GENERAL REPORT ON LANDSLIPS ON 5 NOVEMBER 1993 AT MAN-MADE FEATURES IN LANTAU

GEO REPORT No. 44

H.N. Wong & K.K.S. Ho

GEOTECHNICAL ENGINEERING OFFICE
CIVIL ENGINEERING DEPARTMENT
HONG KONG

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PREFACE

In keeping with our policy of releasing information of general technical interest, we make available some of our internal reports in a series of publications termed the GEO Report series. The reports in this series, of which this is one, are selected from a wide range of reports produced by the staff of the Office and our consultants.

Copies of GEO Reports have previously been made available free of charge in limited numbers. The demand for the reports in this series has increased greatly, necessitating new arrangements for supply. A charge is therefore made to cover the cost of printing.

The Geotechnical Engineering Office also publishes guidance documents and presents the results of research work of general interest in GEO Publications. These publications and the GEO Reports may be obtained from the Government's Information Services Department. Information on how to purchase these publications is given on the last page of this report.

J.B. Massey
Acting Principal Government Geotechnical Engineer
November 1995

FOREWORD

This report summarises the findings of the study of 264 man-made features on Lantau Island which failed in the severe rainstorm on 5 November 1993. The large number of landslips provided an opportunity for a systematic study of the characteristics of landslips at man-made slopes. In addition, it was possible to assess the effectiveness of the design and construction of surface protection and drainage measures for slopes typical of secondary roads and catchwater. Based on the information collected during the inspection, the likely failure mechanisms, effectiveness of routine maintenance and possible use of prescriptive measures in preventing the landslips were evaluated.

The study was carried out by Mr H.N. Wong and Mr K.K.S. Ho, with technical assistance from Mr W.K. Lee, Mr P.H. Wong and Mr C.K. Tai. Dr P.C.Y. Yung also assisted in part of the field work. Useful background information was provided by various individuals in the office including Mr M. Wai and Mr R.C.K. Tam of the Mainland West Division and Mr J. P. King of the Planning Division. Assistance on geological mapping of selected landslips was provided by Dr R. Shaw and Mr P. Kirk of the Planning Division. Their assistance is gratefully acknowledged. This report was reviewed by Mr M.C. Tang, Mr N.P. Koirala and Mr J.M. Shen.

J. Premchitt.

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ABSTRACT

More than 250 landslips occurred at man-made slopes alongside roads and catchwaters on Lantau Island during the severe rainstorm of 5 November 1993. This provided an opportunity for a systematic study of the performance of slopes that have generally not been designed to current geotechnical standards. In addition, it was possible to evaluate the effectiveness of the routinely-adopted slope surface protection and drainage provisions, and to examine the possible use of prescriptive measures in preventing the landslips.

The information collected during field inspections included the nature and dimension of the features, extent of the landslips, consequence of failure, travel distance of the debris, condition of the surface protection and drainage provisions, field evidence of previous instability, together with the mode and causes of failure. A database has been compiled to facilitate data analysis.

The range of failure mechanisms has been identified and may be grouped together as follows :

(a) seepage behind the rigid surface,
(b) wash-out,
(c) perched water pressure in colluvial deposits,
(d) rise in the main groundwater table, and
(e) others, such as relict geological weaknesses and effect of buried streamcourse.

Useful information was obtained of the travel distance of the debris. Important factors that affect the travel distance include the failure mechanism, the gradient of the area downslope of the landslip, and the extent of the slope uphill of a cut face involved in the failure. The data from the present study suggest that for failures involving mainly the cut face and which are not caused by wash-out, the likely travel distance of the debris as measured from the slope toe ranges from 1/3H to H (where H is the height of the cut), with a mean distance of about 0.7H. Where the failure involves a substantial portion of the slope uphill of the cut face, the likely travel distance of the debris may exceed H.

Based on the information collected from the study, the landslip risk along a section of South Lantau Road has been assessed in order to illustrate the application of standard risk assessment methodology. In the risk assessment, various factors, such as the probability of slope failure, average traffic density, temporal probability of a vehicle being present, and the likely consequence with respect to loss of life in the event of failure, were considered.

Assuming routine maintenance had been carried out, the proportion of the observed landslips that could have been prevented was judged to be about 20%. The relatively low figure reflects the general inadequacy of the prevailing surface protection and drainage provisions. The findings also highlight the need to explore possible improvement in the design and construction of the routine protection and drainage measures, particularly for slopes that have not been designed to current geotechnical standards.

It was judged that two-thirds of the landslips could have been prevented by prescriptive measures involving enhanced protection and drainage provisions. If soil nails are also considered as prescriptive measures, the proportion of landslips that could have been prevented was assessed as 90%.

CONTENTS

1. INTRODUCTION

Lantau Island was subjected to a severe rainstorm on 5 November 1993. Landslips occurred at about 300 man-made features and about 600 for natural slopes. The majority (85%) of the man-made features that failed were cut slopes alongside roads and catchwaters. More than 95% of these slopes were formed before the setting up of the GCO, and therefore had not passed through the checking process to determine whether they were designed to the current standards as stipulated in the Geotechnical Manual for Slopes (GCO, 1984).

Most of the landslips reportedly occurred in the morning of 5 November 1993. No casualties or injuries were caused. The main problems associated with the landslips were the economic consequences and disruption to the public as a result of the main road, South Lantau Road, having been blocked by landslip debris at numerous places.

The large number of landslips on Lantau Island provided useful information on the performance of these slope features under severe rainfall conditions, and enabled a systematic study of the characteristics and mechanisms of slope failure to be carried out.

The Special Projects Division undertook an investigation of the landslips in Lantau. The objectives of the study are to :

(a) document the characteristics of the landslips,

(b) assess common failure mechanisms,

(c) identify the consequence of failure and the travel distance of the landslip debris,

(d) evaluate the effectiveness of the routinely-adopted slope surface protection measures and drainage provisions,

(e) assess the feasibility of improved protective measures which can be prescribed to reduce the vulnerability of the slope to failure,

(f) select major landslips for further investigation, and

(g) propose possible areas of improvement in slope design and construction practice, and in landslip preventive measures.

This report summarises the findings of the study on man-made slope failures, based on the data collected from inspection of 264 landslips by the Special Projects Division. More detailed investigation of selected significant landslips will be reported separately.

2. RAINFALL

Heavy rainfall was recorded on 4 and 5 November 1993. The 24-hour rainfall (from 10 a.m. on 4 November 1993) distribution in Hong Kong is shown in Figure 1. It can be seen that the rainfall was concentrated over Lantau Island, with a maximum 24-hour rainfall at Tung Chung (raingauge No. N17) and Ngong Ping (raingauge No. R11) of 742 mm and 602 mm respectively. This may be compared with only 107 mm of rain recorded by the Royal Observatory at Tsim Sha Tsui (raingauge No. R01).

The hourly rainfall recorded by raingauges No. N17 and No. R11 is presented in Figure 2. The rainfall was most intense in the morning of 5 November 1993. It has been estimated conservatively that the 12-hour and 24-hour rainfall at Tung Chung and Ngong Ping represented between a 1-in-50-year and 1-in-100-year event, but it could well have been even more extreme. The limited period of rainfall measurements prevents a more accurate assessment of the actual return periods because of the uncertainties associated with the extrapolation of rainfall statistics.

Based on the findings of a study into the correlation between rainfall and landslip initiation, Brand et al (1984) reported that an hourly rainfall of 70 mm was the trigger intensity for severe landslips in Hong Kong. This threshold was exceeded at Tung Chung by the average hourly rainfall between 2 a.m. and 8 a.m. on 5 November 1993.

3. GENERAL INFORMATION ON THE LANDSLIPS AT MAN-MADE FEATURES

3.1 Location of the Landslips

The locations of the landslips at man-made features are shown on Drawing No. GCSP 8/14.

3.2 Types of Facility Affected

The types of facility affected by, and the types of features involved in, the man-made slope failures are shown in Table 1. It may be noted that the majority of the man-made slope failures affected roads and catchwaters in this study.

3.3 Previous GEO Involvement

Ten inspections were made in response to complaints about slope stability since 1984. According to the records of the Mainland West Division, none of the slopes that were inspected as a result of the complaints failed in the rainstorm on 5 November 1993.

There were 59 inspections of slopes in Lantau Island as a result of landslips reported to the GEO between 1984 and the rainstorm on 5 November 1993.

Up to October 1993, a total of 151 slopes on Lantau Island were inspected by the GEO as part of the Stage 1 Studies of the Landslip Preventive Measures (LPM) Programme. As a result of the Stage 1 Studies, 22 slopes which overlook buildings and pose a direct risk to life are being upgraded under the LPM Programme. In November 1993, works had been completed on 14 of these slopes. Further action on the other 129 slopes have not yet been taken due to their relatively low priority.

None of the 22 slopes which were included for upgrading works were affected by the rainstorm of 5 November 1993. However, fourteen out of the 129 'shelved' slopes failed in the rainstorm. From a review of the Stage 1 study reports, it is noted that many of these noted signs of distress at the time of the inspection, which may be in the form of seepage, cracked chunam, old landslip scars, etc. A summary of the information of the fourteen slopes is given in Table 2.

A total of 81 landslip incidents were reported to the Mainland West Division after the rainstorm on 5 November 1993.

Over 95% of the failures occurred at features constructed prior to the establishment of the GCO.

4. CHARACTERISTICS OF THE LANDSLIPS AT MAN-MADE FEATURES

4.1 General

The man-made slope failures at Lantau affected roads, catchwaters and building lots. The inspections carried out by the Special Projects Division were focused mainly on those that were alongside roads and catchwaters. This is because such landslips form the majority of failures of man-made slopes, and that the landslips that affected building lots were generally minor incidents in this rainstorm. A total of 253 landslips affecting roads and catchwaters were inspected by the Special Projects Division, together with 10 landslips at features overlooking building lots and one flanking a streamcourse. In addition, another 18 landslips, that were not covered by the inspection by the Special Projects Division, had been inspected by the Mainland West Division.

Although the landslips that affected building lots and other areas apart from roads and catchwaters have not been studied in detail in this study, it was noted that the failure mechanisms for these landslips were similar to those for slopes affecting roads and catchwaters.

The fieldwork was carried out between 6 November 1993 and mid December 1993 by three professional staff. The work comprised :

(a) collection of basic landslip data, including the nature and dimensions of the features and the extent of the landslips,

(b) recording the consequence of failure and the travel distance of the landslip debris,

(c) recording the surface protection and surface drainage condition,

(d) assessment of the geology and field evidence of previous instability,

(e) examination of the mode and causes of failure, and

(f) evaluation of the effectiveness of routine maintenance of the prevailing slope protective provisions, and the use of prescriptive measures, in preventing the landslips.

For the purposes of this study, a field record sheet was designed, which was refined during the course of the investigation. The final format of the field record sheet is shown in Figure 3.

Due to time constraints, the time allocated for inspection of each feature was 15 to 20 minutes. A database of the information collected during the field inspection has been compiled to facilitate analysis.

Given the nature of the study, much of the work required an engineering assessment of the landslips. In order to reduce the discrepancy in individual judgement, joint inspections of selected landslips were carried out at an early stage of the fieldwork to allow interpretations to be calibrated. During the course of the study, the more complicated cases were inspected by more than one of the team members for an independent assessment. On completion of the fieldwork, all the cases were reviewed in the meetings of the team members by examining the field records and the photographs taken, and necessary adjustments were made on the records.

The incident reports prepared by the Mainland West Division were examined as part of this study, and adjustments were made to the interpretative records in the database where appropriate. No change was made to the factual data.

The characteristics of the landslips affecting roads and catchwaters are described in the following sections.

4.2 Consequences of Failure

The differing consequences of landslips are summarised in Figure 4. A total of 95 out of the 154 (i.e. 62%) road-side slope failures affected at least one lane of the road. This highlights the fact that road-side cut slope failures can constitute a significant risk to the road users should the roads be occupied by traffic at the time of a landslip.

At two locations along a road, debris from the failure of the upslope cut face caused storm water to spill over the road and led to a major wash-out failure downslope.

Twenty-nine out of the 99 (i.e. 29%) slope failures that affected catchwaters resulted in serious catchwater blockages. Such blockages may lead to overtopping of the catchwater causing downslope wash-out failures, if the landslip locations are fairly remote from overflow weirs provided for the catchwater. In this rainstorm, five major wash-out failures downslope of catchwaters occurred in such manner.

4.3 Size and Mode of Failure

As shown in Figure 5, more than 90% of the landslips were shallow failures (depth of failure within the upper 3 m). This accords with previous observations that the majority of landslips in Hong Kong are in the form of shallow instability (Lumb, 1975; Au, 1993).

Also shown on Figure 5 is the nature of the slope surfacing in relation to the depth of failure. A significant proportion of the landslips occurred at features with a rigid cover. However, as the total number of man-made features with and without a rigid cover is not known, it is not possible to assess the percentage of failures of slopes with different types of surface cover (i.e. rigid cover or vegetated cover).

Information on the failure volume is shown in Figure 6. Overall, about 12% of the landslips involved an estimated volume of failure debris greater than 50 m^3. Thus, most of the landslips were shallow failures and would not have been classified as major failures.

The distribution of landslips with respect to the height of the cut face is shown in Figure 7. It is noted that the majority of the failures occurred at slopes between 5 m and 10 m high. The landslips that occurred at slopes with a height of less than 10 m constitute about 80% of the total number of landslips that had been included in this study. This fact may be simply because most of the man-made slopes on Lantau Island are within this range of heights.

It is noteworthy that most of the catchwater slope failures involved either cut slope failures upslope of the catchwater, or downslope failures as a result of overtopping of catchwaters due to restriction or blockages by debris from upslope failure. Collapse of downslope side wall of catchwaters or failures of downhill slope, leading to collapse of catchwater side wall or base slab, did not take place during this rainstorm.

4.4 Type of Surface Cover in relation to Possible Causes of Failure

The number of incidents with respect to the type of surface cover and the possible causes of failure are shown in Table 3. It may be noted that despite the presence of a chunam or shotcrete cover on the slopes, most of the failures were thought to have involved infiltration. This is thought to be related to the fact that in practically all the cases, the area immediately above the protected cut face was not provided with adequate protection against infiltration. Infiltration through the covered cut face was also possible if the protective cover was not maintained properly and was left in a poor condition.

4.5 Condition of Slope Prior to Failure

Overall, about 65% of the failed slopes had rigid covers, most of which were chunam. The remaining slopes were largely covered by natural vegetation. There are no records to show that these slopes were designed to current geotechnical standards and the conditions indicated that they were not. Many did not have any surface drainage channels beyond the crest of the cut face.

The condition of the surface protection of the slopes that failed have been inferred during the inspection by observation of the adjoining areas. The findings are summarised in Figure 8. Where the slope had drainage channels, 'poor', 'fair' and 'good' conditions corresponded to where the channels were 'fully-blocked', 'partly-blocked', and 'clear from blockages' respectively. In the case of a rigid cover, 'poor', 'fair' and 'good' conditions corresponded to where the surface cover exhibits 'severe cracking', 'minor random cracking', and 'little or no cracking' respectively. The assessment of the condition of the rigid surface is illustrated in Plates 1 to 3. Further examples of the classification of the condition of the rigid cover are given in Appendix B.

Approximately 45% of the road-side cut slope failures took place at slopes with a rigid cover (mainly chunam). About 40% of the rigid cover of these failed slopes were assessed to have been in a poor condition before failure. Overall, it is estimated that about half of the road cuts have been provided with a rigid cover. This implies that slopes in Lantau Island with a rigid surface cover are only slightly less likely to fail compared to slopes without a rigid surface cover in this severe rainstorm. This somewhat unexpected finding may be due to slopes that have been covered are generally steeper compared to slopes without a cover.

Of the landslips that affected catchwaters, 96% occurred at slopes with a rigid surface (again mainly chunam), with about 45% of these slopes judged to have been in a poor condition before failure. It was observed that most (say about 90%) of the cut slopes along catchwaters have been provided with a rigid surface.

The relationship between the depth of failure and the nature of slope surfacing is shown in Figure 5. It may be noted that approximately the same proportion of shallow and deep failures occurred in roadside slopes with and without a rigid surface.

4.6 Past Instability

Signs of past slope failure were observed in 30% of the man-made slopes that were inspected. This was assessed by reference to remnants of landslip scars, or concave depressions (usually well preserved by the surface cover) which are likely to be old landslip scars. Locations with past instabilities in their immediate vicinity are generally susceptible to future instability, in view of their similarity in height, material type and hydrological conditions.

Only about 15% of the man-made slopes that failed had recorded past instability according to the incident reports. It is clear that many of the cases with a history of past instability had not previously been brought to the attention of the GEO.

4.7 Travel Distance of Debris

The approximate profile and travel distance of the landslip debris were recorded for 52 landslips. It was not possible to obtain data on the reach of the debris in the other landslips due to the speed with which the debris had to be cleared fully or partially to open the road to traffic.

The relationship between the height of the cut face (H) and the travel distance of the debris (L) as measured from the toe of the failed slope is plotted in Figure 9. The failure mode has been distinguished as to whether it involved wash-out or not. In addition, the field observations had been grouped in accordance with different ranges of angle of inclination of the area downslope of the feature that failed.

It can be seen from Figure 9 that :

(a) For the cases with a relatively flat ground below the landslip location (i.e. θ within 5°), the reach of debris is generally between 0.33H and H. However, if the landslip involves a substantial portion of the slope uphill of the cut face, such as in some of the failures of thin colluvium caused by development of perched water pressure, L could be as large as 2H.

(b) Debris run-out distance exceeding 2H is not uncommon if the ground below the landslip location is steep (say, θ exceeds 15°), or if the landslip is a wash-out failure.

According to Design Division (1992), a lower priority for further action will be assigned on a cut slope if the facilities (e.g. an occupied building) under threat is more than 0.5H away from the toe of the slope. In the light of the landslip data presented here, such a criterion should be applied with caution, and due consideration should be given to the likely mechanism of failure and the downslope topography.

Based on the observations made in the present study, for failures involving mainly the cut face and which are not caused by wash-out, the likely travel distance of the debris generally ranges from 1/3H to H, with a mean of about 0.7H (Figure 9). Where the failure involves a substantial part of the slope uphill of the cut face, the likely travel distance may exceed H. Large debris run-out distance is also expected if the downslope gradient is steep, or if wash-out mechanism is involved. Further work is clearly necessary to extend this database, and to formulate detailed guidelines for use in assessing the risk category of slopes and the consequence of landslips.

5. LANDSLIDE RISK ASSESSMENT FOR SOUTH LANTAU ROAD

The rainstorm of 5 November 1993 provided a severe test of the adequacy of the man-made slopes in Lautau Island. The data obtained from the systematic study of the landslides allowed an approximate assessment to be carried in respect of the landslide risk arising from the roadside slopes.

As an illustration of the standard risk assessment methodology adopted for this study, the specific landslide risk for the section of South Lantau Road between Mui Wo and Pui O is estimated, taking into account the probability of slope failure, traffic density, temporary probability of a vehicle being within this section of the road at any one time, and the consequence with respect to loss of life in a travelling vehicle in the event of failure.

The details on the assumptions made and how the calculation was conducted are given in Appendix A. It should be cautioned that this type of calculation is approximate and will give an order of magnitude level of risk for comparative purposes. In contrast to similar assessment for nuclear power plants, dams, etc., the assessment for common road sides are rare, and there is no set standard for this purpose. Reference may be made to Fell (1994) for a detailed discussion on the application of quantitative risk assessment techniques for landslides.

This assessment would indicate that specific risk of landslide, defined as the annual probability of a landslide causing fatality in a vehicle travelling on the road, should be of the order of 10^{-4}. There exist no guidelines in Hong Kong or elsewhere for direct comparison to determine acceptability of this risk level for roadside slopes. However, as an indication, the guidelines produced by the Planning Department (1993) on the societal risk of potentially hazardous installations (PHI) may be used for indirect comparison. It is considered that in general the standard for roadside slopes should be less stringent than PHI.

It can be seen in Appendix A that using the PHI criteria the estimated risk is not 'unacceptable' but it is in the ALARP region, namely the risk should be reduced to "as low as reasonably practicable".

6. MECHANISMS OF FAILURE

6.1 General

As the landslips were primarily rain-induced, water infiltration into the slope was obviously an element which contributed to the instability, except where failures were initiated as a result of erosion due to concentrated surface water flow. A range of infiltration pathways were possible, including that through a bare or vegetated surface, through cracks in the rigid surface or drainage channels, or through the ground surface uphill of a covered cut slope face. Infiltration could have been exacerbated by possible presence of natural pipes.

6.2 Principal Failure Mechanisms

The number of landslips as classified by the probable cause of failure are shown in Table 3. It should be noted that a given landslip may have involved more than one type of failure mechanism. A selection of landslips is presented in Appendix B to illustrate the different failure mechanisms.

The principal failure mechanisms observed during the site inspections were summarised below.

(a) Seepage behind the rigid surface
This occurred at 47% of the landslips and took place at slopes where seepage flow paths developed behind an rigid surface cover. Typical paths included flow through the more permeable top soil or colluvium near the slope surface in the upper part of the cut face (or beyond the slope crest), erosion pipes, snake barrels, and gaps between the rigid cover and soil surface (formed as a result of ground settlement, or lifting of the cover by accumulated water pressure). Failure of this kind normally

resulted in 'blow-out' or spalling of the rigid surface and a shallow slip.

(b) Wash-out
This occurred commonly at, though not limited to, bare/vegetated slopes with defective (or severed) surface drainage systems where concentrated surface water flowed down the slopes. Depending on the amount and velocity of the flow, deep failure scars with mobile debris could result.

It was judged that this type of failure mechanism occurred at about 8% of the landslips. This may be compared with about 12% of the landslips in the 8 May 1992 rainstorm having involved wash-out (Evans, 1992). The slightly lower proportion of landslips involving wash-out may be related to the fact that the majority of the slopes in Lantau had no crest channels and that there was little development upslope of the cut face, thus limiting the source of concentrated flows. Furthermore, the short-period rainfall at Lantau was not particularly high compared to that on 8 May 1992.

(c) Perched water pressure
About 25% of the landslips involved this failure mechanism. This is common in slopes of saprolitic soils or weathered rocks overlain by colluvium. Perched water pressure developed in the more permeable colluvium which became unstable. This failure mechanism is similar to that observed at Cheung Shan (Pun & Li, 1993).

It was observed during the present study that the colluvium, where present, is generally loose with a thickness of up to a few metres, and may have a range of boulder/cobble content of between practically zero and up to 50%. Failure was usually limited to the upper part of the cut face but could extend some distance upslope as observed in some cases.

(d) Rise in the main groundwater table
About 2% of the landslips were considered to have been caused by an elevated groundwater table within the body of the slope material. These landslips were generally deep (> 3m).

(e) Others
Other contributory factors leading to failure were evident in a number of landslips. These included the presence of localised relict geological weaknesses, re-activation of transported/failed material, influence of buried streamcourse, presence of tension cracks, release planes resulting from stress relief associated with slope formation, etc.

6.3 Discussion

The assessed failure mechanisms for the majority of the landslips are related to the result of infiltration of surface water, erosion due to concentrated water flow, and surface water leading to a perched water table. This highlights the importance of attention to the design, construction and maintenance of surface protection and surface drainage.

Only a small percentage of the landslips have been judged to have involved an increase of the base groundwater table. This concurs with previous observations that such failure mechanisms are generally rare in Hong Kong (Lumb, 1975) compared to the more near-surface phenomena due to surface water and moisture infiltration as described above.

7. EFFECTIVENESS OF ROUTINE MAINTENANCE IN PREVENTING LANDSLIPS

7.1 Likely Effectiveness of Routine Maintenance in Preventing Landslips

A general review of the effectiveness of the routine slope protective and drainage measures is given in Appendix C. This background discussion is relevant because the adequacy of the routine measures affects the effectiveness of routine maintenance in preventing landslips.

An assessment has been made of the likelihood and proportion of the observed landslips that could have been prevented, should routine slope maintenance have been undertaken. The percentage of slope failures which are likely to have been prevented by routine maintenance is denoted P_1. This assessment is based on the large amount of information collected during the study. It must be acknowledged that aspects of the assessment are necessarily subjective. Examples of the assessment are given in Appendix B for a selection of landslips to illustrate how judgement had been made during the site inspection.

In the present context, routine maintenance relates to preserving the pre-existing slope surface protection and drainage measures in a sound and functional condition. It should be noted that the surface drainage provisions in many of the slopes inspected were sub-standard; in particular, surface drainage channels have often not been provided at the slope crest. In the case of a slope with natural vegetation (i.e. no rigid cover) and without surface drainage channels, routine maintenance is practically irrelevant in preventing failures unless some upgrading works are also carried out.

The assessed effectiveness of routine maintenance in preventing failures of differing depths and of different scale is shown in Figures 10 and 11 respectively. Overall, approximately one-fifth of the landslips are likely to have been prevented given routine maintenance.

The proportion of slopes with a rigid surface cover that failed, where lack of maintenance was judged to have been an important contributory factor in causing the failure, amounted to about 40% . This corresponds mainly to slopes with surface protection or drainage measures in a poor condition. It is judged that about 80% of these slopes with signs of lack of maintenance (i.e. poor condition of protective cover or silted up/blocked drains) could have had the failure prevented given routine maintenance. This assessment takes into account that failures occurred at slopes with a sound and well-maintained surface cover or apparently unblocked drains, whilst there were slopes in a poor state of maintenance that remained stable during the rainstorm, i.e. lack of maintenance may not be the cause of a slope failure.

The likely influence of routine maintenance in preventing landslips of differing failure mode and debris volume has also been examined (Figures 10 & 11). Routine maintenance is considered comparatively more effective in the case of small-scale and/or shallow failures. For large-scale or deep failures, the adequacy of 'conventional' protective and drainage measures is questionable and routine maintenance alone is therefore unlikely to be particularly effective in preventing failure.

7.2 Discussion

The relatively low figure of P_1 (about 20%) reflects the general inadequacy of the protective and drainage measures adopted. Obviously, the effectiveness of routine maintenance in preventing landslips depends on the adequacy of the prevailing protective and drainage measures. If the existing system is deficient, such as use of undersized channels, lack of protection against infiltration and ponding above a covered cut face, routine maintenance alone will not be sufficient.

The findings of this study illustrate the need for improvement in routine slope protection and drainage design and construction in addition to routine maintenance, particularly for slopes which have not been designed to current standards. In the light of this, there is a need to explore possible use of more elaborate protective measures which can be prescribed as discussed in the following section.

8. USE OF PRESCRIPTIVE MEASURES FOR SLOPE PROTECTION

8.1 General

The possible use of prescribed measures for improved detailing of slope protection was described by Malone (1985), and the use of prescriptive measures for geotechnical problems has been mentioned in Eurocode 7 (European Committee for Standardization, 1993). This approach essentially entails the use of standardised and suitably conservative surface protection measures and drainage provisions. A comparison between the use of prescriptive measures and design of stabilisation works by detailed investigation and analysis is made by Wong & Premchitt (1994).

The typical range of prescriptive measures for cut slopes is summarised in Table 4, and details are discussed by Wong & Premchitt (1994). The principal engineering input in such 'prescriptive design' will be the assessment of the overall layout of the drainage measures and the extent of surface cover, together with the possible need of simple support measures (e.g. soil nailing for cases involving a thin colluvial deposit or an over-steep slope face) as appropriate. The principal aim would be to enhance slope protection from surface infiltration and the adverse effects of surface and sub-surface water.

Given the inherent deficiencies in most of the commonly-used slope protection provisions, as in South Lantau Road, improved detailing in such routine measures is called for. Possible improvements include the provision of full-face drainage behind the rigid surface, cut-off drains at the slope crest, protection of area beyond the cut face from infiltration, measures to minimise the susceptibility of surface drainage system to blockages (e.g. use of gratings on top of drainage channels to minimise the intrusion of foreign materials), raised upstand of, say, 0.3m to 0.5 m above ground surface along the downslope side of the crest channel to reduce the likelihood of overflow.

In principle, the majority of landslips in Hong Kong involve shallow failures (less than 3 m depth), which are related to the action of surface water. Lumb (1972) stated that "Slope design in Hong Kong is essentially a matter of protection of the top of the slope, beyond the cut face together with turfing or plastering of the cut face to prevent erosion is usually all that is needed to make a cutting safe. Inadequate drainage is almost always the cause of a failure ....". Such views are consistent with the field observations of slope failures in the twenty years since. This again reinforces the importance of proper detailing of the surface protection and drainage of slopes.

8.2 Likely Effectiveness of Prescriptive Measures in Preventing Landslips

An engineering assessment has been made of the likelihood and proportion of the observed landslips that could have been prevented, given the adoption of prescriptive measures. For the purposes of this study, the percentage of slope failures which are likely to have been prevented by these prescribed measures without the need for design by analysis is denoted P_3. For the purposes of this assessment, the range of prescriptive measures under consideration include large-sized channels with raised wall and improved alignment and gradient, drainage provisions behind an rigid surface, together with sub-soil drains including raking drains and shallow cut-off drains as appropriate.

The assessment made in this report is necessarily somewhat subjective but it had been based on the authors' experience and judgement, together with consideration of the likely failure mechanisms. Examples of the assessment made are given in Appendix B for a selection of landslips as an illustration.

In the prescriptive approach, emphasis is placed on surface works without due consideration of possible 'classical' deep slip surfaces. They are therefore most appropriate where the potential rise in the general water table is not significant. However, it is noted that surface works which prevent infiltration from rainfall and other surface water sources will also reduce, to some extent, the rise in the water table, and hence will contribute to increase the safety margin against deep failures, even though the works may not have been designed specifically against this mode of failure.

The assessed effectiveness of prescriptive measures in preventing failures of differing depths and of different scale is shown in Figures 10 and 11 respectively. Such measures are considered effective in the case of small-scale and/or shallow failures. For large-scale and/or deep failures, the adequacy of prescriptive measures could be less but a general improvement in the stability can be expected.

It should be noted that not all the shallow failures can be precluded by prescriptive measures. Possible exceptions or marginal cases include failure of shallow colluvium where perched water pressure develops, and landslips involving geological weaknesses and numerous erosion pipes or preferential flowpaths. However, the provision of simple support systems such as soil nailing will be expected to significantly increase the likelihood of preventing shallow failures arising from the above factors. The likely effectiveness of prescribed protective measures in relation to the different possible failure mechanisms is shown in Table 5.

If prescriptive measures for surface protective and drainage were implemented along with routine maintenance, it is judged that overall approximately two-thirds of the landslips could have been prevented (i.e. P_3 = 67%). However, if soil nails are also used as part of the prescriptive measures, then it is estimated that approximately 90% of the landslips might not have occurred.

8.3 Discussion

In essence, regular maintenance is most effective in the case of well-designed and well-constructed slopes. For slopes which have not been designed or constructed to current safety standards, the effectiveness of routine maintenance in preventing landslips under severe rainfall conditions will be uncertain, despite satisfactory performance in the past. Nevertheless, the regular maintenance of such slopes should arrest, or at least prolong, general deterioration, and hence is able to upkeep the safety margin for the worst rainfall experienced by the slope in its history. Alternatively, works involving prescriptive measures for protection against the action of surface water will be necessary to increase the confidence and likelihood of satisfactory performance under severe rainfall.

A detailed discussion on the potential use of prescriptive measures, together with the proposed area of application as Landslip Preventive Measures (LPM) works, is given by Wong & Premchitt (1994). It is expected that the adoption of such prescriptive measures in protecting slopes, coupled with the use of soil nailing where appropriate, will prove to be very effective in preventing the majority of shallow landslips.

9. FURTHER STUDIES

More than ten landslips have been chosen for more detailed studies involving topographical survey, geological mapping, aerial photograph interpretation and engineering assessment. The findings will be reported later.

In addition, selected technical subjects, such as travel distance of debris, mechanism of failure and application of prescriptive measures will be examined in more detail, and will be reported separately. A pilot trial of the prescriptive measures is to be pursued to verify their effectiveness, and to allow fine-tuning of the construction aspects.

The study on selected natural slopes failures is in progress to assess the mechanisms and characteristics of the landslips.

10. SUMMARY AND CONCLUSIONS

The Lantau investigation permitted a systematic study of the performance of a large number of man-made slopes, which affected roads and catchwaters, under severe rainfall conditions. Valuable information on the characteristics and mechanism of failure was collected.

The study had also enabled a subjective assessment of the effectiveness of routinely-adopted slope protection and drainage measures to be made. Deficiencies in the conventional slope surface protection and drainage systems were noted. It is estimated that given routine maintenance, only about one-fifth of the landslips could have been prevented. This relatively low figure is related to the general inadequacy of prevailing protective measures, and that many of the slopes may not be up to current safety standards.

The likely effectiveness of prescriptive measures in preventing landslips was also assessed based on engineering judgement. The measures generally involve simple, standardised and suitably conservative modules which can be prescribed to provide the slope with improved protection against the action of surface water. By reference to the different failure mechanisms, it has been estimated that refinement in detailing, coupled with the use of simple support systems such as soil nailing, will substantially reduce the likelihood of landslips even under severe rainfall conditions. The proportion of landslips that could have been prevented given the full set of prescriptive measures, and without the need for design by analysis, is estimated to be around 90%. If prescriptive measures were implemented without soil nailing, it is judged that approximately two-thirds of the landslips would not have occurred during the severe rainstorm of 5 November 1993.

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LIST OF TABLES

Table 1 - Types of Facility Affected by the Man-made Slope Failure

Types of Feature	Types of Facility Affected			Total (Classified by Feature Type)
	Roads	Catchwaters	Buildings and Others	
UC	151	83	29	263
DC	0	0	2	2
UF	0	0	0	0
DF	2	0	3	5
RW	0	1	3	4
Total (Classified by Facility Type)	153	84	37	274

Legend :

UC Cut slope above facility
DC Cut slope below facility
UF Fill slope above facility
DF Fill slope below facility
RW Retaining wall

Notes : (1) Total number of man-made features amounts to 264.
(2) Each landslip may affect more than one type of facility, and some of the failures alongside catchwaters affected the access road only.

Table 2 - Summary of Findings of Stage 1 Study of 'Shelved' Features that Failed on 5 November 1993

Registered Slope No.	Information from Stage 1 Study Report						History of Past Instabilities		Failure on 5-11-1993		
	Date of Study	Risk	Dist. to Risk Struct.	Eng. Judge.	Priority Group	Sign of Distress	Recorded	Observed	Failure Type	Volume m^3	Consequences (Facility Affected)
10SW-C/C 12	22-08-91	L	VC	P	5	Fallen blocks	Y	Y	Shallow	40.8	Road
13NE-A/C 22	23-08-91	N	VC	P	9	Erosion	-	Y	Shallow	47.6	Road
10SW-C/C 20	15-01-92	L	VC	P	5	Old landslip scars	-	-	Landslide	8	Open Space
10SW-C/C 21	15-01-92	L	VC	P	5	Old landslip scars	-	-	Deep	306	Road
10SW-C/C 22	15-01-92	L	VC	HP	5	Rock joints open up, loose blocks	-	-	Landslide	20	Building Access
13NE-A/C 16	17-01-92	L	VC	P	5	Concave depression probably landslip scar	-	-	-	0.2	Road
13NE-B/C 2	20-01-92	L	VC	P	5	Landslip scar cracked chunam	-	-	Shallow	13.2	Road
13NE-B/C 3	20-01-92	L	VC	P	5	Seepage on western slope	-		Shallow	?	-
13NE-B/C 4	20-01-92	L	VC	P	5	Nil	-	-	Shallow	436.8	-
13NE-B/C 6	20-01-92	L	VC	P	5	Stone pitched slope	-	-	Shallow	28.8	Road
13NW-B/C 6	20-01-92	L	VC	P	5	Old landslip scars	-	Y	Shallow	35.1	Road
9SE-B/CR 2	22-01-92	L	VC	P	5	Erosion landslip	-	-	Shallow	21.5	-
9SE-D/C 2	22-01-92	L	VC	P	5	Erosion landslip	-	-	Shallow	53.3	Road
13NW-B/C 9	22-01-92	L	C	P	6	Old landslip scar	-	-	Shallow	86.4	-

Table 3 - Type of Slope Surface Cover and Contributory Causes of Failure

Type of Surface	No. of Failures	Contributory Cause of Failure					
		Infiltration	Seepage Behind Rigid Cover	Erosion / Wash out	Perched Water Table	Rise in Main Groundwater Table	Others
Grass cover, Hydroseed/Natural	98	94	0	12	13	2	2
Chunam	153	141	113	6	44	1	5
Shotcrete	8	6	4	0	3	0	1
Stone pitching, masonry, concrete wall	17	15	8	2	5	1	1
Total	264	246 (93%)	118 (45%)	20 (8%)	61 (23%)	4 (2%)	9 (3%)

Notes :
(1) A given type of surface cover may be associated with more than one possible cause of failure.
(2) A given slope may be associated with more than one type of surface cover. Total number of man-made slope failures inspected is 264.
(3) Other causes of failure include presence of localised relic geological weaknesses, re-activation of transported failure material,influence of buried streamcourse, presence of tension cracks, release planes resulting from stress relief associated with slope formation, etc.
(4) The condition of slope and lack of maintenance being a contributory cause of failure is discussed in Section 4.5 and Section 7.1 respectively.
(5) The data in this Table relates to man-made slopes only.

Table 4 - Possible Prescriptive Measures for Slopes

Protection against	Prescriptive Measures					
	Surface protection measures	Surface drainage measures	Drainage provisions behind rigid surface cover	Subsoil drainage provisions	Nominal supports	Removal of potentially unstable rock wedges, regrading of over-steepened faces, provision of wire mesh to rock face, etc.
(a) Surface water leading to erosion or washout	√	√		*	*	*
(b) Surface infiltration	√	√	√	√	*	
(c) Seepage erosion behind rigid surface cover		*	√	√		
(d) Development of perched water table	√	√	√	√	*	
(e) Rise in base groundwater table	*	*	√	√	*	
(f) Unstable rock wedges, boulders, etc.	*	*			√	√

Legend :

√ Typical works for better protection
* Possible works in some situations

Table 5 - Effectiveness of Prescriptive Measures in Relation to the Mechanism of Failure

Possible Failure Mechanism	Likely Effectiveness of Prescriptive Measures
Seepage behind the 'rigid' surface cover	Expected to be very effective in preventing this type of failure
Wash-out	Most of the landslips of this nature could have been prevented by the prescriptive measures
Perched water pressure (e.g. in the case of saprolitic soils or weathered rocks overlain by colluvium)	The prescriptive measures may not be particularly effective in preventing failure of this kind, unless the colluvium stratum is very thin (say not more than one to two metres thick), or unless soil nails and simple sub-surface drains such as cut-off drains at the crest or short horizontal drains are included as prescriptive measures
Increase in base groundwater pressure	These landslips are generally deep and the prescriptive measures may not be particularly effective in preventing such failures (see also comments given in Section 8.2)
Others including localised relic geological weaknesses, re-activation of transported/failed material, influence of streamcourse, etc.	The prescriptive measures may be partially effective in dealing with these aspects, but the effectiveness will be substantially enhanced if soil nails and simple sub-surface drains such as cut-off drains at the crest or short horizontal drains are included as prescriptive measures

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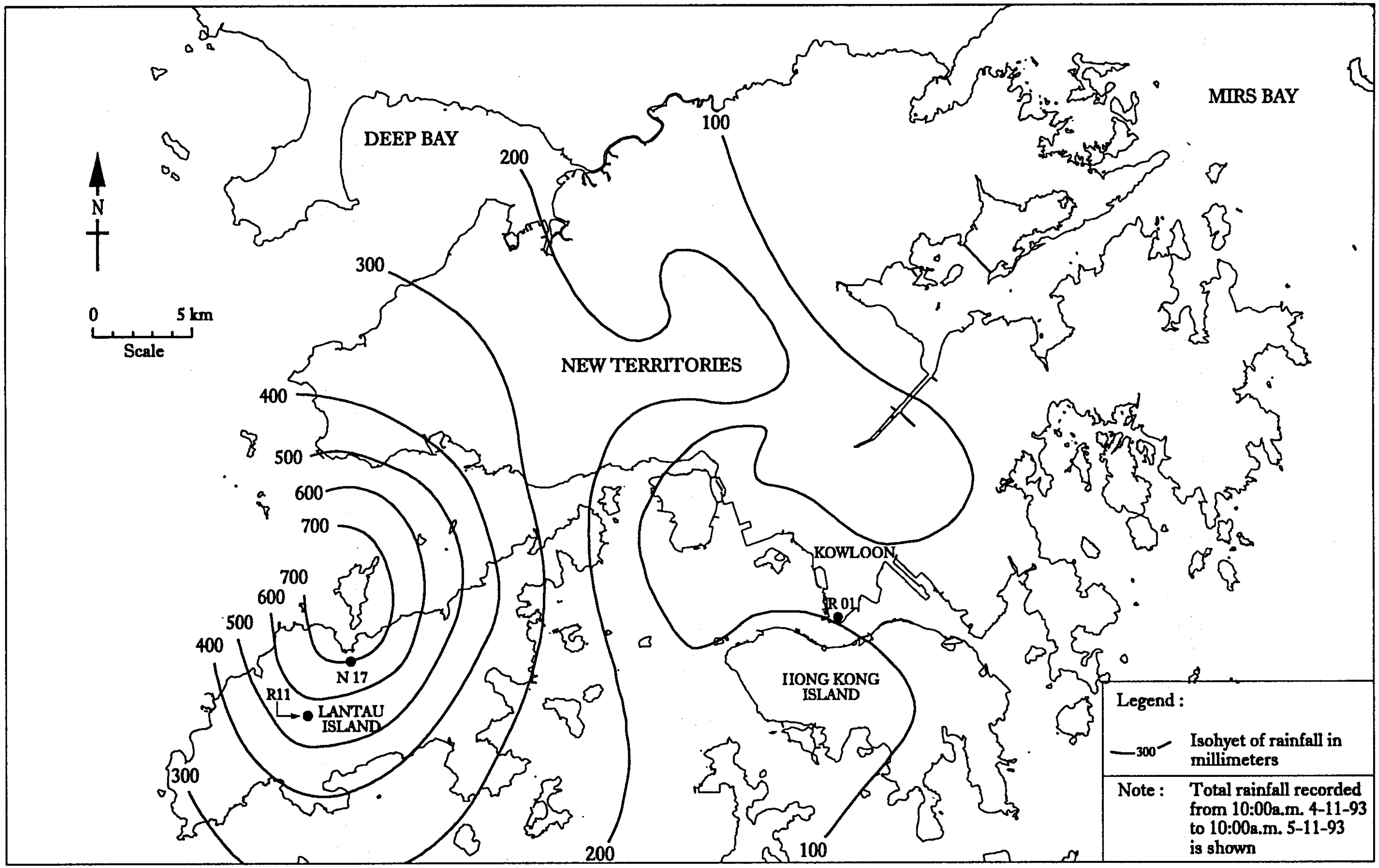


Figure 1 - 24-hour Rainfall Distribution during the Rainstorm of 5 November 1993

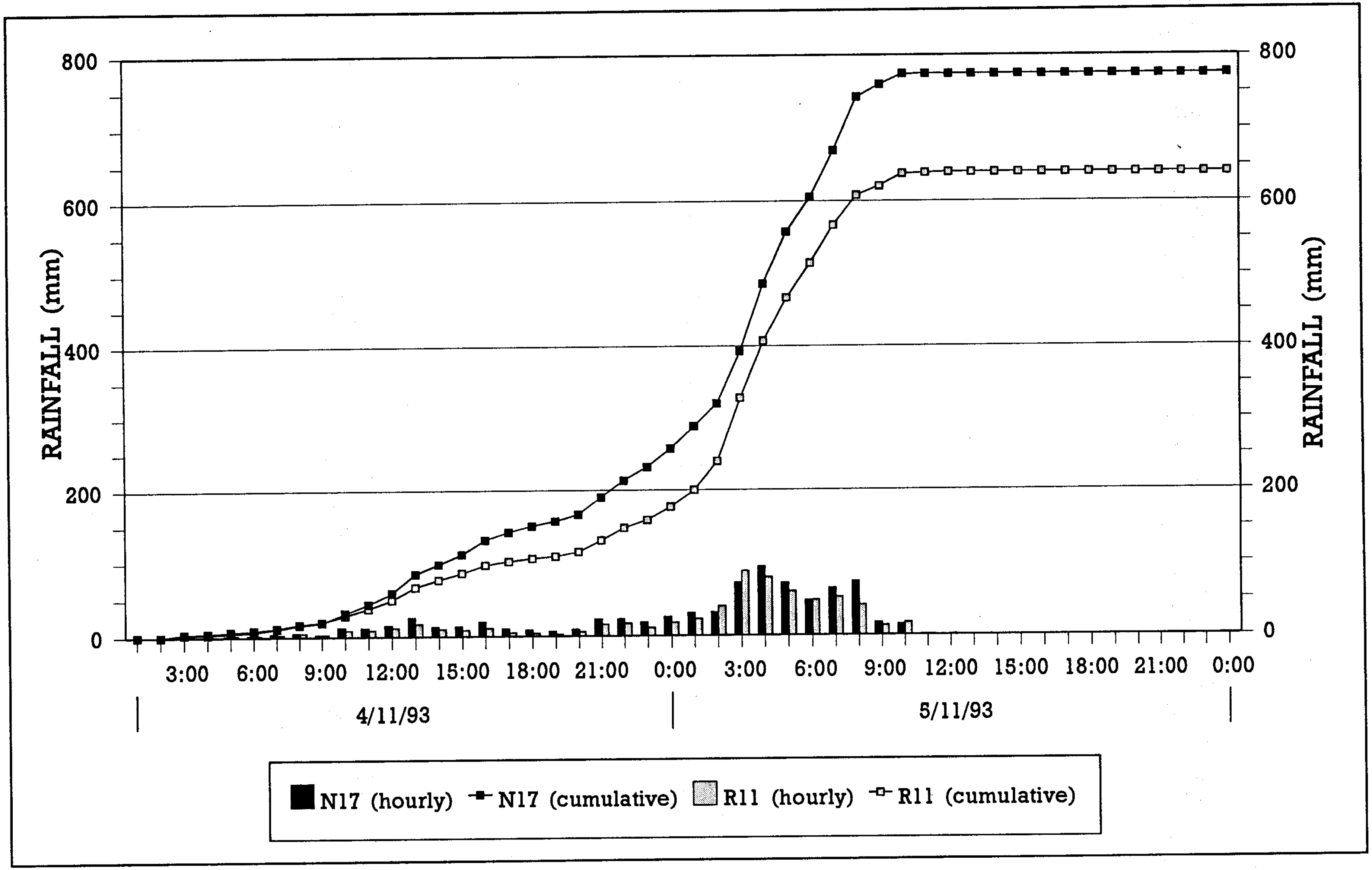


Figure 2 - Hourly Rainfall Recorded by Raingauges N17 and R11

LANTAU 5.11.1993 LANDSLIDE
FIELD INSPECTION RECORD

Recorded by : ____________________ Date : ____________________

Landslide No.		
Dimensions		Slope: H, θ_1, θ_2 — Slip: d, a, w, t — Debris: h, b, ℓ, β_1, x, β_2
Type	Slope	☐ catchwater ☐ road-side ☐ house-side ☐ others ________ ☐ UC ☐ DC ☐ UF ☐ DF ☐ UN ☐ DN ☐ RW
	Failure	☐ surface slabbing ☐ shallow (≤ 3 m) ☐ deep-seated (> 3 m) ☐ signs of erosion at scar ☐ signs of debris wash-out ☐ long debris run-out ☐ with toe/crest wall* failed (Height = m) ☐ with fallen boulder/corestone ☐ crest channel damaged ☐ with presence of pipe(s)
	Consequence	☐ road affected (footway/1st lane/2nd lane/more lane(s)/footway)* (type ________) ☐ catchwater affected (minor/part/serious)* (size ________) ☐ building affected (minor/part/serious)* (type ________) ☐ other ________
Geology	Material involved in landslide	☐ fill ☐ colluvium ☐ residual soil ☐ saprolite ☐ rock (Note : underline the principal component(s), if any identified)
Groundwater	Signs of seepage	☐ yes ☐ no
	Location	☐ fill ☐ colluvium ☐ residual soil ☐ saprolite ☐ rock ☐ interface ________
Slope condition	Surface protection	First slope (e.g. cut face): ☐ base ☐ vegetated (☐ thin ☐ thick) ☐ chunam ☐ shotcrete ☐ stone-pitching (☐ good ☐ fair ☐ poor) Second slope (e.g. up slope of cut face): ☐ base ☐ vegetated (☐ thin ☐ thick) ☐ chunam ☐ shotcrete ☐ stone-pitching (☐ good ☐ fair ☐ poor)
	Surface drainage channel	☐ at crest of first slope: ☐ little/no blocked/cracked ☐ partly blocked/cracked ☐ seriously blocked/cracked ☐ sub-standard ☐ at first slope: ☐ little/no blocked/cracked ☐ partly blocked/cracked ☐ seriously blocked/cracked ☐ sub-standard ☐ at second slope: ☐ little/no blocked/cracked ☐ partly blocked/cracked ☐ seriously blocked/cracked ☐ sub-standard
Cause of failure	Instability element	☐ surface water leading to wash-out/erosion ☐ surface water leading to infiltration ☐ surface water leading perch-water pressure ☐ other ________ ☐ seepage behind impermeable surface ☐ groundwater ☐ unstable blocks, boulders (Note : underline the principal component(s), if any identified)
Slope history	Past instability	☐ field evidence of past instability at/adjoining the failure lication
Engineer's judgement on likelihood of avoiding the landslide	with routine maintenance	☐ verly likely (90%) ☐ likely (70%) ☐ probably (50%) ☐ unlikely (30%) ☐ verly unlikely (10%)
	with also prescriptive works	☐ verly likely (90%) ☐ likely (70%) ☐ probably (50%) ☐ unlikely (30%) ☐ verly unlikely (10%)

Figure 3 - Field Sheet Used for Collection of Data from Landslips (Sheet 1 of 2)

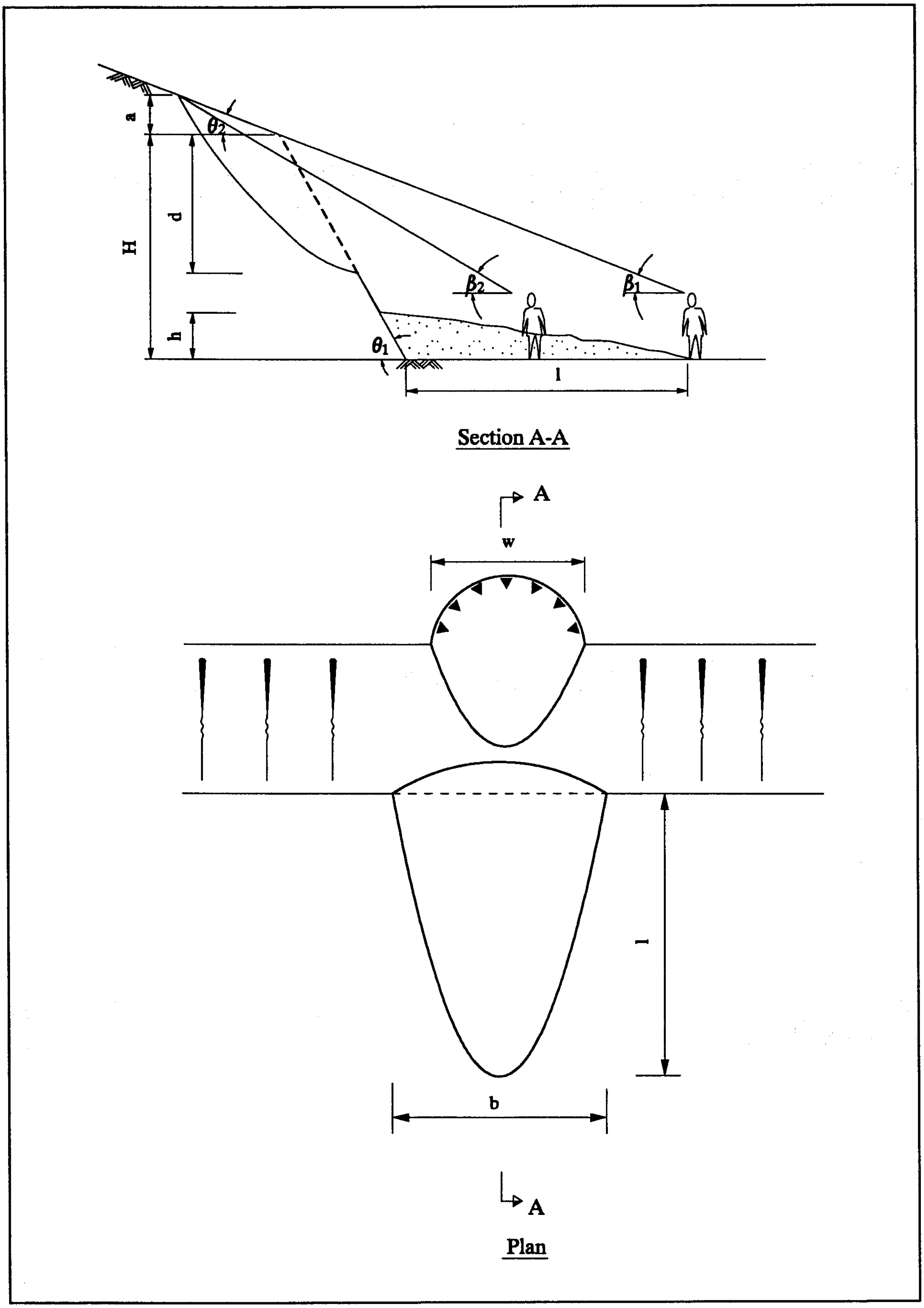
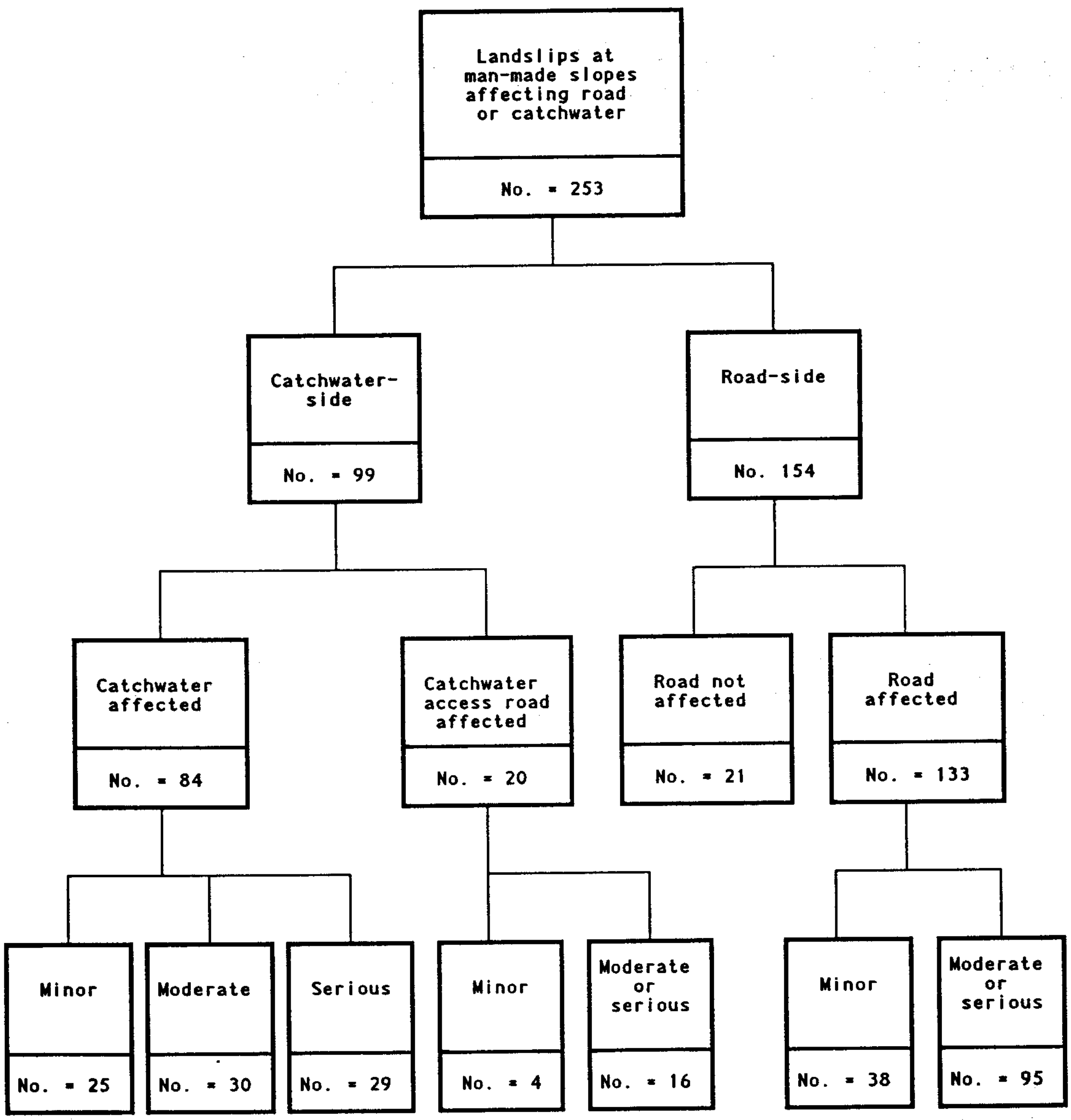


Figure 3 - Field Sheet Used for Collection of Data from Landslips (Sheet 2 of 2)



Notes : (1) For landslips affecting a catchwater, minor, moderate and serious refer to the degree of blockage.

(2) For landslips affecting a road, minor refers to landslips affecting the footway only. Moderate and serious refer to landslips affecting at least one lane of the road.

Figure 4 - Consequence of Landslips at Man-made Slopes

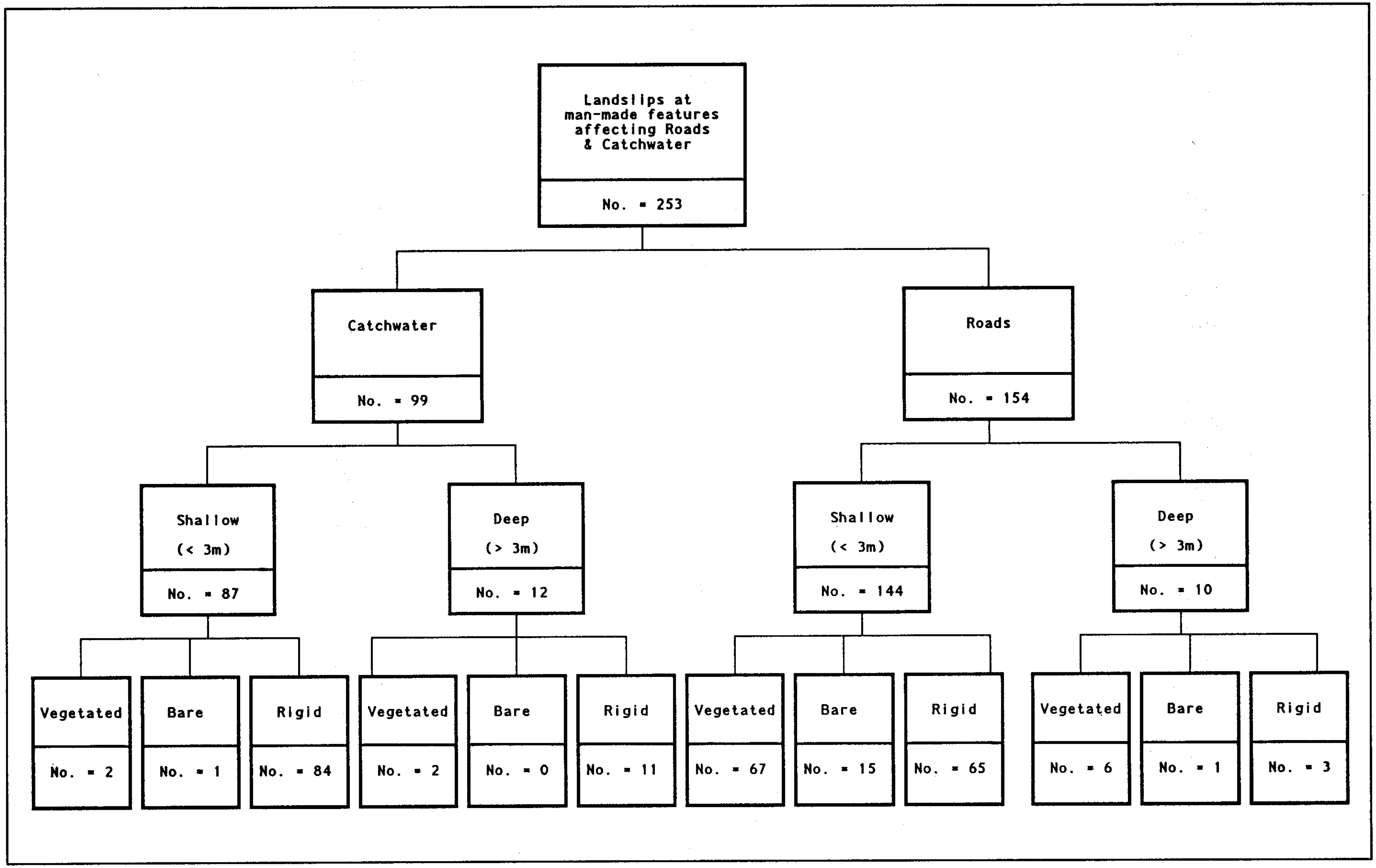


Figure 5 - Depth of Failure and Nature of Slope Surfacing

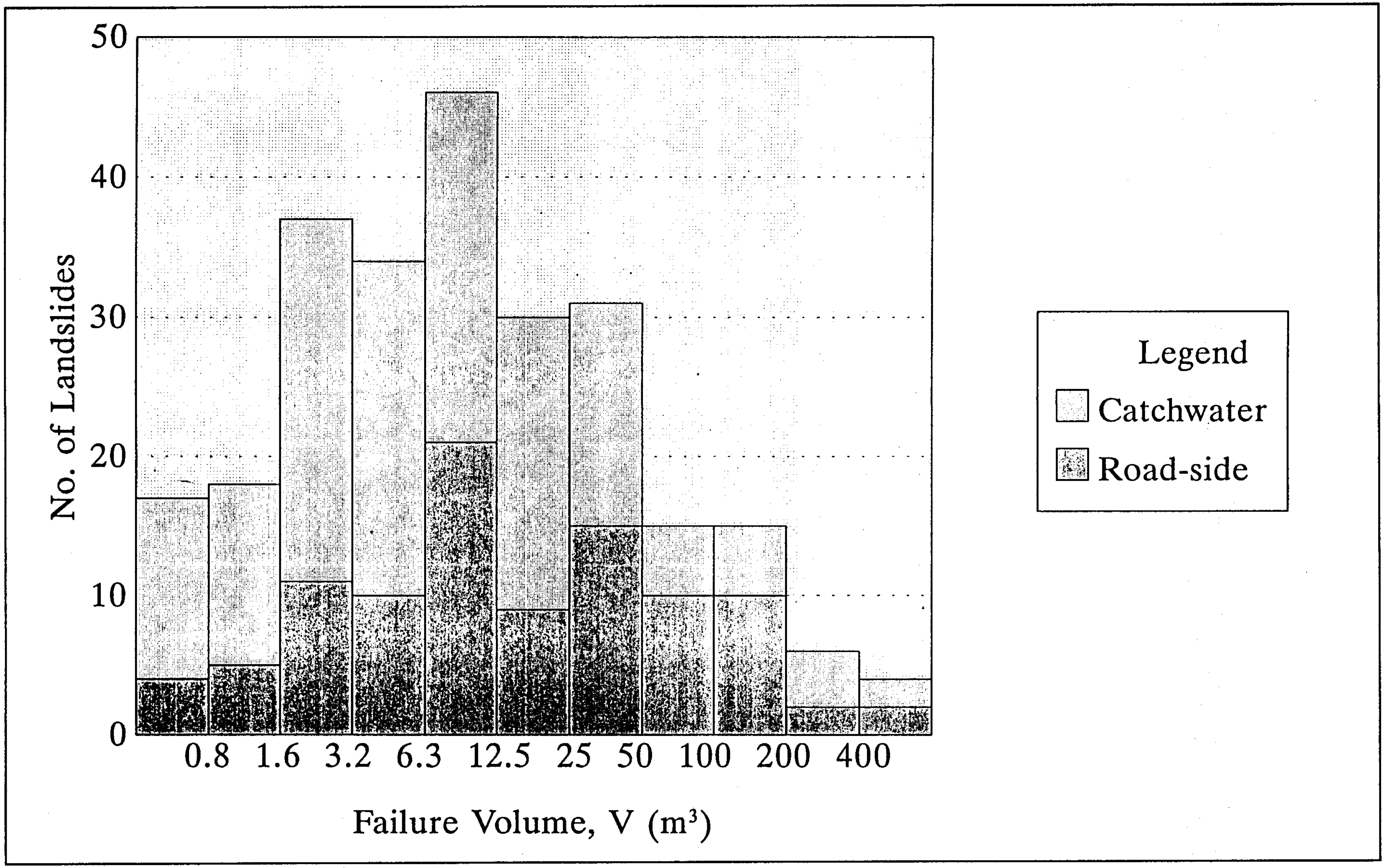


Figure 6 - Failure Volume

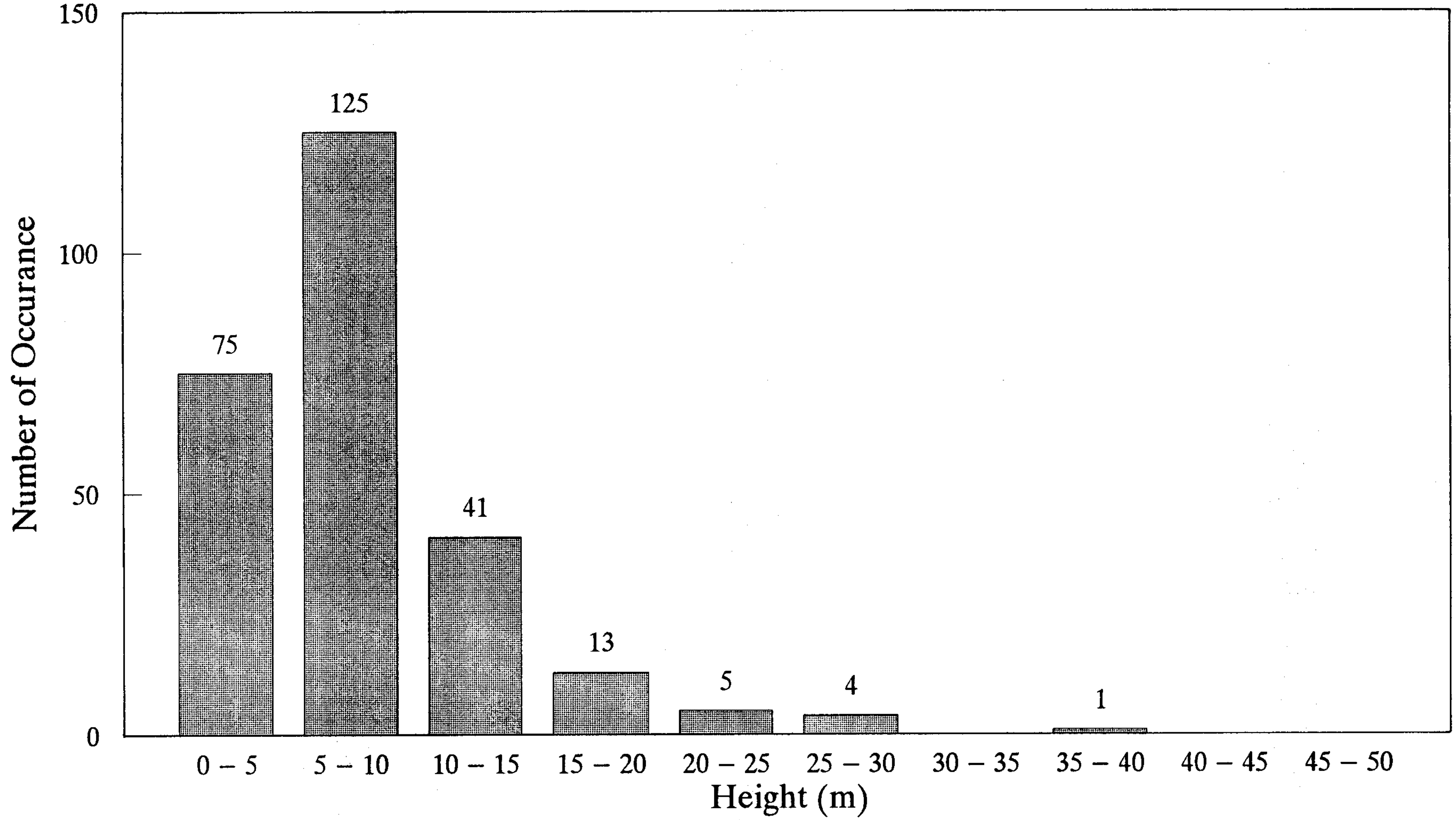


Figure 7 - Height of Cut Face of Failed Slopes

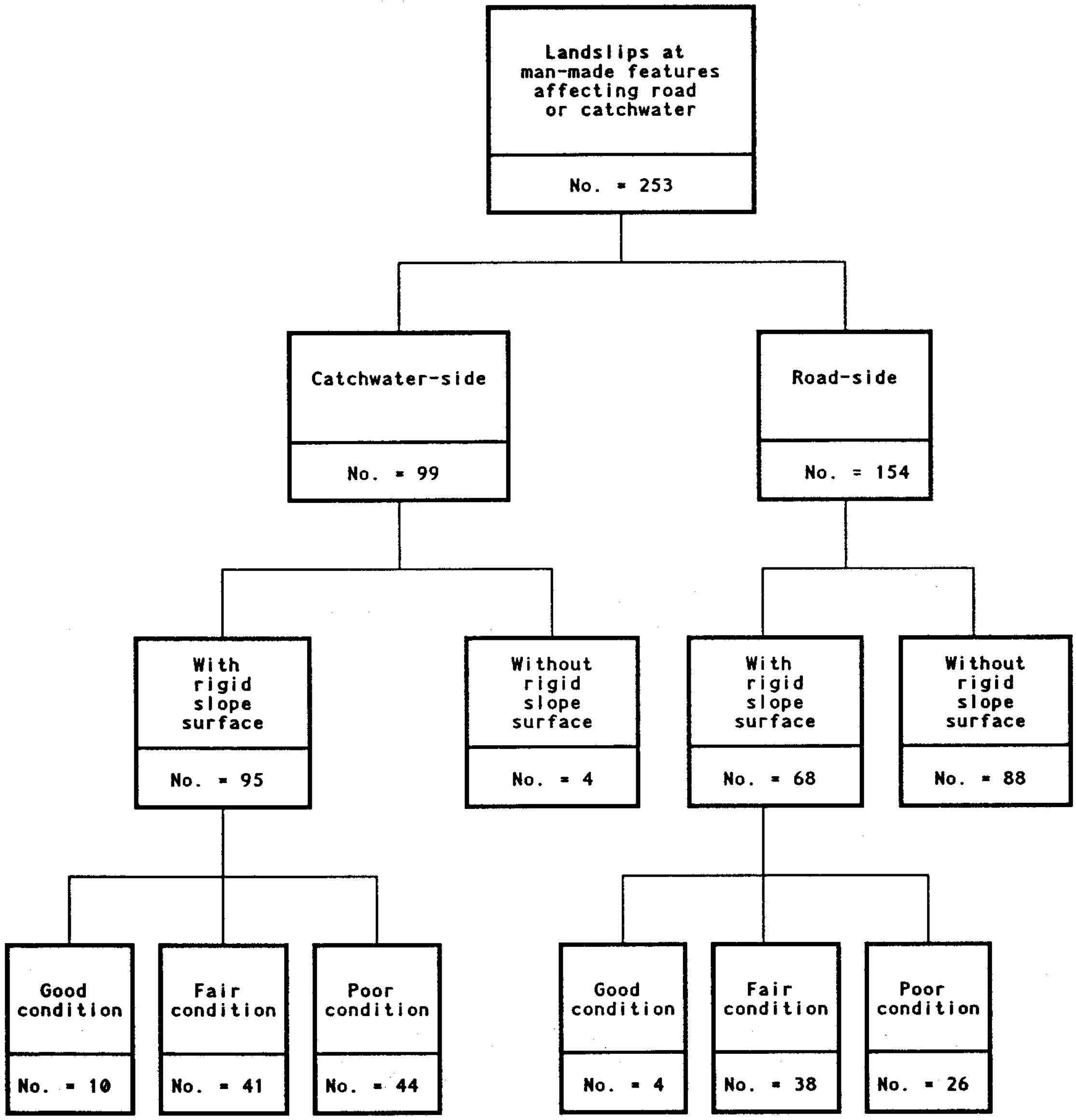
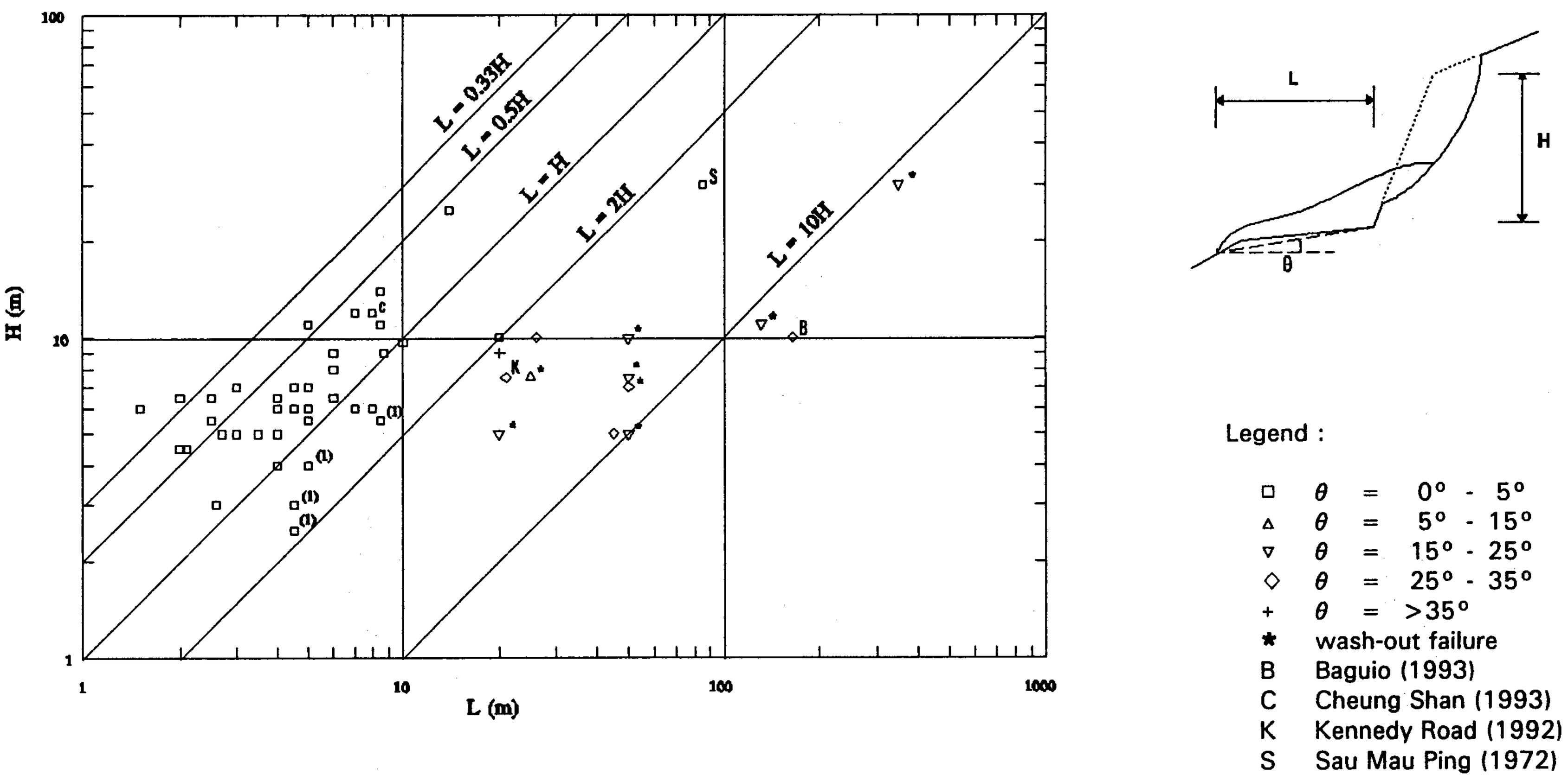
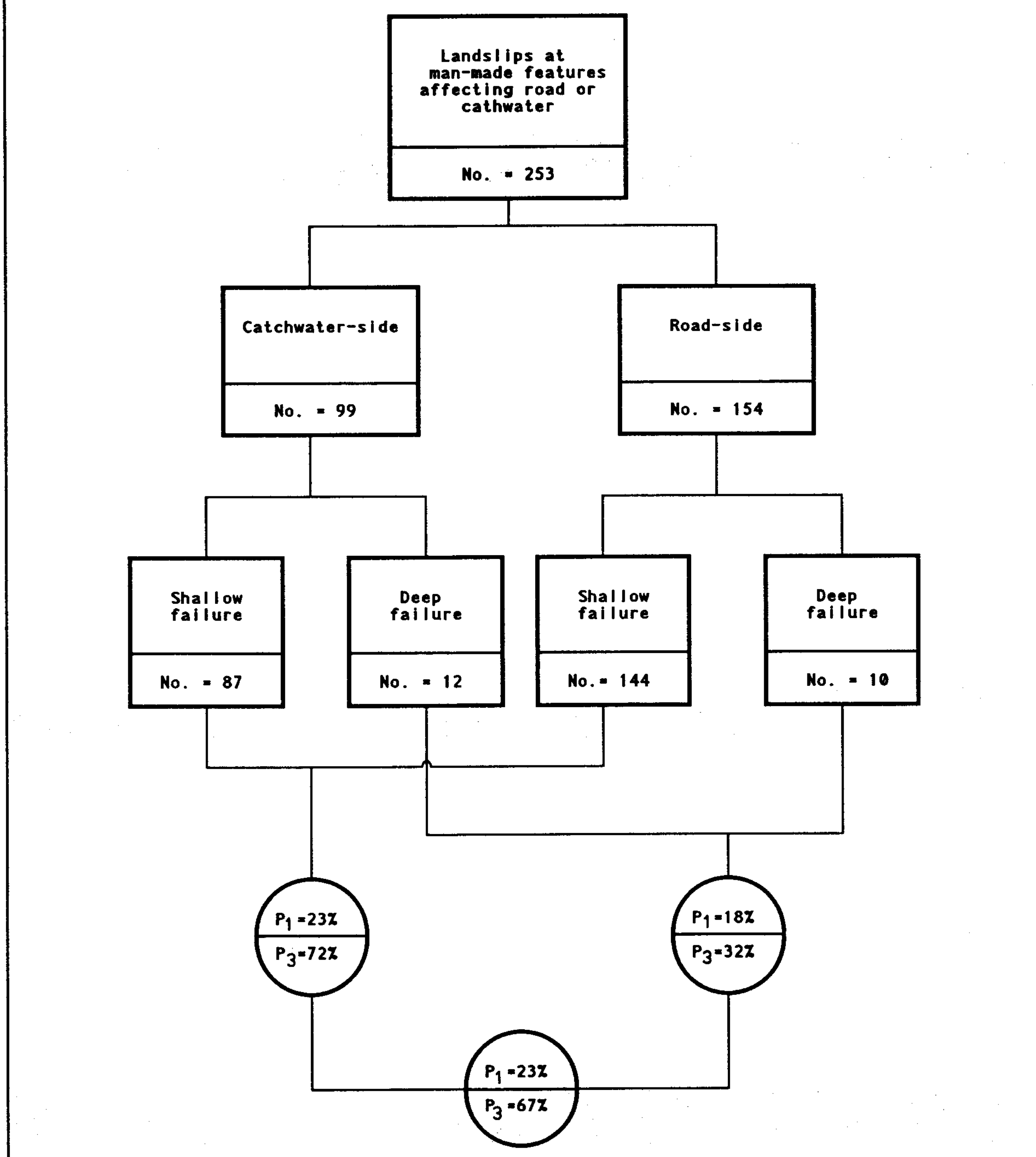


Figure 8 - Condition of Slope Prior to Failure



Note : (1) Denotes landslip involving failure of a substantial portion of the slope uphill of the cut face

Figure 9 - Relationship Between Height of Cut Face and Reach of Debris



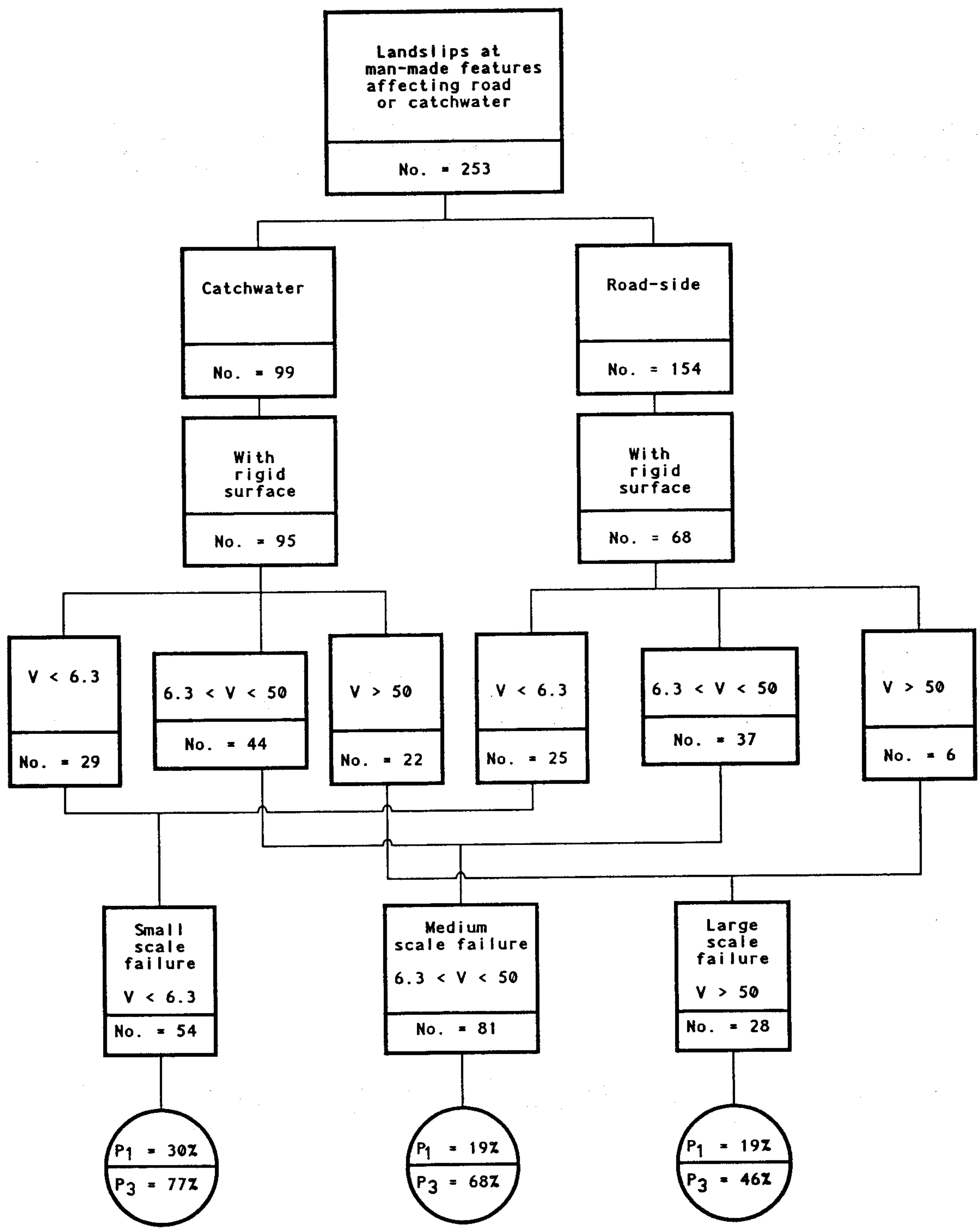
Notes :

(1) P_1 denotes the expected percentage of landslips that may be prevented by routine maintenance.

(2) P_3 denotes the expected percentage of landslips that may be prevented by prescriptive measures, coupled with routine maintenance.

(3) The overall proportion of landslips that could have been prevented if soil nailing were used as a prescriptive measure is judged to be about 90%.

Figure 10 - Effectiveness of Routine Maintenance and Prescriptive Measures in Preventing Landslips of Different Depth



Notes : (1) V denotes failure volume in m^3.
(2) See Figure 10 for definition of P_1 and P_3.
(3) The overall proportion of landslips that could have been prevented if soil nailing were used as a prescriptive measure is judged to be about 90%.

Figure 11 - Effectiveness of Routine Maintenance and Prescriptive Measures in Preventing Landslips of Different Scale

LIST OF PLATES

Negative No. SP93142C16

Plate 1 - Example of Rigid Cover in Good Condition

Negative No. SP9408514

Plate 2 - Example of Rigid Cover in Fair Condition

Negative No. SP9404820

Plate 3 - Example of Rigid Cover in Poor Condition

APPENDIX A

LANDSLIDE RISK ASSESSMENT FOR SOUTH LANTAU ROAD

CONTENTS

A.1 CALCULATION OF SPECIFIC RISK OF LANDSLIDE FOR SOUTH LANTAU ROAD

In calculating the average specific risk of fatality due to failure of the roadside slopes along South Lantau Road between Mui Wo and Pui O, the following simplifying assumptions are made :

(a) only vehicular traffic is considered (pedestrian traffic is not considered because of lack of data),

(b) each vehicle is taken to be travelling with an average speed of 50 km/hour to 70 km/hour (no queuing or hold up by traffic lights or breakdown is considered),

(c) each significant failure (i.e. failure debris burying one road lane) will lead to one or two fatalities if the debris hits the vehicle,

(d) the temporal probability of a failure giving rise to serious damage (i.e. involving fatality) is two-thirds the temporal probability of failure debris hitting the vehicle, and

(e) an average return period of 75 years for the rainstorm of 5 November 1993.

The specific risk of landslide, in the present context, is defined as the annual probability of a landslide causing damage to a vehicle travelling on the road and resulting in fatality, and is equivalent to the product of probability of landslide and the vulnerability. It should be noted that because only the specific risk for vehicular traffic is considered in this calculation, it would not be possible to assess the total risk of landslide.

Data on the number of slope features that failed during the 5 November 1993 rainstorm and the total number of features for the length of road under consideration is given in Table 4(a). Shown in Table 4(b) is the information in terms of feature lengths. It may be noted that out of a total of 3920 m of road being considered, there are a total of 47 features, 13 of which failed on 5 November 1993 (i.e. the probability of failure is approximately 30%). It may be noted that the average length of each feature is about 85 m, whereas the average length of the feature involved in the failure is about 10 m.

For the 13 failures, two of them affected the pedestrian footway only, five affected one lane of the road, and the remaining six affected two road lanes. Thus, on average, it may be taken that a landslide within this section of the road would have serious consequences on one road lane.

Assuming an average vehicular speed of 50 km/hour to 70 km/hour, the temporal probability of sustaining serious damage (i.e. involving fatality) in terms of the 'damage time' (i.e. direct 'hit' by a landslide) per slope feature is between two and three seconds. Assuming a 'stopping time' (i.e. the time involved in stopping a car to avoid driving into the landslide area after noting the start of landsliding) of, say, one second, the temporary risk becomes three to four seconds.

Information on the traffic density is needed for the risk calculation. The annual average daily traffic (AADT) flow, which is used by the Transport Department for the design of different road categories, may be used to quantify the relative traffic density (Wong & Premchitt, 1994). For South Lantau Road, which is classified as a twin-lane rural road (type A), the design AADT is 5000 vehicles per lane (Transport Department, 1984). Information on the actual AADT is also available from the Transport Department on some of the roads, including South Lantau Road. For the year 1992, this amounts to 1345 vehicles per lane (Transport Department, 1993), i.e. about 30% of the design AADT.

Based on the above data and assumptions made, the average specific risks of landslide along South Lantau Road between Mui Wo and Pui O have been calculated and summarised in Table A1.

It may be noted from Table 5 that the calculated upper- and lower-bound specific risks are 3.1×10^{-4} and 2.4×10^{-4} respectively for the actual AADT in 1992, and 1.2×10^{-3} and 8.9×10^{-4} respectively for the design AADT.

A.2 COMPARISON WITH SOCIETAL RISK GUIDELINE

There are, as yet, no specific guidelines on the acceptable risk level with respect to landslide. In order to put the calculation into perspective, the guidelines issued by the Planning Department (1993) on the societal risk of a potentially hazardous installation may be used as a reference. The guidelines are expressed in terms of a plot of annual frequency (f) of accidents with N or more fatalities against the number of fatalities (N), i.e. a f-N curve, with regions designated as 'acceptable', 'unacceptable' and 'ALARP' (which stands for as low as reasonably practicable). If the results plot within the unacceptable region, measures are required to reduce the risks, at whatever costs, until they are not unacceptable. If the results plot within the ALARP region, practicable and cost-effective mitigation measures should be implemented to reduce the risk.

For the present purposes, the assumption is made that one to two fatalities will be involved in each affected vehicle due to landsliding. The calculated f-N curves are shown in Figure A1. It may be noted that the calculated risk for the actual AADT is within the ALARP region. The sensitivity of the risk level to traffic density is also highlighted by Figure A1.

LIST OF TABLES

Table A1 - Summary of Data on Slope Features and Landslides on 5 November 1993 along South Lantau Road between Mui Wo and Pui O

(a) Number of Slope Features and Failed Features

Number of Slope Features Upslope of Road	Number of Slope Features Downslope of Road	Total Number of Slope Features
35 (11)	12 (2)	47 (13)
Note : Number in bracket denotes the number of features that failed during the 5 November 1993 rainstorm.		

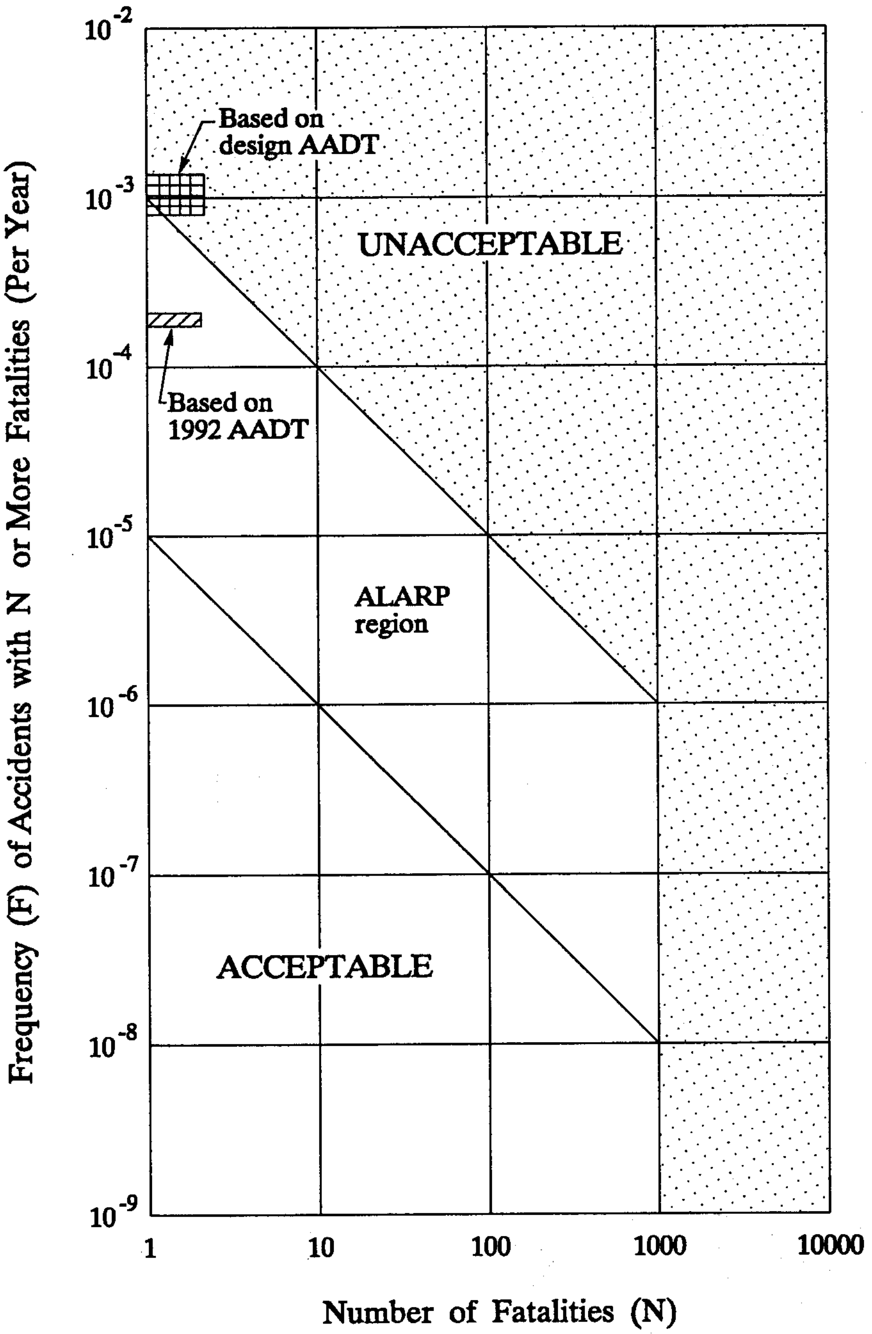
(b) Length of Slope Features and Failed Features

Length of Slope Features Upslope of Road (m)	Length of Slope Features Downslope of Road (m)	Total Length of Slope Features (m)
2380 (111)	1540 (28)	3920 (139)
Note : Number in bracket denotes the length of features that failed during the 5 November 1993 rainstorm.		

Table A2 - Summary of Specific Risk of Landslide along South Lantau Road between Mui Wo and Pui O

	Measured AADT in 1992	Design AADT
Vehicular Speed of 50 km/hour	3.1×10^{-4}	2.4×10^{-4}
Vehicular Speed of 70 km/hour	1.2×10^{-3}	8.9×10^{-4}
Note : AADT denotes annual average daily traffic.		

LIST OF FIGURE



Notes : (1) The societal risk guidelines are for potentially hazardous installations as extracted from Planning Department (1993).
(2) AADT denotes annual average daily traffic.
(3) ALARP denotes as low as reasonably practicable.

Figure A1 - Comparison of Assessed Landslide Risk for a Section of South Lantau Road with Published Societal Risk Guideline

APPENDIX B

EXAMPLES OF LANDSLIPS

CONTENTS

B.1 GENERAL

A selection of landslips are presented in the following to illustrate the different mechanisms of failure, the rating of the condition of the slope's rigid surface cover where appropriate, and the engineer's judgement on the likelihood of preventing the landslip given routine maintenance and with prescriptive measures respectively.

B.2 LANDSLIP INVOLVING PERCHED WATER TABLE

An example of this type of landslip was found near Shum Wat, overlooking the access road of Shum Wat East Catchwater (Landslip No. L223, Drawing No. 1).

The feature is a 55° steep, 5.5 m high cut slope (Plate B1). The cut face was covered by chunam. The chunam was classified as in a fair condition. The ground above the cut face was a 30° natural slope covered by thin vegetation. Surface drainage channel had not been provided.

A cross-section of the slope showing the geology is given in Figure B1. The slope consisted of decomposed volcanics overlain by 1.5 m of loose colluvium.

The landslip took place in the colluvium layer along its interface with the underlying completely to highly weathered volcanics (Plate B2). The landslip scar daylighted at about 2.5 m above the toe of the cut face, and extended for some 4 m high into the natural slope above the cut face.

The principal cause of the landslip was judged to be the build up of perched water pressure in the colluvium layer, as a result of infiltration through the ground above the chunamed cut face.

The landslip debris reached 8.5 m beyond the slope toe, and completely buried the access road. The H/L (Figure 9) ratio is 1.5, suggesting that a relatively long debris run-out distance for this mode of failure which involve a large area upslope of the cut face.

It was judged that it would be 'very unlikely' (i.e. a 10% chance) that the landslip could be prevented given routine maintenance. Given prescriptive measures excluding soil nailing, the chance could be improved to 30%.

B.3 LANDSLIP INVOLVING RISE IN MAIN GROUNDWATER TABLE

A feature which suffered from this mode of failure was located on the northern side of South Lantau Road about 500 m east of Tong Fook Village (Landslip No. L92, Drawing No. 1). Photographs of the failure are shown in Plates B3 and B4.

The feature comprised a 60° steep, 8m high roadside cut slope with shrubs and young trees. It was located at the end of a wide spur. An active spring (estimated flow rate of 10 litres/min) was noted on 7 December 1993 (Plate B5), almost a month after the landslip, and it was still running on 13 January 1994 but with a slightly reduced flow rate.

The slope material comprises a porphyry (mapped as feldsparphytic rhyolite but may well be a porphyritic micro-granite) containing large quartz, feldspar and biotite in a finer, clayey matrix. It is in an advanced state of weathering to Grade V material. The postulated geological model is shown in Figure B2.

The landslip displayed a steep, curved backscar with a large debris mound at the base that still had young trees on the surface, but inclined back towards the slope.

The weathered face showed large slabs of weathered rock spalling off parallel to the face. Several large corestone boulder were present near the crest.

The main cause of the landslip was judged to be due to a rise in groundwater pressure within the body of the slope.

The landslip debris was partly removed when the slope was inspected, at which time one lane of the road was completely blocked. There is therefore insufficient information on the H/L ratio.

It was judged that it would be 'very unlikely' (i.e. a 10% chance) that the landslip could be prevented given routine maintenance. Given prescriptive measures excluding soil nailing, the chance could be improved to 30%.

B.4 LANDSLIP INVOLVING WASH-OUT/EROSION

Two cases are described in this section to illustrate the failure mechanism.

The first case concerns a landslip below South Lantau Road located at about 1 km to the south-west of Mui Wo (landslip No. L32, Drawing No. 1). This is a major landslip involving the failure of the roadside embankment exposing an inclined bedrock slope of well jointed, weathered syenite about 12 m high. Debris ran down the slope for an inclined distance of about 180 m, depositing a terminal rampart of debris that included concrete blocks and a lamp post. The debris dewatered to send a wave (or pulses) of water beyond the ramparts. These flattened the tall vegetation flanking the valley bottom stream and impinged on the perimeter wall of a housing compound. Salient features of the failure are shown in Plates B6 and B7.

Only a thin layer of fill was observed at the crest of the rock slope, forming the road bed. The indication was that the failed material was an embanked veneer of fill built out on a thin layer of weathered syenite bedrock.

The feature showed evidence of fast-moving debris flow, namely :

(a) a narrow track,

(b) scour of the floor of the track,

(c) lateral levees or embankments of debris,

(d) elongate boulders in the track aligned downslope,

(e) trees broken off and aligned downslope,

(f) crag and tail-like features (avalanche debris tails) downslope of bedrock protuberances,

(g) flute marks on floor of track,

(h) scour marks (striae) on bedrock exposures,

(i) debris ribs banked upslope of trees on the margins,

(j) curvilinear debris ridges along the track,

(k) terminal debris ramparts,

(l) large debris from the source area (lamp post) carried rapidly and undamaged to the terminus.

Following the debris flow, a considerable amount of fluvial modification followed, cutting a well-defined water channel asymmetrically along the track. Fines were washed from the water course leaving a lag of deposit of boulders. Fines were deposited in a settling pond behind the terminal rampart.

The probable cause of the failure was judged to be due to concentrated flow of surface water, leading to wash-out and erosion. The feature was located downslope of the outside of a bend in the road. It is possible that the water running along the road was unable to follow the curved profile, and consequently overspilled onto the slope below.

The landslip debris travelled a distance of about 130 m downslope. The H/L ratio is about 12.5, indicating a very mobile debris as a result of the action of running surface water and the steep downslope gradient.

Bearing in mind this failure involved a grassed slope, it was judged very unlikely that the landslip could have been prevented by routine maintenance works. Given prescriptive measures, the likelihood of preventing the landslip was judged to be about 70%, assuming suitable concrete walls or parapet would be constructed at similar road bends to minimise the likelihood of significant spilling of surface water or storm water over the road.

The second case involves a landslip at a cut slope overlooking Keung Shan South Catchwater (Landslip No. L162, Drawing No. 1). The cut slope was 60° steep and 10 m high, and comprised weather volcanics. The cut face was covered by chunam which was judged to be in a poor condition, in view of the serious cracking and growth of unplanned vegetation (Plate B8). The ground above the cut face was a 25° natural slope covered by thick vegetation. The landslip was confined to the cut slope, and the natural slope was not affected.

No signs of previously landslip were observed at this feature.

A 300 mm drainage channel was present at the crest of the cut face. The section of the channel immediately above the landslip was seriously blocked by vegetation (Figure B3).

The main cause of the landslip was judged to be wash-out. Large amount of storm water collected from the natural slope would be flowing along the 300 mm channel during heavy rain. At the location where the channel was blocked, the storm water overflowed from the channel onto the cut slope. The concentrated flow of storm water onto the cut slope washed away the cracked chunam, eroded the cut slope and resulted in the landslip.

The debris reach was not assessed, as all the debris was retained by the catchwater at the toe of the cut slope.

It was assessed that the landslip would 'very likely' (i.e. 90% chance) be avoided given such routine maintenance as clearing of block drains and repairing cracked chunam. The chances that the landslip might have been prevented given prescriptive measures was also judged to be 'very likely'.

B.5 LANDSLIP INVOLVING INFILTRATION THROUGH CREST SLOPE

This feature, shown in Plate B9, is a typical example where the probable causes of the failure were judged to be due to infiltration through the upper vegetated natural slope (Landslip No. L30, Drawing No. 1). The slope was a 6.5 m high cut slope overlooking South Lantau Road, about 1 km to the south-west of Mui Wo. The dominant material involved in the landslip was residual soil. There was evidence of past instability at the failure location.

The cut face was covered by shotcrete which was assessed to be in a good condition. The failure was related to the inadequacy of the drainage provisions at and beyond slope crest. The ground above the cut face was a 15° steep natural slope covered by thick vegetation. The ground was susceptible to infiltration, and there was no drainage channel to intercept and direct surface water.

One and a half lanes of the road were blocked by the debris from the landslip. The H/L ratio is about 0.9.

Given that the slope cover was in a good condition, it is considered that routine maintenance would have been 'very unlikely' (i.e. a 10% chance) to prevent the landslip. Given prescriptive measures, the likelihood of preventing the landslip was judged to be about 70%.

B.6 LANDSLIP INVOLVING SEEPAGE BEHIND RIGID SLOPE COVER

Three cases are described in this section to illustrate typical landslips which were judged to have been triggered by seepage behind the rigid slope cover. Landslips caused by this factor may be of different extent as shown in Figure B4. Typical preferential flow paths leading to seepage behind an rigid slope cover are shown in Figure B5.

Landslip No. L264 occurred at a 6 m high cut slope overlooking the catchwater between Cheung Sha and Pui O. The cut slope was covered by chunam. The chunam was classified as in a fair condition, as there were some but not serious cracking and unplanned vegetation. The landslip involved three localised blow-out type failures at the upper part of the cut slope (Plate B10). Signs of piping/erosion behind the chunam at the failure location were evident. The weepholes at the chunam covered were apparently not adequate to effectively drain away the water that reached the soil behind the chunam. It was judged that routine maintenance would have been 'unlikely' (i.e. 30% chance) to prevent the landslip. Given prescriptive measures, the landslip is 'likely' (i.e. 70% chance) to have been avoided.

Landslip No. L200 took place at a 3 m high cut slope along Keung Shan North Catchwater (Drawing No. 1). As shown in Plate B11, the failure involved almost the full height of the cut slope and was 'more developed' than the case described above. The chunam was classified as in a fair condition. Signs of past instabilities at the slope adjoining the landslip location were evident. A pipe, probably a snake barrel, was present near the crest of the failure scar (Plate B12). This was possibly the main path of preferential water flow in the slope behind the chunam surface, which led to the failure. It is 'very unlikely' (i.e. 10% chance) that the landslip could be prevented by routine maintenance. Given prescriptive measures, the landslip is 'very likely' (i.e. 90% chance) to have been avoided.

A larger scale failure involving seepage behind the rigid surface is Landslip No. L108 at a cut slope overlooking South Lantau Road near Shek Pik Reservoir (Drawing No. 1). The cut slope was about 11 m high covered by chunam (Plate B13). The chunam was generally in a fair condition. The landslip took place at the top 4 m of the covered cut slope.

The surface 1 m of the slope consisted of permeable top soil, which was loose and contained pipes. The top soil would form a seepage path in the slope for water which infiltrated via the vegetated upslope surface into the slope. The water seepage would have been hindered at the chunam surface, and the shallow slip occurred probably upon saturation of the soil behind the chunam and building up of water pressure. Routine maintenance was considered 'very unlikely' (i.e. 10% chance) to prevent the landslip. However, given prescriptive measures, the likelihood of preventing the failure was judged to improve to about 90%.

LIST OF FIGURES

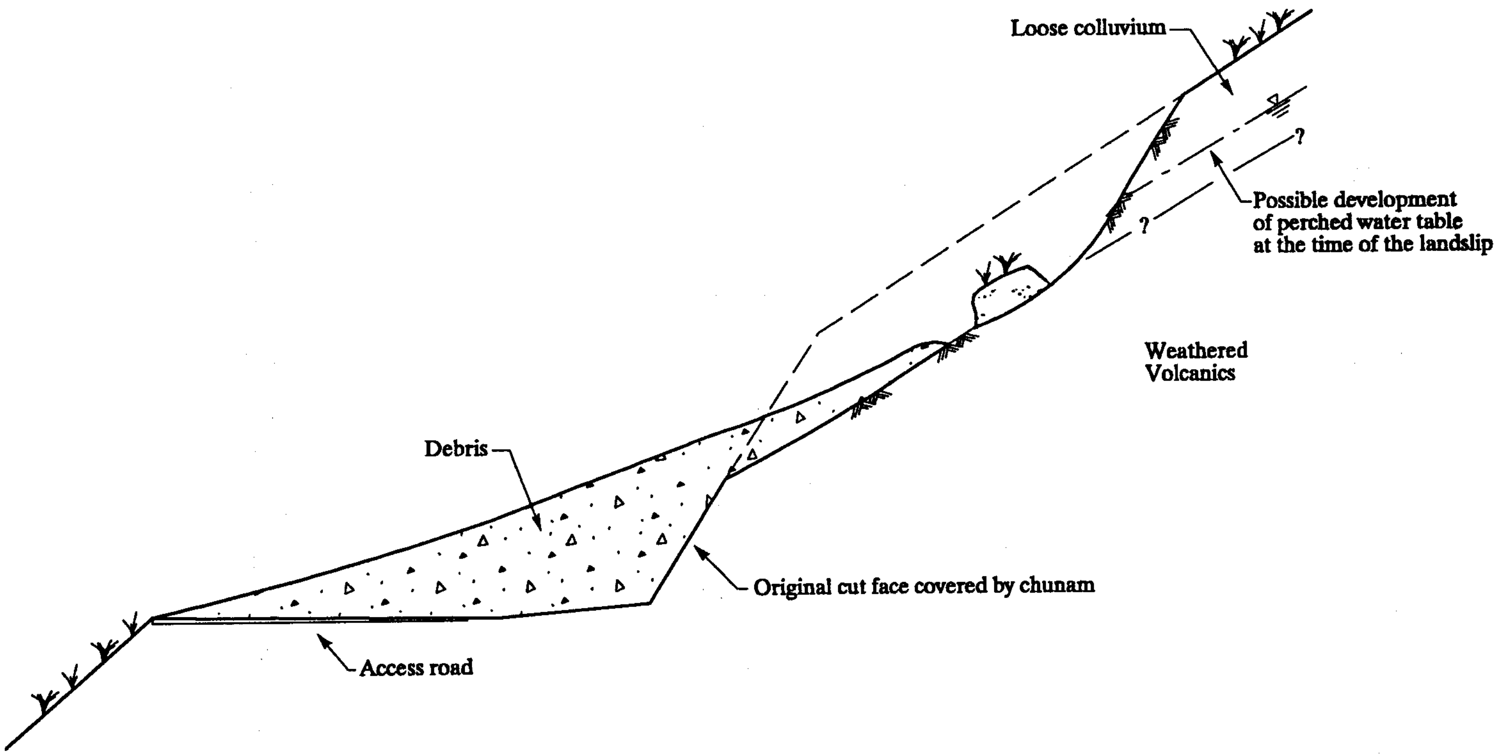


Figure B1 - Cross-section of Landslip No.L223

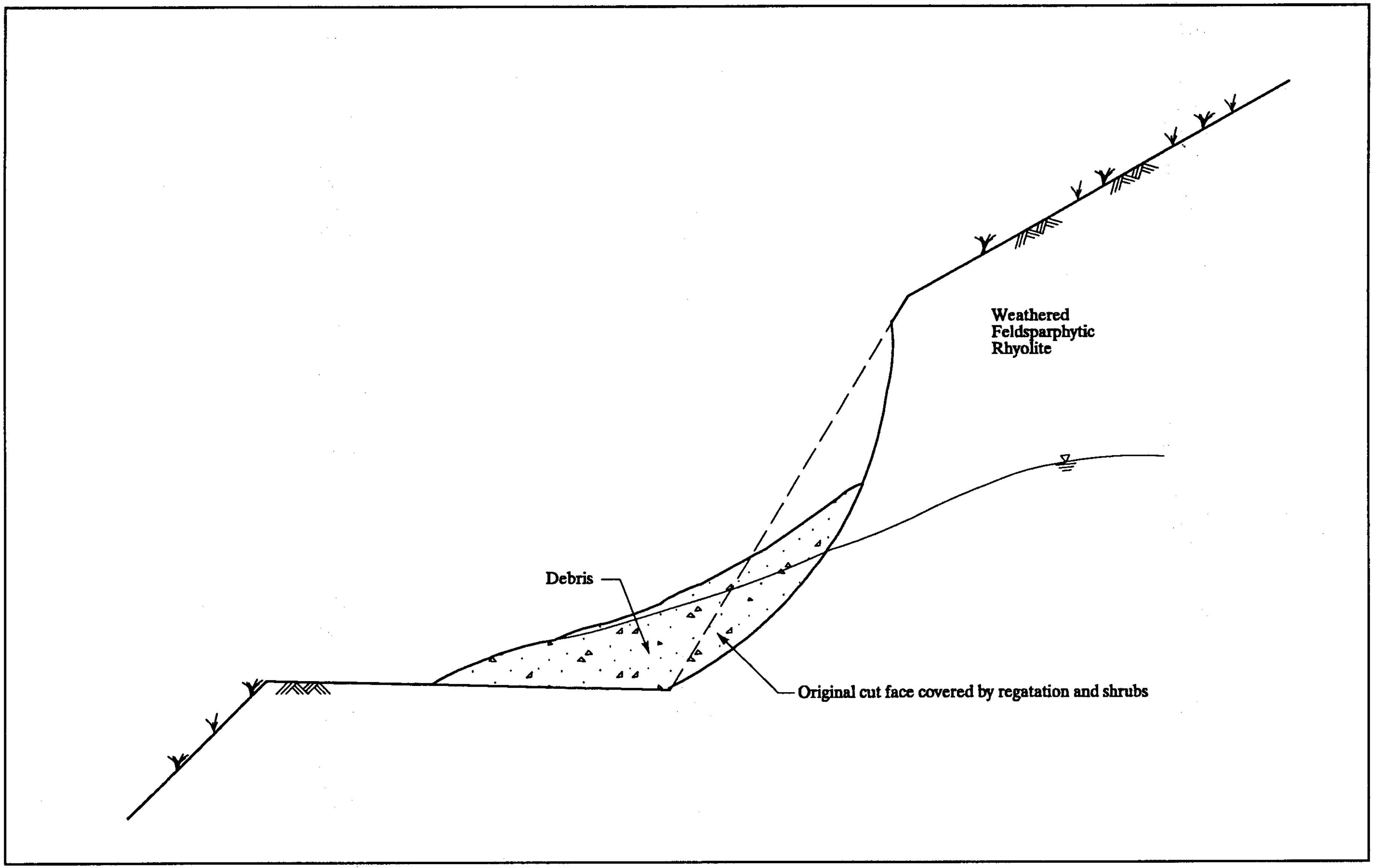


Figure B2 - Cross-section of Landslip No.L92

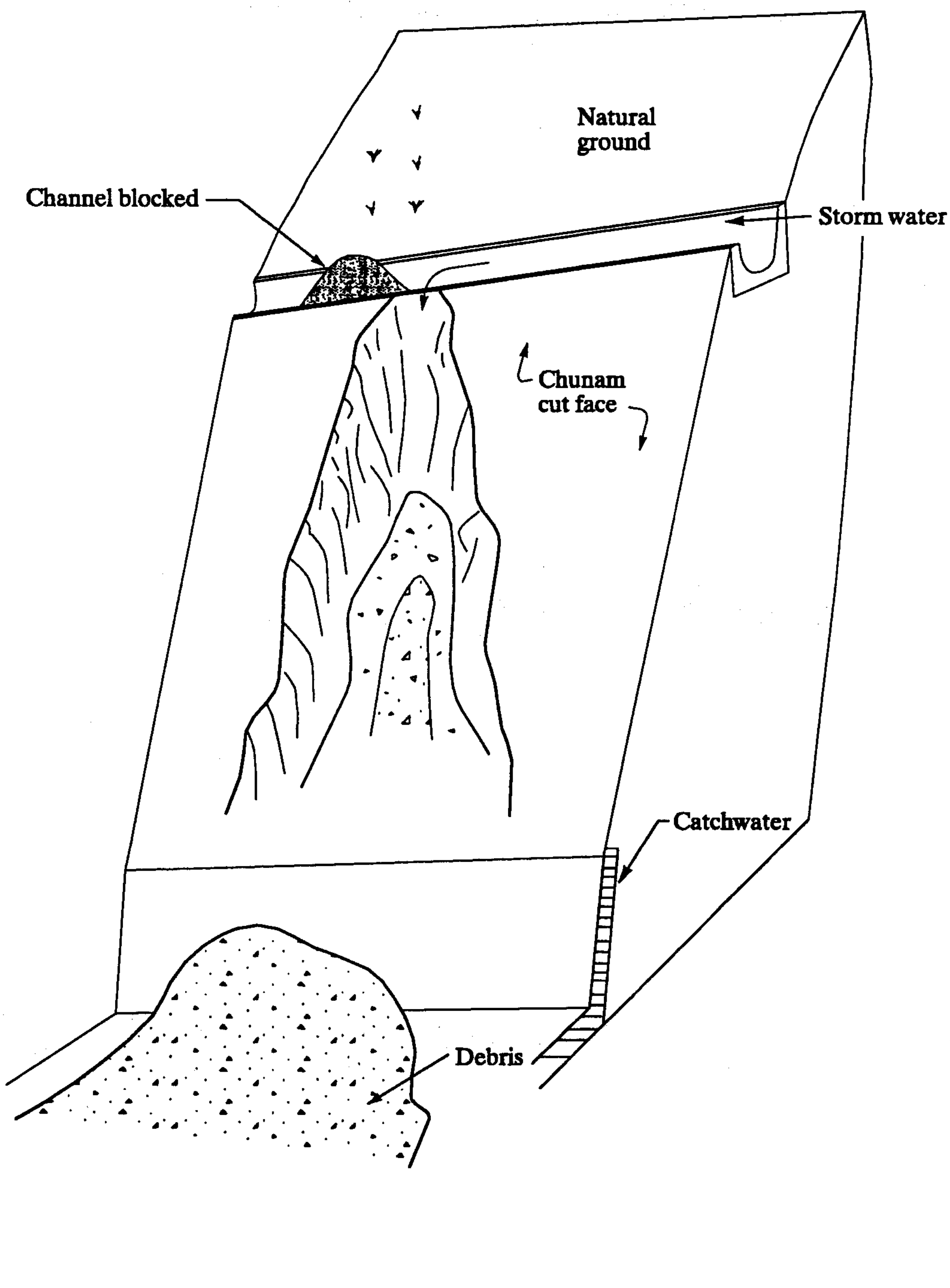
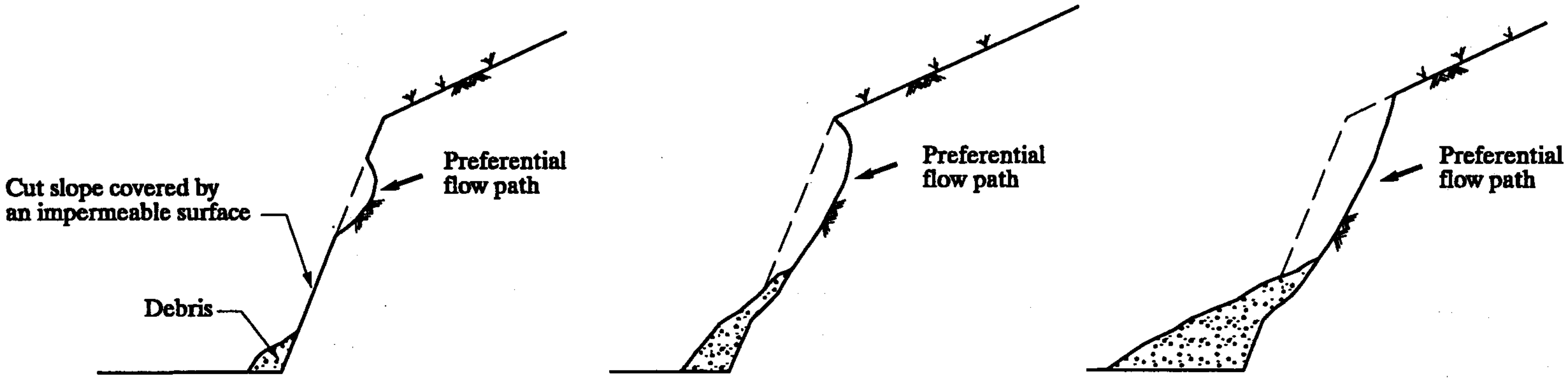


Figure B3 - Schematic View of Landslip No.L162



(a) 'Blow-out' Failure (b) Localised Failure (c) Shallow Landslip

Note : For typical preferential flow path, see Figure B5.

Figure B4 - Landslip of Different Extent Caused by Seepage Behind the Rigid Slope Cover

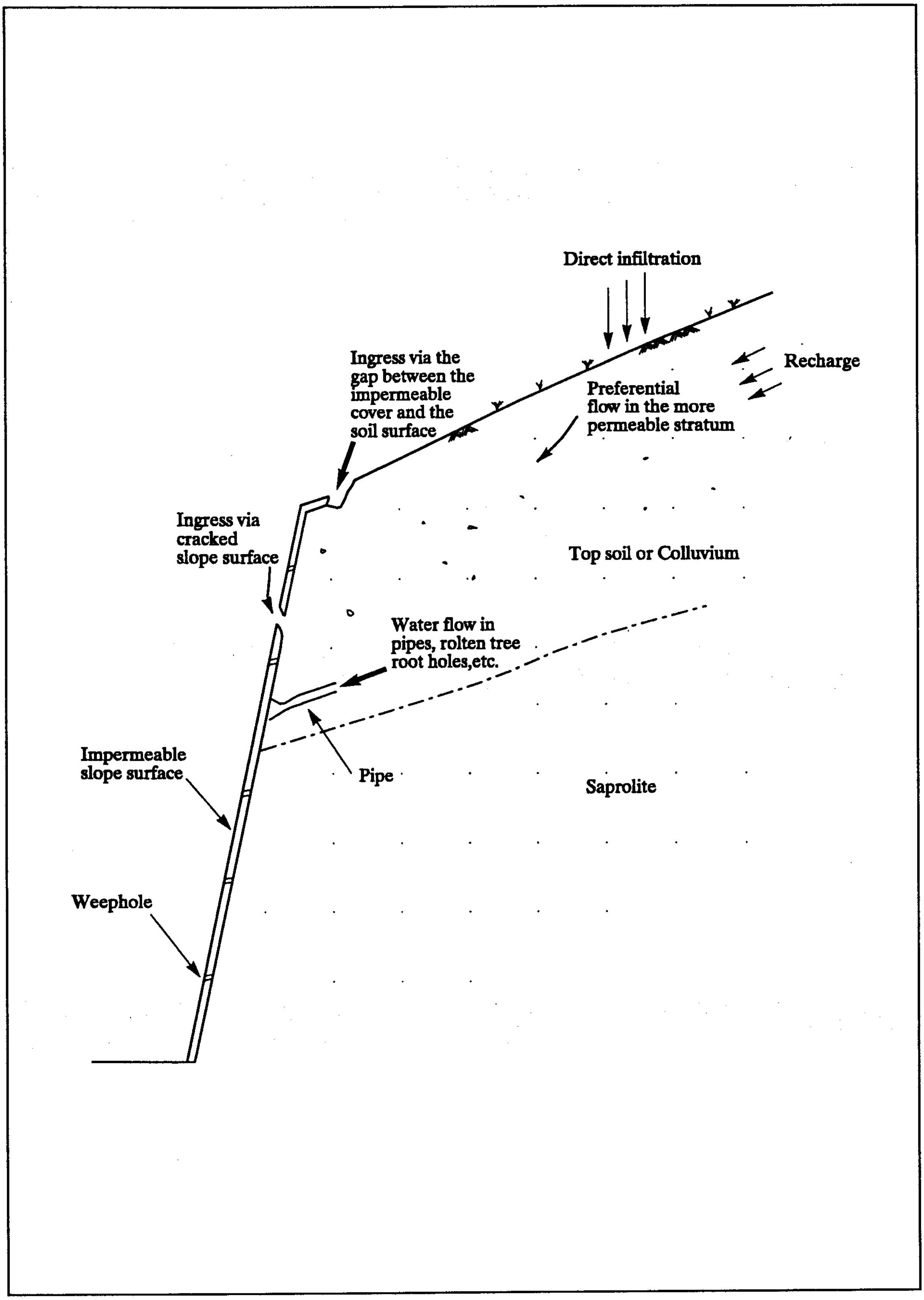
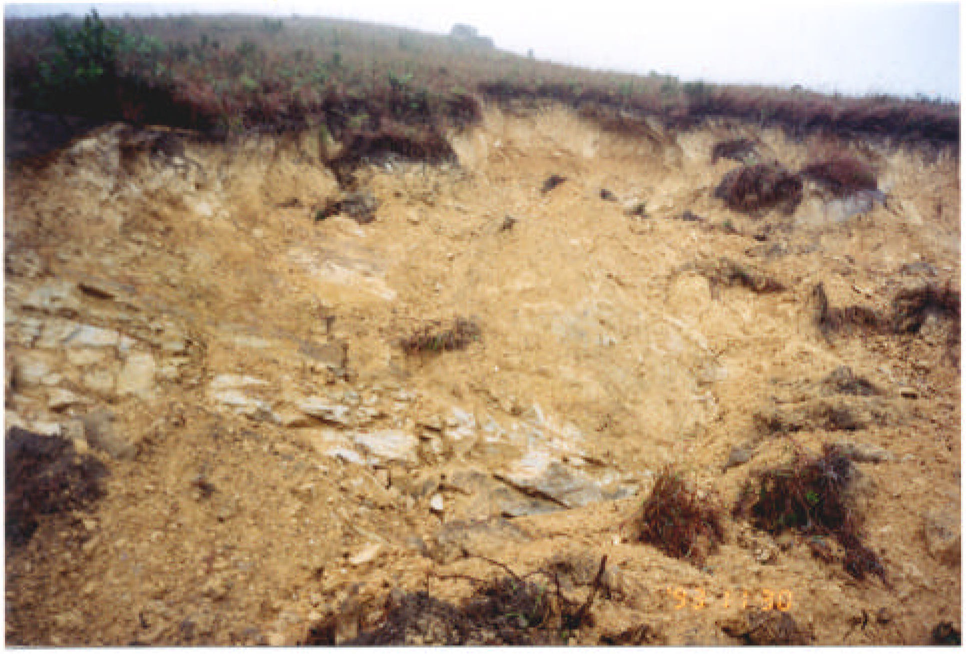


Figure B5 - Typical Preferential Flow Path Leading to Seepage Behind a Rigid Slope Cover

LIST OF PLATES



Negative No. SP93206C33

Plate B1 - Landslip No. L223 Caused by Development of Perched Water Pressure

Negative No. SP9319826

Plate B2 - Scarp of Landslip No. L223 Exposing the Thin Colluvium Layer Overlying Weathered Volcanics

Negative No. SP9320530

Plate B3 - Landslip No. L92 Caused by Rise in Main Groundwater Table

Negative No.SP93209C06

Plate B4 - Debris of Landslip No. L92

Negative No.SP93209C04

Plate B5 - Scar of Landslip No. L92 where Water Seepage was Observed

Negative No. TP243/4

Plate B6 - Aerial View of Landslip No. L32 Caused by Wash-out

Negative No. MW93337-23

Plate B7 - Salient Features of Landslip No. L32

Negative No. SP93156C10 & SP93156C11

Plate B8 - Landslip No. L162 Caused by Wash-out

Negative No. SP93142C16

Plate B9 - Landslip No. L30 Caused by Infiltration Through Crest Slope

Negative No. SP9318812

Plate B10 - Landslip No.L264 Caused by Seepage Behind the Rigid Surface

Negative No. SP9317220

Plate B11 - Landslip No. L200 Caused by Seepage Behind the Rigid Surface

Negative No. SP9319725

Plate B12 - The Upper Part of Landslip No. L200 Showing the Presence of a Pipe (Possibly a Snake Barrel)

Negative No. SP9319024

Plate B13 - Landslip No. L108 Caused by Seepage Behind the Rigid Surface

APPENDIX C

EFFECTIVENESS OF ROUTINE SLOPE PROTECTIVE MEASURES

C.1 EFFECTIVENESS OF ROUTINE SLOPE PROTECTIVE MEASURES

The routinely-adopted slope surface protective measures include chunam, shotcrete, stone-pitching or vegetation. The primary function of the rigid surfacing is to reduce surface infiltration and minimise effects of surface erosion (Wood, 1981). In most of the failed slopes, the rigid surface protection, where this has been provided, was not extended beyond the crest of the cut slope. In the cases where the cover is extended some way beyond the cut face, the distance was only nominal and may not be sufficient. Infiltration can therefore take place, the extent of which will be dependent on the backslope topography (Anderson et al, 1983), presence of erosion pipes or similar preferential flow paths, etc. Also, it is possible for the rigid surfacing to be 'lifted' away from the underlying surface of the soil due to a build up of water pressure, relative movement of the surfacing and the soil, seepage erosion of the soil at the interface with the surfacing, etc. In addition, it is possible for the surfacing to be broken as a result of concentrated erosion of surface water where this cannot be dealt with satisfactorily by surface drainage. Such design deficiencies, coupled with possible general deterioration, will reduce the effectiveness of the protective cover in preventing slope failure.

It has been found that generally a rigid surfacing can be effective in preventing infiltration compared to vegetated surface (Premchitt et al, 1992). The actual effectiveness of the rigid protective cover is primarily affected by its effective permeability, extent of cracking, degree of bonding at the cover-soil interface, quality of the mix, shrinkage characteristics, long-term durability, etc. (Anderson & Shen, 1987). The condition of the rigid surfacing is normally classified on the basis of visual inspection only (Brand & Hudson, 1982).

Vegetation can be an effective erosion control measure. The extent of protection effected to a slope depends on the species, maturity, density, etc. of the cover. In addition, vegetation may provide anchorage by its root system (Yim et al, 1988).

The effectiveness of typical surface drainage including channels, trash grills, sand-traps, etc. is very much dependent on the degree of blockages or cracking sustained. The most common causes of blockage include natural vegetation, such as due to creeper plants or dead leaves, etc., and unscrupulous littering or dumping. In general, it may be necessary to give consideration beyond the immediate surround of the slope in assessing the susceptibility to the problem of surface water concentration or channelling, effects of road geometry on storm spillage, etc. (Au & Suen, 1991), which may produce concentrated flow that cannot be accommodated by the surface drainage measures. The effectiveness of drainage is also affected by factors related to detailing and construction. For instance, channels with an insufficient gradient for self-flushing will be prone to blockages.

LIST OF DRAWING

Drawing No.	
GCSP 8/14	Location Plan of Lantau 5 November 1993 Landslips