soil	3	10	5	4	-	3	-	-
	Soil/Rock	-	5	1	5	1	1	-	2
	Rock	-	-	-	5	-	-	-	-
Retaining Wall		5	2	-	1	-	2	-	-
Natural Hillside		6	9	-	7	1	2	-	-
Disturbed Terrain		-	5	-	-	-	1	-	-

Notes: (1) A failure may give rise to more than one key type of consequence.
(2) The types of facility affected by landslide incidents are generally classified based on information given in GEO Incident Reports.

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Table 3 - Distribution of Facility Groups Affected by Sizeable Landslides

	Facility Group Affected by Sizeable Landslides				
	Group No. 1	Group No. 2	Group No. 3	Group No. 4	Group No. 5
All Sizeable Landslides	5	0	2	4	6
Sizeable Landslides on Man-made Slope	4	0	1	2	1
Sizeable Landslides on Natural Hillside	1	0	1	2	5

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 key type of facility.

Table 4 - Number of Landslides as Classified by Type of Slope Failure

Type of Failure		No.	Percentage (%)
Fill Slope		12 (2)	5.6
Cut Slope	Soil	84 (2)	39.3
	Soil/Rock	25 (0)	11.7
	Rock	9 (0)	4.2
Retaining Wall		18 (3)	8.4
Natural Hillside		61 (8)	28.5
Disturbed Terrain		5 (1)	2.3
Total		214 (16)	100

Legend:

11 (2) Eleven landslides of which two were sizeable failures (i.e. failure volume $\geq 50\ m^3$).

Note: Where a landslide involved more than one type of failure, the predominant type of failure has been assumed in the above classification.

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Table 5 - Breakdown of Scale of Failures for Different Classes of Slopes

	Number of Minor Failure ($< 50\ m^3$)	Number of Major Failure (50 to $500\ m^3$)	Number of Massive Failure ($> 500\ m^3$)	
Registered man-made slopes	98	2	1	$\Sigma = 101$
Small unregisterable man-made slopes	38	1	0	$\Sigma = 39$
Registerable man-made slopes not yet registered at time of failure	$9^{(1)}$	$4^{(1)}$	0	$\Sigma = 13$
Natural hillside	53	7	1	$\Sigma = 61$
	$\Sigma = 198$	$\Sigma = 14$	$\Sigma = 2$	$\Sigma = 214$

Note: $4^{(1)}$ denotes 4 major landslides that occurred on registerable man-made slopes that were yet to be registered at the time of landslide, one of which involved an active construction site.

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Table 6 - Annual Failure Rates of Registered Slope Features Based on Landslides Reported in 2001

	Non-Engineered Slopes			Engineered Slopes		
	Fill/Retaining Wall	Soil/Rock Cut	Overall	Fill/Retaining Wall	Soil/Rock Cut	Overall
Number of Slopes Involved in Landslides in 2001	8	72	82	3	14	17
Number of Slopes Involved in Sizeable Landslides in 2001	0	0	0	2	1	3
Number of Slopes Involved in Minor Landslides in 2001	8	72	82	1	13	14
Number of Slopes	11,140	21,550	35,000	8,900	10,100	19,000
Annual Failure Rates (All Landslides)	0.07%	0.33%	0.23%	0.03%	0.14%	0.09%
Annual Failure Rates (Sizeable Landslides)	0%	0%	0%	0.02%	0.01%	0.02%

Note: For clarity, the number of slope features and the number of landslides involving Disturbed Terrain have not been separately presented.

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Table 7 - Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 1 of 5)

1. Slopes Upgraded Under the LPM Programme

Slope No.	Incident No.	Location	Volume (m^3)	Type of Slope	Remarks
6SE-B/C4	LI2001/145M [1]	Route Twisk, Tsuen Wan	5	Soil cut	LPM works completed in 2000.
6SE-D/C52	LI2001/146M	Route Twisk, Tsuen Wan	2	Soil cut	LPM works completed in 2000.
6NE-D/C6	LI2001/158M	Route Twisk, Tsuen Wan	3	Soil cut	LPM works completed in 2000.
11SE-C/C54	HK2001/06/002	Tai Hang Road	0.1 (boulder fall)	Soil/rock cut	LPM works completed in 2001.
11SE-A/FR61	2001/09/0109	Tin Hau Temple Road, Fortress Hill	6	Fill slope	LPM works completed in 1992.

2. Slopes Assessed under the LPM Programme with No Upgrading Works Required

Slope No.	Incident No.	Location	Volume (m^3)	Type of Slope	Remarks
11NE-D/C20	ME2001/06/001	Hiu Kwong Street, Kwun Tong	0.1 (rockfall)	Soil/rock cut	Stage 2 Study carried out by GEO's Design Division in 1993 concluded that no upgrading works were required for the failed (rock cut) portion.

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Table 7 - Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 2 of 5)

3. Slopes Assessed by Studies in the Late 1970's to mid-1980's with No Upgrading Works/Further Study Required

Slope No.	Incident No.	Location	Volume (m^3)	Type of Slope	Remarks
11NE-C/C71	ME2001/06/004	Kung Lok Road, Kwun Tong	1 (rockfall)	Soil/rock cut	Stage 1 Study carried out by GCO's Planning Division in 1988 concluded that no upgrading works were required.

4. Slopes Assessed by Government Departments and Checked by GEO with No Upgrading Works Required

Slope No.	Incident No.	Location	Volume (m^3)	Type of Slope	Remarks
3SE-C/CR147	2001/09/0102	Ting Kok Road, Tai Po	30	Soil cut	The failed portion was assessed by TDD's consultants in 1997 as being up to the required standards. Geotechnical design was checked by GEO in 2000.

Table 7 - Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 3 of 5)

5. Slopes Assessed by Private Owners and Checked by GEO with No Upgrading Works Required

Slope No.	Incident No.	Location	Volume (m^3)	Type of Slope	Remarks
11NW-A/C58	MW2001/06/007	Castle Peak Road below Wah Yuen Chuen, Kwai Chung	0.05 (rockfall)	Soil/rock cut	The slope was assessed by consultants in 1980 as being up to the required standards. Geotechnical submission was checked by BOO. A safety-screening study was completed in 1998 and a DH Order was issued to the owners in 1999.
7NW-B/C416	ME2001/06/032	Classical Garden, Tai Po	8	Soil cut	The slope was assessed by consultants in 1991 as being up to the required standards. Geotechnical submission was checked by GEO.
11NE-B/FR249	2001/09/0066	Denon Terrace, Tseng Lan Shue, Sai Kung	50	Fill slope	The failed portion was assessed by consultants in 1993 as being up to the required standards. Geotechnical submission was checked by GEO.

Table 7 - Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 4 of 5)

6. Slopes Formed or Upgraded by Government Departments and Checked by GEO

Slope No.	Incident No.	Location	Volume (m^3)	Type of Slope	Remarks
3NW-D/C254	2001/07/0042	NENT Landfill, Sha Tau Kok	8,000 (volume of displaced mass)	Soil cut	Design of remedial works prepared by CED's consultants following repeated failures was checked by GEO in 1996. Works were carried out in 1997.
7SW-C/C903	2001/08/0054	Tsuen Tsing Interchange, Kwai Chung	0.3 (rockfall)	Rock cut	Slope works were carried out in the period of 1977-1981. Geotechnical design prepared by HyD was checked by GCO in 1981.
11SE-C/F103	2001/07/0020	Broadwood Road, Happy Valley	50	Fill slope	Geotechnical design on the subject fill slope prepared by consultants was checked by GCO in 1985.
12SW-A/C175	ME2001/06/049	Tseung Kwan O Landfill (Phase 1)	15 (rock slide)	Soil/rock cut	Geotechnical design on the subject slope prepared by CED was checked by GCO in 1985.

7. Slopes Formed or Upgraded by Private Owners and Checked by GEO

Slope No.	Incident No.	Location	Volume (m^3)	Type of Slope	Remarks
11SE-A/C5	2001/09/0069	Sun Sing Street, Sai Wan Ho	0.07 (rockfall)	Soil/rock cut	Geotechnical submission was checked by GCO in 1980's.

Table 7 - Landslide Incidents Involving Slopes Processed under the Slope Safety System (Sheet 5 of 5)

8. Slopes Upgraded Following Service of DH Orders and Checked by GEO

Slope No.	Incident No.	Location	Volume (m^3)	Type of Slope	Remarks
11SE-A/C561	HK2001/06/008	King's Road, Tin Hau	0.1 (rockfall)	Rock cut	Geotechnical submission was checked by GCO in 1983. Slope upgrading works were carried out in 1984.

9. Slopes Assessed as Not Requiring Upgrading Works But with Outstanding GEO Comments

Nil.

10. Slopes Assessed as Requiring Upgrading Works But with Outstanding GEO Comments

Nil.

Notes:
(1) Two landslides with failure volume of 2 m^3 and 3 m^3 respectively occurred on the slope.
(2) Slopes under Categories 1 to 8 are classified as engineered slopes.
(3) Slopes under Categories 9 and 10 are post-1977 features but are not taken as engineered slopes.

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Table 8 - Classification of Engineered Slopes

Feature Type	Classification
Post-1977 Features (i.e. formed or upgraded after 1977)	1
Newly Formed	1N
Upgraded by LPM	1A
Upgraded by Other Government Departments	1B
Upgraded by Private Owners	1C
Upgraded following issue of DH Orders	1D
Pre-1977 Features (i.e. formed before 1977 and subsequently assessed under the slope safety system)	2
Assessed by LPM Stage 2 or Stage 3 Studies	2A
Assessed by Other Government Departments	2B
Assessed by Private Owners	2C
Assessed by Old Studies (e.g. Planning Division Stage 1 Study, Binnie & Partners Phase II Study, Existing Slopes Division Stage 1 Study)	2D

Note: The classification may be extended where possible by adding S, T, U, Y or N which are defined as follows:

S = detailed design calculations based on site-specific ground investigation and laboratory testing

T = detailed design calculations without site-specific ground investigation and laboratory testing

U = no detailed design calculations

Y = upgrading works/assessments were audited and accepted by the GEO

N = no evidence that the works/assessments were audited and accepted by the GEO

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Table 9 - Summary of Key Findings of Follow-up Landslide Studies (Sheet 1 of 6)

Landslide	Slope Status (classification)*	Worst Rain	Deterioration	Massive Relict Failure		Previous Failure/ Distress after Slope Assessed or Modified to Current Standards		Deficiency in Design/Assessment			Deficiency in Upgrading Works	Poor Condition of Maintenance	GEO Checking		Unauthorized Construction	Volume of Failure (m^3)		Remarks
				Recorded	More from API	Recorded	More from API	G/W	Material Strength	Others #			Submitted to GEO for Checking	Outstanding GEO comment not resolved		Detached	Deformed	
1.9.2001 Hillside above Lei Pui Street, Kwai Chung (DS)	Not engineered	N	Y	N	N	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	780	0	Debris flow on natural hillside following an initial rock slide in the upper reaches of the hillside during heavy rainfall. The landslide was probably caused by build-up of water pressure within the near-surface materials which had undergone continuous deterioration following the heavy rainfall that immediately preceded the failure.
9.6.2001 Castle Peak Road near Wah Yuen Chuen, Kwai Chung (11NW-A/C58) (DS)	Engineered (Geotechnical submission checked by BOO in 1980) (1NSY)	N	Sig	N	N	Y (soil cut portion)	N	Little	Little	Min	N/A	Sig	Y	N	N	0.05	0	Rockfall triggered by rainfall. Poor slope maintenance was a key factor in the failure. Poor detailing of surface drainage provisions led to discharge directly onto exposed rock portion of the slope and probably promoted progressive deterioration of the exposed rock portion and growth of unplanned vegetation. The unplanned vegetation, which in turn exploited the rock joints and led to progressive opening of the joints, allowed further water ingress and the local build-up of water pressure in the jointed rock mass.
25.6.2001 King's Road, Tin Hau (11SE-A/C561) (DS)	Engineered (Upgraded in 1984 for discharging a DH Order) (1CSY)	N	N	N	Not Done	N	Not Done	N	N	Min	Little	Sig	Y	N	N	0.1	0	The detached rock block was probably in a metastable condition as a result of progressive tree root growth due to unplanned vegetation penetrating into adversely orientated joint apertures and wedging the joints open.
14.9.2001 Tin Hau Temple Road, Fortress Hill (11SE-A/FR61) (DS)	Engineered (Upgraded under LPM in 1992 (1ASY)	N	Y	N	N	N	N	Y	N	N	N	N	Y	N	N	6	0	Prolonged internal erosion on a fill slope which straddles a major drainage line. The failure was probably as a result of high seasonal groundwater level and poor detailing of subsurface drainage provisions.

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Table 9 - Summary of Key Findings of Follow-up Landslide Studies (Sheet 2 of 6)

Landslide	Slope Status (classification)*	Worst Rain	Deterioration	Massive Relict Failure		Previous Failure/ Distress after Slope Assessed or Modified to Current Standards		Deficiency in Design/Assessment			Deficiency in Upgrading Works	Poor Condition of Maintenance	GEO Checking		Unauthorized Construction	Volume of Failure (m^3)		Remarks
				Recorded	More from API	Recorded	More from API	G/W	Material Strength	Others #			Submitted to GEO for Checking	Outstanding GEO comment not resolved		Detached	Deformed	
14.12.2001 Pokfield Road (unregistered fill slope) (DS)	Not engineered	N	N	N	Not Done	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	30	0	A significant washout incident which occurred on a hillside overlain by a layer of fill covered with shotcrete. The failure was caused by the bursting of a pressurised watermain located along a curved section of Pokfield Road. Two previous incidents probably due to leakage or bursting of water-carrying services also occurred at approximately the same location.
8.6.2001 Tai Hang Road (11SE-C/C54) (LR)	Engineered (Upgraded under LPM in April 2001) (1ASY)	First wet season after upgrading	N	N	Not done	N	Not done	N	N	N	Po	N	Y	N	N	0.1	0	The boulder was probably destabilised by erosion or loss of support from the surrounding soil mass, probably as a result of direct infiltration and surface runoff on the slope face. Inadequate backfill to trial pits dug as part of the ground investigation was probably a contributory factor to the failure.
2.9.2001 Hillside below Kwun Ping Road (LR)	Not engineered	N	Po	N	N	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N	20	0	The failure involving a thin veneer of fill on hillside below a road was probably caused by elevated groundwater pressure within the near-surface material. Loose backfill for pipe-laying work on the road along its downhill edge resulted in severe cracking of the road surface which allowed infiltration of surface runoff into the ground below. A very minor landslide on the uphill side of the road blocked the toe drainage channel and resulted in channelling of additional surface runoff towards the area directly above landslide site which exacerbated water ingress into the landslide site.

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Table 9 - Summary of Key Findings of Follow-up Landslide Studies (Sheet 3 of 6)

Landslide	Slope Status (classification)*	Worst Rain	Deterioration	Massive Relict Failure		Previous Failure/ Distress after Slope Assessed or Modified to Current Standards		Deficiency in Design/Assessment			Deficiency in Upgrading Works	Poor Condition of Maintenance	GEO Checking		Unauthorized Construction	Volume of Failure (m^3)		Remarks
				Recorded	More from API	Recorded	More from API	G/W	Material Strength	Others #			Submitted to GEO for Checking	Outstanding GEO comment not resolved		Detached	Deformed	
1.9.2001 Denon Terrace, Tseng Lan Shue, Sai Kung (11NE-B/FR249) (LR)	Engineered (Geotechnical submission checked by GEO in 1993) (2CSY)	N	N	N	N	N	N	N	N	N	N/A	N	Y	N	N	50	0	Failure was probably triggered by rainfall and mainly attributed to continuous ingress of water onto the slope associated with a damaged overflow pipe leading from septic tanks in nearby village houses.
11.6.2001 Tin Sum Village, Fanling (Unregistered masonry retaining wall) (LR)	Not engineered	Y (36 years return period)	Y	N	N	N/A	N/A	N/A	N/A	N/A	N/A	Mod	N/A	N/A	N	90	0	Failure of the 5 m high slender masonry wall was probably caused by elevated water pressure behind the wall due to rise of base groundwater table.
10.7.2001 NENT Landfill, Sha Tau Kok (3NW-D/C254) (LR)	Engineered (Geotechnical submission of remedial works was checked by GEO in 1996)	Y (180 years return period)	N	Y	N	Y	N	Sig	Mod	Mod	N	N	Y	N	N	0	8,000	Displacement of a large volume of material associated with deep-seated landslide was probably caused by a significant rise of the base groundwater table following heavy rainfall. Repeated 'slow-moving' landslides have occurred since formation of cut slope in the early 1990's.
9.6.2001 Kung Lok Road, Kwun Tong (11NE-C/C71) (LR)	Engineered (GCO Stage 1 Study in 1988) (2DTY)	N	Y	N	Not Done	N	Not Done	N	N	N/A	N	Sig	Y	N	N	1	0	The rockfall was probably caused by build-up of cleft water pressure resulting from concentrated ingress of surface water runoff due to overflow from a blocked U-channel into open or weathered joints.
Reported on 13.7.2001 Broadwood Road, Happy Valley (11SE-C/F103) (LR)	Engineered (Geotechnical submission checked by GCO in 1985) (1NSY)	Not assessed	Y	N	Not Done	N	Not Done	N/A	N/A	N/A	N/A	Y	Y	N	N	50	0	Failure of the fill slope was probably caused by concentrated water ingress as a result of a blocked catchpit.
About July 2001 Tsuen Tsing Interchange, Kwai Chung (7SW-C/C903) (LR)	Engineered (Geotechnical submission checked by GCO in 1978) (1NST)	N	N	N	Not Done	N	Not Done	N	N	Little	N	N	Y	N	N	0.3	0	Minor rockfall triggered by rainfall was probably associated with a locally adversely orientated joint.

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Table 9 - Summary of Key Findings of Follow-up Landslide Studies (Sheet 4 of 6)

Landslide	Slope Status (classification)*	Worst Rain	Deterioration	Massive Relict Failure		Previous Failure/ Distress after Slope Assessed or Modified to Current Standards		Deficiency in Design/Assessment			Deficiency in Upgrading Works	Poor Condition of Maintenance	GEO Checking		Unauthorized Construction	Volume of Failure (m³)		Remarks
				Recorded	More from API	Recorded	More from API	G/W	Material Strength	Others #			Submitted to GEO for Checking	Outstanding GEO comment not resolved		Detached	Deformed	
13.6.2001 Classical Gardens, Tai Po (7NW-B/C416) (LR)	Engineered (Geotechnical submission checked by GEO in 1996) (2CSY)	N	N	N	Not Done	N	Not Done	N	N	N	N	Sig	Y	N	N	8	0	A washout failure which was probably caused by concentrated surface water flow due to overflow from a blocked drainage channel.
8.6.2001 Tseung Kwan O Landfill (12SW-A/C175) (LR)	Engineered (Geotechnical submission checked by GCO in 1985) (1NSY)	N	Y	N	Not Done	N	Not Done	N	N	N	Y	Min	Y	N	N	15	0	The landslide was probably caused by elevated water pressure developed within open joints and inter-bedded HDT layers due to surface infiltration.
9.4.2001 Tam Kon Shan Road, Tsing Yi (within active construction site) (LR)	Not engineered (Construction works were being carried out at the time of failure)	N/A	N	N	Not Done	N/A	N/A	N	N	N	N	N/A	Y	N	N	35	0	Concentrated surface runoff due to inadequate temporary surface water diversions damaged the foundation of a partly completed reinforced fill wall within an active construction site.
9.4.2001 Po Kok Branch School, Yuen Long (Unregistered RC retaining wall) (LR)	Not engineered	N	Sig	N	Not Done	N/A	N/A	N/A	N/A	N/A	N/A	N	N/A	N/A	N	50	0	Failure was probably caused by infiltration through the cracked crest drainage channel as well as cracks along the interface between the wall and drainage channel during heavy rainfall. The wall had evidence of significant deterioration.
2001 Hiu Kwong Street, Kwun Tong (11NE-D/C20) (LR)	Engineered (Rock portion assessed under LPM in 1993)	Not assessed	Y	N	Not Done	N	Not Done	N	N	N	N/A	Mod	Y	N	N	0.1	0	The rockfall was probably caused by root action of unplanned vegetation and persistent seepage at the heavily jointed rock face.
12.6.2001 Hillside above Kwai Shing Circuit, Kwai Chung (LR)	Not engineered	Y (26 years return period)	Po	N	Not Done	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.7	0	A 0.5 m boulder fell from hillside onto the footpath below and came to rest at a bus shelter. The boulder was probably destabilised by surface water erosion following heavy rainfall.

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Table 9 - Summary of Key Findings of Follow-up Landslide Studies (Sheet 5 of 6)

Landslide	Slope Status (classification)*	Worst Rain	Deterioration	Massive Relict Failure		Previous Failure/ Distress after Slope Assessed or Modified to Current Standards		Deficiency in Design/Assessment			Deficiency in Upgrading Works	Poor Condition of Maintenance	GEO Checking		Unauthorized Construction	Volume of Failure (m^3)		Remarks
				Recorded	More from API	Recorded	More from API	G/W	Material Strength	Others #			Submitted to GEO for Checking	Outstanding GEO comment not resolved		Detached	Deformed	
12.6.2001 Hillside above Hong Ning Road Park Phase II, Kwun Tong (LR)	Not engineered	Not assessed	N	N	Not Done	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N	5	0	Landslides debris together with a boulder (~ 1 m³) fell from natural hillside onto Hong Ning Road Park. The boulder was probably destabilised by erosion due to surface water flow following heavy rainfall.
10-11.6.2001 Route Twisk, Tsuen Wan (6SE-B/C4) (LR)	Engineered (Upgraded under LPM in 2000) (1ASY)	One year after upgrading	N	N	Not Done	N	Not Done	N	N	Mod	N	N	Y	N	N	2	0	Shallow landslides probably caused by enhanced infiltration of surface runoff from the shotcreted surface above, with inadequate drainage detailing.
			N	N	Not Done	N	Not Done	N	N	Mod	N	N	Y	N	N	3	0	
10-11.6.2001 Route Twisk, Tsuen Wan (6SE-D/C52) (LR)	Engineered (Upgraded under LPM in 2000) (1ASY)	One year after upgrading	N	N	Not done	N	Not done	N	N	Mod	Little	N	Y	N	N	2	0	Shallow landslides probably caused by enhanced infiltration of surface runoff.
27.6.2001 Route Twisk, Tsuen Wan (6NE-D/C6) (LR)	Engineered (Upgraded under LPM in 2000 (1ASY)	One year after upgrading	N	N	Not done	N	Not done	N	N	Sig	N	N	Y	N	N	3	0	Shallow landslides probably caused by enhanced infiltration. Inadequate drainage detailing was a contributing factor.
Around 2.9.2001 Ting Kok Road (3SE-C/CR147) (LR)	Engineered (Geotechnical submission checked by GEO in 2000) (2BSY)	N	N	N	Not Done	N	Not Done	N	N	N	N/A	Po	Y	N	N	30	0	Landslide was probably caused by infiltration through dilapidated chunam cover of the slope during rainfall.

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Table 9 - Summary of Key Findings of Follow-up Landslide Studies (Sheet 6 of 6)

Landslide	Slope Status (classification)*	Worst Rain	Deterioration	Massive Relict Failure		Previous Failure/ Distress after Slope Assessed or Modified to Current Standards		Deficiency in Design/Assessment			Deficiency in Upgrading Works	Poor Condition of Maintenance	GEO Checking		Unauthorized Construction	Volume of Failure (m^3)		Remarks
				Recorded	More from API	Recorded	More from API	G/W	Material Strength	Others #			Submitted to GEO for Checking	Outstanding GEO comment not resolved		Detached	Deformed	
2.9.2001 Sun Sing Street, Sai Wan Hoi (11SE-A/C5) (LR)	Engineered (Geotechncial submission checked by BOO in 1982) (1NSY)	N	Po	N	N	N	N	N	N	Po	N	Sig	Y	N	N	0.07	N	The rockfall was probably caused by build-up of cleft water pressure due to ingress of surface water runoff and overflow from a blocked U-channel into open or weathered joints.

Legend:

Y	Yes	N	No	Po	Possible		
Sig	Significant contribution	Mod	Moderate contribution	Min	Minor contribution	Little	Little contribution
(DS)	Detailed Study	(LR)	Landslide Review				

Notes:

(1) Massive failure denotes incident with failure volume (detached + deformed volume) > 500 m^3.
Major failure denotes incident with failure volume between 50 m^3 and 500 m^3.
Minor failure denotes incident with failure volume < 50 m^3.

(2) * denotes classification of slope status in accordance with Table 8 of this report.

(3) # denotes other deficiency in design/assessment, including poor detailing, inappropriate geological model, incorrect slope stability analysis, inadequate drainage provisions, etc.

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Table 10 - Breakdown of Landslides on Engineered Slopes

	Soil Cut Slope	Rock Cut Slope	Fill Slope	Retaining Wall	
All Landslides	6	8	3	0	$\sum = 17$
Massive Failure (> 500 m^3)	1	0	0	0	$\sum = 1$ (6%)
Major Failure (50 to 500 m^3)	0	0	2	0	$\sum = 2$ (12%)
Minor Failure (< 50 m^3)	5	8	1	0	$\sum = 14$ (82%)

Table 11 - Breakdown of Landslides on Slopes Previously Treated under the LPM Programme

	Soil Cut Slope	Rock Cut Slope	Fill Slope	Retaining Wall	
All Landslides	3	1	1	0	
Massive Failure (> 500 m^3)	0	0	0	0	
Major Failure (50 to 500 m^3)	0	0	0	0	
Minor Failure (< 50 m^3)	3	1	1	0	$\sum = 5$

Table 12 - Breakdown of Key Contributory Factors in Landslides on Engineered Unsupported Soil Cut Slopes

	All Landslides ($\sum = 3$ no.)	Local Minor Failures ($\sum = 2$ no.)	Sizeable Failures ($\sum = 1$ no.)
Adverse Groundwater	1 (33%)	0	1 (100%)
Adverse Geological Material	1 (33%)	0	1 (100%)
Inadequate Slope Maintenance	2 (67%)	2 (100%)	0
Note: A given landslide may be associated with more than one key contributory factors to the failure.			

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Table 13 - Progress of Follow-up Actions on the Improvement Measures Recommended in the Review of 2000 Landslides

Recommended Improvement Measures	Progress
Technical Improvement Measures	
1. Promulgate enhanced slope engineering practice in respect of rock cut slopes based on lessons learnt from landslides.	Draft GEO Technical Guidance Notes (TGN) is being prepared.
2. Promulgate enhanced slope engineering practice in respect of robust design and improved detailing based on lessons learnt from landslides.	Report on "Enhancing the Reliability and Robustness of Engineered Slopes" is being finalised.
3. Prepare a Code of Practice/Technical Guide on trench excavations near slopes to promulgate improved technical guidelines and to enhance good geotechnical practice in respect of trench excavations.	The Technical Guide on trench excavations is being finalised by Highways Department with the assistance of the GEO.
Administrative Improvement Measures	
1. Promulgate improvement measures for the supervision of active construction sites involving slopes, retaining walls and trench excavations.	Notable landslides within active construction sites have been reviewed. Draft report under preparation.
2. Advise the maintenance departments to set up an inventory of maintenance-related problems for individual slope features (i.e. those not reported to the GEO, or not registered as GEO landslide incidents), including the follow-up works carried out, as a record of slope performance in order to complement GEO's database on reported landslide incidents and facilitate Engineer Inspections.	GEO and Works Bureau have issued memos dated 10.4.2002 and 30.5.2002 respectively, together with sample incident record form and guidance notes, to the seven slope maintenance departments to request them to keep a central record of all landslide incidents and report the incidents to the GEO. **Action completed.**
3. Compile an inventory of slopes with a ducting system for water-carrying services to facilitate future auditing of such special measures and promulgate the need to highlight such special measures and the corresponding monitoring requirements in the Maintenance Manuals.	Reminders were sent by GEO's Special Projects Division to government departments, District Chiefs and geotechnical consultants regarding the need to highlight such special measures and the corresponding monitoring requirements in the Maintenance Manuals. An additional SIS layer on special ducting system for water-carrying services was set up in July 2002. **Action completed.**

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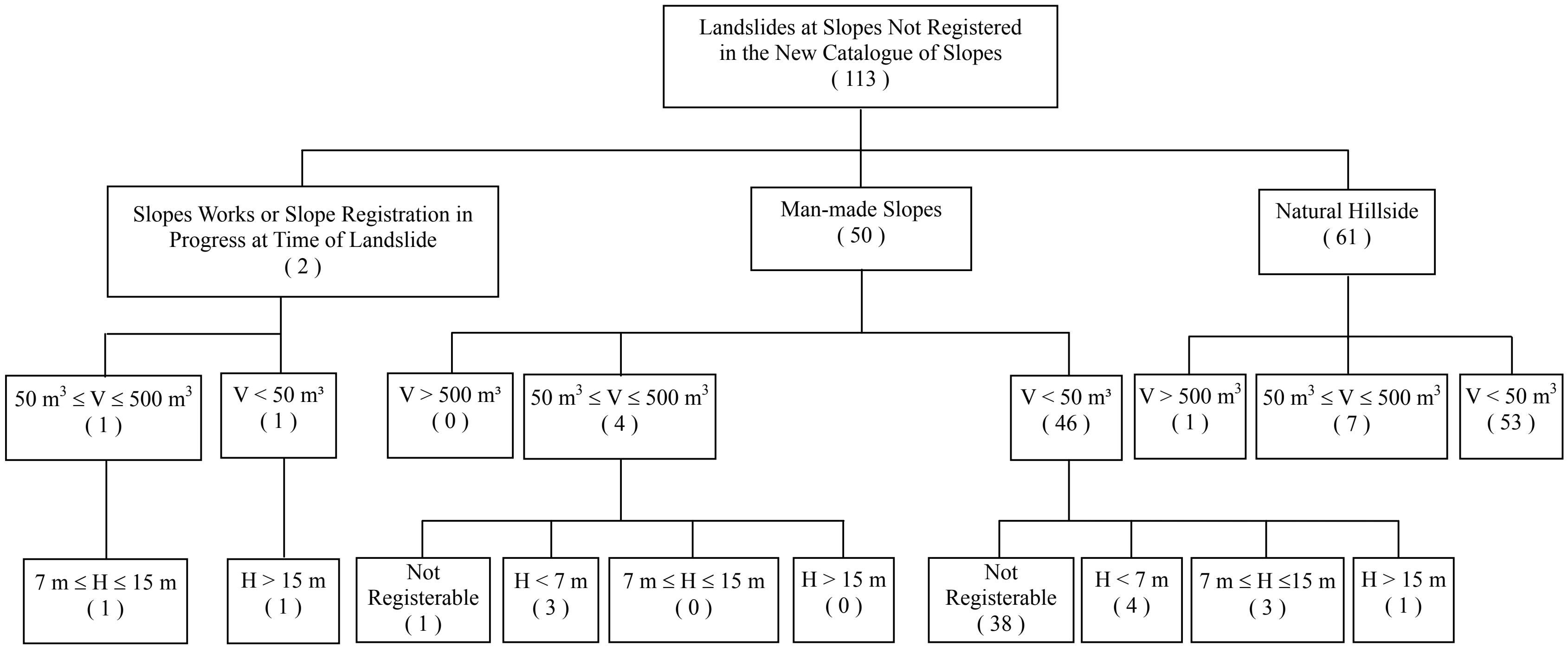

Legend:

V Failure volume in m^3 H Slope height in m (2) Number of cases = 2

Note: 'Not Registerable' refers to cases involving slopes that do not satisfy the feature height criteria for registration in the New Catalogue of Slopes

Figure 1 - Breakdown of Landslides at Unregistered Slopes in 2001

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

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.

GEOGUIDES

Geoguide 1	Guide to Retaining Wall Design, 2nd Edition (1993), 258 p. (Reprinted, 2000).
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.

GEOSPECS

Geospec 1	Model Specification for Prestressed Ground Anchors, 2nd Edition (1989), 164 p. (Reprinted, 1997).
Geospec 2	Model Specification for Reinforced Fill Structures (1989), 135 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. 1/96	Pile Design and Construction (1996), 348 p. (Reprinted, 2003).
GEO Publication No. 1/2000	Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls (2000), 146 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