DETAILED STUDY OF THE 25 JUNE 2001 ROCKFALL INCIDENT ON SLOPE NO. 11SE-A/C561 ABOVE KING'S ROAD

GEO REPORT No. 150

Fugro Maunsell Scott Wilson Joint Venture

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

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This report was originally produced in March 2002
as GEO Landslide Study Report No. LSR 3/2002

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First published, September 2004

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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 2004

FOREWORD

This report presents the findings of a detailed study of a rockfall incident (GEO Incident No. HK2001/06/008) on rock cut slope No. 11SE-A/C561 above King's Road, Tin Hau, which was reported on 25 June 2001. The detached rock block landed on the pedestrian footway at the toe of the slope. No casualties were reported as a result of the failure. The westbound lane of King's Road and a pedestrian footway at the slope toe were temporarily closed following the incident.

The key objectives of the detailed study were to document the facts about the rockfall incident, present relevant background information and establish the probable causes of the failure. The scope of the study comprised a review of relevant documents relating to the history of the site, geological mapping, and detailed observations and measurements at the landslide site, analysis of rainfall records and diagnosis of the probable causes of the landslide. Recommendations for follow-up actions are reported separately.

The report was prepared as part of the 2000/2001 Landslide Investigation Consultancy (LIC) for Hong Kong Island and Outlying Islands, for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED) under Agreement No. CE 1/2000. This is one of a series of reports produced during the consultancy by Fugro Maunsell Scott Wilson Joint Venture (FMSW).

Y C Koo
Project Director
Fugro Maunsell Scott Wilson Joint Venture

Agreement No. CE 1/2000
2000 and 2001 Landslide Investigation Consultancy for Hong Kong Island and Outlying Islands

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1. INTRODUCTION

At around 8:00 p.m. on 25 June 2001, a rockfall (GEO Incident No. HK2001/06/008) occurred on rock cut slope No. 11SE-A/C561 located above King's Road, Tin Hau (Figure 1 and Plate 1). The incident involved the detachment of a single rock block (size about 1.1 m by 0.4 m by 0.4 m) and resulted in the temporary closure of the westbound lane of King's Road and a pedestrian footway at the slope toe. No injuries were reported as a result of the rockfall.

Following the landslide, Fugro Maunsell Scott Wilson Joint Venture (FMSW, the 2000/2001 Landslide Investigation Consultants for Hong Kong Island and Outlying Islands) carried out a detailed study of the failure for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 1/2000.

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

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

(a) a review of relevant documents relating to the history of the site,

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

(c) analysis of rainfall records, and

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

2. SITE DESCRIPTION

The location of the site is shown in Figure 1. King's Road has been cut into the hillside locally on a north-south axis at an elevation of about 7.3 mPD. Tin Hau Temple Road rises on a similar axis from the junction with King's Road, located about 200 m to the south of the 2001 rockfall. The area between the two roads has been extensively developed and is occupied primarily by multi-storey residential buildings.

Slope No. 11SE-A/C561 (Plate 1) extends above King's Road and is about 40 m long. The surface profile of the slope comprises an 85° to 90° cut face in rock (slightly to moderately decomposed, medium-grained granite) with a maximum height of about 15 m. The residential buildings 'Serene Court' and 'Piedmont Garden' (Nos. 41 and 37-39A Tin Hau Temple Road respectively) are situated above the slope crest. A 35° to 40° soil cut slope about 3 m to 4 m high with a shotcrete facing extends above the crest of the rock cut face to the underside of the carpark floor slab of Serene Court. The soil cut slope was not registered at the time of the 2001 rockfall.

The rock cut face of slope No. 11SE-A/C561 exposes a large wedge, formed by the intersection of two persistent joint sets, below Serene Court (Plate 1). The toe of the wedge daylights about 3 m above the slope toe and the wedge is about 20 m wide at the slope crest. The wedge has previously been assessed and stabilised (see Section 4) by the installation of twenty rock bolts, the concrete heads of which are visible on the slope face.

A 300 mm U-channel located at the crest of a 0.6 m high concrete toe wall extends along the toe of the slope, adjacent to the King's Road pedestrian footway.

Buried water-carrying services in the vicinity of slope No. 11SE-A/C561 are shown in Figure 2.

3. MAINTENANCE RESPONSIBILITY

According to the Slope Maintenance Responsibility Information System of the Lands Department, slope No. 11SE-A/C561, comprising the rock cut slope face above King's Road, is under the maintenance responsibility of the Highways Department (HyD). The 3 m to 4 m high unregistered soil cut slope above slope No. 11SE-A/C561 is within the lot boundary of No. 41 Tin Hau Temple Road.

4. SITE HISTORY AND PREVIOUS INSTABILITY

4.1 Site History

The rock cutting extending along the eastern edge of King's Road and including slope No. 11SE-A/C561 was formed in the late 1960's. The portion of the rock cutting below No. 41 Tin Hau Temple Road (Lot No. I.L. 7926), including the portion involved in the June 2001 rockfall, was formed by the private lot owners as a condition of the Government lease agreement for development of the site. The lease conditions required that the area between the edge of King's Road at that time and the lot boundary be excavated to the King's Road level (for the widening of King's Road), at the expense of the private lot owners, prior to being taken over by the Government. The lease agreement also stated that the lot owners would be responsible for the provision of any stabilisation measures required as a result of the slope formation.

The rock cut slope below Piedmont Garden to the south was formed under a similar arrangement (i.e. by the private lot owners). The rock cut slope slope No. 11SE-A/C14 (Figure 1) to the north was formed by the Government at the same time.

Slope No. 11SE-A/C561 comprises the southern portion of the slope feature originally registered as slope No. 11SE-A/C14 in the 1977/78 Catalogue of Slopes. Slope No. 11SE-A/C561 was identified as a separate feature by the SIFT study in 1995 (see Section 5.4). The originally formed slope geometry (i.e. prior to discharging a Dangerous Hillside (DH) Order in 1984, see Section 5.3) in the vicinity of the June 2001 rockfall comprised the current 15 m high sub-vertical rock cut face, overlain by a 3 m to 4 m high sub-vertical soil cut in completely decomposed granite. The rock cut slope face was formed by small diameter continuous line drilling, with individual break-outs of about 0.6 m height.

Slope upgrading works for the portion of slope No. 11SE-A/C561 within the lot boundary of No. 41 Tin Hau Temple Road were carried out by the private lot owners between mid-1983 and mid-1984 in response to the DH Order served by the Building Authority (BA) in March 1982 (see Section 5.3). These works related primarily to the stabilisation of the large wedge exposed in the rock slope face (see Section 2) using rock bolts and horizontal drains. Additionally, the soil face above the rock slope was cut back beneath the Serene Court carpark to an angle of about 35° to 40° and covered with chunam. It is, however, noted that the current boundary of slope No. 11SE-A/C561 incorporates the rock cut face only in the Slope Information System (SIS).

There were no other major changes recorded at the site to the present time. Replacement of the chunam surfacing on the soil cut slope face above the crest of slope No. 11SE-A/C561 with shotcrete was carried out in early to mid-2000 by the lot owners of No. 41 Tin Hau Temple Road in response to a Type 2 Advisory Letter issued by the Buildings Department (BD) in 1999 (see Section 5.5).

4.2 Previous Instability

No previous landslide incidents were recorded in the GEO landslide database for Slope No. 11SE-A/C561. However, two previous incidents (GEO Incident Nos. HK 85/6/1 and HK 97/3/1) were recorded for slopes Nos. 11SE-A/C14 and 11SE-A/C15 to the north and south respectively.

GEO Incident No. HK 85/6/1 comprised a 70 m^3 landslide located immediately north of No. 41 Tin Hau Temple Road, which occurred while slope upgrading works under the Landslip Preventive Measures (LPM) Programme were underway. The GEO Incident Report indicated that the cause of failure was an "Unidentified jointed daylighting as a result of nearby excavation for LPM works". It is noted that slope No. 11SE-A/C561 was part of slope No. 11SE-A/C14 (for which the Highways Office, now the HyD, had the maintenance responsibility) at the time of the 1985 incident. Record photographs show a number of 1 m to 2 m diameter rock blocks were involved in the failure and had fallen onto the King's Road pedestrian footway, damaging a section of the site hoarding. No injuries from the failure were recorded.

GEO Incident No. 97/3/1 recorded for slope No. 11SE-A/C15 involved a small (0.05 m^3) rockfall from near the crest of the slope face adjacent to the southern boundary of Nos. 37-39A Tin Hau Temple Road. The cause of failure was indicated as "weathering". Record photographs show the source area to be located at the soil/rock interface, about 10 m above the slope toe, and a number of small rock fragments on the King's Road pedestrian footway. No injuries were reported as a result of this failure.

According to GEO records, a portion of the soil face above the crest of slope No. 11SE-A/C561 reportedly failed during the ground investigation associated with the 1983/84 slope upgrading works. The failure was reported as being the result of saturation of the soil by drilling fluid from drillhole DV3 (Figure 3). The debris from this failure (estimated volume of 2 m^3 to 3 m^3) fell onto the King's Road pedestrian footway. No injuries were reported as a result of the incident. The failure was not recorded as a GEO Incident.

5. PAST ASSESSMENTS

5.1 Binnie & Partners

The slope feature registered as slope No. 11SE-A/C14 in the 1977/78 Catalogue of Slopes (including the current area of slope No. 11SE-A/C561) was inspected by Binnie & Partners (B&P) as part of the "Phase I Re-appraisal of Cut & Natural Slopes and Retaining Walls Study" in March 1978. The field sheet prepared for the slope recorded that the slope was in fair condition and that "high seepage" was observed through rock joints and from the slope crest.

Signs of distress were observed on the southern half of the slope (i.e currently slope No. 11SE-A/C561) comprising about 2 mm of outward movement of a rock wedge and scars of previous instability in the form of two small wedge failures were observed in the same portion of the slope. A recommendation was made for the checking of adjacent water-carrying services for leakage.

5.2 Geotechnical Control Office

The Existing Slopes Division of the Geotechnical Control Office (GCO) completed a Stage 1 Study of slope No. 11SE-A/C14 in January 1980. The report described the southern portion of the feature as comprising a 15 m high rock cut overlain by up to 3 m of vertical soil cut of decomposed granite with clear demarcation between soil and rock. The study focused on the large wedge identified in the rock cut slope face below Serene Court. Inspection of the exposed surfaces of the wedge had indicated about 2 mm of movement along the joint planes.

A joint survey of the rock face carried out as part of the Stage 1 Study identified two main groups of joint orientations, joint set "A" (62°/255°) and joint set "B" (68°/328°), which defined the planes forming the large wedge. The joints from both sets defining the wedge were described as "open, smooth and planar". Crushed quartz seams and dark brown staining were visible on joints comprising set "B", while the other joint sets identified on the face were described as "tight, smooth and clean". Kinematically permissible wedges were identified elsewhere on the slope face by the GCO where minor sets combined with one another or with sets "A" and "B". The GCO considered that the large wedge formed by sets "A" and "B" was the least stable.

Significant seepage from several joint apertures was observed by the GCO, which was considered most likely to have been derived from the leaking services beneath Serene Court or Piedmont Garden. Seepage observed during an inspection carried out by the GCO in December 1979 was reportedly greater than that observed during an inspection in July 1979.

A sensitivity analysis of the rock wedge stability was undertaken by the GCO as part of the Stage 1 Study using the Hoek & Bray (1981) solution for a range of discontinuity shear strength parameters ($c' = 0$ kPa to 30 kPa, $\phi' = 20°$ to 40°) and assuming wet and dry conditions along the sliding surfaces. The results of the analyses indicated that for an assumed friction angle along joint surfaces of 38°, cohesion values of 16 kPa and 31 kPa were required to maintain a factor of safety of 1 for dry and wet conditions respectively (joint planes were taken to be "fully saturated" but the assumed water pressure distribution was not

elaborated). The magnitude of the stabilising force required to improve the factor of safety (FOS) to 1.4 was reported to lie in the range of 1.0 MN to 2.5 MN. The assessment did not include consideration of footing loads from Serene Court on the rock wedge, as foundation details were not available at the time.

The report made recommendations for the determination of foundation details of Serene Court and adjacent structures, investigation of the source of the seepage through a check on existing services, cleaning of the rock face to allow detailed investigation of the rock joints, stability analysis and subsequent design of suitable preventive works. The recommended action for the portion of slope No. 11SE-A/C14 below No. 41 Tin Hau Temple Road was to carry out "Stage 3 Investigation and/or Design".

The Stage 1 Study report was issued to the Private Slopes Division of the GCO. Because the main area of potential instability (i.e. the large wedge) was located within a portion of the feature which had been formed by private lot owners, the Private Slopes Division made a recommendation to the BA, on the basis of the Stage 1 Study report, for the service of a DH Order on the lot owners of No. 41 Tin Hau Temple Road. The DH Order was subsequently served by the BA on 5 March 1982.

5.3 Ho Fei Geotechnical Construction and Engineering Co.

In response to the DH Order, the lot owners of No. 41 Tin Hau Temple Road appointed Quartrect and Partners Architects as the Authorised Person for the slope upgrading works, who subsequently appointed Ho Fei Geotechnical Construction and Engineering Company (Ho Fei) as Geotechnical Consultant in June 1982.

A geotechnical report prepared by Ho Fei was submitted to the BA in December 1982. The report presented the results of a "stability study" of the portion of slope No. 11SE-A/C14 below Serene Court and detailed the proposed upgrading works, which comprised, inter alia, the installation of twenty 5 m to 8 m long 40 mm diameter rock bolts to stabilise the large wedge. The stability assessment was subsequently revised by Ho Fei in response to comments by the GCO with regard to the design assumptions. A supplementary geotechnical report was prepared by Ho Fei and submitted to the BA in March 1983. The BA approved the revised design on 29 April 1983.

The stability assessment of the large rock wedge was based on site-specific ground investigation, which included geological mapping of the slope face, three coreholes and monitoring of groundwater levels. Mapping of the slope face identified four joint sets, labelled J1 to J4 (67°/316°, 58°/253°, 73°/43° and 85°/265° respectively), of which joint sets J1 and J2 were the major sets defining the large wedge (Figures 3 to 5). The apertures of J1 and J2 were described as extremely narrow (<3 mm) with surface staining. The remaining minor joint sets were described as tight. Joint planes were described as generally rough and moderately weathered.

Three drillholes were located between 1 m and 4 m behind the slope crest (drillholes DV1 to DV3 on Figure 3) and terminated in rock between 3.5 m and 12 m above the slope toe. Drillhole logs typically describe slightly weathered medium- to coarse-grained granite below the soil/rock interface. Impression packer testing was carried out in each drillhole and the

results were compared with the rock core samples. Joint set J2 was absent in the rock core retrieved from drillhole DV2 (joint sets J1 and J2 were located in drillholes DV1 and DV3 respectively), leading to the postulation by Ho Fei that J2 was of low lateral persistence into the slope (i.e. the large wedge was not completely detached from the surrounding rock mass along the joint planes).

A piezometer was installed at the base of drillhole DV1 (10.5 mPD). Monitoring data from 15 November to 27 November 1982 (3 readings) indicated a "base" groundwater table at an elevation of about 18.5 mPD (i.e. 11.2 m above the slope toe). Ho Fei postulated that the recorded water levels comprised the accumulated seepage from the joint set J1 defining the wedge. Based on the "regional hydrogeological conditions", Ho Fei postulated that the actual base groundwater table was below the toe of the slope, the seepage from the major joint planes resulting from "leakage of underground sewers".

The stability of the wedge was analysed using the Hoek & Bray (1977) method. Joint shear strength parameters as input to the calculation were evaluated using the empirical method of Barton (1973) producing an "equivalent friction angle" of 61°, generalised shear strength parameters from Hoek and Bray (1977) of c' = 50 kPa, ϕ'= 40°, and back-analysis of the wedge assuming an FOS of 1 which produced c' = 25 kPa, ϕ'= 40°. Joint shear strength parameters of c' = 0 kPa and ϕ'= 55° were used in the revised analysis, reportedly based on the comments of the GCO, and obtained an FOS equal to 1 when dry conditions were assumed. Based on the presumed low lateral persistence of joint set J2 into the slope, Ho Fei considered the chosen parameters to be conservative.

Groundwater assumptions used for the determination of the required stabilising force to achieve an FOS of 1.4 comprised a 1.9 m hydrostatic head applied in an assumed "tension crack" at the rear of the wedge. The basis for this assumption was not presented in the assessment. External loadings on the wedge from the Serene Court carpark footings were also considered in the analysis (570 kN, 890 kN and 850 kN at footings C56, C57 and C58 respectively in Figure 3), as well as a surcharge loading from the soil layer overlying the rock (1720 kN). The shear strength of the soil layer was not considered.

The total stabilising force required to achieve an FOS of 1.4 was found to be 2290 kN. Based on a design working load of 154 kN/bolt, the proposed configuration of twenty rock bolts would achieve an FOS of 1.6. Additional measures applied in a prescriptive manner included the installation of three horizontal drains near the toe of the wedge. Twenty one monitoring points (tell-tales and movement gauges) were also installed to assess any movement of the wedge. Design drawings Nos. PF1 to PF3 (extracts shown in Figures 3 to 5) presented details of the rock wedge assessment and the proposed slope upgrading works. Handwritten annotations dated 26 April 1983 shown on drawing No. PF2 (Rev.1) and signed by the AP include the reduction of the rock bolt bar diameter from 40 mm to 38 mm; however, the reason for this change is not known.

Further revision to the drawing (Rev.2, dated 12 November 1983) included an increase in the rock bolt drillhole diameter from 76 mm to 90 mm and a revised slope angle for the soil cut above the rock slope crest of 40° (previously 35°). The factor of safety of the soil cut slope was not assessed by Ho Fei in either of their reports.

5.4 SIFT & SIRST

In April 1995, slope No. 11SE-A/C561 was assigned as a Class "C1" feature, i.e. a slope "…formed or substantially modified before 30.6.78 or to have been illegally formed after 30.6.78" by the SIFT study. According to the SIS, slope No. 11SE-A/C561 was not ranked under the New Priority Classification System (NPCS) by the GEO, i.e. no NPCS score is available. A SIRST inspection carried out in April 1996 indicated that no signs of seepage or distress were observed. Record photographs taken at this time (Plate 2) show seepage on the slope face, as well as a tree (unplanned vegetation) at the June 2001 rockfall source area.

5.5 Slope Maintenance Inspections

HyD Routine Maintenance Inspection records indicate that slope No. 11SE-A/C561 was not inspected as an individual feature until August 2000. Prior to this time, the slope was part of slope No. 11SE-A/C14. The reasons for the subsequent revision in the slope boundaries are not certain. Routine Maintenance Inspections carried out in October 1994, March 1996, February 1997 and May 1998 indicated that no action was required for slope No. 11SE-A/C14. Vegetation clearance, and in particular, the unplanned tree located at the 2001 rockfall site was recommended following the inspection carried out in December 1998 (Plate 3). Vegetation clearance was also recommended following the August 2000 Routine Maintenance Inspection for slope No. 11SE-A/C561, but the specific location was not indicated. A works order was issued by the HyD in November 2000, which included an item for vegetation clearance; however the tree at the June 2001 rockfall site was not removed. The January 2000 and February 2001 Routine Maintenance Inspections for slope No. 11SE-A/C561 indicated that no maintenance works were necessary.

An Engineer Inspection for slope No. 11SE-A/C14, including the present extent of slope No. 11SE-A/C561, was carried out by FMR Consultants (FMR) in July 1995. FMR made no specific recommendations for the removal of vegetation, but noted the presence of bolts and recommended a "Specialist Inspection" and stability assessment be carried out.

An Engineer Inspection for slope No. 11SE-A/C14, including the present extent of slope No. 11SE-A/C561, was carried out by Halcrow Asia Partnership (HAP) in May 1998. HAP made a general recommendation for the removal of vegetation from the slope and noted in respect of the portion of slope now comprising slope No. 11SE-A/C561 that "minor" trimming of trees was required.

The GEO inspected slope No. 11SE-A/C561 in June 1999 in relation to the chunamed soil cut slope located above the rock slope crest and beneath the Serene Court carpark. The GEO subsequently recommended to the BD that a Type 2 Advisory Letter be served on the parties responsible for the slope maintenance on the basis that the chunam surfacing was found to be defective. The repair and maintenance works specified in the Advisory Letter comprised the removal of defective chunam and the application of shotcrete with weepholes. This work appears to have been carried out, based on observations by FMSW following the June 2001 rockfall (see Section 7).

The next Engineer Inspection for slope No. 11SE-A/C561 was carried out by Maunsell Geotechnical Services Ltd (MGS) in March 2000. The inspection record stated that

moderate cracking of surface drainage channels at the slope toe was observed, as well as recent seepage from open joints in the slope face (at the base of the large wedge with rock bolts). Unplanned vegetation was observed on the slope face, notably the tree present at the location of the June 2001 rockfall (Plate 4). Recommendations for routine maintenance works were for the repair of cracks in the surface drainage system and removal of undesirable vegetation at the location near the June 2001 rockfall. Recommendations on preventive maintenance works were for the provision of an access ladder to the slope face in order to facilitate proper inspection.

MGS also completed a Record Sheet for slope No. 11SE-A/C561, dated July 2000, which included additional recommendations on slope maintenance works. These included the removal of debris and vegetation from drainage channels, clearing of weepholes, the installation of drains to open rock joints, the removal of loose rock debris and trimming of overhangs on the slope face.

None of the slope inspection records reviewed made mention of the tell-tales, movement gauges or raking drains which were installed as part of the slope upgrading works carried out in 1983/84.

6. THE JUNE 2001 ROCKFALL

The GEO Incident Report (No. HK2001/06/008) indicates that the rockfall of 25 June 2001 occurred at about 8:00 p.m. and primarily involved a single wedge-shaped rock block of about 1.1 m by 0.4 m by 0.4 m (i.e. volume of the order of 0.1 m^3). The detached rock block originated from a location on the southern margin of the large wedge exposed in the slope face (Section 2 and Figure 4) about 10 m above the slope toe where the small tree (unplanned vegetation) identified in record photographs was growing from the slope face (Plates 1 and 5).

The detached rock block (Plate 6) probably struck the toe wall (Plate 7), as evidenced by recent minor damage, which broke a number of smaller fragments from the block. The detached rock block and smaller fragments came to rest on the King's Road pedestrian footway. The footway and westbound lane of King's Road were temporarily closed as a result of the rockfall. No injuries or other damage resulted from the incident.

7. OBSERVATIONS FROM FIELD INSPECTIONS

FMSW visited the site on 26 June 2001. The rock slope face exposed slightly to moderately decomposed medium-grained granite. The structural geology of the slope was controlled by two predominant joint sets, with measured orientations of 70°/247° and 68°/310° respectively (Plate 1), which are in general agreement with the previous assessments. Apart from the obvious and large bolted wedge, a number of other smaller potential wedges were identified on the slope face, which were considered in the previous assessments (Plate 5). Joint apertures for the smaller wedges appear to be relatively tight overall, and the undulating nature and variable persistence of the joint surfaces would generally contribute to the stability of the slope face.

The joints defining the large bolted wedge had variable aperture (about 2 mm to 5 mm) and were generally more open than other rock joints in the surrounding slope face. However, there were no obvious signs of recent movement along these planes. A significant flow of groundwater seepage was observed issuing from the joints defining the large bolted wedge to a height of about 9 m above the slope toe (Plate 1). Moss and algae growth on the slope face below the joints suggested that the seepage flow had been ongoing for some time. Seepage was also observed issuing from three raking drains installed in the lower portion of the wedge. A device believed to be one of the movement monitoring gauges, as well as the mortar bedding for a single tell-tale installed in 1983/84 were observed at the toe of the wedge.

Root growth from the tree on the slope face near the source area of the June 2001 rockfall (Plate 5) was observed to extend above and below the trunk along joint apertures. Due to the relative location of the source area on the slope face, close inspection was not possible. However, the source area was located in the area affected by tree root growth. From the road level, the exposed surfaces in the source area appeared relatively clean and free of infill and/or staining (Plate 5). No seepage was observed issuing from joint apertures in the vicinity of the source area at the time of the inspection when there was no rain.

The detached rock block was identified at the slope toe (Plates 6 and 8), prior to its removal. The block comprised slightly to moderately decomposed, medium-grained granite. Discoloration of certain faces of the block provided an indication as to which had been exposed prior to detachment, and thereby, the approximate orientation of the block on the slope face. This, combined with the appearance of the source area, suggested that it comprised a wedge defined by the major joint sets exposed in the slope face. The faces of the block, which would have been in contact with the rock mass prior to detachment, were also clean and free of infill or staining, suggesting that the joint aperture had been relatively tight prior to the incident.

Another larger tree was observed growing on the face of slope No. 11SE-A/C561 about 10 m to the south of the source area and below Piedmont Garden (Plate 1), with extensive root growth covering the slope. Significant seepage was also observed issuing from joint apertures in the vicinity of the tree.

The shotcrete surfacing on the soil cut face above the crest of slope No. 11SE-A/C561 appeared to have been applied recently.

8. OTHER OBSERVATIONS BY FMSW

Record photographs from previous site inspections in 1983, 1984 and 1999, the April 1996 SIRST inspection, and the May 1998 and March 2000 Engineer Inspections by HAP and MGS respectively are presented as Plates 2, 4, and 9 to 12. These show recurrent features relating to the condition of the slope face comprising prolonged heavy seepage and growth of unplanned vegetation along the major joint sets defining the large bolted wedge, including tree growth at the northern extent of the wedge and the tree at the 2001 rockfall site.

The 1984 photograph (Plate 10) shows that vegetation along the large bolted wedge was removed from the slope face during the slope upgrading works carried out under the DH Order. The record photograph from the June 1999 inspection (Plate 12) shows the tree

adjacent to the 2001 rockfall source area to have been heavily trimmed to the main trunk, but not entirely removed. The photograph also shows an area with an apparently 'missing' small wedge (estimated size about 0.3 m by 0.3 m by 0.3 m) adjacent to the base of the tree, which is coincident with the lower extent of the June 2001 rockfall source area, suggesting possible previous minor failure.

A follow-up inspection of slope No. 11SE-A/C561 was carried out by FMSW on 7 November 2001. Plate 13 provides a view of the slope in the vicinity of the June 2001 rockfall source area. This shows that the tree, which was trimmed to the main trunk after the June 2001 rockfall, had started to regenerate.

9. ANALYSIS OF RAINFALL RECORDS

The nearest GEO automatic raingauge (No. H09) to slope No. 11SE-A/C561 is located at the Kiangsu Chekiang College at No. 20 Braemar Hill Road, about 900 m northeast of the site. For the purposes of rainfall analysis, it is assumed that the rockfall occurred at 8:00 p.m. on 25 June 2001.

The daily rainfall for the period of one month preceding and two days following the incident, together with hourly rainfall for 48 hours before and 5 hours following the incident are given in Figure 6. The daily rainfall record shows that heavy rainfall was recorded over the two days prior to the rockfall, with the hourly data indicating that the highest rainfall intensities, in the range of about 30 mm/hr to 45 mm/hr, were recorded in the 2 hours prior to the rockfall.

Table 1 presents the estimated return periods for the maximum rolling rainfall for various durations based on historical rainfall data at the Hong Kong Observatory (Lam & Leung, 1994). The results indicate that the 31-day maximum rolling rainfall of 941 mm was the most severe with a return period of about 10 years. However, the return periods for the shorter durations in the week prior to the rockfall were all less than 2 years.

10. DISCUSSION

The 25 June 2001 rockfall occurred on a rock cut slope with adverse jointing promoting the formation of potentially unstable wedge features. The location of the 2001 rockfall source area was at the margin of a large bolted wedge feature defined by the predominant joint sets present in the slope face. The geometry of the detached rock block was consistent with the predominant joint sets, indicating that the June 2001 rockfall failure was structurally controlled.

There are no obvious signs of the June 2001 rockfall being a precursor to a larger scale instability involving the large wedge, which was previously treated with rock bolts in the early 1980's.

Slope No. 11SE-A/C561 has a history of prolonged heavy seepage from the joint sets defining the large wedge, which has promoted the growth of unplanned vegetation on the slope face. Notable amongst the unplanned vegetation is a tree of the type with exposed

roots, which have followed the joint apertures above and below the main trunk, located at the June 2001 rockfall source area. Vegetation clearance has previously been carried out on the slope face, but in the past 15 or so years the tree was only trimmed back to the main stump. The tree regenerated relatively quickly with time as evidenced by Plates 4 and 12 over a time scale of some 15 months, resulting in the continued growth of the tree roots along and into joint apertures. A number of specific recommendations have been made since 1998 for the removal of the unplanned tree following routine Maintenance Inspections or Engineer Inspections on the slope, the latest being in March 2000.

Follow-up inspection by FMSW in November 2001 showed that the tree, which had been trimmed to the main trunk in July 2001 following the rockfall incident, had already started to regenerate (Plate 13).

The detached rock block was probably in a metastable condition as a result of progressive tree root growth penetrating into adverse joint apertures and wedging them open. The exposed surfaces of the detached rock block and the source area of the June 2001 rockfall were generally clean and free from staining or infill material, suggesting that the destabilising mechanism involved displacement of the block (by the jacking action of the tree roots and possible build-up of cleft water pressure in the open joint) as opposed to deterioration of the joint surfaces. Record photographs indicate that a small wedge failure may have occurred below the toe of the failed block in 1999, which could have contributed to the June 2001 rockfall.

The close correlation between the rainfall recorded in the days prior to the rockfall and the timing of the incident suggests that the rockfall was probably triggered by rainfall. However, the corresponding return periods for short duration rainfall are less than 2 years (see Table 1). The location of the source area is above the level of heavy seepage issuing from the predominant joints. Localised build-up of cleft water pressures behind the detached rock block resulting from surface infiltration into the open joints may also have been a contributory factor to the rockfall.

11. CONCLUSIONS

It is concluded that the 25 June 2001 rockfall on slope No. 11SE-A/C561 was triggered by the rainfall preceding the failure.

The incident was a “near miss” event in that the detached rock block affected a heavily-used pedestrian footway and could have bounced out further to affect the busy road. The detached rock block was probably in a metastable condition as a result of progressive tree root growth penetrating into adverse joint apertures and wedging the joints open. Localised build-up of cleft water pressures behind the affected rock block as a result of surface infiltration into the open joints may have been a contributory factor to the rockfall.

The unplanned tree which played a key role in the rockfall incident was previously identified for removal during slope maintenance inspections. The tree was trimmed back to the main stump but it regenerated relatively quickly, resulting in the continued growth of the tree roots along and into the joint apertures.

12. REFERENCES

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Hoek, E. & Bray, J.W. (1977). Rock Slope Engineering (Revised Second Edition). Chapman and Hall, London, 358 p.

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Table 1 - Maximum Rolling Rainfall at GEO Raingauge No. H09 for Selected Durations Preceding the Rockfall Incident of 25 June 2001 and the Estimated Return Periods

Duration	Maximum Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years)
5 Minutes	7.5	18:55 on 25 June 2001	< 2
15 Minutes	19.0	19:05 on 25 June 2001	< 2
1 Hour	50.5	19:35 on 25 June 2001	< 2
2 Hours	72.0	20:00 on 25 June 2001	< 2
4 Hours	74.5	20:00 on 25 June 2001	< 2
12 Hours	100.5	20:00 on 25 June 2001	< 2
24 Hours	123.5	20:00 on 25 June 2001	< 2
48 Hours	186.5	20:00 on 25 June 2001	< 2
4 Days	186.5	20:00 on 25 June 2001	< 2
7 Days	186.5	20:00 on 25 June 2001	< 2
15 Days	663.5	07:25 on 20 June 2001	< 10
31 Days	941.0	20:00 on 25 June 2001	10

Notes:
(1) Return periods were derived from Table 3 of Lam & Leung (1994).
(2) Maximum rolling rainfall was calculated from 5-minute data.
(3) The use of 5-minute data for durations between 4 hours and 31 daysresults in better data resolution, but may slightly over-estimate the return periods using Lam & Leung (1994)'s data, which are based on hourly rainfall for these durations.
(4) The landslide was assumed to have occurred at 20:00 hrs on 25 June 2001.

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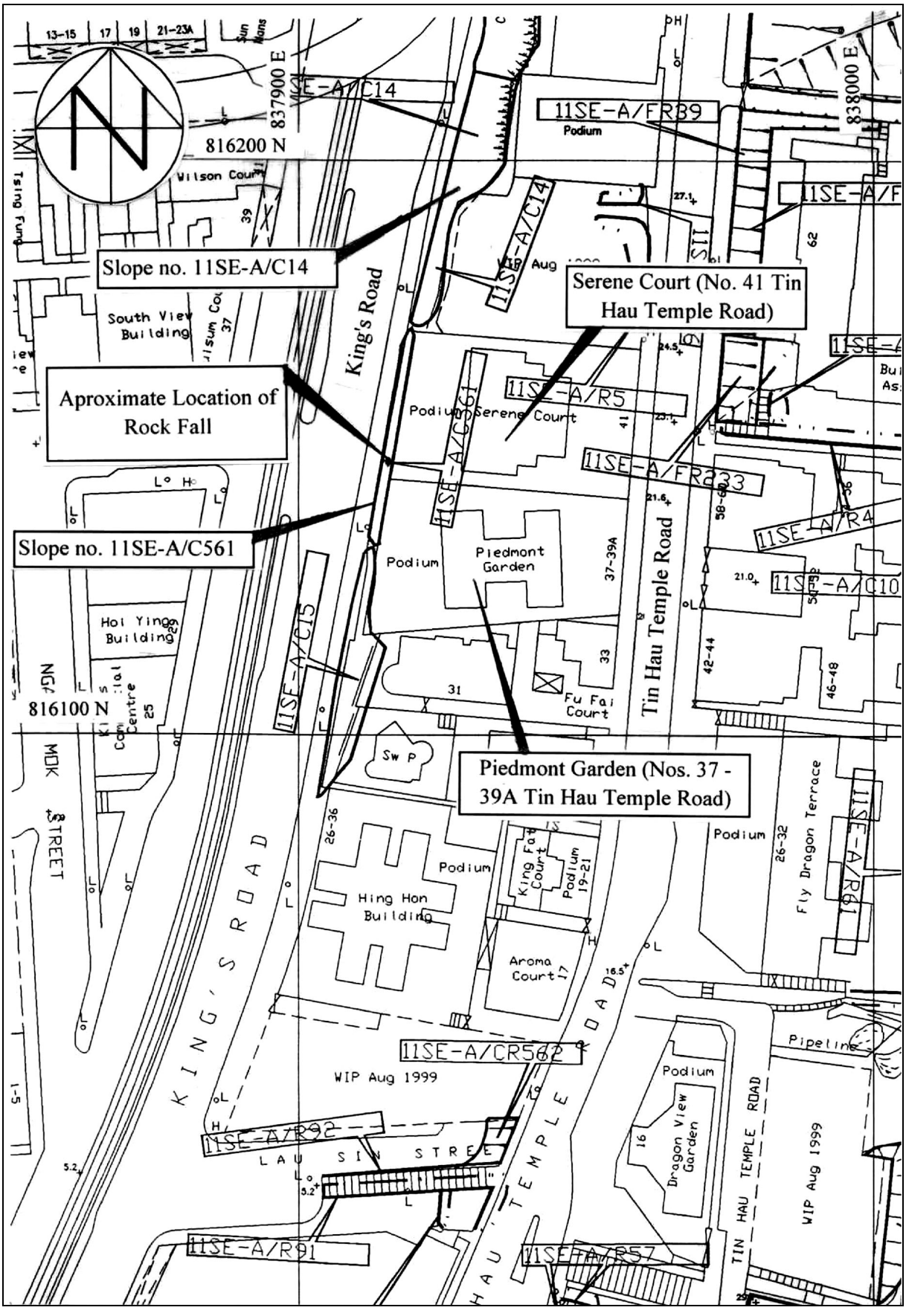


Figure 1 - Site Location Plan

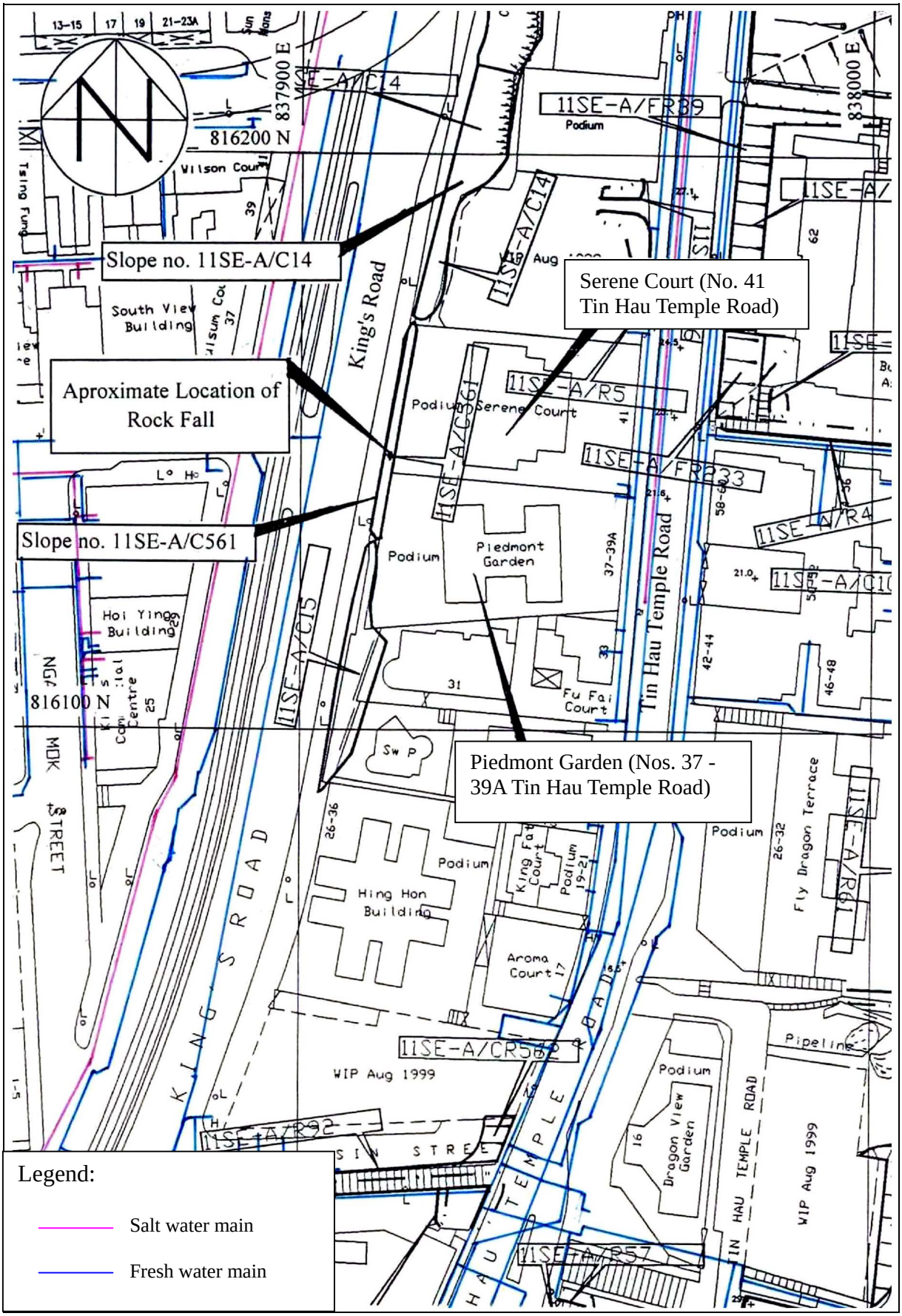
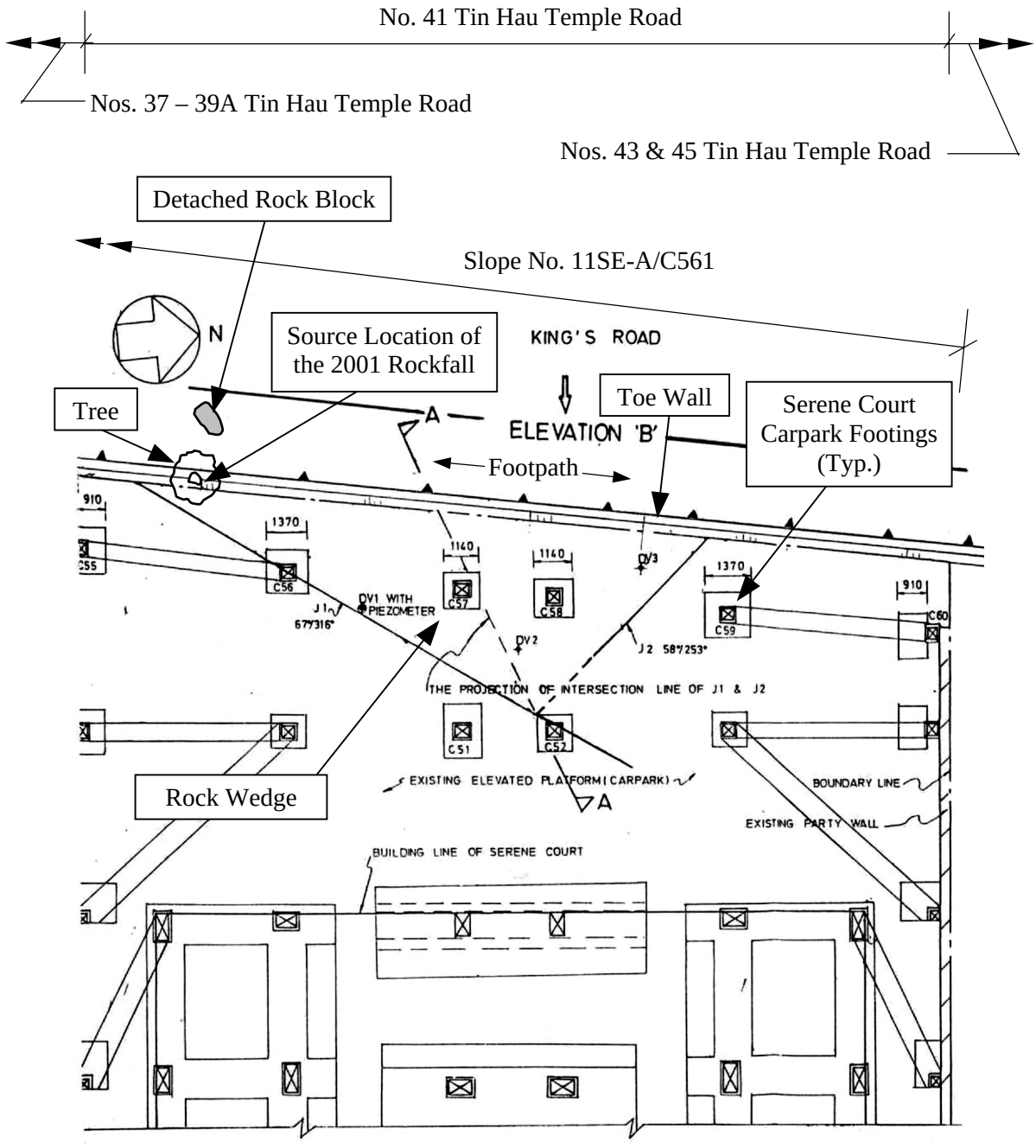


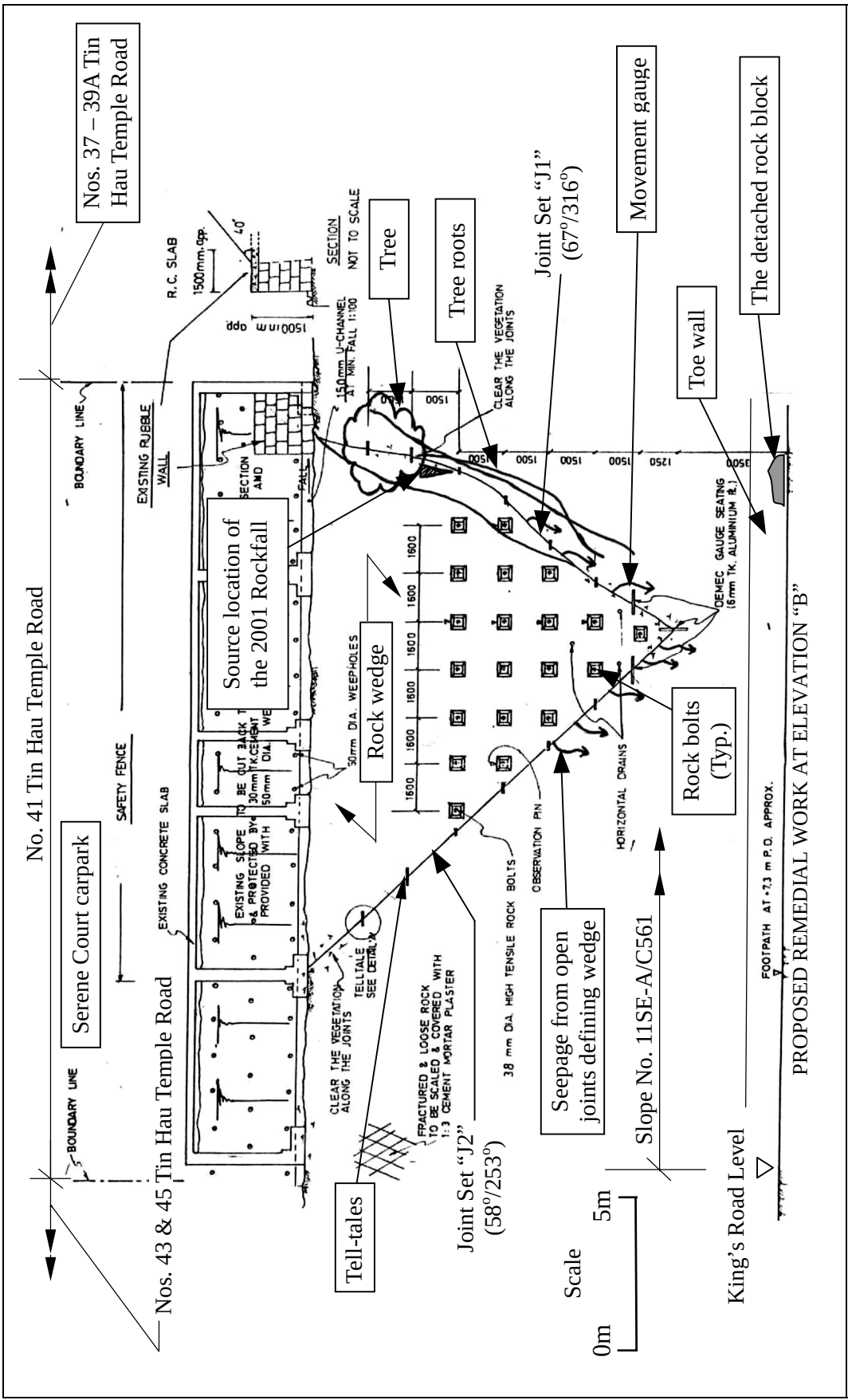
Figure 2 - Existing Water-carrying Services



FOUNDATION PLAN SHOWING THE EXTENTS OF MAJOR JOINT J1 & J2

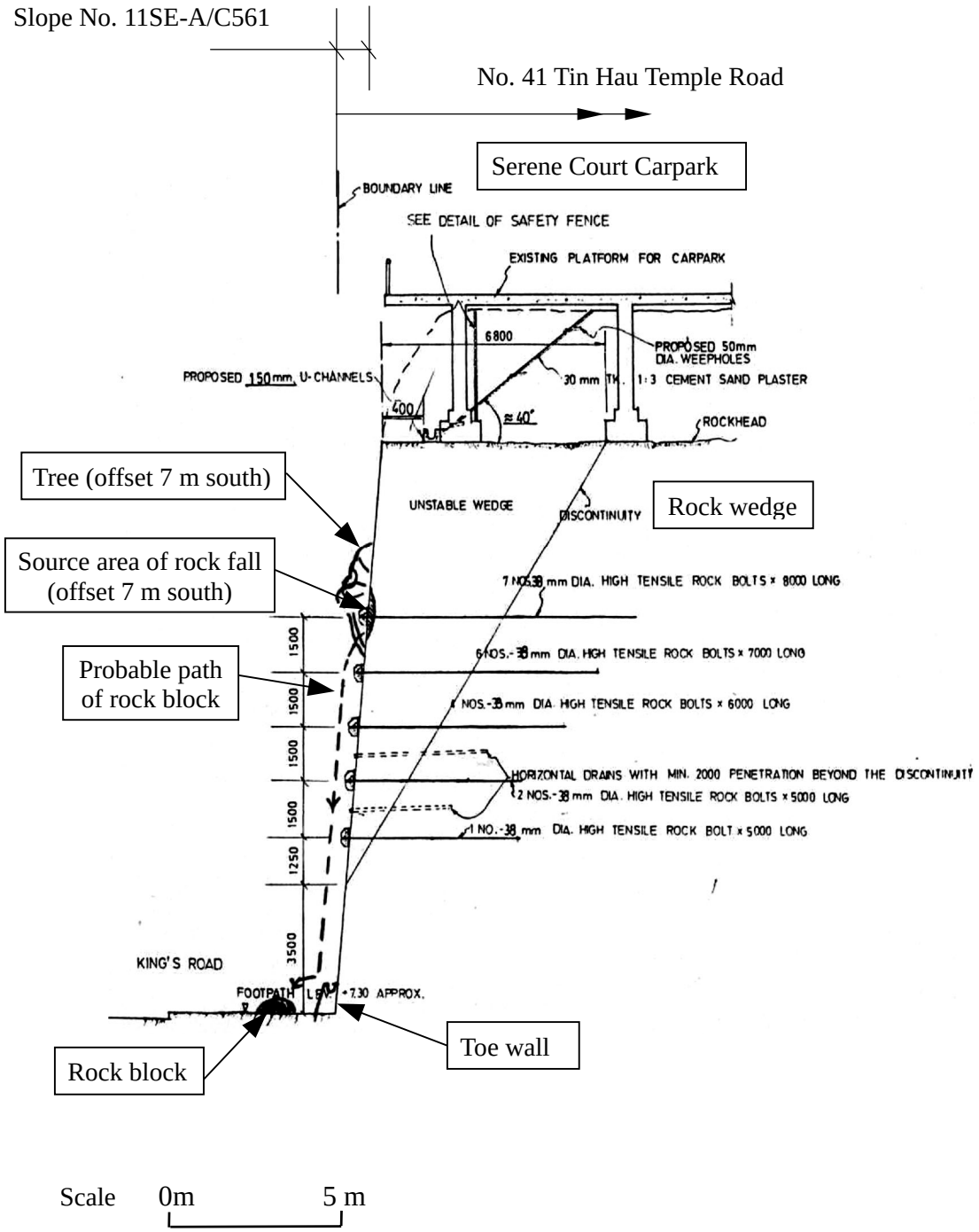
Note: The base plan of this figure is extracted from Drawing No. PF1 (Ho Fei, 1982)

Figure 3 - Plan View of the Site



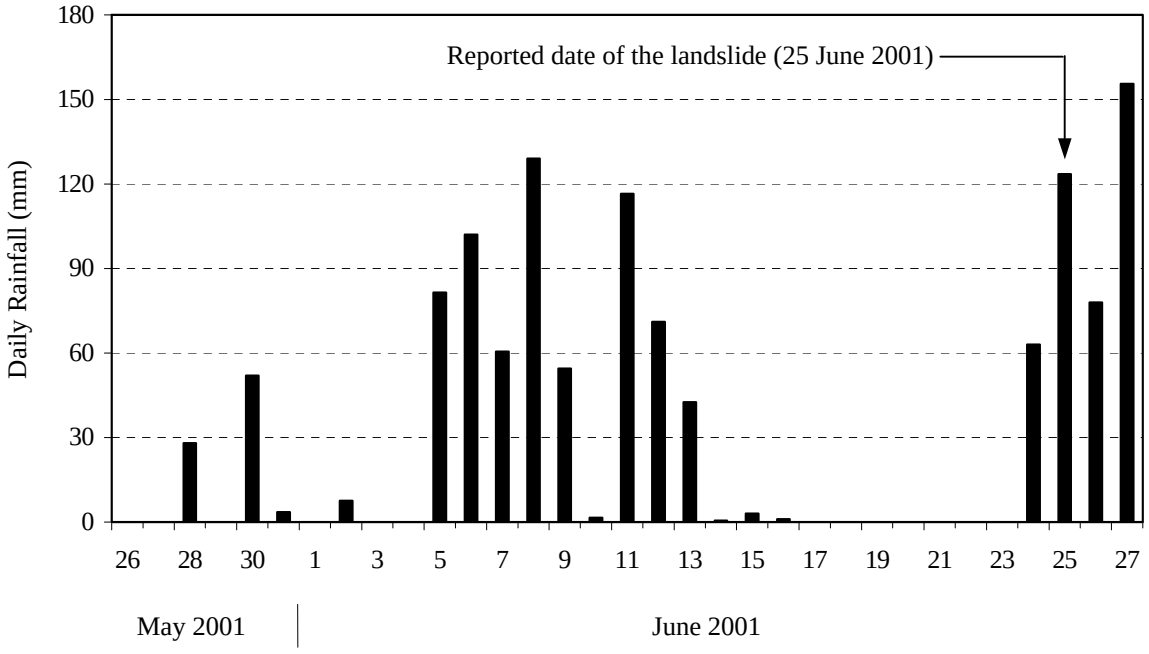
Note: The base plan of this figure is extracted from Drawing No. PF2 (Rev. 2) (Ho Fei, 1983).

Figure 4 - Part Elevation of Slope No. 11SE-A/C561

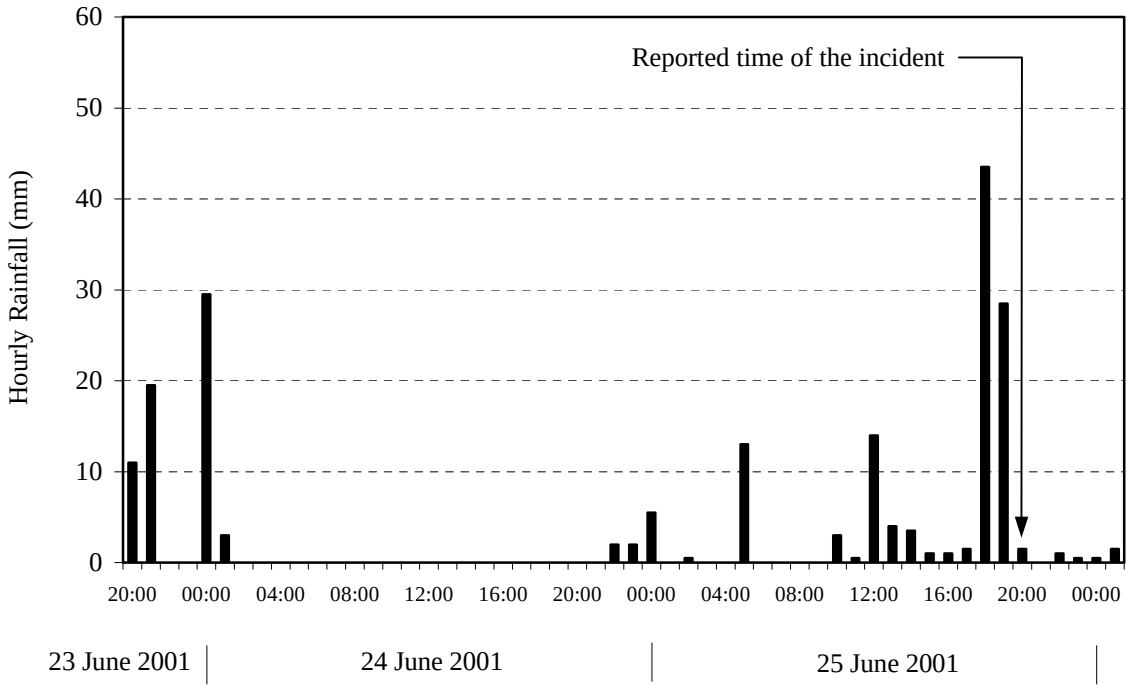


Notes: (1) Refer to Figure 2 for location of section.
(2) The base plan of this figure is extracted from Drawing No. PF2 (Rev 2) (Ho Fei, 1983).

Figure 5 - Section A-A through the Slope



(a) Daily Rainfall Recorded between 25 May and 27 June 2001



(b) Hourly Rainfall Recorded between 20:00 hours on 23 June and 01:00 hours on 25 June 2001

Figure 6 - Rainfall Recorded at GEO Raingauge No. H09

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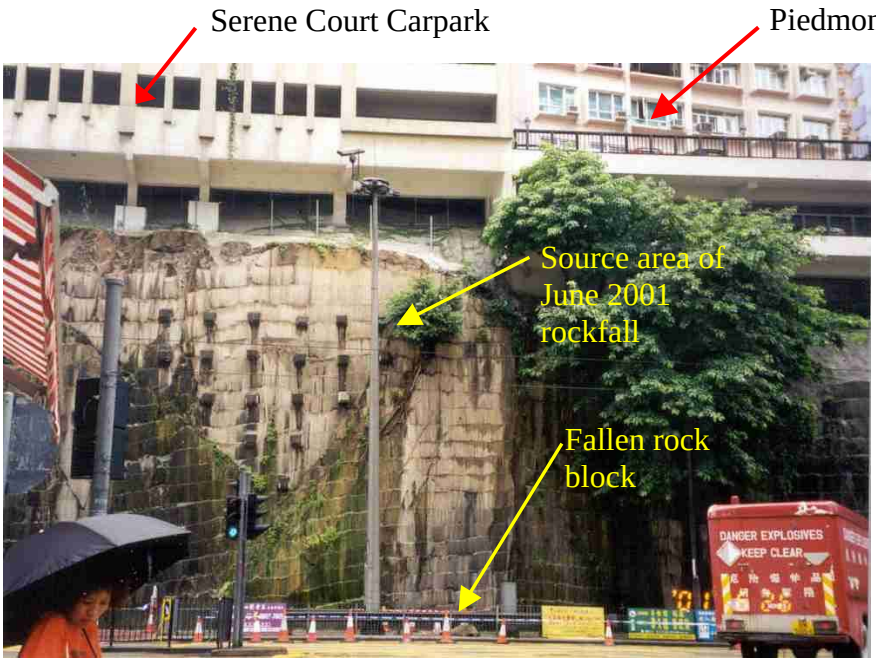

Plate 1 - View East across King's Road towards Slope No. 11SE-A/C561 Showing Large Bolted Wedge Exposed in Slope Face, Source of Fallen Rock Block and Location of Fallen Block at Road Level (Photograph Taken on 26 June 2001)

Plate 2 - View Southeast across King's Road towards Slope No. 11SE-A/C561 Showing Vegetation Growing on Slope Face and Seepage Issuing from Joints Defining Large Wedge (Photograph Taken in April 1996)

Plate 3 - View East towards Slope No. 11SE-A/C561 Showing Vegetation Growing on Slope Face. Handwritten Annotations are by the HyD and Identify Recommended Vegetation Clearance Following Routine Maintenance Inspection in December 1998.

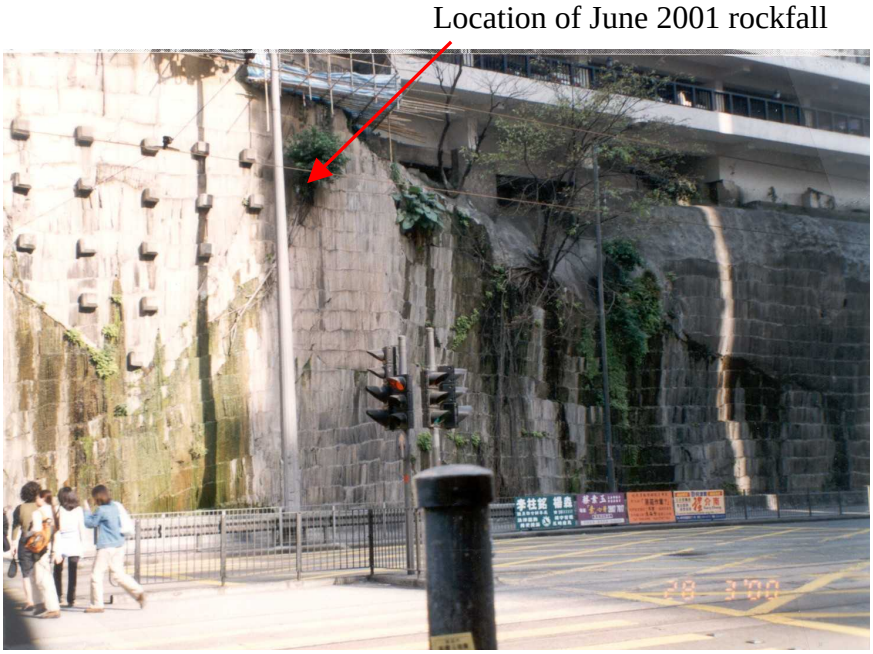

Plate 4 - View East across King's Road towards Slope No. 11SE-A/C561 Showing Tree Growing on Slope Face at Location of June 2001 Rockfall (Photograph Taken by MGS in March 2000)

Plate 5 - Close View of Slope Face Showing Source Location of Rock Fall Immediately above Tree (Unplanned Vegetation) Growing on Slope Face. Intersection of Predominant Joint Orientations Results in Potential Sliding Wedges (Photograph Taken on 26 June 2001)

Plate 6 - View South along King's Road Footway Showing Detached Rock Block and Associated Fragments. Note Wedge-shaped Geometry of Block. (Photograph Taken on 26 June 2001)

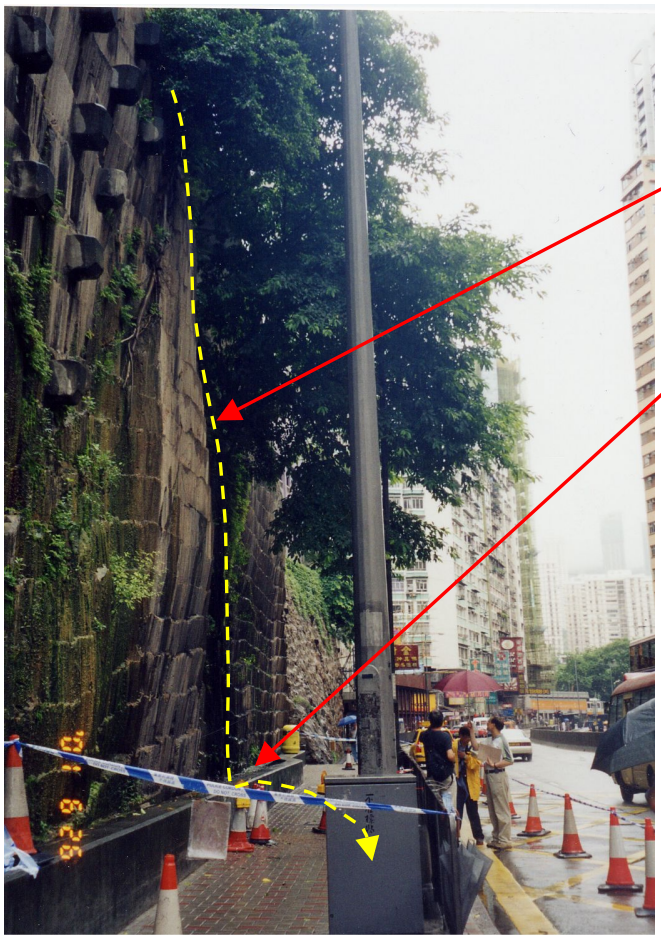

Plate 7 - View South along King's Road Footway Showing Near-vertical Face of Slope No. 11SE-A/C561 and Probable Path of Fallen Rock Block, with Impact on Toe Wall. (Photograph Taken on 26 June 2001)

Plate 8 - Close View of Detached Rock Block Showing Clean Joint Surfaces Free of Staining and/or Infill Material. (Photograph Taken on 26 June 2001)

Plate 9 - View East across King's Road towards Slope No. 11SE-A/C14 Prior to Installation of Rock Bolts in Large Wedge Exposed in Slope Face. Note Seepage from Joint Sets Forming Wedge and Vegetation Growing on Slope Face, Notably at Location of June 2001 Rockfall. (Photograph Taken in 1983)

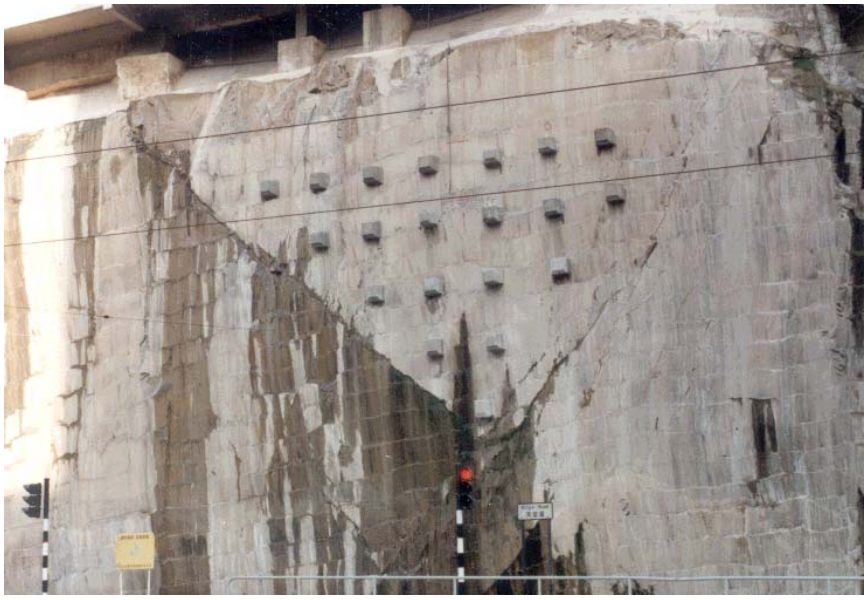

Plate 10 - View East across King's Road towards Slope No. 11SE-A/C14 Following Installation of Rock Bolts in Large Wedge Exposed in Slope Face. Note Seepage from Joint Sets Forming Wedge. Vegetation on Slope Face in 1983 Photograph (Plate 9) Removed. (Photograph Taken by the GEO in January 1984)

Plate 11 - View Southeast across King's Road towards Slope No. 11SE-A/C561 Showing Vegetation Growing on Slope Face and Seepage Issuing from Joints Defining the Large Wedge. (Photograph Taken by HAP in May 1998)

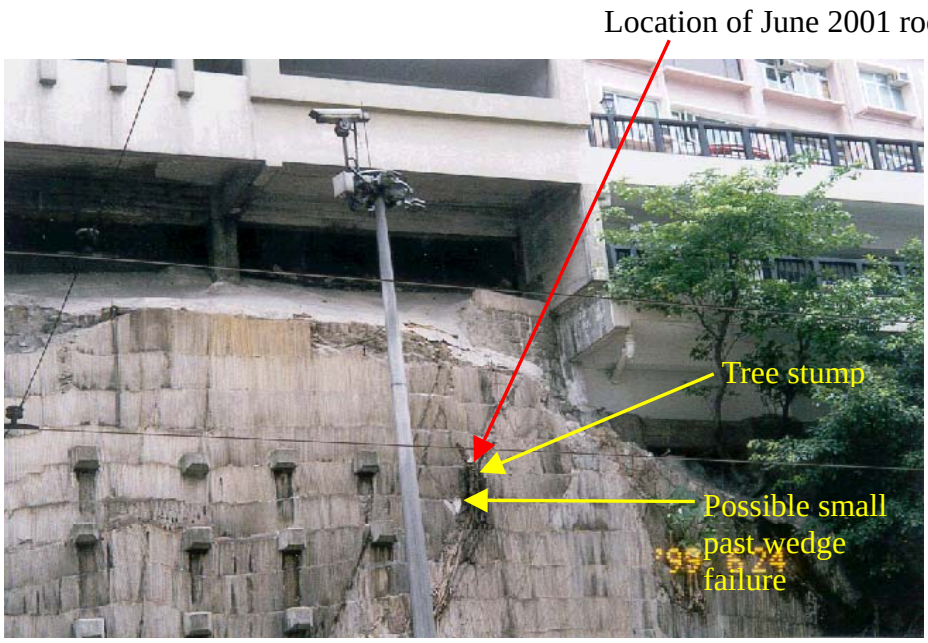

Plate 12 - View East towards Slope No. 11SE-A/C561 Showing Tree Stump at Source Location of June 2001 Rockfall Remaining on Slope Face Following Routine Maintenance Works. Note also Possible Small Past Wedge Failure Adjacent to Tree Stump. (Photograph Taken by the GE on 24 June 1999)

Plate 13 - View East towards Slope No. 11SE-A/C561 in November 2001 Showing Tree Remaining on Slope Face and Regeneration to have Commenced. (Photograph Taken on 7 November 2001)