DETAILED STUDY OF THE 5 MAY 2003 AND 13 JUNE 2003 LANDSLIDES ON SLOPE NO. 6NE-B/C8 FAN KAM ROAD, PAT HEUNG

GEO REPORT No. 190

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
September 2006

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FOREWORD

This report presents the findings of a detailed study of two landslide incidents (viz. Incident No. 2003/05/0009 which involved a landslide on slope No. 6NE-B/C8 and a boulder fall from the natural terrain above, and Incident No. 2003/06/0126 which involved another landslide on slope No. 6NE-B/C8) above Fan Kam Road, Pat Heung. No casualties were reported as a result of the two landslide incidents.

The first landslide incident occurred at about 5:00 a.m. on 5 May 2003 during heavy rainfall when a Red Rainstorm Warning was hoisted and the boulder fall occurred about one to two hours following the landslide. The landslide involved a failure volume of about 20 m^3. Most of the landslide debris was deposited on the berm of the slope and some on the northeast bound lane of Fan Kam Road below. One lane of Fan Kam Road was closed temporarily as a result of the incident. The boulder fall involved a boulder with a volume of about 4 m^3 that originated from the natural terrain above slope No. 6NE-B/C8. The boulder travelled some 80 m downhill and across both lanes of Fan Kam Road before coming to rest on the pedestrian pavement on the opposite side of the road. The boulder narrowly missed a vehicle parked on the opposite side of the road, shortly after the driver got out of the vehicle. A section of the pedestrian pavement close to the toe of slope No. 6NE-B/C8 was damaged by the impact of the boulder.

The second landslide incident occurred at about 2:00 p.m. on 13 June 2003 during modest rainfall and involved a failure volume of about 3 m^3. The landslide debris was deposited on the berm immediately below the failure scar.

The key objectives of the detailed study were to document the facts about the landslides, present relevant background information and establish the probable causes of the incidents. Recommendations for follow-up actions are presented separately.

The report was prepared as part of the 2003/2004 Landslide Investigation Consultancy for landslides occurring in Kowloon and the New Territories in 2003 and 2004, for the Geotechnical Engineering Office, Civil Engineering Department, under Agreement No. CE 94/2002 (GE). This is one of a series of reports produced during the consultancy by Maunsell Geotechnical Services Limited.

L. J. Endicott.

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Project Director
Maunsell Geotechnical Services Limited

Agreement No. CE 94/2002 (GE)
Study of Landslides Occurring in Kowloon and the New Territories in 2003 and 2004 – Feasibility Study

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1. INTRODUCTION

At about 5:00 a.m. on 5 May 2003 when a Red Rainstorm Warning was hoisted, a landslide (Incident No. 2003/05/0009) with a failure volume of about 20 m^3 occurred, near the crest of a 23 m high, 40° steep vegetated soil cut slope (No. 6NE-B/C8) above Fan Kam Road, Pat Heung (Figure 1 and Plate 1). Some of the landslide debris was deposited on the pavement and the northeast bound lane of Fan Kam Road and as a result, this lane was closed temporarily. A boulder fall involving a large boulder (approximately 4.2 m^3 in volume) that originated from the natural terrain some 60 m above the crest of slope No. 6NE-B/C8 (at an elevation of approximately 110 mPD), occurred about one to two hours after the above soil cut failure. The boulder travelled down the cut face and across both lanes of Fan Kam Road before coming to rest on the pedestrian pavement on the opposite side of the road. The large boulder narrowly missed a vehicle parked on the opposite side of the road, shortly after the driver got out of the vehicle. A section of the pedestrian pavement close to the toe of slope No. 6NE-B/C8 was damaged by the impact of the boulder. The landslide and boulder fall did not result in any casualties.

At about 2:00 p.m. on 13 June 2003 during moderate rainfall, a landslide with a failure volume of about 3 m^3 (Incident No. 2003/06/0126), occurred on slope No. 6NE-B/C8 at about 10 m above slope toe (Figure 2 and Plate 2). The landslide debris was deposited on the slope berm below the failure and Fan Kam Road was not affected by the incident.

Maunsell Geotechnical Services Limited (MGSL), the 2003/2004 Landslide Investigation Consultant for Kowloon and the New Territories, carried out a detailed study of the landslide incidents for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 94/2002 (GE). The key objectives of the detailed study were to document the facts about the landslides, present relevant background information and establish the probable causes of the failures. Recommendations for follow-up actions are presented separately.

The boulder fall incident was attended to by the Mainland West Division of the GEO who provided advice on the necessary emergency works to remove immediate danger and also subsequently carried out an assessment of boulder fall hazard following vegetation clearance on the natural terrain. Further stabilisation measures on about 20 boulders recommended by the Mainland West Division of the GEO were carried out by the Highways Department (HyD) in July 2003. In view of the above, the focus of the present study has been on the two landslides on the man-made cut slope (No. 6NE-B/C8) and only some relevant background information on the boulder fall incident is summarised in Appendix A.

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

(a) review of all known relevant documents relating to the development of the slope and the sequence of events leading up to the incidents,

(b) topographical surveys, engineering geological mapping and detailed field inspections and measurements,

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(c) aerial photograph interpretation (API),

(d) analysis of rainfall records,

(e) theoretical stability analysis of the slope that failed, and

(f) diagnosis of the probable causes of the landslide incidents.

2. THE SITE

2.1 Site Description

A layout plan of the landslide site is presented in Figure 2. Slope No. 6NE-B/C8 is a southeast-facing soil cut slope located above the two-lane, two-way Fan Kam Road (Figure 2 and Plate 3). The slope is about 45 m long, up to 23 m in height and has an average gradient of about 40°. Slope No. 6NE-B/C8 is bounded to the northeast and southwest by slopes Nos. 6NE-B/C27 and 6NE-B/C30 respectively. The three slopes were upgraded in 2000 under the LPM Programme (Figure 2).

The 5 May 2003 landslide occurred within the upper part of slope No. 6NE-B/C8. The crown of the landslide scar was located about 1 m below the crest of the cut (Figures 2 and 3). The area between the crown of the 5 May 2003 landslide and the slope crest has a fairly gentle gradient of about 20° (locally up to between 35° and 40° near the slope crest), see Plate 4. The landslide is located above the southwest end of the only berm of the slope (about 1 m wide) within the southeast portion of slope No. 6NE-B/C8, some 10 m above the slope toe (Figure 2 and Plate 5).

The lower 2.5 m of the upper slope batter has a steeper local gradient of between 50° and 55° compared with the average gradient of the slope. The 13 June 2003 landslide is located within this steeper part of the cut face (Figures 2 and 4 and Plate 2).

Under the LPM Programme, soil nails were installed over most of the slope, i.e. except for the upper 20% (in terms of total slope surface area) where the 5 May 2003 landslide was located. The nominal spacing of the soil nails is 4 m horizontal and 1 m vertical (staggered).

The cut slope has a vegetation cover comprising grass and shrubs (Plate 1), together with an erosion control mat (Plate 6). The layout of the surface drainage provisions is shown in Figure 2. A 450 mm wide by 300 mm deep surface drainage channel with an approximately 350 mm wide concrete apron runs along the crest of the cut slope (Plate 7) and a 250 mm wide by 120 mm deep surface drainage channel runs along the 1 m wide berm (Plate 5). This berm channel is connected to a catchpit, which discharges into a 250 mm wide stepped channel near the southwest end of the slope (Plate 1). The stepped channel in turn discharges into a catchpit at the slope toe. A maintenance stairway runs along the northeast side of the slope (Plate 3).

The natural hillside above the cut, which has an average gradient of about 30°, is strewn with boulders and covered with dense vegetation comprising grass, shrubs and small trees.

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2.2 Regional Geology

According to the Hong Kong Geological Survey (HKGS) 1:20,000 geological map sheet for the area (GCO, 1988), the landslide site is underlain by Upper Jurassic coarse ash crystal tuff of the Tai Mo Shan Formation (Figure 5).

A northeast trending fault is shown about 50 m southeast of the site. Several quartz veins are indicated on the geological map about 300 m to the north and east but none is shown in the immediate vicinity of the landslide site.

2.3 Maintenance Responsibility and Land Status

According to the Slope Maintenance Responsibility Information System (SMRIS) of the Lands Department (Lands D), the maintenance responsibility of slope No. 6NE-B/C8 rests with HyD.

2.4 Water-carrying Services

Based on the information provided by the Water Supplies Department and Drainage Services Department, no water-carrying services are located on or along the crest or toe of slope No. 6NE-B/C8.

2.5 Site History

The history of site development has been determined from an interpretation of all the available aerial photographs together with a review of relevant documentary information and site observations (see Figure 6). Detailed observations from the Aerial Photograph Interpretation (API) are summarised in Appendix B.

The earliest available aerial photographs taken in 1949 show that the study area was located along the toe of a southeast-facing natural hillside in a shallow depression (as defined by a rounded concave break in slope) between two rounded spurs trending southeast and south-southeast. The study area was bounded to the southeast by a strip of cultivation terraces and an unpaved track (Figure 6). This track ran within 10 m of the alignment of the present-day Fan Kam Road, which in 1949 was yet to be constructed.

The lower portion of the present-day cut slope No. 6NE-B/C8 together with the adjacent slopes Nos. 6NE-B/C27 and 6NE-B/C30 were formed some time between 1949 and 1963 in conjunction with the construction of Fan Kam Road. In 1963, all three cuts were covered with sparse vegetation.

Based on API and old topographic maps, some time between 1968 and 1972 slope No. 6NE-B/C8 was extended uphill so that the crest line corresponded to the present-day layout (Figure 6). The slope portion where the 5 May 2003 landslide is located was inclined at about 35° to the horizontal before it was cut back between 1968 and 1972. The further cutting back was probably carried out as part of the remedial works following a landslide

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(see Section 2.6 below). Also, a probably concrete surface drainage channel was constructed along the crest of the present-day slopes Nos. 6NE-B/C8, 6NE-B/C27 and 6NE-B/C30, and chunam cover was provided to slope No. 6NE-B/C8. Records of these slope works could not be located in the files reviewed. The change in the reflectivity of the surface of slope No. 6NE-B/C8 in the aerial photographs taken in 1987 and 1988 suggests that a new chunam cover might have been provided.

Based on API, a hillfire on the natural hillside above the crest of slopes Nos. 6NE-B/C8, 6NE-B/C27 and 6NE-B/C30 probably occurred between 1992 and 1993. This has been deduced by the disappearance of vegetation cover from an extensive area, which includes the source of the 5 May 2003 boulder fall (Figure 6). By 1995, light vegetation had re-established on this area of the natural hillside. Since 1996 the natural hillside has developed a dense vegetation cover.

The chunam cover to slope No. 6NE-B/C8 was replaced with shotcrete in 1996/1997 by HyD under the Roadside Slope Improvement Programme. Slope No. 6NE-B/C8 was included in the 1999/2000 LPM Programme and the slope upgrading works were carried out between September 1999 and March 2000 (see Section 3.5).

2.6 Past Instabilities

On the 1949 aerial photographs, a relict landslide scar is visible just above the crest line of the present-day slope No. 6NE-B/C8 within the shallow depression (see Section 2.5 and Figure 7). On the 1963 aerial photographs, two possible degraded relict landslide scars are visible within the depression between the two spurs, about 15 m above the crest of the cut slope (Figure 7).

Based on an area of high reflectivity which was first visible in the 1972 aerial photographs, a landslide probably occurred some time between 1968 and 1972 near the crest of the cut.

A shallow landslide scar near the crest of slope No. 6NE-B/C8 is visible on a record photograph (Plate 8) taken in 1978 by Binnie & Partners (Hong Kong) under the project entitled “Phase I Re-Appraisal of Cut and Natural Slopes and Retaining Walls Study” (see also Section 3.1).

In May 1989, a cluster of minor landslides (Incident No. MW89/5/19) occurred on a number of cut slopes along Fan Kam Road, including a small failure near the toe of slope No. 6NE-B/C8 (Figure 7). According to the GEO’s landslide incident report, the landslide scar was about 2 m wide by 0.75 m deep. The volume of the failure was not recorded. The pedestrian pavement of Fan Kam Road was closed temporarily as a result of the landslides. The incident report noted that “Groundwater”, “Infiltration” and “Strong Wind on trees” were the possible causes of failure.

According to the Natural Terrain Landslide Inventory (NTLI), a landslide (Tag No. 6NEB0598) on the west flank of the south-southeast trending spur on the natural hillside above the cut occurred between 1993 and 1994 (Figure 7). The NTLI recorded that the slope angle across the landslide was 34°, the width of the landslide head was less than

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20 m and that the surface of the landslide source was bare. Based on examination of low-level aerial photographs by MGSL, this landslide probably occurred between April 1992 and November 1993.

According to the GEO's Large Landslide database, there are no records of landslides in the vicinity of slope No. 6NE-B/C8.

Following the 5 May 2003 landslide, Babtie BMT Harris & Sutherland (Hong Kong) Limited (BBHS), the LPM consultant for slope No. 6NE-B/C8, informed GEO that "a small (3 m × 2 m × 0.5 m) shallow translational slide " involving a volume of about 6 m^3 occurred near the slope crest in April 2000 (i.e. about one month after completion of the slope upgrading works). It was reported that the failure "was located approximately at the same place as the 5 May 2003 landslide" (Plate 9) and the associated landslide debris was deposited on the berm below. BBHS advised MGSL in July 2003 that they "believe GEO was notified of the incident by the RSS". According to the Works Division of the GEO, "after searching the files, we [Works Division] cannot identify any record" regarding the April 2000 incident. There are no records of this failure in the GEO's landslide database.

BBHS noted the following with respect to the April 2000 landslide: "The failure was small and shallow and it was concluded that it had occurred due to heavy rain falling on the slope before the hydroseed surface cover had had sufficient time to establish well. At the time the contractor was instructed to make good the surface, reattach the erosion control mat and rehydroseed, and to provide extra protection, such as tarpaulin sheeting, during this early stage in the hydroseed establishment". Because of the above, "no post-construction review was considered necessary" by BBHS. According to BBHS, "Given that the reinstatement works were very minor it was considered that detailed records of the reinstatement works were not necessary".

There are no documentary records of any boulder falls from the natural hillside above the cut slope prior to the 5 May 2003 boulder fall incident.

3. PREVIOUS ASSESSMENTS AND SLOPE WORKS

3.1 Phase I Re-Appraisal of Cut and Natural Slopes and Retaining Walls

Binnie & Partners (Hong Kong) (B&P) were commissioned by the Geotechnical Control Office (GCO, renamed GEO in 1991) to prepare, inter alia, the 1977/78 Slope Catalogue under the project entitled "Phase I Re-appraisal of Cut and Natural Slopes and Retaining Walls". The B&P's fieldsheet on the inspection carried out in April 1978 recorded the following: "previous failure likely" (Plate 8) and "cracks in chunam".

3.2 Stage 1 Study

In September 1992, the Design Division of the GEO completed a Stage 1 Study Report for the cut slope which recorded, inter alia, "cracked chunam" and "seepage at 3.5 m above toe".

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3.3 SIFT and SIRST Studies

In 1992, the GEO initiated a project entitled "Systematic Inspection of Features in the Territory" (SIFT). This project aimed to search systematically for slopes not included in the 1977/78 Slope Catalogue and to update information on previously registered features by studying aerial photographs together with limited site inspections. In January 1997, the SIFT study of slope No. 6NE-B/C8 was carried out and the slope was designated SIFT Class 'C1', i.e. a slope that had "been formed or substantially modified before 30.6.78".

In July 1994, the GEO commenced a project entitled "Systematic Identification and Registration of Slopes in the Territory" (SIRST), to update the 1977/78 Slope Catalogue. The record of inspection of slope No. 6NE-B/C8 in October 1997 by the SIRST consultant noted that the shotcrete cover was in fair condition with signs of seepage (locations not given) and minor distress at the slope toe.

3.4 Stage 3 Study

In April 1996, slope No. 6NE-B/C8 was included in the LPM Programme by the GEO under Agreement No. CE 12/96 (Plate 10). The consultant Harris & Sutherland (Far East) Limited (H&S, renamed BBHS in 1998) completed the Stage 3 Study of the cut slope in January 1998.

The API carried out for the Stage 3 Study covered aerial photographs taken in 1963, 1986, 1988 and 1996. The report noted that a slope failure occurred between 1963 and 1986 and referred to the inferred failure recorded in the B&P fieldsheet [see Section 3.1]. It was concluded that the "present day slope is the result of a pre-1976 failure". The report did not note the occurrence of the May 1989 landslide that was covered by a Incident Report.

As part of the Stage 3 Study, a ground investigation (GI) comprising two drillholes (Nos. DH11/1 and DH11/2), two trial pits and one slope surface strip, was carried out by Bachy Soletanche Group (BSG) between March and April 1997 under the supervision of H&S (Figure 2).

The geological section closest to the location of the 5 May 2003 landslide (as extracted from the Stage 3 Study Report) shows a thin layer of colluvium (about 1.5 m thick) overlying completely decomposed volcanics (CDV) which in turn overlie bedrock.

Two piezometers without Halcrow buckets were installed in each of the drillholes. In drillhole No. DH11/1, the piezometers were installed at depths of 3.1 m and 7.4 m in Grade IV/V material and Grade III rock respectively. In drillhole No. DH11/2, the piezometers were installed at depths of 1.5 m and 9.4 m in colluvium and Grade IV/V material respectively.

In October 1997, Geotechnics & Concrete Engineering (H.K.) Limited (GCE) carried out multi-stage consolidated undrained triaxial compression tests on undisturbed samples of colluvium (one set of triaxial tests) and CDV (three sets of triaxial tests). The average dry densities of colluvium and CDV were 1.49 Mg/m^3 and 1.63 Mg/m^3 respectively. In the

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stability analyses, shear strength parameters of c' = 0 kPa and ϕ' = 33° for colluvium and c' = 7 kPa and ϕ' = 36° for CDV were adopted by H&S.

Groundwater monitoring was carried out between April and December 1997, generally at weekly intervals. No perched water was recorded by the piezometer (with no Halcrow buckets) in the colluvium. The design groundwater conditions corresponding to a 1-in-10 return period rainstorm comprised a base groundwater level at 2 m above rockhead and a perched water level at 1 m above the colluvium/CDV interface.

The consequence-to-life category for slope No. 6NE-B/C8 was assessed as ‘1’ because of “the importance of Fan Kam Road to emergency services traffic serving small communities in the area”. The minimum factor of safety (FOS) adopted for slope design was 1.2.

The stability analyses for the Stage 3 Study indicated that slope No. 6NE-B/C8 had inadequate factors of safety (minimum calculated FOS = 1.01 for the critical slip surface with a maximum depth of about 5 m). The recommended slope upgrading works consisted of soil nails, prescriptive raking drains, vegetation to replace the shotcrete cover and enhanced surface drainage provisions.

Stability analyses for the section closest to the 5 May 2003 landslide indicated a minimum FOS of 1.45 (Figure 8). On this basis, no soil nails were considered necessary for the upper portion of the cut. Shallow slip surfaces within the colluvium similar to the 5 May 2003 landslide were not considered in stability analyses.

In the design analyses, the soil nail spacing was proposed to be 2 m both horizontally and vertically. In the design drawing, a soil nail spacing of 4 m horizontally and 1 m vertically was specified. It is noted that the area coverage per soil nail is similar for the above two soil nail arrangements.

The Stage 3 Study Report was checked and accepted by the Mainland West Division of the GEO in April 1998.

3.5 LPM Works

The LPM works were carried out between September 1999 and March 2000 under the supervision of the resident site staff of BBHS. These comprised 217 soil nails (8 m to 11 m long) and 22 raking drains (15 m long) near the slope toe, replacement of the shotcrete cover with hydroseeding together with erosion control mat.

BBHS advised MGSL in June 2003 that the engineering geological mapping of the cut face that was carried out following removal of shotcrete confirmed the assumed geological model.

The available groundwater records between December 1999 and March 2000 during the LPM works indicate that all the piezometers remained dry during that period.

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4. SLOPE MAINTENANCE INSPECTIONS

In August 1995, the cut slope was inspected by HyD's consultant, Fugro (Hong Kong) Limited, Mouchel Asia Limited and Rendel Palmer Tritton (Asia) of High Point Rendel (Hong Kong) Limited joint venture (FMR) under Agreement No. CE 29/94 as part of the "Roadside Slope Inventory and Inspections" project. The inspection report noted the following: "Cover lost contact with soil underneath in small area". The inspection recommended clearing of drainage channels in the vicinity of the feature, repairing cracked/damaged channels, repairing damaged slope surface cover, unblocking weepholes, etc. The overall state of maintenance of the subject slope was assessed as "Fair".

After completion of the LPM works, Routine Maintenance Inspections (RMIs) were undertaken in 2000, 2001 and 2002 by HyD. Routine maintenance works recommended by the RMIs were generally minor and included clearing of drainage channels, unblocking of weepholes, removal of surface debris and vegetation, etc.

5. DESCRIPTION OF THE LANDSLIDES

5.1 The 5 May 2003 Landslide

The landslide was reported to the Police at 4:57 a.m. on 5 May 2003 at a time when a Red Rainstorm Warning had just been hoisted and after an Amber Rainstorm Warning had been in effect for about 3 hours. The landslide occurred on the un-nailed portion (inclined at 40°) of slope No. 6NE-B/C8 near the slope crest (Figure 2 and Plate 1) and involved a failure volume of about 20 m^3. The landslide debris travelled a maximum distance of about 25 m along the surface of the slope and was deposited on the berm of the slope and the northeast bound lane of Fan Kam Road. The travel angle of the landslide debris was estimated to be 37°. The failure led to the temporary closure of one lane of Fan Kam Road. No casualties were reported as a result of the landslide.

Following the incident, MGSL inspected the site on 6 May 2003 and on several occasions during the course of this landslide study.

The landslide scar was about 7.2 m wide by 5 m long by a maximum 1 m deep and the crown of the scar was about 1 m below the slope crest (Figure 2 and Plate 11). A geological cross-section through the landslide scar is shown in Figure 3. The material exposed on the landslide scar was colluvium comprising soft greyish brown, sandy silt with cobbles and boulders of coarse ash tuff, which constitutes about 15% to 20% by volume of the slope-forming material. No erosion pipes were observed on the landslide scar.

Landslide debris comprising material similar to that exposed on the landslide scar was found to have been deposited on the berm and in the 300 mm U-channel along the toe of the slope below the landslide scar, both over a length of about 7 m (Figure 2 and Plate 5). Some of the debris reached as far as the northeast bound lane of Fan Kam Road (Figure 2).

Remnants of the erosion control mat could be found in places around the periphery of the landslide scar (Plate 6). The erosion control mat was fixed to the slope by pins spaced at about 1 m centres vertically (measured on the slope face) and between 0.5 m and 1 m horizontally. The upper edge of the mat was not embedded beneath the concrete apron of

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the crest surface channel (Plate 7). With the exception of the 50° to 55° steep portion of the upper batter of the slope (see Section 5.2), the erosion control mat was found to rest tightly against the slope surface.

Apart from the sections of the U-channels on the berm and along the slope toe that were affected by the landslide debris, the other surface channels were found to be clear at the time of inspection.

An approximately 6.5 m long by 10 mm (maximum) wide and 120 mm to 140 mm deep crack was found at the interface between the crest surface channel and the adjoining concrete apron (Plate 7). Also, an approximately 3.7 m long, up to 2 mm wide crack, with a level difference of about 2 mm across itself, was found along the crest channel (Plate 7).

The soil nail heads immediately below the 5 May 2003 landslide site were spaced between 2.2 m (uppermost row) and 4.8 m horizontally and between 0.8 m and 1.3 m vertically.

An erosion scar was observed on the lower batter of the slope below the northeast side of the 5 May 2003 landslide scar (Figure 2 and Plate 12). This erosion scar was possibly formed by concentrated surface water flow from overspilling of the berm U-channel after it became blocked by the landslide debris derived from the 5 May 2003 landslide (see Figure 2 and Plate 5).

During inspections on 6 and 18 August 2003, water was observed to be issuing from a raking drain located close to the northeast end of slope No. 6NE-B/C8 (Figure 2 and Plate 13) and seepage was observed from another raking drain located directly below the 5 May 2003 landslide scar (Figure 2). During an inspection on 6 August 2003, water was observed to be seeping from the interface between the toe channel and the pedestrian pavement near the 250 mm stepped channel (Figure 2 and Plate 13).

Shortly (probably about one to two hours) after the landslide on slope No. 6NE-B/C8, a boulder fall (see Appendix A), which involved the detachment of a 4.2 m^3 boulder from the natural hillside, occurred at an elevation of approximately 110 mPD, some 60 m above the crest of slope No. 6NE-B/C8. The boulder landed at the toe of the cut slope and travelled across both lanes of Fan Kam Road and stopped on the pedestrian pavement on the opposite side of the road. The large boulder narrowly missed a vehicle parked on the opposite side of the road, shortly after the driver got out of the vehicle. The impact of the boulder locally damaged a section of the pedestrian pavement at the toe of slope No. 6NE-B/C8.

5.2 The 13 June 2003 Landslide

Another landslide (Incident No. 2003/06/0126) involving an estimated volume of 3 m^3 occurred between the soil nail heads (horizontal spacing of 3.5 m and vertical spacing of 1 m as measured on site) just above the berm on the northeast portion of slope No. 6NE-B/C8, at about 2:00 p.m. on 13 June 2003 (Figure 2 and Plate 2). The landslide debris was deposited on the berm just below the landslide scar. No casualties or road closure were reported as a result of this incident.

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Following the incident, MGSL inspected the site on 14 June 2003 and on several occasions during the course of this study.

The landslide scar, which was located on the 50° to 55° steep portion of slope No. 6NE-B/C8, measured about 3 m wide by 2.8 m high by 0.4 m deep and was delineated by three soil nail heads (Figure 9 and Plate 14).

Detailed engineering geological mapping of the landslide scar was carried out by MGSL. The result of the mapping is presented in Figure 9 and a geological cross-section through the landslide scar is shown in Figure 4. The material exposed on the scar was extremely weak, yellowish brown, completely decomposed coarse ash tuff comprising sandy silt with occasional cobbles. No signs of seepage were observed on the landslide scar.

Landslide debris, which comprised firm, yellowish brown, sandy silt with occasional cobbles of volcanic origin, intact displaced vegetation and remnants of erosion control mat, was deposited on the berm and piled up against the lower portion of the landslide scar to a height of about 1 m.

During a site inspection carried out by MGSL on 6 May 2003 in conjunction with the investigation of the 5 May 2003 landslide, dish-shaped scars (measuring up to about 1 m wide by 1 m long by 0.15 m deep) and holes (measuring up to 250 mm in diameter by 400 mm deep) were observed on slope No. 6NE-B/C8. These small scars/holes were found to be adjacent to some of the nail heads located on the second row above the berm (i.e. the 50° to 55° steep portion) at the northeast side of the slope (see Figures 2 and 9 and Plate 15) and were not observed elsewhere on the slope. At the north-eastern boundary of the 13 June 2003 landslide scar, a soil nail head was noted to have separated slightly (Figure 9 and Plate 16) from the adjoining ground, which may probably be due to the loss of support to the concrete nail head following the failure.

The material exposed on the surfaces of the scars/holes was extremely weak, yellowish brown, completely decomposed coarse ash tuff comprising firm, sandy silt with some fine to medium gravel and light vegetation, including small ferns and grass. Moss and a few cobbles were also observed at the scars. Occasional minor sub-vertical relict joints dipping into the slope were observed within the scars. Scars/holes appeared to have been in existence for some time (probably more than one year) based on their surface texture and the presence of sparse vegetation and moss.

No seepage was noted at these scars/holes on the slope surface at the time of the site inspections. The surface of the steep portion of the slope just above the berm was found to be slightly undulating and, in places, the erosion control mat was loosely attached to the slope.

A survey of the soil nail heads exposed on the slope surface indicated that the nails in the vicinity of the landslide site were spaced between 3.5 m and 4.4 m horizontally and between 0.6 m and 1.9 m vertically.

During the site inspection carried out by MGSL in June 2003, no signs of potential incipient large-scale instability of slope No. 6NE-B/C8 were observed.

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6. ANALYSIS OF RAINFALL RECORDS

6.1 General

Rainfall data were obtained from GEO automatic raingauge No. N36, the nearest raingauge to the site, located at Kadoorie Agricultural Research Centre, Shek Kong, approximately 3.5 km to the southeast of the landslide (Figure 1). The raingauge records and transmits rainfall data at 5-minute intervals via a telephone line to the Hong Kong Observatory and the GEO.

6.2 Rainfall Preceding the 5 May 2003 Landslide

The 5 May 2003 landslide was reported to the Police at 4:57 a.m. on 5 May 2003. For the purpose of rainfall analysis, the time of the landslide was assumed to be 4:45 a.m. when the peak hourly rainfall was recorded. Amber and Red Rainstorm Warnings were hoisted on 5 May 2003 at 1:45 a.m. and 4:45 a.m. respectively.

The daily rainfall recorded by raingauge No. N36 over the month preceding the 5 May 2003 landslide and two days following the 13 June 2003 landslide incident, together with the hourly rainfall readings for the period between 3 and 5 May 2003, are presented in Figure 10. The rain was heavy on the morning of 5 May 2003 between 2:10 a.m. and 10:00 a.m. The 24-hour and 12-hour rainfall before the landslide was 314.5 mm and 272 mm respectively. The maximum 1-hour rolling rainfall was recorded as 118 mm between 3:45 a.m. and 4:45 a.m. on 5 May 2003 (Table 1).

Table 1 presents the estimated return periods for the maximum rolling rainfall for various durations recorded by raingauge No. N36 with reference to historical rainfall data at the Hong Kong Observatory in Tsim Sha Tsui (Lam & Leung, 1994). The results show that the 15-minute rolling rainfall of 46 mm before the landslide was the most severe, with a corresponding return period of about 47 years. For the other rainfall durations considered, the corresponding return periods range from 2 years to 27 years.

The maximum rolling rainfalls for the rainstorm on 5 May 2003 have been compared with that of the past major rainstorms between 1983 and 2001 recorded by raingauge No. N05 (which began operation in March 1983 and is located about 5.8 km to the northeast of the landslide) and No. N36 (which began operation in October 1999) (see Figure 11). The maximum rolling rainfall for the rainstorm prior to 4:45 a.m. on 5 May 2003 exceeds that from previous rainstorms for durations up to 4 hours (Figure 11).

6.3 Rainfall Preceding the 13 June 2003 Landslide

The 13 June 2003 landslide was reported to the GEO in the afternoon on 13 June 2003. For the purpose of rainfall analysis, the 13 June 2003 landslide was assumed to have occurred at 2:00 p.m. on 13 June 2003 (as recorded in the Incident Report).

The daily rainfall recorded by raingauge No. N36 over the month preceding the 13 June 2003 landslide and two days following the 13 June 2003 landslide incident is

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presented in Figure 10. The daily rainfall recorded on 12 and 13 June 2003 was less than 25 mm.

Analysis of the return periods of the rainfall intensities preceding the 13 June 2003 landslide is given in Table 2. The results show that the return periods for the maximum rolling rainfall for the various durations considered are less than 2 years, which indicates that the rainfall was not heavy. The rainfall analysis also confirmed that the cut slope had experienced more intense rainstorms in the past than that preceding the 13 June 2003 landslide (Figure 11).

7. THEORETICAL SLOPE STABILIY ANALYSES

Theoretical slope stability analyses were carried out to assist in the diagnosis of the mechanism and probable causes of the 5 May 2003 landslide. The analyses may be used to assess the probable operational mass shear strength parameters given the range of possible groundwater conditions at the time of the landslide.

The cross-section through the landslide for the stability analyses using the Morgenstern & Price (1965) method is shown in Figure 12. The pre-failure slope profile was inferred from the LPM as-built drawings, photographic records and post-failure field observations. The geometry of the surface of rupture and ground profile is based on the post-failure topographical survey and observations by MGSL.

Based on detailed engineering geological mapping carried out by MGSL, the surface of rupture of the 5 May 2003 landslide was within colluvium.

Only very limited laboratory testing was carried out on the colluvium. Based on the one set of multi-stage triaxial tests carried out on the matrix material of the colluvium, the shear strength parameters correspond to $c' = 0$ kPa and $\phi' = 33°$. In assessing the likely range of mass shear strength parameters, the effects of the coarse fraction (i.e. cobbles and boulders) in the colluvium should also be considered.

According to Irfan & Tang (1993), an increase in the angle of shearing resistance by 1° and 2° could correspond to a coarse fraction of 27.5% and 30% by volume respectively. Based on MGSL's mapping of the landslide scar, the coarse fraction within the colluvium was between 15% and 20% by volume.

The results of the stability analyses are presented in Figure 12. If the shear strength parameters of colluvium are taken to be $c' = 0$ kPa and $\phi' = 35°$, the calculated FOS would fall below unity. For the probable range of mass shear strength parameters for the colluvium, the analyses suggest that failure could occur upon near saturation of the colluvium (possibly with a small amount of residual suction in the ground mass) or build-up of a small transient groundwater pressure (possibly with a low c' value and/or some residual suction in the ground mass). The analyses confirm the vulnerability of the steep, unsupported slope portion to failure in colluvium.

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8. DIAGNOSIS OF THE PROBABLE CAUSES OF THE LANDSLIDES

8.1 The 5 May 2003 Landslide

Based on the information collected during the landslide investigation, it is postulated that the 5 May 2003 failure (20 m^3) probably resulted from two principal factors:

(a) water ingress during intense rainfall resulting in saturation (or near saturation) of the surface mantle of colluvium or possible development of transient groundwater pressure, and

(b) the presence of weak material in the steep (40°), unsupported cut near the slope crest.

The rainstorm preceding the landslide was intense, with an estimated return period of about 50 years for short duration rainfall. The cut face together with the natural terrain above was vegetated and water ingress into the ground would have taken place through direct infiltration. The ground profile immediately above the backscarp of the failure has a relatively gentle local gradient (about 20° steep, see Figure 3). The local site setting above the source of the landslide is therefore susceptible to enhanced infiltration.

The colluvium involved in the failure consisted of sandy silt with cobbles and boulders. Based on the available laboratory test results on the matrix material and mapping of the landslide scarp and debris, the theoretical stability analyses suggest that the steep cutting in colluvium was probably of marginal stability. Given the over-steep cut face with a relatively weak surface mantle of colluvium that was not supported by soil nails, the landslide was likely to have been caused by water ingress leading to loss of suction (i.e. saturation or near saturation of the ground mass) and/or the local build-up of transient perched groundwater pressure above the colluvium/CDV interface due to the contrast in mass permeabilities.

The reliance on suction for slope stability in the colluvium in feature No. 6NE-B/C8 in the past is reflected by the fact that there had been no failure since the provision of a hard surface cover in the late 1960s/early 1970s (see Section 2.6) whereas two failures occurred in the colluvium about one month and three years respectively following the completion of slope upgrading works in March 2000 which involved, inter alia, the replacement of the hard surface cover with a vegetated cover and no soil nail support or cutting back of the colluvium.

The change in the hydrogeological setting of the slope involving enhanced direct infiltration following removal of the hard surface cover was detrimental to the maintenance of suction in the colluvium and would have contributed to render the upper, unsupported portion of the cut slope more vulnerable to rain-induced failures.

The pre-existing cracks with unplanned vegetation (Plate 7) in the crest channel were not extensive and probably did not constitute a major source of concentrated water ingress into the slope. Thus, the slope maintenance condition was unlikely to have been a major contributory factor to the landslide.

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8.2 The 13 June 2003 Landslide

The 13 June 2003 landslide involved the minor failure of CDV (3 m^3) between the soil nail heads during moderate rainfall on the locally steep (50° to 55°) portion of the cut slope which has a general overall gradient of about 40°. Within the locally oversteep slope portion above the berm at about the mid-height of the feature, there is evidence of what appears to be minor scars on the slope face beneath the erosion control mat (see Section 5.2), which might have been associated with minor near-surface detachments or local erosion, whereas similar minor scars are not present in the other gentler parts of the cut. The 13 June 2003 failure was not controlled by local adverse geological features and no signs of local seepage were noted in the post-landslide mapping. The 13 June 2003 failure was comparatively more extensive than the other scars in the vicinity. It is not certain whether these minor scars within the locally steeper slope portion, had developed prior to, or after, the placement of the erosion control mat.

The geometry of the minor scars on the steeper portion of the slope face is such that it is liable to lead to local enhanced infiltration into the slope. However, it is not certain whether the 13 June 2003 failure involved further instability in an area with pre-existing minor detachments prior to the failure or not.

The very shallow nature of the minor detachment of near-surface material is not amendable to conventional stability analyses. The susceptibility to such a failure mode is largely dependent on the operational cohesion of the material at very low stress level. The actual effective cohesion value of the near-surface material could be influenced by environmental factors, such as surface water flow, wetting and drying cycle, etc. and it is very difficult to quantify.

The 13 June 2003 detachment was probably the result of wetting up of the near-surface soil mass within the locally steeper portion following direct rainfall infiltration. Given the heterogeneity and spatial variability of the weathered volcanics, the presence of locally more weathered and weaker material is conceivable and the possibility of such locally weaker material having played a contributory role in the failure cannot be precluded. It is also possible that past intense rainfall (e.g. the 5 May 2003 rainstorm) could have given rise to small detachments from the near-surface ground mass which may render the soil in close proximity to be more vulnerable to further, possibly somewhat larger, failures in subsequent rainstorms.

The horizontal and vertical spacings of the soil nails (with 650 mm square reinforced concrete nail heads) are at 4 m and 1 m respectively. The vegetated portion in between the soil nail heads was protected by an erosion control mat. No wire mesh, structurally connected to the soil nail heads, was provided for this slope. Given this soil nail configuration and the surface protection detailing, it is evident that surface detachments could not be prevented by development of arching action onto the adjacent soil nails given the nature of the material in the locally steeper slope portion.

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9. DISCUSSION

The two landslide incidents on the engineered soil cut slope were distinct and related to different issues.

The subject slope had a history of instability following the formation of the cut some time before 1963. When the slope was provided with a hard cover after it was further cut back to the present-day profile in the late 1960s/early 1970s, probably after a landslide, it had essentially remained stable, except for a very minor failure near the slope toe in 1989, up to the time of the LPM works.

In the LPM design, the assumed geological model, which involved a thin surface mantle of colluvium overlying volcanic saprolite, was generally consistent with the site observations. Although the information on the groundwater condition was limited (mainly because no Halcrow buckets were installed in the piezometers to monitor the peak response to rainfall), the assumed design groundwater condition had allowed for the potential development of a 1 m high perched water table in the colluvium. Given the constraint of the groundwater monitoring data, it would appear that the assumed hydrogeological model for stability analyses was not unreasonable.

In the Stage 3 Study Report, the implications of the past failures and the potentially adverse effects of the change in environmental condition associated with the replacement of the hard cover with vegetated cover were not discussed in detail. Soil nails, together with one row of prescriptive raking drains, were proposed for the lower two thirds of the cut slope on the basis of conventional stability analyses. No soil nails or prescriptive subsurface drainage provisions were considered necessary for the upper slope portion based on the calculation of a minimum factor of safety of 1.445 for the most critical circular slip surface that passes through the colluvium and mainly CDV. The more critical condition associated with a shallow slip surface confined to the surface mantle of colluvium, as suggested by the adverse hydrogeological condition (i.e. a thin colluvium layer overlying saprolite) and as subsequently confirmed by the 5 May 2003 landslide, was not examined in the stability analyses. For potential slip surfaces within the colluvium, the calculated FOS would fall below unity for the assumed design soil and groundwater parameters. The basis upon which the stability of the upper 7 m of the cut slope was considered to meet the current safety standard was therefore not valid.

The April 2000 minor failure that affected the colluvium near the slope crest occurred approximately one month after completion of LPM works during moderate rainfall (based on rainfall records). There are no detailed records kept of this minor failure and of the remedial works that were subsequently carried out. Also, the occurrence of the failure was not mentioned in the Maintenance Manual and no post-construction performance review was carried out to examine if the design assumptions are compatible with observations on actual performance of the slope. It would appear that the potential implications of the April 2000 landslide in terms of possible inadequacy of the stability analyses and slope upgrading works were not fully appreciated.

The rainfall that triggered the 5 May 2003 landslide was heavy but it was not a very severe rainstorm in that it did not result in the failure of a large number of engineered slopes within the area affected by the rainstorm in the vicinity. This failure on slope No. 6NE-B/C8

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was the only landslide incident for all the man-made slopes along Fan Kam Road. The minimum factor of safety (of 1.2) and the groundwater condition corresponding to the 1-in-10 year storm adopted for slope design should mean that the stability of the engineered slope would not be unduly sensitive to heavy rainstorms. The key issues in the 5 May 2003 landslide are primarily related to the design input and the lack of robust slope stabilisation measures at the failed portion rather than the severity of the rainstorm which has a return period exceeding the 1-in-10 year rainstorm.

As far as the 13 June 2003 failure is concerned, the key issues are related to the assessment and treatment of locally steep portions of the cut face (i.e. need for local trimming or not) and detailing of surface protective measures for the ground between the soil nail heads in a vegetated slope to mitigate shallow detachments.

10. CONCLUSIONS

It is concluded that the 5 May 2003 landslide was probably caused by direct infiltration resulting in the loss of suction and/or the local build-up of transient perched water pressure in the colluvium during intense, short duration rainfall. The failure occurred on the unsupported upper slope portion and did not affect the soil-nailed portion below.

The minor detachment on 13 June 2003 from the cut face between the soil nail heads was probably caused by the wetting up of the near-surface material due to direct rainfall infiltration, which was probably exacerbated by the locally steeper gradient of the cut face within which the failure occurred.

Based on detailed field mapping, no obvious signs of incipient large-scale instability were observed during the course of the landslide study.

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Table 1 - Maximum Rolling Rainfall at GEO Raingauge No. N36 for Selected Durations Preceding the Landslide on 5 May 2003 and the Estimated Return Periods

Duration	Maximum Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years) (See Note 2)
5 Minutes	18.0	2:45 a.m. on 5 May 2003	13
15 Minutes	46.0	2:45 a.m. on 5 May 2003	47
1 Hour	118.0	4:45 a.m. on 5 May 2003	24
2 Hours	171.5	4:30 a.m. on 5 May 2003	27
4 Hours	227.0	4:45 a.m. on 5 May 2003	24
12 Hours	272.0	4:45 a.m. on 5 May 2003	8
24 Hours	314.5	4:45 a.m. on 5 May 2003	5
48 Hours	363.0	4:45 a.m. on 5 May 2003	5
4 Days	363.0	4:45 a.m. on 5 May 2003	3
7 Days	374.5	4:45 a.m. on 5 May 2003	2
15 Days	374.5	4:45 a.m. on 5 May 2003	< 2
31 Days	428.5	4:45 a.m. on 5 May 2003	< 2

Notes:
(1) Maximum rolling rainfall was calculated from 5-minute rainfall data.
(2) Return periods were derived from the rainfall data recorded at Hong Kong Observatory between 1884 and 1939 and between 1947 and 1990 (Lam & Leung, 1994).
(3) The 5 May 2003 landslide was reported to the Police at 4:57 a.m. on 5 May 2003. The exact time of the incident is not known since no eye-witness accounts of the landslide could be obtained. The 5 May 2003 landslide was assumed to have occurred at 4:45 a.m. on 5 May 2003 for the purpose of rainfall analysis.
(4) The nearest GEO raingauge to the landslide site is raingauge No. N36 which is situated about 3.5 km to the southeast of the site and became operational on 1 October 1999.

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Table 2 - Maximum Rolling Rainfall at GEO Raingauge No. N36 for Selected Durations Preceding the Landslide on 13 June 2003 and the Estimated Return Periods

Duration	Maximum Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years) (See Note 2)
5 Minutes	6.0	2:30 p.m. on 12 June 2003	< 2
15 Minutes	13.0	2:35 p.m. on 12 June 2003	< 2
1 Hour	18.0	2:40 p.m. on 12 June 2003	< 2
2 Hours	19.5	3:30 p.m. on 12 June 2003	< 2
4 Hours	21.5	4:45 p.m. on 12 June 2003	< 2
12 Hours	22.0	4:45 p.m. on 12 June 2003	< 2
24 Hours	24.5	11:30 a.m. on 13 June 2003	< 2
48 Hours	227.5	4:45 p.m. on 12 June 2003	< 2
4 Days	303.0	4:45 p.m. on 12 June 2003	< 2
7 Days	330.5	9:50 a.m. on 13 June 2003	< 2
15 Days	332.0	11:30 a.m. on 13 June 2003	< 2
31 Days	369.0	11:30 a.m. on 13 June 2003	< 2

Notes:
(1) Maximum rolling rainfall was calculated from 5-minute rainfall data.
(2) Return periods were derived from the rainfall data recorded at Hong Kong Observatory between 1884 and 1939 and between 1947 and 1990 (Lam & Leung, 1994).
(3) According to the information collected by the GEO, the landslide occurred at about 2:00 p.m. on 13 June 2003.
(4) The nearest GEO raingauge to the landslide site is raingauge No. N36 which is situated about 3.5 km to the southeast of the site and became operational on 1 October 1999.

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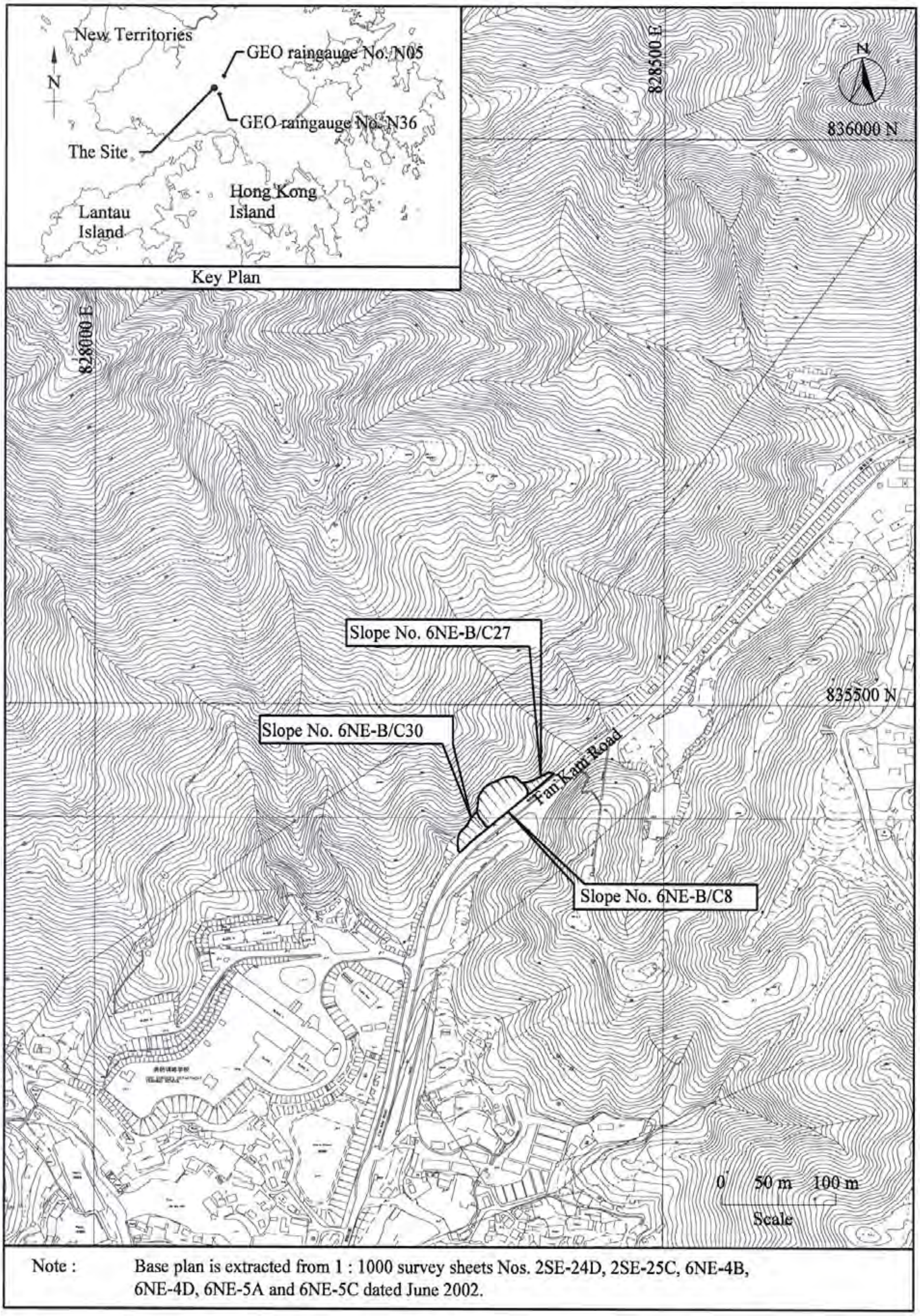

Figure 1 - Site Location Plan

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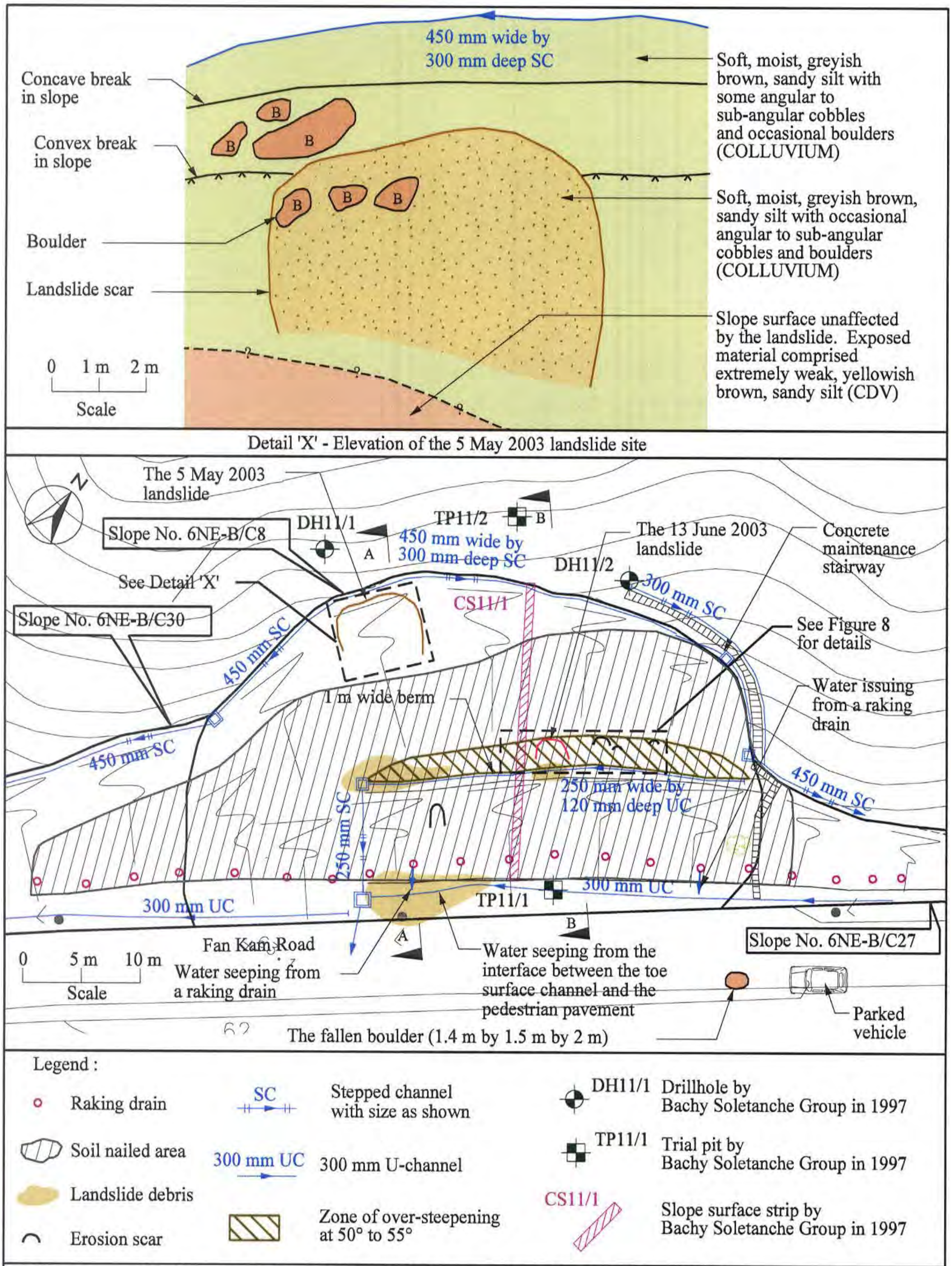

Notes : (1) Base plan is extracted from 1 : 1000 survey sheets Nos. 6NE-4B and 6NE-4D dated June 2002.

(2) Soil nail head and raking drain locations are extracted from as built drawing No. LPM/9720/022 of Maintenance Maunual MM001/2000.

Figure 2 - Site Observations

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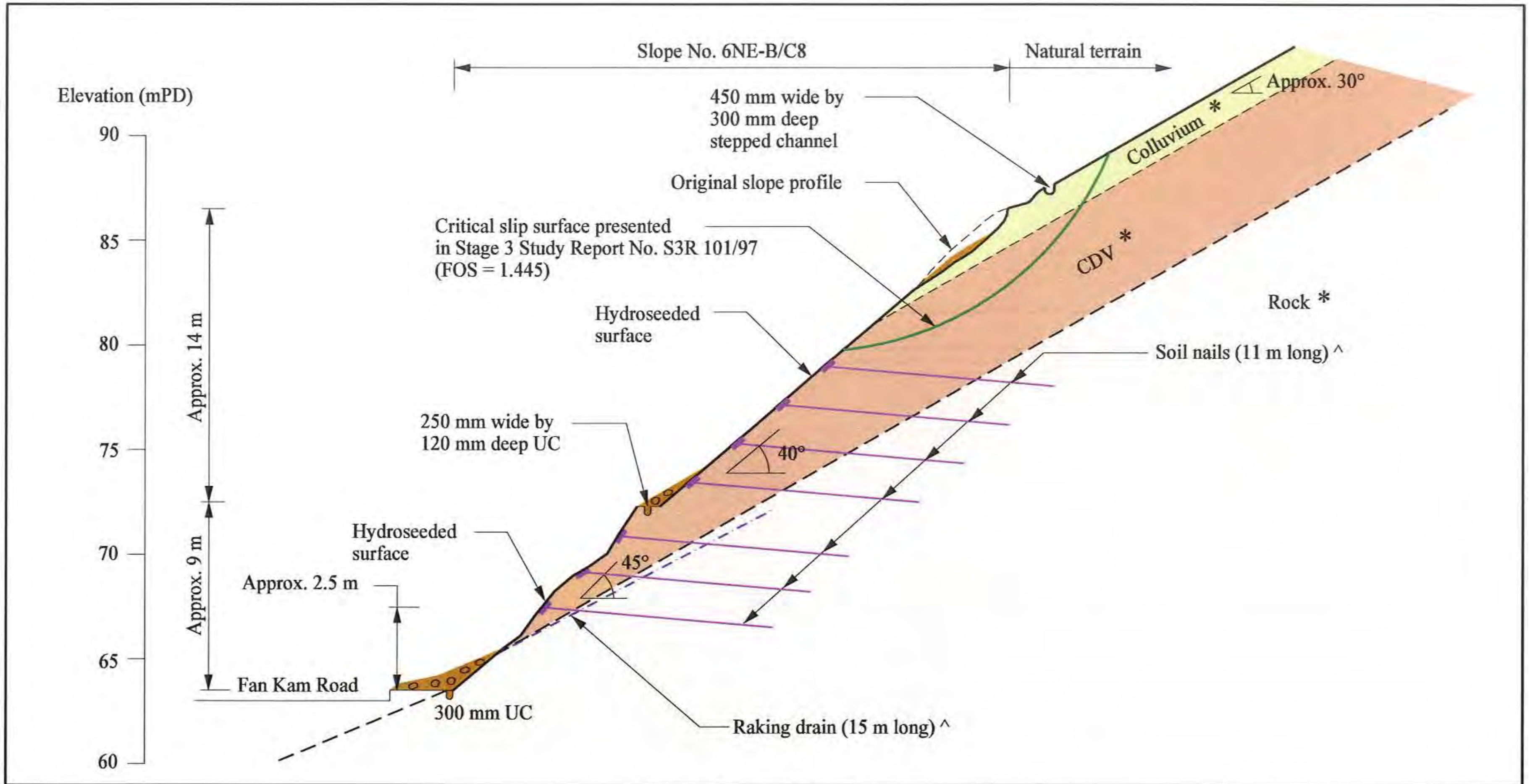

Legend :

- Soil nail head
- Landslide debris comprising soft, greyish brown, sandy silt with occasional angular to sub-angular cobbles

Notes :

(1) See Figure 2 for location of Section A-A.
(2) * denotes information extracted from Stage 3 Study Report No. S3R 101/97.
(3) ^ denotes information extracted from LPM as-built drawings Nos. LPM/9720/022 and LPM/9720/023 and projected onto this figure.

Figure 3 - Section A-A through the 5 May 2003 Landslide Site

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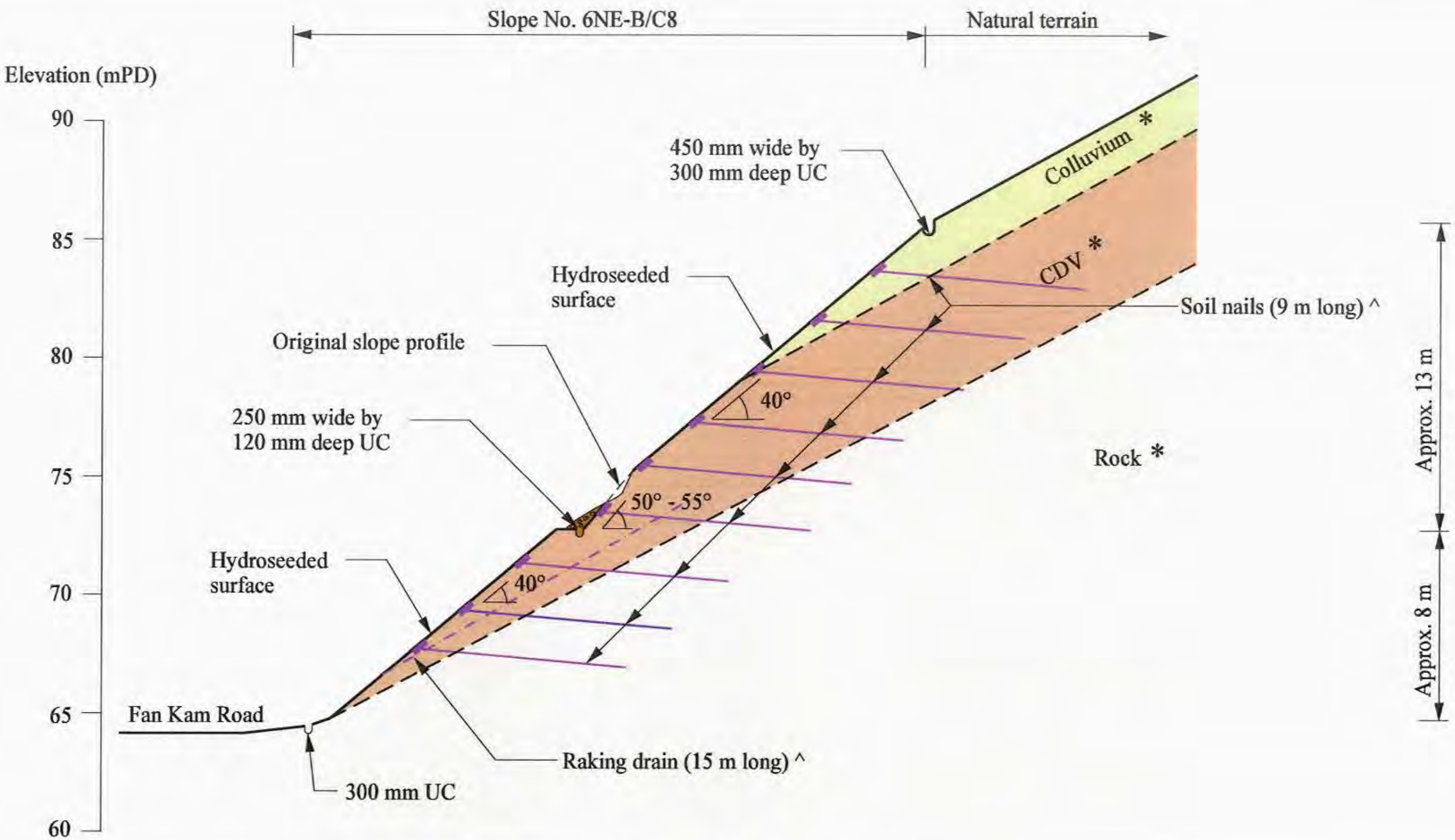


Legend :

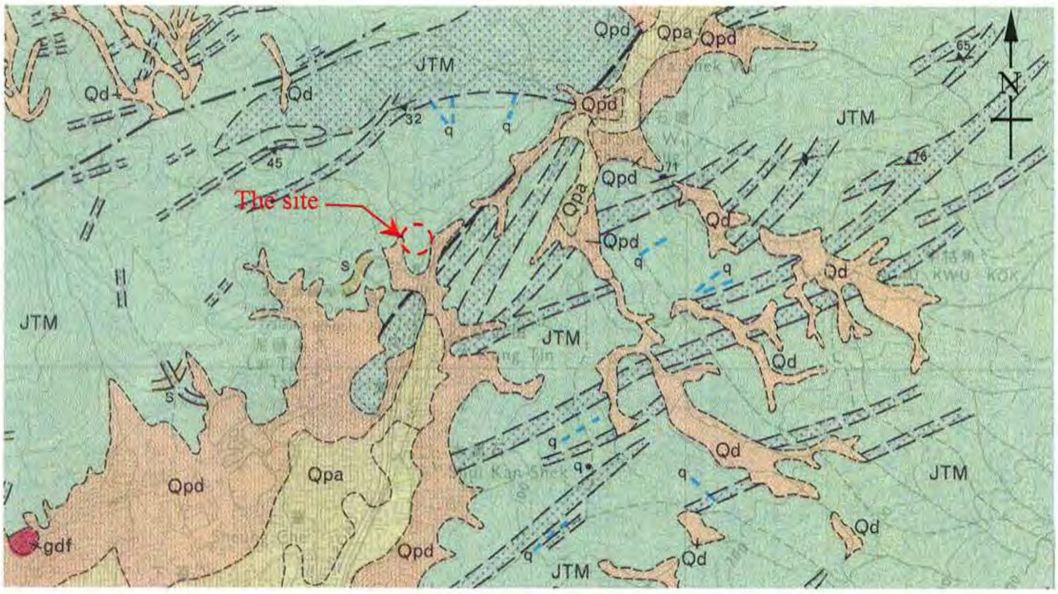
Soil nail head

Landslide debris comprising firm, yellowish brown, sandy silt with occasional cobbles of volcanic origin and intact displaced vegetation and erosion mat

Notes :

(1) See Figure 2 for location of Section C-C.
(2) * denotes geological information inferred from G.I. carried out under Stage 3 Study (see report No. S3R 101/97).
(3) ^ denotes information extracted from LPM as-built drawings Nos. LPM/9720/022 and LPM/9720/023 and projected onto this figure.

Figure 4 - Section B-B through the 13 June 2003 Landslide Site



LEGEND:

0m 1000 m

SUPERFICIAL DEPOSITS

Qd	Unsorted sand, gravel, cobbles and boulders; clay/silt matrix (Debris flow deposits)	Qpd	Silt/sand, gravelly, clayed with cobbles and boulders; unsorted (Debris flow deposits)
Qpa	Clay/silt, gravelly sandy, Well-sorted to semi-sorted (Terraced alluvium)		

SOLID GEOLOGY

JTM	Coarse ash crystal tuff (Tai Mo Shan Formation, undivided)	gdf	Fine-grained granodiorite, <2 mm (Jurassic-cretaceous)
s	Sandstone		Metamorphosed (Jurassic-cretaceous)

GEOLOGICAL LINES

- Geological boundary, superficial deposits
- Fill boundary, with limit of reclamation at date shown
- Geological boundary, solid rock (* Broken lines denote uncertainty)
- Fault (crossmark indicates downthrow side)
- Mineral vein
- Photogeological lineament

STRUCTURAL SYMBOLS

- 71 Jointing for inclined
- Foliation for vertical
- 45 Foliation for inclined

MINERAL SYMBOLS

- •q Mineral occurrence (Quartz)

Note: Figure is extracted from Hong Kong Geological Survey, Map Series HGM20, Sheet No. 6, 1:20 000 scale (GCO, 1988a).

Figure 5 - Regional Geology

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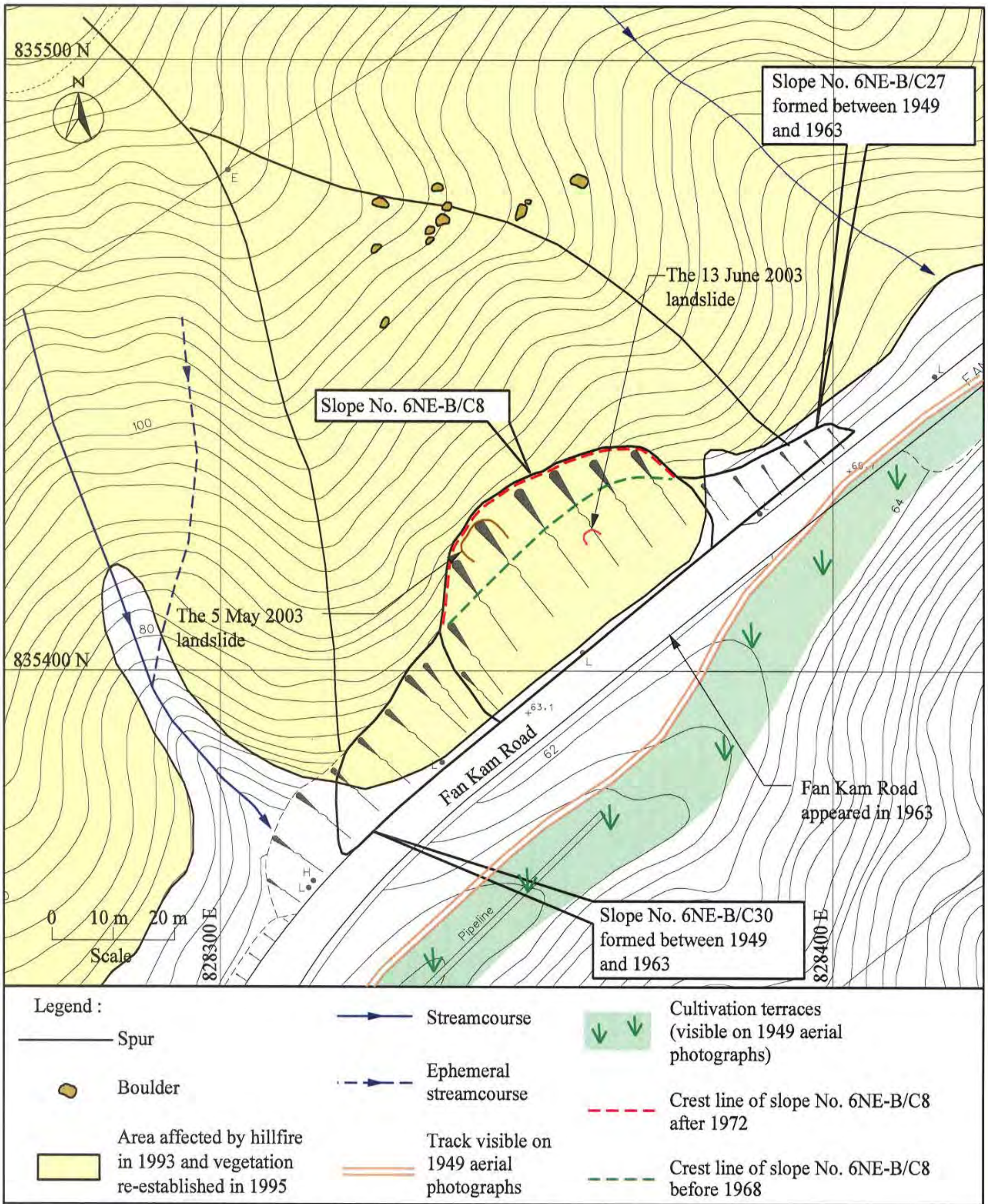

Notes :

(1) Base plan is extracted from 1 : 1000 survey sheets Nos. 6NE-4B and 6NE-4D dated June 2002.

(2) Slope No. 6NE-B/C8 was covered with sparse vegetation in 1963 and the surface cover was changed to chunam sometime between 1964 and 1972. The slope was shotcreted between 1996 and 1997 and the shotcrete cover was replaced with vegetation in 1999/2000 under the LPM Programme.

(3) Based on API and old topographic maps, the crest line of slope No. 6NE-B/C8 was extended uphill some time between 1968 and 1972.

Figure 6 - Site History

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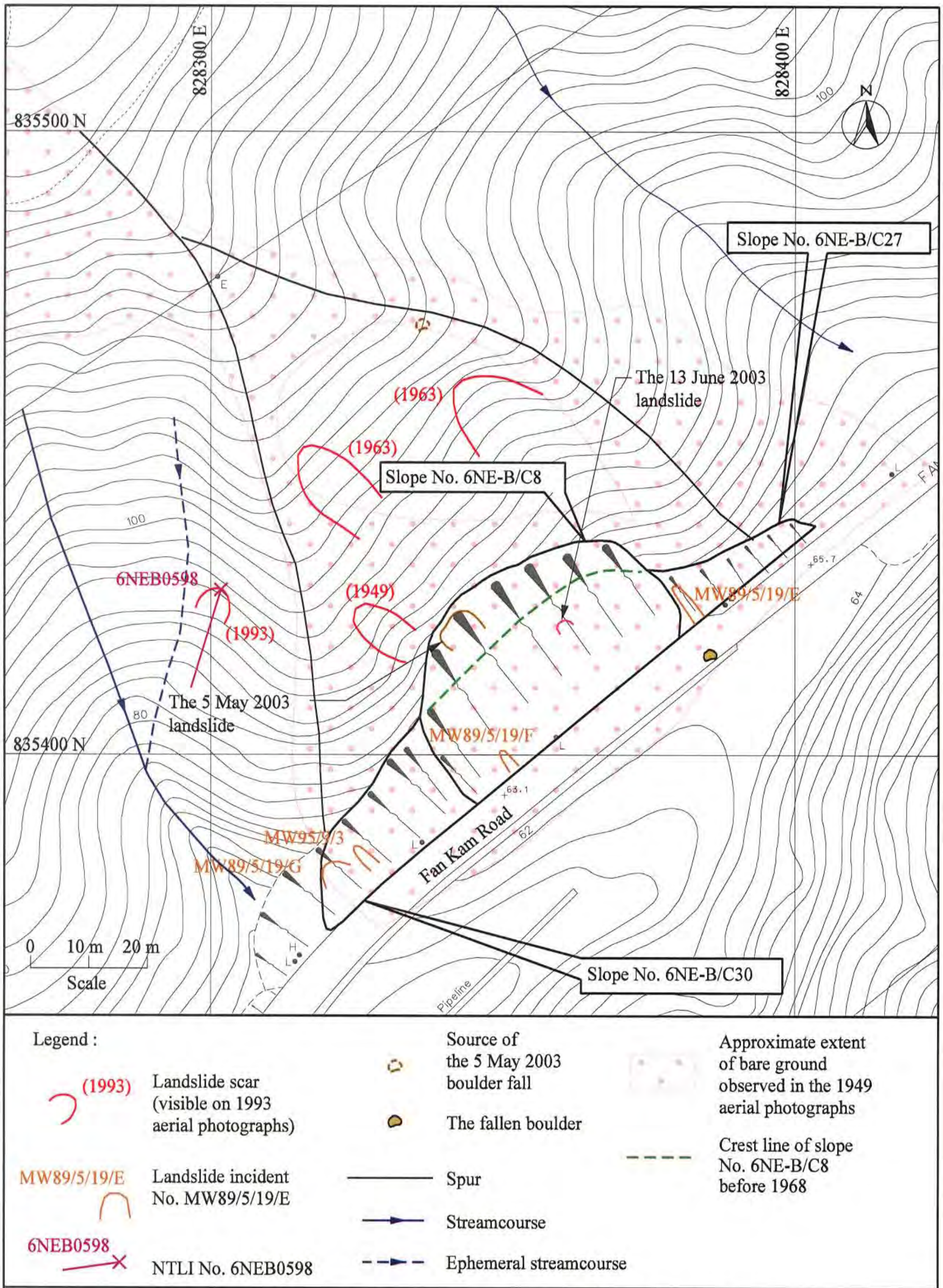

Note : Base plan is extracted from 1 : 1000 survey sheets Nos. 6NE-4B and 6NE-4D dated June 2002.

Figure 7 - Past Instability

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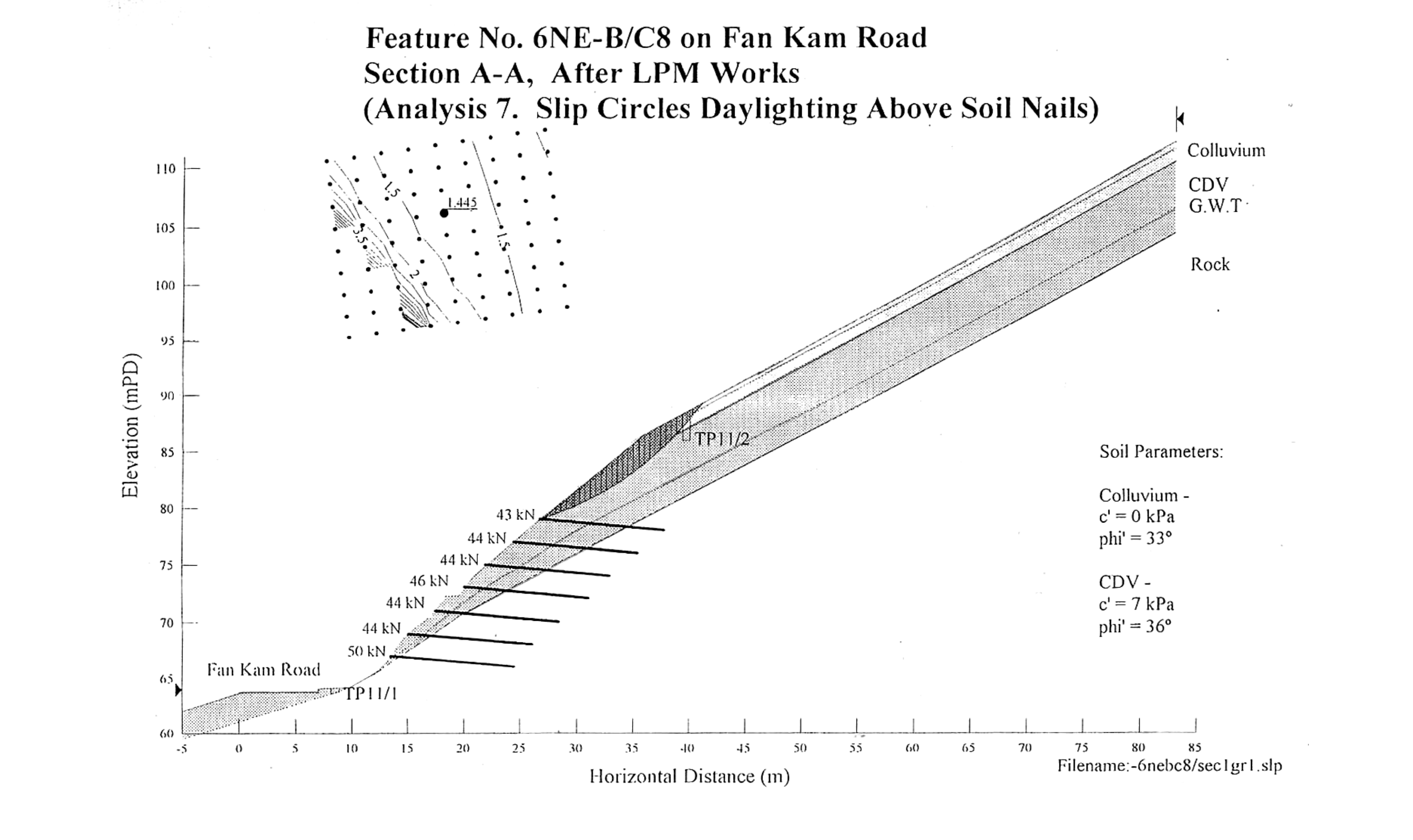

Note: This figure is reproduced from Stage 3 Study Report No. S3R 101/97.

Figure 8 - Stability Analysis of Slope No. 6NE-B/C8 through the 5 May 2003 Landslide

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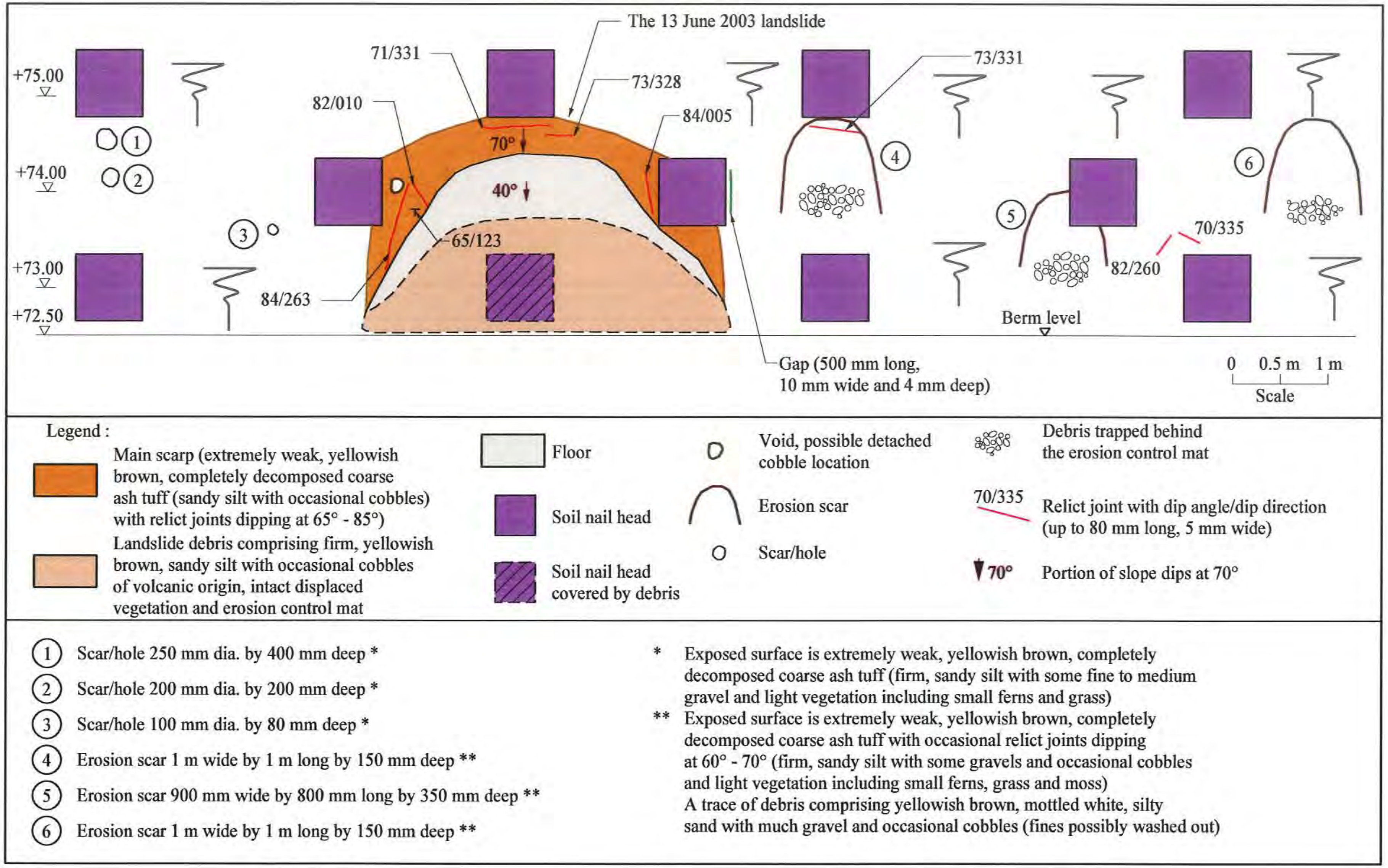

Figure 9 - Elevation of the 13 June 2003 Landslide Site and the Erosion Scars in the Vicinity

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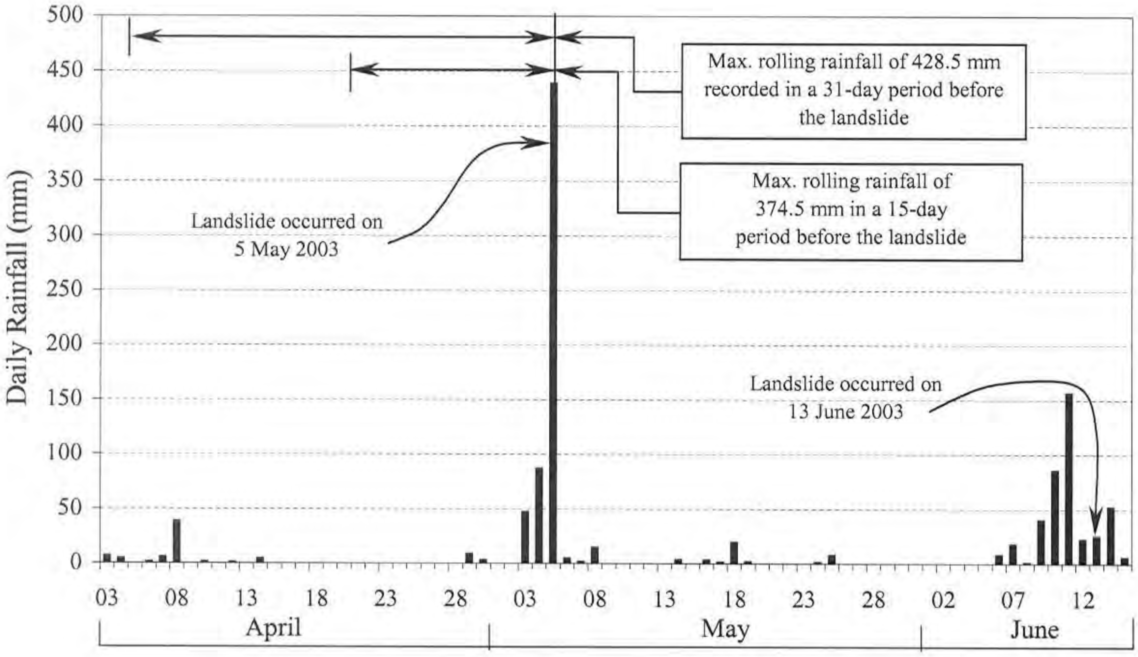
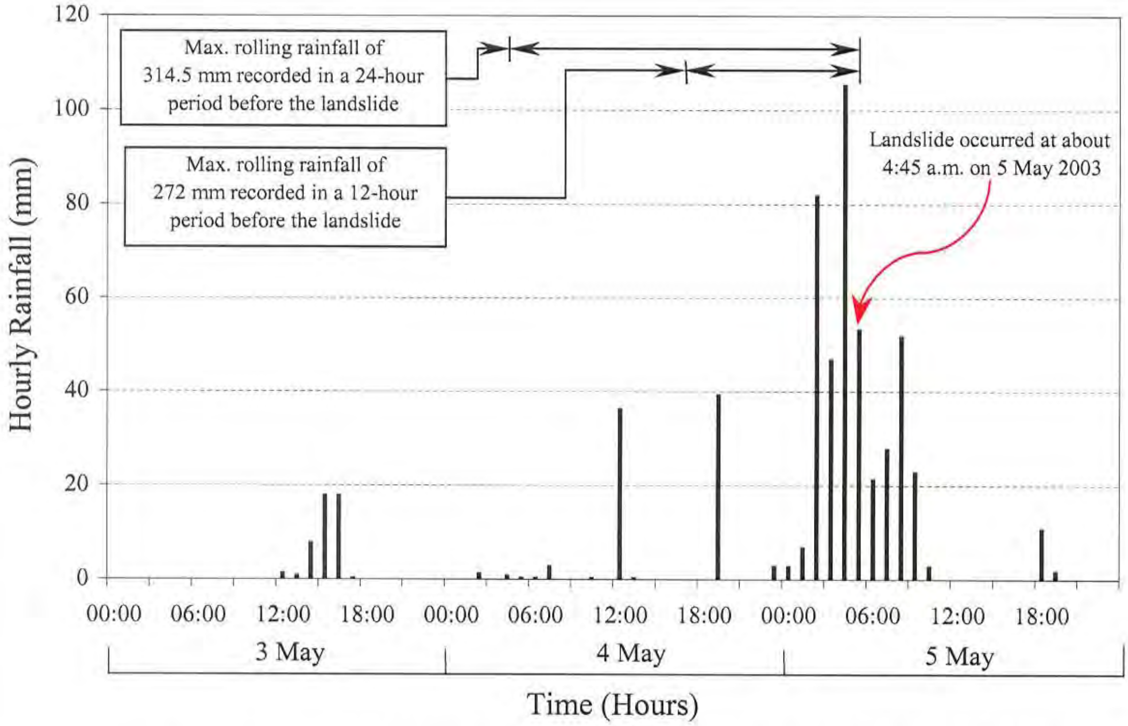


(a) Daily Rainfall Recorded at GEO Raingauge No. N36 between 3 April 2003 and 15 June 2003



(b) Hourly Rainfall Recorded at GEO Raingauge No. N36 between 3 May 2003 and 5 May 2003

Figure 10 - Daily and Hourly Rainfall Recorded at GEO Raingauge No. N36

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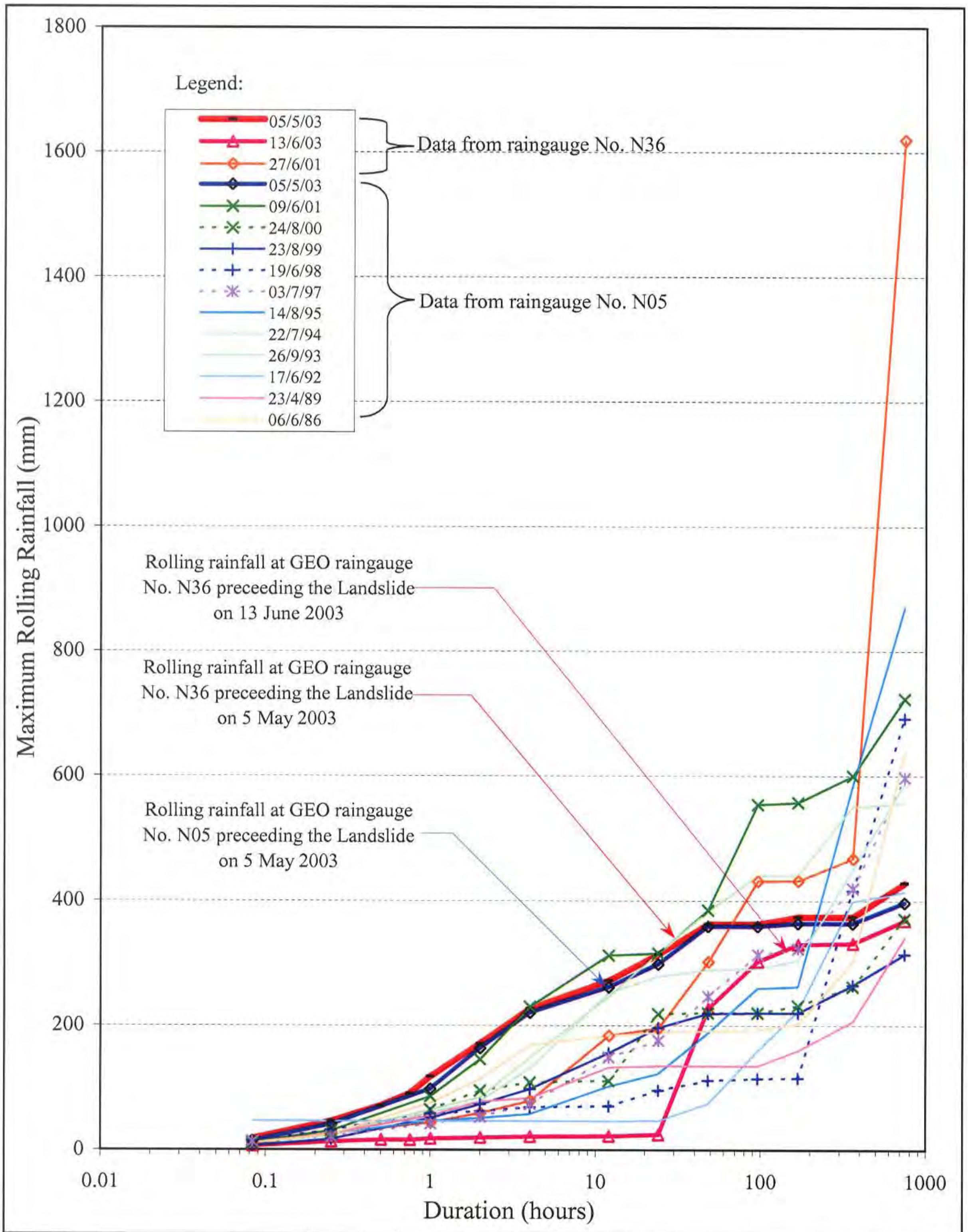

Notes: (1) Rainfall data evaluated from 5-minute readings from GEO raingauge Nos. N36 (about 3.5 km southeast of the landslide site) & N05 (about 5.8 km northeast of the landslide site).
(2) Rolling rainfall of previous rainstorms calculated at GEO raingauge No. N36 since October 1999 and at GEO raingauge No. N05 since March 1983.

Figure 11 - Maximum Rolling Rainfall for Previous Major Rainstorms at GEO Raingauges Nos. N36 and N05

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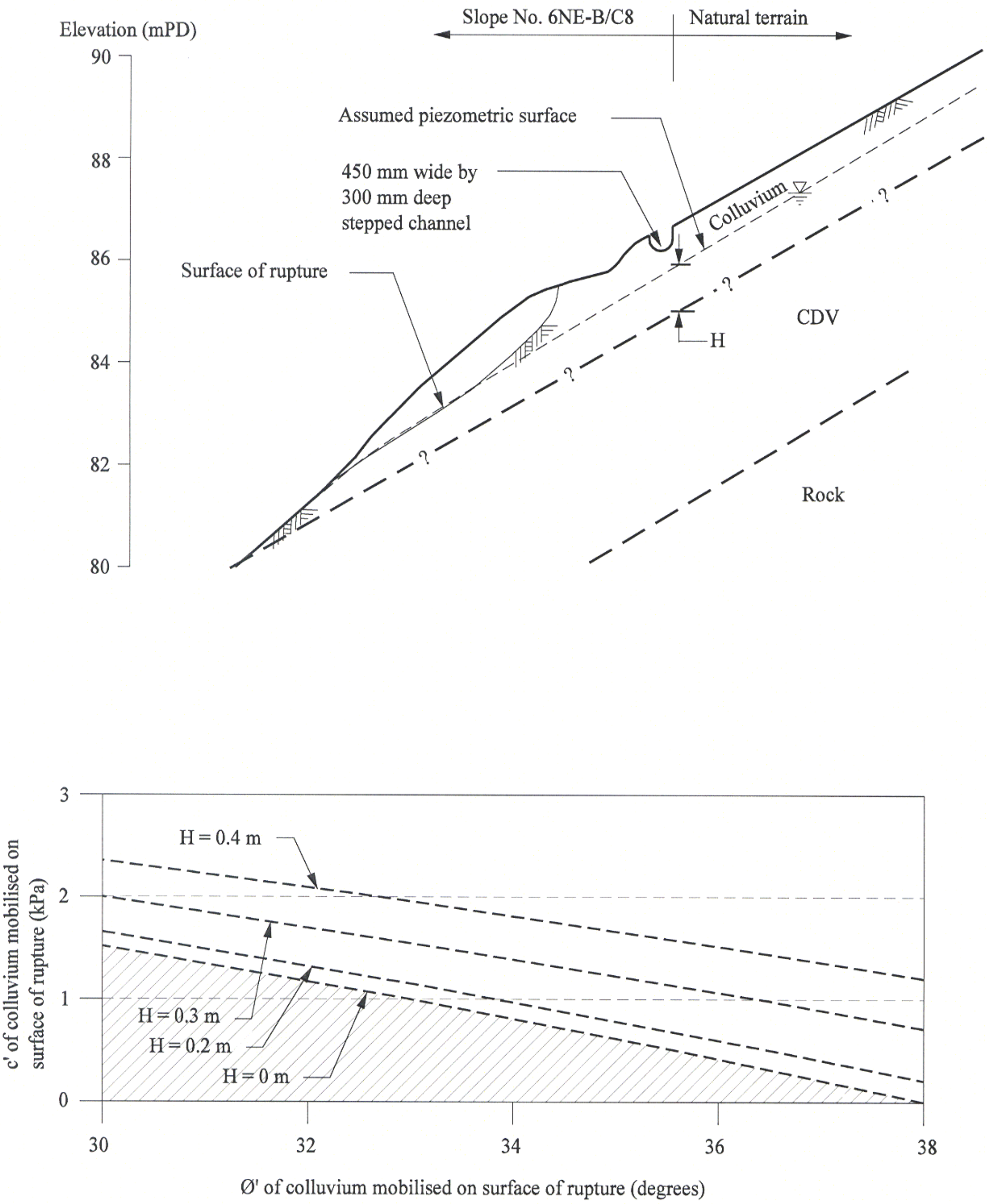

Legend :	Factor of safety equal to unity (i.e. Limiting Equilibrium)	Unsaturated zone
Note :	The cross-section for the stability analysis is extracted from Figure 3.	

Figure 12 - Summary of Sensitivity Analyses

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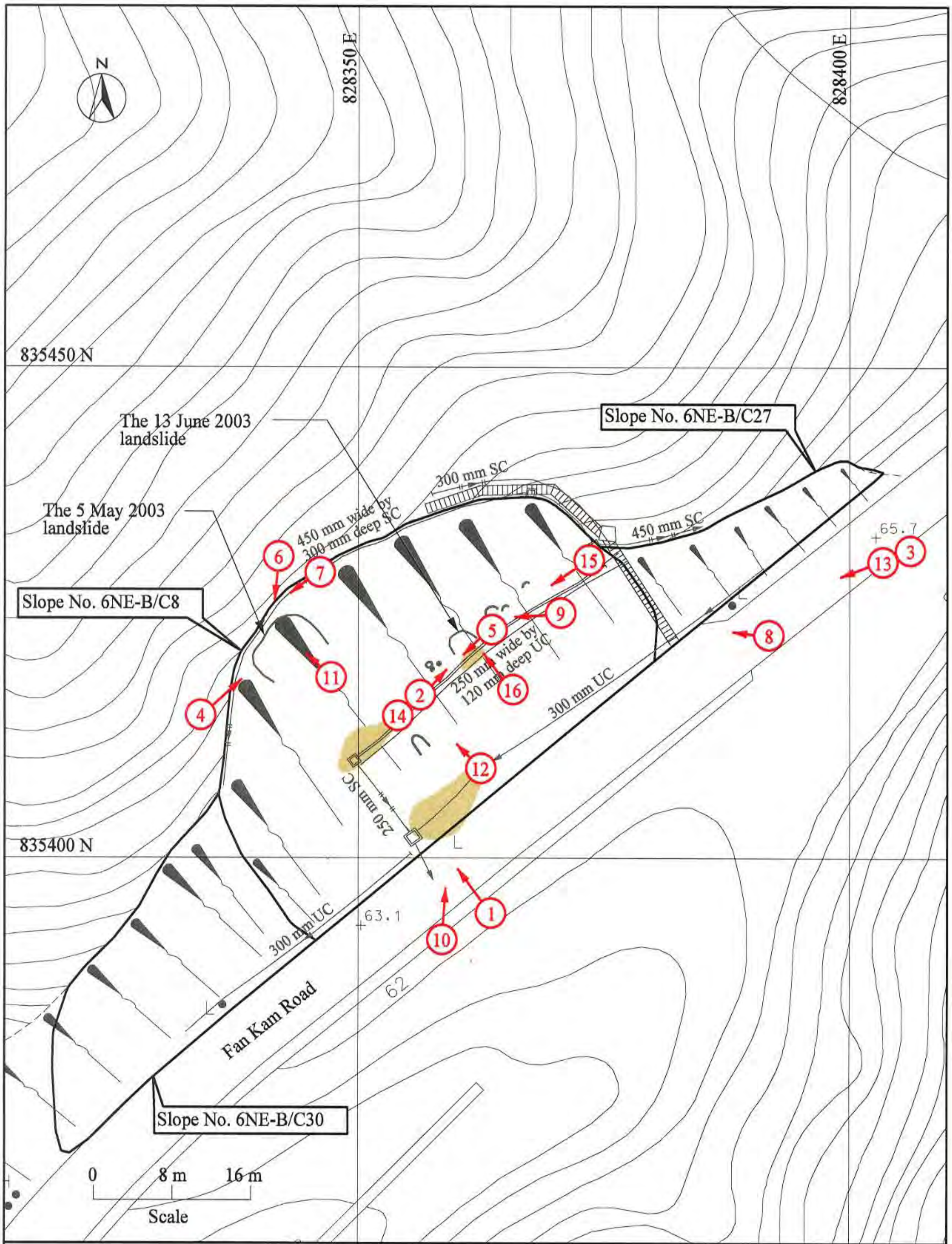

Legend : Location and direction of photograph

Note : Base plan is extracted from 1 : 1000 survey sheets Nos. 6NE-4B and 6NE-4D dated June 2002.

Figure 13 - Locations and Directions of Photographs Taken

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Plate 1 - General View of the 5 May 2003 Landslide on Slope No. 6NE-B/C8
(Photograph taken on 16 May 2003)

Note: See Figure 13 for location and direction of photograph.

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Plate 2 - View of the 13 June 2003 Landslide on Slope No. 6NE-B/C8
(Photograph taken on 14 June 2003)

Plate 3 - General View of Slope No. 6NE-B/C8 and the Fallen Boulder
(Photograph taken on 16 May 2003)

Note: See Figure 13 for location and direction of photograph.

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Plate 4 - Side View of the Area Immediately above the 5 May 2003 Landslide Site
(Photograph taken on 16 May 2003)

Plate 5 - View of the 1 m Wide Berm on Slope No. 6NE-B/C8
(Photograph taken on 6 May 2003)

Note: See Figure 13 for location and direction of photograph.

Plate 6 - View of Remnants of Erosion Control Mat around the Crest of the 5 May 2003 Landslide Site
(Photograph taken on 14 June 2003)

Note: See Figure 13 for location and direction of photograph.

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Plate 7 - View of the Surface Drainage Channel along the Crest of Slope No. 6NE-B/C8 (Photograph taken on 6 May 2003)

Note: See Figure 13 for location and direction of photograph.

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Plate 8 - General View of Slope No. 6NE-B/C8 in 1978 (Photograph taken by Binnie & Partners (Hong Kong) on 18 April 1978)

Plate 9 - View of Slope No. 6NE-B/C8 in April 2000 (Photograph taken by ESA Consulting Engineers Ltd on 25 April 2000)

Note: See Figure 13 for location and direction of photograph.

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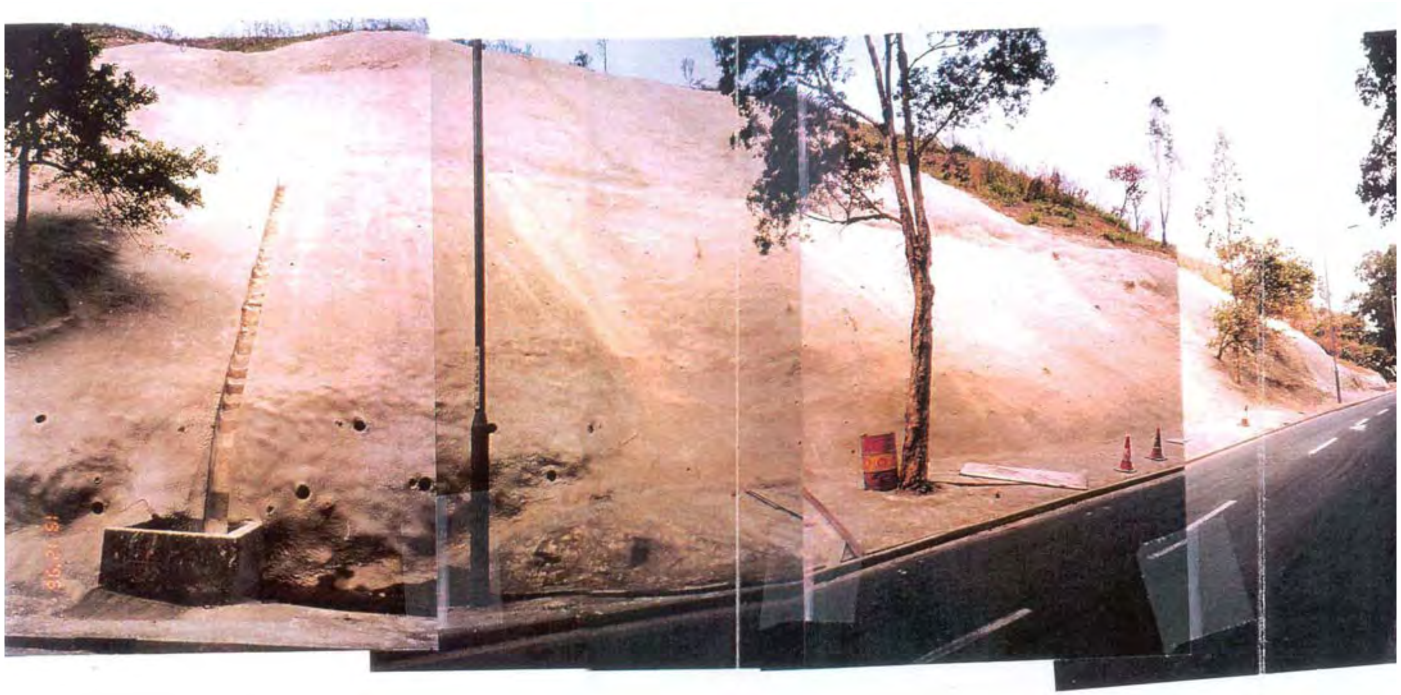

Plate 10 - View of Slope No. 6NE-B/C8 in December 1996 (Photograph taken by ESA Consulting Engineers Ltd on 19 December 1996)

Note: See Figure 13 for location and direction of photograph.

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Plate 11 - Close-up View of the 5 May 2003 Landslide (Photograph taken on 16 May 2003)

Note: See Figure 13 for location and direction of photograph.

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Plate 12 - View of the Erosion Scar on the Lower Batter of Slope No. 6NE-B/C8
(Photograph taken on 14 June 2003)

Note: See Figure 13 for location and direction of photograph.

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Plate 13 - View of Water Flowing from a Raking Drain and Seeping from the Interface between the Toe Surface Channel and the Pedestrian Pavement (Photograph taken on 6 August 2003)

Note: See Figure 13 for location and direction of photograph.

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Plate 14 - View of the 13 June 2003 Landslide Following Surface Preparation for Urgent Repair Works (Photograph taken on 19 June 2003)

Note: See Figure 13 for location and direction of photograph.

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Plate 15 - View of the Erosion Scars on Slope No. 6NE-B/C8 above the Berm
(Photograph taken on 14 June 2003)

Note: See Figure 13 for location and direction of photograph.

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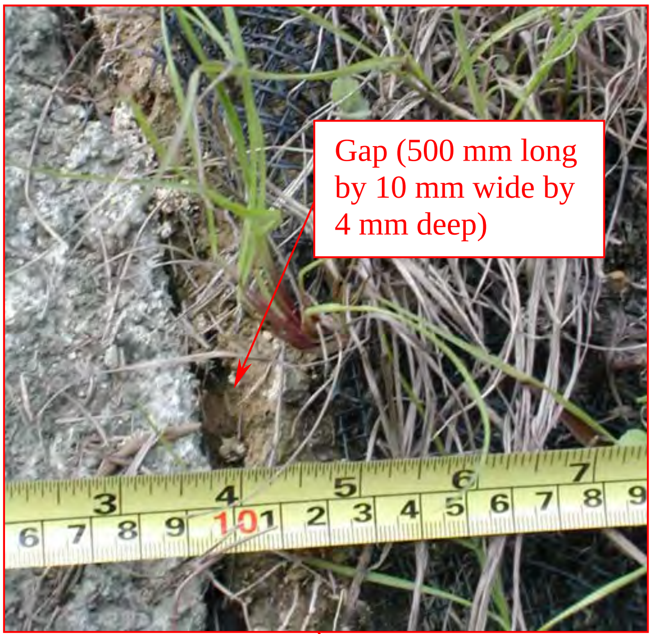

Plate 16 - Close-up View of a Gap between a Soil Nail Head and the Slope at the 13 June 2003 Landslide Site (Photograph taken on 19 June 2003)

Note: See Figure 13 for location and direction of photograph.

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APPENDIX A

THE 5 MAY 2003 BOULDER FALL

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A1. INTRODUCTION

A boulder fall (Incident No. 2003/05/0009) involving a large boulder (approximately 4.2 m^3 in volume) that originated from the natural terrain some 60 m above the crest of slope No. 6NE-B/C8 (at an elevation of approximately 110 mPD), occurred about one to two hours after the 5 May 2003 landslide, when a Red Rainstorm Warning was hoisted (Figures A1 and A2 and Plate A1). The boulder came to rest on the pedestrian pavement on the opposite side of Fan Kam Road (Plate A2). In the process, the boulder narrowly missed a vehicle parked on the opposite side of the road, just after the driver left the vehicle. This appendix documents the relevant background information on the boulder fall.

A2. SOURCE AREA OF THE FALLEN BOULDER

The source of the boulder is located on the 30° steep natural hillside above slope No. 6NE-B/C8 (Figures A2 and A3 and Plate A3). The hillside is strewn with boulders and covered with vegetation comprising grass, shrubs and small trees (Plate A1). Two rounded spurs trending southeast and south-southeast form the northeastern and western boundaries of the triangular-shaped catchment with boulders being present above slope No. 6NE-B/C8 (Figure A2). The boulders, which are clustered within an area at least about 40 m (in plan) above the cut slope, are up to approximately 2.5 m wide and are generally located on the southeast trending spur.

A3. PAST ASSESSMENT

A3.1 Preliminary Geotechnical Assessment for Proposed Improvement to Fan Kam Road

In February 2000, the Advisory Division of the GEO completed a Preliminary Geotechnical Assessment (Lam, 2000) for the Improvement to Fan Kam Road project for HyD. Regarding the potential for boulder fall hazards, the report recommended that "detailed field mapping will be required at the design stage of the project to assess the sizes of potentially unstable boulders or blocks of rocks, the paths that the boulder would follow and its estimated travel distance".

A4. DESCRIPTIONS OF THE BOULDER FALL

The fallen boulder (4.2 m^3) was moderately to slightly decomposed (Grade II/III) coarse ash tuff and measured approximately 1.4 m by 1.5 m by 2 m (Plate A4). Based on the extent of soil staining on the surface of the boulder, the boulder was likely to have been embedded into the natural hillside to a depth of between 100 mm and 200 mm before detachment (Plate A4). Also, it is probable that the boulder was positioned with its longest dimension (about 2 m) across the hillside, with about 1 m protruding above the surface of the hillside (see Figure A3).

The fallen boulder left a depression/void at its source area which measured about 2.5 m by 1 m (Plate A5). No major tree roots were found within the depression/void. Smaller boulders with sizes ranging from about 0.5 m to 1 m were found immediately above the source area of the fallen boulder (Plate A6).

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The results of engineering geological mapping of the depression/void at the source of the boulder fall are summarised in Figure A2. A geological cross-section through the source area is presented in Figure A3. Colluvium comprising soft, moist, dark greyish brown sandy silt with many sub-angular to sub-rounded cobbles and occasional boulders (Grade II/III coarse ash tuff up to 0.7 m in size) was found in the source area. Soil pipes of about 60 mm in diameter were identified near the base of the depression (Plate A6). No seepage was observed at the time of inspections by MGSL in May and June 2003.

The boulder fall left a trail of about 1 m to 1.5 m in width and 400 mm in depth on the natural terrain (Figure A2 and Plates A1, A7 and A8). A catchpit (Plate A9) and a section of the maintenance stairway (Plate A10) on the northeast side of slope No. 6NE-B/C8 were severely damaged by the boulder.

The impact of the boulder on the pedestrian pavement at the slope toe left an indentation which measured approximately 1.9 m by 2.2 m and 350 mm deep (Plate A10). The boulder came to rest on the pedestrian pavement on the opposite side of Fan Kam Road (Plate A2).

MGSL carried out a survey of the 22 sub-angular boulders in the immediate vicinity of the source area of the fallen boulder (Figure A2). This revealed that three (14%) of the boulders measured less than 1 m, 17 (77%) have a dimension of between 1 m and 2 m, and two (9%) have a dimension of greater than 2 m.

Following the 5 May 2003 incident, the Mainland West Division of the GEO recommended that HyD should carry out boulder stabilisation works which comprised concrete buttresses and shotcrete cover for about 20 boulders in the vicinity of the source of the 5 May 2003 boulder fall. These boulder stabilisation works were completed in August 2003.

A5. REFERENCES

Geotechnical Control Office (1988). Guide to Rock and Soil Descriptions (Geoguide 3). Geotechnical Control Office, Hong Kong, 186 p.

Lam, A.Y.T. (2000). Improvement to Fam Kam Road, Preliminary Geotechnical Assessment. Preliminary Geotechnical Assessment Report No. PGA 1/2000, Geotechnical Engineering Office, Hong Kong, 23 p. plus 2 appendices and 7 drgs.

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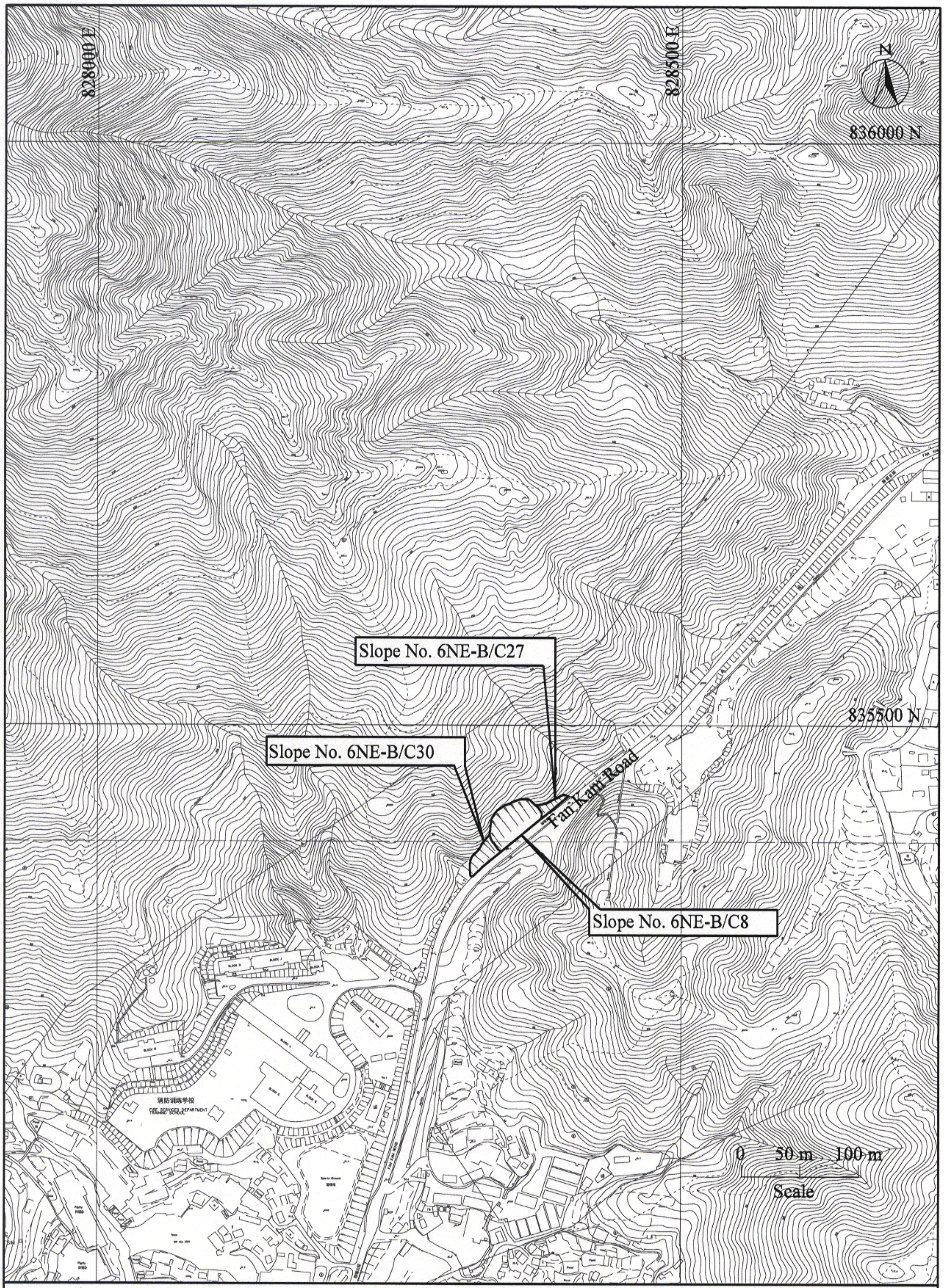

Note :	Base plan is extracted from 1 : 1000 survey sheets Nos. 2SE-24D, 2SE-25C, 6NE-4B, 6NE-4D, 6NE-5A and 6NE-5C dated June 2002.

Figure A1 - Site Location Plan

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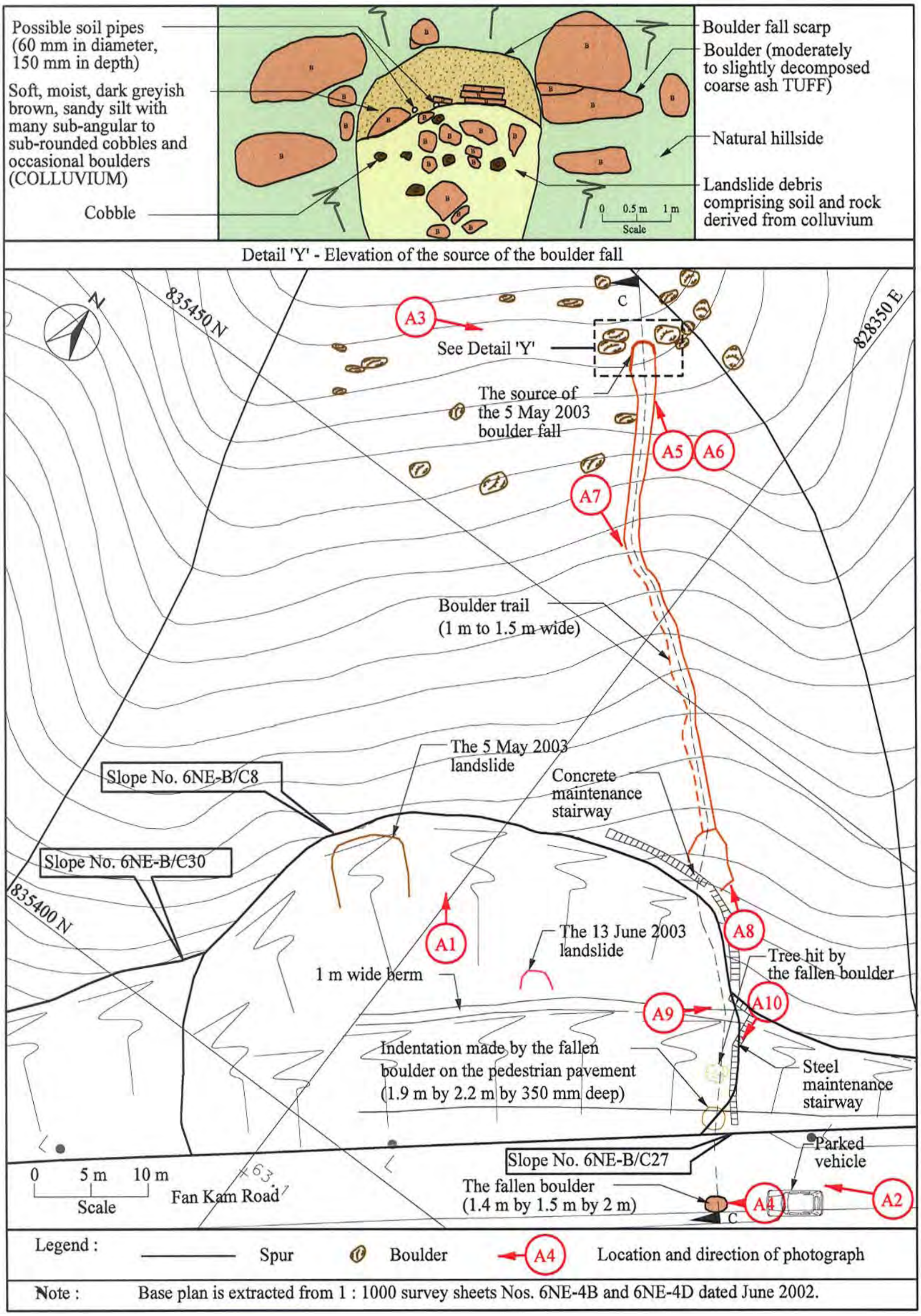

Figure A2 - Site Observations

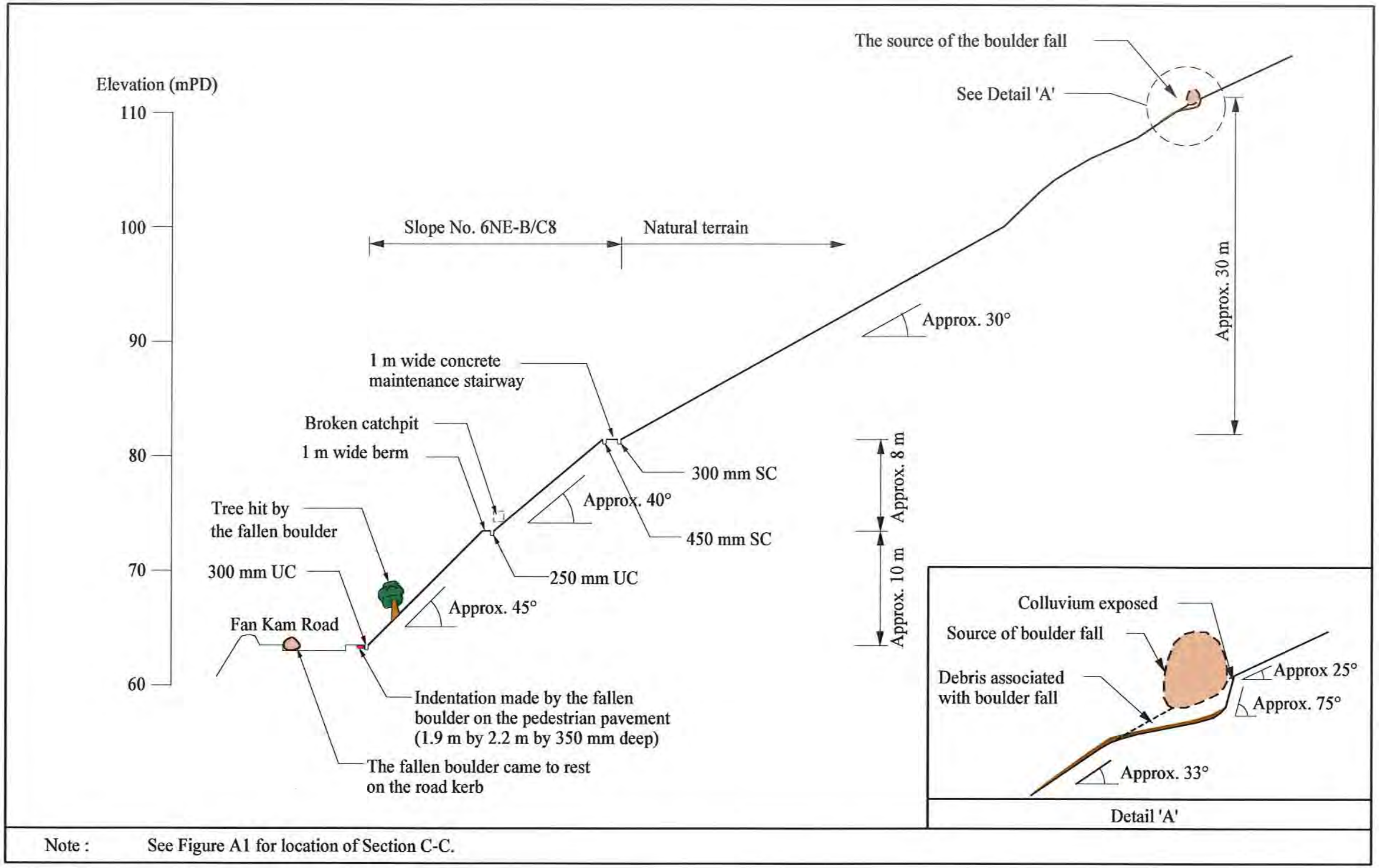

Figure A3 - Section C-C through the 5 May 2003 Boulder Fall Site

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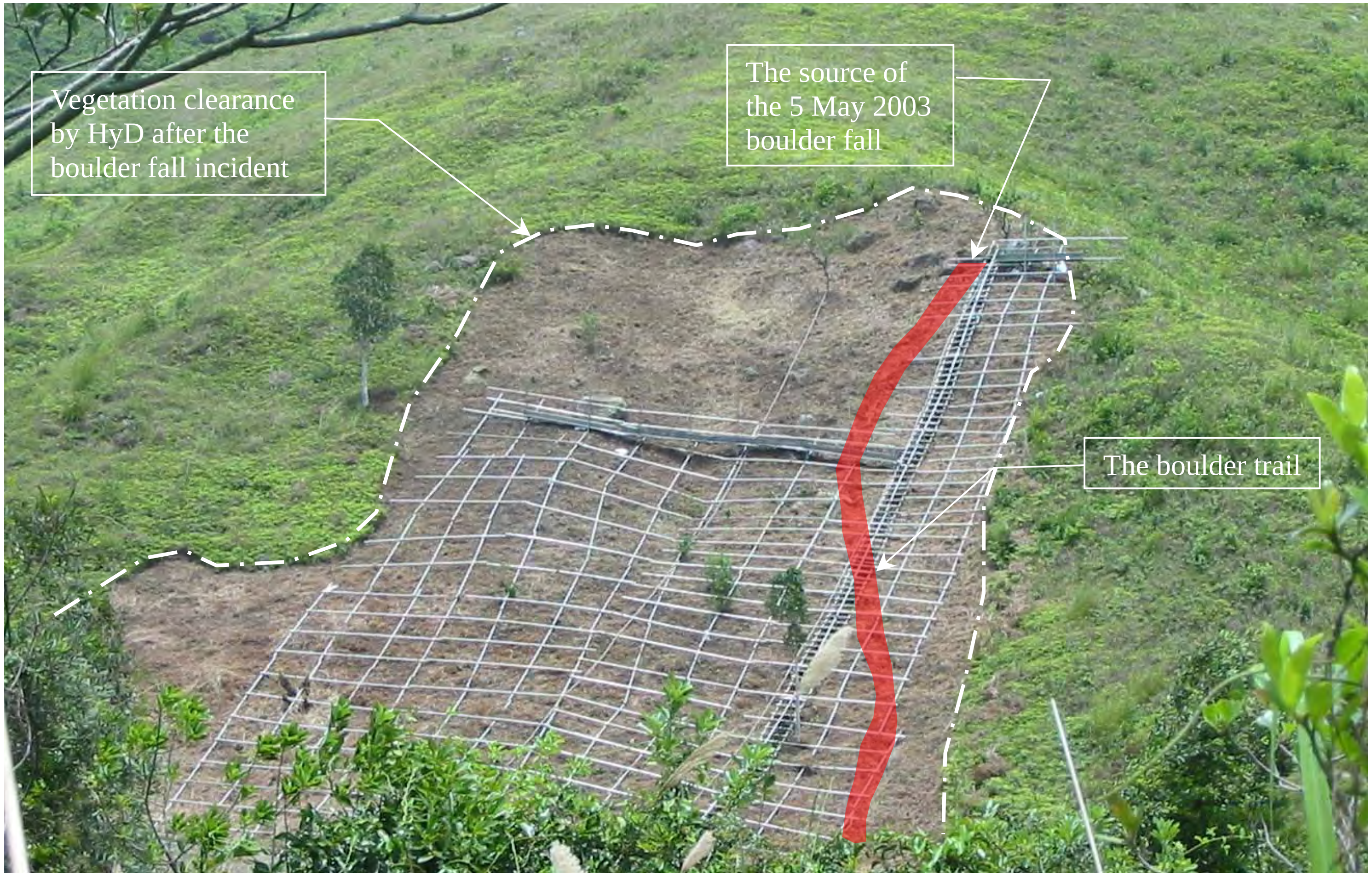

Plate A1 - General View of the Source of the 5 May 2003 Boulder Fall and the Upper Section of the Boulder Trail (Photograph taken on 16 May 2003)

Note: See Figure A2 for location and direction of photograph.

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Plate A2 - General View of Slope No. 6NE-B/C8 and the Fallen Boulder
(Photograph taken on 16 May 2003)

Note: See Figure A2 for location and direction of photograph.

Plate A3 - Side View of the Natural Hillside above the Source of the 5 May 2003 Boulder Fall after Vegetation Clearance (Photograph taken on 16 May 2003)

Note: See Figure A2 for location and direction of photograph.

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Plate A4 - Close-up View of the Fallen Boulder (Photograph taken on 16 May 2003)

Note: See Figure A2 for location and direction of photograph.

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Plate A5 - View of the Source of the 5 May 2003 Boulder Fall
(Photograph taken on 6 May 2003)

Note: See Figure A2 for location and direction of photograph.

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Plate A6 - Close-up View of the Source of the 5 May 2003 Boulder Fall after Vegetation Clearance (Photograph taken on 16 May 2003)

Note: See Figure A2 for location and direction of photograph.

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Plate A7 - Close-up View of the Boulder Trail Looking Downhill
(Photograph taken on 6 May 2003)

Note: See Figure A2 for location and direction of photograph.

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Plate A8 - The Boulder Trail Looking Uphill (Photograph taken on 16 May 2003)

Plate A9 - View Showing a Catchpit Damaged by the Fallen Boulder (Photograph taken on 6 May 2003)

Note: See Figure A2 for location and direction of photograph.

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Plate A10 - View of the Maintenance Stairway and Pedestrian Pavement Damaged by the Fallen Boulder (Photograph taken on 6 May 2003)

Note: See Figure A2 for location and direction of photograph.

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APPENDIX B

AERIAL PHOTOGRAPH INTERPRETATION

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B1 DETAILED OBSERVATIONS

This appendix sets out the detailed observations made from an interpretation of aerial photographs taken between 1949 and 2001. A list of the aerial photographs studied is presented in Table B1 and a location plan (Figure B1) is also attached.

YEAR	OBSERVATIONS
1949	The study area is located along the toe of a southeast-facing natural hillside in a shallow depression (defined by a rounded concave break in slope) between two rounded spurs trending southeast and south-southeast, and adjacent to a valley.
	A narrow strip of cultivation terraces and an unpaved track can be seen along the valley (at the approximate location of the present-day Fan Kam Road). Fan Kam Road has not been formed yet.
	Highly reflective areas interpreted as patches of bare soil surface can be seen generally along the ridge above the study area and the spurs either side of the study area, indicating signs of probable surface erosion.
	A relict landslide scar can be seen above the present-day slope No. 6NE-B/C8.
1963	The 1963 photographs are very clear (taken from a low level).
	Fan Kam Road has been constructed and is in its present-day alignment. Slopes Nos. 6NE-B/C30, 6NE-B/C27 and 6NE-B/C8 (lower portion only) have been formed by cutting into the natural hillside and appear to be covered with sparse vegetation.
	Scattered boulders were present on the southeast trending spur, approximately 50 m uphill of the present-day location of slope No. 6NE-B/C8.
	The natural hillside is generally covered with thin vegetation comprising grass and bushes. From the good resolution photographs, two possible degraded relict landslide scars are visible within the depression between the two spurs.
1964	No observable changes.
1972	An area of high reflectivity (light tone) can be seen above the lower portion of slope No. 6NE-B/C8, described in the 1963 aerial photographs. This is inferred as an area of instability and resulted in the slope having its crest line extended in the northwest direction to its present location.
	Slope No. 6NE-B/C8 appears to be covered with a hard surface (as indicated by an area of high reflectivity), while slopes Nos. 6NE-B/C30 and 6NE-B/C27 are covered with vegetation.
	A man-made drainage channel can be seen along the crests of slopes Nos. 6NE-B/C8, 6NE-B/C30 and 6NE-B/C27.

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YEAR	**OBSERVATIONS**
1974	No observable changes.
1975	No observable changes.
1976	No observable changes.
1977	No observable changes.
1979	No observable changes.
1981	No observable changes.
1982	No observable changes.
1983	No observable changes.
1986	No observable changes.
1987	The density of vegetation (shrubs and small trees) on the natural hillside has increased.
1988	Slope No. 6NE-B/C8 has a highly reflective appearance indicating that it is possibly covered with a hard surface. The natural hillside above it remained unchanged.
1992	No observable changes.
1993	A recent landslide scar can be seen on the west flank of the south-southeast trending spur. Vegetation disappeared from an extensive area on the natural hillside above probably as a result of a hillfire.
1994	No observable changes.
1995	Light vegetation re-established itself on the natural hillside above. The northeast portion of slope No. 6NE-B/C8 is covered with dense vegetation and the remaining portion is covered with light vegetation.
1996	The lower batter of slope No. 6NE-B/C8 has been shotcreted recently as inferred from an area of high reflectivity.
1997	Slopes Nos. 6NE-B/C30, 6NE-B/C27 and the upper batter of slope No. 6NE-B/C8 have been shotcreted recently as inferred from an area of high reflectivity.
1998	No observable changes.

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YEAR	OBSERVATIONS
1999	No observable changes.
2000	Slopes Nos. 6NE-B/C8, 6NEB/C30 and 6NE-B/C27 have recently been covered with vegetation.
2001	No observable changes.

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Table B1 - List of Aerial Photographs used in Aerial Photograph Interpretation

Date Taken	Altitude (ft)	Photograph Number
8 May 1949	Unknown	Y01851-52
1963	3900	Y09650-51
13 December 1964	12500	Y13039-40
3 October 1972	13000	2241-42
21 November 1974	12500	9869-70
23 December 1975	12500	Y16262-63
23 December 1976	12500	16449-50
9 December 1977	11500	19874
29 November 1979	10000	28275-76
19 May 1981	10000	37993-94
7 July 1982	4000	42927-28
22 December 1983	10000	52284-85
3 August 1986	4000	A05616-17
10 June 1987	4000	A09444-45
2 June 1988	4000	A13044-45
28 April 1992	4000	A30650-51
2 November 1993	3000	CN5124-25
6 May 1994	4000	A38205-06
19 July 1995	3200	CN10127-28
6 June 1996	3500	CN13815-16
23 July 1997	3300	CN17745-46
11 November 1998	8000	CN21738-39
5 November 1999	3500	CN24473-74
1 June 2000	3500	CN26469-70
20 September 2001	4000	CW32986-87

Notes: (1) Aerial photographs are in black and white except for those prefixed with CN or CW.
(2) Aerial photographs taken in 2002 have been borrowed by other parties.

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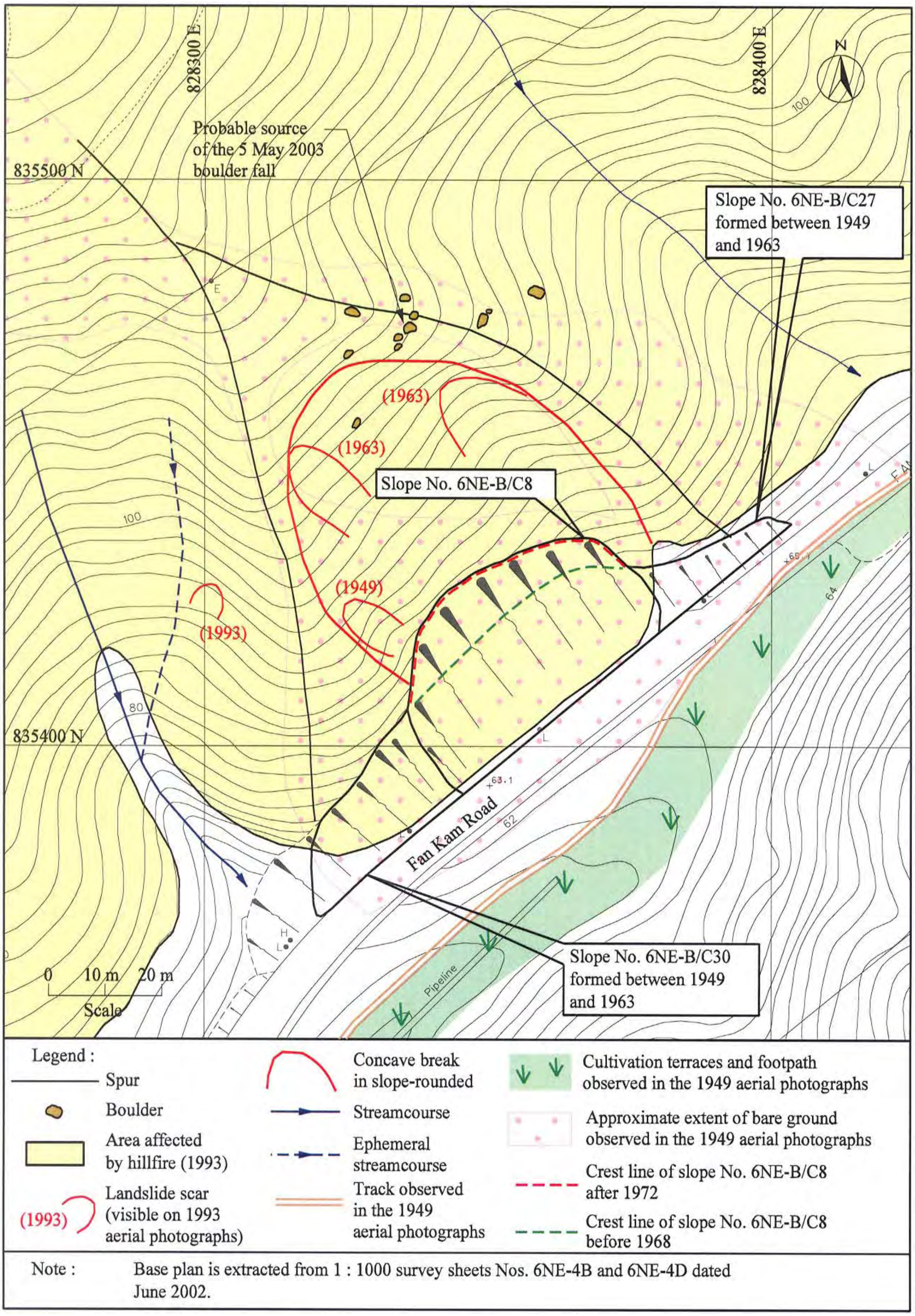

Figure B1 - Aerial Photograph Interpretation

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

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

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

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

<u>writing to</u>
Publications Sales Section,
Information Services Department,
Room 402, 4th Floor, Murray Building,
Garden Road, Central, Hong Kong.
Fax: (852) 2598 7482

<u>or</u>

- Calling the Publications Sales Section of Information Services Department (ISD) at (852) 2537 1910
- Visiting the online Government Bookstore at http://bookstore.esdlife.com
- Downloading the order form from the ISD website at http://www.isd.gov.hk and submit the order online or by fax to (852) 2523 7195
- Placing order with ISD by e-mail at puborder@isd.gov.hk

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美利大廈4樓402室
政府新聞處
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<u>或</u>

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

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香港九龍何文田公主道101號
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土力工程處
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傳真: (852) 2714 0247
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MAJOR GEOTECHNICAL ENGINEERING OFFICE PUBLICATIONS
土力工程處之主要刊物

GEOTECHNICAL MANUALS

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

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

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TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents