DETAILED STUDY OF THE 23 MARCH 2002 ROCKFALL INCIDENT AT SLOPE NO. 11NW-A/C61 AT CASTLE PEAK ROAD, KWAI CHUNG

GEO REPORT No. 157

Maunsell Geotechnical Services Limited

GEOTECHNICAL ENGINEERING OFFICE
CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT
THE GOVERNMENT OF THE HONG KONG
SPECIAL ADMINISTRATIVE REGION

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PREFACE

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

The Geotechnical Engineering Office also produces documents specifically for publication. These include guidance documents and results of comprehensive reviews. These publications and the printed GEO Reports may be obtained from the Government's Information Services Department. Information on how to purchase these documents is given on the last page of this report.

R.K.S. Chan
Head, Geotechnical Engineering Office
January 2005

FOREWORD

This report presents the findings of a detailed study of a rockfall incident (GEO Incident No. 2002/03/0012), with a failure volume of about 0.1 m^3, on cut slope No. 11NW-A/C61 adjacent to Castle Peak Road, Kwai Chung which was recently upgraded under the LPM Programme in June 2000. The rockfall incident occurred at about 10:15 a.m. on 23 March 2002, when the Amber Rainstorm Warning was hoisted. Most of the debris fell onto the footpath at the toe of the slope and the remainder fell onto the road causing temporary closure of one of the road lanes. No casualties were reported as a result of the incident.

The key objectives of the detailed study were to document the facts about the rockfall incident, present relevant background information and establish the probable causes of the failure. No ground investigation works were carried out as part of the study. Recommendations for follow-up actions are reported separately.

The report was prepared as part of the 2001/2002 Landslide Investigation Consultancy for landslides reported within Kowloon and the New Territories between April 2001 and the end of 2002, for the Geotechnical Engineering Office, Civil Engineering Department, under Agreement No. CE72/2000. This is one of a series of reports produced during the consultancy by Maunsell Geotechnical Services Ltd.

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Dr. L.J. Endicott
Project Director
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Agreement No. CE 72/2000
Landslide Investigation Consultancy for Landslides Reported within Kowloon and the New Territories between April 2001 and the End of 2002

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1. INTRODUCTION

At about 10:15 a.m. on 23 March 2002, when the Amber Rainstorm Warning was hoisted, a rockfall (GEO Incident No. 2002/03/0012), with a failure volume of about 0.1 m^3, occurred on cut slope No. 11NW-A/C61 adjacent to Castle Peak Road, Kwai Chung (Figure 1). Most of the debris fell onto the footpath at the toe of the slope (Plate 1) and the remainder fell onto the road (Plate 2) causing temporary closure of one of the road lanes. No casualties were reported as a result of the incident.

Slope No. 11NW-A/C61 was recently upgraded under the LPM Programme. Slope upgrading works, which consisted of installation of soil nails, concrete buttresses, rock dowels, rock bolts, raking drains, shotcreting of local areas, removal of loose rock blocks and provision of surface water drainage channels, were completed on 30 June 2000.

Following the rockfall incident, Maunsell Geotechnical Services Limited (MGSL), the 2001/2002 Landslide Investigation Consultants for Kowloon and the New Territories, carried out a detailed study of the rockfall incident for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 72/2000.

This report presents the findings of the detailed study, which comprised the following key tasks:

(a) a review of relevant documentary records relating to the development history of the site and the sequence of events leading to the incident,

(b) geological mapping and detailed inspections and measurements at the landslide site,

(c) analysis of rainfall data, and

(d) diagnosis of the probable causes of the incident.

2. THE SITE

2.1 Site Description

The rockfall occurred on soil/rock cut slope No. 11NW-A/C61 on the north side of Castle Peak Road, Kwai Chung (Figure 2). Castle Peak Road, which is situated at the toe of the slope, is a two-way four-lane dual carriageway with a 1 m wide footpath and a narrow reserve on the north side. Slope No. 11NW-A/C61, which is approximately 130 m long and up to about 27 m high, comprises a 10 m high rock cut portion inclined at approximately 80° to 85° and a soil-nailed soil portion, up to a maximum height of about 17 m, formed at between 30° and 50° to the horizontal with a single berm. A portion of the hillside above the crest of slope No. 11NW-A/C61 was also soil nailed (Figure 2).

The soil portion and parts of the rock cut portion of the slope No. 11NW-A/C61 and the soil nailed hillside above are protected with shotcrete cover (Figure 2). Masonry clad concrete buttresses, ranging from about 3 m to 8 m in width and up to 7 m in height, have

been constructed at seven locations along the slope toe with the largest, which comprises three tiers and located at about Ch. 67 (Ch. 0 being designated at the west end of the slope for this report), being close to the source of the March 2002 rockfall (Figure 2).

Unplanned vegetation, comprising small trees, shrubs and grass, was present on the exposed rock portion of the slope, particularly along the rock joints on the upper portion of the rock face. Two steel maintenance stairways had been erected on the shotcreted soil portion of slope No. 11NW-A/C61 to provide access between the berm and the crest of the slope. A concrete maintenance stairway had been constructed from the east end of the berm to an existing stairway, which provides access from Castle Peak Road to a former squatter area on the hillside about 50 m to the northeast of slope No. 11NW-A/C61 (Figure 2). The hillside above the slope is densely vegetated with tall trees and bushes.

The surface drainage provisions on the slope comprise a 300 mm U-channel at the crest of the soil portion of the slope. At either end, this 300 mm U-channel connects into catchpits CP1 and CP2, which in turn connect to a 400 mm U-channel, a 450 mm stepped channel and a steeper 250 mm stepped channel that connects to a 450 mm stepped channel on the east side and 450 mm stepped channels on the west side of the slope and the central portion of the slope above the berm. The stepped channels discharge into natural drainage lines at either end of the slope. A 300 mm U-channel runs along the berm on the soil portion of the slope and connects to a 450 mm stepped channel before discharging into the stream course at the east end of the slope. There are no surface drainage provisions directly above the exposed rock portion of the slope. At the toe of the slope, a 300 mm covered drainage channel runs along the inside edge of the footpath.

There are no water-carrying services within or in the vicinity of slope No. 11NW-A/C61.

2.2 Maintenance Responsibility

According to the Slope Maintenance Responsibility Information System (SMRIS) of the Lands Department, Highways Department (HyD) is responsible for the maintenance of slope No. 11NW-A/C61.

2.3 Previous Instability

In June 1977, Binnie & Partners (B&P) inspected slope No. 11NW-A/C61 under the project entitled “Landslide Studies, Phase I Re-appraisal, Cut & Natural Slopes and Retaining Walls” for the purpose of slope registration in the 1977/78 Catalogue of Slopes. A landslide scar on slope No. 11NW-A/C61 was reported by B&P (Figure 3) although there are no records of past instability at the slope in the GEO landslide database. No other information, such as dimensions, estimated failure volume and probable causes of failure, was given by B&P.

2.4 Geology

The 1:20,000 scale geological map sheet 11 of Hong Kong and Kowloon (GEO, 1986) indicates that the site is underlain by Jurassic/Cretaceous coarse-grained granite and fine-grained granite which make contact at the location of slope No. 11NW-A/C61. The geological map indicates that no faults or lineaments pass through the immediate vicinity of the site.

The Planning Division of the GEO produced Geological Report No. GR 2/2001 (Law & Li, 2001) of the regional geology of the Kwai Chung Area that included slope No. 11NW-A/C61. The report highlighted that sub-vertical joints and sets of steeply dipping joints with variable strike directions are the prominent structural features in the granite and that these could give rise to the potential for toppling failures. The report gives details of the rock cut portion of slope No. 11NW-A/C61 (Section 3.4), indicating that a crush zone possibly related to faulting and complex jointing exists in the rock cut portion, about 25 m to the west of the source area of the March 2002 rockfall.

3. PREVIOUS STUDIES/UPGRADING WORKS

3.1 General

Based on an aerial photographic interpretation carried out by the LPM Consultants, Mott Connell Limited (MCL), for slope No. 11NW-A/C61 under a Stage 3 Study in 1998 (see Section 3.2), it is noted that the slope was formed between 1954 and 1959 in association with the widening of Castle Peak Road. In July 1994, under the "Systematic Inspection of Features in the Territory" (SIFT) project, the slope was assigned as SIFT "Class C1" (i.e. "Assumed formed pre-1978"). According to the available information in GEO, slope No. 11NW-A/C61 had not been studied and processed by the slope safety system prior to its inclusion in the 1996/97 LPM Programme.

3.2 Stage 3 Study

Slope No. 11NW-A/C61 was selected for inclusion in the LPM Programme. The Stage 3 Study was carried out in 1997 by MCL under Agreement No. CE 33/93. As part of the Stage 3 Study, a ground investigation was carried out by Bachy Soletanche Group Limited in October 1997. Two drillholes (Nos. DH091 and DH092) were located on the hillside about 20 m above the crest of slope No. 11NW-A/C61 (see Figure 4).

Drillhole No. DH091, which was drilled above the slope crest in an area of disturbed hillside associated with former squatter development (Section 2.1), revealed about 5 m of fill as indicated by a Standard Penetration Test N value of 5 overlying about 4 m of completely decomposed granite (CDG) and 2.5 m of highly decomposed granite (HDG) overlying bedrock which comprised moderately decomposed medium-grained granite (MDG) and slightly decomposed granite (SDG). In drillhole No. DH092, approximately 0.5 m of topsoil/colluvium was found to overlie some 4 m of residual soil and about 7.8 m of CDG and HDG. SDG and MDG (Grade II and III granite respectively) were encountered at about 11.5 m and 12.3 m below ground surface in drillholes Nos. DH091 and DH092 respectively, with closely to medium spaced jointing, limonite and chlorite stained surfaces in the rock

mass dipping at between 10° and 20° in drillhole No. DH091 (Figure 5) and between 5° and 65° in drillhole No. DH092. Dip directions and infilling were not indicated in the report.

The groundwater condition was investigated using two standpipe piezometers installed in each of the drillholes. Monitoring of groundwater level in the piezometers was carried out between 28 October 1997 and 4 November 1997 (i.e. 8 days). The groundwater level of the lower piezometer in drillhole No. DH091 (which had been installed at 1 m below the top of Grade III granite) dropped during the monitoring period and the last recorded groundwater level was about 1.7 m above rockhead. During the same period, the other piezometers, two of which were installed within soil at depths of about 9 m (drillhole No. DH091) and 4 m (drillhole No. DH092) below ground surface respectively and the other one in bedrock at a depth of 13.5 m below ground surface in drillhole No. DH092, remained dry. One further set of groundwater level readings was taken on 17 January 1998 which indicated that the groundwater level was at about 0.5 m above rockhead in the lower piezometer in drillhole No. DH091 and at the rockhead in the lower piezometer in drillhole No. DH092 while the upper piezometer of each of the drillholes was dry.

MCL inspected the slope between March and October 1997. Since the face of the rock portion was covered with dense unplanned vegetation comprising small trees, shrubs and grass (Plate 3), only the lowest 2 m of the rock cut portion of slope No. 11NW-A/C61 could be inspected. MCL reported that "A number of unstable blocks with potential wedge, toppling, and locally, plane failure were identified". MCL also observed seepage and dampness on the exposed rock cut portion of the slope between May and October 1997 and in January 1998 and February 1998. The Stage 3 Study Report did not record any observation of the landslide scar identified by B&P in 1977.

The lowest 2 m section of the exposed rock cut portion of slope No. 11NW-A/C61 was mapped by MCL between late 1997 and early 1998 for the preparation of the Stage 3 Study Report, prior to commencement of LPM works. The rock cut portion at the toe of slope No. 11NW-A/C61 was described as "sub-vertical to overhanging, and generally formed of M/SDG. Discontinuities are generally closely to medium spaced, locally very closely spaced" in the Stage 3 Study Report. The central part of the rock cut slope was described as "moderately to slightly decomposed, fine- and medium- to coarse-grained granite. The dominant joints are very closely spaced. The central part also contained a number of sub-vertical shear planes". The discontinuities were further described as "Spacing: very close to close (<50 to 300 mm) and close to moderate (50 mm to 1 m). Roughness: slightly rough to rough and smooth to slightly rough, occasionally slickensided. Separation: tight to moderately open (0.1 to 5 mm). Infilling: stained surfaces or hard walls. Local seepage of water. Dominant potential failure modes are wedge and toppling, locally plane". Results of MCL's rock joint/discontinuity survey are presented in a stereographic plot in the Stage 3 Study Report, which is reproduced in Figure 6. MCL concluded that "Planes representing two persistent moderately- to widely- spaced joint sets (Sets J1 and J2) likely to define potentially unstable wedges are highlighted on the stereographic plot" and "a number of joints do give rise to both potential plane and toppling failure".

The Stage 3 Study Report stated that detailed design of the rock cut portion of slope No. 11NW-A/C61 would be undertaken after a detailed rock joint/discontinuity mapping following vegetation clearance during the LPM works. "Potential plane, and toppling failures, if identified, will be addressed on a case-by-case basis, and in accordance with design

methods described in Hoek & Bray". The design approach and a specimen calculation for dealing with potential wedge failures, which were in general in accordance with the design method described in Hoek & Bray (1981), were presented in the Stage 3 Study Report by MCL.

The Stage 3 Study Report was submitted to the GEO on 18 March 1998 for checking. The Mainland West Division of the GEO commented on the design of the proposed upgrading works to the soil slope in the Stage 3 Study Report and requested that "the overall stability of the rock slope should be confirmed prior to the commencement of the soil nailing works". On 1 June 1998, MCL submitted a revised Stage 3 Study Report, which was checked independently within MCL by an Independent Checking Engineer (ICE), to the GEO for comment. The report included no significant amendments to the sections of the report covering the rock cut portion of the slope. GEO made no further comments on the revised Stage 3 Study Report.

3.3 LPM Works

The LPM upgrading works were carried out between 6 September 1999 and 30 June 2000 under Contract No. GE/98/02 by the contractor, Kwan On Construction Company Limited, under the supervision of MCL.

After the removal of the dense unplanned vegetation covering the rock cut portion of slope No. 11NW-A/C61, MCL carried out a detailed rock joint discontinuity survey (Figure 6) in early February 2000. MCL concluded that, while rock joints could give rise to planar and toppling failures, large-scale wedge failures were unlikely. The rock joint discontinuity survey indicated the dip and dip direction only of the joint planes with no further information given as to the condition of the rock joint surfaces. According to MCL's working sketches of the rock face, locations of unstable blocks, overhanging faces and potential wedge or planar failure were identified. There is no mention in the Stage 3 Study Report of the "crushed zone", which daylights the rock cut face with a dip angle of 18°, as documented by Law & Li (2001).

By 22 February 2000, the design of the rock slope upgrading works was finalised for the whole of the rock cut portion. These included the installation of rock dowels and rock bolts, buttressing with relief drains, dentition works, scaling of loose rock blocks, shotcreting of local areas and installation of raking drains. No stabilisation works were considered necessary in the immediate vicinity of the source area of the detached rock block. Field notes made at the time of the LPM works by MCL recorded that some rock above the potential wedge area of the source of the rock fall had been removed. It is understood that the reason for not shotcreting the entire rock portion was to keep more natural rock exposed for good visual appearance. There are no records to indicate that the finalised rock slope upgrading works had been reviewed by an ICE.

The LPM works on slope No. 11NW-A/C61 were completed on 30 June 2000 and the maintenance period of the works contract ended on 30 June 2001. HyD took over the maintenance responsibility for the slope on 22 August 2000. The maintenance manual prepared by MCL, which documents the completed works in the as-built drawings (Appendix A), indicates the potential maintenance actions in the future for slope

No. 11NW-A/C61. These include removal of any loose rock debris and any undesirable vegetation from the rock slope or around boulders during the slope upgrading works, with particular recommendations to note any abnormality such as widening or propagation of cracks, or a sudden or significant increase in seepage. The maintenance manual did not contain the finalised design for the rock cut portion of slope No. 11NW-A/C61.

3.4 Assessment of Geological Features Related to Recent Landslides in Kwai Chung

A regional engineering geology study of the Kwai Chung area carried out by the Planning Division of the GEO (Law & Li, 2001) examined the geological features related to recent landslides in the Kwai Chung area. The objective of the report was to identify slopes with geological characteristics that were adverse to slope stability, particularly geological characteristics that may be similar to those related to the Fei Tsui Road landslide and Shum Wan Road landslide in 1995, and to identify slopes that have a history of persistent seepage and multiple minor failures.

Slope No. 11NW-A/C61 was inspected by the Planning Division in March 2000. Law & Li (2001) recognised that "Persistent seepage and complex joint pattern…are distinctive features of this slope. The absence of seepage on the immediately adjacent slopes on both sides implies that the stability of this slope may be controlled by localised very closely spaced fracture, possibly related to faulting. At least one crushed zone is observed in the slope, dipping out the cut slope face at about 18°".

4. MAINTENANCE INSPECTIONS/WORKS

Following the completion of the slope upgrading works under the LPM Programme at the end of June 2000, routine maintenance inspection (RMI) by HyD on the 28 November 2000 recommended follow-up actions comprising removal of overgrown vegetation from the slope (Plate 4) and clearing blocked channels and catchpits. According to HyD's record, the recommended works were carried out by HyD in December 2000. The next RMI on 6 December 2001 (before the March 2002 rockfall) indicated that no follow-up action was recommended as a result of the inspection (Plate 5).

5. THE MARCH 2002 ROCKFALL INCIDENT

At about 10:15 a.m. on 23 March 2002, when the Amber Rainstorm Warning was hoisted, the rockfall (GEO Incident No. 2002/03/0012) occurred approximately 60 m from the western end of slope No. 11NW-A/C61 (Figure 2), adjacent to Castle Peak Road, Kwai Chung. Most of the rockfall debris, which had an estimated failure volume of 0.1 m^3, fell from the upper part of the rock cut portion (about 10 m from the slope toe) onto the footpath at the toe of the slope (Plate 1). The remainder of the debris fell onto the road (Plate 2) causing the temporary closure of one lane of the road. No casualties were reported as a result of the incident.

At the recommendation of the GEO, following the 23 March 2002 rockfall incident, HyD completed urgent repair works which comprised clearance of rockfall debris and

removal of unplanned vegetation and loose rock blocks (about 0.5 m^3 in total) from the exposed portion of the rock slope. Installation of rock mesh netting over selected areas of the exposed rock cut portion of slope No. 11NW-A/C61 was also carried out by HyD between April and May 2002 as preventive maintenance works at the recommendation of the GEO.

6. FIELD OBSERVATIONS FOLLOWING THE ROCKFALL

Following the incident, MGSL inspected the site on 27 March 2002 and carried out a rock joint discontinuity survey on 19 April 2002. The location of the source of the rockfall was established by comparing stereopairs of photographs taken by MCL before and after completion of the LPM works with photographs taken after the rockfall incident (Plates 6, 7 and 8). The detached rock block appears to have originated from just below the interface between the shotcreted soil portion and the exposed rock cut portions of the slope, some 10 m above the toe. The detached rock block was about 0.6 m wide by 0.6 m long and between about 0.15 m and 0.2 m thick, with a failure volume of about 0.1 m^3.

MGSL carried out a detailed rock joint discontinuity survey during the subsequent urgent repair works by HyD in April 2002, for the rock cut portion in the immediate vicinity of the source area of the March 2002 rockfall. The exposed moderately decomposed rock at the failure location comprised moderately strong, greyish yellow to brownish yellow spotted white, fine grained granite with extremely narrow, medium to closely spaced, iron and manganese stained, smooth planar joints, with a persistence of between about 0.5 m and 5.0 m. Four major joint sets were recorded by MGSL with dips and dip directions of 33°/241°, 77°/044°, 59°/083° and 82°/166°, and the dip and orientation of the rock cut portion in the vicinity of the source area of the March 2002 rockfall were recorded as 65°/215°.

Results of rock joint mapping carried out by MGSL presented in a stereoplot (Figure 7) indicates the potential for toppling failure and a low potential for sizeable wedge and planar failures. The combination of sub-vertical and adversely inclined joints, which are closely spaced, would give rise to the potential for local failures. MGSL's mapping of the rock face indicated that no sizeable failures were apparent and locally planar, wedge or toppling potential was minor for unrestrained rock blocks.

The overall rock cut portion has an average dip and orientation of 65°/195°. The nature of the joint infill was limited to the remains of thin roots of shrubs at the interface of the detached rock block and the rock mass but locally the infill was silty sand up to 30 mm thick. Seepage was observed from rock joints at seven locations in the mapped area as shown in Figure 2, up to a height of about 5 m from the toe of the slope. MGSL also observed seepage from weepholes, about 2 m above the slope toe on the shotcrete covered areas of the rock slope (Figure 2). A zone of crushed rock, some 300 mm thick, is present in the rock cut portion about 20 m to the west of the source of the rockfall. At the time of the inspection on 19 April 2002 before the urgent repair works, a few loose blocks were still present on the rock face, approximately 2.5 m and 3.0 m to the east of the March 2002 rockfall source at heights of about 6.5 m and 7.0 m respectively. At the time of the inspection, some unplanned vegetation such as grass was observed to be growing from the rock joints just below the source area of the detached rock block. MGSL did not observe any signs of large-scale incipient instability for the rock portion of the cut slope.

MGSL noted that unplanned vegetation comprising tall grass and small shrubs had quickly re-established on the slope (since the removal of vegetation as part of the slope upgrading works in January 2000, see Plate 6), particularly on the upper rock portion of the slope, by examination of photographs taken by MCL in July 2000 (Plate 7). No signs of blockage of the surface drainage system on the berms or slopes were observed by MGSL's inspection in March 2002. There were no indications to suggest that the berm drainage system had overtopped during heavy rainfall. MGSL's observation in the vicinity of the source area of the March 2002 rockfall also confirmed that the shotcrete cover of the slope was generally in a good condition and no significant cracks were present at the interface between the shotcrete cover and the 300 mm U-channel at the berm.

MGSL did not observe the landslide scar on slope No. 11NW-A/C61 identified by B&P in 1977. Inspections of slope No. 11NW-A/C61 carried out by MGSL after the March 2002 rockfall incident did not identify any signs of potential for large-scale incipient instability.

7. ANALYSIS OF RAINFALL RECORDS

The nearest GEO automatic raingauge (No. N04) to the March 2002 rockfall site is located at Kai Kwong Lau, Cho Yiu Estate, about 800 m to the west of the site (Figure 1). The incident occurred at about 10:15 a.m. on 23 March 2002 when the Amber Rainstorm Warning was hoisted.

The daily rainfall recorded by the raingauge over the preceding month and the three days following the incident is presented in Figure 8. The hourly rainfall readings for the period between 21 March and 23 March 2002 are also shown in Figure 8. The peak hourly rainfall of approximately 18 mm was recorded between 6:00 a.m. and 7:00 a.m. in the 24-hour period preceding the 23 March 2002 rockfall incident.

Analysis of the return periods of rainfall intensities before the incident for different rainfall durations based on historical rainfall data at the Hong Kong Observatory (Lam & Leung, 1994) is given in Table 1. The results show that return periods for rainfall durations of between 5 minutes and 31 days are all less than 2 years. The return periods based on the data recorded by raingauge No. N04 between 1984 and 1997 have also been assessed using the statistical parameters derived by Evans & Yu (2001). There is no significant difference between the estimated return periods based on the historical rainfall data at the Hong Kong Observatory and the data at raingauge No. N04.

The results of an analysis of the return periods of the intensities of the previous rainfall records between the completion date of the works, 30 June 2000, and the date of the rockfall incident, are given in Table 2. The most severe rainfall in this period was recorded on 1 and 2 September 2001. The results show that the rainfall return periods for durations were more than 2 years and the critical rainfall duration was for 2 hours, which corresponds to a return period of 13 years (Table 2). A comparison of the patterns of selected past major rainstorms recorded at raingauge No. N04 since it became operational in September 1978 is presented in Figure 9. The maximum rolling rainfall indicates that the rainstorm on 23 March 2002 was much less severe than the 1 September 2001 rainstorm and other rainstorms experienced since the completion of the slope upgrading works in 2000.

8. DIAGNOSIS OF THE PROBABLE CAUSES OF THE ROCKFALL

The source of the rockfall was located just below the interface of the newly shotcreted soil portion (previously covered with chunam, see Plate 6) and the exposed rock cut portion below where locally a set of adversely orientated joints and unplanned vegetation provided the potential for toppling of marginally stable blocks. The detachment of the rock blocks, which occurred shortly after a period of moderate rainfall, was probably caused by the development of cleft water pressure in the sub-vertical joints behind the rock blocks, which had probably been exacerbated by the gradual opening up of the rock joints as a result of progressive deterioration. The progressive deterioration of the rock face was possibly promoted by root action due to unplanned vegetation, which apparently had quickly spread across the slope following the upgrading works.

Prior to the slope upgrading works under the LPM Programme in 2000, there was no reported rockfall incident for slope No. 11NW-A/C61. The stabilisation measures for the soil portion of the slope included, inter alia, replacement of chunam cover with shotcrete cover. The hard cover could have directed concentrated surface runoff onto the area of the source of the March 2002 rockfall, thus promoting progressive deterioration and rapid growth of unplanned vegetation. Given the generally good condition of the shotcrete cover and the interface between the shotcrete cover and the 300 mm U-channel at the berm immediately above the source area of the March 2002 rockfall, the major source of the water ingress would probably be from concentrated surface runoff from directly above the source area.

The rock slope portion was covered with dense unplanned vegetation comprising trees and shrubs prior to LPM works (Plate 3). Unplanned vegetation comprising tall grass and small shrubs had quickly re-established on the upper rock portion some six months after completion of LPM works (Plate 7). The presence of unplanned vegetation may have been a contributing factor to the failure.

9. CONCLUSION

On 23 March 2002, a small rockfall occurred on slope No. 11NW-A/C61 at about 10:15 a.m.. Most of the rockfall debris fell about 10 m from the exposed rock cut portion of the slope onto a narrow footpath (1 m wide) at the toe of the slope and the remainder fell onto the road causing the temporary closure of one lane of the road. Although the volume of the rockfall was relatively small, the consequences could have been serious given the heavy traffic on the affected section of Castle Peak Road.

The detachment of the rock blocks was probably caused by the development of cleft water pressure in the sub-vertical joints behind the rock blocks, which was probably been exacerbated by the gradual opening up of the rock joints as a result of progressive deterioration.

The slope was upgraded under the LPM Programme between September 1999 and June 2000. MCL carried out detailed mapping of the rock cut portion of the slope during the LPM upgrading works, after vegetation clearance. Extensive rock slope stabilisation works were carried out but no stabilisation works were considered necessary in the immediate vicinity of the source area of the March 2002 rockfall incident during LPM works.

Inspections of slope No. 11NW-A/C61 carried out by MGSL after the March 2002 rockfall incident did not identify any signs of potential for large-scale incipient instability.

10. REFERENCES

Bachy Soletanche (1997). Ground Investigation - LPM Term Contract - Factual Fieldwork Report for Contract No. GE/95/06 for Features No. 11NW-A/C59 & C61 Along Castle Peak Road, Hong Kong. Report Prepared for the Geotechnical Engineering Office, Hong Kong, 8 p. (plus appendices).

Evans, N.C. & Yu, Y.F. (2001). Regional Variation in Extreme Rainfall Values. Geotechnical Engineering Office, Hong Kong, 81 p. (GEO Report No. 115).

Geotechnical Control Office (1986). Hong Kong and Kowloon: Solid and Superficial Geology, Hong Kong Geology Survey, Map Series HGM20, Sheet 11, 1:20 000 Scale. Geotechnical Control Office, Hong Kong.

Geotechnical Engineering Office (1994). Phase 2 Systematic Inspection of Features in the Territories Study, Slope No. 11NW-A/C61. Geotechnical Engineering Office, Hong Kong, 1 p.

Hoek E. & Bray, J. (1981). Rock Slope Engineering (Revised Third Edition). Institution of Mining and Metallurgy, 358 p.

Lam, C.C. & Leung, Y.K. (1994). Extreme Rainfall Statistics and Design Rainstorm Profiles at Selected Locations in Hong Kong. Royal Observatory, Hong Kong, Technical Note No. 86, 89 p.

Law, H.Y., & Li, X.C. (2001). Assessment of Geological Features Related to Recent Landslides in Hong Kong: Phase 3E - Kwai Chung Study Area. Geotechnical Engineering Office, Hong Kong, (GEO Geological Report No. GR 2/2001), 133 p.

Mott Connell Limited (1998). Stage 3 Study Report No. S3R 206/97, 11NW-A/C61, Castle Peak Road, Kwai Chung, New Territories. Report prepared for the Geotechnical Engineering Office, Hong Kong, 13 p. (plus appendices).

Mott Connell Limited (2000). Maintenance Manual No. MM 260/99 for 11NW-A/C61, Castle Peak Road, Kwai Chung, M.S. 5.5, New Territories. Report prepared for the Geotechnical Engineering Office, Hong Kong, 6 p. (plus appendices).

LIST OF TABLES

Table 1 - Maximum Rolling Rainfall at GEO Raingauge No. N04 for Selected Durations Preceding the Rockfall on 23 March 2002 and the Estimated Return Periods

Duration	Maximum Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years) (See Note 2)
5 Minutes	3.0	06:40 hours on 23 March 2002	< 2
15 Minutes	8.5	06:50 hours on 23 March 2002	< 2
1 Hour	18.0	07:00 hours on 23 March 2002	< 2
2 Hours	35.0	07:00 hours on 23 March 2002	< 2
4 Hours	48.0	07:15 hours on 23 March 2002	< 2
12 Hours	65.5	09:40 hours on 23 March 2002	< 2
24 Hours	66.5	09:40 hours on 23 March 2002	< 2
48 Hours	66.5	09:40 hours on 23 March 2002	< 2
4 Days	66.5	09:40 hours on 23 March 2002	< 2
7 Days	67.0	09:40 hours on 23 March 2002	< 2
15 Days	68.0	09:40 hours on 23 March 2002	< 2
31 Days	68.0	09:40 hours on 23 March 2002	< 2

Notes:
(1) Maximum rolling rainfall was calculated from 5-minute rainfall data.
(2) Return periods were derived from Table 3 of Lam & Leung (1994) and using data from Evans & Yu (2000). The return periods obtained by the two methods do not show a significant difference.
(3) The use of 5-minute data for return period of rainfall durations between 2 hours and 31 days results in better data resolution, but may slightly over-estimate the return periods using Lam & Leung (1994)'s data, which are based on hourly rainfall for these durations.
(4) The time of the rockfall was taken to be at 10:15 a.m. on 23 March 2002.
(5) The nearest GEO raingauge to the site is raingauge No. N04 at a distance of 0.8 km to the west of the site.

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Table 2 - Maximum Rolling Rainfall at GEO Raingauge No. N04 for Rainfall in 2001 and the Estimated Return Periods

Duration	Maximum Rolling Rainfall (mm)	End of Period (See Note 4)	Estimated Return Period (Years) (See Note 2)
5 Minutes	12.0	22:40 hours on 1 September 2001	< 2
15 Minutes	32.5	22:40 hours on 1 September 2001	4
1 Hour	102.5	22:45 hours on 1 September 2001	10
2 Hours	153.5	23:30 hours on 1 September 2001	13
4 Hours	193.5	00:35 hours on 2 September 2001	10
12 Hours	220.0	00:35 hours on 2 September 2001	4
24 Hours	240.0	00:35 hours on 2 September 2001	3
48 Hours	243.0	00:35 hours on 2 September 2001	< 2
4 Days	400.0	00:35 hours on 2 September 2001	4
7 Days	445.5	00:35 hours on 2 September 2001	4
15 Days	453.5	00:35 hours on 2 September 2001	< 2
31 Days	672.0	00:35 hours on 2 September 2001	2

Notes:
(1) Maximum rolling rainfall was calculated from 5-minute rainfall data.
(2) Return periods were derived from Table 3 of Lam & Leung (1994) and using data from Evans & Yu (2000). The return periods obtained by the two methods do not show a significant difference.
(3) The use of 5-minute data for return period of rainfall durations between 2 hours and 31 days results in better data resolution, but may slightly over-estimate the return periods using Lam & Leung (1994)'s data, which are based on hourly rainfall for these durations.
(4) The rainstorm ended at approximately 12:35 a.m. on 2 September 2001.
(5) The nearest GEO raingauge to the site is raingauge No. N04 at a distance of 0.8 km to the west of the site.

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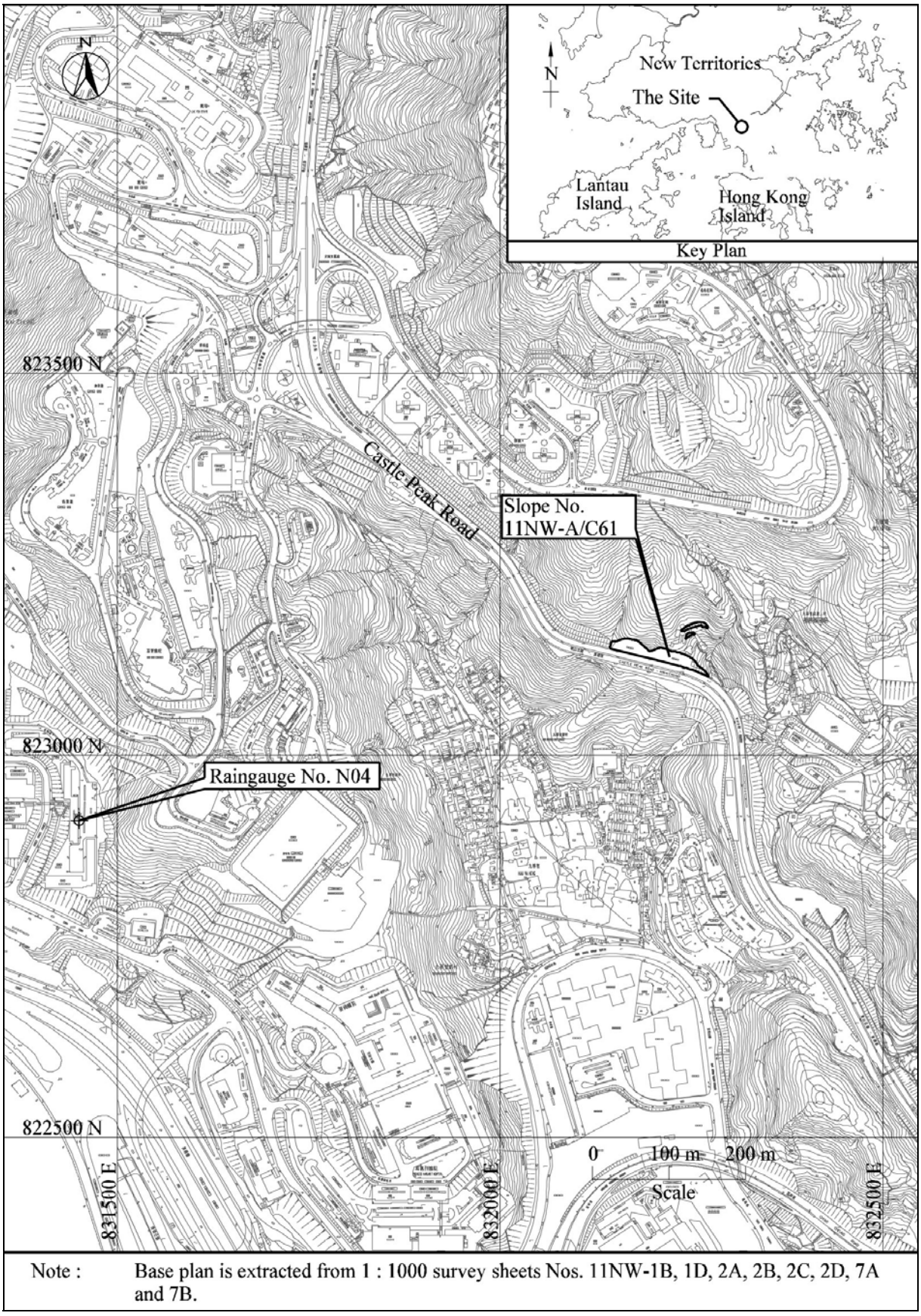

Figure 1 - Location Plan

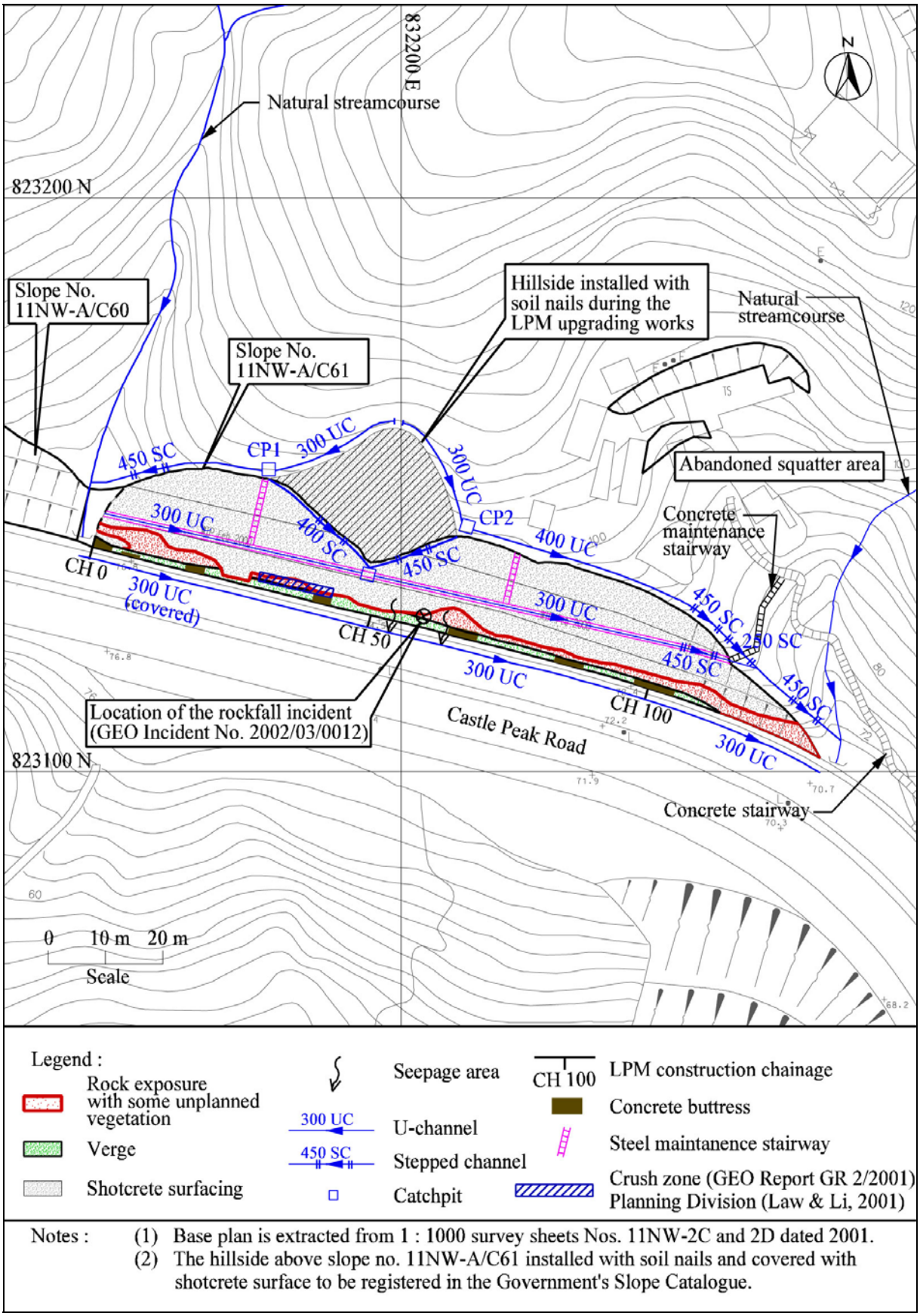

Figure 2 - Field Observations Following the Rockfall

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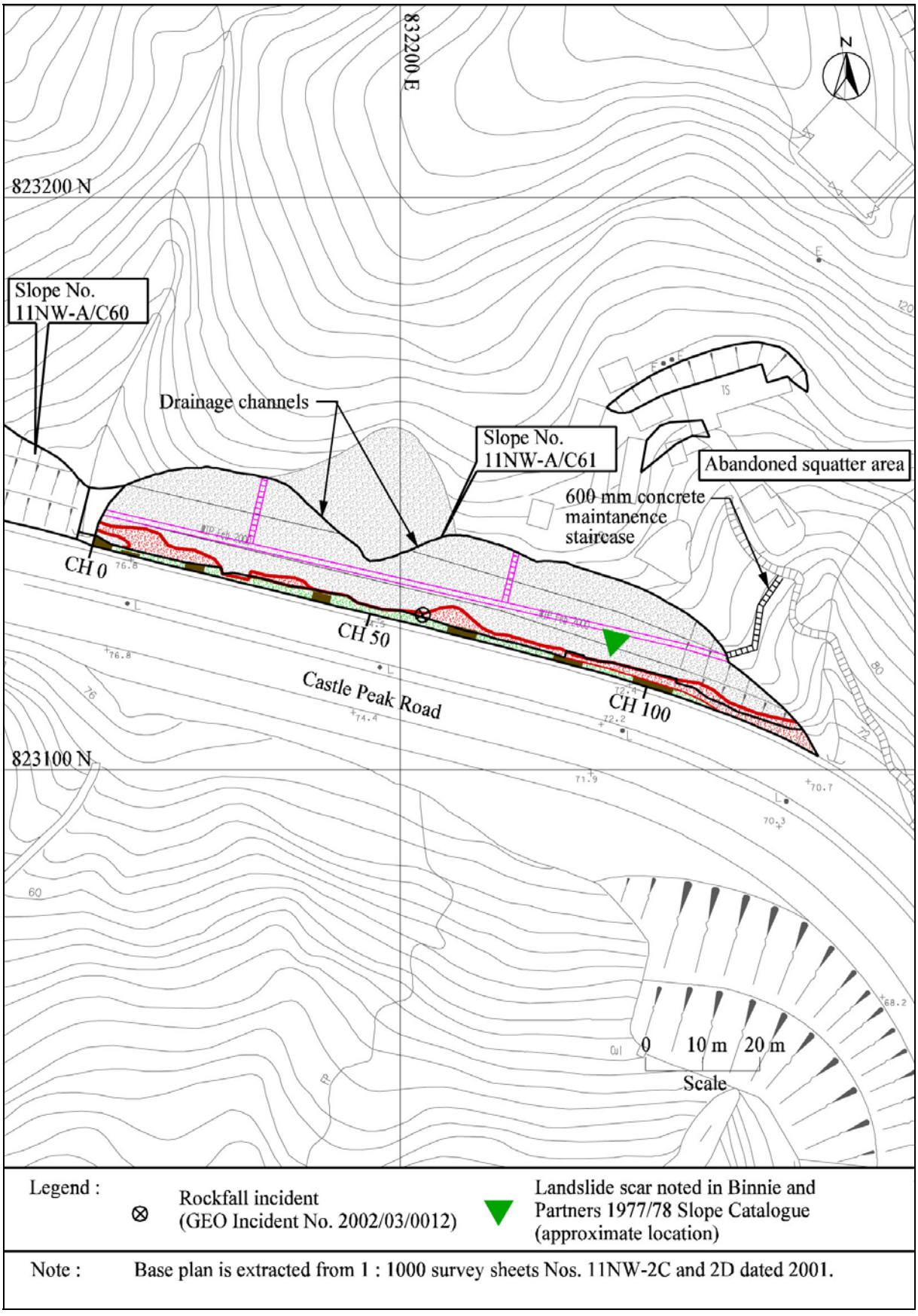

Figure 3 - Previous Landslides

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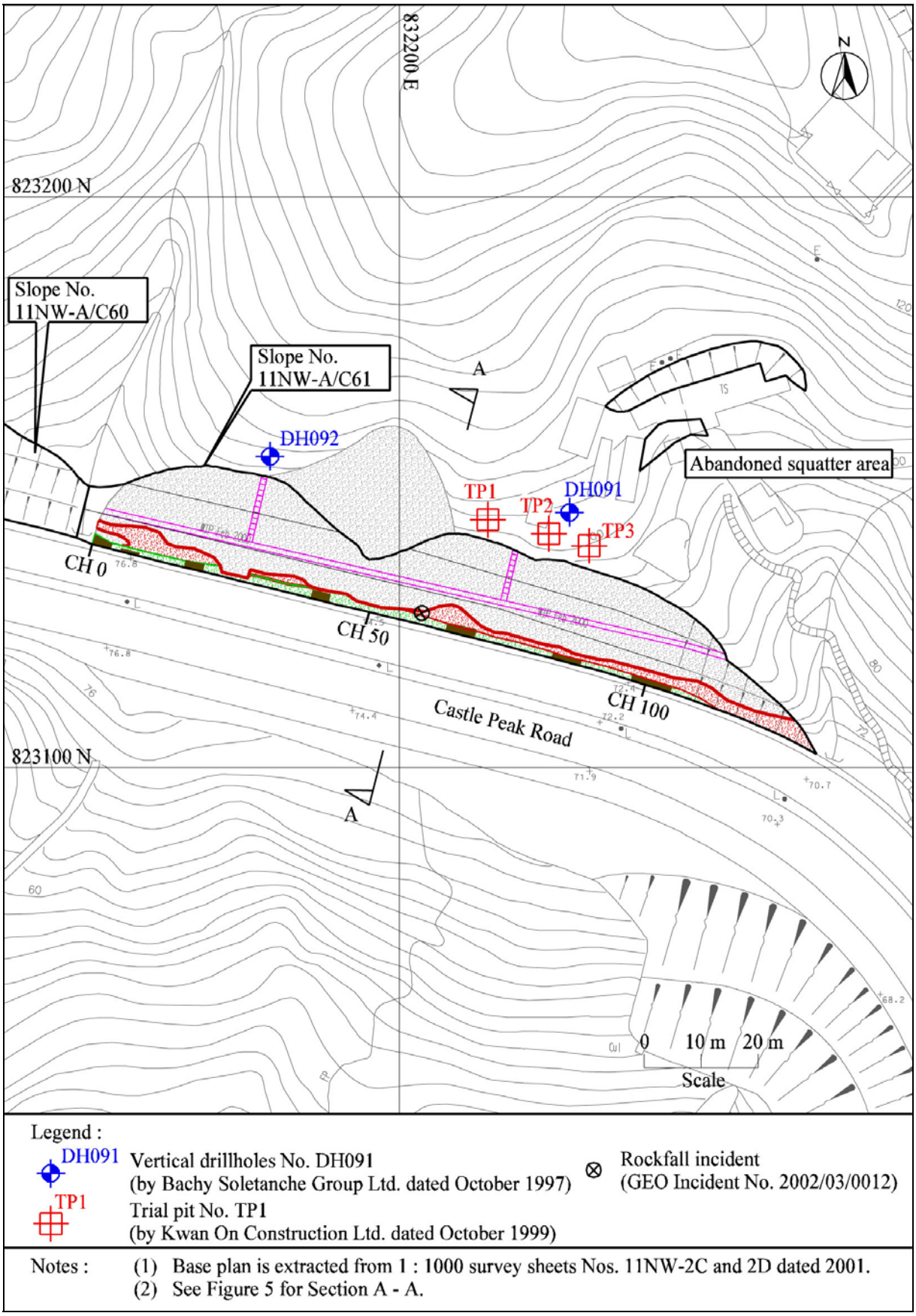

Figure 4 - Previous Ground Investigation Stations

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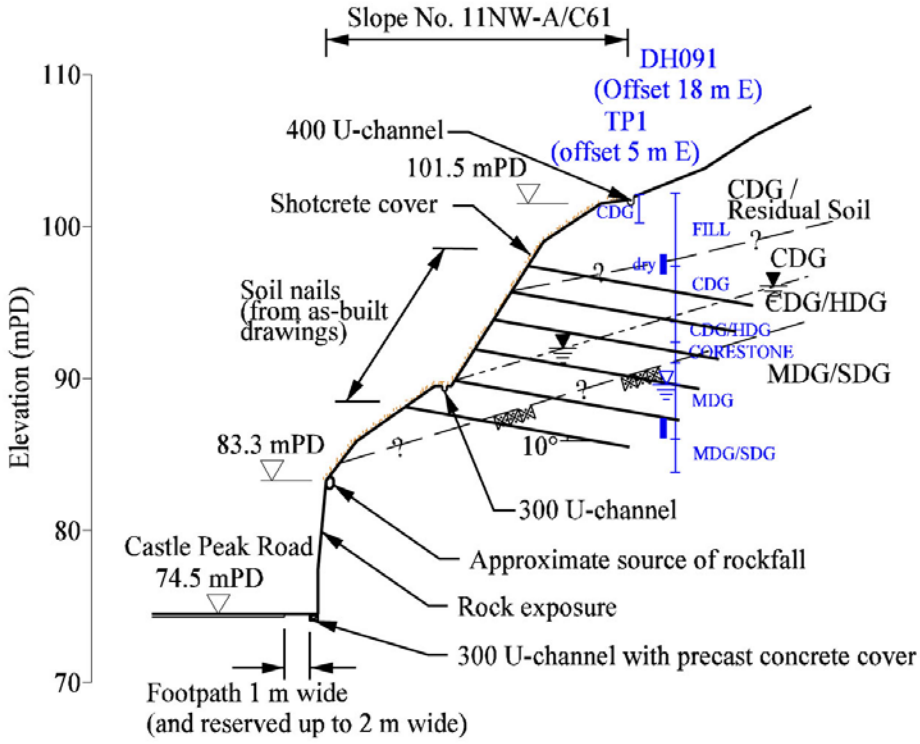
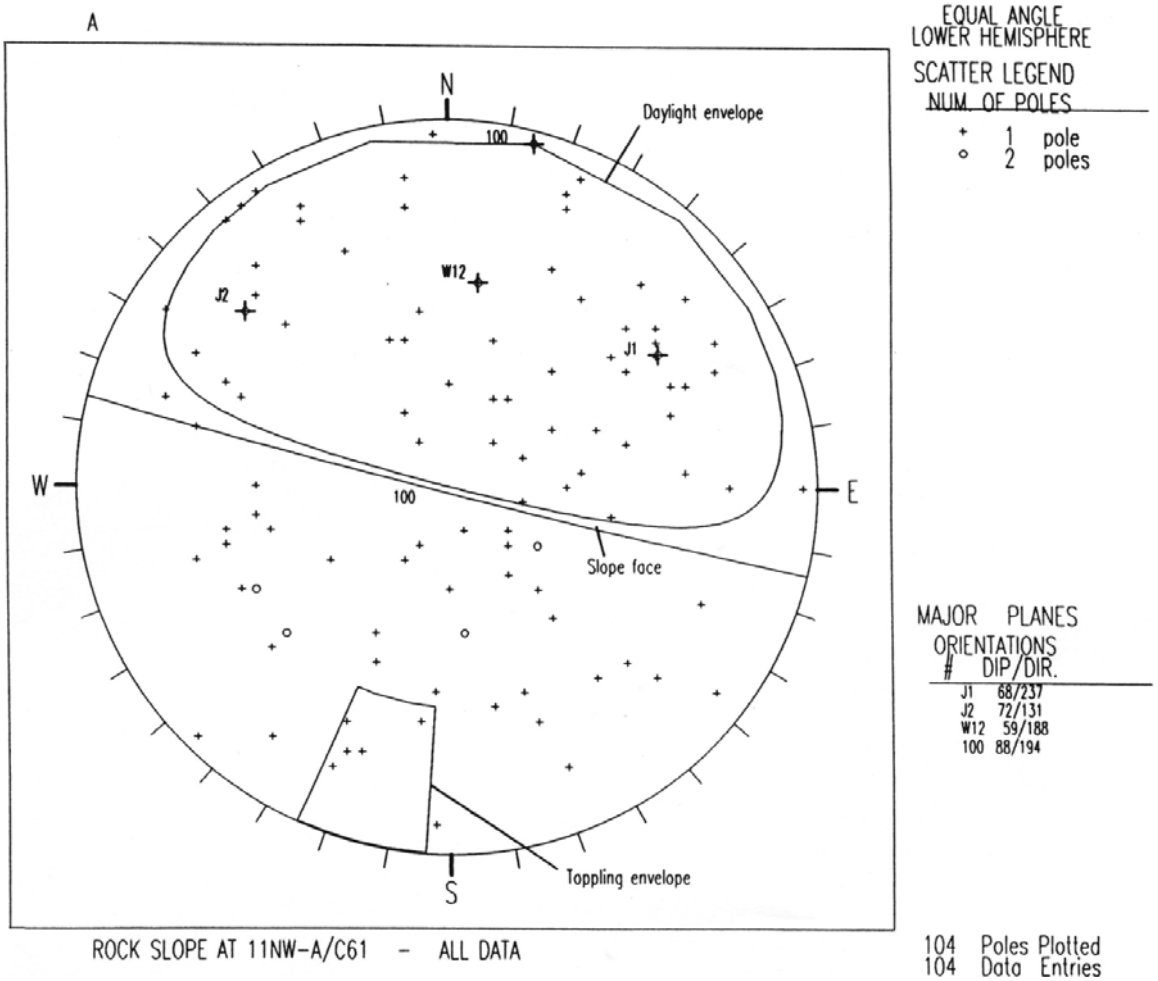


Section A-A

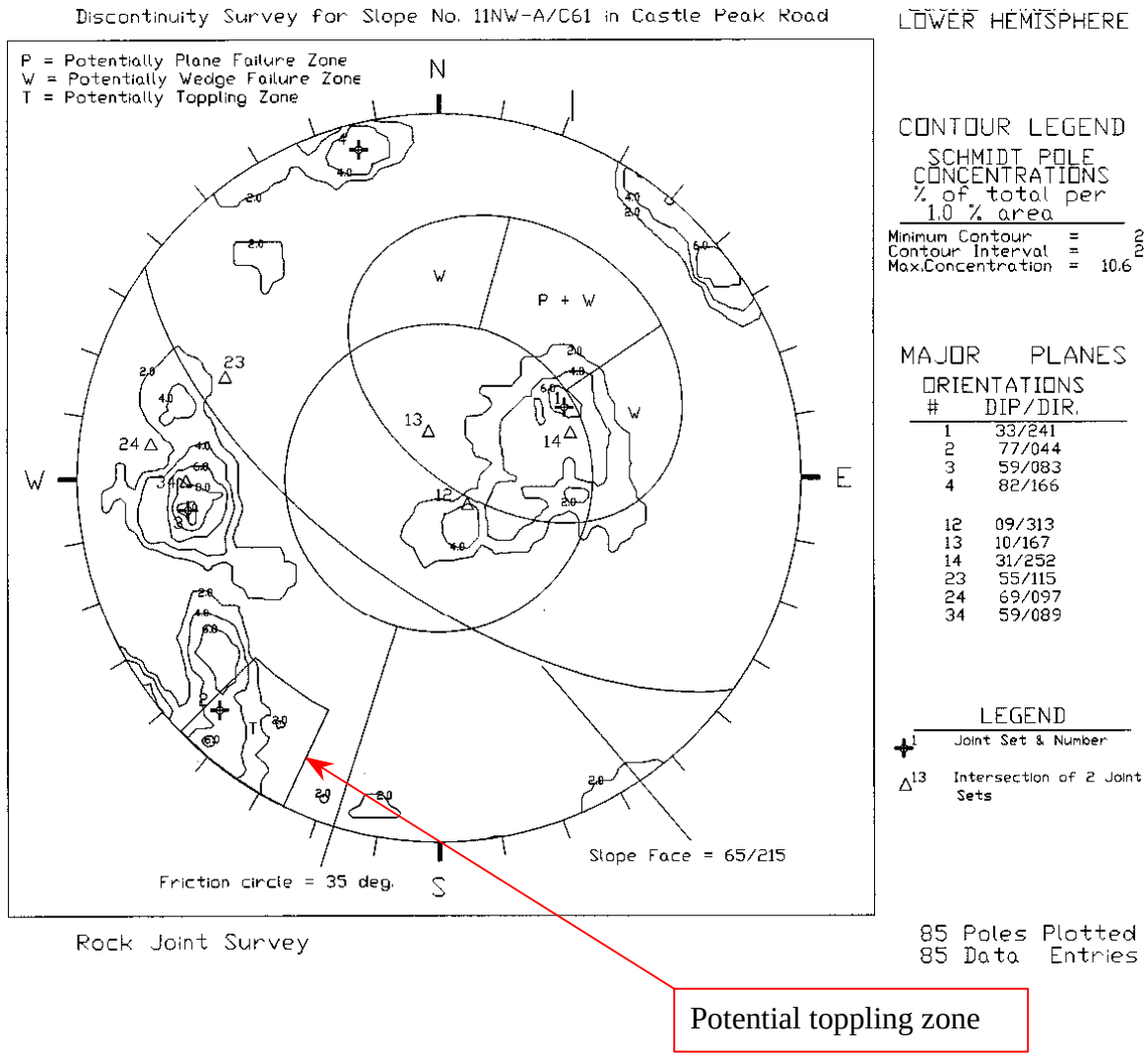
Legend :	Fill	Fill (locally associated with squatter area)		Inferred rockhead
	CDG	Completely decomposed granite		Piezometer tip level
	HDG	Highly decomposed granite		Groundwater level (design)
	MDG	Moderately decomposed granite		Groundwater level (measured) (28.10.97 to 4.11.97 and 17.1.98)
	SDG	Slightly decomposed granite		
Note :	See Figure 4 for location of Section A - A.			

Figure 5 - Geological Section A-A



Notes: (1) Average rock face orientation 65º/195º.
(2) Survey carried out in February 2000.

Figure 6 - MCL Stereoplot of the Entire Rock Portion of Slope No. 11NW-A/C61
(Extracted from MCL Stage 3 Report No. S3R 206/97)



Notes: (1) Average rock face orientation 65º/195º.
(2) Survey carried out in April 2002.

Figure 7 - MGSL Stereoplot of Rock Portion of Slope No. 11NW-A/C61 in the Vicinity of the Rockfall Incident

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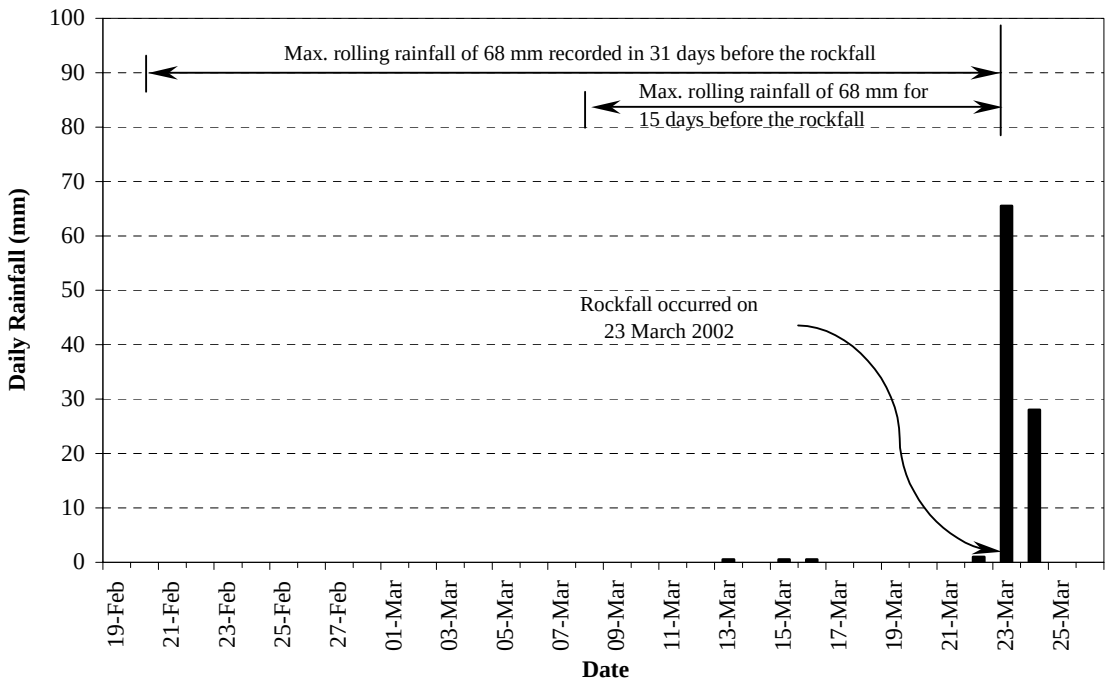
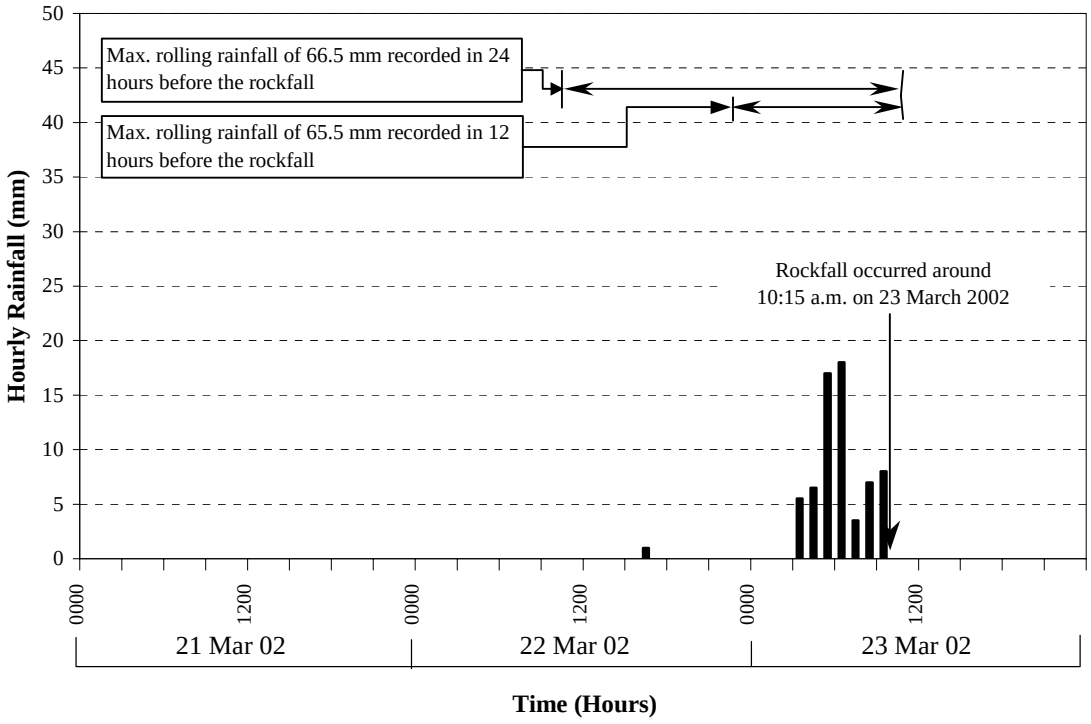


(a) Daily Rainfall Recorded at GEO Raingauge No. N04 from 19 February to 26 March 2002



(b) Hourly Rainfall Recorded at GEO Raingauge No. N04 from 21 to 23 March 2002

Figure 8 - Rainfall Recorded at GEO Raingauge No. N04 for the March 2002 Rainstorm

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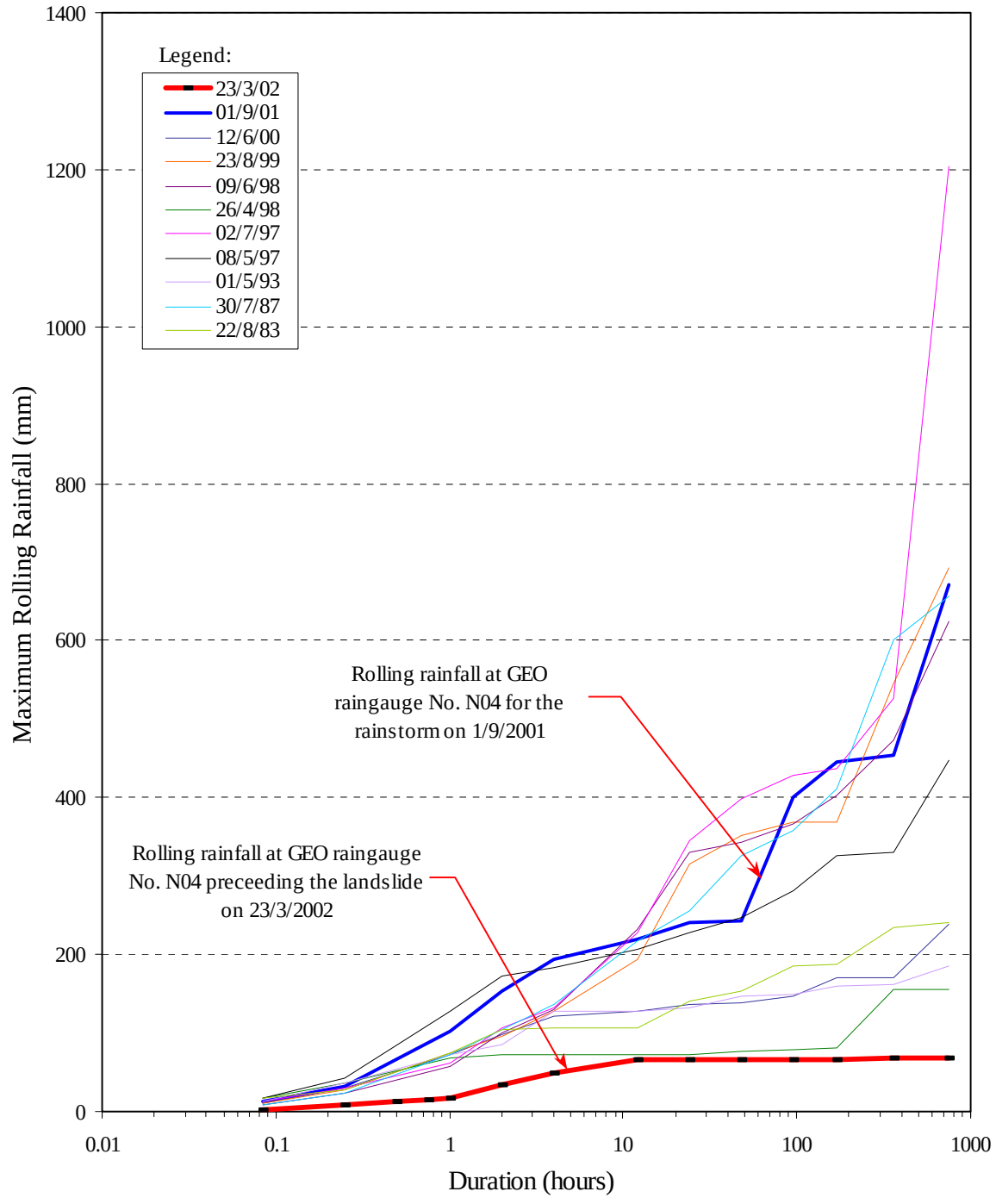

Notes:
(1) Previous rainstorms are selected for GEO raingauge No. N04 given in GEO Report No. 62 - "Areal Extent of Intense Rainfall in Hong Kong 1975 to 1995" (Malone, 1997) and selected rainstorms from 1996 to 2001.
(2) Rainfall data evaluated from 5-minute readings from GEO raingauge No. N04 (about 0.8 km west to the site).
(3) Rolling rainfall of previous rainstorm calculated at GEO raingauge No. N04 since September 1978 when the raingauge began operation.

Figure 9 - Maximum Rolling Rainfall for Previous Major Rainstorms at GEO Raingauge No. N04

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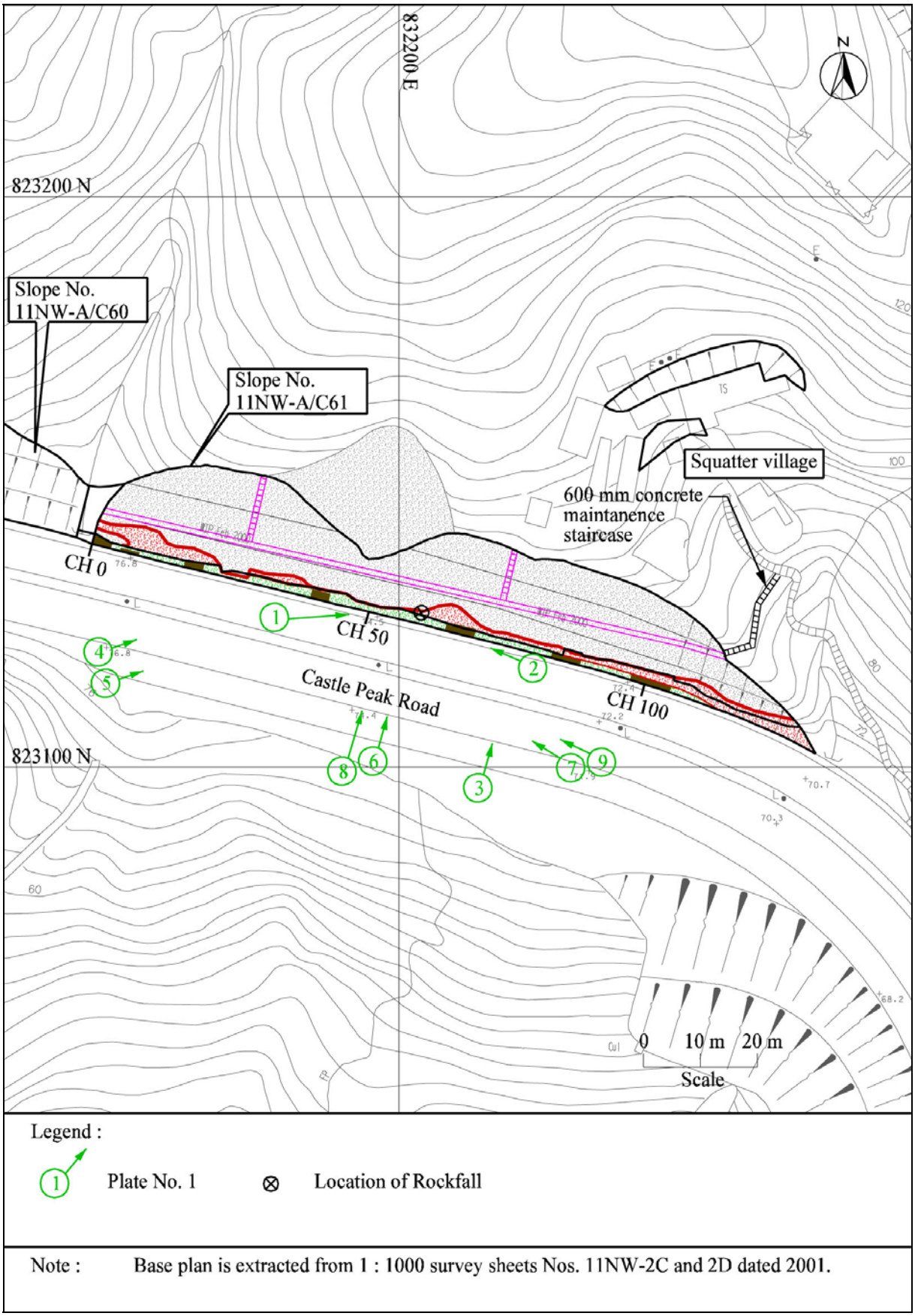

Figure 10 - Locations and Directions of Photographs

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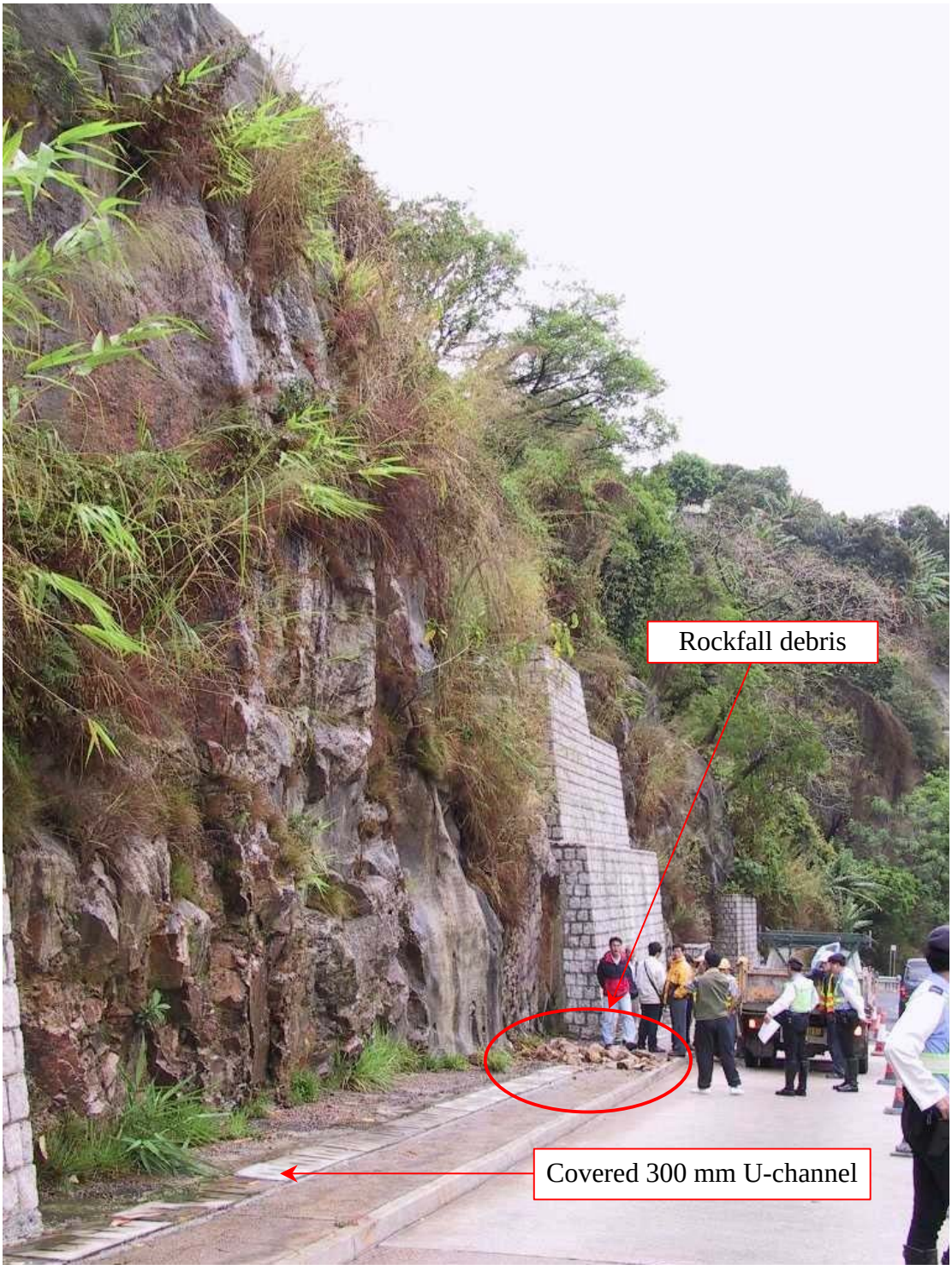

Plate 1 - View of Slope No. 11NW-A/C61 Looking East Showing Debris on the Footpath (Photograph taken by GEO on 23 March 2002)

Note: See Figure 10 for location and direction of photograph.

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Plate 2 - View of Slope No. 11NW-A/C61 Looking West Showing Rockfall Debris
(Photograph taken by GEO on 23 March 2002)

Note: See Figure 10 for location and direction of photograph.

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Plate 3 - View of Slope No. 11NW-A/C61 Showing Unplanned Vegetation on the Rock Cut Portion in 1997
(Photograph taken by Mott Connell Ltd on 25 March 1997)

Note: See Figure 10 for location and direction of photograph.

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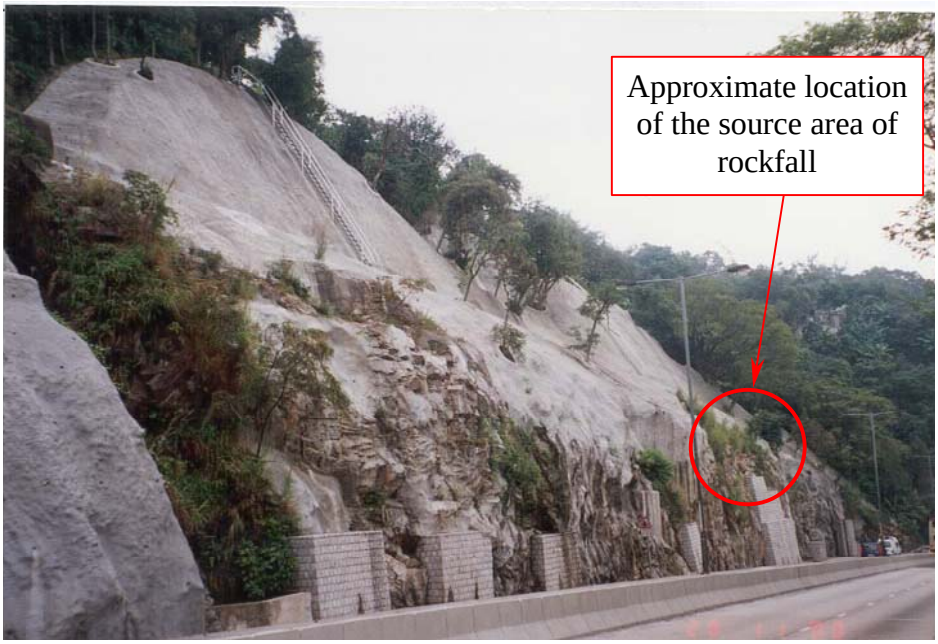

Plate 4 - View of Slope No. 11NW-A/C61 in November 2000 during a Routine Maintenance Inspection (Photograph taken by Highways Department on 28 November 2000)

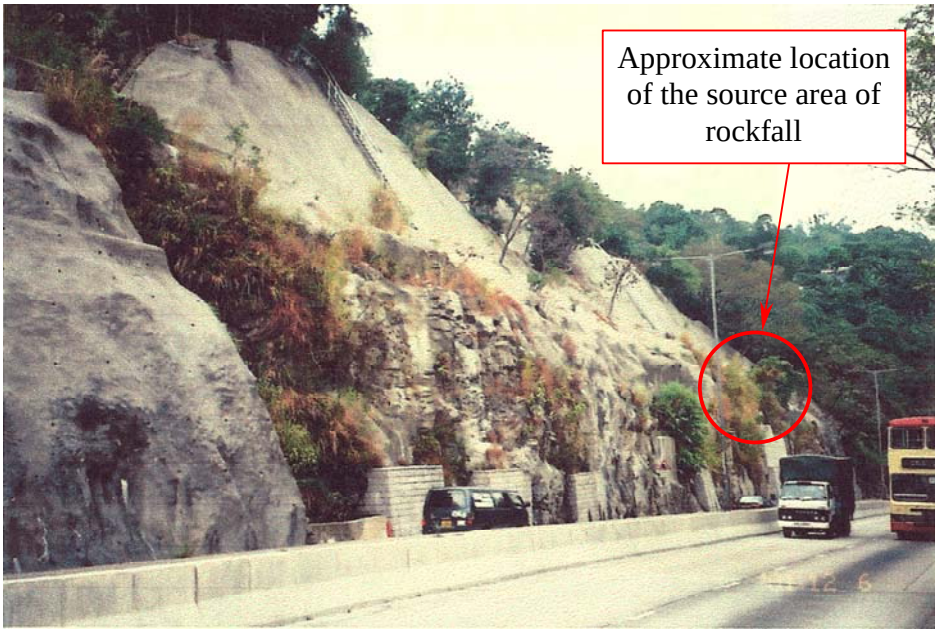

Plate 5 - View of Slope No. 11NW-A/C61 in December 2001 during a Routine Maintenance Inspection (Photograph taken by Highways Department on 6 December 2001)

Note: See Figure 10 for location and direction of photograph.

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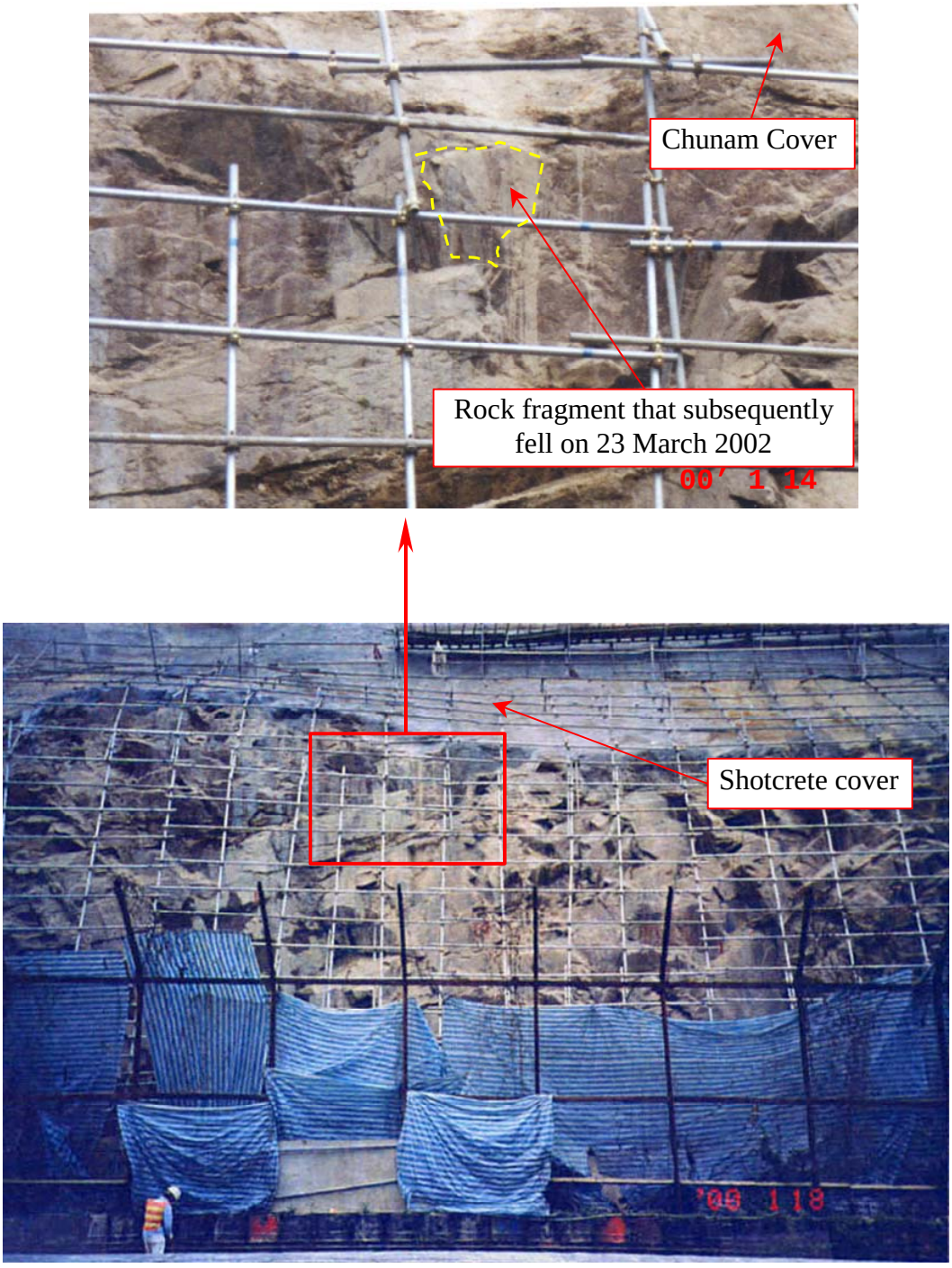

Plate 6 - View of Slope No. 11NW-A/C61 during LPM Works (Photographs taken by Mott Connell Ltd on 14 and 18 January 2000)

Note: See Figure 10 for location and direction of photograph.

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Plate 7 - View of Slope No. 11NW-A/C61 Showing Some Unplanned Vegetation immediately after Completion of LPM Works (Photograph taken by Mott Connell Ltd on 13 July 2000)

Note: See Figure 10 for location and direction of photograph.

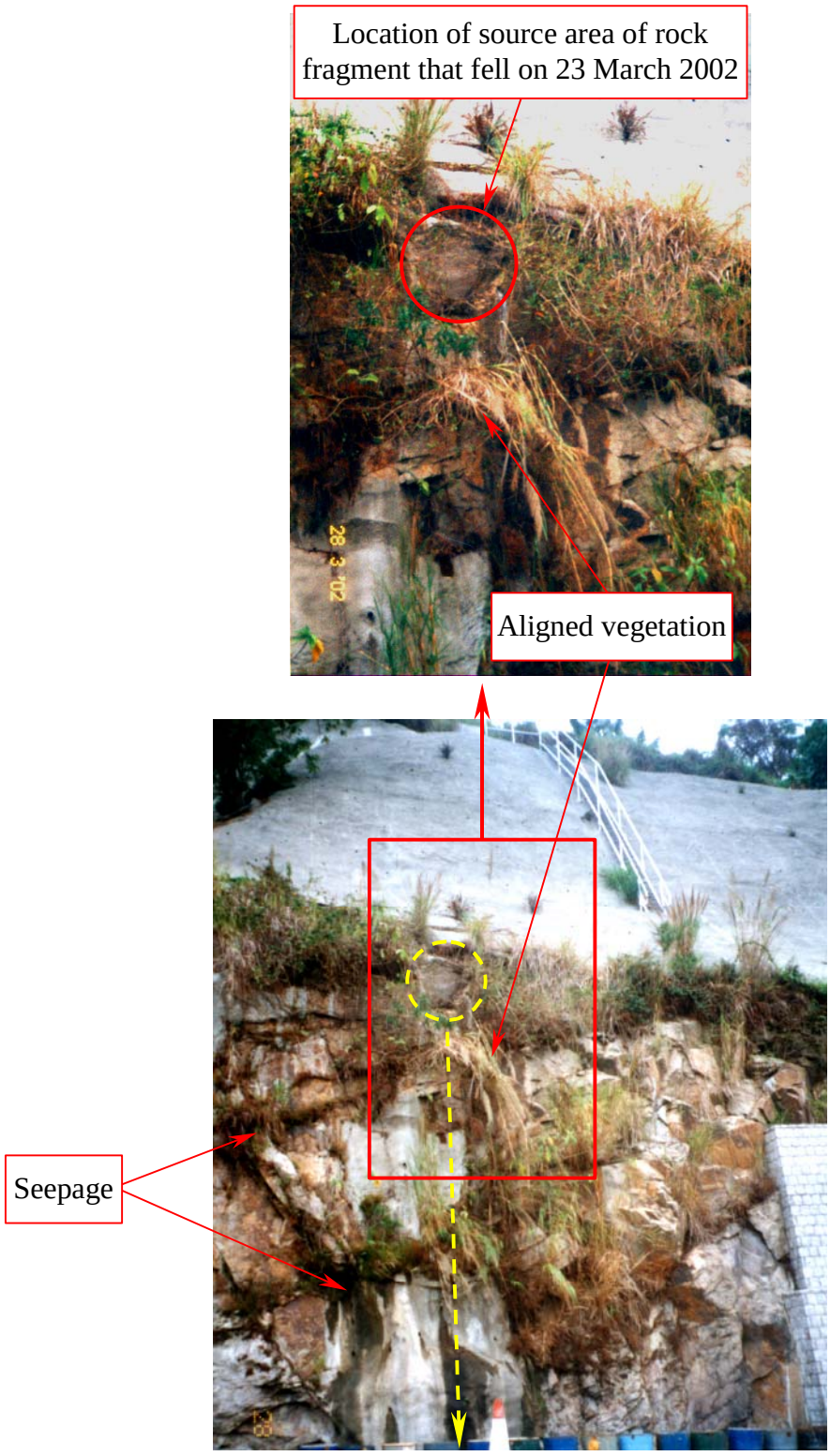

Plate 8 - View of Slope No. 11NW-A/C61 Showing Source Area of the Rockfall (Photographs taken on 28 March 2002)

Note: See Figure 10 for location and direction of photograph.

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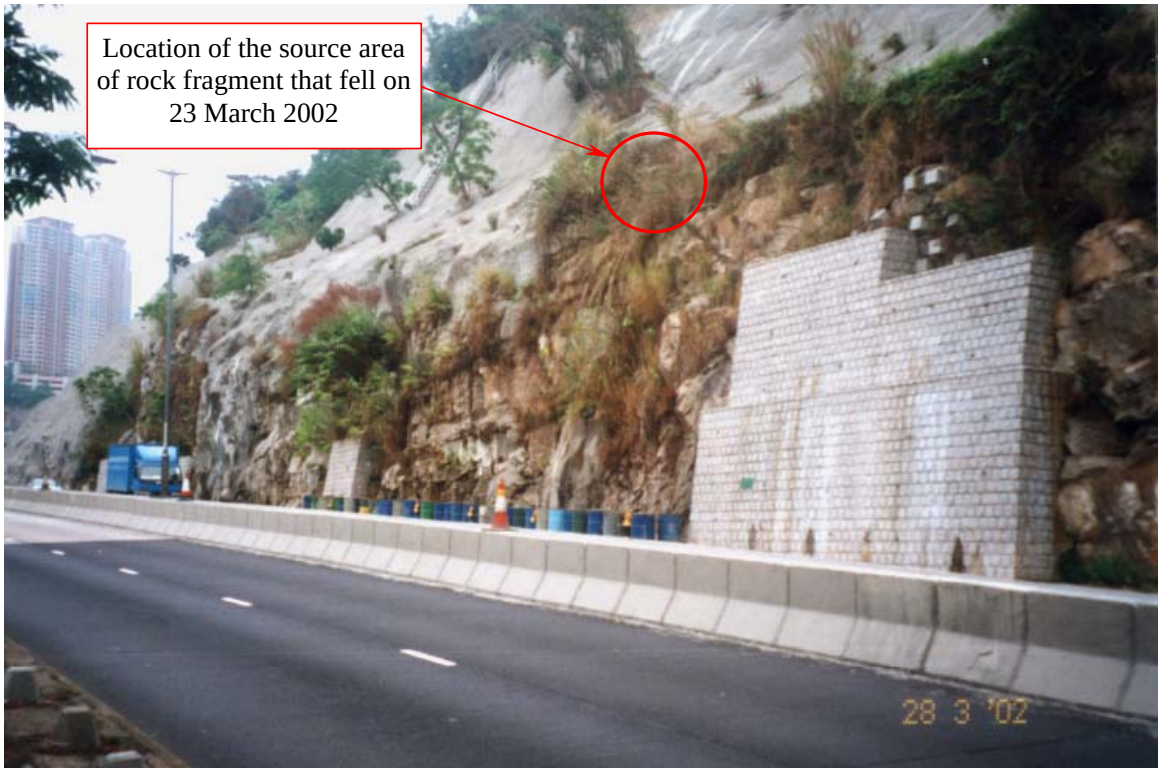

Plate 9 - View of Slope No. 11NW-A/C61 Showing Growth of Unplanned Vegetation on the Rock Portion (Photograph taken on 28 March 2002)

Note: See Figure 10 for location and direction of photograph.

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APPENDIX A

PART PLAN OF LPM AS-BUILT DRAWINGS FOR SLOPE NO. 11NW-A/C61

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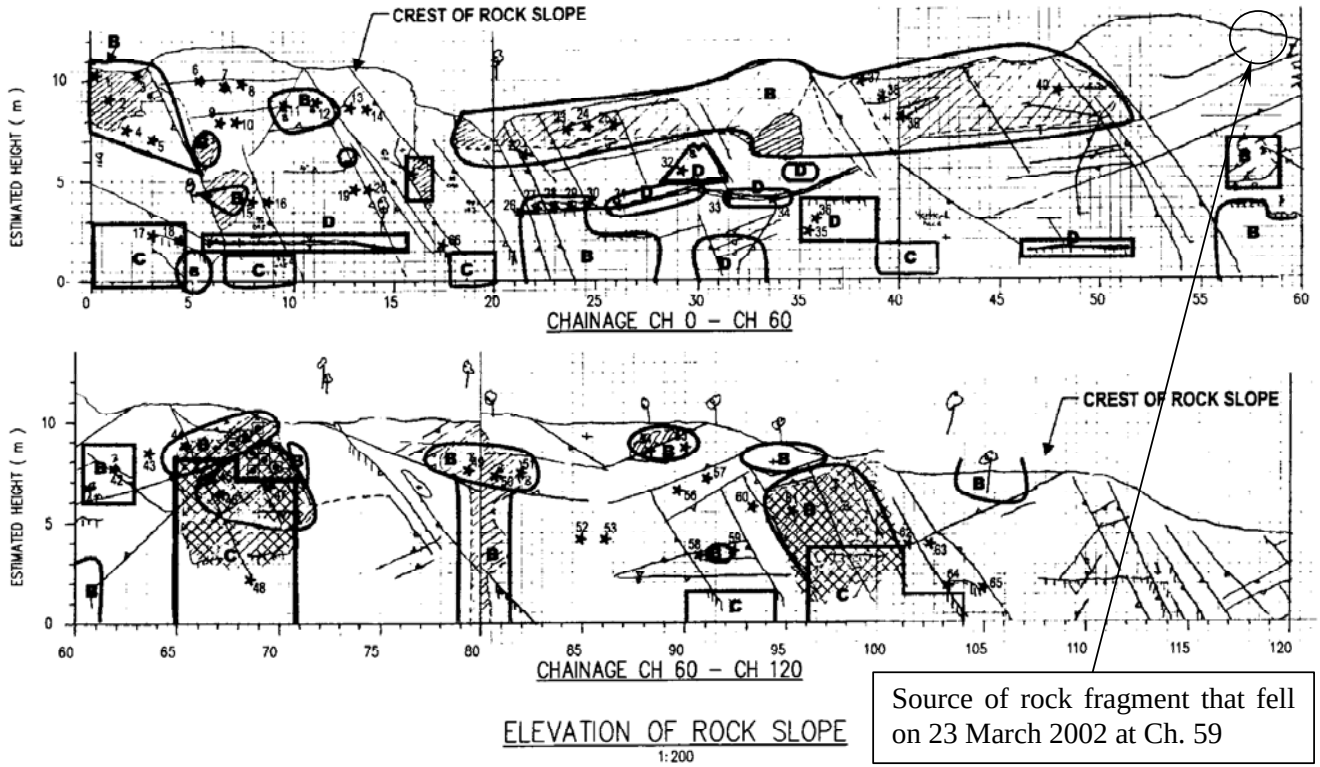

Legend:

	Area of fractured rock near surface of rock face	B	75 mm thick reinforced sprayed concrete	*	Rock dowels
	Area of open fractured rock extending to 1 to 3 m behind rock face	C	Concrete buttress with relief drainage	⊡	Rock bolts
	Overhanging rock	D	Concrete dentition with relief drainage		

Note: LPM As-Built Drawings issued in October 2000 Extracted from Maintenance Manual, MM 260/99.

Figure A1 - Part Plan of LPM As-Built Drawings for Slope No. 11NW-A/C61

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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.

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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.

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GEOLOGICAL PUBLICATIONS

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

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

TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents

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