# DETAILED STUDY OF THE 7 JUNE 2008 LANDSLIDE ON SLOPE NO. 11SE-A/C502 AT PAK FUK ROAD, NORTH POINT

**GEO REPORT No. 289**

**Fugro 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 is largely based on GEO Landslide Study Report No. LSR 6/2010 produced in December 2010**

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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 in print. These include guidance documents and results of comprehensive reviews. They can also be downloaded from the above website.

The 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 second last page of this report.

H.N. Wong
Head, Geotechnical Engineering Office
November 2013

# FOREWORD

This report presents the findings of a detailed study of a landslide (Incident No. 2008/06/0144) that occurred on an unsupported soil and rock cut slope No. 11SE-A/C502 at Pak Fuk Road, North Point on 7 June 2008 during heavy rainfall. Both Landslip Warning and Black Rainstorm Warning were in effect at the time of the failure. The landslide involved a failure volume of about 1,270 $m^3$. The landslide debris was mostly deposited on the carriageway and pedestrian pavements of Pak Fuk Road, resulting in temporary closure of Pak Fuk Road for 16 days. No casualty was reported as a result of the incident.

The report was prepared as part of the Landslide Investigation Consultancy for landslides occurring in Hong Kong Island and Outlying Islands in 2008 and 2009, for the Geotechnical Engineering Office of the Civil Engineering and Development Department, under Agreement No. CE 40/2007 (GE). This is one of a series of reports produced during the consultancy by Fugro Scott Wilson Joint Venture.

Y.C. Koo
Project Director
Fugro Scott Wilson Joint Venture

Agreement No. CE 40/2007 (GE)
Study of Landslides Occurring in Hong Kong Island and Outlying Islands in 2008 and 2009 – Feasibility Study

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## 1. INTRODUCTION

At about 8:40 a.m. on 7 June 2008 when both Landslip Warning and Black Rainstorm Warning were in effect, a major landslide (Incident No. 2008/06/0144) occurred on slope No. 11SE-A/C502, located between Pak Fuk Road and Tin Hau Temple Road, North Point (Figure 1, Plates 1 and 2). Most of the landslide debris was deposited on Pak Fuk Road with a small amount of soil debris and muddy surface runoff travelling down to Bedford Gardens (Plate 3). The landslide resulted in the temporary closure of Pak Fuk Road for 16 days. Pak Fuk Road was re-opened on 24 June 2008. No casualty was reported as a result of the incident.

Fugro Scott Wilson Joint Venture (FSW) has been engaged by the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department (CEDD) to establish the probable causes of the landslide. This report documents the findings.

## 2. DESCRIPTION OF THE SITE

The 7 June 2008 landslide occurred on the eastern portion of slope No. 11SE-A/C502 (Figure 2), which is a northerly facing, unsupported soil and rock cut. The eastern portion of the slope was about 45 m long, 15 m high and was generally inclined at 40°. This part of the slope was largely vegetated with some bare and shotcreted areas (Plate 4). An approximately 4 m high concrete buttress was located at the toe of the eastern slope portion.

The western portion of the slope is approximately 40 m long, 7 m high, with the lower 2.5 m being a 75° rock cut in moderately decomposed granite covered with wire mesh (Plate 5) and the upper 4.5 m being a 40° vegetated cut slope.

Slope No. 11SE-A/C502 has a surface drainage system, comprising 300 mm wide U-channels at the toe, mid-height and crest of the slope, as well as a 400 mm wide stepped channel on the slope (Figure 2). A natural drainage line is present to the east of the landslide site (Plate 6) although it has been intercepted by both Tin Hau Temple Road and Pak Fuk Road (Figure 2).

Pak Fuk Road is located at the toe of slope No. 11SE-A/C502. Pak Fuk Road is a two-lane carriageway with pedestrian pavements on both sides and has an overall width of 13 m (Plate 4). A residential complex, namely Bedford Gardens, is located downhill approximately 50 m (on plan) to the north of slope No. 11SE-A/C502 and Pak Fuk Road (Figure 1). Tin Hau Temple Road is located at the crest of slope No. 11SE-A/C502, which is also a two-lane carriageway.

Slope Nos. 11SE-A/C720 and 11SE-A/C710 are located to the east of the landslide site, which are rock cuts in moderately decomposed granite (Figure 2 and Plate 7) both with a near-vertical rock face up to about 14 m high.

Buried water-carrying services are present along Tin Hau Temple Road above the crest of the 7 June 2008 landslide site, comprising 150 mm to 300 mm diameter sewer drains, a 375 mm diameter stormwater drain, a 200 mm diameter fresh water main and a 200 mm diameter salt water main (Figure 2). The salt and fresh water mains both traverse the slope

between Tin Hau Temple Road and Pak Fuk Road at about 65 m to the west of the landslide site. According to Drainage Services Department and Water Supplies Department, there were no reported incidents of leakage from their water-carrying utilities in the vicinity of the 7 June 2008 landslide around the time of the failure.

## 3. MAINTENANCE RESPONSIBILITY

According to the Slope Maintenance Responsibility Information System (SMRIS) of the Lands Department (Lands D), slope No. 11SE-A/C502 falls within Government land and the maintenance responsibility rests with the Highways Department (HyD).

## 4. THE 7 JUNE 2008 LANDSLIDE

At about 8:40 a.m. on 7 June 2008, a major landslide occurred above Pak Fuk Road, North Point on an unsupported soil and rock cut slope No. 11SE-A/C502 (Figure 2). The landslide involved a failure volume of about 1,270 $m^3$ and resulted in the closure of all two lanes of Pak Fuk Road for 16 days from 7 to 23 June 2008. The impact of the landslide debris toppled a lamp post and damaged the roadside parapet (Plate 1).

An eye-witness saw an abundance of muddy water flowing along Pak Fuk Road at 8:40 a.m. on 7 June 2008. Shortly afterward, he saw a large boulder being pushed down to the carriageway by the landslide debris. According to the eye-witness, it was raining heavily at the time of the landslide.

The landslide debris was largely deposited on Pak Fuk Road with some debris being retained on the slope (Figure 3, Plates 1 and 2). The travel distance of the landslide debris was approximately 43 m on plan as measured from the crown of the landslide to the distal end of the landslide debris (i.e. at the roadside parapet of Pak Fuk Road). Muddy surface runoff continued beyond Pak Fuk Road and reached Bedford Gardens some 50 m away (Plate 3).

Emergency repair works, mainly comprising the removal of landslide debris, provision of a shotcrete cover to the landslide scar and the re-construction of the slope surface drainage channels, were carried out by the HyD between 7 and 23 June 2008 (Plate 8).

## 5. SITE DEVELOPMENT HISTORY AND PAST INSTABILITY

The development history and past instability of the landslide site has been established from an interpretation of the available aerial photographs, together with a review of relevant documentary information (Figure 4). Detailed observations from the aerial photograph interpretation (API) are presented in Appendix A.

Prior to 1963, the landslide site and the adjacent area is a largely undeveloped, northerly facing natural terrain of a gently rounded peak, which is bi-sected by a well-defined natural drainage line in a northeast-southwest orientation (Figures A1 and A2 in Appendix A). A number of other drainage lines are also present in the general area.

Slope No. 11SE-A/C502 was substantially formed to the west of the well-defined drainage line between 1978 and 1980 in association with the construction of Pak Fuk Road Extension under a private development project (Figure 4 and Plate 9). Slope Nos. 11SE-A/C710 and 11SE-A/C720 were also formed during this period of time to the east of the natural drainage line. Tin Hau Temple Road was formed pre-1963 to the south of slope No. 11SE-A/C502.

On 3 June 1983, a landslide (Incident No. HK83/6/1), with a failure volume of about 50 $m^3$, was reported to have occurred on the lower eastern portion of slope No. 11SE-A/C502 (Figure 4, Plates 10 and 11). The landslide scar measured about 7 m high and 10 m wide. The landslide debris with boulders came to rest on the pedestrian pavement and did not affect Pak Fuk Road. The landslide was probably caused by saturation of the near-surface groundmass as a result of infiltration during heavy rainfall.

Following the 1983 landslide, urgent repair works were carried out by the then Highways Office (HO). The works comprised the provision of a chunam cover to the trimmed landslide scar and a concrete buttress at the slope toe to support some boulders. The extent of the chunam cover, as well as the concrete buttress, can be seen in the November 1983 and January 1984 aerial photographs (Plate A2 in Appendix A).

Between 1986 and 2005, no significant changes relevant to the landslide site could be observed in aerial photographs.

In the morning of 13 September 2006, a minor landslide (Incident No. 2006/09/0713) occurred on the eastern end of slope No. 11SE-A/C502 adjacent to the 1983 concrete buttress. The landslide debris affected the pedestrian pavement and blocked one lane of Pak Fuk Road (Figure 4 and Plate 12). The landslide scar was about 3 m high and 5 m wide, with a failure volume of 3 $m^3$. During the follow-up inspection by the GEO on 13 September 2006 at which time the weather was rainy, seepage was observed at the failure location. Infiltration and unfavourable groundwater conditions were possible contributory factors to the landslide. Following the 2006 landslide, urgent repair works, comprising the removal of loose materials and provision of a sprayed concrete cover to the landslide scar, were arranged by the HyD and completed on 28 September 2006 (Plate 13).

The Enhanced Natural Terrain Landslide Inventory and the Large Landslide Database do not record any landslides in the vicinity of the 7 June 2008 landslide site.

## 6. PREVIOUS ASSESSMENTS AND INSPECTIONS

### 6.1 Pak Fuk Road Extension under the Development of Kai Yuen Terrace, North Point

Slope No. 11SE-A/C502 and the adjacent cut slopes were formed in association with the construction of Pak Fuk Road Extension between the late 1970's and the early 1980's (see Section 5). The project was undertaken by a private developer under a lease requirement for the development of the present-day Bedford Gardens. The works comprised the formation of the building platform for Bedford Gardens and the associated access road to the south of the development site, together with the construction of Pak Fuk Road Extension between the access road and Tin Hau Temple Road. The site formation works involved excavation into the northerly facing terrain to form a number of soil and rock cuts.

The geotechnical submissions were checked and accepted by the Geotechnical Control Office (GCO, renamed GEO in 1991) in 1980. Although details of the geotechnical design for slope No. 11SE-A/C502 could not be identified, it is noted in the correspondence of 26 September 1980 from the geotechnical consultant of GCO that "The boulders on the natural slope above the middle section of the Pak Fuk Road [i.e. natural slope above slope No. 11SE-A/C502] has either been removed or stabilised. During the site inspection [on 4 September 1980], GCO and B&P [the geotechnical consultant of GCO] are reasonably satisfied with the stabilisation works completed on site." However, the exact locations of the boulders referred to could not be ascertained.

Limited information on the proposed cutting extent and drainage layout of slope No. 11SE-A/C502 is shown on the approved site formation plan for the development of Kai Yuen Terrace dated 2 January 1980 (Figure 5). The likely actual cutting extent for slope No. 11SE-A/C502 has been deduced (Figure 3) by comparing the pre-landslide ground profile from the airborne light detection and ranging (LiDAR) survey with the pre-development ground profile as shown on the approved site formation plan. Upon completion of the works, the Pak Fuk Road Extension was handed over to the Government as a public road in July 1982.

## 6.2 SIFT and SIRST Studies

In November 1994, slope No. 11SE-A/C502 was identified under the GEO's project entitled "Systematic Inspection of Features in the Territory" (SIFT) and categorised as a Class 'C2' feature, i.e. cut feature "considered to meet the GEO criteria for slope registration" and "assumed formed post-1977".

In March 1996, slope No. 11SE-A/C502 was inspected under the GEO's project entitled "Systematic Identification and Registration of Slopes in the Territory" (SIRST). The SIRST field sheet noted that about 65% of the slope face was covered by hard surface and the remaining slope face was either vegetated or bare. No signs of distress nor seepage were observed on the slope.

## 6.3 Maintenance Inspections of Slope No. 11SE-A/C502

Regular maintenance inspections of slope No. 11SE-A/C502 were carried out by HyD or his consultants since 1998. Detailed observations from these inspections are presented in Appendix B. Overall, no signs of major distress in the form of tension cracks nor seepage were observed during all the maintenance inspections. The last inspection prior to the 7 June 2008 landslide was conducted in August 2007.

The maintenance records showed that the eastern portion of slope No. 11SE-A/C502, where the 7 June 2008 landslide occurred, was largely vegetated (Plate 14).

## 6.4 Other Geotechnical Inspections of Slope No. 11SE-A/C502

On 12 February 1999, an inspection of slope No. 11SE-A/C502 was carried out by the Geotechnical Advisory Unit (GAU) of HyD and noted that the lower portion of the slope was

predominantly a granitic rock cut and a persistent rock joint daylighted at about 1.2 m above the toe of the western slope portion with a dip angle of 22° to 28°. The GAU recommended the removal of loose material and rock blocks from the western slope face, as well as to arrange an Engineer Inspection (EI) for the slope.

On 19 July 2003, slope No. 11SE-A/C502 was inspected by the GEO's consultant under the project entitled "Inspection and Registration of Marginally Registrable Slopes Identified from Aerial Photograph Interpretations". The inspection findings are in general consistent with other inspections in that no signs of distress nor seepage were observed. It is also recorded that 80% and 15% of the slope face was vegetated and bare respectively (Plate 15), with the remaining 5% covered by chunam.

## 7. ANALYSIS OF RAINFALL RECORDS

Rainfall data were obtained from GEO automatic raingauge No. H18 (Figure 1), instead of raingauge No. H09 which is nearer to the landslide site, because the latter raingauge malfunctioned during the 7 June 2008 rainstorm. Raingauge No. H18 is located about 1.7 km southeast of the 7 June 2008 landslide site. The raingauge records and transmits rainfall data at 5-minute intervals to the Hong Kong Observatory (HKO) and the GEO.

For the purpose of the rainfall analysis, the landslide was assumed to have occurred at 8:40 a.m. on 7 June 2008. The daily rainfall recorded by raingauge No. H18 from 4 May to 10 June 2008, together with the hourly rainfall for the period between 6 and 7 June 2008, are presented in Figure 6. The maximum 24-hour and 12-hour rolling rainfall preceding the landslide were 374.5 mm and 236.5 mm respectively.

Table 1 presents the estimated return periods for the maximum rolling rainfall for various durations recorded by raingauge No. H18 with reference to the historical rainfall data at the HKO in Tsim Sha Tsui (Lam & Leung, 1994) and the local rainfall data of raingauge No. H18 (Evans & Yu, 2001). The results show that the 4-hour rolling rainfall of 208 mm preceding the landslide was the most severe, with a return period of about 24 years.

The maximum rolling rainfall for the rainstorm of 7 June 2008 has been compared with the past major rainstorms between 1983 and 2008 as recorded at raingauge No. H18 (Figure 7). The results indicate that short duration rainfalls preceding the 7 June 2008 landslide are amongst the most severe in the history of raingauge No. H18, which came into operation in March 1983.

## 8. POST-LANDSLIDE OBSERVATIONS

Key post-landslide observations are summarised below based primarily upon the inspections of the landslide site carried out by HyD, GEO and FSW between 7 and 18 June 2008, together with the subsequent inspections by FSW between November 2008 and June 2010. Detailed observations relevant to the geology and hydrogeology of the landslide site are presented in Section 9.

The 7 June 2008 landslide was estimated to be 30 m wide, 30 m long and up to 3 m

deep, with a debris volume of about 1,270 m³ (Plates 1 and 2). The surface of rupture, in particular the basal slip plane, was irregular in nature (Plate 16), which was likely related to the corestone-bearing groundmass as evidenced by the record photograph of the slope (Plate 11) and the presence of large corestones/boulders in the debris (Plate 2).

The landslide debris was wet and predominantly comprised residual soil and fine- to medium-grained completely decomposed granite (CDG) with many boulders of less than 1.2 m in diameter and considerable amount of mature trees and vegetation. Several large boulders were evident within the debris mass (Figure 2, Plates 17 and 18), some of which appeared to have been exposed prior to the landslide and others appeared to be corestones within the failed groundmass based on the relative discoloration (Plate 18). One of these large boulders measured about 8.4 m by 4.0 m by 1.4 m (i.e. Boulder A in Plate 17).

A block of concrete approximately 1 m by 1 m in section and 4 m in length was also noted (Figure 2 and Plate 17) within the debris mass, possibly from the 1983 concrete buttress (Plate 4). Moreover, a 300 mm surface drainage channel at the mid-height of slope No. 11SE-A/C502 was severed by the landslide (Plate 19). Parts of the broken drainage channel were found in the landslide debris (Figure 2 and Plate 20). The remaining section of the drainage channel at the western flank of the landslide scar was generally clear of debris and in reasonably good condition (Plate 19).

The crest area above slope No. 11SE-A/C502, including Tin Hau Temple Road, was also inspected. In consideration of the road alignment, topography and surface drainage provisions, there was no apparent indication that significant overflow of surface runoff from Tin Hau Temple Road towards the landslide site could have taken place prior to the landslide. There was also no evidence of leaking buried water-carrying services at the crest of slope No. 11SE-A/C502.

## 9. SUBSURFACE CONDITIONS

### 9.1 General

The subsurface conditions at the 7 June 2008 landslide site were determined from a review of the pre-landslide and post-landslide ground investigation (GI) information, as well as from the geological mapping of the landslide scar.

The post-landslide GI works, comprising 6 vertical drillholes, 8 trial pits and 4 slope surface strips, were carried out by DrilTech Ground Engineering Limited between May and July 2009. In November 2009, 13 inspection pits were formed on the shotcrete cover at the landslide location to expose the underlying materials. The locations of relevant GI stations are shown in Figure 8.

### 9.2 Geology

The geology at the landslide site predominantly comprises weathered granitic rock overlain by a mantle of colluvium and residual soil. Colluvium up to about 1 m thick overlying residual soil and weathered granitic rock was exposed at the main scarp of the 2008 landslide, whereas highly to moderately decomposed granite was exposed on the basal slip

plane. The weathered rock consists of completely to moderately decomposed granite. Competent bedrock, viz. moderately decomposed rock or better, was encountered at a shallow depth of about 2.9 m behind the crest of the landslide scar. Outcrops of moderately decomposed granite are also observed along the toe of the slope. An interpreted geological section through the 7 June 2008 landslide is shown in Figure 9.

The solid geology underlying the landslide site was mapped by the Hong Kong Geological Survey (GCO, 1986) as fine- to medium-grained granite. The western portion of slope No. 11SE-A/C502 is close to the contact between the fine- to medium-grained granite and the fine-grained granite (Figure 10). The geological map indicates vertical jointing in fine-grained granite at a location above Tin Hau Temple Road to the south of the landslide site.

The basal slip plane of the 7 June 2008 landslide was defined by a combination of subparallel, undulating, kaolin-infilled relict sheeting joints within a kaolin-rich zone in the completely to highly decomposed granitic rock. A schematic illustration of the simplified geology of the landslide site is shown in Figure 9.

The kaolin-rich zone was laterally-extensive and exposed over the lower central part of the basal slip plane during the subsequent slope upgrading works in mid 2010. The inferred extent of the kaolin-rich zone is indicated in Figure 8. The zone measured about 0.5 m to 1.0 m in thickness and comprised kaolin-infilled relict sheeting joints dipping at 25° out of the slope face (Figure 9). Remnants of the kaolin infill were also exposed in trial pit No. TP6, slope surface strip Nos. SS1 and SS2, as well as inspection pit No. IP13 (Figure 8). The kaolin infill could be generally described as buff, slightly sandy silty clay, within the mottled weathering zone of decomposed granite. The thickness of the kaolin infill varies along the length and width of the landslide, ranging from 10 mm to 50 mm (Plates 21 to 23).

Immediately to the east of the landslide scar, an undulating discontinuity dipping at 26°/355° to 29°/017° with up to 2 mm thick kaolin infill and slickensides was observed (Plate 24). The observed slickensides were not in the direction of the 7 June 2008 landslide.

Soft, bluish grey, manganese oxide infill was also present locally on the relict sheeting joints forming the basal slip plane. The infill was about 80 mm to 100 mm thick as observed in slope surface strip No. SS2 on the landslide scar (Plate 25). The manganese oxide infill was rich in rootlets, indicating a possible preferential seepage flowpath that favoured the growth of vegetation (Plate 26).

The relict sheeting joints exploited by the basal slip plane were adversely orientated, dipping at 16° to 30° out of the slope with a dip direction of 330° to 010° (Plate 16). Some of the lateral release surfaces exploited subvertical relict joints within the groundmass, dipping at 73° to 90° with a dip direction of 220° to 032°. Similar subhorizontal and subvertical joint sets are also present on the unfailed lower western portion of slope No. 11SE-A/C502 (Plate 5) and on the adjoining slope Nos. 11SE-A/C710 and 11SE-A/C720 (Plate 7). Some of the sheeting joints are open (Plate 5).

## 9.3 Material Properties

A series of geotechnical laboratory tests was conducted on soil samples retrieved

during the ground investigation, with an aim to determine the geotechnical properties of the materials at the landslide site. The tests comprised particle size distribution tests, Atterburg limit tests and isotropically consolidated undrained triaxial compression tests. The triaxial compression test results for CDG are shown in Figure 11. The results of the classification and index tests are summarised in Table 2.

All the triaxial compression tests on CDG samples displayed a dilative behaviour upon shearing. The estimated shear strength parameters for CDG are c' = 3 kPa, $\phi'$ = 39°, which are within the typical range for CDG in Hong Kong (GEO, 1993). The average fines (i.e. clay and silt) content of CDG and samples taken from the kaolin-rich zone are found to be 19% and 41% respectively.

For the purpose of identifying the clay mineralogy of the kaolin infill, clay mineralogical tests, viz. scanning electron microscopy (SEM) and X-ray diffraction (XRD) (Churchman et al, 2010), were carried out on 6 samples of kaolin infill by the University of Adelaide in Australia. The micrographs for the samples, in general, show a mixture of platy particles (i.e. kaolinite) with some small tubular particles (i.e. halloysite) (Figure 12). The XRD results are fairly consistent in that the relative proportion of halloysite and kaolinite in the samples ranges from 31% to 39% and from 61% to 69% respectively. The corresponding peak and residual frictional angle of the kaolin infill is in the order of about 23° and 16° respectively (Figure 13), based on a previous study (Campbell & Parry, 2002).

## 9.4 Groundwater Conditions

The groundwater conditions at the site were evaluated from a review of the available groundwater monitoring data, together with post-landslide seepage observations. As part of the post-landslide GI, standpipes were installed in 5 drillholes (Nos. DH1, DH1A, DH2, DH3 and DH3A) and 2 trial pits (Nos. TP2 and TP3) (Figure 8). Groundwater monitoring of the standpipes was carried out since May 2009.

The monitoring data suggest that the main groundwater table is probably close to the toe of the slope and approximately 6 m below ground level at the crest of the landslide scar. A perched water level was detected locally at drillhole No. DH1 and about 2 m below ground surface immediately behind the crest of the landslide scar.

Subsurface seepage flows along preferential flowpaths within the near-surface groundmass and above the less permeable kaolin-rich zone were evidenced by many post-landslide observations. Notable observations included:

(a) On 7 June 2008, heavy seepage was noted flowing from two weepholes on a concrete buttress located immediately to the east of the landslide (Figure 2 and Plate 2), as well as from rock joints adjoining the landslide scar (Plates 27 and 28);

(b) On 18 June 2008 prior to the provision of the shotcrete cover to the landslide scar, seepage above the colluvium/CDG interface was noted at the western flank of the main scarp (Plate 29) although no soil pipes could be observed;

(c) On 25 May 2009 following 157.5 mm of rainfall over the previous two days, heavy seepage from a soil pipe of approximately 12 mm in diameter at the CDG/HDG interface was observed in trial pit No. TP5 (Figure 14 and Plate 30); and

(d) On 26 May 2009, light to moderate seepage was noted at the kaolin-rich zone within the mottled weathering zone of decomposed granite at slope surface strip No. SS1 (Figure 14).

Moreover, signs of seepage from weepholes and scaffolding supports in the shotcrete cover were noted between November 2008 and November 2009, predominantly over the western flank of the main scarp and the central part of the basal slip plane where the kaolin-rich zone was present (Figure 14 and Plate 31).

The 7 June 2008 landslide site is located about 25 m to the east of a natural drainage line (Figure 2). Given its close proximity, the surface flow in the natural drainage line could have been a possible source of water ingress, contributing to the subsurface seepage flows towards the landslide site.

## 10. THEORETICAL STABILITY ANALYSES

Theoretical stability analyses were carried out to assess the likely range of operational shear strength parameters of the materials along the rupture surface under different perched water levels. The results of the analyses are summarised in Figure 15.

The results indicate that, for a factor of safety of unity, the angle of shearing resistance (i.e. $\phi'$) along the rupture surface was assessed to range between 25° and 33° for a perched water table varying from 0 m to 1.5 m. The back-calculated shear strength parameters are considered to be credible and representative of the operational strength along the rupture surface, which are theoretically bounded between $\phi' = 23°$ (i.e. the peak strength of kaolin infill) and $\phi' = 39°$ (i.e. the material strength of CDG).

## 11. DISCUSSION

The 7 June 2008 landslide occurred on a 15 m high, unsupported soil and rock cut (slope No. 11SE-A/C502), with an overall slope angle of about 40°. The landslide involved a shallow, translational failure of which the surface of rupture exploited kaolin-infilled relict joints within the groundmass. The failure volume was about 1,270 $m^3$, with a travel distance of 43 m and a debris travel angle of about 23°. The landslide debris was relatively mobile as compared with rain-induced landslides on cut slopes in Hong Kong, for which the debris travel angle is generally greater than 30° (Wong & Ho, 1996). The presence of weak geological features combined with the local build-up of groundwater pressure could have accounted for a relatively low apparent angle of friction and the high debris mobility.

The landslide occurred during the severe rainstorm of 7 June 2008. The close

correlation between the rainfall and the timing of the failure suggests that the landslide was triggered by the heavy rainfall preceding the landslide. The short duration rainfalls were amongst the most severe that the slope had experienced since its formation 26 years ago.

The presence of extensive, adversely orientated, kaolin-infilled relict sheeting joints within the kaolin-rich zone in the groundmass was considered to be a key factor contributing to the failure. Field mapping revealed that the basal slip plane of the 7 June 2008 landslide was developed largely in the 'weak' kaolin-rich zone, with the lateral release surfaces exploiting subvertical relict joints present in the weathered rock. The mass strength of the groundmass would have been adversely affected by the presence of kaolin-infilled relict joints and kaolin-rich zone.

The hydrogeological condition of the landslide site is complex. Subsurface seepage flows could have taken place towards the landslide site as evidenced by an 'active' soil pipe present immediately behind the main scarp of the landslide. The seepage from the soil pipe appeared to increase quickly with rainfall. Moreover, local, transient perching of groundwater was evident by post-landslide groundwater monitoring and observed seepage above the kaolin-rich zone. The combination of subsurface seepage flows and perching of groundwater might have led to the build-up of local groundwater pressure above the rupture surface at times of heavy rainfall.

The soil and rock cut that failed on 7 June 2008 has a history of previous failures, viz. a major landslide in 1983 and a minor landslide in 2006 (see Section 4). This indicates that the slope was of marginal stability and might have been subject to progressive deterioration. Previous landsliding could also have caused local weakening of the groundmass through shearing of the kaolin-rich zone, as evidenced by the presence of buff clay and slickensides at the northeastern edge of the landslide scar.

Following the 1983 landslide, a chunam cover was provided to the eastern portion of slope No. 11SE-A/C502 (see Section 4). The hard cover was subsequently replaced by vegetation. This probably took place between 1996 and 1999, based on a review of the available inspection records. The adverse environmental change would likely have promoted water ingress into the groundmass through the vegetated slope surface under heavy rainfall.

The unsupported cut was formed between 1978 and 1980 predominantly by trimming back without the provision of reinforcement or structural support or subsurface drainage measures. This incident highlights that the stability of an unsupported cut is vulnerable to the presence of adverse geological and hydrogeological conditions.

## 12. CONCLUSIONS

The 7 June 2008 landslide involved the failure of an unsupported soil and rock cut. The basal slip plane was developed largely in a kaolin-rich zone with adversely orientated relict sheeting joints. The failure was probably caused by the build-up of transient perched groundwater pressure above the less permeable kaolin-rich zone within the groundmass, following heavy rainfall that preceded the failure.

Other factors that probably contributed to the landslide include the following:

(a) adverse geological and hydrogeological conditions due to the presence of kaolin-infilled relict joints,

(b) progressive slope deterioration as evidenced by the history of previous landslides, and

(c) adverse change to the site setting due to the replacement of the hard surface cover of the slope by vegetation in the late 1990's.

This incident served as a vivid example to highlight the less robust nature of an engineered unsupported cut, which could have been more susceptible to large-scale failure due to the presence of weak geological features and unfavourable hydrogeological conditions. It also highlighted the need for caution in replacing hard surface cover of a slope with vegetation.

## 13. REFERENCES

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LIST OF TABLES

Table 1 - Maximum Rolling Rainfall at GEO Raingauge No. H18 for Selected Durations Preceding the 7 June 2008 Landslide and the Estimated Return Periods

| Duration | Maximum Rolling Rainfall (mm) | End of Period | Estimated Return Period (Years) | |
|---|---|---|---|---|
| | | | Lam & Leung (1994) | Evans & Yu (2001) |
| 5 Minutes | 13.5 | 6:35 a.m. on 7 June 2008 | 2 | 3 |
| 15 Minutes | 36.5 | 6:35 a.m. on 7 June 2008 | 8 | 9 |
| 1 Hour | 112 | 6:45 a.m. on 7 June 2008 | 16 | 15 |
| 2 Hours | 141 | 7:30 a.m. on 7 June 2008 | 8 | 11 |
| 4 Hours | 208 | 8:40 a.m. on 7 June 2008 | 14 | 24 |
| 12 Hours | 236.5 | 8:40 a.m. on 7 June 2008 | 5 | 6 |
| 24 Hours | 374.5 | 8:40 a.m. on 7 June 2008 | 10 | 15 |
| 2 Days | 379.5 | 8:40 a.m. on 7 June 2008 | 6 | 5 |
| 4 Days | 425 | 8:40 a.m. on 7 June 2008 | 5 | 3 |
| 7 Days | 505.5 | 8:40 a.m. on 7 June 2008 | 6 | 5 |
| 15 Days | 614.5 | 8:40 a.m. on 7 June 2008 | 4 | 3 |
| 31 Days | 691 | 8:40 a.m. on 7 June 2008 | 2 | 2 |

Notes:
(1) The landslide is assumed to have occurred at 8:40 a.m. on 7 June 2008 for the purpose of rainfall analysis.
(2) Maximum rolling rainfalls were calculated from 5-minute rainfall data recorded at GEO raingauge No. H18, which is located about 1.7 km to the southeast of the landslide site and has been operational since 22 March 1983.
(3) Return periods were derived from the statistical parameters extracted from Table 3 of Lam & Leung (1994) and the statistical parameters of raingauge No. H18 extracted from Appendix B of Evans & Yu (2001).

Table 2 - Summary of Classification and Index Test Results

| Material Type | Sample Location | Depth (m) | Sample Type | Particle Size Distribution | | | | LL (%) | PL (%) | PI (%) | Moisture Content (%) | Specific Gravity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | | | | | |
| RS | TP5 | 1.0 | U100 | 16 | 35 | 17 | 32 | 68 | 29 | 39 | 22 | 2.61 |
| COLL | TP2 | 0.5 | Block | 19 | 47 | 23 | 11 | 81 | 33 | 48 | 20 | 2.56 |
| CDG | DH1A | 2.0 | Mazier | 6 | 78 | 8 | 8 | Non-plastic | | | 19 | 2.63 |
| CDG | DH3 | 1.9 | Mazier | 18 | 73 | 9 | | - | - | - | 16 | 2.58 |
| CDG | DH3A | 2.0 | Mazier | 25 | 67 | 8 | | - | - | - | 13 | 2.58 |
| CDG | TP2 | 1.5 | Mazier | 11 | 46 | 29 | 14 | 74 | 31 | 43 | 23 | 2.55 |
| Clay | SS2 | Near surface | Disturbed | 17 | 41 | 11 | 31 | 63 | 26 | 37 | - | - |
| Clay | SS2 | Near surface | Disturbed | 18 | 40 | 11 | 31 | 64 | 27 | 37 | - | - |
| Clay | SS2 | Near surface | Disturbed | 15 | 46 | 10 | 29 | 64 | 28 | 36 | - | - |

Legend:

| | | | | | |
|---|---|---|---|---|---|
| RS | Residual soil | TP | Trial pit | LL | Liquid limit |
| COLL | Colluvium | DH | Drillhole | PL | Plastic limit |
| CDG | Completely decomposed granite | SS | Slope surface strip | PI | Plasticity index |
| Clay | Kaolin-rich material | | | | |



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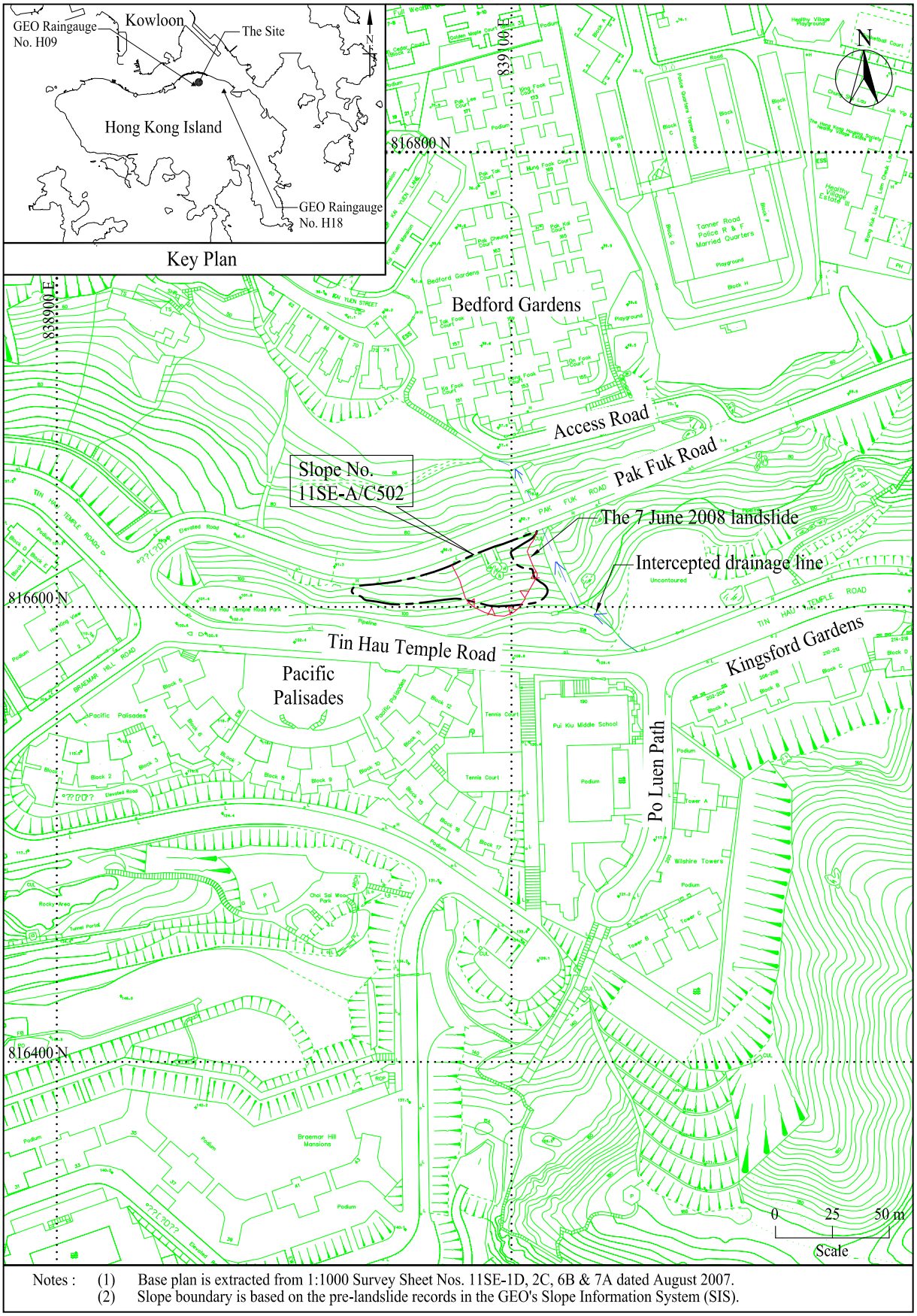
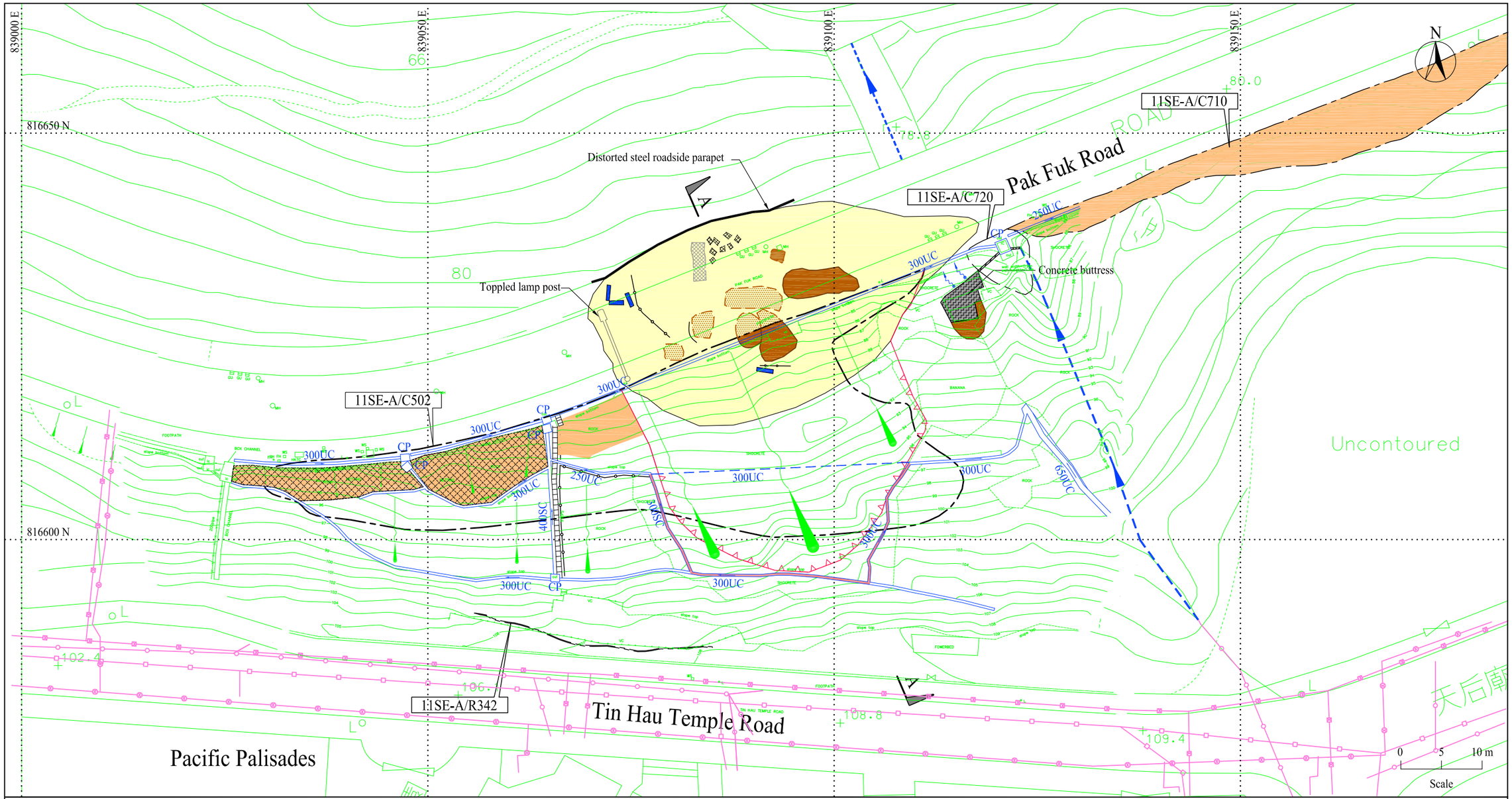


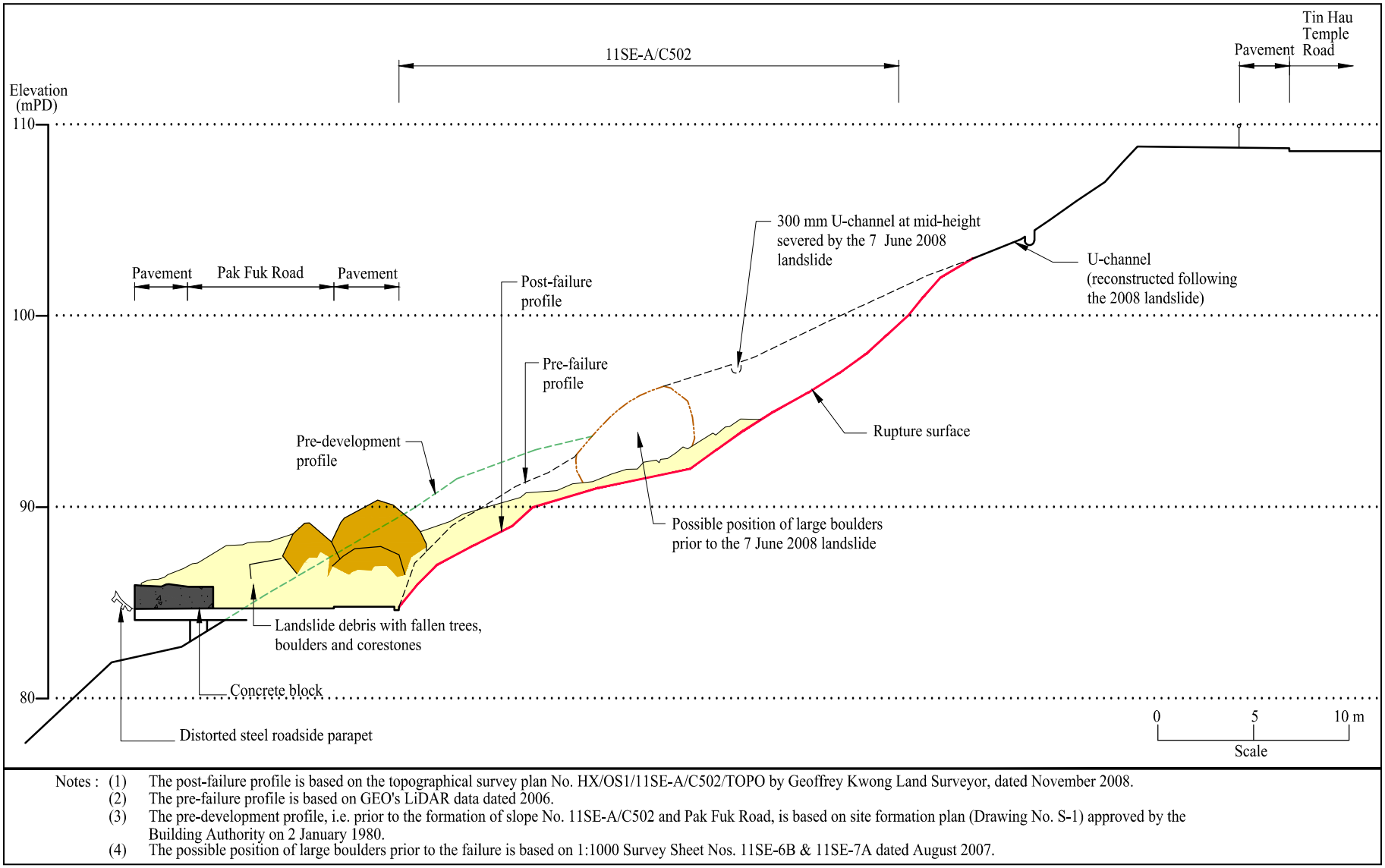

Notes : (1) Base plan is extracted from 1:1000 Survey Sheet Nos. 11SE-1D, 2C, 6B & 7A dated August 2007.
(2) Slope boundary is based on the pre-landslide records in the GEO's Slope Information System (SIS).

Figure 1 - Location Plan




Notes :
(1) Base plan is extracted from topographical survey plan No. HX/051/11-SE-A/C502/TOPO by Geoffrey Kwong Land Surveyor, dated November 2008.
(2) Slope boundaries are based on the pre-landslide records in the GEO's SIS.
(3) Utilities and services along Pak Fuk Road are not shown for clarity.
(4) See Figure 3 for Section A - A.

Figure 2 - Site Layout Plan and Field Observations




Notes : (1) The post-failure profile is based on the topographical survey plan No. HX/OS1/11SE-A/C502/TOPO by Geoffrey Kwong Land Surveyor, dated November 2008.
(2) The pre-failure profile is based on GEO's LiDAR data dated 2006.
(3) The pre-development profile, i.e. prior to the formation of slope No. 11SE-A/C502 and Pak Fuk Road, is based on site formation plan (Drawing No. S-1) approved by the Building Authority on 2 January 1980.
(4) The possible position of large boulders prior to the failure is based on 1:1000 Survey Sheet Nos. 11SE-6B & 11SE-7A dated August 2007.

Figure 3 - Cross-section A - A of the 7 June 2008 Landslide Site

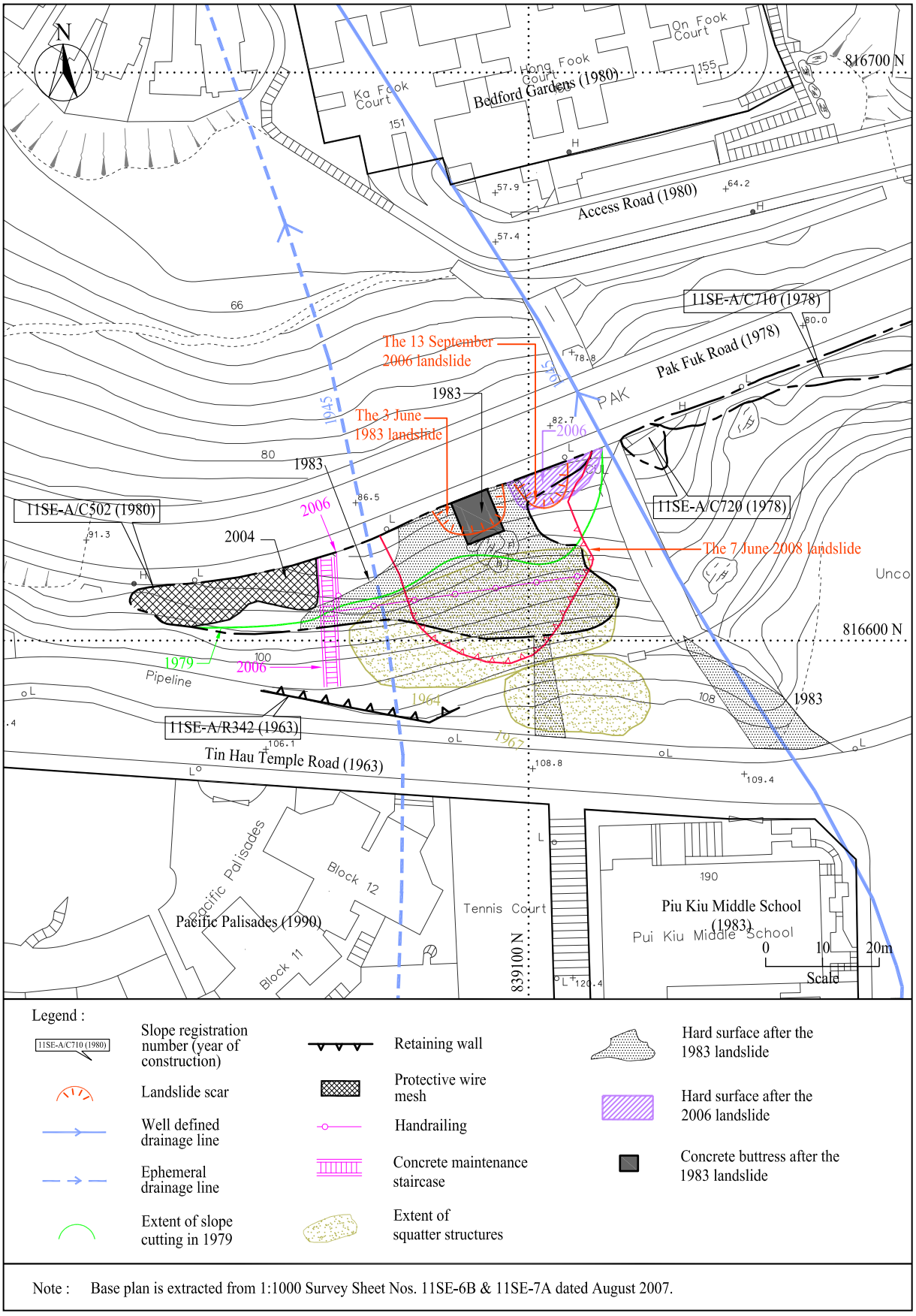
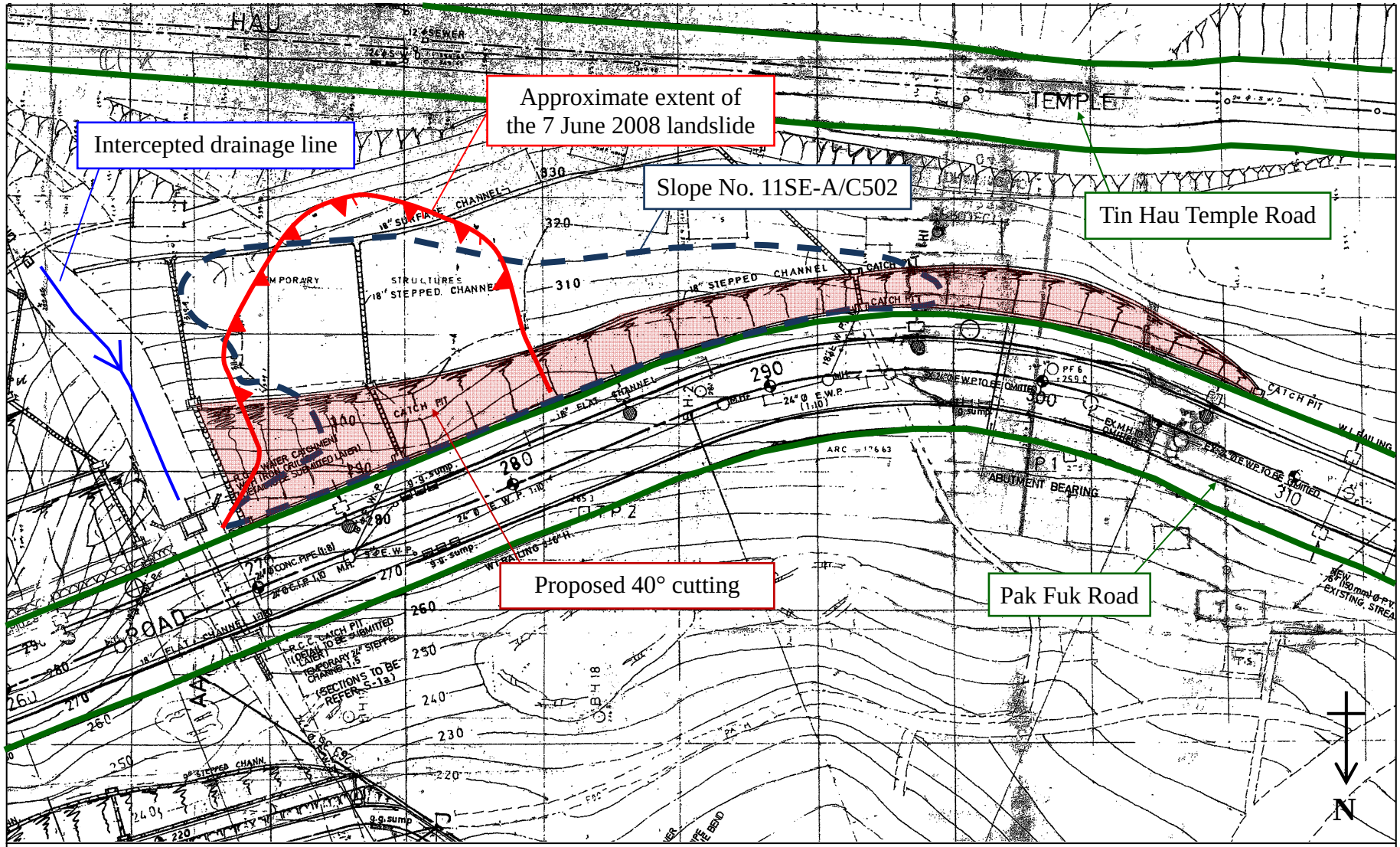



Figure 4 - Site Development History and Past Instability




Note: The figure is based on Site Formation Plan (Drawing No. S-1) approved by the Building Authority on 2 January 1980.

Figure 5 - Proposed Cutting Extent of Slope No. 11SE A/C502



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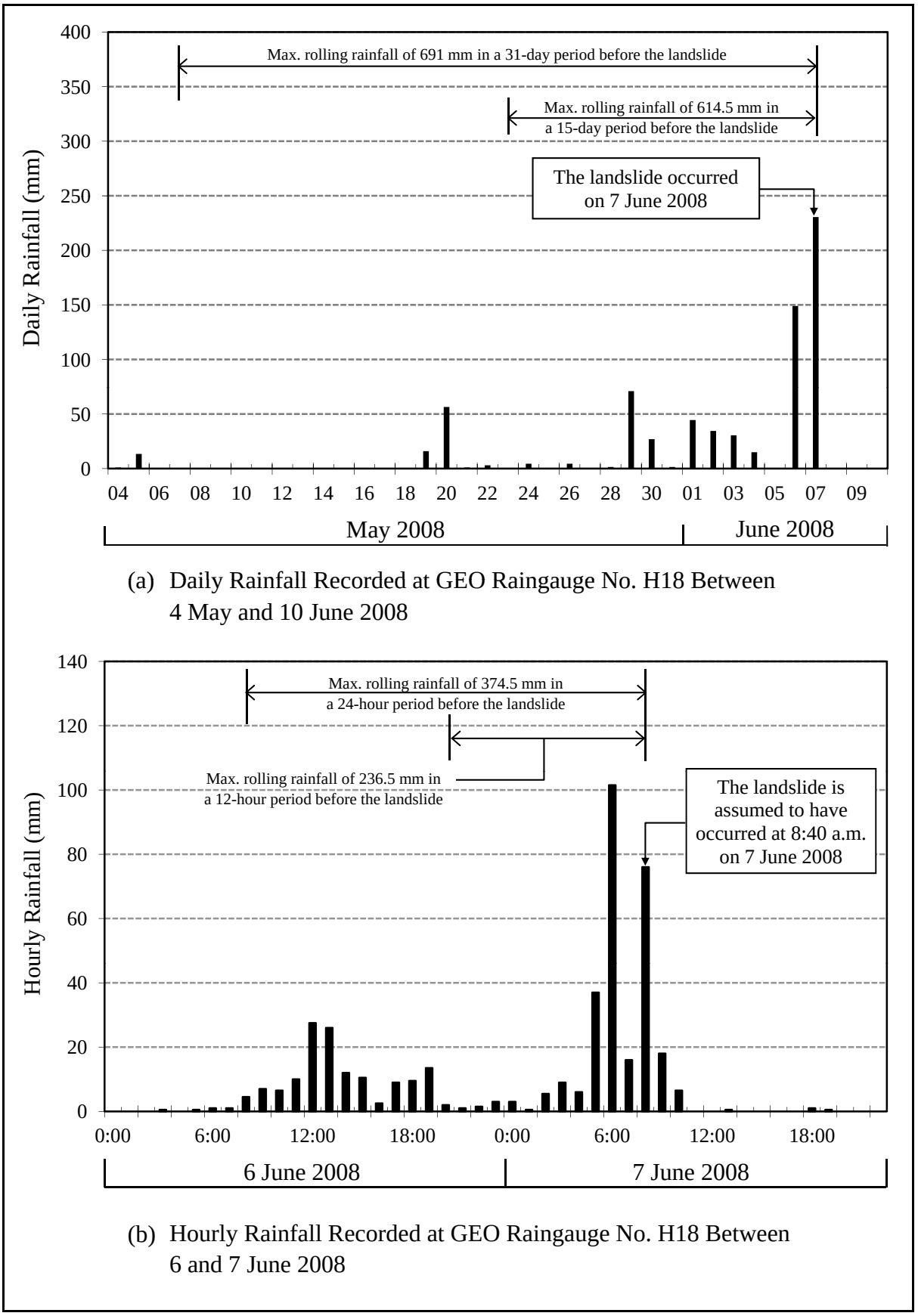
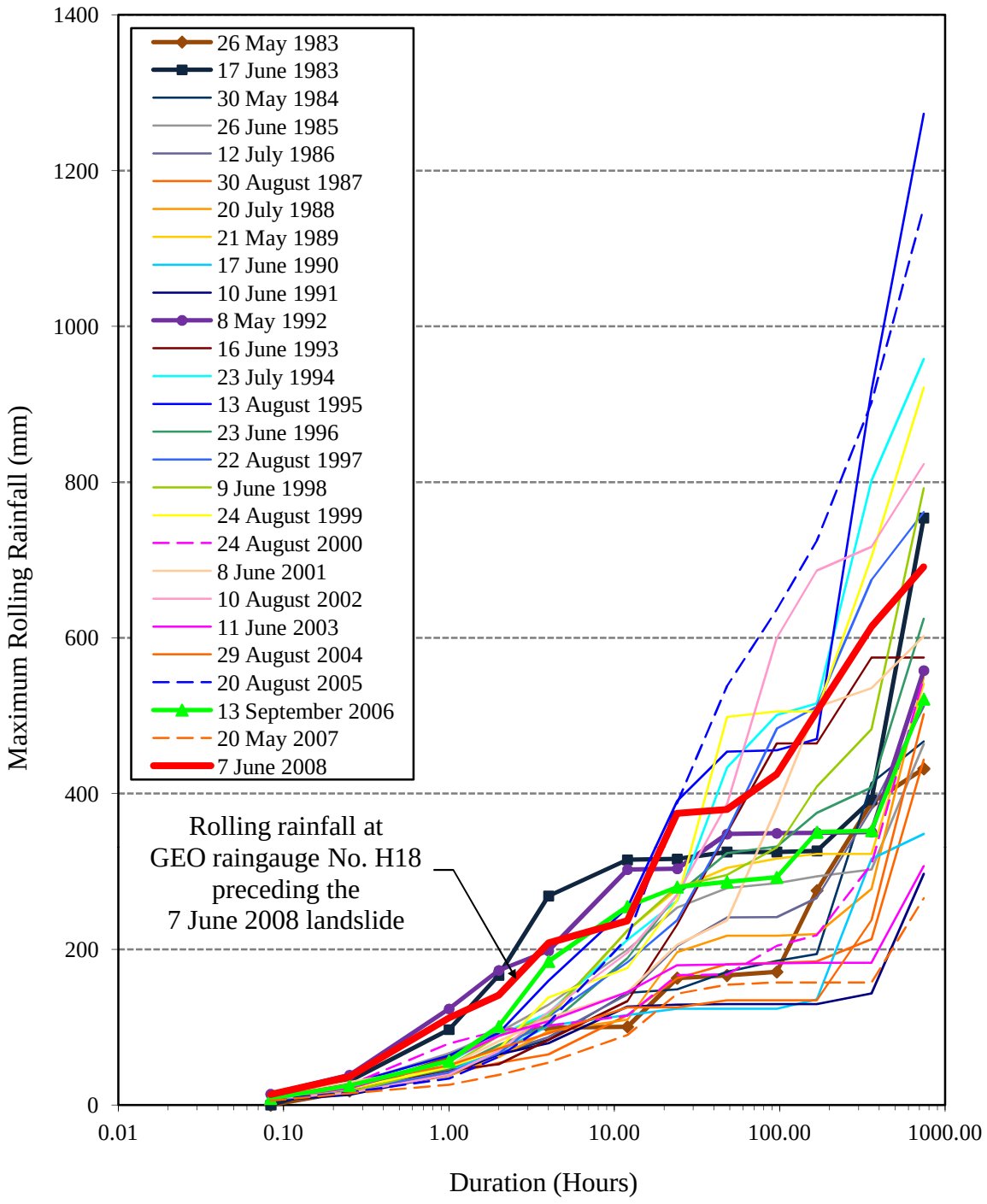



(a) Daily Rainfall Recorded at GEO Raingauge No. H18 Between 4 May and 10 June 2008

(b) Hourly Rainfall Recorded at GEO Raingauge No. H18 Between 6 and 7 June 2008

Figure 6 - Daily and Hourly Rainfall Recorded at GEO Raingauge No. H18




Notes: (1) Maximum rolling rainfalls for the rainstorms of 26 May and 17 June 1983 are evaluated from 15-minute rainfall data recorded at GEO raingauge No. H18, which is located at about 1.7 km to the southeast of the landslide site and came into operation in March 1983.

(2) Maximum rolling rainfalls for the other rainstorms are evaluated from 5-minute rainfall data recorded at GEO raingauge No. H18.

Figure 7 - Maximum Rolling Rainfalls for Major Rainstorms at GEO Raingauge No. H18

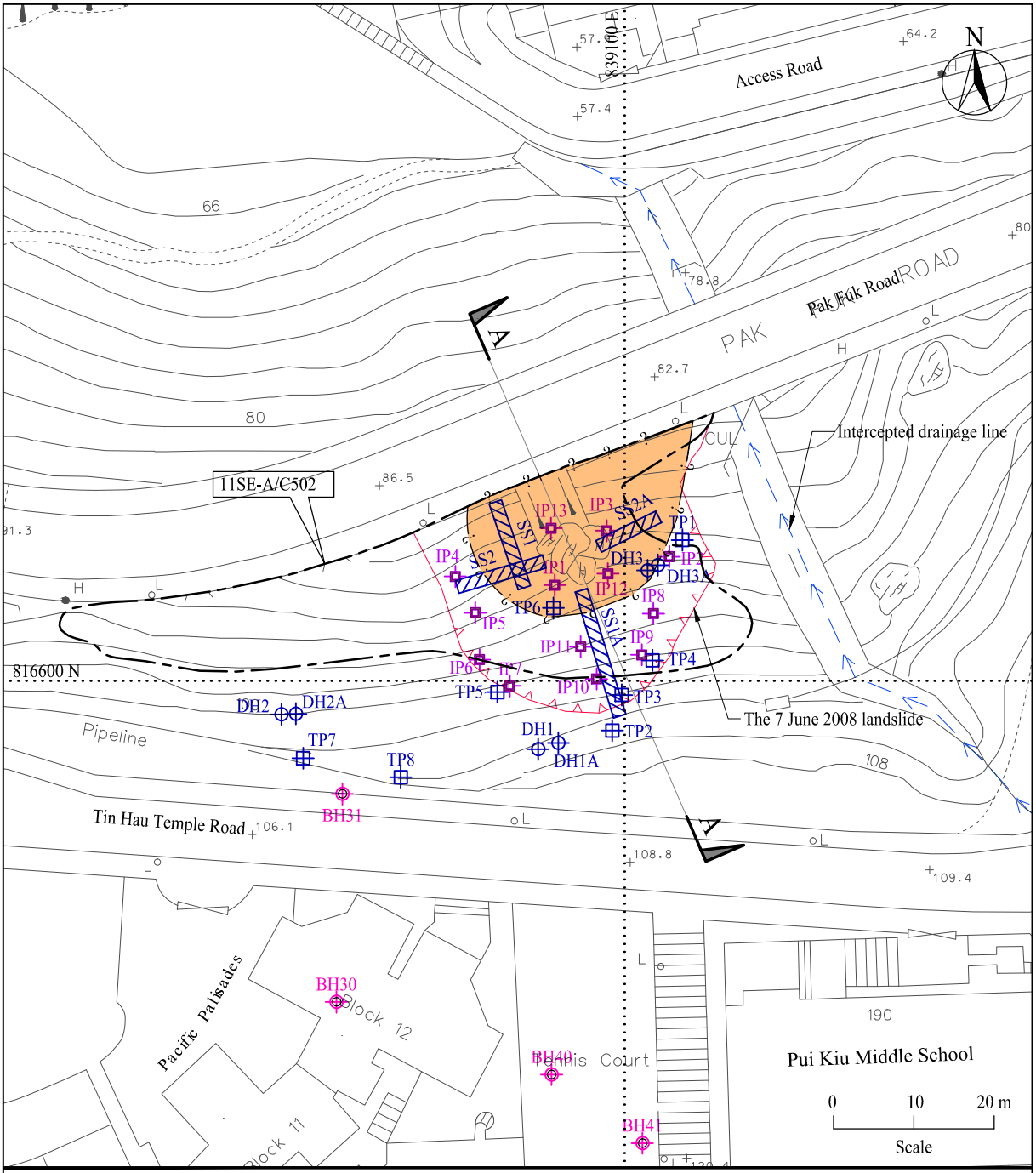



Figure 8 - Location Plan of Ground Investigation Stations

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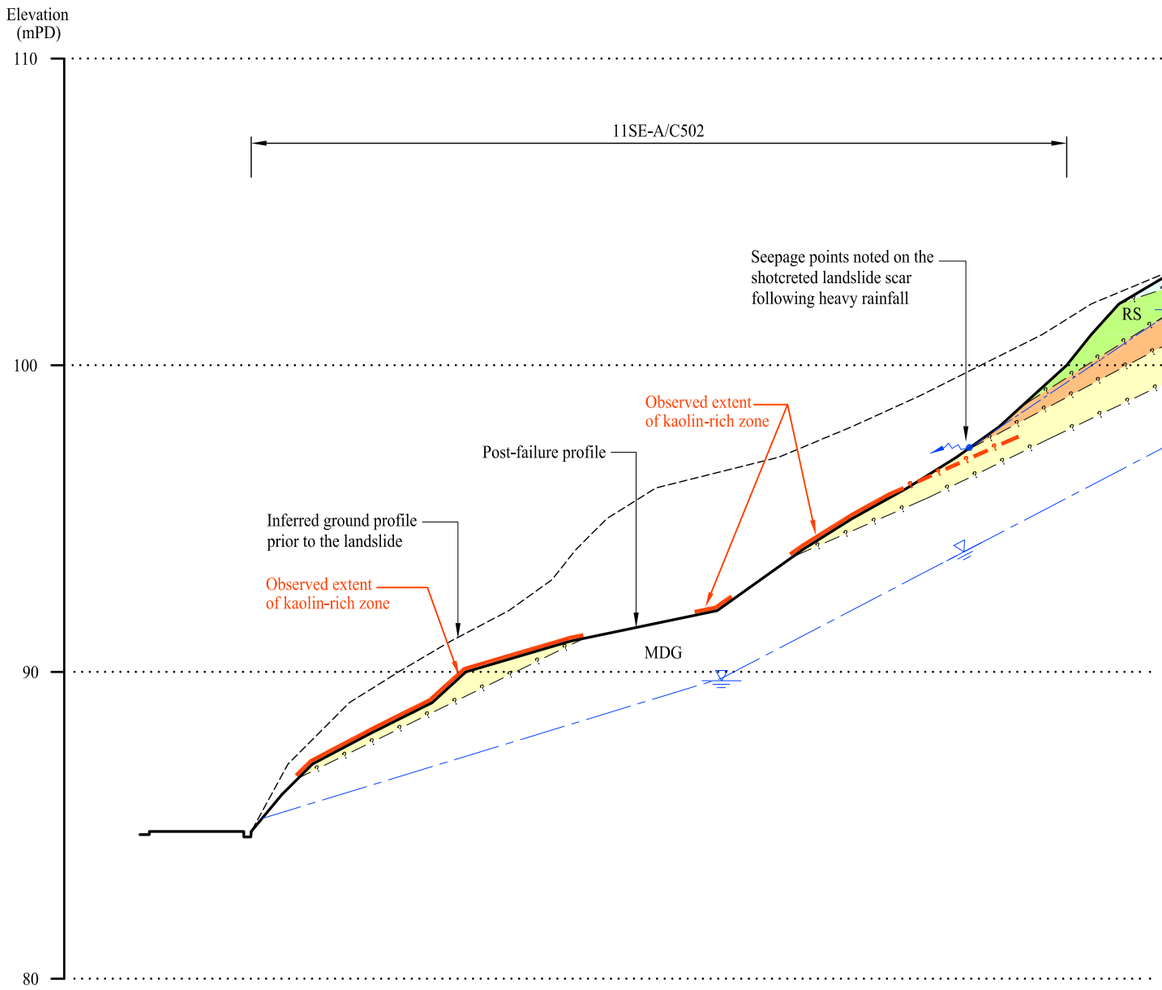
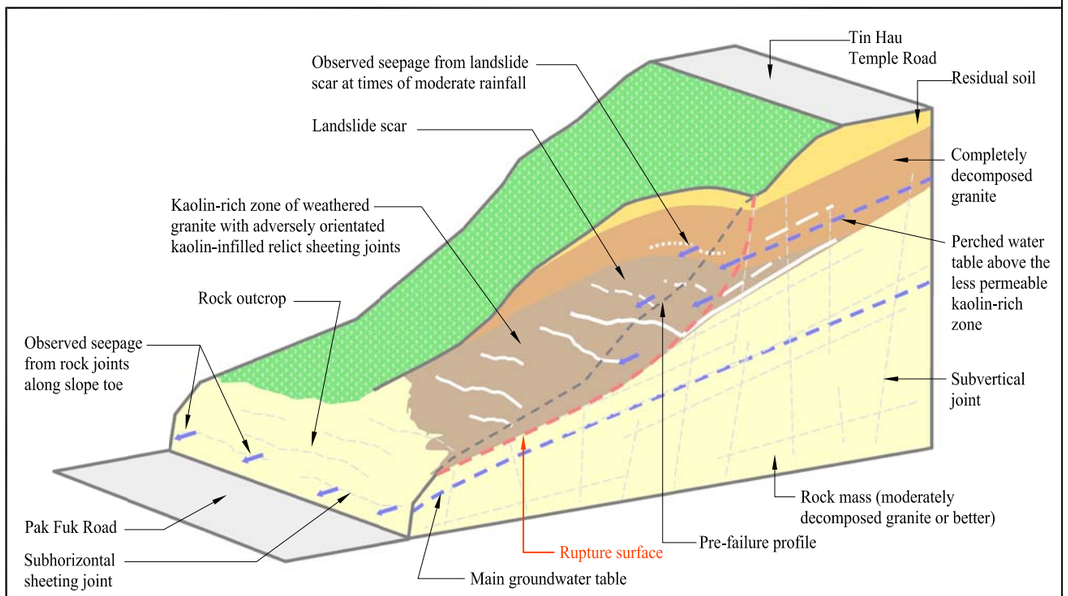



Schematic Illustration of the Simplified Geology of the Landslide Site

Legend :

— ? — ? — ? — Inferred geological profile

FILL Fill

COLL Colluvium (COLL)

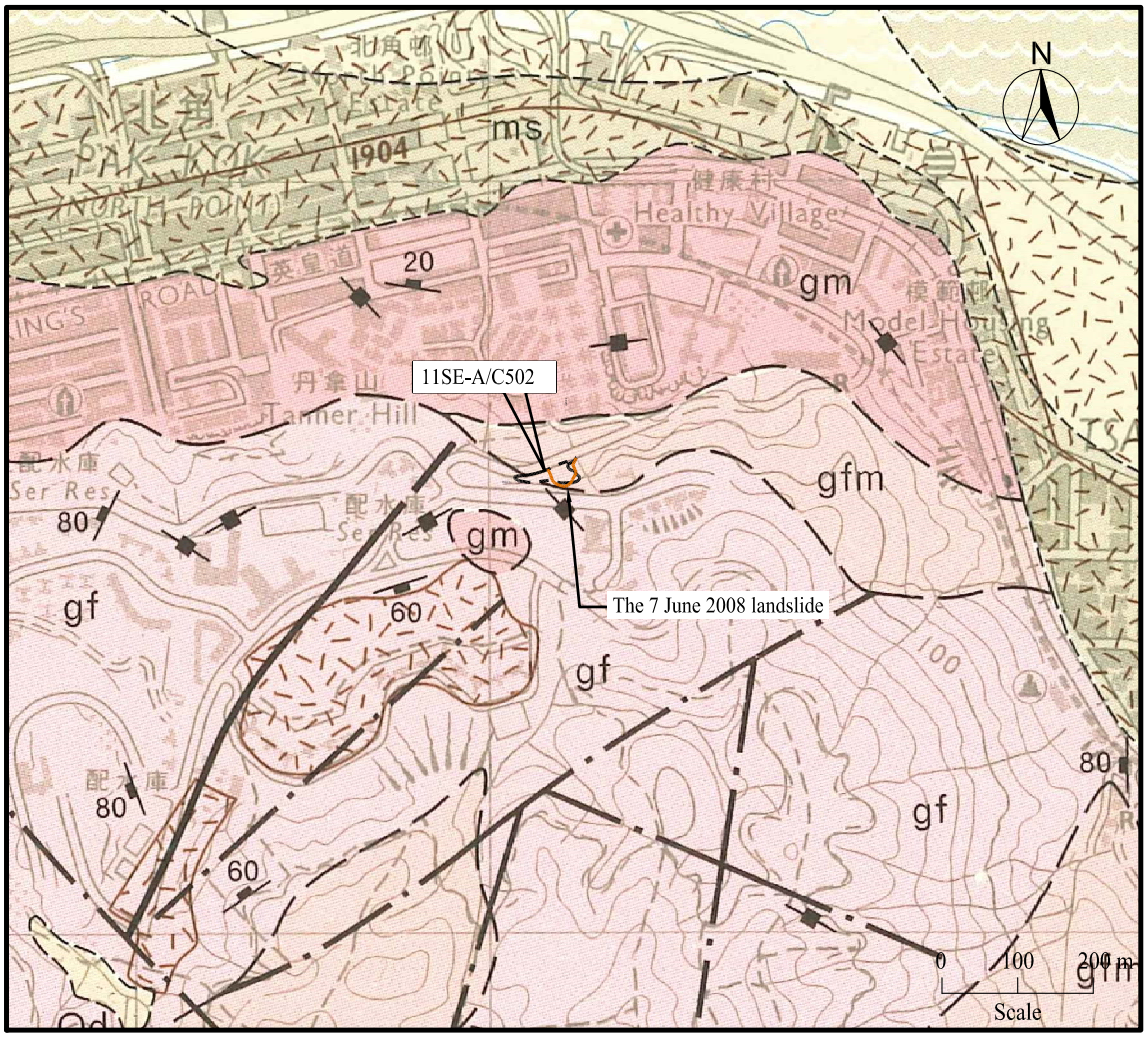
RS Residual soil (RS)

CDG Completely decomposed granite (CDG)

HDG Highly decomposed granite (HDG)

Notes : (1) The post-failure profile is based on the topographical survey plan No. HX/051/11SE-A/C502/TOPO by Geoffrey Kwong Land Surveyor, dated November 2008.
(2) The pre-failure profile is based on GEO's LIDAR data dated 2006.
(3) The pre-development profile, i.e. prior to the formation of slope No. 11SE-A/C502 and the construction of Pak Fuk Road, is based on Site Formation Plan, (Drawing No. S-1) approved by the Building Authority on 2 Jan 1980.

Figure 9 - Geological Section A - A through the 7 June 2008 Landslide




Legend :

MAJOR INTRUSIVE IGNEOUS ROCKS

- gf — Fine-grained granite, < 2 mm
- gfm — Fine- to medium-grained granite
- gm — Medium-grained granite
- Fill; sanitary (Qfs)

GEOLOGICAL LINES

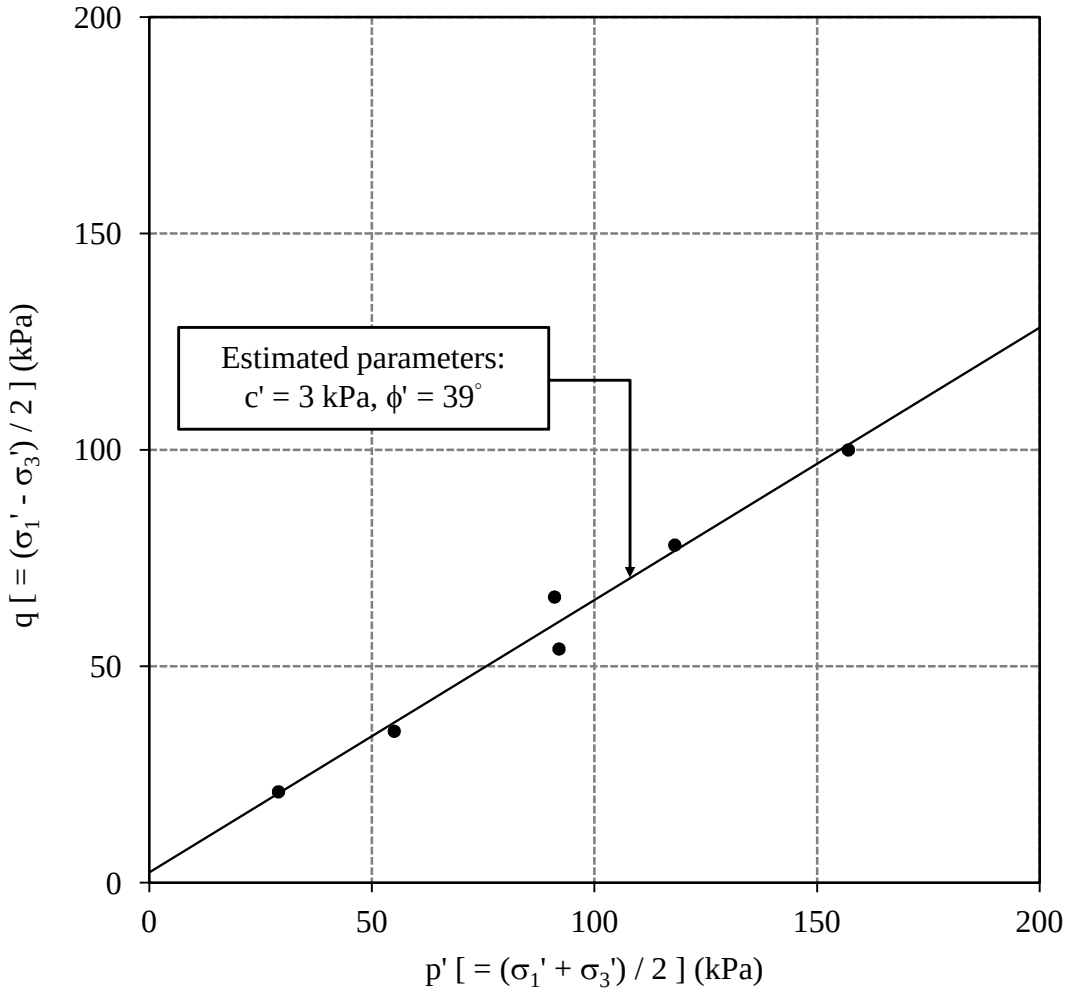
- Geological boundary, superficial deposit
- 1863 — Fill boundary, with limit of reclamation at date shown
- Mineral vein
- Photogeological lineament

STRUCTURAL SYMBOLS

- 20 — Inclined jointing
- Vertical jointing

Notes : (1) The map is extracted from Hong Kong Geological Survey, Map Series HGM20, Sheet No. 11, 1:20000 scale (GCO, 1986).
(2) All dips and plunges measured in degrees from horizontal.
(3) Broken lines on map face denote uncertainty.

Figure 10 - Regional Geology




Legend:

| | | | |
|---|---|---|---|
| $\sigma_1'$ | Major principal effective stress | c' | Cohesion |
| $\sigma_3'$ | Minor principal effective stress | $\phi'$ | Angle of shearing resistance |

Note: The plot presents the test results from multi-stage isotropically consolidated undrained triaxial compression tests with pore pressure measurement.

Figure 11 - Triaxial Compression Test Results for Completely Decomposed Granite

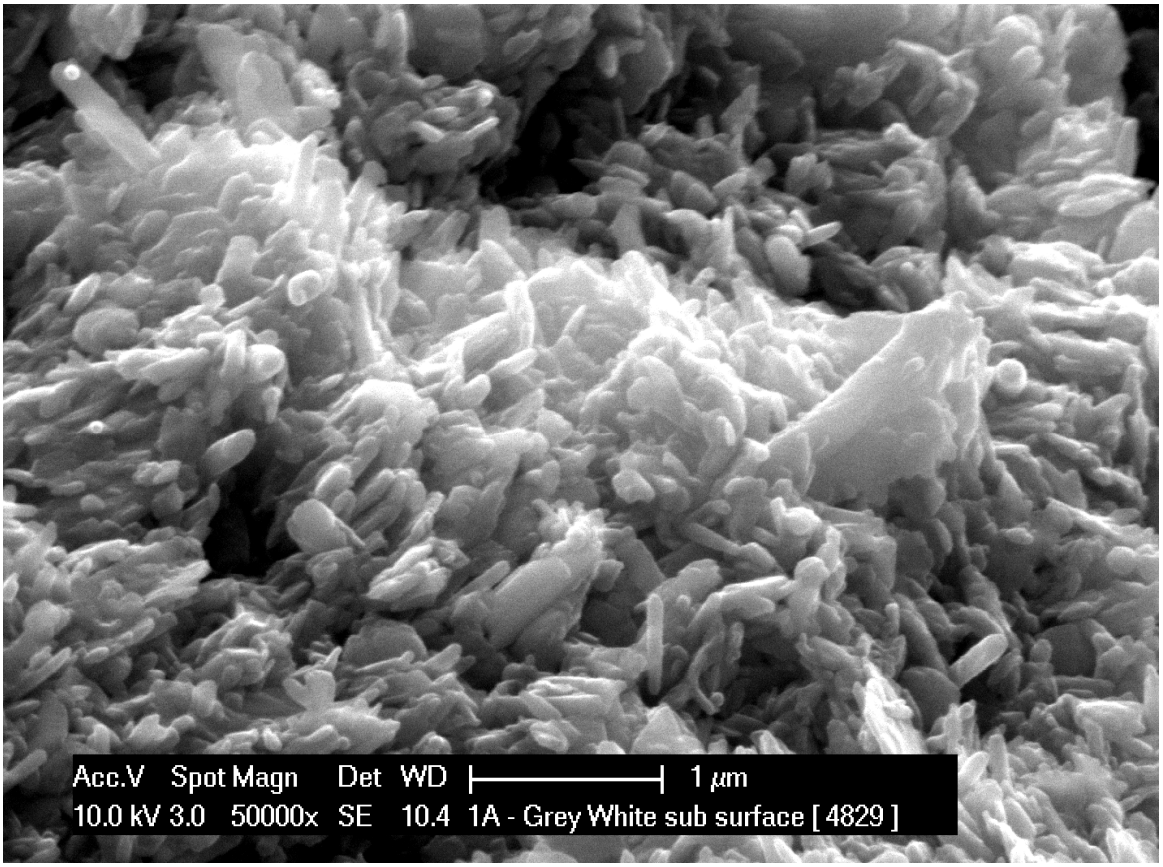
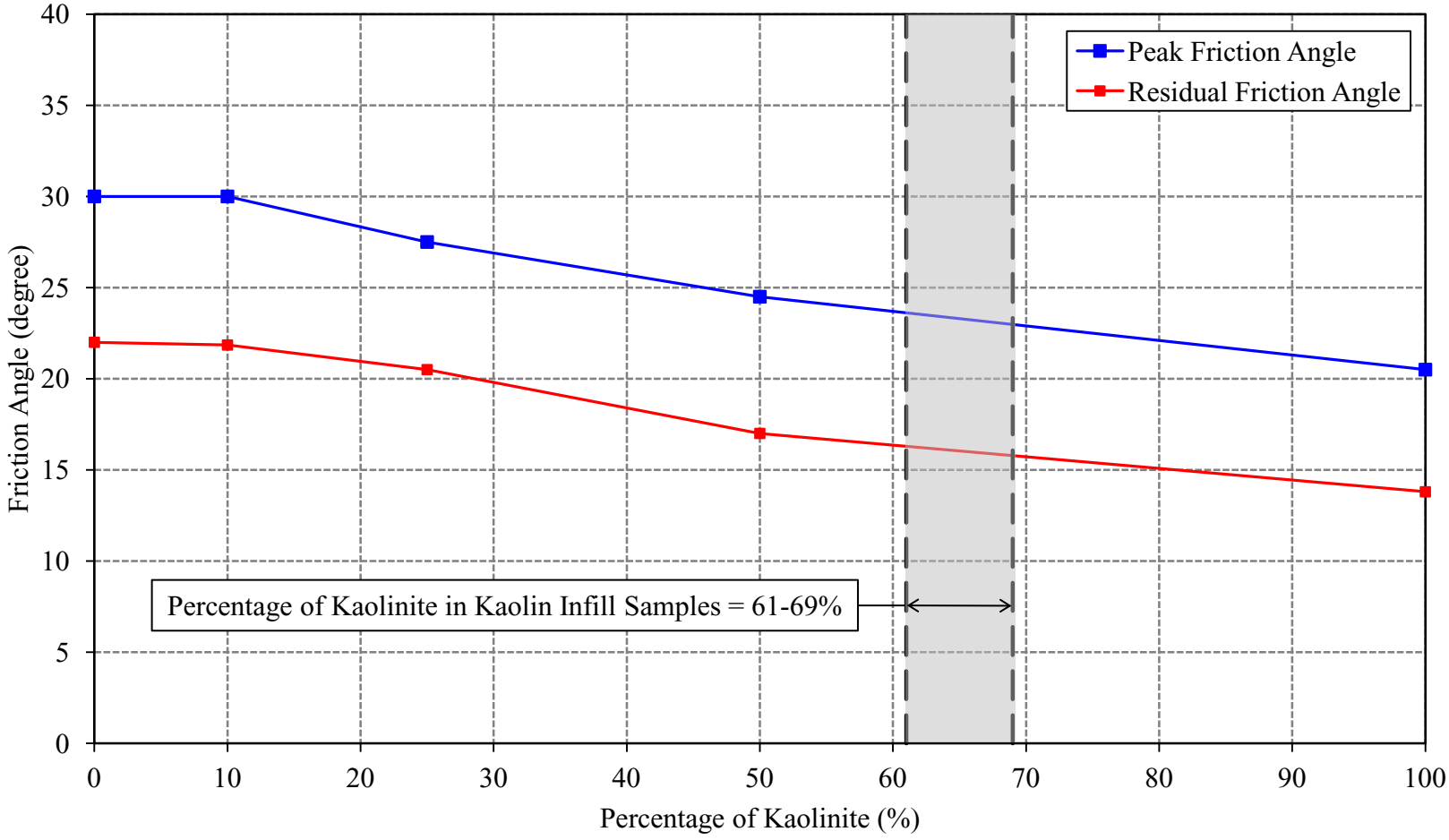



Figure 12 - Scanning Electron Microscopic Image of the Kaolin Infill Sample Showing a Mixture of Platy Particles with Small Tubular Particles




Notes: (1) The relationship between the percentage of kaolinite and shear strength of kaolin is based on Figure 3 of Campbell & Parry (2002).
(2) The peak and residual strength were determined from direct shear and ring shear tests on artificially constituted samples respectively.

Figure 13 - Peak and Residual Friction Angle of Kaolin Infill

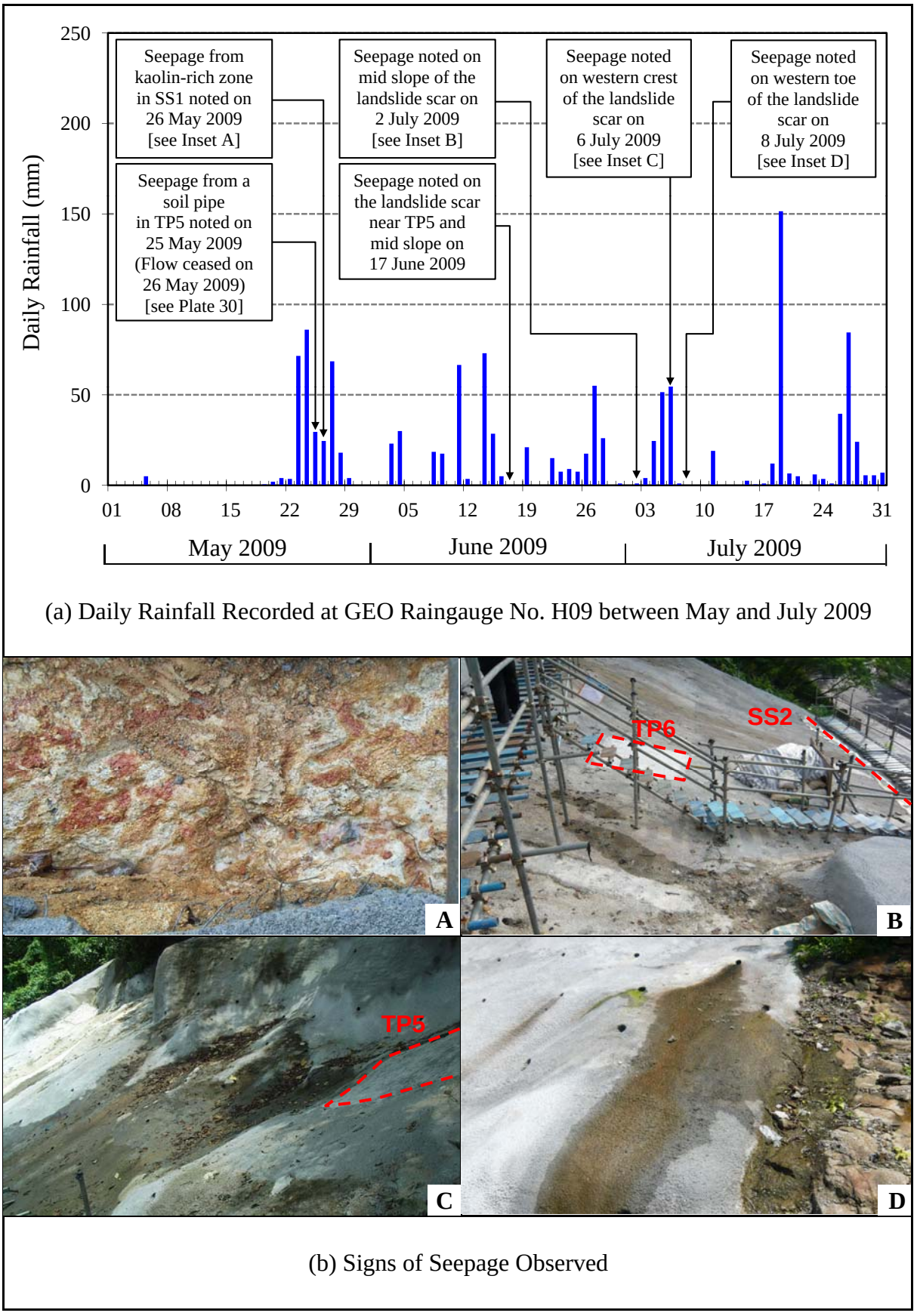



Figure 14 - Signs of Seepage Observed between May and July 2009

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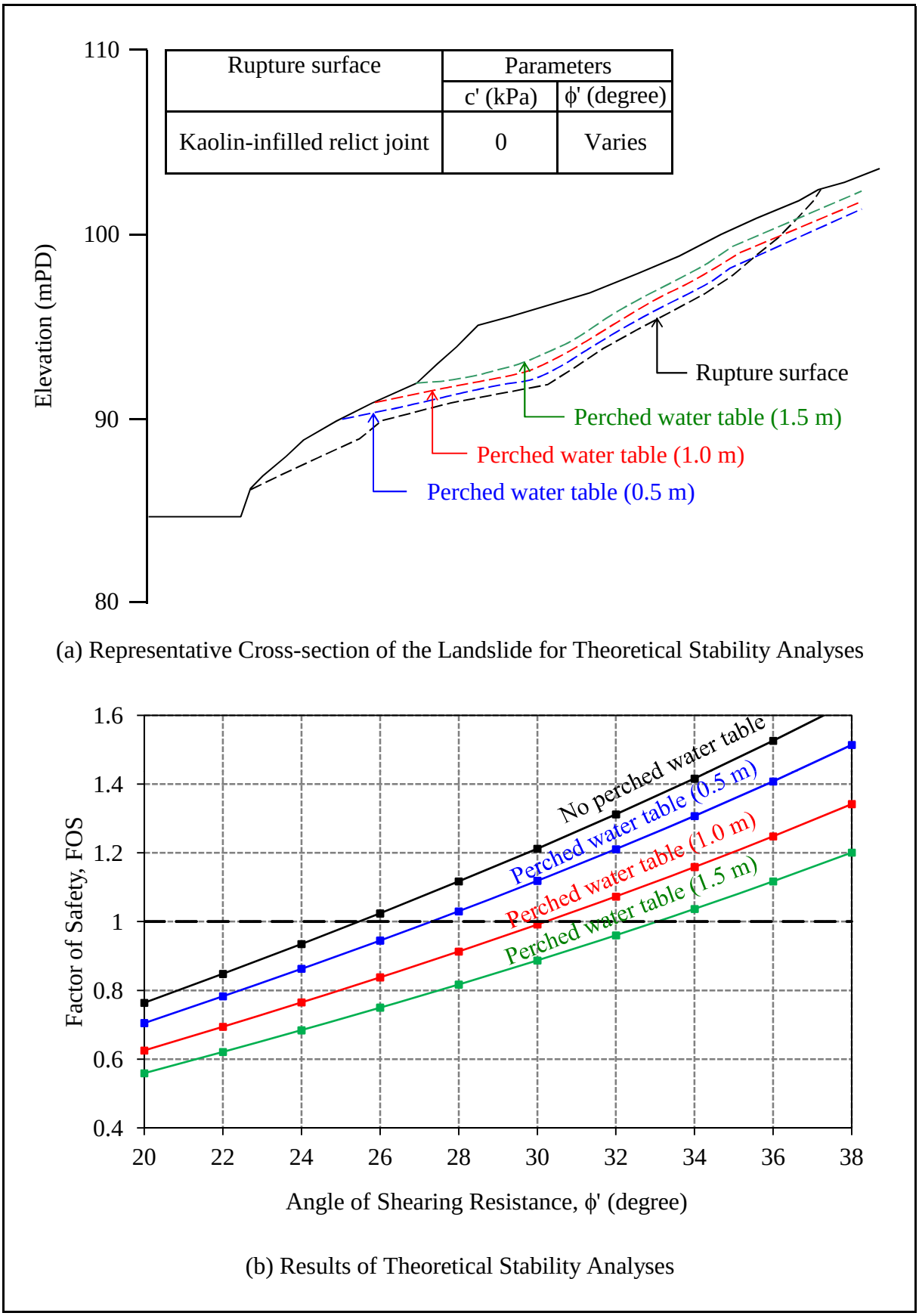
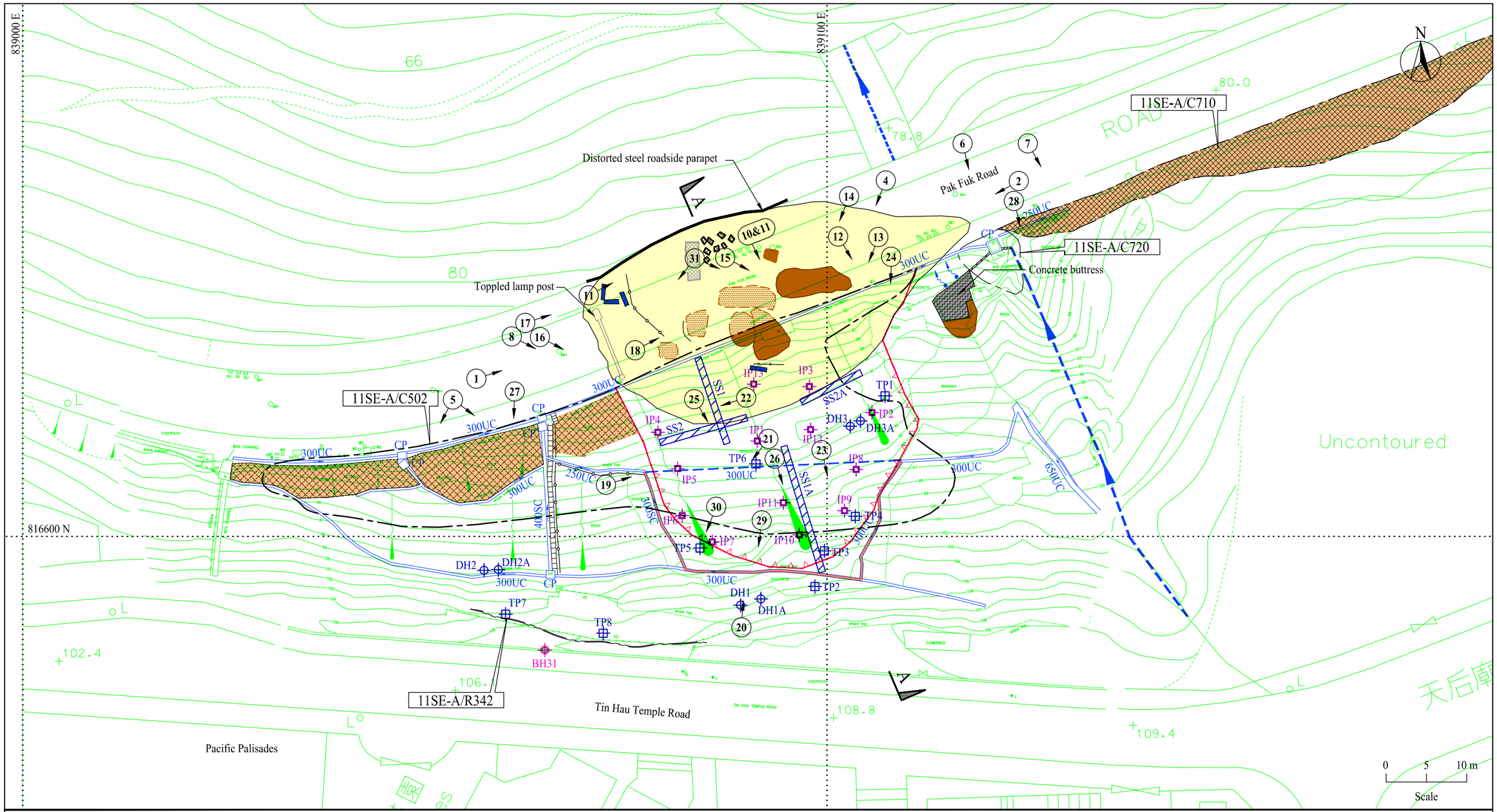



(a) Representative Cross-section of the Landslide for Theoretical Stability Analyses

(b) Results of Theoretical Stability Analyses

Figure 15 - Summary of Theoretical Stability Analyses




Legend :

11SE-A/C502 — Slope registration number

1 — Location and direction of plates

The 7 June 2008 landslide scar

Notes :

(1) Base plan is extracted from topographical survey plan No. HX/051/11-SE-A/C502/TOPO by Geoffrey Kwong Land Surveyor, dated November 2008.
(2) Slope boundaries are based on pre-landslide records of GEO's SIS.
(3) See Figures 2 and 8 for the other legends.

Figure 16 - Locations and Directions of Photographs

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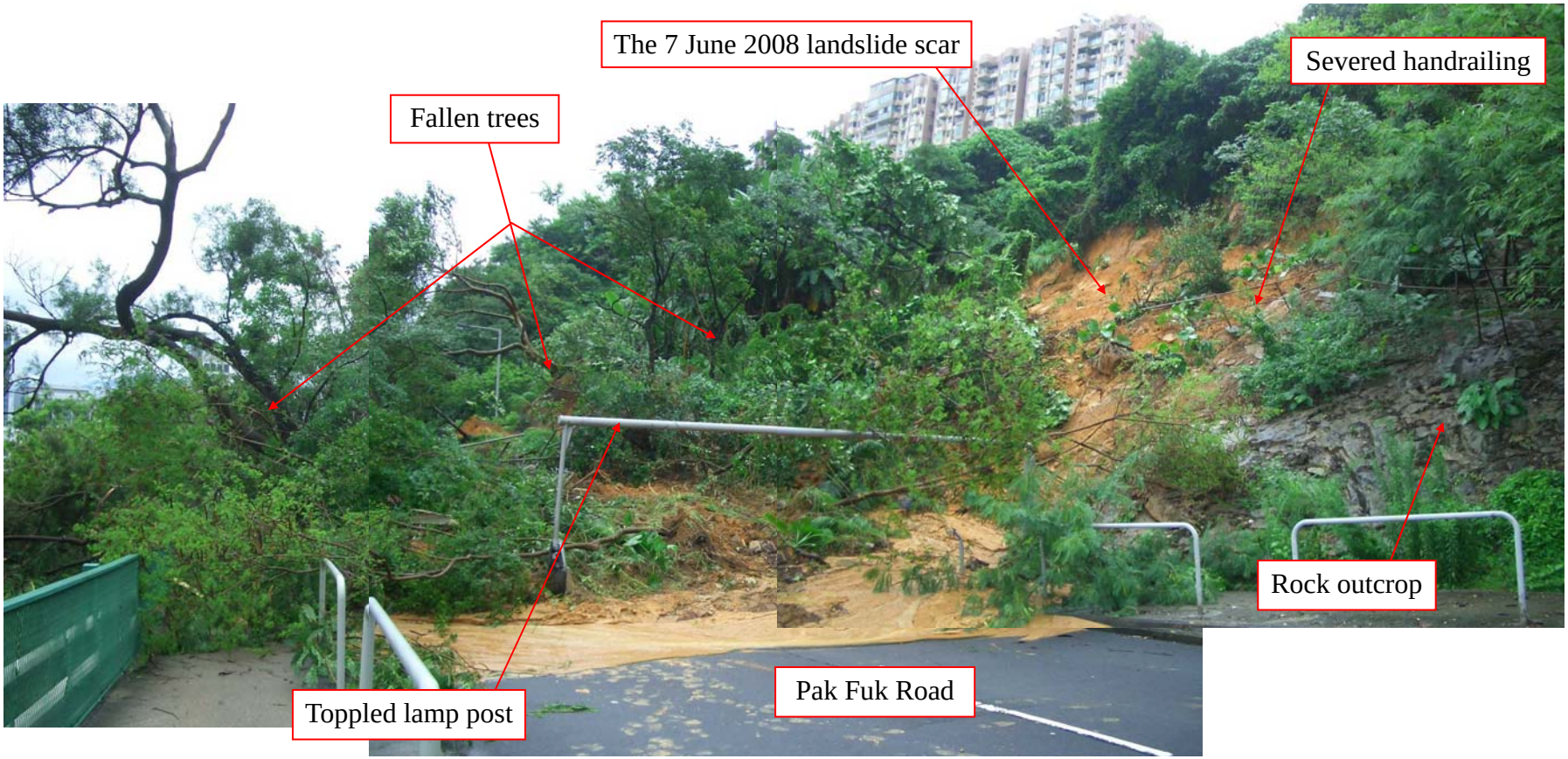


Plate 1 - General View of the 7 June 2008 Landslide (Looking East)
(Photograph taken on 7 June 2008)

Note: See Figure 16 for location and direction of photograph.



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Plate 2 - General View of the 7 June 2008 Landslide (Looking West)
(Photograph taken on 7 June 2008)

Note: See Figure 16 for location and direction of photograph.


Plate 3 - Muddy Surface Runoff Travelling Down to Bedford Gardens
(Photograph taken on 7 June 2008)

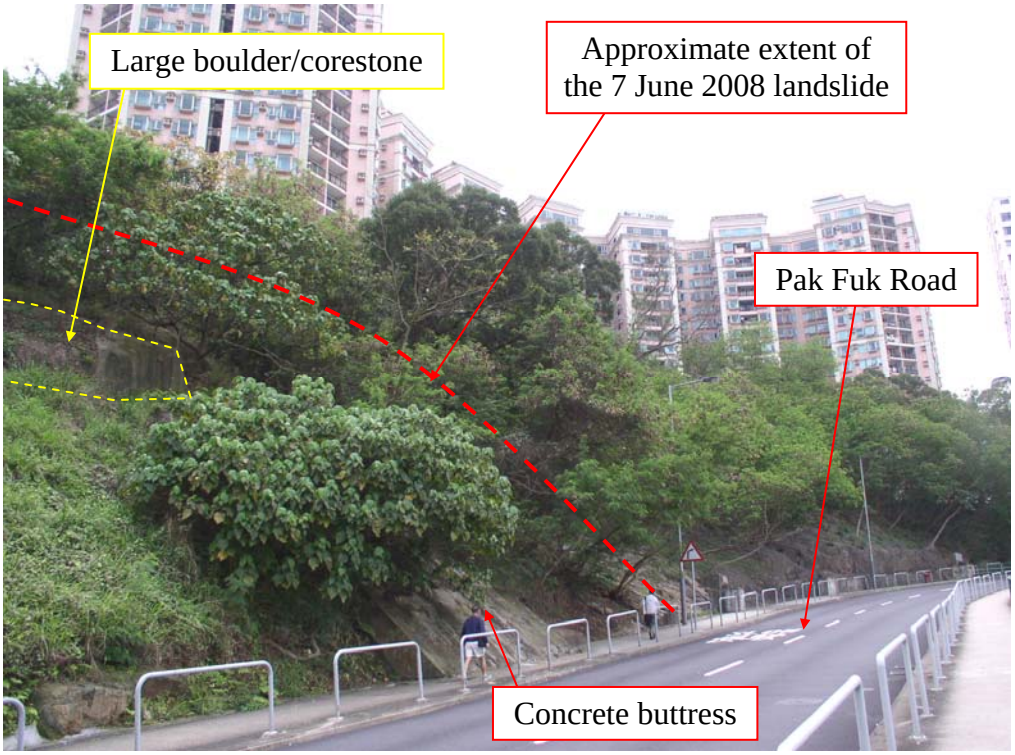


Plate 4 - Eastern Portion of Slope No. 11SE-A/C502 in 2005
(Photograph taken on 14 April 2005)

Note: See Figure 16 for location and direction of photograph.

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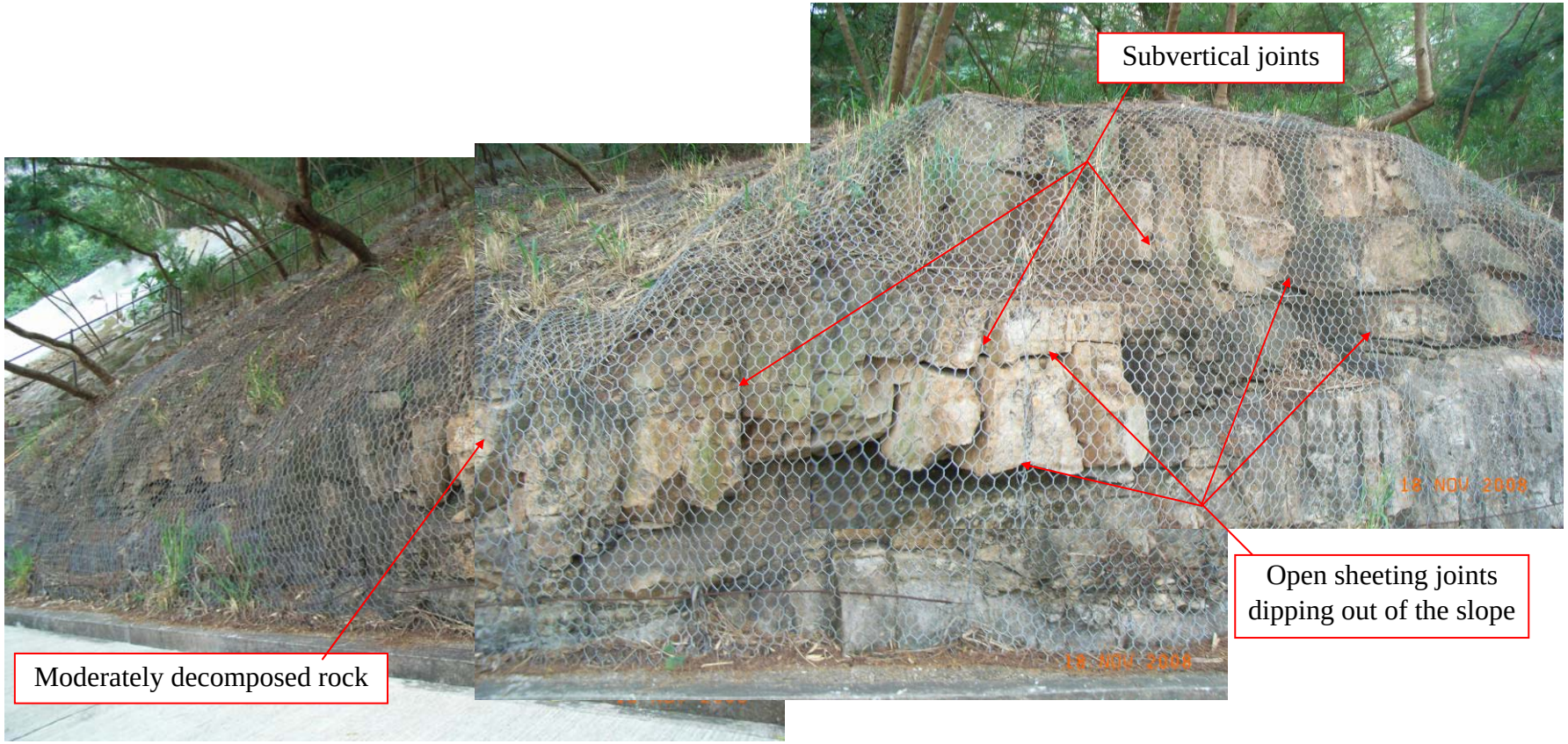


Plate 5 - Lower Western Portion of Slope No. 11SE-A/C502
(Photograph taken on 18 November 2008)

Note: See Figure 16 for location and direction of photograph.


Plate 6 - Intercepted Drainage Line with Large Boulders
(Photograph taken on 10 June 2008)


Plate 7 - Rock Outcrop on Slope No. 11SE-A/C710
(Photograph taken on 10 June 2008)

Note: See Figure 16 for location and direction of photograph.

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Plate 8 - The 2008 Landslide Scar after Completion of Emergency Repair Works
(Photograph taken on 23 June 2008)

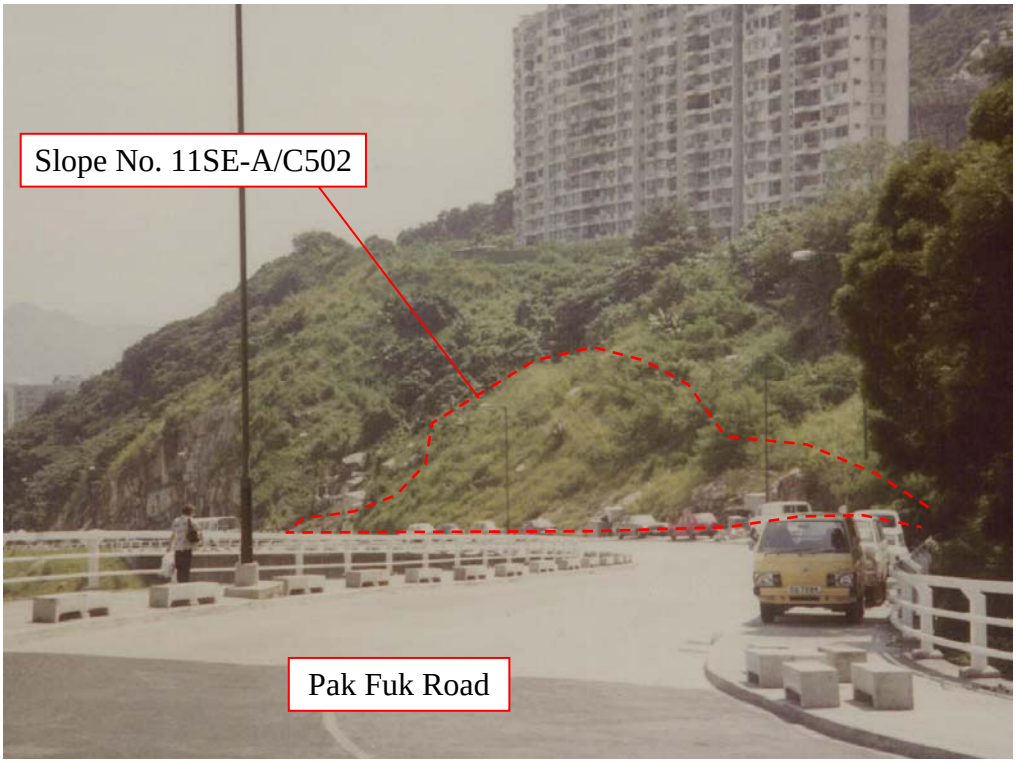


Plate 9 - General View of Slope No. 11SE-A/C502 in 1981
(Photograph taken on 20 August 1981)

Note: See Figure 16 for location and direction of photograph.

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Plate 10 - General View of the 3 June 1983 Landslide
(Photograph taken on 3 June 1983)

Note: See Figure 16 for location and direction of photograph.



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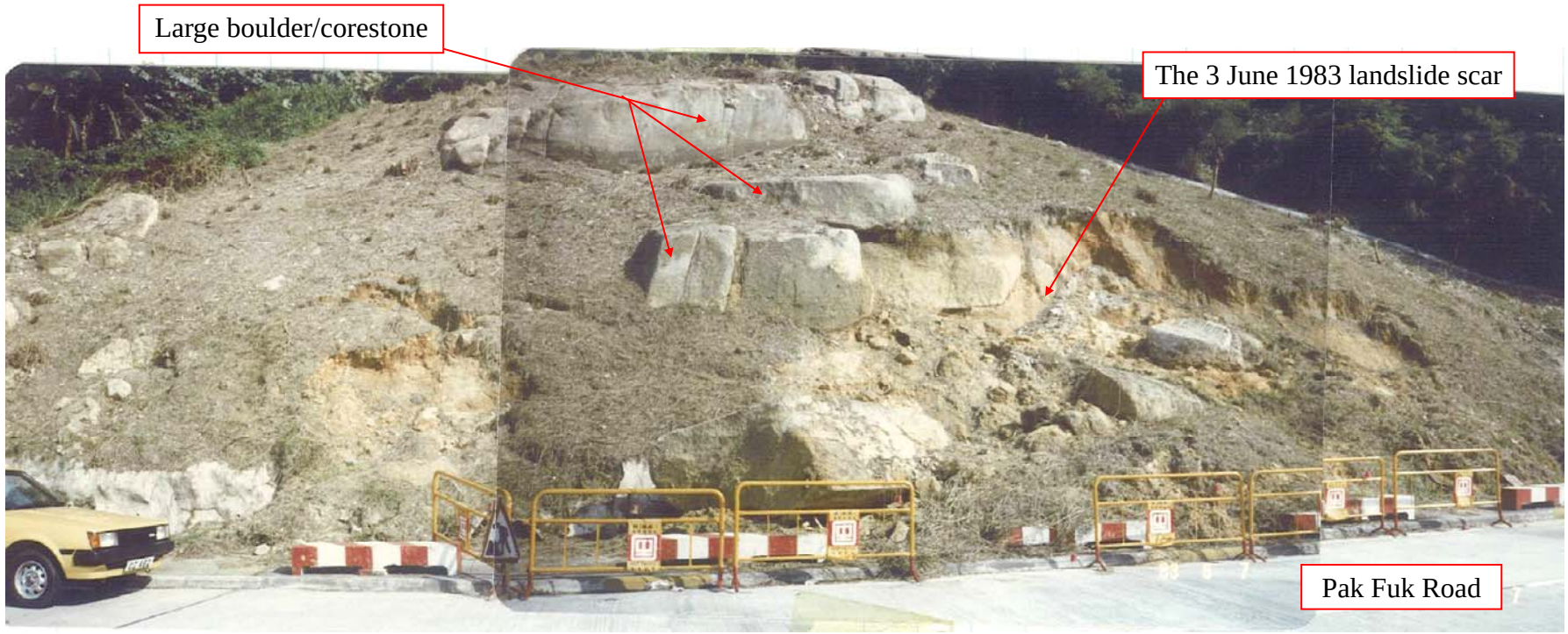


Plate 11 - General View of the 3 June 1983 Landslide Scar after Vegetation Clearance
(Photograph taken on 7 June 1983)

Note: See Figure 16 for location and direction of photograph.



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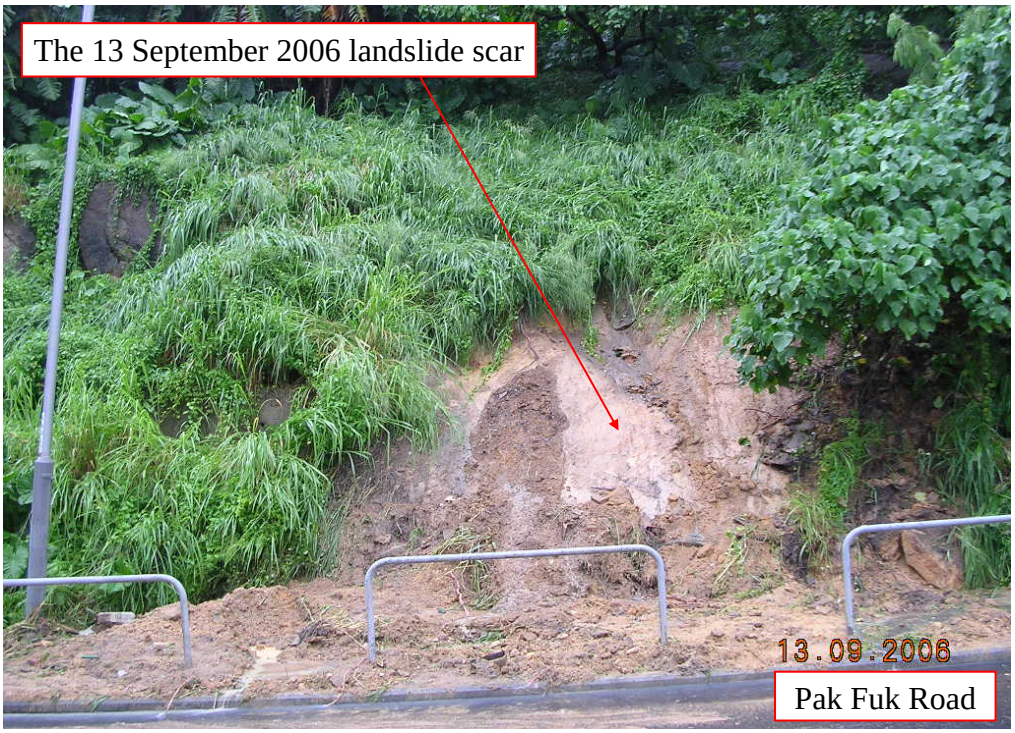


Plate 12 - General View of the 13 September 2006 Landslide
(Photograph taken on 13 September 2006)

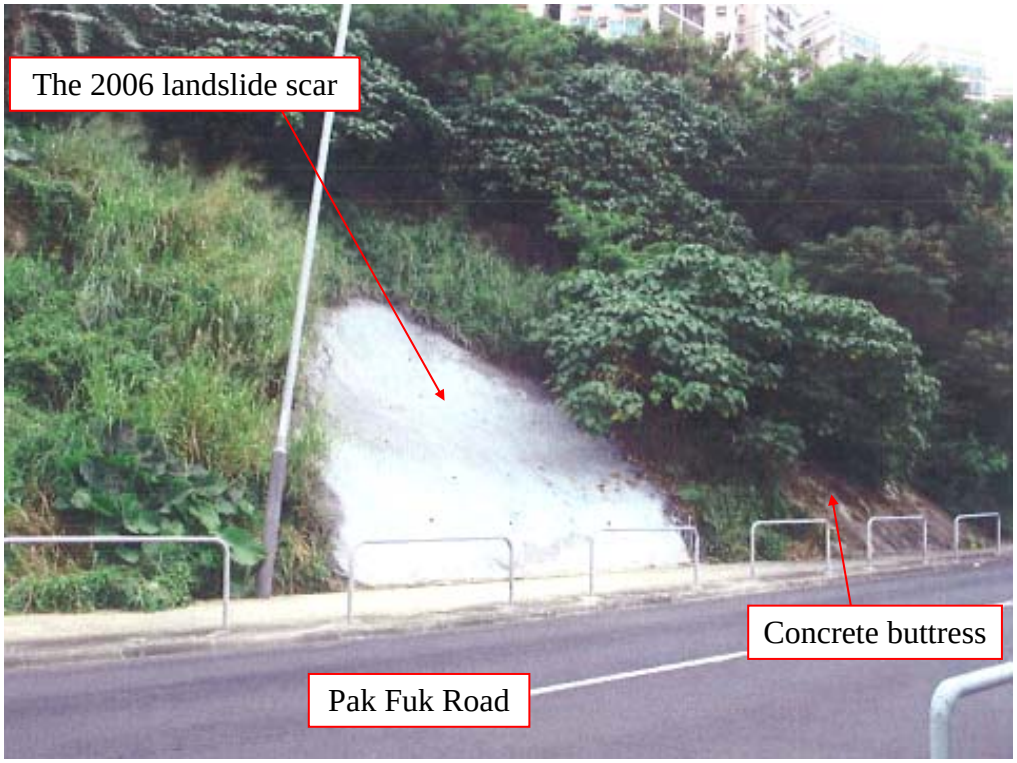


Plate 13 - The 2006 Landslide Scar after Completion of Emergency Repair Works
(Photograph taken on 9 October 2006)

Note: See Figure 16 for location and direction of photograph.

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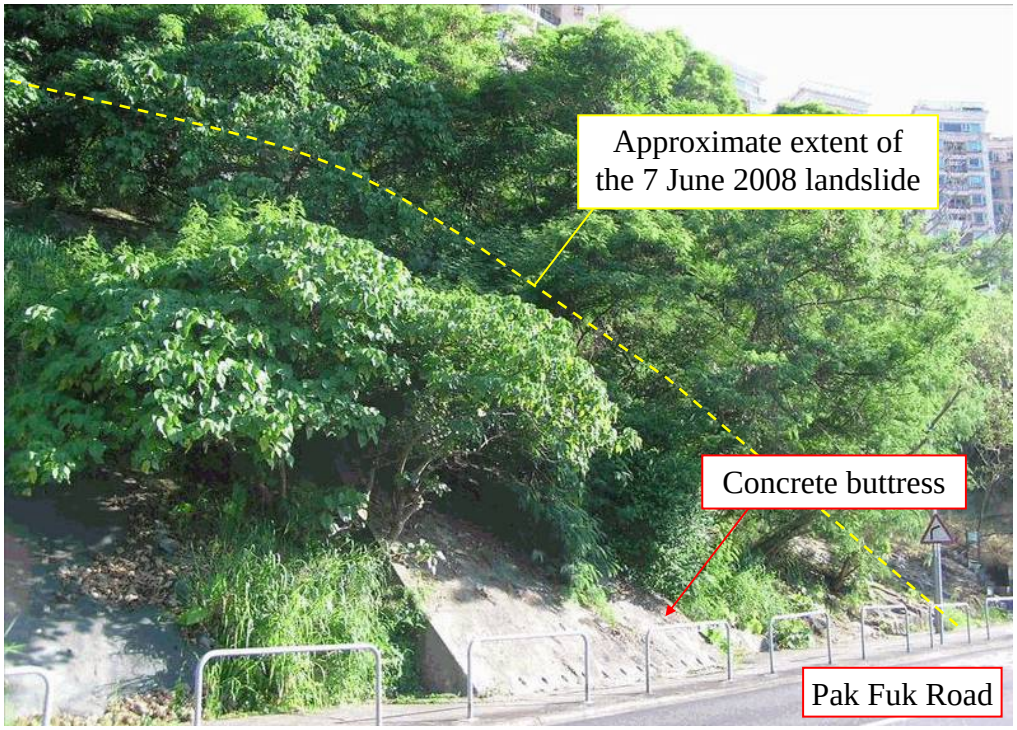


Plate 14 - General View of Slope No. 11SE-A/C502 in 2007
(Photograph taken during RMI on 23 August 2007)


Plate 15 - Eastern Portion of Slope No. 11SE-A/C502 in 2003
(Photograph taken on 19 July 2003)

Note: See Figure 16 for location and direction of photograph.

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Plate 16 - Rupture Surface of the 7 June 2008 Landslide
(Photograph taken on 18 June 2008)

Note: See Figure 16 for location and direction of photograph.

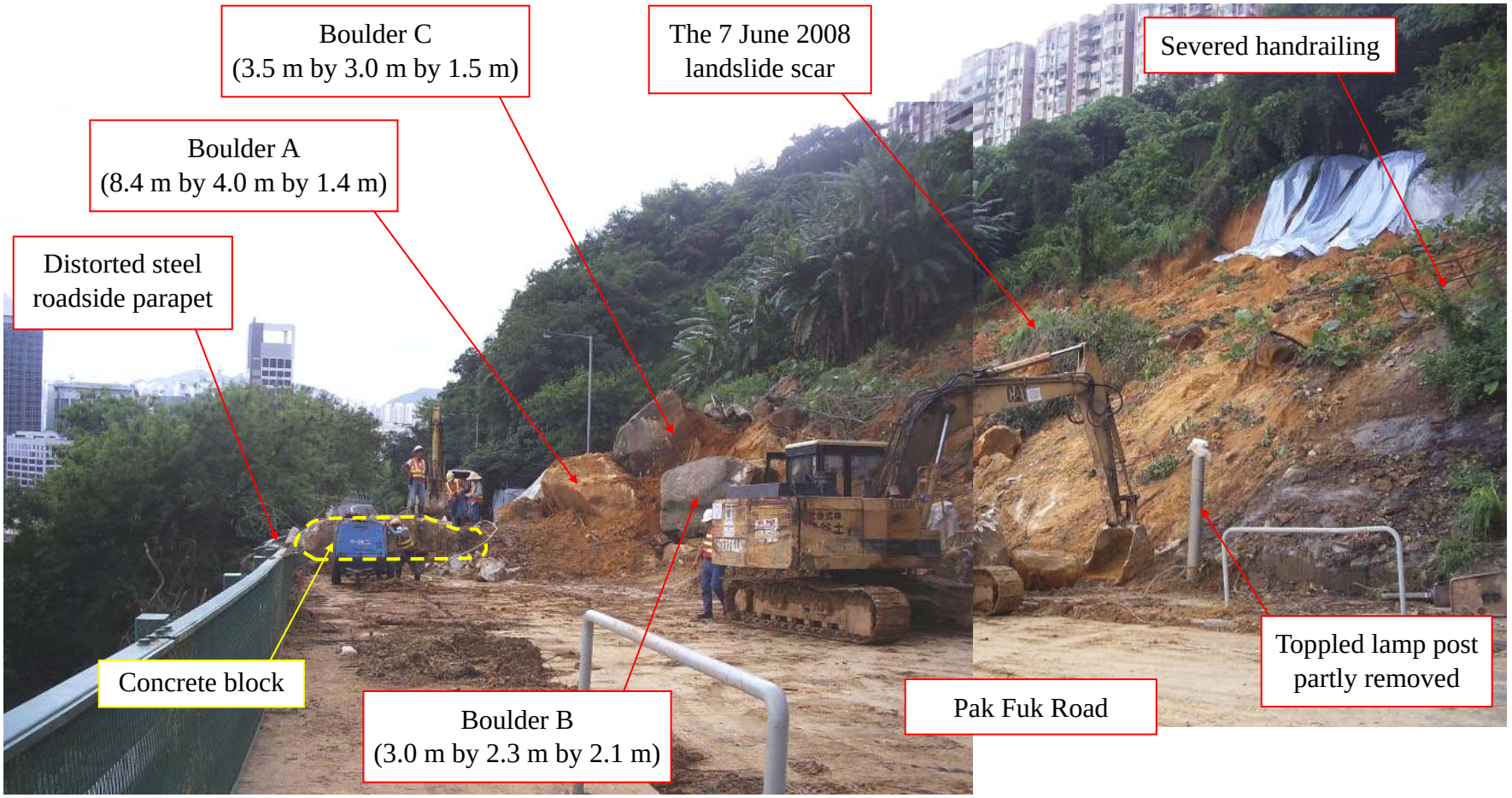


Plate 17 - General View of the 7 June 2008 Landslide Site during Emergency Repair Works
(Photograph taken on 10 June 2008)

Note: See Figure 16 for location and direction of photograph.



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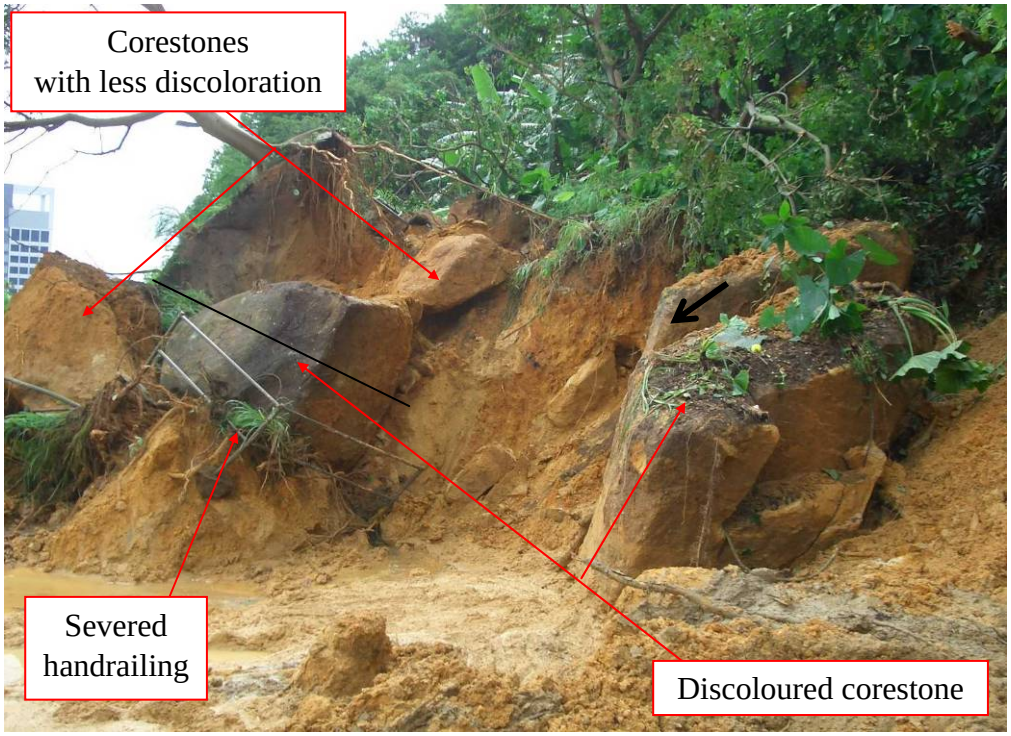


Plate 18 - Large Boulders in the Landslide Debris
(Photograph taken on 8 June 2008)


Plate 19 - Severed Drainage Channel at Mid-height of the Slope
(Photograph taken on 10 June 2008)

Note: See Figure 16 for location and direction of photograph.

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Plate 20 - General View of Landslide Debris from Crest Area
(Photograph taken on 10 June 2008)

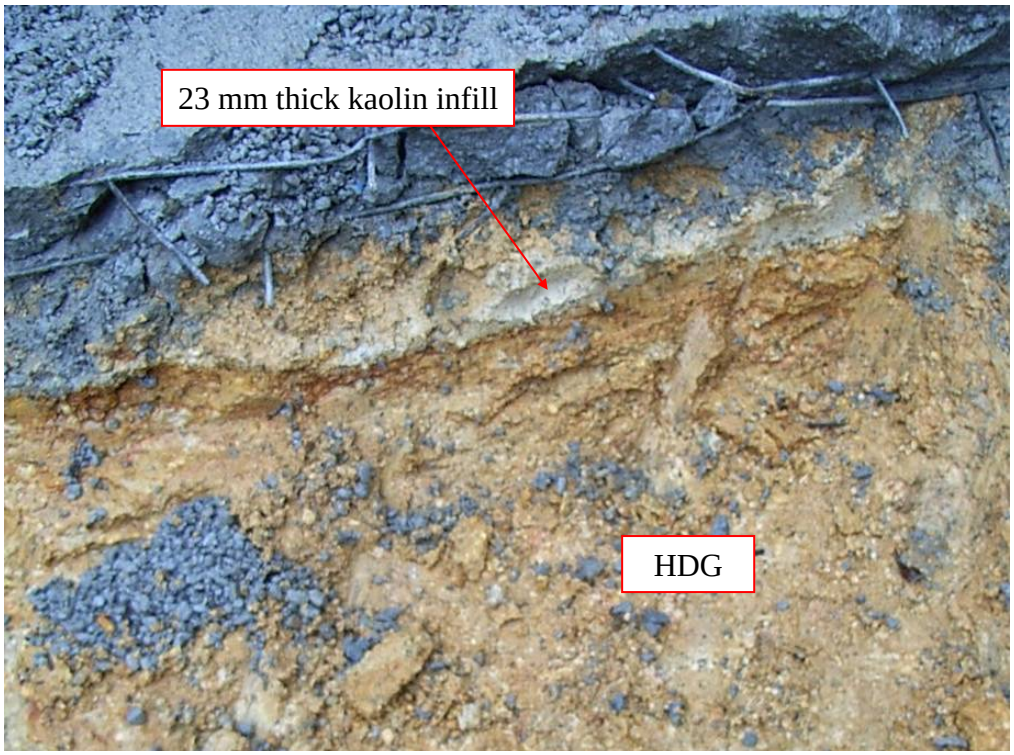


Plate 21 - Kaolin Infill Observed in Trial Pit No. TP6
(Photograph taken on 26 May 2009)

Note: See Figure 16 for location and direction of photograph.

Plate 22 - Kaolin Infill Observed in Slope Surface Strip No. SS1
(Photograph taken on 26 May 2009)

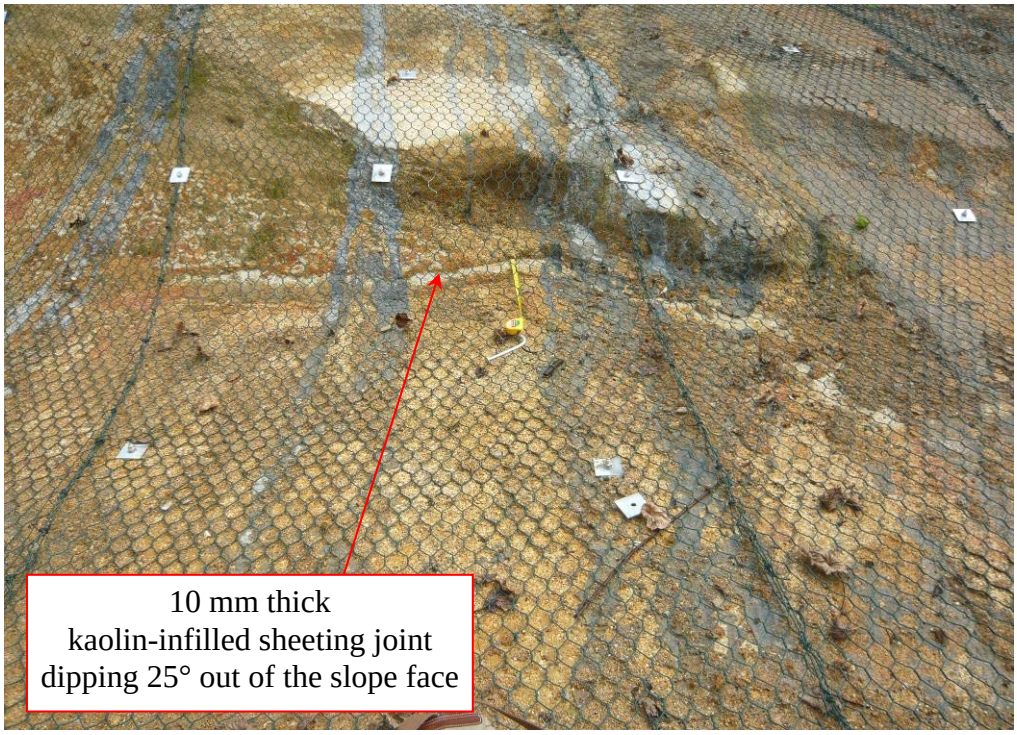


Plate 23 - Kaolin-infilled Sheeting Joint Exposed during LPM Works
(Photograph taken on 4 June 2010)

Note: See Figure 16 for location and direction of photograph.

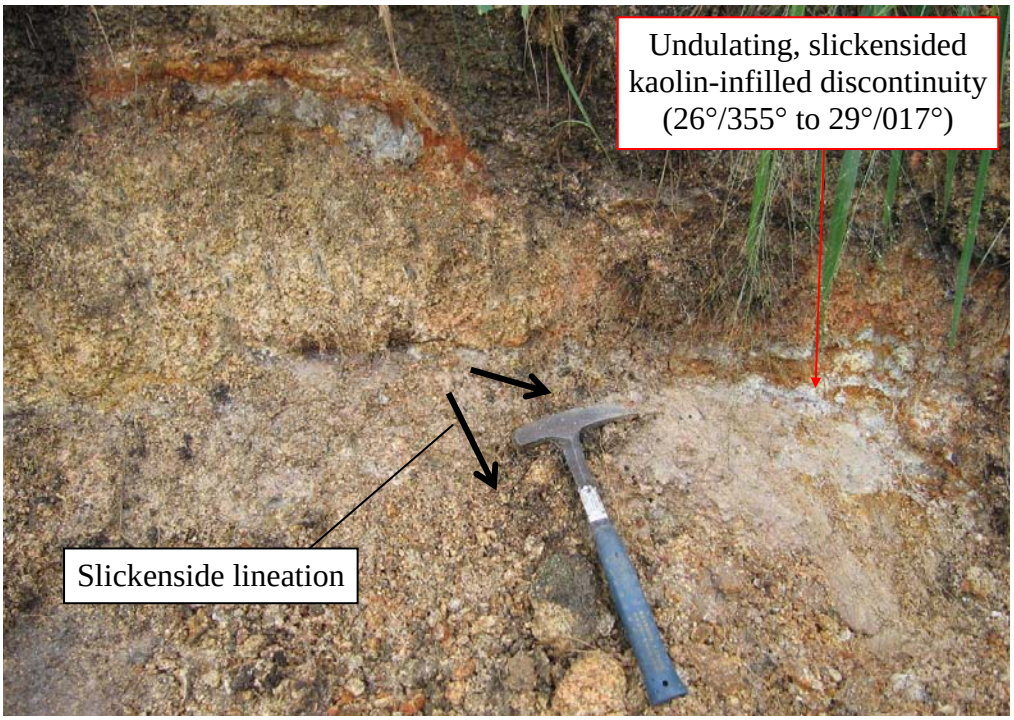


Plate 24 - Slickensided Kaolin-infilled Discontinuity
(Photograph taken on 18 June 2008)

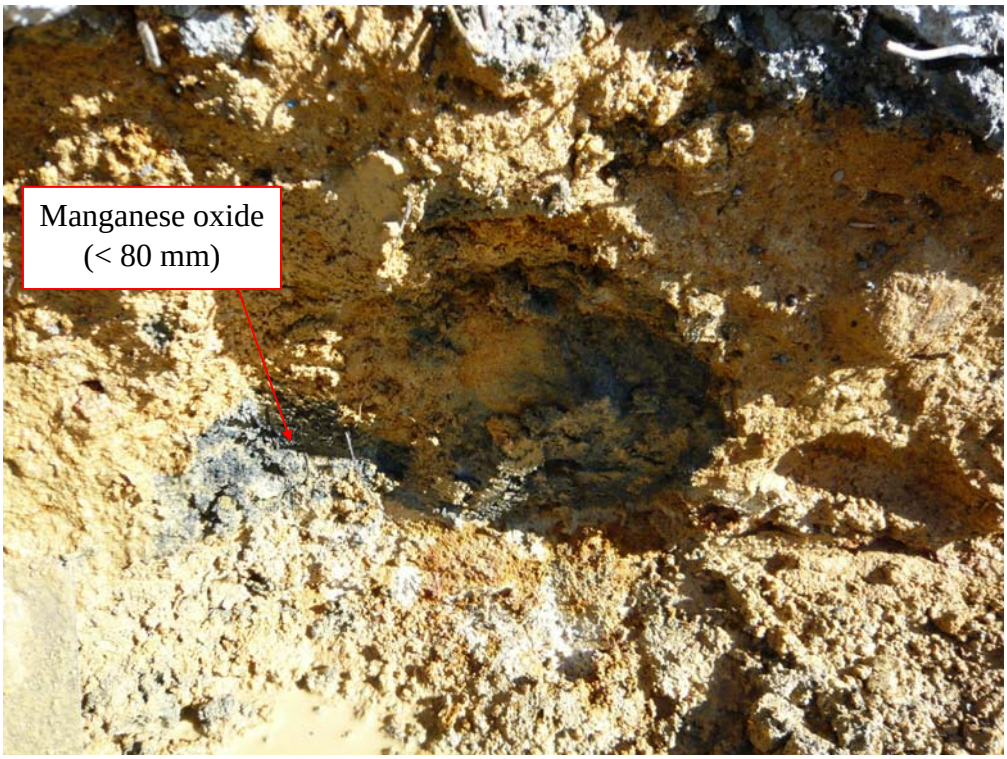


Plate 25 - Manganese Oxide Observed in Slope Surface Strip No. SS2
(Photograph taken on 26 May 2009)

Note: See Figure 16 for location and direction of photograph.

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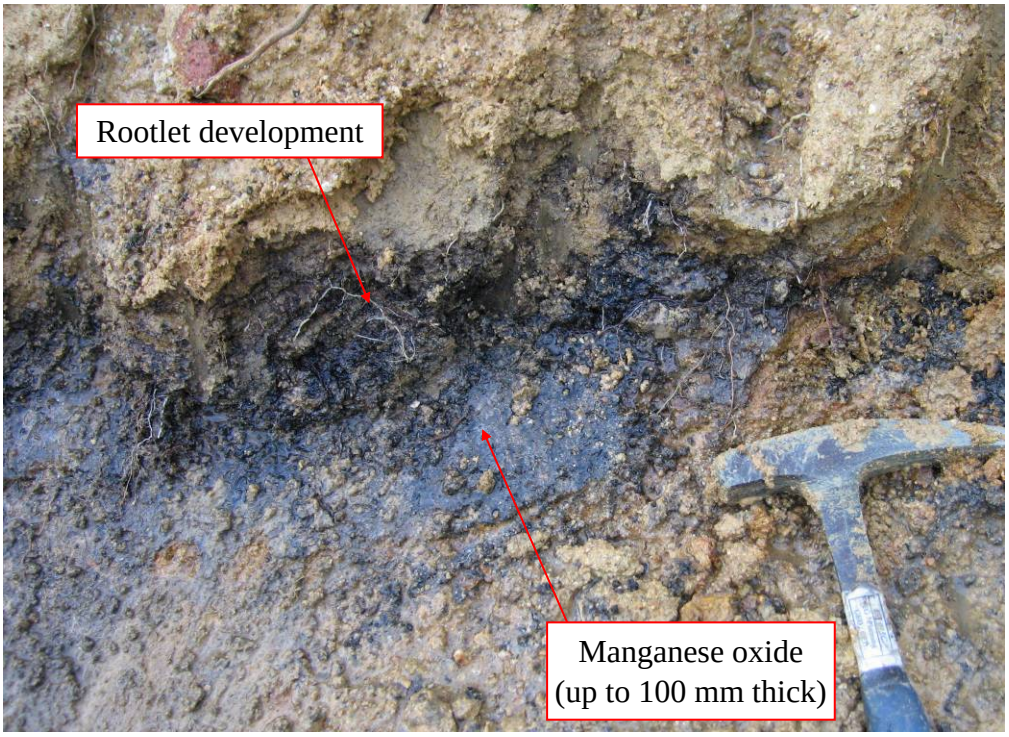


Plate 26 - Manganese Oxide Coated Sheeting Joint
(Photograph taken on 18 June 2008)

Plate 27 - Seepage from Toe of Western Portion of Slope No. 11SE-A/C502
(Photograph taken on 10 June 2008)

Note: See Figure 16 for location and direction of photograph.

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Plate 28 - Seepage at the Lower Portion of Slope No. 11SE-A/C710
(Photograph taken on 10 June 2008)

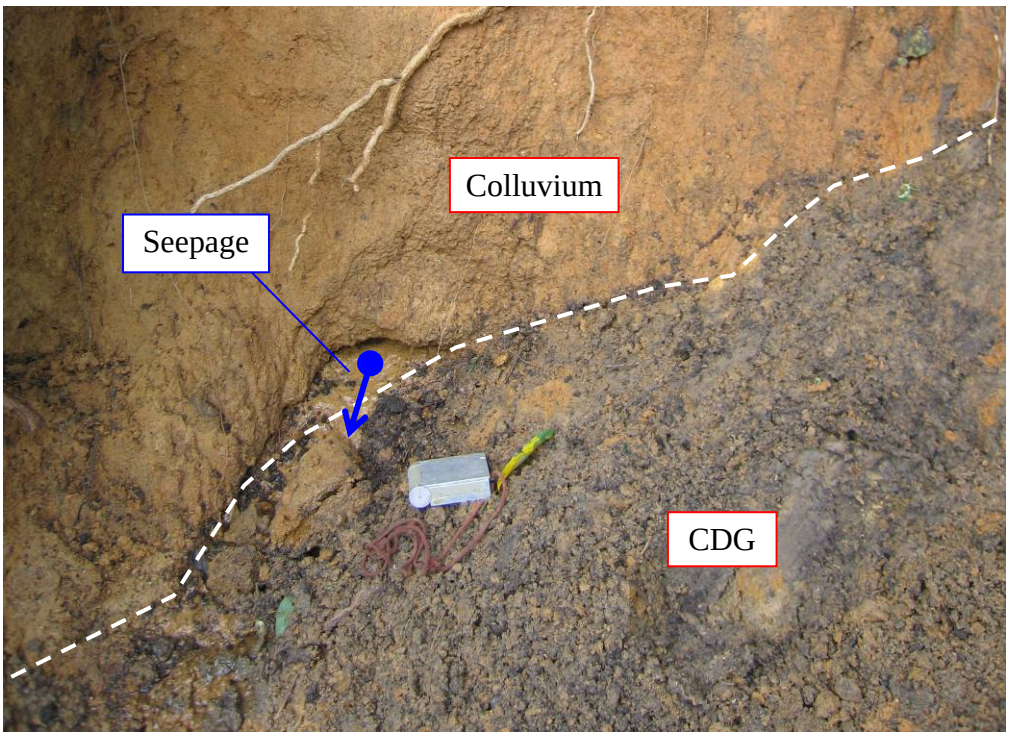


Plate 29 - Seepage at the Base of Colluvium in the Landslide Scarp
(Photograph taken on 18 June 2008)

Note: See Figure 16 for location and direction of photograph.

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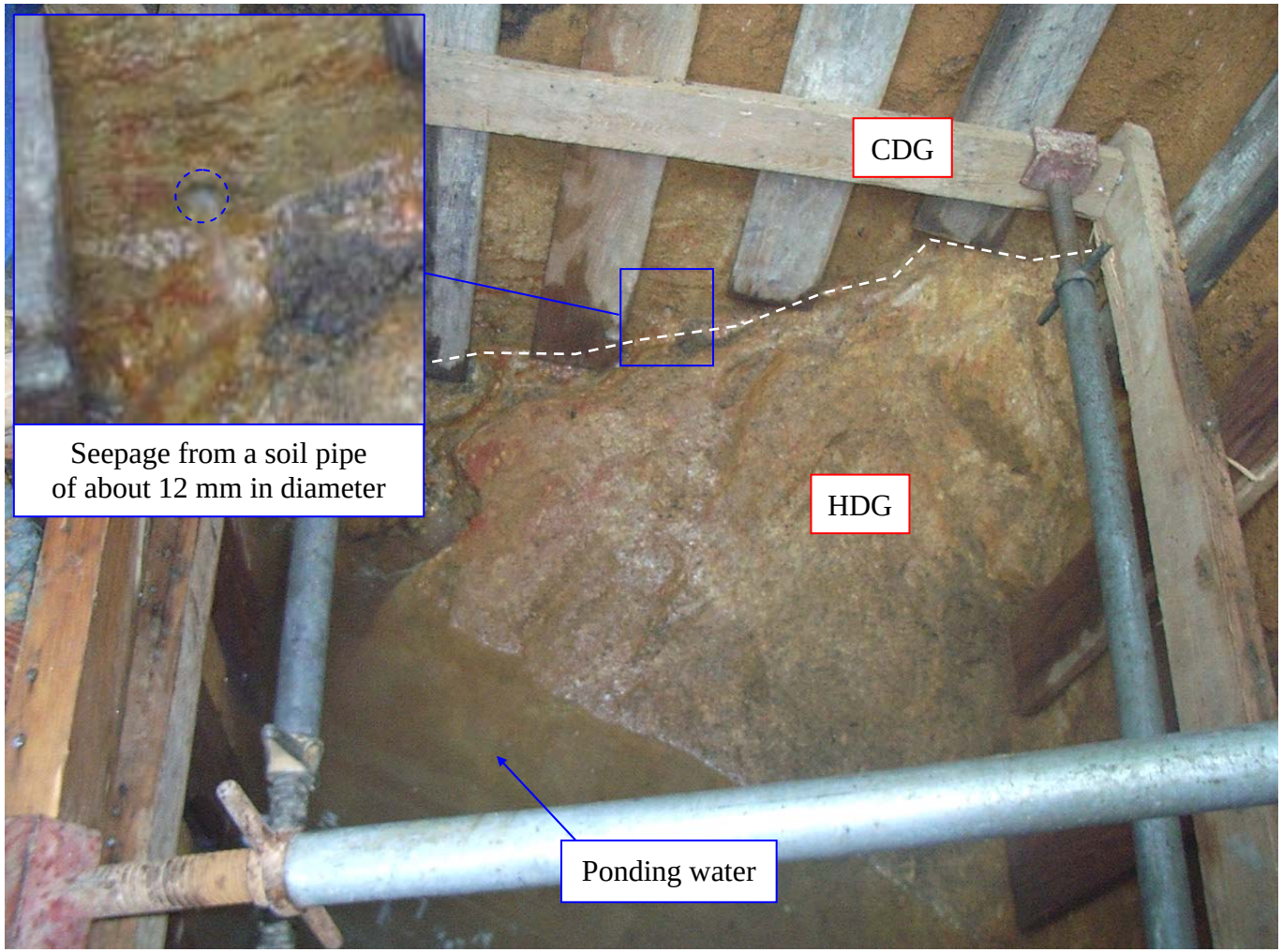


Plate 30 - Seepage from a Soil Pipe in Trial Pit No. TP5
(Photograph taken on 25 May 2009)

Note: See Figure 16 for location and direction of photograph.

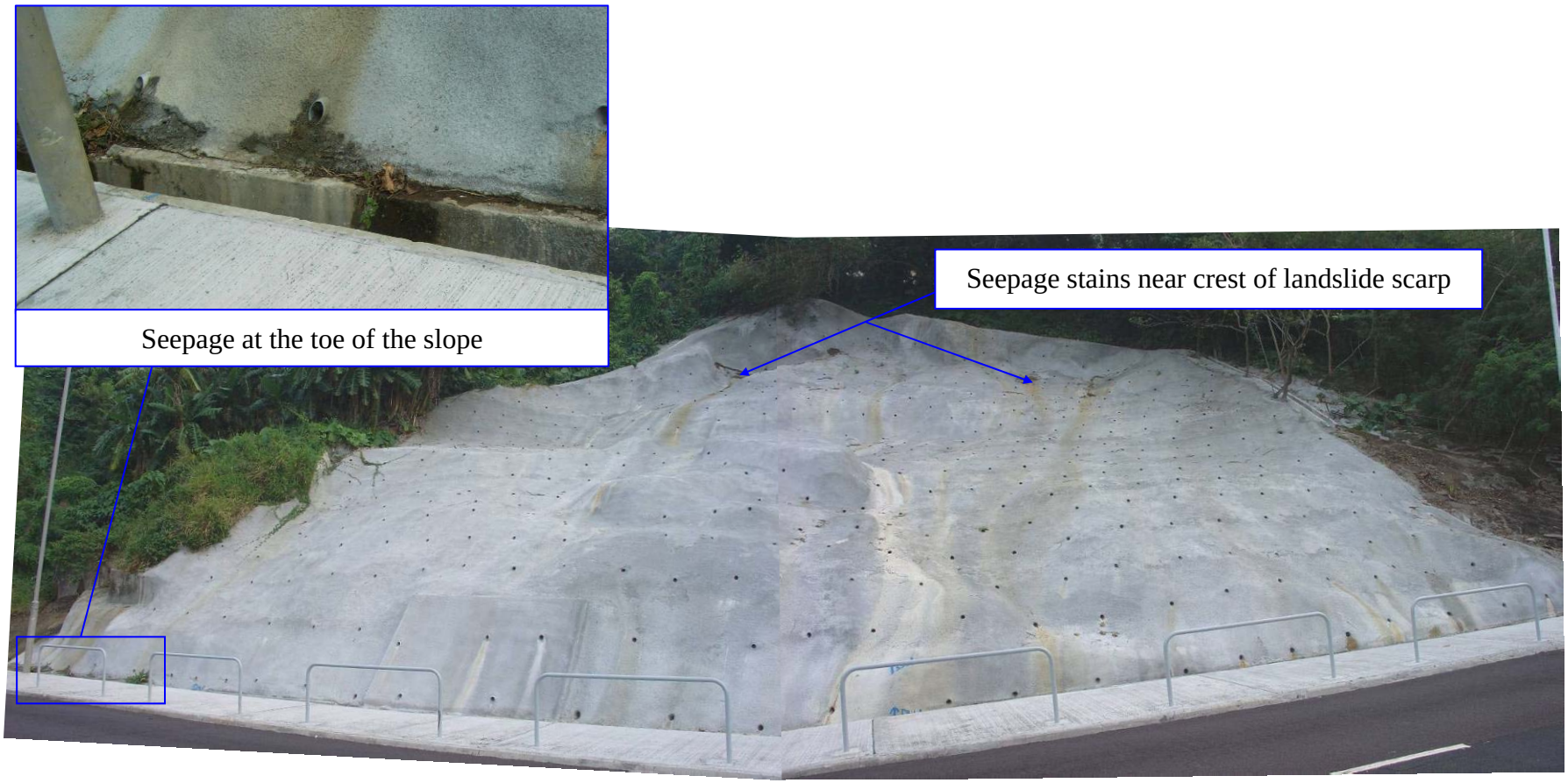


Plate 31 - Seepage Stains on the Shotcreted Landslide Scar
(Photograph taken on 18 November 2008)

Note: See Figure 16 for location and direction of photograph.



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# APPENDIX A

# AERIAL PHOTOGRAPH INTERPRETATION

CONTENTS

## A1. DETAILED OBSERVATIONS

Detailed observations from a review of the available aerial photographs taken between 1945 and 2008 are presented below. A list of the aerial photographs reviewed is given in Table A1 and the major site development history is shown on Figures A1 and A2, as well as on Plates A1 and A2.

**YEAR OBSERVATIONS**

1945 High altitude photographs (Figure A2).

The area of slope No. 11SE-A/C502 and its vicinity is a largely undeveloped, generally northerly sloping natural terrain belonging to a gently rounded peak, which is bi-sected by a drainage line in a northeast-southwest orientation. A number of other drainage lines are also present in the general area. A well-defined drainage line lies just east of the present-day location of slope No. 11SE-A/C502 in which several large boulders are present. Upstream, this drainage line is intercepted by Braemar Hill Reservoir. Downstream near Kai Yuen Street, a box culvert has been formed. Two other minor drainage lines are present within the northerly facing slope of the rounded peak, one of which passes through the present-day location of slope No. 11SE-A/C502. The upper portions of these two drainage lines are well-defined but become less prominent around the present-day location of Tin Hau Temple Road. Footpaths are present on the sloping terrain.

Development in the general area consists of Kai Yuen Street and two structures at the locations of the present-day Bedford Gardens and Kai Yuen Mansion to the north of the present-day slope No. 11SE-A/C502.

1949 High altitude photographs.

The area still remains largely undeveloped. Two possible relict landslide scars are located on the northerly facing terrain at the upper parts of the minor drainage lines. The minor drainage lines are less apparent due to vegetation growth. More footpaths have been formed.

1963 Low altitude photographs.

Major development has commenced in the area. Tin Hau Temple Road has been formed through a series of cutting and filling to the south of the present-day slope No. 11SE-A/C502 up to the point of the present-day Po Luen Path. At the eastern end of Tin Hau Temple Road, site formation works for Kingsford Gardens are in progress. Tin Hau Temple Road and the site formation works have intercepted the well-defined and minor drainage lines. Slope No. 11SE-A/R342 has been formed alongside Tin Hau Temple Road, approximately 15 m south of the present-day slope No. 11SE-A/C502, traversing one of the minor drainage lines. A few squatter structures are evident on the northerly facing hillside downslope of Tin Hau Temple Road. A landslide has occurred at the head of the drainage line which bi-sects the rounded peak.

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| YEAR | OBSERVATIONS |
|---|---|
| 1964 | High altitude photographs.<br><br>No significant changes are observed on the northerly facing hillside. More small squatter structures have been formed on the hillside in the vicinity of the present-day slope No. 11SE-A/C502. Development of Kingsford Gardens is continuing. |
| 1967 | Low altitude photographs.<br><br>The small squatter structures are clearly seen on the northerly facing hillside adjacent to Tin Hau Temple Road and further downslope area adjacent to the well-defined drainage line. The general area of the small squatter structures is clear of vegetation. Site formation works at the present-day location of Pacific Palisades has commenced and the first two blocks of Kingsford Gardens have been erected. |
| 1969 | No apparent changes are observed in the area of the present-day slope No. 11SE-A/C502 and its vicinity. Construction of Kingsford Gardens is completed. |
| 1972 | High altitude photographs.<br><br>No apparent changes are observed in the area of the present-day slope No. 11SE-A/C502 and its vicinity. A spillway and box culvert has been formed at the eastern end of Braemar Hill Reservoir connecting to a culvert at the location of the present-day Po Luen Path. |
| 1973 | Low altitude photographs.<br><br>No apparent changes are observed in the area of the present-day slope No. 11SE-A/C502 and its vicinity. The structure observed in 1945 at the location of the present-day Bedford Gardens has been demolished. |
| 1974 | Single, high altitude photograph.<br><br>No apparent changes are observed in the area of the present-day slope No. 11SE-A/C502 and its vicinity. |
| 1975 | High altitude photographs.<br><br>No apparent changes are observed in the area of the present-day slope No. 11SE-A/C502 and its vicinity. Braemar Hill Reservoir has been filled and the associated major drainage inlet has been diverted to the culvert constructed at the spillway observed in 1972. |
| 1976 | Single, low altitude photograph.<br><br>No apparent changes are observed in the area of the present-day slope No. 11SE-A/C502 and its vicinity. |

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| YEAR | OBSERVATIONS |
|---|---|
| 1978 | Single, low altitude photograph.<br><br>Development of Bedford Gardens is in progress. The section of Pak Fuk Road from Tin Hau Temple Road to the elevated access road leading to Bedford Gardens has been partly constructed. Formation of slope No. 11SE-A/C502 has commenced but the lower portion of the slope is covered with excavated material. A small failure is located above the crest of the western slope portion. At the crest of the cut slope, the slope has been cleared of all the previous squatter structures and the cleared area is less vegetated than the surrounding slope. A sizeable boulder is evident within the cleared extent.<br><br>Slope Nos. 11SE-A/C710 and 11SE-A/C720 have been formed to the east of the well-defined drainage line but the excavated material covers much of the toe area along Pak Fuk Road. Construction works at the present-day location of Pacific Palisades appear to have ceased for some time and vegetation cover is establishing on the site. |
| 1979 | Low altitude photographs.<br><br>Development of Bedford Gardens is continuing. The excavated material along Pak Fuk Road has been cleared and the rock cut at the toe of slope No. 11SE-A/C502 is visible. However, the slope has not yet been cut back to its present-day alignment along the toe. Large outcrop/corestone within the cut extent is visible. |
| 1980 | Low altitude photographs (Plate A1).<br><br>Slope No. 11SE-A/C502 has been formed by further cutting back at the toe and the pedestrian pavement of Pak Fuk Road is formed. The extent of the slope crest is difficult to delineate due to vegetation growth and shadow over the feature. Development of Bedford Gardens and its access road have largely been completed. |
| 1981 | High altitude photographs.<br><br>No apparent changes are observed on slope No. 11SE-A/C502 and its vicinity. Site formation for Pui Kiu Middle School is in progress. |
| 1982 | Low altitude photographs.<br><br>No apparent changes are observed on slope No. 11SE-A/C502 and its vicinity. |
| 1983 | The vegetation over the eastern portion of slope No. 11SE-A/C502 has been cleared and the area is covered with a hard surface. The western slope portion remains largely vegetated. A concrete buttress has been constructed at the eastern slope toe supporting boulders/corestones. Pui Kiu Middle School has been constructed. |

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| YEAR | OBSERVATIONS |
|---|---|
| 1984 | Low altitude photographs (Plate A2).<br><br>The extent of the hard surface cover over the eastern portion of slope No. 11SE-A/C502 is clearly visible, which includes a small area beyond the crest of the feature. A crest surface channel is visible over the eastern portion of the slope. Within the extent of the hard surface cover, large boulders/corestones are visible. |
| 1985 | Low altitude photographs.<br><br>Vegetation has established on the slope No. 11SE-A/C502 and the canopy covers much of the slope area. No other changes of significance are observed on slope No. 11SE-A/C502 and its vicinity. |
| 1986 to 1993 | No changes of significance are observed on slope No. 11SE-A/C502 and its vicinity. To the south of the slope, construction of Pacific Palisades has commenced in 1988 and is largely completed by 1990. |
| 1994 | Low altitude photographs.<br><br>Vegetation had been cleared over the western portion of slope No. 11SE-A/C502. |
| 1995 | Low altitude photographs.<br><br>Vegetation had re-established over the western portion of slope No. 11SE-A/C502. |
| 1996 to 2007 | No changes of significance are observed on slope No. 11SE-A/C502 and its vicinity. |
| 2008 | Low altitude photographs.<br><br>Emergency works for the 7 June 2008 landslide are apparent over the eastern portion of slope No. 11SE-A/C502. |

# LIST OF TABLES

Table A1 – List of Aerial Photographs Reviewed

| Date Taken | Altitude (ft) | Photograph Number |
|---|---|---|
| 11 November 1945 | 20,000 | Y00428/29 |
| 8 May 1949 | 8,600 | Y01548/49 |
| 1 February 1963 | 2,700 | Y7649/50 |
| 13 December 1964 | 12,500 | Y12902/03 |
| 16 May 1967 | 6,250 | Y13334/35 |
| 1969 | – | Y14718/19 |
| 3 October 1972 | 130,000 | 2288/89 |
| 23 October 1973 | 5,000 | 5301/02 |
| 21 November 1974 | 12,500 | 9695 |
| 24 December 1975 | 12,500 | 12050/51 |
| 28 January 1976 | 4,000 | 12587 |
| 5 December 1978 | 4,000 | 23919 |
| 8 September 1979 | 4,000 | 26567/68 |
| 12 November 1980 | 4,000 | 32698/99 |
| 26 October 1981 | 10,000 | 39041/42 |
| 29 July 1982 | 4,000 | 43296/97 |
| 28 September 1983 | 4,000 | 49823/26 |
| 30 November 1983 | 10,000 | 51381/82 |
| 27 January 1984 | 3,500 | 53362/63 |
| 6 December 1985 | 4,000 | A03712/13 |
| 3 March 1986 | 4,000 | A04267/68 |
| 5 January 1987 | 20,000 | A08399/400 |
| 3 November 1988 | 10,000 | A15234/35 |
| 15 August 1989 | 4,000 | A17617/18 |
| 14 November 1990 | 4,000 | A23737 |
| 20 September 1991 | 4,000 | A27351/52 |
| 15 October 1992 | 4,000 | A32477/78 |
| 18 August 1993 | 10,000 | CN4031/32 |
| 17 November 1994 | 4,000 | CN7869/70 |
| 27 September 1995 | 3,500 | CN11210/11 |
| 12 June 1996 | 4,000 | CN14295/96 |
| 26 May 1997 | 4,000 | CN17123/24 |
| 4 August 1998 | 4,000 | CN20949/50 |
| 9 December 1999 | 8,000 | CN25707/08 |
| 26 July 2000 | 4,000 | CN27416/17 |
| 1 March 2001 | 4,000 | CN30070/71 |
| 9 October 2002 | 8,000 | CW45462/63 |
| 25 September 2003 | 8,000 | CW50122/23 |
| 11 September 2004 | 4,000 | CW58846/47 |
| 24 October 2005 | 4,000 | CW65729/30 |
| 9 November 2006 | 8,000 | CW75162/63 |
| 23 November 2007 | 6,000 | CS08928/30 |
| 25 November 2008 | 6,000 | CS19616/17 |
| Note: Aerial photographs are in black and white, except for those prefixed with CN, CW & CS. | | |

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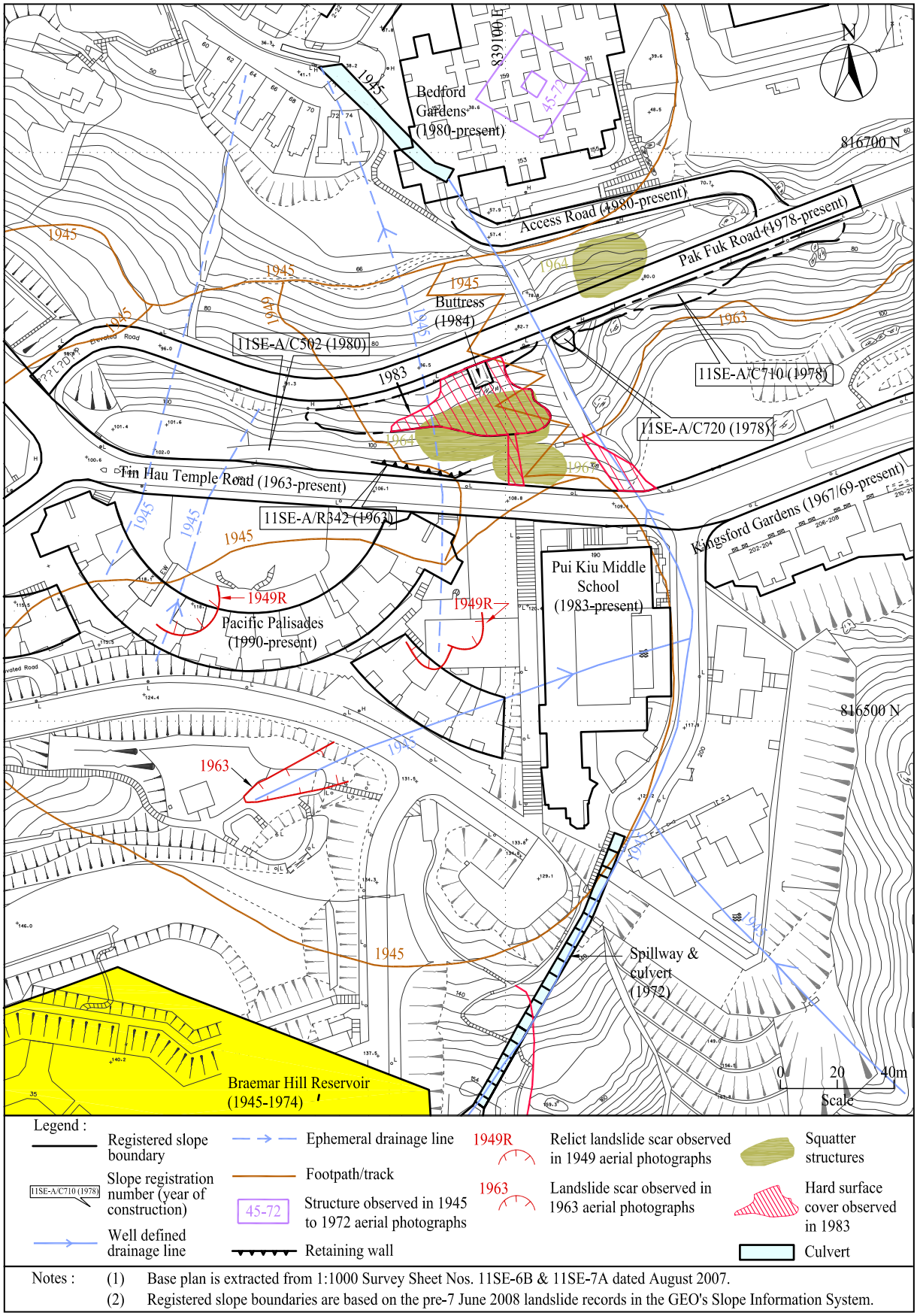
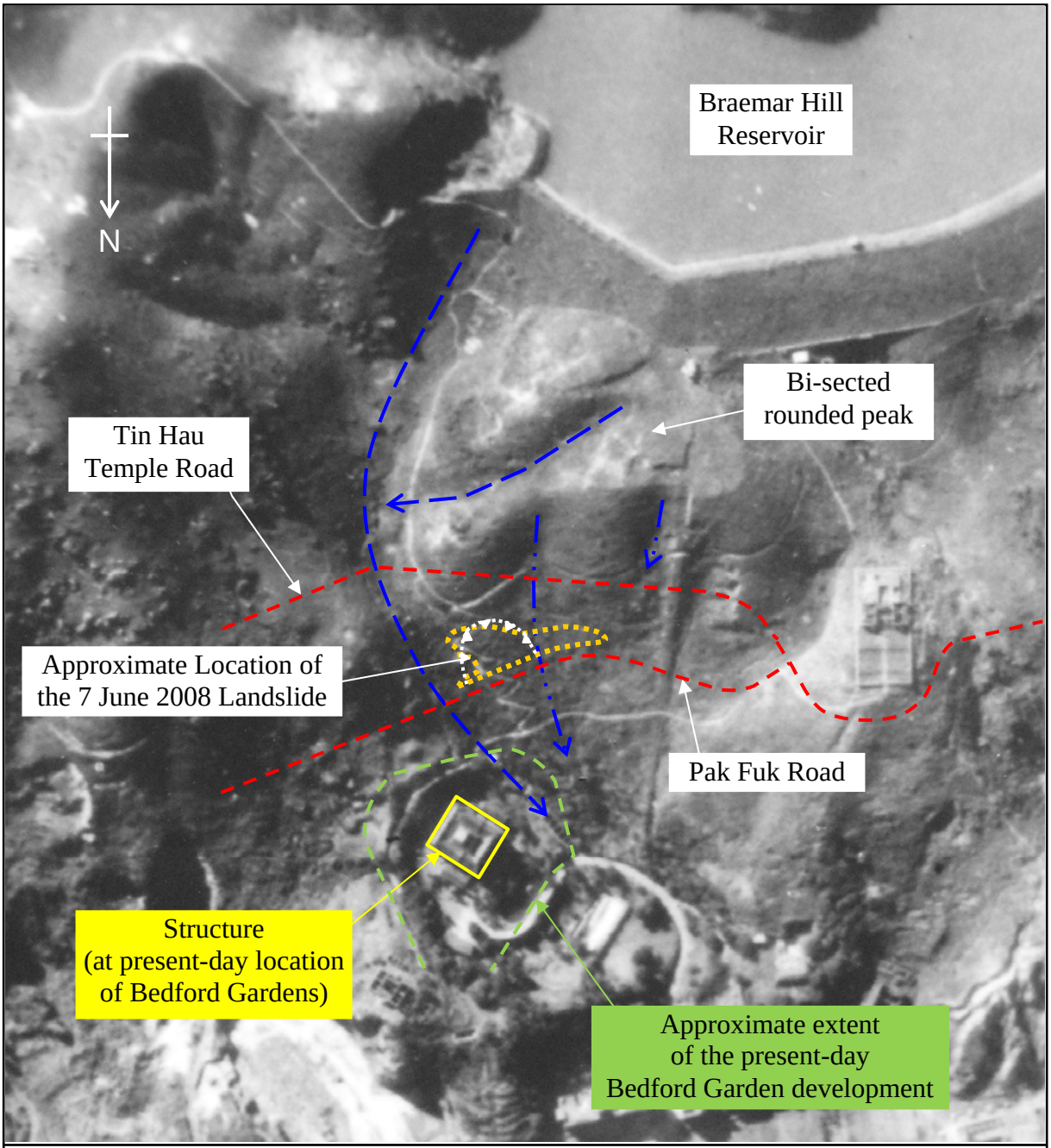



Figure A1 - Detailed API Observations




Legend:

- Well-defined drainage line
- Ephemeral drainage line
- Road
- Approximate extent of slope No. 11SE-A/C502

Notes:
(1) The figure is based on Aerial Photograph No. Y00429 taken on 11 November 1945.
(2) The slope and roads marked are indicative of their approximate locations at the time of the 7 June 2008 landslide.

Figure A2 – General Site Setting in 1945 Prior to Major Developments

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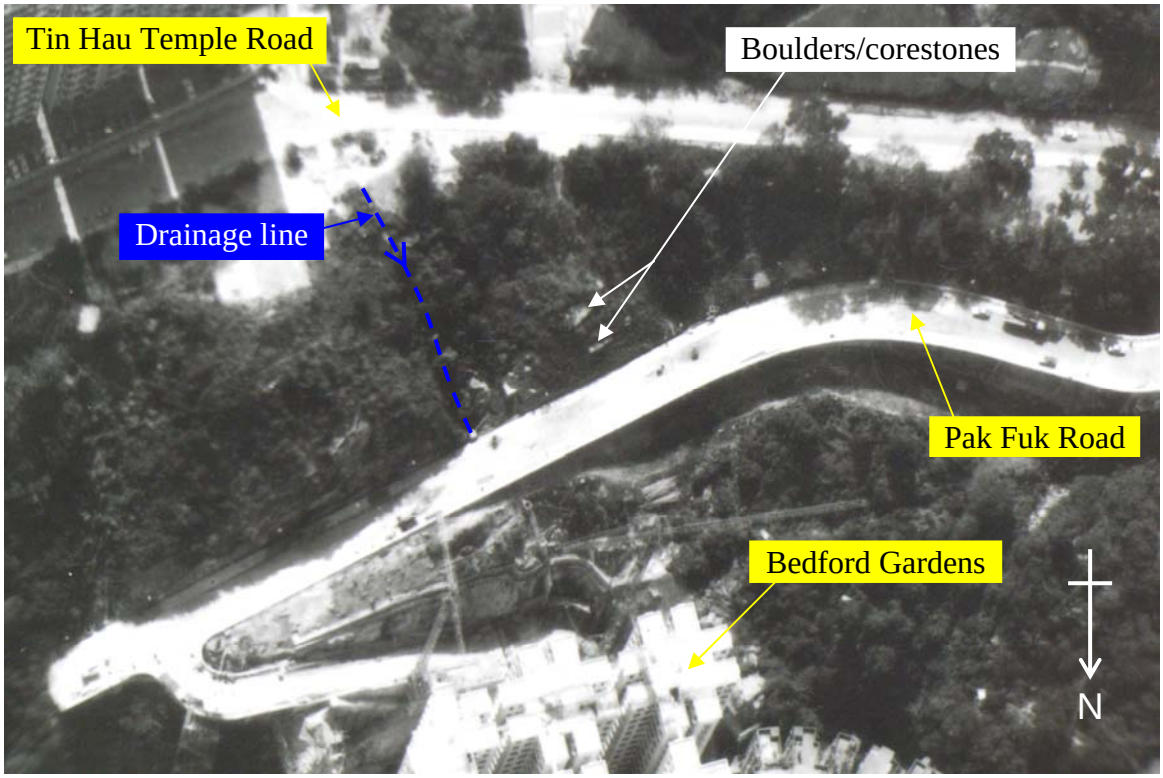


Plate A1 – Slope No. 11SE-A/C502 Observed in the 1980 Aerial Photograph
(Aerial Photograph No. 32698 taken on 12 November 1980)

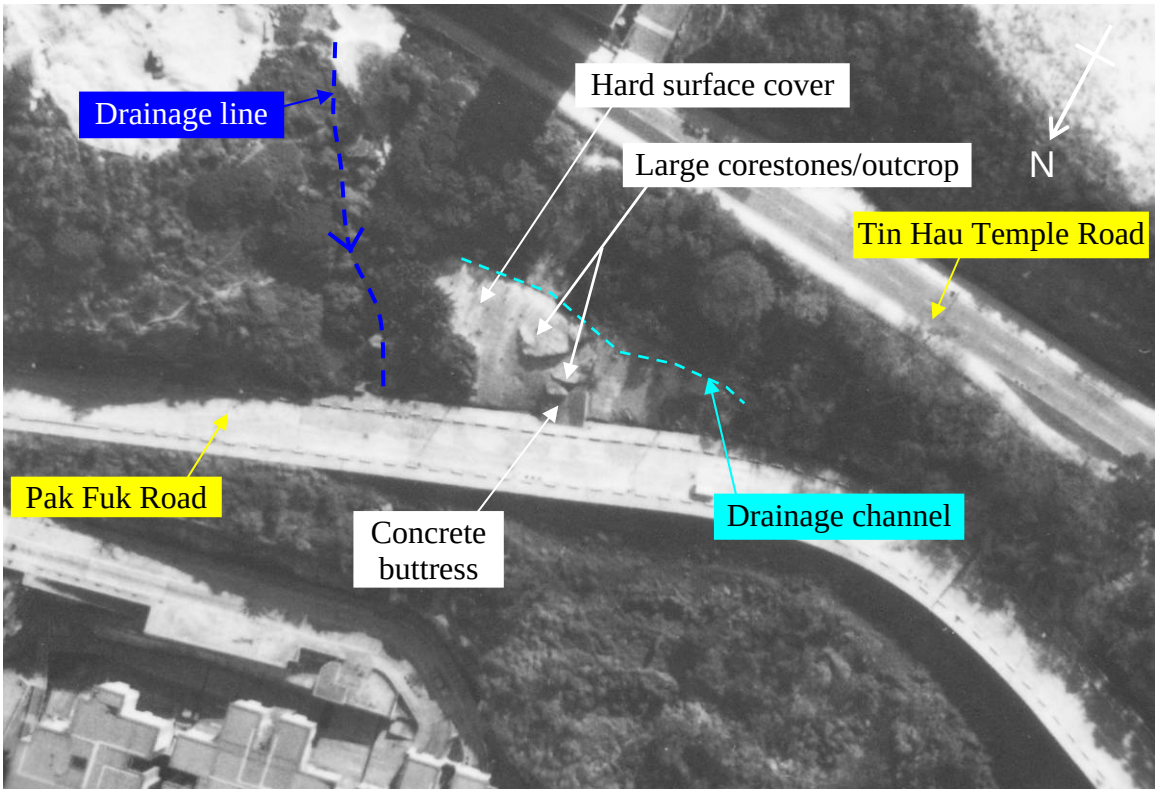


Plate A2 – Hard Surface Cover Noted in the 1984 Aerial Photograph
(Aerial Photograph No. 53362 taken on 27 January 1984)

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APPENDIX B

MAINTENANCE INSPECTIONS OF SLOPE NO. 11SE-A/C502
PRIOR TO THE 7 JUNE 2008 LANDSLIDE

CONTENTS

## B1. INTRODUCTION

Regular maintenance inspections of slope No. 11SE-A/C502 were carried out by HyD or his consultants since 1998. Relevant observations from a review of the available maintenance records prior to the 7 June 2008 landslide are presented below and summarised in Tables B1 and B2.

## B2. ROUTINE MAINTENANCE INSPECTIONS

Routine Maintenance Inspections (RMI) of slope No. 11SE-A/C502 were undertaken in general annually between 1998 and 2007 by HyD or his consultants (Table B1). Overall, no signs of distress or seepage were noted in any of the RMIs.

Routine Maintenance Works (RMWs), typically comprising the clearance of blocked drainage channels, repair of damaged slope surface cover, etc., were recommended in 1999, 2001 and 2004 to 2007. All the recommended RMWs were completed accordingly.

## B3. ENGINEER INSPECTIONS FOR MAINTENANCE

Engineer Inspections (EIs) of slope No. 11SE-A/C502 were carried out in June 1999 and January 2004 by the HyD's consultants (Table B2). Overall, no signs of significant distress nor seepage were observed during the 1999 and 2004 EIs.

Based on the 1999 EI, the overall state of maintenance for slope No. 11SE-A/C502 was assessed to be "fair", i.e. only minor maintenance works required (GEO, 1998). Records of the 1999 EI noted partially blocked and moderately cracked surface drainage channels and loose rock blocks at the toe of the western slope portion, and clearly indicated that the eastern portion of the slope, where the 7 June 2008 landslide occurred, was largely vegetated.

Based on the 2004 EI, the overall state of maintenance for slope No. 11SE-A/C502 was assessed as "Class 1", i.e. none or minor defects are identified and the overall state of maintenance is satisfactory in general (GEO, 2003). Records of the 2004 EI noted minor cracks on surface drainage channel at the slope toe and loose rock blocks at the western end of the slope, as well as an open joint on the rock cut along slope toe. Necessary maintenance works, including the installation of rock mesh protection, were carried out in September 2004.

## B4. REFERENCES

Geotechnical Engineering Office (1998). Guide to Slope Maintenance (Geoguide 5). Second Edition. Geotechnical Engineering Office, Hong Kong, 91 p.

Geotechnical Engineering Office (2003). Guide to Slope Maintenance (Geoguide 5). Third Edition. Geotechnical Engineering Office, Hong Kong, 132 p.

LIST OF TABLES

Table B1 – Summary of Observations and Recommendations Made in Routine Maintenance Inspections

| Date of RMI | | 13 Oct 98 | 2 Nov 99 | 18 Dec 00 | 6 Dec 01 | 31 Dec 02 | 2 Jan 04 | 18 Jan 05 | 5 Oct 06 | 23 Aug 07 |
|---|---|---|---|---|---|---|---|---|---|---|
| Routine Maintenance Works (RMWs) [see (1)] | Clear drainage channels of accumulated debris | No | Yes | No | Yes | No | Yes | Yes | Yes | Yes |
| | Repair cracked/damaged drainage channels or pavements along crest and toe of slope and retaining wall | No | Yes | No | No | No | No | No | No | No |
| | Repair or replace cracked or damaged impermeable slope surface cover | No | Yes | N/A | N/A | No | Yes | No | Yes | No |
| | Remove surface debris and vegetation causing severe cracking of slope surface cover and drainage channels | No | Yes | No | Yes | No | No | Yes | No | Yes |
| | Remove loose rock debris and undesirable vegetation from rock slopes or boulders | [see (2)] | [see (2)] | [see (2)] | [see (2)] | [see (2)] | [see (2)] | No | No | No |
| | Re-vegetate bare soil slope surface | [see (2)] | [see (2)] | [see (2)] | [see (2)] | [see (2)] | [see (2)] | No | No | No |
| | Unblock weepholes & outlet drains | No | N/A | N/A | N/A | No | N/A | Yes | Yes | No |
| | Repair leaky exposed water-carrying services | [see (2)] | [see (2)] | [see (2)] | [see (2)] | [see (2)] | [see (2)] | No | No | No |
| | Other works specified | Nil | Nil | Nil | Nil | Nil | Trim overgrown vegetation | Nil | Nil | Nil |
| Other observations of relevance to the present landslide study | | No | No | No | No | No staircase was noted | No staircase was noted | No | No | No |
| Immediate EI needed | | No | No | No | No | No | No | No | No | No |
| Immediate arrangement for investigation and repair of water-carrying services needed? | | No | No | No | No | No | No | No | No | No |
| Completion date of RMWs | | Nil | Nov 99 | Nil | Mar 02 | Nil | Apr 04 | Feb 05 | Oct 06 | Sep 07 |

Notes: (1) Other RMWs of no direct relevance to the present landslide study, viz. repair pointing in masonry walls, repair or replace rusted slope furniture and remove debris from defence measures, are not included.
(2) No such item was included in the respective RMI records.

Table B2 – Summary of Observations and Recommendations Made in Engineer Inspections

| Date of EI | | 16 Jun 99 | 19 Jan 04 |
|---|---|---|---|
| Condition of Soil Slope | Condition of rigid surface cover/vegetated surface | Fair | Fair |
| | Condition of drainage channels | Partly blocked, moderate cracking | Partly blocked, moderate cracking |
| | Condition of catchpits and sand traps | Clear, no cracking | Blocked, no cracking |
| | Any recent slope failure/erosion/movement/seepage, tension cracks at the crest, or other signs of instability? | No | No |
| Condition of Rock Slope | Condition of rigid surface cover | No | Fair |
| | Condition of drainage channels | Partly blocked, moderate cracking | Partly blocked, moderate cracking |
| | Condition of catchpits and sand traps | Clear, no cracking | Blocked, no cracking |
| | Any recent rock fall/seepage, loose wedges on slope, badly fractured zones, open joints at the crest or other signs of instability? | No | No |
| | Any loose blocks on slope? | Yes | Yes |
| Overall | Any major defects in surface protection / surface drainage system/special measures? | [see (2)] | No |
| | Any major leakage in water-carrying services? | [see (2)] | No |
| General | Overall state of maintenance | Fair [see (3)] | Class 1 [see (4)] |
| | Has the stability of the slope previously been assessed or upgraded to be adequate? | Yes | No |
| | Do any services need immediate leakage testing? | No | No |
| | Have RMWs been satisfactorily carried out? | Yes | Yes |
| | Is there adequate access to the slope or retaining wall for maintenance inspections? | Yes | No |
| | Slope stability may be affected by water-carrying services | Yes | Yes |
| | Other remarks of relevance to the present landslide study | - No stability assessment could be identified | - Inspection of the slope crest is not possible due to access problem |
| Recommendations | Clear debris, undesirable vegetation and other obstructions from surface drainage system | Yes | Yes |
| | Repair cracks/spalling of rigid surface cover | Yes | Yes |
| | Remove loose rock debris | Yes | Yes |
| | Rebuild severely cracked channels | Yes | No |
| | Seal cracks in surface drainage system | No | Yes |
| | Seal open joints of rock slope or boulders with provision of drain pipes and surface protection to prevent ingress of water | No | Yes |
| | Remove undesirable vegetation on rock slope or boulders | No | Yes |
| | Remove/stabilize unstable boulders/corestones | Yes | No |
| | Other recommendations of relevance to the present landslide study | No | - Stability assessment recommended as no previous assessment could be found |

Notes:
(1) Other observations or remarks in the EI records of no direct relevance to the present landslide study are not included.
(2) No such item was included in the 1999 EI record.
(3) Refer to Table 2 of GEO (1998) for details.
(4) Refer to Table 4.2 of GEO (2003) for details.

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

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

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

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

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Information Services Department,
Room 626, 6th Floor,
North Point Government Offices,
333 Java Road, North Point, Hong Kong.

or

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政府新聞處
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或

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333 Java Road, North Point, Hong Kong.
Tel: (852) 2231 3187
Fax: (852) 2116 0774

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(Attn: Hong Kong Geological Survey Section)
Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
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# MAJOR GEOTECHNICAL ENGINEERING OFFICE PUBLICATIONS
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## GEOTECHNICAL MANUALS

Geotechnical Manual for Slopes, 2nd Edition (1984), 302 p. (English Version), (Reprinted, 2011).

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.

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| Geoguide 1 | Guide to Retaining Wall Design, 2nd Edition (1993), 258 p. (Reprinted, 2007). |
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| Geoguide 3 | Guide to Rock and Soil Descriptions (1988), 186 p. (Reprinted, 2000). |
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| Geospec 1 | Model Specification for Prestressed Ground Anchors, 2nd Edition (1989), 164 p. (Reprinted, 1997). |
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| GCO Publication No. 1/90 | Review of Design Methods for Excavations (1990), 187 p. (Reprinted, 2002). |
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| GEO Publication No. 1/2011 | Technical Guidelines on Landscape Treatment for Slopes (2011), 217 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.

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