DETAILED STUDY
OF THE 6 JUNE 2003
ROCKFALL INCIDENT ON
SLOPE NO. 11NE-C/C71
AT KUNG LOK ROAD
KWUN TONG

GEO REPORT No. 192

T.H.H. Hui

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

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Table of Contents
Table of Contents
Table of Contents
Table of Contents

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Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents
Table of Contents

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
October 2006

FOREWORD

This report presents the findings of a detailed study of a rockfall incident (GEO incident No. 2003/06/0099) on slope No. 11NE-C/C71, located at Kung Lok Road, Kwun Tong. The incident involved the detachment of a rock block, with a failure volume of about 1 m^3, from the western end of the slope. The rock block broke up into several pieces and came to rest on the pedestrian pavement at the slope toe. No casualties were reported. The pedestrian pavement was temporarily closed as a result of the incident.

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

This report was prepared by Mr T.H.H. Hui under the supervision of Dr H.W. Sun and myself. Maunsell Geotechnical Services Limited, the 2003 landslide investigation consultant, provided support in respect of engineering geological mapping of the site and tree survey. Their assistance and contribution are gratefully acknowledged.

K.K.S. Ho
Chief Geotechnical Engineer/Landslip Preventive Measures Division 1

Table of Contents
Table of Contents
Table of Contents
Table of Contents

CONTENTS

Table of Contents

1. INTRODUCTION

At about 1:00 p.m. on 6 June 2003, a rockfall (Incident No. 2003/06/0099) occurred on soil/rock cut slope No. 11NE-C/C71 at Kung Lok Road, Kwun Tong (Figure 1). The incident involved the detachment of a rock block, with a failure volume of about 1 m^3, from the western end of the slope. The rock block broke up into several pieces and came to rest on the pedestrian pavement at the slope toe. No casualties were reported and the pedestrian pavement was temporarily closed as a result of the incident.

Following the incident, the Landslip Preventive Measures (LPM) Division 1 of the Geotechnical Engineering Office (GEO) carried out a detailed study of the rockfall. The key objectives of the detailed study were to document the facts about the June 2003 rockfall, present relevant background information and establish the probable causes of the failure. Recommendations for follow-up actions are presented separately.

Table of Contents

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 incident,

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

(c) aerial photograph interpretation (API),

Table of Contents

(d) analysis of rainfall records,

(e) survey of the trees on the slope and assessment of their root characteristics, and

(f) diagnosis of the probable causes of the rockfall.

2. THE SITE

2.1 Site Description

A site plan showing the registered boundary of slope No. 11NE-C/C71, together with the location of the rockfall, is presented in Figure 2, and a general view of the slope is shown in Plate 1. The rockfall occurred near the western end of the slope, about 2 m above the slope toe (Plates 2 and 3).

Table of Contents

St. Catharine’s School for Girls (hereinafter referred to as the ‘School’) and Hong Lee Court are located on a platform above the western and eastern sections of the slope crest respectively. Kung Lok Road, which is a dual lane, single carriageway with an approximately 2.5 m wide pedestrian pavement, runs along the toe of the slope. Many school buses and vehicles were often parked along the pedestrian pavement of Kung Lok Road in close proximity to the slope.

Slope No. 11NE-C/C71 is a soil/rock cut slope, which is about 170 m long and up to 22 m high. The lower portion of the slope comprises rock with a maximum height of about 20 m, inclined at angles of up to 85°. The slope has three batters inclined generally at angles of between 60° and 80°, which are separated by two benches of up to about 1.5 m wide. The rock portion is sparsely vegetated with some shrubs and trees in local areas, which are concentrated predominantly along weathered or open joints (see Section 5.2).

The upper portion of the slope typically comprises soil with a variable height of up to about 8 m, is inclined at an angle of approximately 60° and covered with shotcrete. Tree rings are commonly provided for the trees on the upper portion of the slope.

Surface drainage provisions (see Figure 3) mainly comprise a 400 mm wide U-channel running along the slope toe and a 350 mm U-channel running along the crest. The crest channel drains to the west and connects to the surface drainage of the adjoining slope No. 11NE-C/C74, where surface water is discharged down to Kung Lok Road via stepped channels.

2.2 Maintenance Responsibility

According to the Slope Maintenance Responsibility Information System (SMRIS) of the Lands Department, slope No. 11NE-C/C71 is of mixed maintenance responsibility (Figure 2). The western portion of the slope (where the 6 June 2003 rockfall occurred), which falls within Lot No. NKIL 5214, is under the maintenance responsibility (MR) of the School. The eastern portion of the slope, which falls within Lot No. NKIL 5202, is under the MR of the incorporated owners of Hong Lee Court.

2.3 Water-carrying Services

Based on the information provided by the relevant Government Departments (including Architectural Services Department (Arch SD), Buildings Department (BD), Water Supplies Department and Drainage Services Department), the School and utility companies, the approximate locations of water-carrying services in the vicinity of the site are shown in Figure 3. It is noted that there are two foul water drains (229 mm and 305 mm in diameter) located at the crest of the slope.

2.4 Regional Geology

According to the Hong Kong Geological Survey (HKGS) 1:20,000 Solid and Superficial Geology Map Sheet 11 - Hong Kong and Kowloon (GCO, 1986), the site is underlain by fine to medium-grained granite. Two sub-parallel northwest-southeast trending photogeological lineaments are shown about 50 m to 200 m to the northeast of the site. Northeast-southwest striking vertical joints are shown about 60 m to the west of the site (Figure 4).

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents
Table of Contents

3. HISTORY OF THE SITE AND PAST INSTABILITIES

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 5). Detailed observations from the Aerial Photograph Interpretation (API) are summarised in Appendix A.

The earliest available aerial photographs (taken in 1945) show that, prior to development, the study area was located on a northeast-facing natural hillside at Crocodile Hill (Ngok Yue Shan) and a minor spur can be seen to descend from the ridgeline and pass perpendicularly through the centre of what is now slope No. 11NE-C/C71 (Figure A1 in Appendix A).

Based on API, slope No. 11NE-C/C71 was formed some time between 1963 and 1967 in conjunction with the construction of Kung Lok Road. The School was built on a platform above the slope between 1967 and 1970. Construction of Hong Lee Court was evident on the 1970 aerial photographs and was completed by 1972. In 1967, the eastern and western portions of slope No. 11NE-C/C71 were covered by chunam and the middle rock portion was bare. Since 1990, vegetation has gradually become established on the slope.

On the 1967 aerial photographs, an approximately 5 m wide gully feature can be observed originating just below the slope crest on the eastern side of slope No. 11NE-C/C71 (Figure 5). Since most of the adjacent cut slopes had been formed before 1967, this gully was probably a failure or erosion scar.

According to the GEO's Landslide Database, two rockfall incidents (Incidents Nos. K86/6/30 and ME2001/06/004) occurred on slope No. 11NE-C/C71 on 6 June 1986 and 9 June 2001 respectively. The approximate locations of these incidents are shown in Figure 5. Based on the GEO Incident Report, Incident No. K86/6/30 occurred near the centre of the slope and involved the detachment of several rock blocks with a total volume of about 1 m^3. No casualties or road closure were reported.

Incident No. ME2001/06/004 involved the detachment of several rock blocks (total volume about 1 m^3) from the western end of the slope and resulted in temporary closure of the pedestrian pavement at the slope toe. No casualties were reported. A landslide review was subsequently carried out by GEO's landslide investigation consultant, Halcrow China Limited (HCL), under Agreement No. CE 2/2000 (see Section 4.4).

In September 1999, an incident (No. K1999/9/2) involving a tree fall from the slope face near the crest occurred at the middle portion of the slope (within the Lot boundary of the School). Following the incident, the Mainland East (ME) Division of the GEO issued a Type 3 Advisory Letter to the School in March 2000. The Advisory Letter made reference to concerns over the "presence of numerous loose rock fragments" and recommended that maintenance works, comprising removal of loose rock fragments from around the location where the tree fell, should be carried out "as soon as possible" (see Section 4.3).

4. PREVIOUS ASSESSMENT AND SLOPE MAINTENANCE

4.1 Stage 1 Study

In November 1988, a Stage 1 Study was carried out by the Planning Division of the Geotechnical Control Office (renamed GEO in 1991). The scope of the assessment included a detailed rock joint survey and stability assessment of the soil/rock cut slope.

According to the above study, "locally completely decomposed granite seams up to 0.3 m thick" were identified at the rock portion of the slope. The study also noted that "significant amount of seepage occurs mostly along the sheeting joints" near the eastern end of the slope, which may be caused by a "defective water pipe".

The Stage 1 Study noted that "NO FURTHER STUDY" was required for the slope and recommended that maintenance works be carried out, which comprised the removal of overhanging and loose rock blocks, survey of water-carrying services and clearance of debris from drainage channels.

Following the recommendation given in the Stage 1 Study, Type 2 Advisory Letters were issued by the BD to the owners of Lots Nos. NKIL 5202 (Hong Lee Court) and NKIL 5214 (the School) in April 1990 and June 1990 respectively.

In late 1992, joint site meetings were arranged between the GEO and the respective slope owners to inspect the maintenance works carried out. According to the Arch SD which was providing technical advice to the School, a leaking pipe at the slope crest within the Lot boundary of the School was located and repaired in October 1992. The location of the leaking pipe could not be found in their file records.

In March 1993, GEO confirmed to BD that slope maintenance works for slope No. 11NE-C/C71, which comprised buttresses, dowels, dentition and removal of loose rock blocks and overgrown vegetation, were completed by the respective owners.

4.2 SIFT and SIRST Studies

In November 1994, under the project entitled "Systematic Inspection of Features in the Territory" (SIFT), slope No. 11NE-C/C71 was designated SIFT Class 'C1', i.e. a slope that had "been formed or substantially modified before 30.6.78".

In September 1995, under the "Systematic Identification and Registration of Slopes in the Territory" (SIRST) project, slope No. 11NE-C/C71 was inspected by MGSL. The SIRST inspection record noted that "Previous Failure" and minor signs of seepage were observed at the slope toe. The overall maintenance condition of the cut slope was assessed as "fair". The consequence category of the slope was assessed as "High" and the corresponding CNPCS score was 11.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents

Table of Contents

Table of Contents

Table of Contents

4.3 Engineer Inspection in 2000

In March 2000 (i.e. following the September 1999 tree fall incident, as discussed in Section 3), the GEO issued a Type 3 Advisory Letter to the School. The School engaged Binnie, Black & Veatch Limited (BBV) to carry out an Engineer Inspection (EI) of slope No. 11NE-C/C71.

The EI was carried out in April 2000 for the slope portion under the MR of the School (Figure 2). The overall state of maintenance of the slope portion that BBV studied was assessed as “FAIR”. Slope maintenance works comprising removal of undesirable vegetation, sealing of open joints and removal of loose rock blocks/rock fragments were recommended (see Section 4.5). Details of the slope maintenance works (e.g. exact locations of rock blocks to be removed and joints to be sealed) were not explicitly specified in BBV’s EI recommendations. The Maintenance Manual prepared by BBV in May 2000 recommended that routine maintenance inspections and Engineer Inspections should be carried out at annual and 5-yearly intervals respectively.

4.4 Past Landslide Study

Following the June 2001 rockfall incident (No. ME2001/06/004, see Section 3), a landslide review (HCL, 2002) was carried out by HCL, the 2001 landslide investigation consultant, under Agreement No. CE 2/2000. According to the review report, slope No. 11NE-C/C71 had a history of minor failures. It was also noted that the density of unplanned vegetation on the western portion of the slope increased significantly between 1992 and 2001. The report indicated that the June 2001 rockfall was “probably triggered by rainfall” and was “possibly caused by water ingress into open or weathered joints around the rock block, causing the build-up of cleft water pressures”. The primary source of water ingress for the 2001 rockfall incident was probably surface runoff that overflowed from a blocked U-channel located on a berm above the source of the rockfall. The presence of unplanned vegetation was noted as providing “evidence of progressive opening up (i.e. root-jacking effects) of the joints prior to the rockfall”. The report also noted that the western portion of the slope with an exposed rock portion (under the MR of the School) appeared “to have inadequate maintenance prior to the 2001 rockfall incident, which was probably a major contributory factor to the failure”.

4.5 Slope Maintenance Works

During the course of carrying out slope maintenance works by Arch SD on the slope portion below the School, many joints were “found on the exposed rock slope surface after vegetation clearance”. On 8 August 2001, Arch SD wrote to BBV and GEO to express their concern that “sealing up all the rock joints would block up the discharge of rainwater and would adversely affect the slope stability”, as no details on the slope maintenance works were given in BBV’s EI report.

A joint site inspection was subsequently conducted by Arch SD and BBV on 21 August 2001 to identify rock joints “which require sealing”. On 13 September 2001, another joint site inspection was carried out by Arch SD, GEO and BBV. In a memo dated 19 September 2001 to Arch SD, the GEO recommended that “loose blocks and rock fragments to be removed" should be identified and "extensive sealing of joints already completed" should be inspected to ensure that there is "adequate drainage provision for all sealed joints". Also, GEO noted that "extensive sealing of narrow and sub-vertical joints had been carried out" prior to the joint site inspection on 13 September 2001, which was "apparently not as recommended, and due to inadequate specification of the locations and extent of the works".

In a memo dated 12 October 2001 to GEO, Arch SD stated that BBV was of the view that further field works to identify the extent of the slope maintenance works "was out of their original scope of service".

In January 2002, BBV submitted to the School and Arch SD a set of sketch plans with photographs showing the approximate extent of slope areas where removal of loose rock blocks/boulders, sealing of rock joints with weepholes (50 mm in diameter) to be provided at 1.5 m centres, repair of cracked chunam and provision of "sprayed concrete for soil surface with drainage behind impermeable slope surface cover" were recommended.

On 14 May 2002, Arch SD sought advice from GEO regarding the need for "professional engineer" input to determine the locations of the specified works as well as supervision of the works. In response, GEO recommended that Arch SD should employ a geotechnical engineer "who clearly understands the recommendations" to identify specific rock blocks and joints on site and "to mark the locations of all works on site". The geotechnical engineer should "inspect the works as necessary while they are being carried out and confirm they are completed as intended". In July 2002, Greg Wong & Associates Limited (GWAL) was commissioned by the School to supervise the slope maintenance works and the scope of the services to be provided by GWAL comprised the following:

(a) "clearly mark all defects for features 11NE-C/C71 and 11NE-C/C73 for which maintenance works are required with ASD term contractor on site by a professional staff";

(b) "liaise with ASD term contractor to carry out such maintenance works";

(c) "provide adequate periodic supervision till satisfactory completion of the maintenance work"; and

(d) "certify the completion of the maintenance works in accordance with recommendation forenoted in the Engineer Inspection Report".

According to Arch SD, the slope maintenance works were carried out by their term contractor. In a letter dated 22 May 2003 (about three weeks before the June 2003 rockfall) to the School, which was copied to Arch SD, GWAL certified that the maintenance works on the slope portion under the MR of the School were completed on 21 May 2003, "in accordance with the recommendations of the Engineer Inspection Report" by BBV. According to Arch SD, no record is available to show the details of the inspections by GWAL and the extent and nature of the maintenance works actually carried out.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents
Table of Contents

4.6 LPM Stage 2 Study

Slope No. 11NE-C/C71 was included in the LPM Programme under Agreement No. CE 35/99, based on a recommendation by the Landslip Investigation Division (renamed LPM Division 1 in July 2004) following the landslide study of the June 2001 rockfall (see Section 4.4). The Stage 2 Study was carried out by MGSL and the consultancy agreement was administered by the Advisory Division (renamed Geotechnical Projects Division in July 2004) of the GEO. At the time of the June 2003 rockfall, the Stage 2 Study for the slope was on-going.

During the Stage 2 study, there were discussions amongst MGSL, the Advisory Division and the ME Division of the GEO on possible adverse effects of tree roots on the rock slope. In a letter dated 3 June 2003 to GEO, MGSL recommended that "Preventive Maintenance Works (PMW) such as identifying the zone affected by root action and subsequently, if necessary, removal of the selected trees might be required". MGSL also stated that details of PMW would be incorporated in the Advisory Letter to be sent to the Lot owners.

Following the 6 June 2003 rockfall, MGSL re-assessed the stability of the soil and rock portions of the slope taking into account the recurrence of rockfalls. The Stage 2 Report was finalised by MGSL in May 2004 and concluded that DH Orders should be served to the owners of slope No. 11NE-C/C71 in accordance with Criterion F of GEO Circular No. 24. On 27 May 2004, DH Orders to the respective owners of the School and Hong Lee Court were recommended by the Advisory Division of the GEO to Buildings Department.

5. THE JUNE 2003 ROCKFALL AND POST-FAILURE OBSERVATIONS

5.1 General

According to the GEO Incident Report, the rockfall incident was reported to the GEO at 4.30 p.m. on 6 June 2003. The incident occurred within the rock cut portion of slope No. 11NE-C/C71 and primarily involved the detachment of a tabular rock block from a source area with maximum dimensions of about 1.8 m by 1.5 m by 0.4 m (approximately 1 m^3 in volume). The rockfall source was near the western end of the slope (i.e. the portion under the MR of the School) and about 2 m above the toe (Figure 2 and Plate 4). The rockfall debris was deposited on the pedestrian pavement at the slope toe and comprised four rock blocks with a maximum dimension of about 1.8 m by 0.6 m by 0.4 m (Plate 3). A section of the pedestrian pavement was temporarily closed as a result of the incident. No casualties or damage were reported.

Field inspections of slope No. 11NE-C/C71 were carried out by the LPM Division 1 on several occasions during the course of this study.

The rock cut portion of slope No. 11NE-C/C71, within and adjacent to the source area of the June 2003 rockfall, comprises strong to moderately strong, pinkish grey, slightly to moderately decomposed (Grade II/III) fine to medium-grained granite (Plates 4 and 5). Within this rock mass, shallow-dipping bands of weathered rock, comprising completely to highly decomposed (Grade IV/V) granite, were identified (see Section 5.2). Evidence of blasting to form the rock cut portion of the slope can be seen in the form of partly exposed drillholes parallel to the slope surface. Sub-vertical blast-induced minor fractures were observed to be aligned perpendicular to the slope face in some of these drillholes (Plate 5).

The exposed back-release surface within the upper part of the rockfall was steeply dipping (>60º) and clean, apart from local iron and manganese oxide staining. In contrast, the lower part of the back-release surface was slightly wavy with dip angle of generally less than 60º (see Plate 4). Thus, the overall dip angle of the back-release surface (about 60º) daylights with respect to the adjacent rock mass, which has a slope aspect of approximately 65º/350º. Numerous tree roots between 15 mm and 50 mm in diameter were exposed on the back-release surface (Plate 5). The June 2003 rockfall appears to have involved a planar failure of a rock block with a dilated sub-vertical release surface, and blast-induced fractures probably formed the back-release and side-release surfaces of the June 2003 rockfall. Remnants of cement mortar infilling were observed on the rock surface alongside the edge of the source of the June 2003 rockfall (Figure 6 and Plate 5).

Without safe access (e.g. scaffolding), it was not possible to examine closely large areas of the steep slope. Nonetheless, some potentially unstable, overhanging rock blocks were observed at the western portion of the rock face (Plate 6). Several rock blocks with the potential for being progressively destabilised by tree root action were observed (Plates 7 and 8). Also, several joints were observed to have been sealed with cement mortar with little or no drainage provision (Plate 9).

During the site inspections carried out in June 2003, no signs of potential incipient large-scale instability of slope No. 11NE-C/C71 were identified.

5.2 Rock Mass and Rock Joint Characteristics

Based on site observations and joint orientation measurements, an assessment of the rock mass characteristics of the rock portion of slope No. 11NE-C/C71 was carried out. A kinematic analysis, based on a stereoplot of the joint data (Figure 7), identified four major joint sets (referred to as joint sets Nos. J1 to J4, see Figures 8 and 9) and two minor joint sets (referred to as joint sets Nos. J5 and J6).

Most discontinuities are natural except for occasional sub-vertical fractures, which were probably caused by blasting during slope formation (see Section 5.1). A kinematic analysis of the rock mass joint data from previous studies and from site measurements that were made during the current study is presented in Figure 7. The kinematic analysis indicates that based on the average slope geometry, the rock slope portion is stable with the contoured poles of the major joint sets plotting outside the potentially unstable zones. However, isolated poles are located within the wedge failure envelope arising from the intersection of minor joint sets Nos. J2/J5, J2/J6 and J5/J6. This is confirmed by site observations, which identified scars of past small wedge failures. It should be noted that as the slope is curved in plan at each end, is irregular in section and has undulating joint sets, some localised, potentially unstable, blocks may not be reflected in the stereoplot.

The blast-induced sub-vertical fractures, which have rough, planar to stepped joint surfaces and little or no weathering, generally strike parallel to the slope surface and dip out of the slope at about 80º (similar in orientation to joint set No. J4). Most of these fractures were dilated with an average aperture of up to 10 mm, locally increasing to about 50 mm,

Table of Contents
Table of Contents
Table of Contents
Table of Contents

where the rock blocks had become loosened and/or had tree roots in the joints. Steeply dipping joints (with inclinations of about 80° to the horizontal) may also deserve further attention because root-wedging effect or build-up of cleft water pressure may potentially cause the rock block concerned to become unstable.

The most prominent joint set within the rock mass is a very persistent sub-horizontal joint (joint set No. J1 - 09°/306°) where joint surface weathering has resulted in seams of completely to highly decomposed granite, up to 250 mm wide (Plates 10 and 11). These weathered joints are probably stress-relief (sheeting) joints that form a distinctive set of undulating joints, which are widely to very widely spaced, permeable and appear to act as pathways for tree roots to propagate extensively across the slope (Figure 10). The significant undulations on this joint set are such that there is a large scatter in the dip angles, with the majority falling within the range from 5° to 20° as indicated in the stereoplot (Figure 7). Figures 8 and 9 further illustrate the large-scale undulations of joint set No. J1, which may have a higher variability in terms of both dip angle and dip direction than that indicated by the stereoplot where joint readings were taken from several isolated locations only.

Growth of tree roots within the sub-horizontal weathered seams (Plate B12 in Appendix B) and the adjacent sub-vertical joints is common. This joint set can be traced throughout slope No. 11NE-C/C71 but it is more prevalent in the central and western rock portions of the slope. Continuous but light seepage was noticed at the base of one of these joints in the eastern portion of the slope (Plates 12 and 13 and Figures 2 and 8, see Section 5.4).

5.3 Tree Root Characteristics

A survey of trees growing on slope No. 11NE-C/C71 and an assessment of their root characteristics were carried out in October 2003. The findings of the assessment are summarised below and the details are presented in Appendix B.

Trees are found mainly on the soil portion (i.e. along the slope crest and at both ends of the slope) and in places on the rock portion of the slope. Within the rock portion, the larger trees with the most extensive root systems were predominately located along the persistent, weathered joint seam of joint set No. J1, and more densely grouped at the intersection of this joint set with the more persistent sub-vertical joint sets including joint set J3 (Figures 8 and 9). Few large trees were observed in areas where the rock is relatively massive or the joint apertures are narrow (i.e. <5 mm).

Ten tree species were recorded on the slope (Table B1 and Plates B3 and B9 to B15 in Appendix B) and they are of the types commonly found in Hong Kong. Three of the identified tree species, *Ficus virens var. sublanceolata* (referred to as *F. virens* hereinafter), *Ficus microcarpa* and *Acacia confusa* have strong, spreading and penetrative root systems which are also fast-growing (Plate B5 in Appendix B). Both *F. virens* and *Ficus microcarpa* are common in Hong Kong on rock slopes and masonry walls. Based on the field observations (see Section 5.2), it would appear that slope No. 11NE-C/C71 has favourable joint and infilling characteristics favourable for the development of extensive, strong and penetrative tree root systems.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents Table of Contents Table of Contents Table of Contents

One relatively mature (about 7 m high) example of *F. virens* was seen to be growing approximately 8 m above the source area of the June 2003 rockfall (Plate 14). The roots of this tree were up to 100 mm in diameter and were growing over the rock surface, including the exposed surface of the June 2003 rockfall source (where the roots were up to 50 mm in diameter, see Plate B8 in Appendix B). The roots of this species were also observed in other rock joints on the slope (Appendix B). Based on the API, this tree became established over a period of approximately 10 years.

5.4 Seepage

Site inspection carried out on 7 June 2003 noted slight seepage along the exposed surfaces of the 6 June 2003 rockfall source (Plate 5) and elsewhere on the rock slope. Subsequent inspections revealed continuous minor seepage, particularly at the eastern portion of the slope, and moss-covered surfaces within the weathered bands of the sub-vertical joint set No. J1.

Since the seepage rate at the western portion of the slope was too low for collection of water sample, water samples were only collected from the eastern portion of the slope for chemical tests at the Public Works Central Laboratories. Results of laboratory tests indicate that the seepage at the eastern portion of the slope had a chloride ion concentration of 854 mg/l and an E.Coli bacteria concentration of 180 cfu/100 ml, which are much higher than that typically found in potable water (i.e. chloride ion concentration of 16 mg/l and E.Coli bacteria concentration of 0 cfu/100 ml, based on information given by the WSD). According to the Public Works Central Laboratory, the seepage is “not a typical unpolluted rain water”. It is possible that the seepage may be related to leakage of foul water drains at the slope crest (Figure 3).

6. ANALYSIS OF RAINFALL RECORDS

Rainfall data were obtained from the nearest GEO automatic raingauge No. K03, which is located at the PNG Radio Monitoring Station, Hong Ning Road, approximately 550 m to the east of the rockfall site (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. The rockfall incident was reported by the Police at 1:19 p.m. on 6 June 2003. For the purposes of rainfall analysis, it is assumed that the rockfall occurred at 1:00 p.m. on 6 June 2003.

The daily rainfall over the preceding month and three days following the incident, together with the hourly rainfall data for the period between 4 and 6 June 2003, is presented in Figure 11. The daily rainfall record shows that relatively light rainfall occurred during the 12 hours preceding the rockfall, with the maximum 1-hour rolling rainfall of about 20 mm between 10:15 a.m. and 11:15 a.m. on 6 June 2003. Table 1 presents the estimated return periods for the maximum rolling rainfall for various durations recorded by raingauge No. K03 with reference to historical rainfall data at the Hong Kong Observatory in Tsim Sha Tsui (Lam & Leung, 1994). The results show that the return period of the 6 June 2003 rainstorm was less than 2 years.

Table of Contents

Table of Contents

Table of Contents

Table of Contents

The maximum rolling rainfall for the rainfall on 6 June 2003 has been compared with that of the past major rainstorms between 1983 and 2001 recorded by raingauge No. K03. The maximum rolling rainfall indicates that the rainfall on 6 June 2003 was not particularly severe as compared with the previous rainstorms (Figure 12).

7. DIAGNOSIS OF THE PROBABLE CAUSES OF THE ROCKFALL

The 6 June 2003 rockfall involved a planar sliding failure of a rock block along an adversely orientated steeply dipping (60º) back-release surface on a steep (65° to 85°) rock cut, shortly after a relatively light rainfall (return period of less than 2 years). The close correlation between the rainfall and the rockfall suggests that the failure was probably triggered by rainfall. Water ingress into the dilated sub-vertical rock joints resulting in possible build-up of local cleft water pressure behind the rock block was probably the primary cause of the rockfall. The presence of remnants of cement mortar infilling on the slope face alongside the western edge of the source of the rockfall (Figure 6 and Plate 5) suggests that this may have contributed to the build-up of local cleft water pressure.

The slope was formed in the mid-1960's by blasting. Occasional sub-vertical blast-induced fractures were observed on the slope and some of these fractures were exploited by tree root action. The back-release and side-release surfaces of the June 2003 rockfall were probably blast-induced and were opened up due to the jacking action of tree roots of up to about 50 mm in diameter (Plate 5). Root action associated with unplanned vegetation probably promoted the progressive deterioration of the slope by causing dilation of rock joints and fractures, and probably played a key contributory role in the June 2003 rockfall. This is corroborated by the fact that the rockfall occurred during a rainfall event that is much less severe than that experienced by the slope previously.

According to the findings of the tree survey, some of the trees on the slope have fast-growing, strong, spreading and penetrative root systems. The strong growth of unplanned vegetation was possibly promoted, to some extent, by water seepage on the slope, including the area above the source of the June 2003 rockfall (Section 5.4).

8. DISCUSSION

The 6 June 2003 rockfall occurred on an old, non-engineered, private soil/rock cut slope, which has a history of rockfalls (in 1986 and 2001).

The slope has been subjected to maintenance since about 2000. Extensive growth of unplanned trees renders the slope vulnerable to detachment of rock blocks. The vigorous growth of large and strong tree roots, which tend to exploit the joints of the more fractured rock mass and thick weathered seams, gave rise to jacking action on the open rock joints. The present setting of an old rock cut formed by blasting, which probably resulted in fracturing of the rock mass and dilation of rock joints, means that the slope is prone to deterioration and destabilising effects associated with extensive tree root growth, especially for the type of trees at this site which are of a fast-growing nature with a strong root system. The proper maintenance of rock slopes with such unplanned mature trees is fraught with difficulty in practice, given that felling of mature trees may not necessarily be an acceptable option from an environmental point of view.

Table of Contents Table of Contents Table of Contents Table of Contents

In the present instance, the Maintenance Manual for the slope prepared following the EI did not incorporate any special maintenance requirements (such as more frequent EI inspection) to account for the likelihood of progressive deterioration and the susceptible slope setting (i.e. presence of thick weathered seams, trees with a strong root system of a fast-growing nature, etc.). Protective measures such as rock mesh netting, which might have been of use especially in more fractured zones, were not deemed necessary during past EI or subsequent to previous tree fall/rockfall incidents.

It would appear that the rock face of this 22 m high cut could not be inspected in full during EI because of lack of safe access. The previously recommended maintenance works (i.e. in 2000) were essentially indicative only and were not specified in detail for the different areas. The details of the necessary maintenance works may be confirmed during the course of the works when access is provided. In the event, a separate geotechnical consultant was engaged to supervise the maintenance works carried out in 2002/03. The maintenance works were certified by a separate geotechnical consultant to have been completed in accordance with the EI recommendations, although there is no record in Arch SD's files to show that the details of the inspections by the geotechnical consultant and the extent and nature of the maintenance works actually carried out.

In the source area of the detached rock block (located about 2 m above the slope toe) which exposed large tree roots on the rock face following the June 2003 rockfall, scaling of the concerned rock block was not considered necessary at the time of the past maintenance and no preventive measures (such as rock dowels) were provided. The indication that the open joint associated with the subsequently detached rock block was sealed up by means of cement mortar highlights the potential danger of indiscriminate sealing of joints (without judicious provision of relief drains where warranted), which may lead to transient build-up of local cleft water pressure during rainfall and trigger a rockfall.

In view of the close proximity of the rock cut to a pedestrian pavement and a road that leads to a school, the potentially significant consequences due to rockfalls (even of relatively small sizes) and the vulnerable site setting as discussed above, more frequent maintenance, together with provision of suitable protective measures, appears to be warranted.

The vulnerable site setting also highlights the importance of carrying out detailed field mapping and exercising engineering judgment to directly assess those problematic rock blocks that require attention and follow-up instead of relying entirely on conventional stereographic projection methods based on contoured rock joints using standard computer programs.

9. CONCLUSIONS

It is concluded that the 6 June 2003 rockfall was probably caused by water ingress into dilated sub-vertical rock joints, resulting in the build-up of cleft water pressure behind the rock block. Progressive deterioration of the rock slope, as indicated by the opening up of rock joints prior to the rockfall, and tree root jacking action of unplanned mature trees were probable key contributory factors to the June 2003 rockfall.

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

Table of Contents
Table of Contents
Table of Contents
Table of Contents

10. REFERENCES

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Halcrow China Limited (2002). Review of the 9 June 2001 Rockfall on Slope No.11NE-C/C71 at Kung Lok Road, Kwun Tong. Landslide Review Report, Geotechnical Engineering Office, Hong Kong, 33 p.

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

Maunsell Geotechnical Services Ltd (2004). Feature No.11NE-C/C71, NKIL 5214 & NKIL 5202, Kung Lok Road. Stage 2 Study Report No. 4/2004, Geotechnical Engineering Office, Hong Kong.

LIST OF TABLES

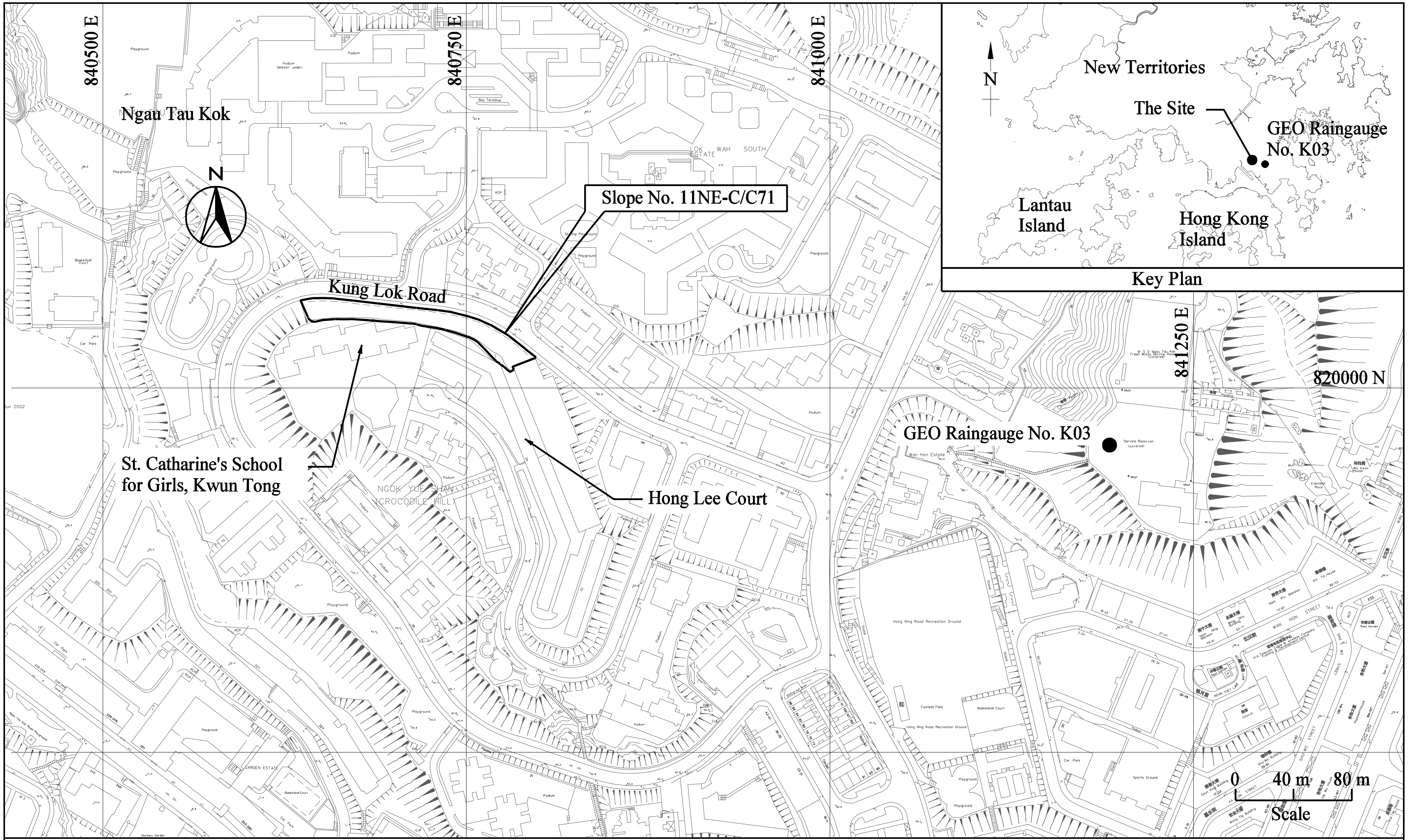
Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 1 - Maximum Rolling Rainfall at GEO Raingauge No. K03 for Selected Durations Preceding the Rockfall on 6 June 2003 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	9.5	11:00 a.m. on 6 June 2003	< 2
15 Minutes	18.5	11:05 a.m. on 6 June 2003	< 2
1 Hour	23.5	11:15 a.m. on 6 June 2003	< 2
2 Hours	25.0	11:40 a.m. on 6 June 2003	< 2
4 Hours	28.0	11:40 a.m. on 6 June 2003	< 2
12 Hours	28.0	11:40 a.m. on 6 June 2003	< 2
24 Hours	28.0	11:40 a.m. on 6 June 2003	< 2
48 Hours	28.0	11:40 a.m. on 6 June 2003	< 2
4 Days	28.0	11:40 a.m. on 6 June 2003	< 2
7 Days	28.0	11:40 a.m. on 6 June 2003	< 2
15 Days	64.0	11:40 a.m. on 6 June 2003	< 2
31 Days	235.5	11:55 p.m. on 4 June 2003	< 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 of Raingauge No. K03 from Evans & Yu (2000). The return periods obtained by data of Evans & Yu and Lam & Leung do not show 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's 1994 data, which are based on hourly rainfall for these durations.
(4) According to the information collected by the GEO, the rockfall occurred at about 1:00 p.m. on 6 June 2003.
(5) The nearest GEO raingauge to the rockfall site is raingauge No. K03 which is situated at about 550 m to the east of the site and became operational since February 1979.

LIST OF FIGURES



Note: Base plan is extracted from 1:1000 survey sheets Nos. 11NE-17B, 11NE-17D, 11NE-18A, 11NE-18B, 11NE-18C, and 11NE-18D dated June 2002.

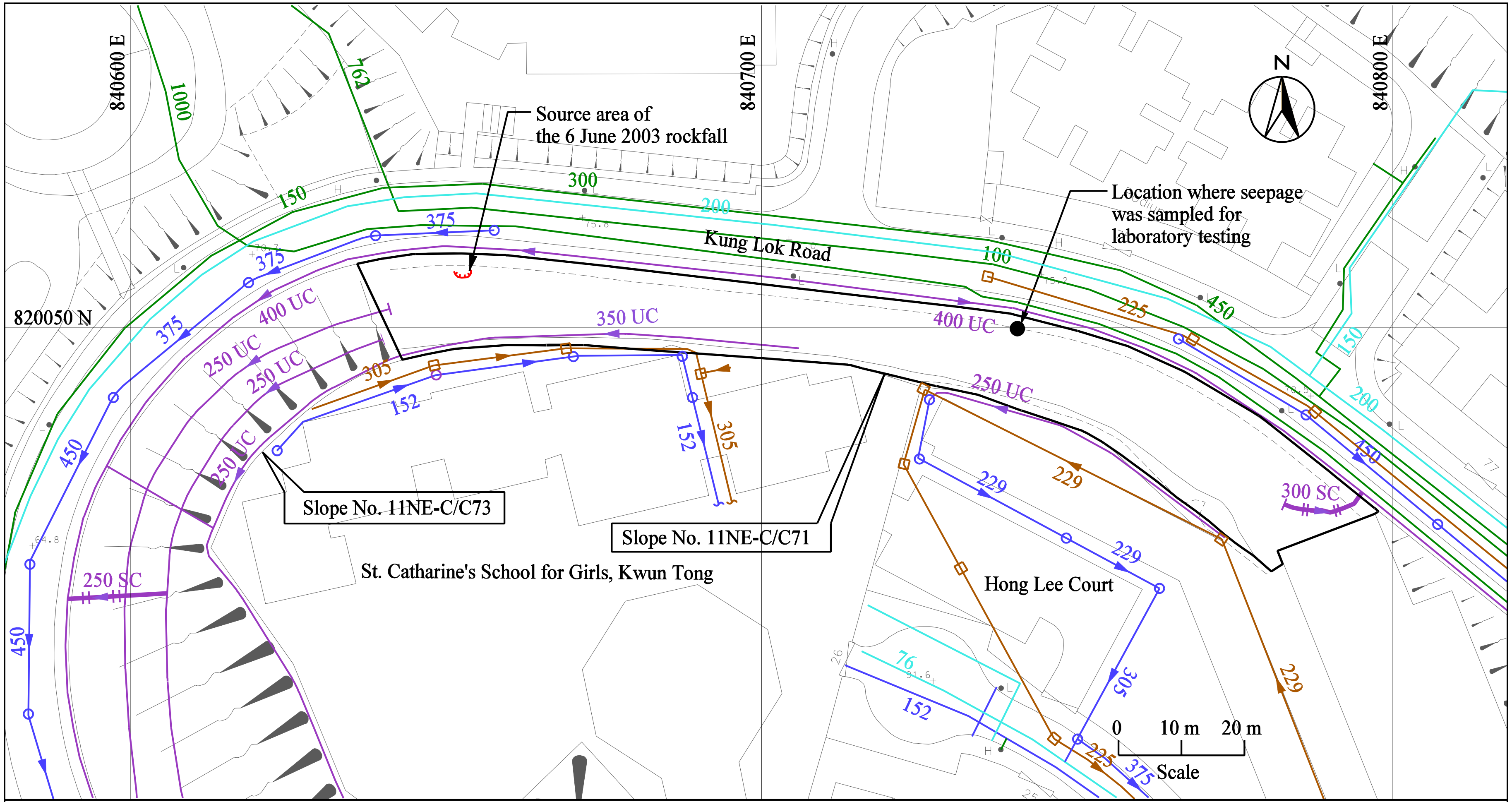
Figure 1 - Location Plan

Table of Contents
Table of Contents
Table of Contents

Note: Base plan extracted from 1:1000 survey sheets Nos. 11NE-18A dated June 2002.

Figure 2 - Site Plan

Table of Contents
Table of Contents
Table of Contents

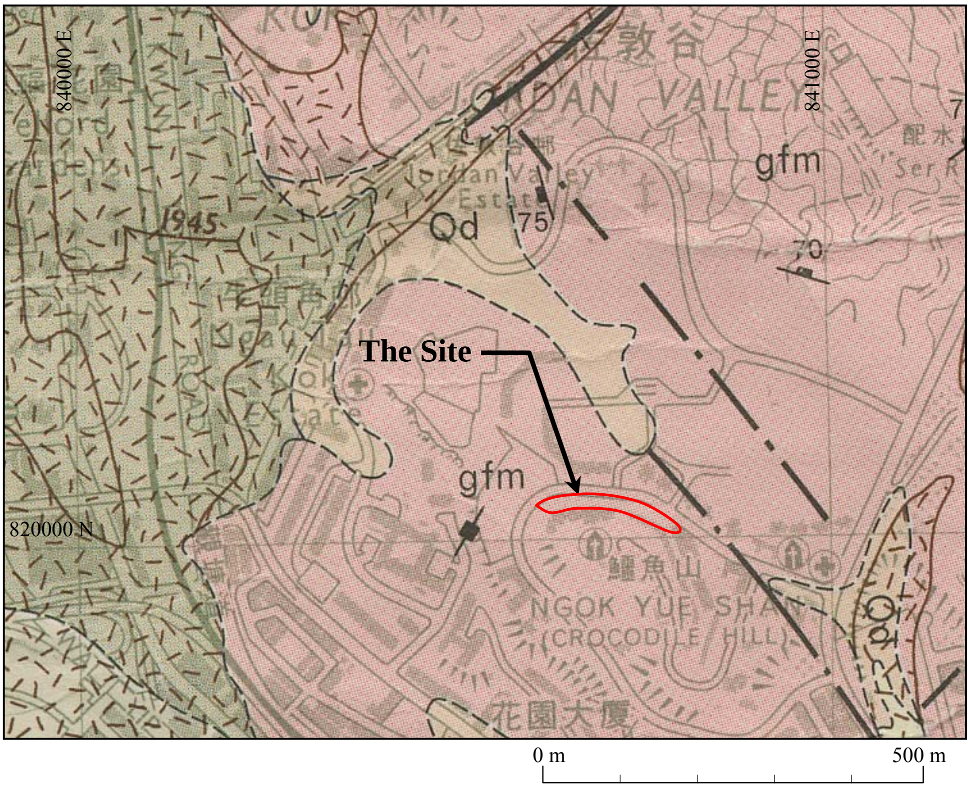


Legend :		The 6 June 2003 rockfall	1000	Fresh watermain (1000 mm diameter)
		Stormwater drain		
		Foulwater drain	200	Salt watermain (200 mm diameter)
		Surface drainage channel		

Notes:
(1) Base plan extracted from 1:1000 survey sheets Nos. 11NE-18A dated June 2002.
(2) All surface channel and pipe dimensions are in mm.

Figure 3 - Locations of Water-carring Services

Table of Contents
Table of Contents
Table of Contents



LEGEND:

SUPERFICIAL DEPOSITS

Qa	Alluvium	▨	Fill
Qd	Debris flow deposits		

SOLID GEOLOGY

gfm	Fine- to medium-grained granite

GEOLOGICAL LINES

- - - - - -	Geological boundary, superficial deposits	— · — ·	Photogeological lineament
————	Fill boundary, with limit of reclamation at date shown		

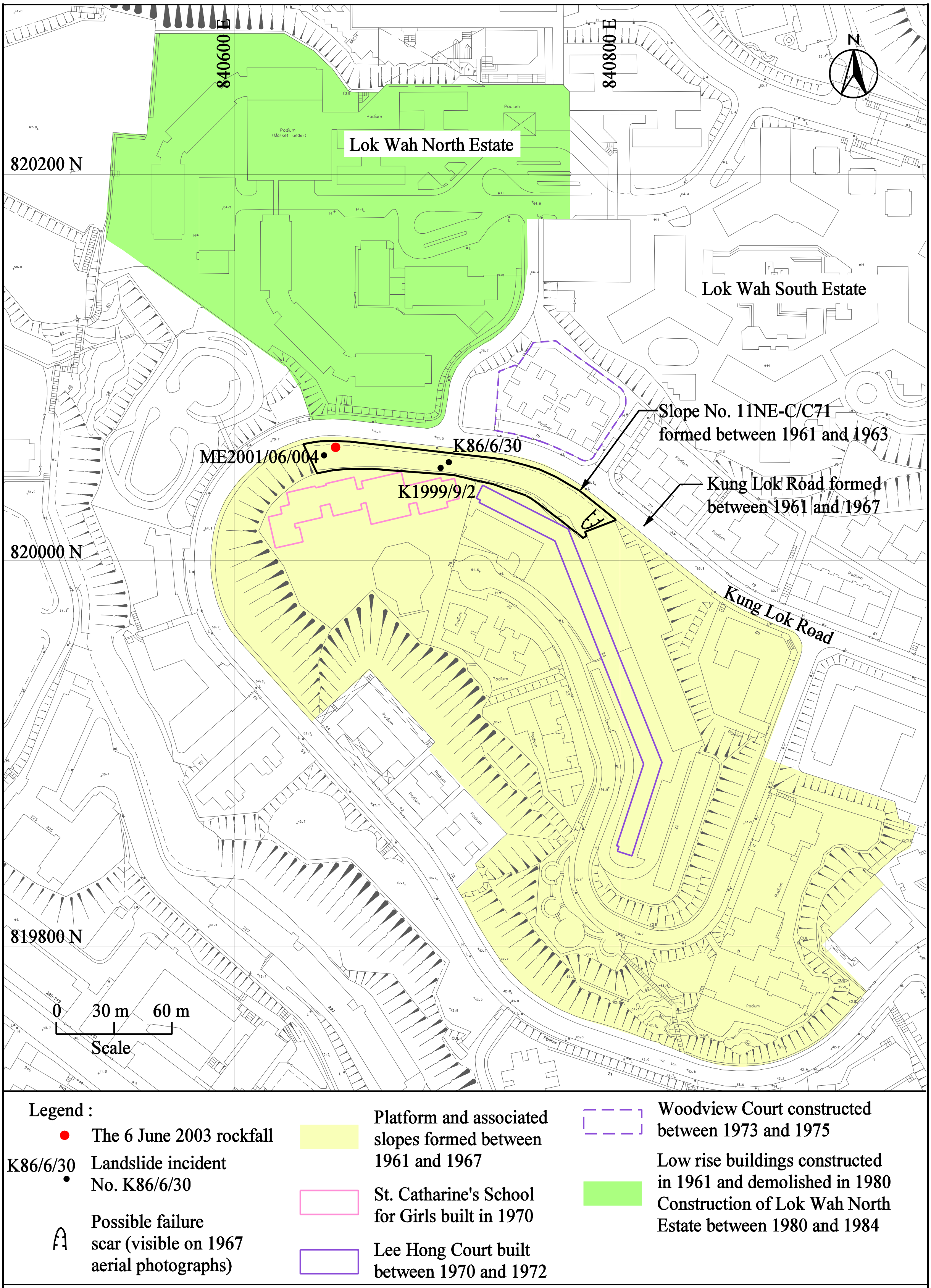
STRUCTURAL SYMBOLS

Inclined 75	Vertical	Jointing

Note: Extracted from Hong Kong Geological Survey, Map Series HGM20, Sheet No. 11, 1:20 000 Scale (GCO, 1986).

Figure 4 - Regional Geology

Table of Contents
Table of Contents
Table of Contents
Table of Contents

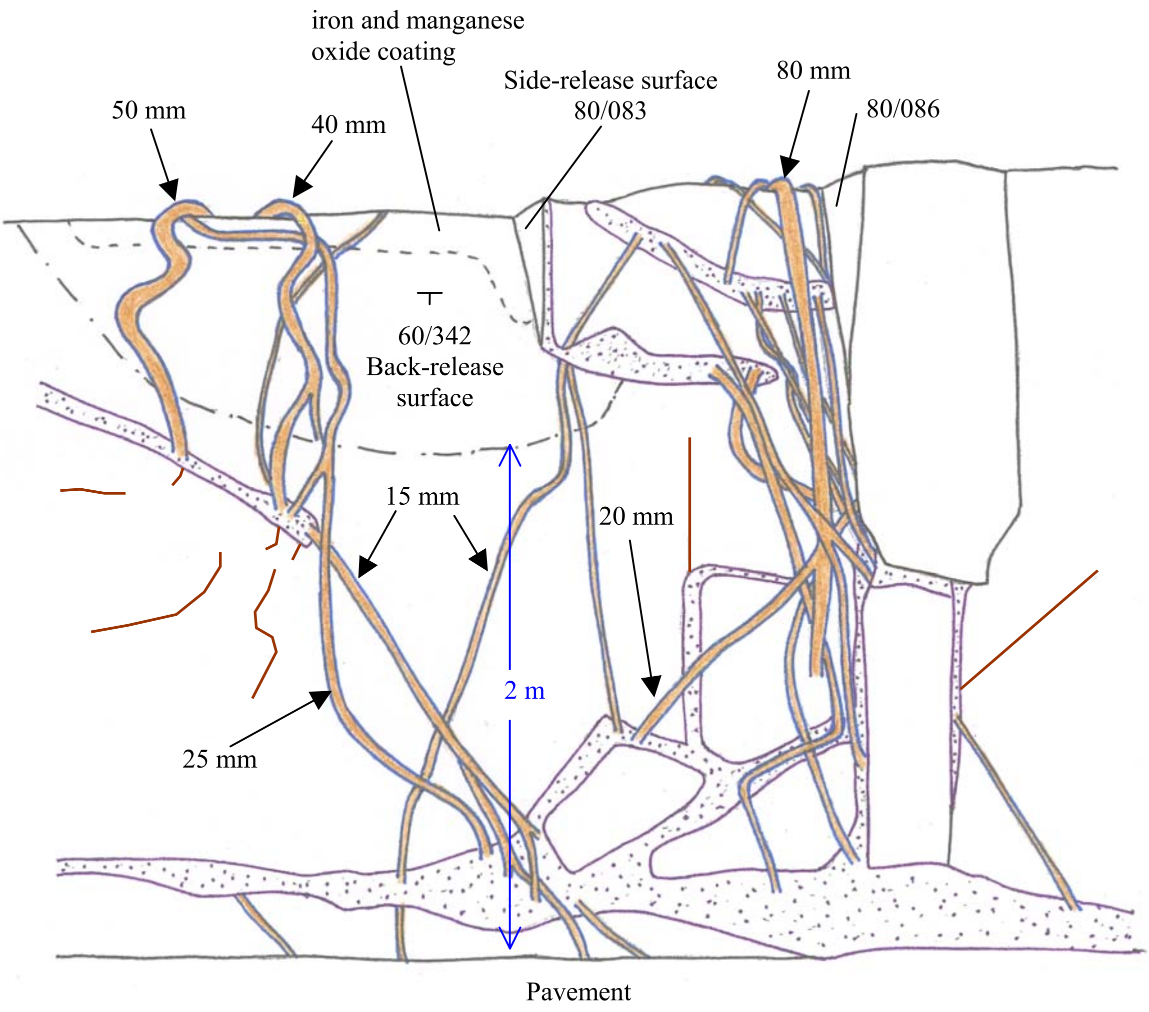


Note: Base plan is extracted from 1:1000 survey sheets Nos. 11NE-17B, 11NE-17D, 11NE-18A and 11NE-18B dated June 2002.

Figure 5 - History of Site Development and Past Instabilities

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents
Table of Contents



Not to scale

Legend:

◌ Approximate extent of the June 2003 rockfall source area

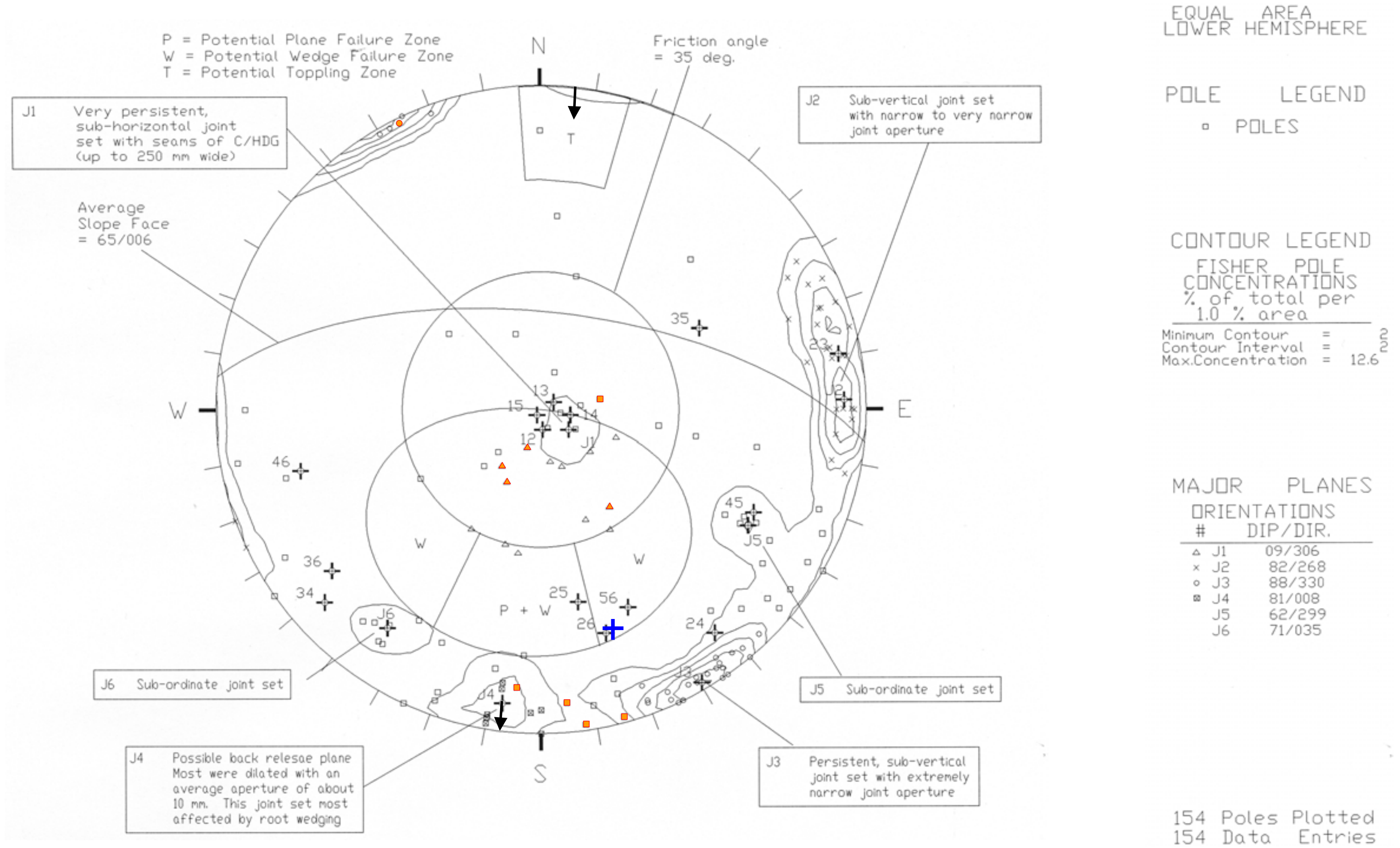
Tree roots (with diameter) observed on the slope surface

Open joint with aperture up to 2 mm wide

▨ Cement mortar joint sealant

Notes:
(1) The orientation of the slope surgace is 350^{o}.
(2) Tree roots without measurement shown on the sketch are generallly betweeen 5 mm and 10 mm in diameter.

Figure 6 - Sketch of the June 2003 Rockfall Scar

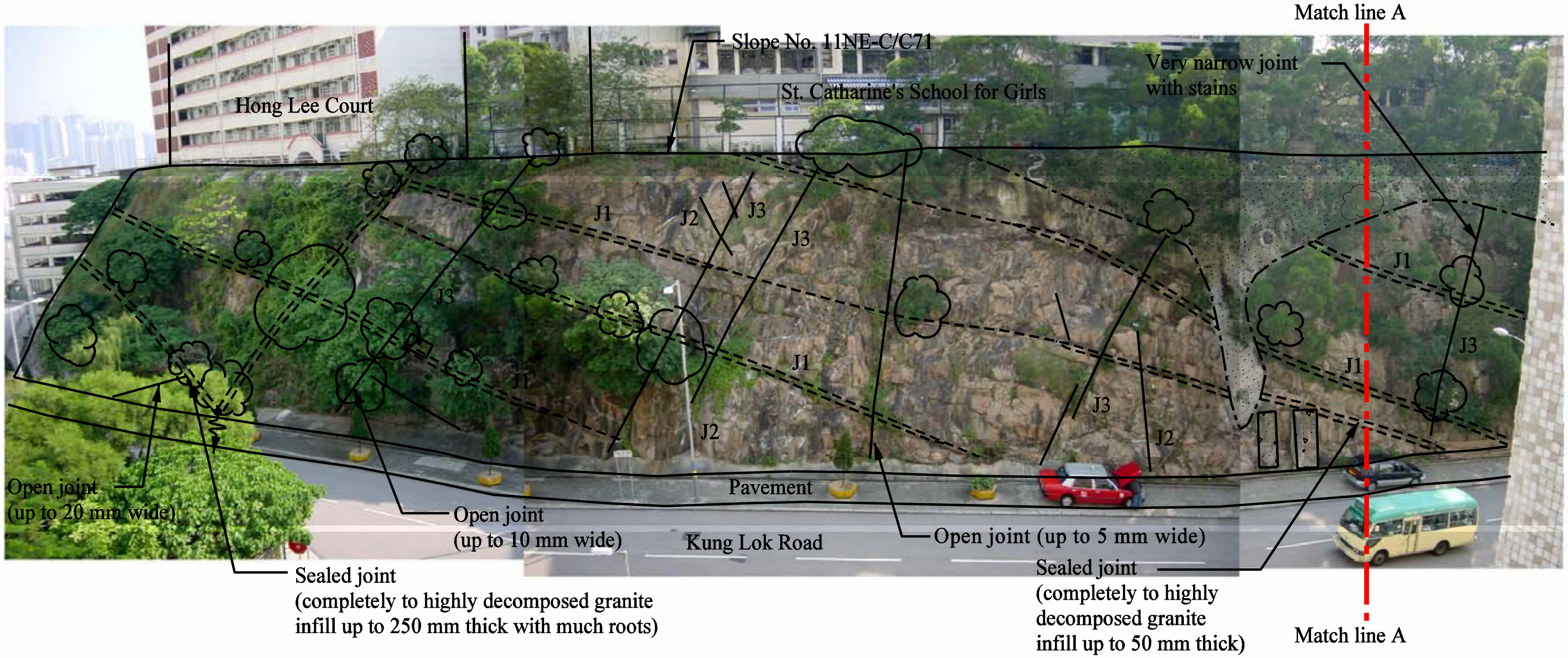


Legend:

↓	Effect of root wedging on joint set No. J4 i.e. moving towards toppling failure envelope	△×○□	Joint data extracted from Stage 2 Study Report No. S2R 326/2000
		△×●■	Joint data from site measurement for this study
		+	Back-release surface of the 6 June 2003 rockfall

Figure 7 - Kinematic Analysis

Table of Contents Table of Contents Table of Contents



Legend :

The 6 June 2003 Rockfall location

Location of trees with significant root network

J1 Sub-horizontal joint infilled with completely to highly decomposed granite

J3 Sub-vertical joint

Shotcreted area

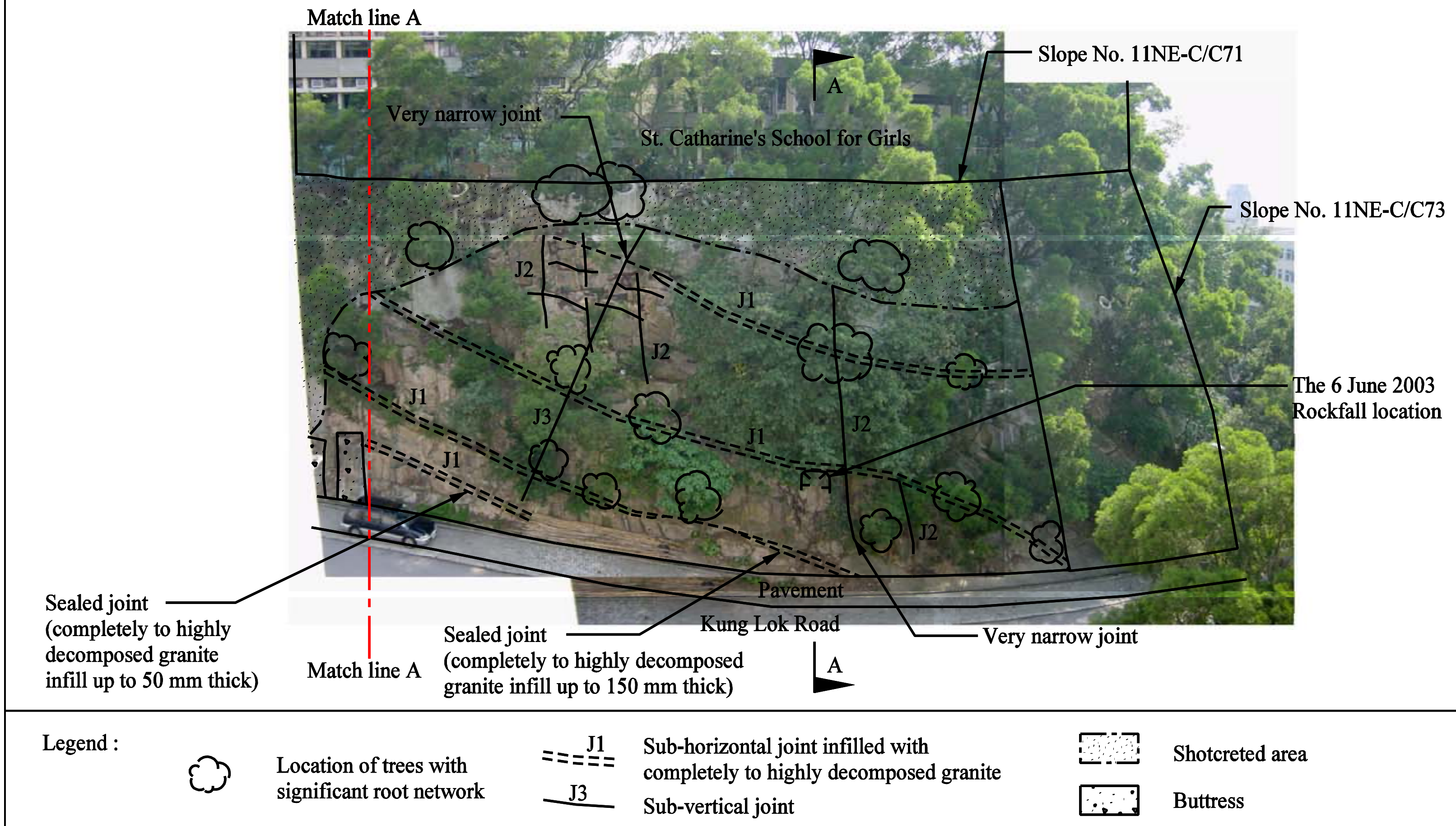
Buttress

Seepage

Notes: (1) See Figure 2 for location on site plan.
(2) See Figure 7 for definition of joint sets Nos. J1 to J3.

Figure 8 - Site Observations - Eastern and Middle Portions of the Slope

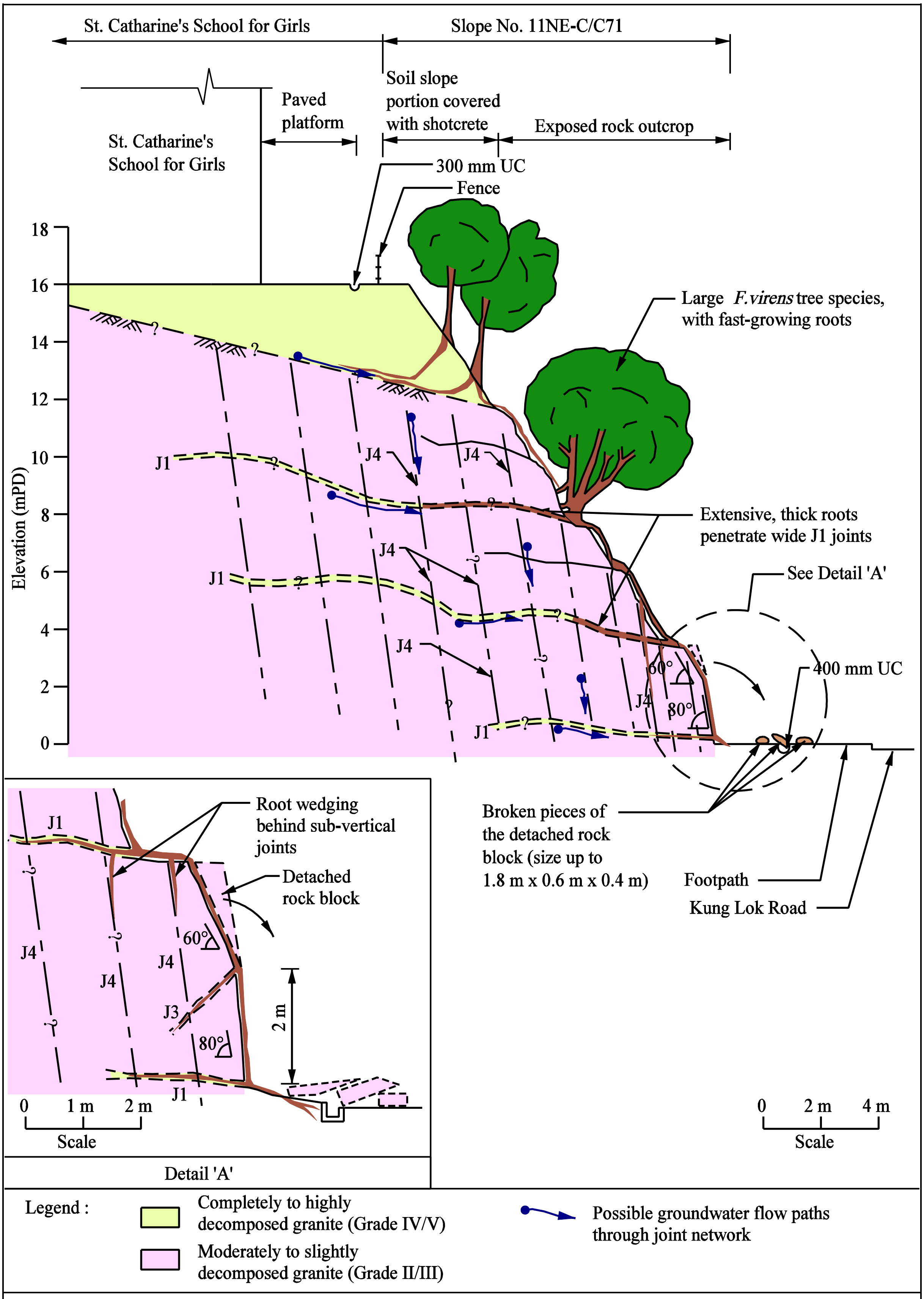
Table of Contents
Table of Contents
Table of Contents



Notes:
(1) See Figure 2 for location on site plan.
(2) See Figure 7 for definition of joint sets Nos. J1 to J3.
(3) See Figure 10 for Section A-A.

Figure 9 - Site Observations - Western Portion of the Slope

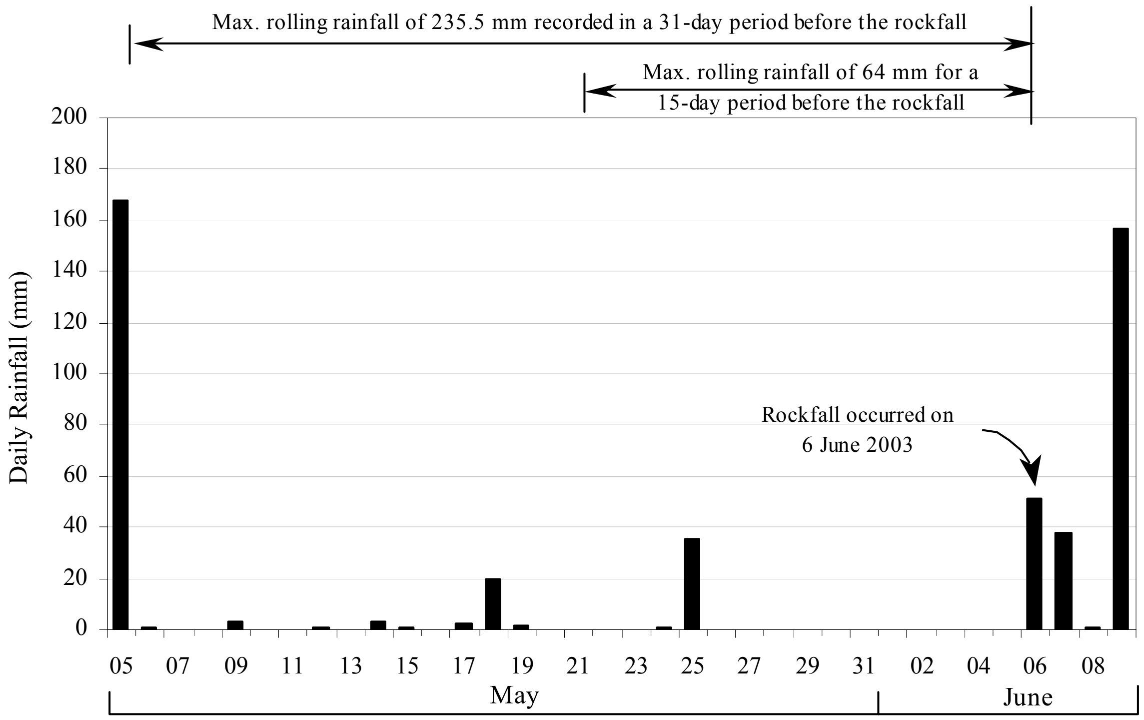
Table of Contents
Table of Contents
Table of Contents



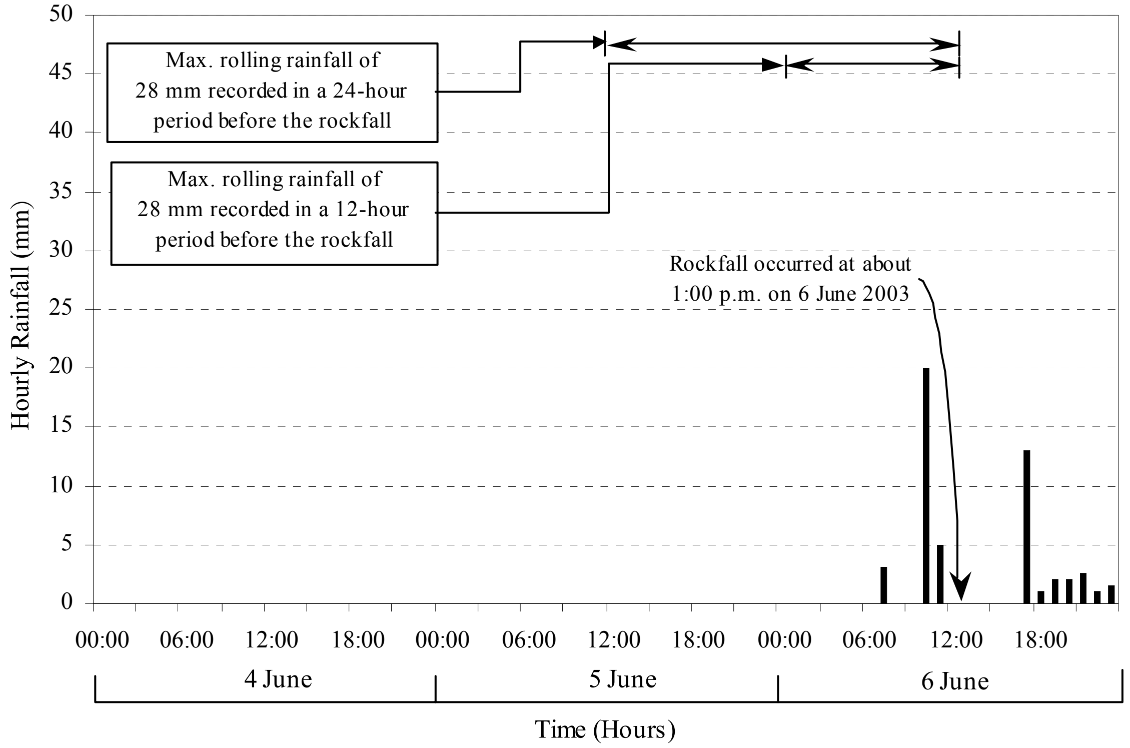
Note: See Figure 2 and 9 for location of cross-section.

Figure 10 - Section A-A through the June 2003 Rockfall Location

Table of Contents
Table of Contents
Table of Contents
Table of Contents



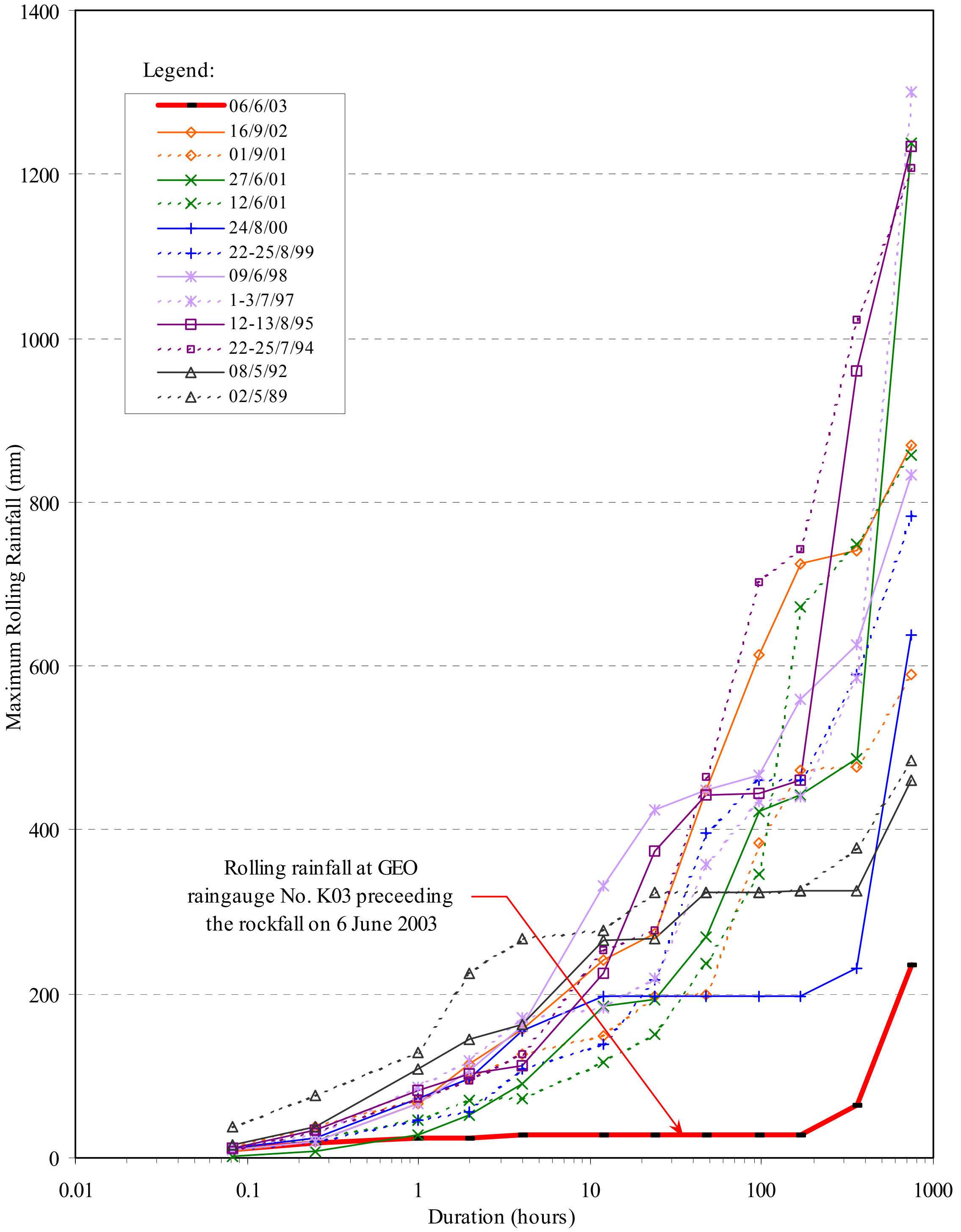
(a) Daily Rainfall Recorded at GEO Raingauge No. K03 between 5 May and 9 June 2003



(b) Hourly Rainfall Recorded at GEO Raingauge No. K03 between 4 June and 6 June 2003

Figure 11 - Daily and Hourly Rainfall Recorded at GEO Raingauge No. K03

Table of Contents
Table of Contents
Table of Contents
Table of Contents

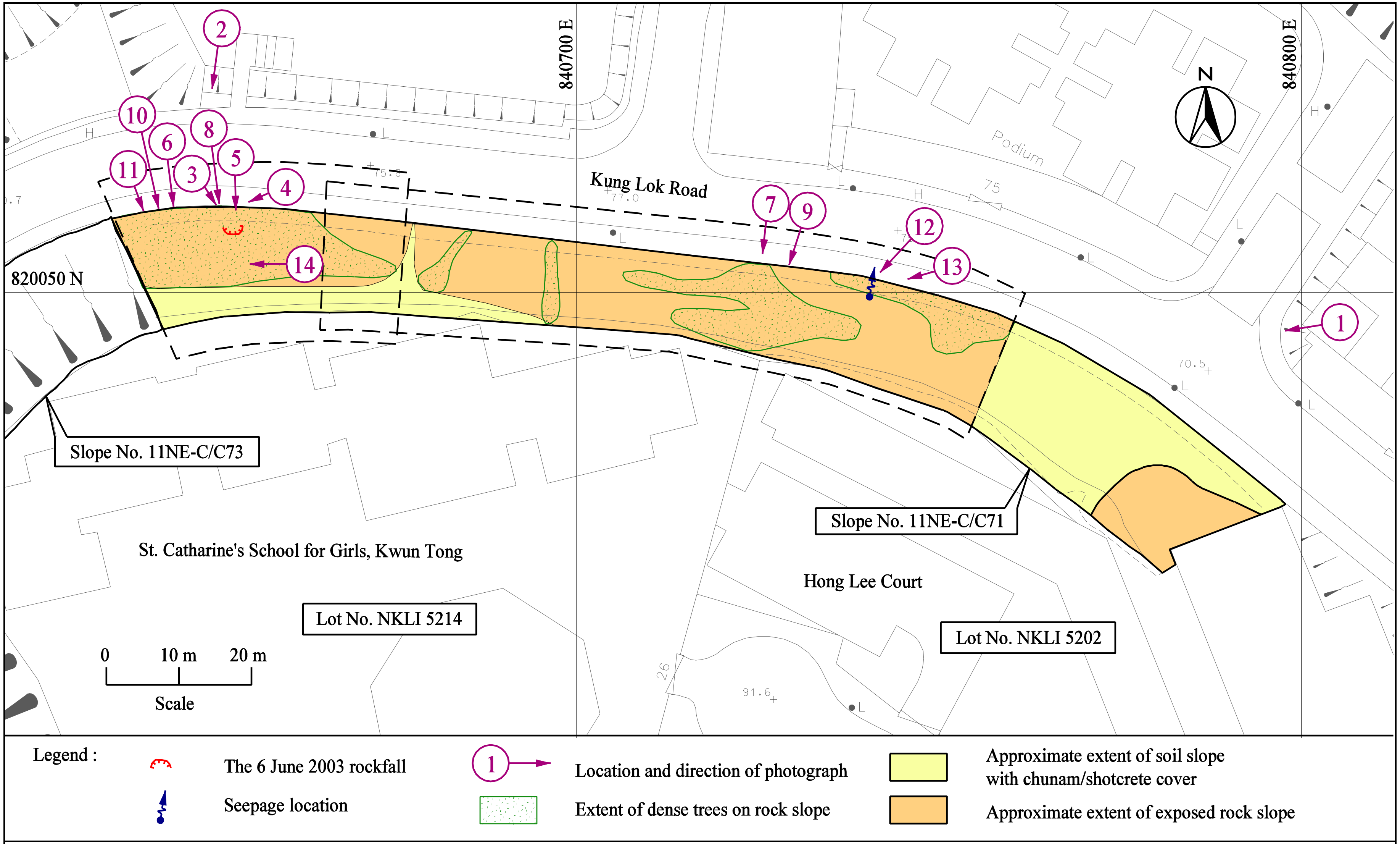


Notes: (1) Rainfall data evaluated from 5-minute readings from GEO raingauge No. K03 (about 550 m to the east of the rockfall site).

(2) Rolling rainfall of previous rainstorms calculated at GEO raingauge No. K03 since February 1979.

Figure 12 - Maximum Rolling Rainfall for Previous Major Rainstorms at GEO Raingauge No. K03

Table of Contents
Table of Contents
Table of Contents
Table of Contents



Note: Base plan extracted from 1:1000 survey sheets Nos. 11NE-18A dated June 2002.

Figure 13 - Locations and Directions of Photographs Taken

Table of Contents
Table of Contents
Table of Contents

LIST OF PLATES

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents
Table of Contents

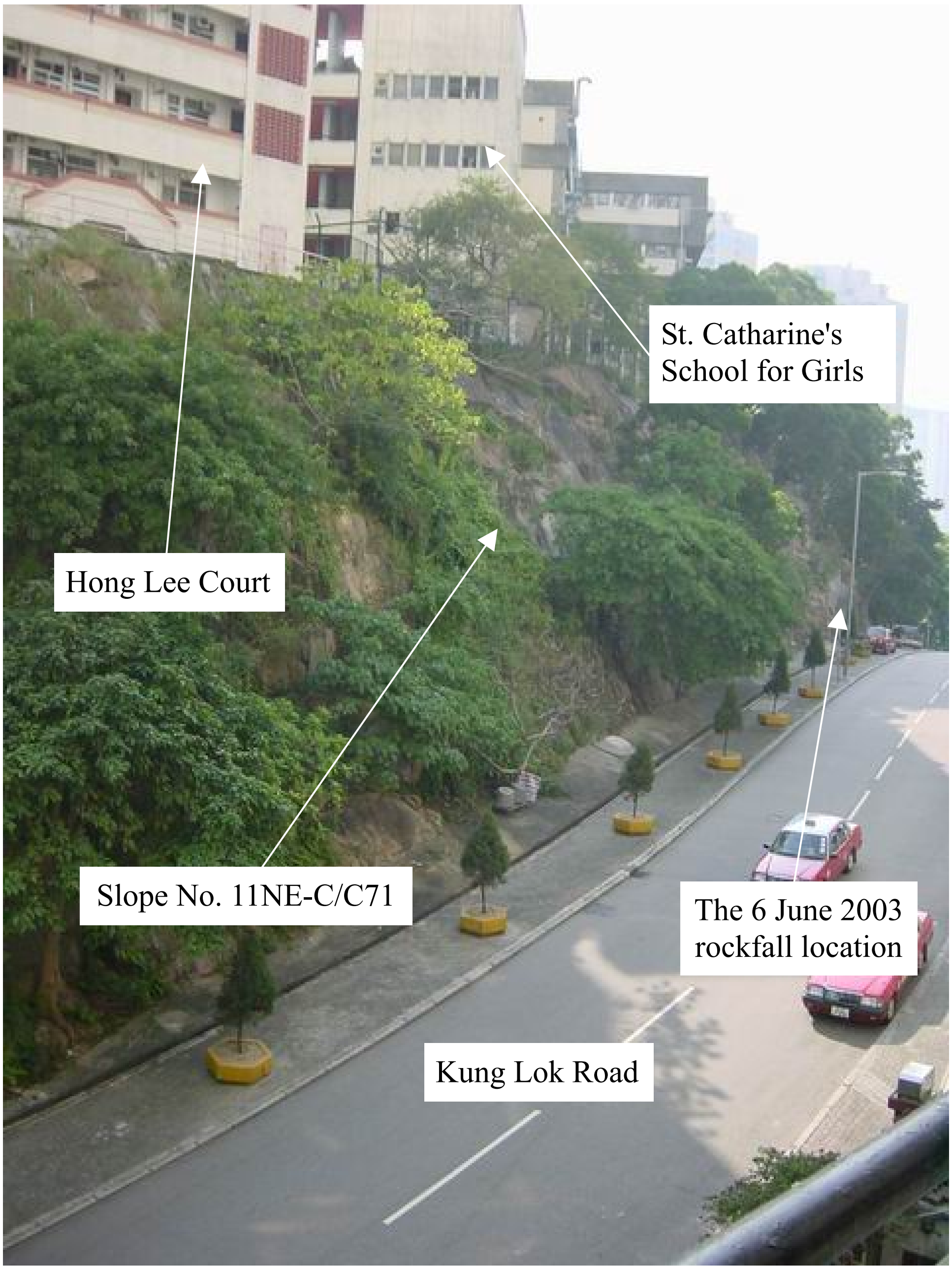


Plate 1 - General View of Slope No. 11NE-C/C71
(Photograph taken on 21 October 2003)

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

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Plate 2 - View of the Eastern Portion of Slope No. 11NE-C/C71
(Photograph taken on 21 October 2003)

Plate 3 - View of the Detached Granite Blocks from the 6 June 2003 Rockfall
(Photograph taken on 7 June 2003)

Note: See Figure 13 for locations and directions of photographs.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

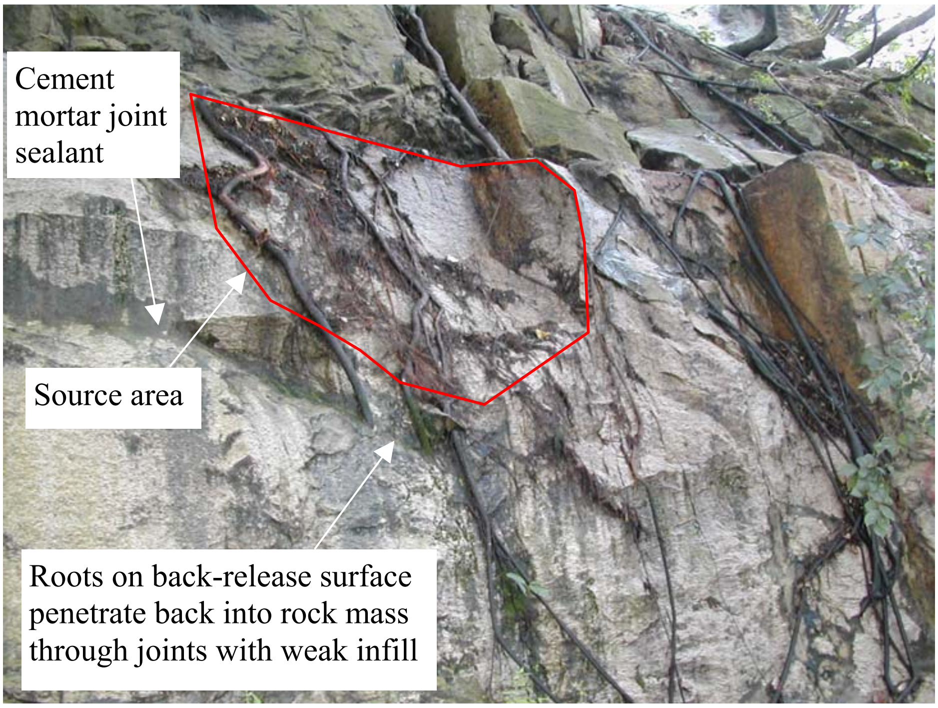


Plate 4 - View of the Source Area of the 6 June 2003 Rockfall
(Photograph taken on 7 June 2003)

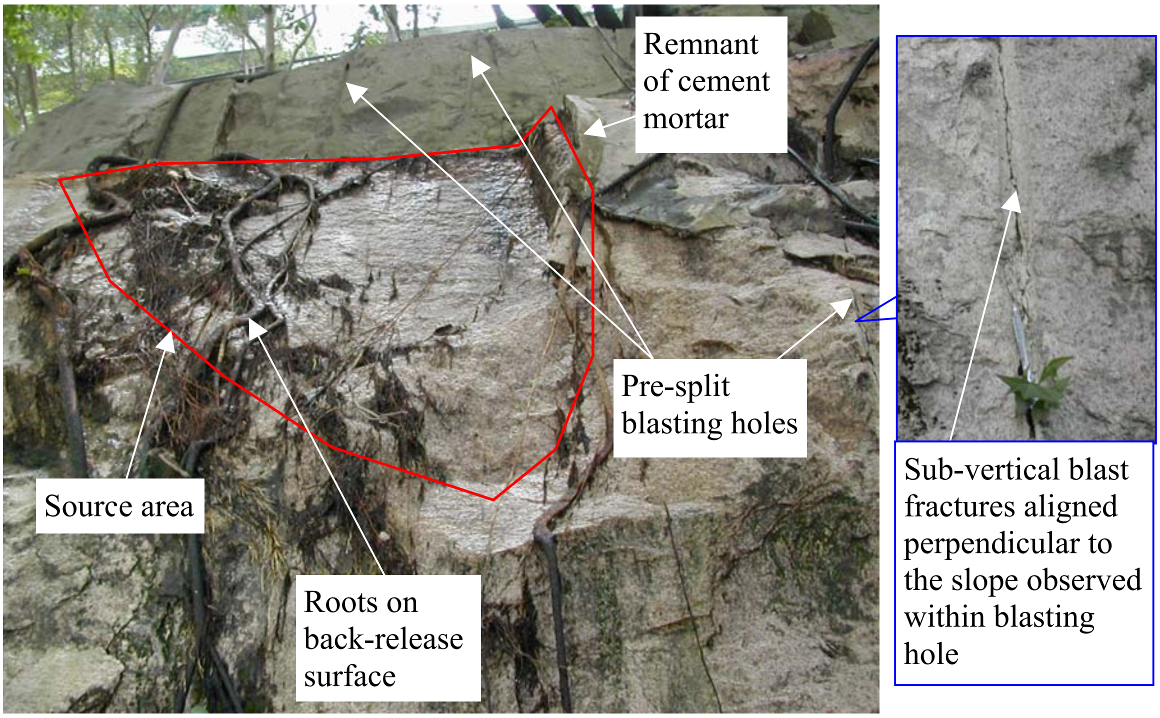


Plate 5 - Close-up View of the Source Area of the 6 June 2003 Rockfall
(Photograph taken on 17 June 2003)

Note: See Figure 13 for locations and directions of photographs.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

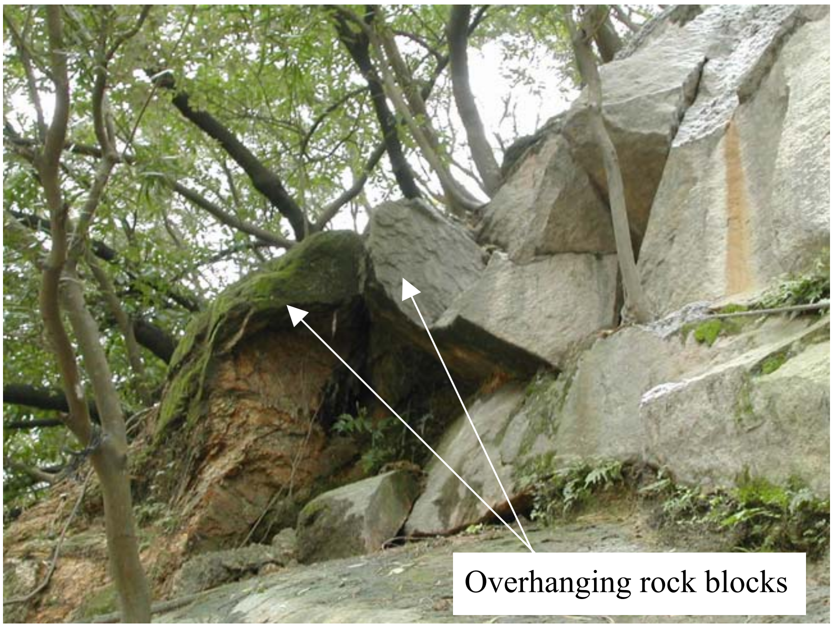


Plate 6 - Basal Joint Along Joint Set No. J1
(Photograph taken on 17 June 2003)

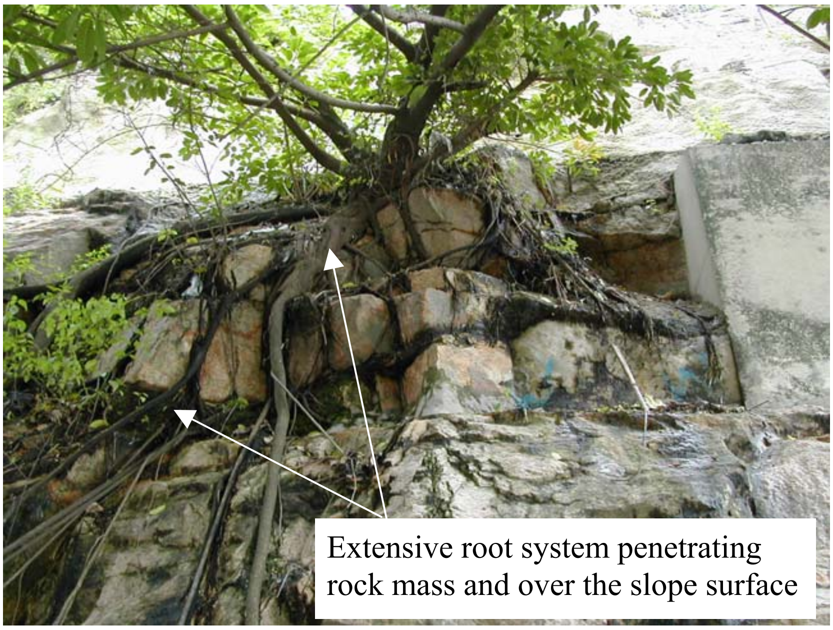


Plate 7 - View Looking South at Another Large Example of the *F. virens* Tree Species Located at the Western Portion of the Subject Slope
(Photograph taken on 21 October 2003)

Note: See Figure 13 for locations and directions of photographs.

Table of Contents Table of Contents Table of Contents Table of Contents

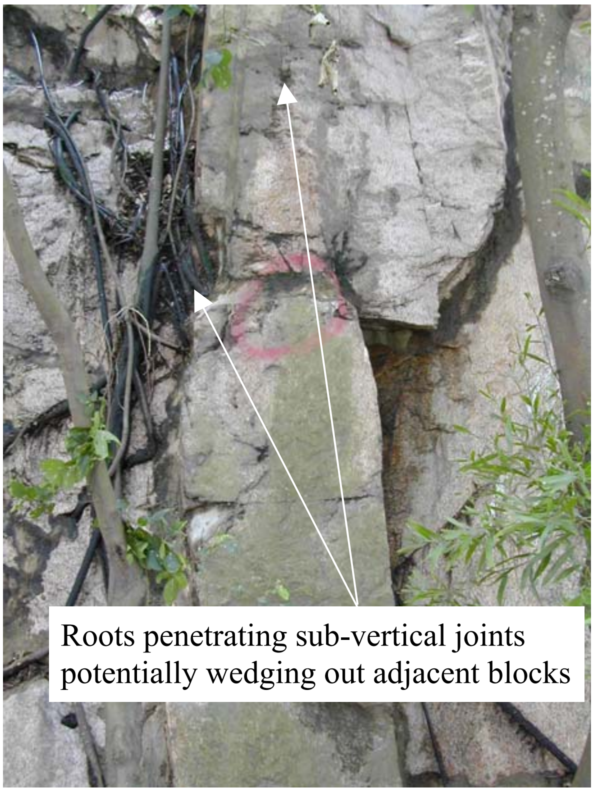


Plate 8 - Roots Penetrating Open Sub-vertical Joints at the Eastern Portion of the Subject Slope Creating Potentially Unstable Rock Blocks (Photograph taken on 17 June 2003)

Plate 9 - Wide Sub-horizontal Joints Sealed with Cement Mortar to Prevent Erosion of Weak Weathered Granite Infill Material (Photograph taken on 17 June 2003)

Note: See Figure 13 for locations and directions of photographs.

Table of Contents

Table of Contents

Table of Contents

Table of Contents

Plate 10 - Weathered Joint Infill along Sheeting Joints (Joint Set No. J1)
(Photograph taken on 17 June 2003)

Plate 11 - Close-up View of Weathered Joint Infill up to 150 mm Thick
along A Sheeting Joint (Joint Set No. J1)
(Photograph taken on 21 October 2003)

Note: See Figure 13 for locations and directions of photographs.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Plate 12 - Close-up View of Seepage at the Eastern Portion of the Rock Slope
(Photograph taken on 17 June 2003)

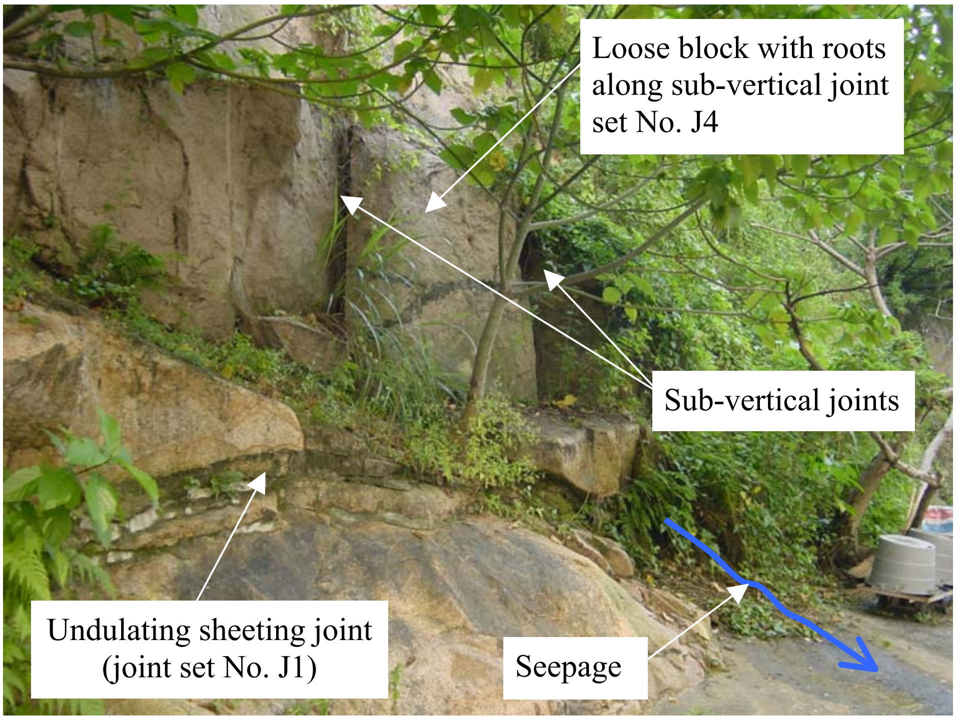


Plate 13 - Seepage Observed at Intersection of Sheeting Joint (Joint Set No. J1) and Persistent Sub-vertical Joint (Joint Set No. J3)
(Photograph taken on 21 October 2003)

Note: See Figure 13 for locations and directions of photographs.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

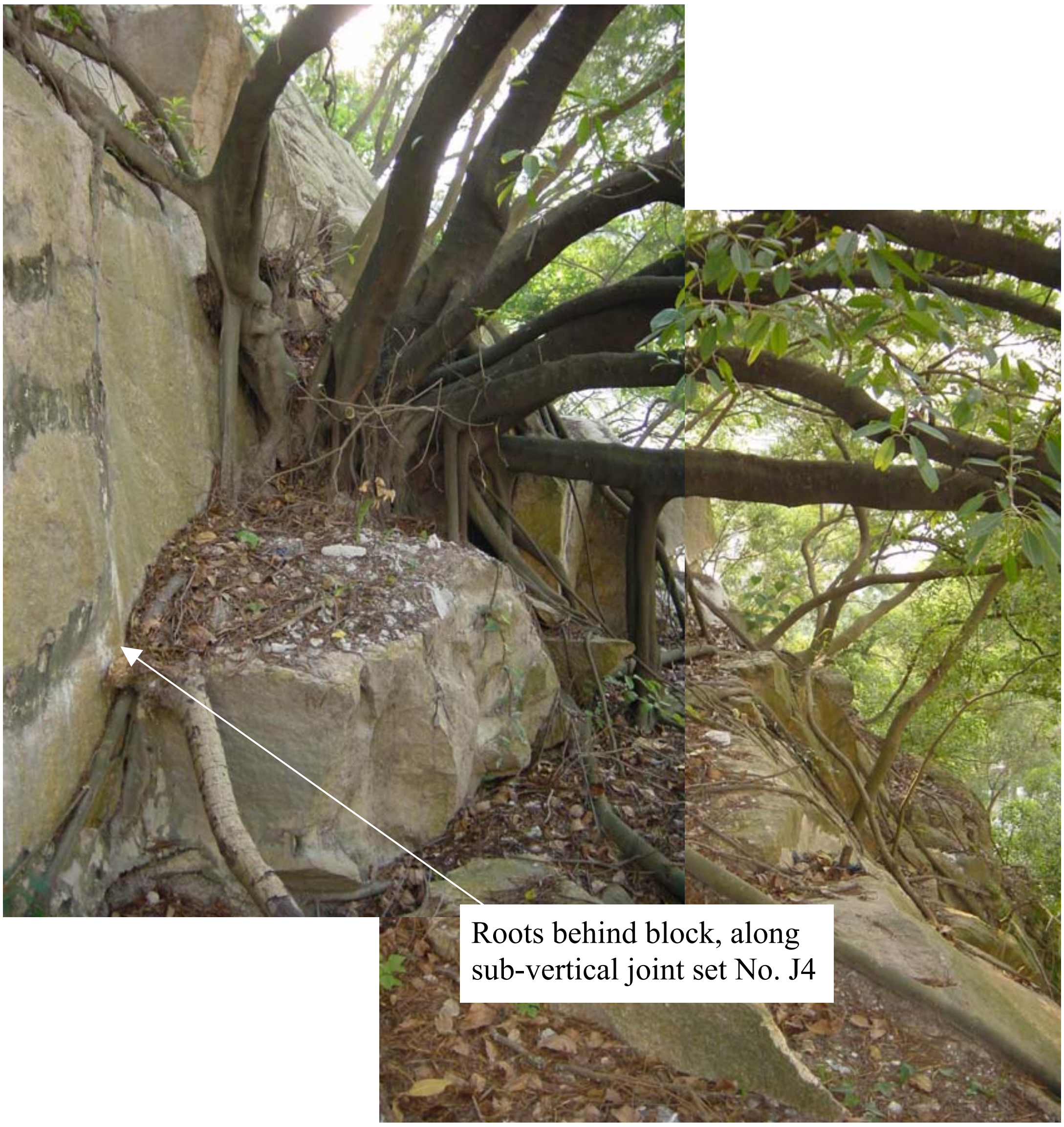


Plate 14 - View Looking West at the Large *F. virens* Tree Species Whose Extensive Root System Probably Contributed to the 6 June 2003 Rockfall (Photograph taken on 21 October 2003)

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

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents
Table of Contents

APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

CONTENTS

A1. DETAILED OBSERVATIONS

The following report comprises the detailed observations made from a review of aerial photographs taken between 1949 and 1999. A list of the aerial photographs studied is presented in Table A1 and the main observations of the API are shown in Figure A1.

YEAR	**OBSERVATIONS**
1949	The study area is located immediately to the northeast of a ridgeline that trends northwest-southeast on the northeast flank. Two drainage lines can be seen trending northwest and northeast respectively. Severe surface and gully erosion can be seen along the ridge of the hillside.
1954	No observable changes.
1961	Low rise buildings can be seen on the north-northwest trending spur to the north of the study area. The crocodile Hill Site Formation Project is in its early stages with some access roads constructed. Surface erosion can still be seen on the hillside.
1963	Extensive site formation works have been carried out on the natural hillside. The eastern portion of Slope No. 11NE-C/C71 has been formed and the formation of Kung Lok Road was in progress.
1967	Slope No. 11NE-C/C71 has been formed with Kung Lok Road at the slope toe and a cut platform at the slope crest (present-day St. Catharine’s School for Girls and Hong Lee Court). Slope No. 11NE-C/C71 appears to be bare in the middle portion of the slope and the eastern and western portions appears to be covered by chunam. A possible failure scar can be seen near the eastern end of slope No. 11NE-C/C71.
1970	Rock exposure is apparent in the middle portion of the slope with sub-horizontal joint dipping towards west. St. Catharine’s School for Girls has been built on the platform along the slope crest and Lee Hong Court still under construction.
1972	The construction of Hong Lee Court has been completed.
1973	The slope is obstructed by the shadow. The construction of Woodview Court on the opposite side of Kung Lok Road to the north of the slope was in progress.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

YEAR	**OBSERVATIONS**
1975	The slope appears to be covered with light vegetation. The construction of Woodview Court was completed.
1977	No observable changes.
1978	No observable changes.
1980	Site formation works has been carried out on the opposite side of Kung Lok Road near the western portion of the slope (present-day Lok Wah South Estate).
1984	Dark streak is seen near the toe surface of slope No. 11NE-C/C71, possibly indicating seepage. The construction of Lok Wah South Estate has been completed.
1986	The eastern portion of the slope is now covered with denser vegetation.
1990	The eastern and western portions of the slope is now thickly vegetated.
1991	No observable changes.
1993	No observable changes.
1996	No observable changes.
1997	No observable changes.
1999	No observable changes.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

LIST OF TABLES

Table A1 - List of Aerial Photographs

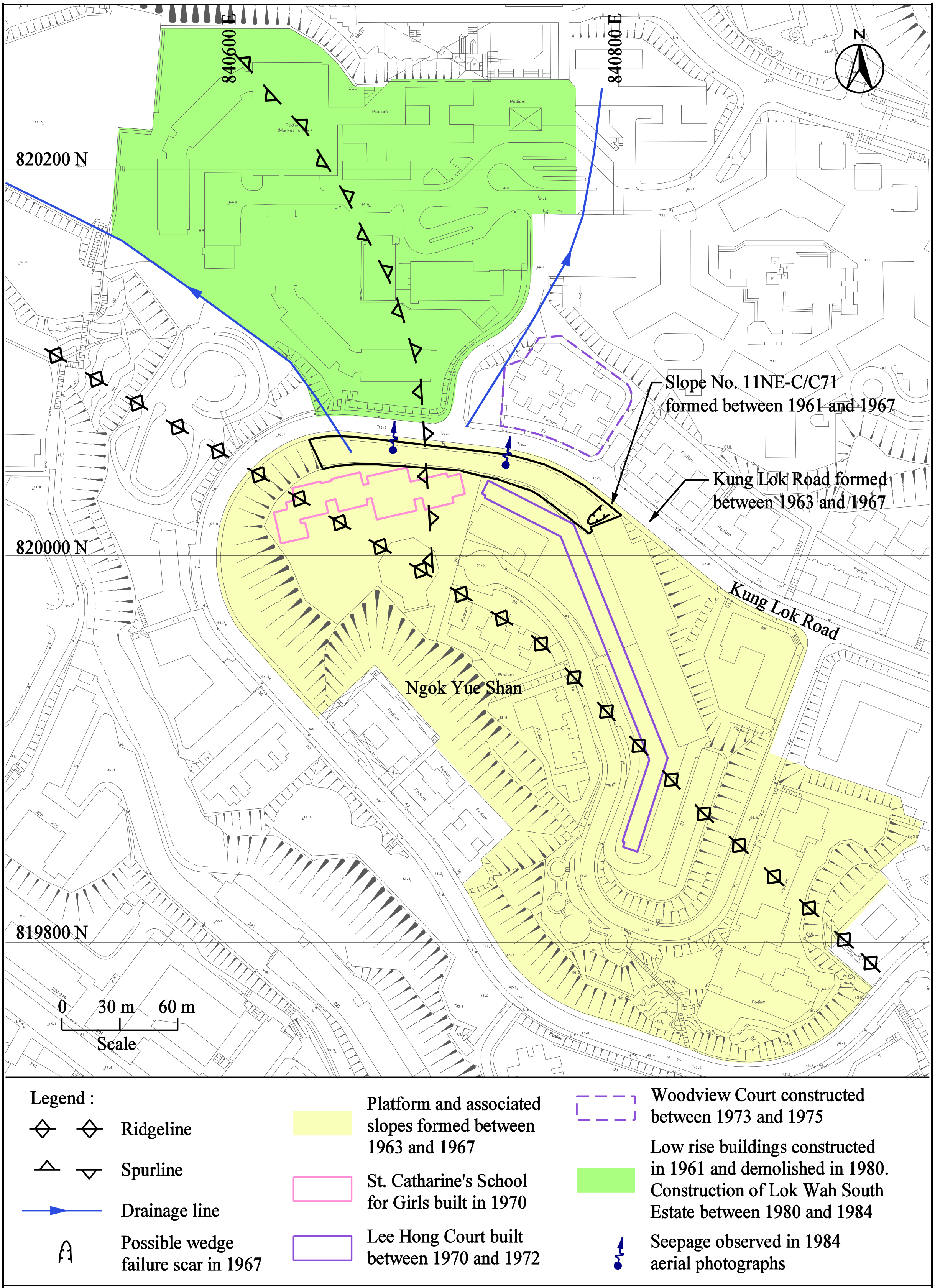
Date Taken	Altitude (ft)	Photograph Number
24 April 1949	8000	Y1675-76
2 November 1954	28300	Y02646-47
1961	30000	Y04868-69
29 January 1963	2700	Y07906-07
16 May 1967	6250	Y13354-55
1970	1200	Y16035-36
3 October 1972	13000	2351-522275-76
12 December 1973	3000	6972
2 February 1975	2000	11491
21 December 1977	4000	20341
7 December 1978	4000	24180
12 November 1980	4000	32772
27 January 1984	Unknown	53497
22 September 1986	4000	A06333-34
21 March 1990	4000	A20883-84
20 September 1991	4000	A27445-46
26 July 1993	4000	A35608
12 June 1996	4000	CN17207-08
26 May 1997	4000	CN18866-67
11 December 1999	4000	CN25220-21

Note: All aerial photographs are in black and white except for those prefixed with CN, CW or RW.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

LIST OF FIGURES

Table of Contents
Table of Contents
Table of Contents
Table of Contents



Note: Base plan is extracted from 1:1000 survey sheets Nos. 11NE-17B, 11NE-17D, 11NE-18A and 11NE-18B dated June 2002.

Figure A1 - Aerial Photograph Interpretation

Table of Contents

Table of Contents

Table of Contents

Table of Contents

APPENDIX B

VEGETATION SURVEY

CONTENTS

B1. INTRODUCTION

A survey of trees growing on slope No. 11NE-C/C71 at Kung Lok Road, Kwun Tong, was conducted following a rockfall occurred on 6 June 2003 with the assistance of Maunsell Geotechnical Services Limited. The aims of the survey were as follows:

(a) Identify tree species in those areas of the rock slope which have extensive root networks within the rock joints,

(b) assess the general prevalence and status of the identified tree species throughout Hong Kong,

(c) assess the preferred soil conditions of the identified species, and

(d) assess the tree root properties of identified species that may influence slope stability.

Trees on the slope were surveyed on 28 October 2003. Note was taken of tree species present, and the characteristics of tree roots on the rock slope. Information available in the literature regarding tree status and occurrence, habitat requirements and root properties was reviewed (AFCD, 2002; Xing et al., 2000; Webb, 1991 and Jim, 1990).

B2. FINDINGS OF THE SURVEY

Slope No. 11NE-C/C71 is an almost vertical rock slope, supporting a number of trees (Figure 8 and 9). A total of ten tree species were recorded on the slope (Table B1 and Plate B1 and Plates B7 to B13). Nine of the trees recorded on the slope were common and widespread native species. One commonly planted exotic species, *Acacia confusa*, was also recorded growing on the slope.

Information on the rooting characteristics and preferred soil conditions of Hong Kong trees is limited (available information is summarized in Table B1). *Ficus virens* var. *sublanceolata* (referred to as *F. virens* hereafter), which had a frequent occurrence on the slope, is noted to have a strong root system that grows close to the surface, and can damage paving when growing in urban areas (Jim, 1990). Both *F. virens* and *F. microcarpa* are noted to commonly grow on stonewalls in Hong Kong.

One relatively large *F. virens* was recorded on slope No. 11NE-C/C71 growing approximately 7 m above the 6 June 2003 rockfall area. The roots of this tree were observed growing over the rock surface, extending to the base of the slope. Roots were also observed in rock joints on the slope (Plates B2 to B6).

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents Table of Contents Table of Contents Table of Contents

B3. DISCUSSION AND CONCLUSIONS

Ten tree species were recorded growing on slope No. 11NE-C/C71. Except for the exotic and commonly planted *Acacia confusa*, all recorded trees are common and widespread native species.

Information on the rooting characteristics and preferred soil conditions of Hong Kong trees is limited. However, *F. virens* which was recorded above the 6 June 2003 rockfall area, is noted to have a strong root system that grows close to the surface, and can damage paving when growing in urban areas.

It is possible that the roots of *F. virens* and other tree species growing on the slope contributed to the 6 June 2003 rockfall. Potentially, roots growing along rock joints could exert stress on the surrounding rock, exacerbating existing weaknesses. It is apparent that unplanned tree root growth has influenced slope stability in this particular slope however, given the lack of existing data, it is difficult to quantify the exact nature of the problem.

B4. REFERENCES

AFCD (2002). Checklist of Hong Kong Plants: 2001. Dong Sheng Printing Company, Guangzhou, 515 p.

Xing, F.W., Ng., S.C. and Chau, L, (2000). Gymnosperms and Angiosperms of Hong Kong. Memoirs Of The Hong Kong Natural History Society 23, pp. 21-136.

Jim, C.Y. (1990). Trees in Hong Kong Species for Landscape Planting. Hong Kong University Press, 434 p.

Webb, R. (1991). Tree Planting and Maintenance in Hong Kong. Hong Kong Government, 53 p.

LIST OF TABLES

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table B1 - Summary of Tree Species and Characteristics (Sheet 1 of 2)

Tree Species on Rock Slope	Form/Max Height in HK	Abundance on Rock Slope	Distribution in Hong Kong	Preferred Soil Condition	Growth Rate	Tree Root Character	Remarks
Ficus virens var. *sublanceolata* (1)	Tree/15 m	Frequent	Common	- All soil condition.	Fast	- Surface. - Strong surface roots may damage pavings	- Good tolerance to exposure and strong wind - Common wall tree
Acacia confusa	Tree/15 m	Frequent	Common, Exotic	- Excellent pioneer tree, can establish on barren & exposed slopes with thin and infertile soils. - Drought tolerant.	Fast	- Spreading, Deep. - Very strong root anchorage. - Long & thick vertical sinker and laterals.	-
Ficus microcarpa	Tree/20 m	Occasional	Common	- All soil condition	Fast	- Surface, Spreading	- Develop aerial roots - Wind tolerant - Most common wall tree
Ficus hispida	Shrub or small tree/5 m	Occasional	Common	-	-	-	-
Macaranga tanarius	Tree/5 m	Occasional	Common	- Tolerant to dry, stony and shallow soil, can grow on sand. - Pioneer tree	Fast	- Surface	-
Celtis sinensis	Tree/20 m	Occasional	Common	- Grow well in acidic to neutral wet soil - tolerant to inadequate nutrient supply	Slow	- Surface, Spreading, Deep - Penetrating & extensive roots - Need a deep soil layer to prosper - Strong anchorage	-
Sapium sebiferum	Tree/16 m	Occasional	Common	- Prefer friable, deep, rich & moist soil - pH adaptable - Withstand periodic wet & dry condition - Require good drainage	-	- Deep tap root & extensive lateral root	- Wind tolerant

Table of Contents
Table of Contents
Table of Contents

Table B1 - Summary of Tree Species and Characteristics (Sheet 2 of 2)

Tree Species on Rock Slope	Form/Max Height in HK	Abundance on Rock Slope	Distribution in Hong Kong	Preferred Soil Condition	Growth Rate	Tree Root Character	Remarks
Ficus variegata	Tree or Shrub/ 14 m	Scarce	Common	- Tolerant to poor soil conditions	-	-	-
Mallotus paniculatus	Tree	Scarce	Common	-	-	-	-
Rhus hypoleuca	Tree	Scarce	Common	-	-	-	-

Notes:
(1) *Ficus virens* var. *sublanceolata* was located approximately 7 m above the 6 June 2003 rockfall location.
(2) The characteristics (i.e. form, maximum height, distribution, etc.) of the tree species are made reference to Webb (1991) and Jim (1990).

Table of Contents
Table of Contents
Table of Contents

LIST OF PLATES

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Plate B1 - *Ficus virens var. sublanceolata*

Plate B2 - *Ficus virens* var. *sublanceolata* (Exposed root systems extending to base of slope)

Table of Contents
Table of Contents
Table of Contents

Plate B3 - *Ficus virens* var. *sublanceolata* (Root system growing over rock face and in rock joints)

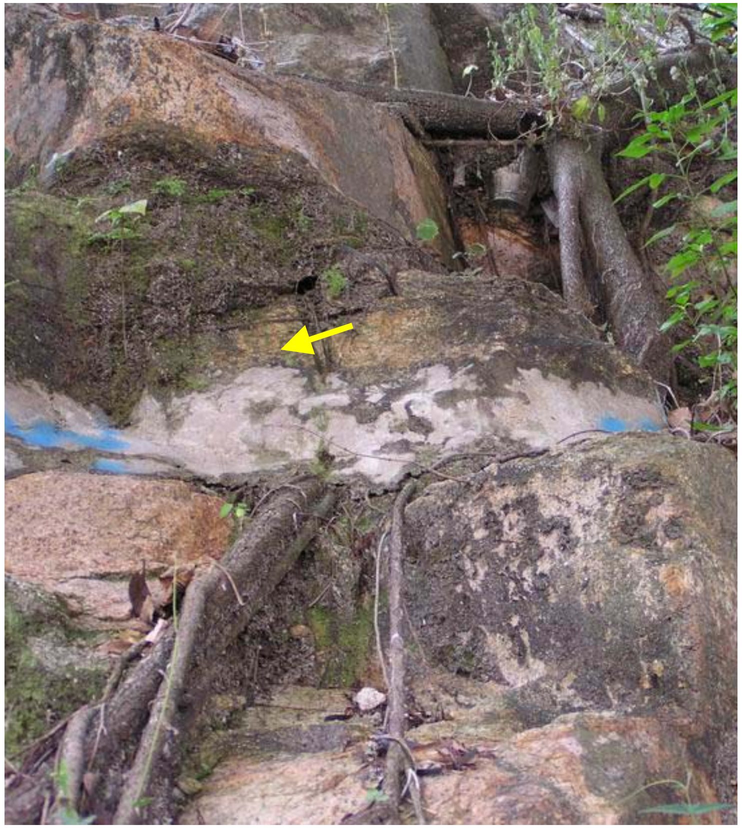


Plate B4 - *Ficus virens* var. *sublanceolata* (Root emerging from a concrete covered rock joint)

Table of Contents
Table of Contents
Table of Contents

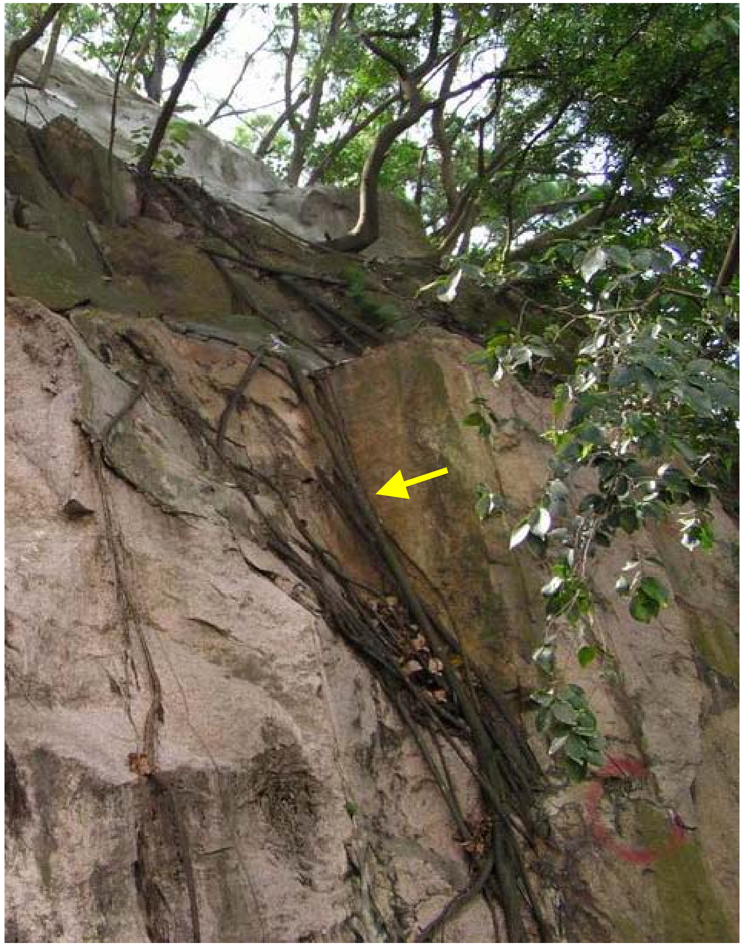


Plate B5 - *Ficus virens* var. *sublanceolata* (The 6 June 2003 rockfall area - View 1)

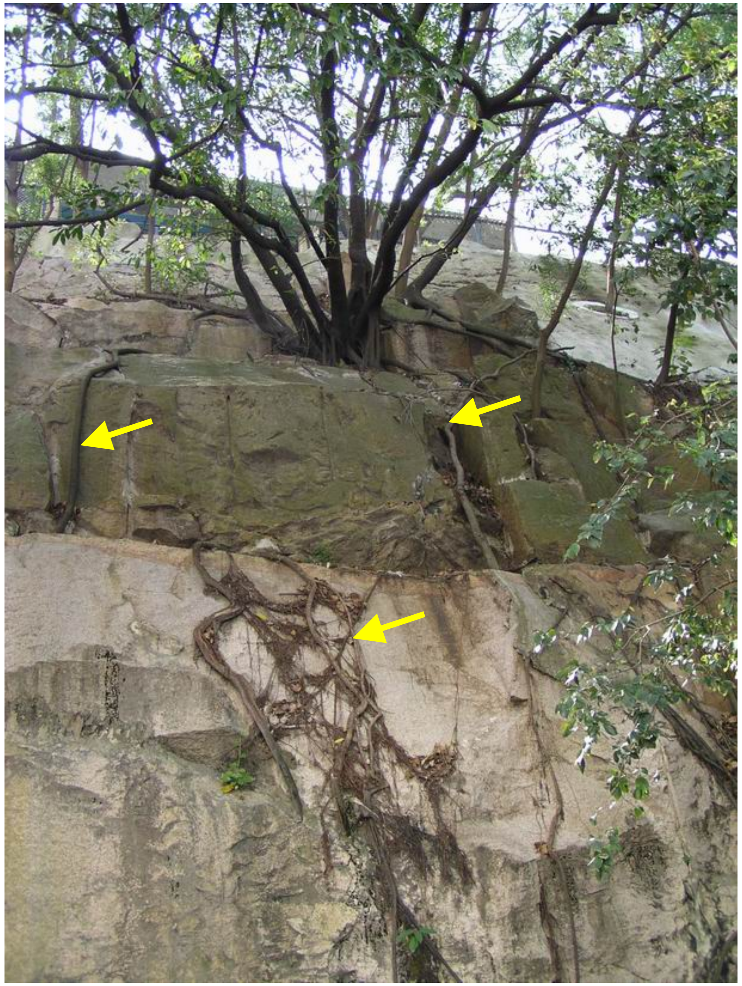


Plate B6 - Root systems extended from *Ficus virens* var. *sublanceolata* (The 6 June 2003 rockfall area - View 2)

Table of Contents
Table of Contents
Table of Contents

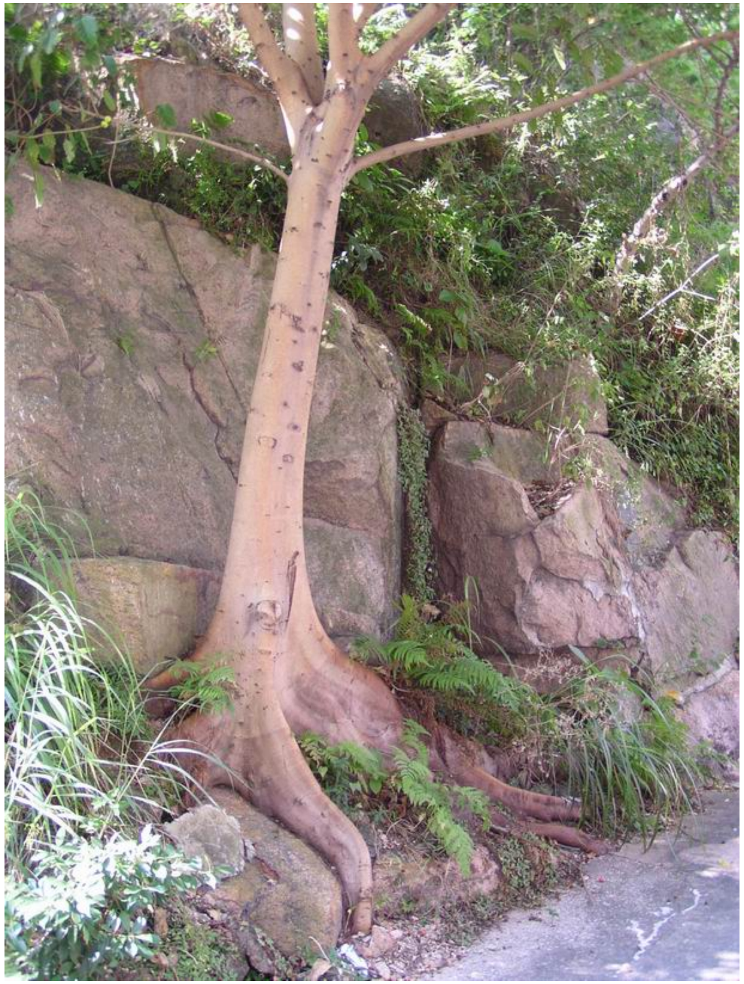


Plate B7 - *Ficus variegata*

Plate B8 - *Celtis sinensis*

Table of Contents

Table of Contents

Table of Contents

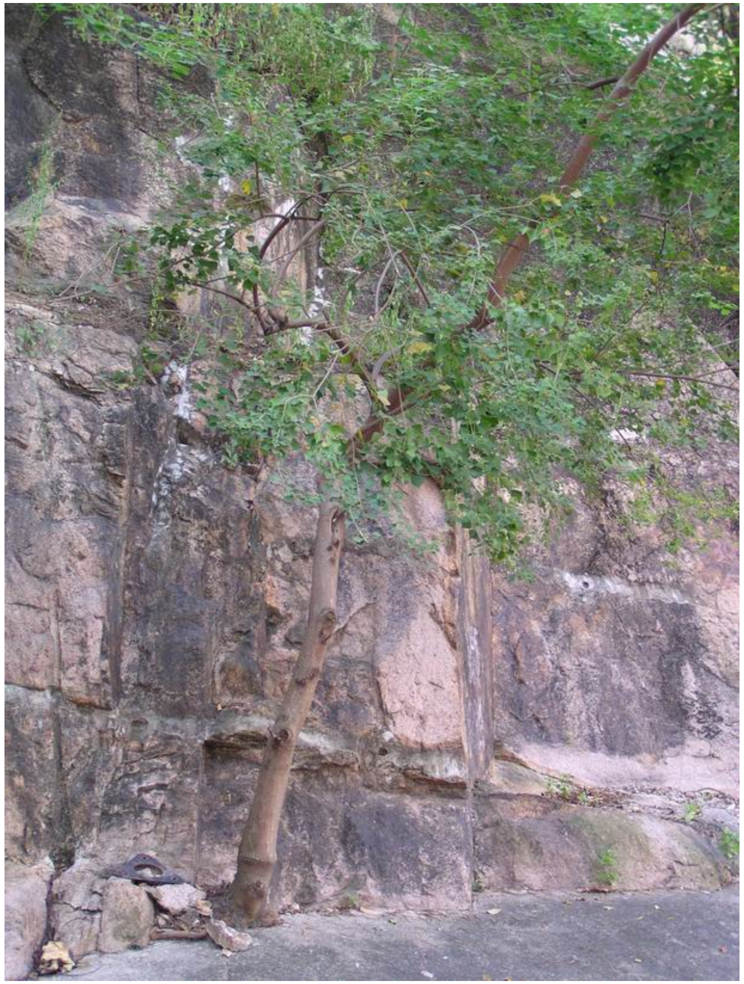


Plate B9 - *Sapium sebiferum*

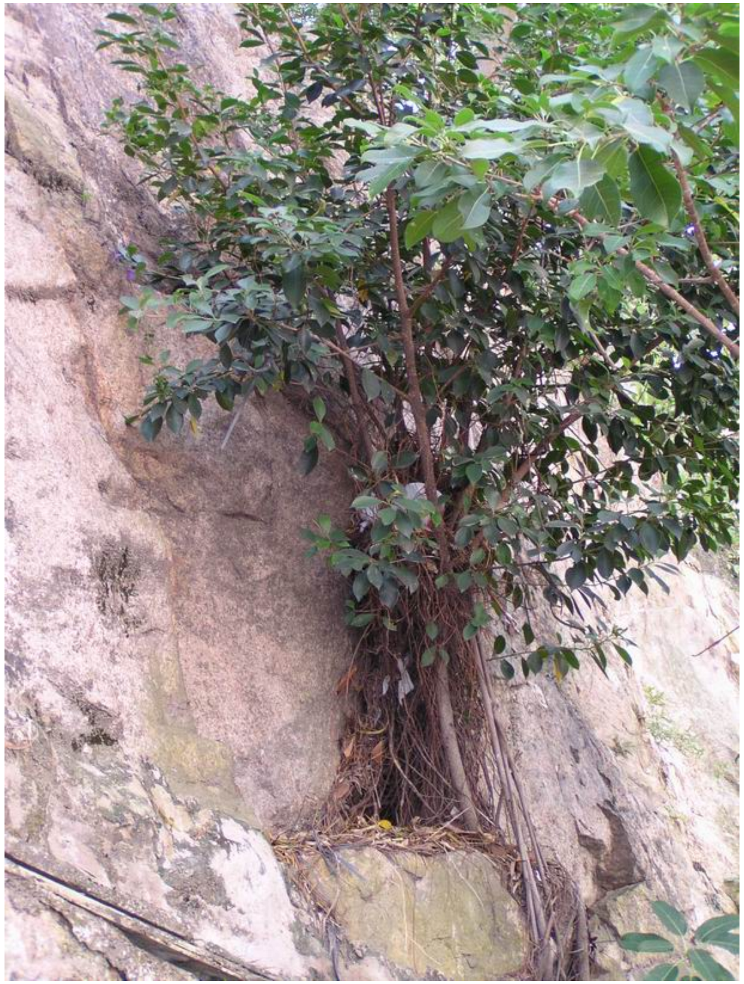


Plate B10 - *Ficus microcarpa*

Table of Contents
Table of Contents
Table of Contents

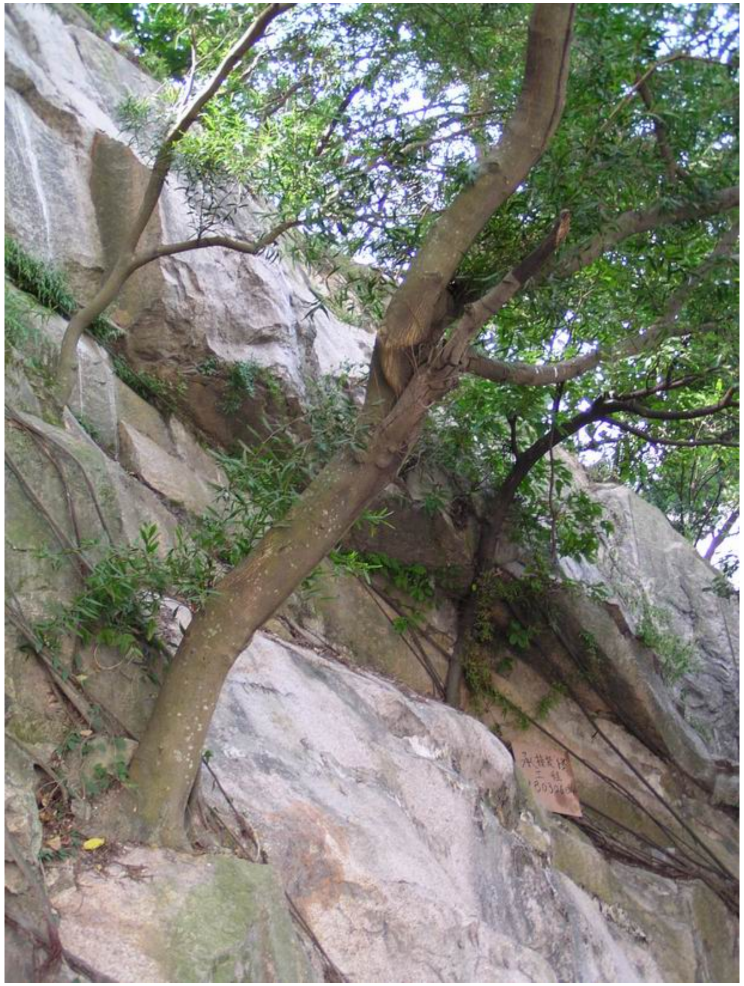


Plate B11 - *Acacia confusa*

Plate B12 - *Macaranga tanarius*

Table of Contents
Table of Contents
Table of Contents

Plate B13 - *Ficus hispida*

Table of Contents

Table of Contents

Table of Contents

Table of Contents

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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.

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Table of Contents
Table of Contents
Table of Contents
Table of Contents

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土力工程處之主要刊物

GEOTECHNICAL MANUALS

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

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

GEOGUIDES

Geoguide 1	Guide to Retaining Wall Design, 2nd Edition (1993), 258 p. (Reprinted, 2000).
Geoguide 2	Guide to Site Investigation (1987), 359 p. (Reprinted, 2000).
Geoguide 3	Guide to Rock and Soil Descriptions (1988), 186 p. (Reprinted, 2000).
Geoguide 4	Guide to Cavern Engineering (1992), 148 p. (Reprinted, 1998).
Geoguide 5	Guide to Slope Maintenance, 3rd Edition (2003), 132 p. (English Version).
岩土指南第五冊	斜坡維修指南，第三版(2003)，120頁(中文版)。
Geoguide 6	Guide to Reinforced Fill Structure and Slope Design (2002), 236 p.

GEOSPECS

Geospec 1	Model Specification for Prestressed Ground Anchors, 2nd Edition (1989), 164 p. (Reprinted, 1997).
Geospec 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. 1/2000	Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls (2000), 146 p.
GEO Publication No. 1/2006	Foundation Design and Construction (2006), 376 p.

GEOLOGICAL PUBLICATIONS

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

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

TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents

Table of Contents
Table of Contents
Table of Contents
Table of Contents