REVIEW OF THE 21 AUGUST 2005 LANDSLIDE INCIDENT ON SLOPES AT THE SHING MUN CATCHWATER TSO KUNG TAM TSUEN WAN

GEO REPORT No. 291

Halcrow China Limited

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 12/2009 produced in December 2009

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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.

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

FOREWORD

This report presents the review findings of a landslide (Incident No. 2005/08/0391) which occurred on slopes Nos. 6SE-B/CR193 and 6SE-B/CR212 above the Shing Mun Catchwater between chainage 7010 and chainage 7050, Tso Kung Tam, Tsuen Wan on 21 August 2005. The landslide debris blocked the open catchwater channel below, resulting in overbank flow and subsequent washout failure of fill slope No. 6SE-B/F69 on the downhill side of the catchwater. Extensive washout failures also occurred on slope No. 6SE-B/DT15 adjoining the fill slope. The total volume of failures was more than 1,000 m^3. As a result of the incident, a 15 m long section of the catchwater collapsed and an adjacent concrete access road at the crest of slopes Nos. 6SE-B/F69 and 6SE-B/DT15 was also undermined. No casualties were reported.

The key objectives of this review were to document the facts about the incident and to present relevant background information and pertinent site observations made under this review. The scope of the review does not include any ground investigation or detailed diagnosis of the causes of the incident. Recommendations for follow-up actions are reported separately.

The report was prepared as part of the Landslide Investigation Consultancy for landslides occurring in Kowloon and the New Territories, for the Geotechnical Engineering Office, Civil Engineering and Development Department, under Agreement No. CE 53/2006 (GE). This is one of a series of reports produced during the consultancy by Halcrow China Limited.

Gerry Daughton
Project Director
Halcrow China Limited

Agreement No. CE 53/2006 (GE)
Study of Landslides Occurring in Kowloon and the New Territories in 2007 – Feasibility Study

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1. INTRODUCTION

At about 9:30 a.m. on 21 August 2005 after a Landslip Warning had been in effect for about 36 hours, a landslide incident (Incident No. 2005/08/0391) occurred on the man-made slopes at the Shing Mun Catchwater between chainage 7010 and chainage 7050, Tso Kung Tam, Tsuen Wan (Figure 1).

Halcrow China Limited (HCL), the Landslide Investigation Consultants for Kowloon and the New Territories, undertook a review of the incident for GEO under Agreement No. CE 53/2006 (GE). This report documents the findings of the review study.

2. DESCRIPTION OF THE SITE

The August 2005 landslide incident involved four slopes (viz. slopes Nos. 6SE-B/CR193, 6SE-B/CR212, 6SE-B/F69 and 6SE-B/DT15) located along the Shing Mun Catchwater in Tsuen Wan at about 208 mPD, approximately 170 m to the southeast of the Hong Kong Gun Club (Figure 1). A site layout plan showing the boundaries of the registered slopes, together with the approximate location of the August 2005 incident, is presented in Figure 2. A general view of the slopes is shown in Plate 1.

The section of the Shing Mun Catchwater is an open trapezoidal channel, with a depth of 1.6 m, and a top and base width of 3 m and 1.8 m respectively. The catchwater channel runs from the south (upstream) to the north (downstream). Along the catchwater channel on the downhill side is a 2.5 m wide concrete-paved access road. Two overflow weirs, OW1 and OW2, are located approximately 200 m upstream from slope No. 6SE-B/CR212 and at the northern end of slope No. 6SE-B/CR193 respectively (Figure 1).

Slopes Nos. 6SE-B/CR193 and 6SE-B/CR212, are largely soil cut slopes located above the catchwater channel (Figures 1 and 5). Both slopes have a 1.6 m high concrete toe wall which also forms the sidewall of the catchwater channel. Beyond the crest of the slopes is a natural hillside inclined at about 30^{o}. Slope No. 6SE-B/CR193 is about 78 m long and has a maximum overall height of about 9.1 m, including the toe wall. The cut slope portion comprises two batters (about 4 m and 3.5 m high respectively) with an intervening berm of about 1 m in width. The slope batters are covered with vegetation and are inclined at about 65^{o}. Slope No. 6SE-B/CR212 adjoins slope No. 6SE-B/CR193 to the south and is about 20 m long with a maximum overall height of about 7.6 m, comprising a 6 m high cut slope above the toe wall. The slope is covered with vegetation and inclined at about 65^{o}. The surface drainage system for the two slopes comprises 300 mm wide U-channels, running along the berm and crests. The channels intercept and direct surface runoff from the upslope catchment to the catchwater channel at the slope toe. Based on the available information, no catchpit was provided at the junctions of the U-channels. The layout of the drainage system is shown in Figure 2.

Slopes Nos. 6SE-B/F69 and 6SE-B/DT15 are located on the downhill side of the catchwater channel (Figures 5 and 6). Slope No. 6SE-B/F69 is a 65 m long fill slope of up to 5 m high. The slope is covered with vegetation and inclined at about 35^{o}. Slope No. 6SE-B/DT15 adjoins the fill slope to the east and is a disturbed terrain (DT) feature of about 115 m in length. This DT feature, comprising cultivated terraces of about 1.5 m in

height supported by random rubble walls, has a maximum overall height of about 11 m. The feature is generally inclined at about 30° and up to 40° locally and covered with mature trees and crops. No surface drainage system was provided for these two slopes.

According to the information provided by the utility undertakings together with field observations made after the landslide, an 80 mm diameter ductile iron fresh watermain is located underneath the access road along the catchwater channel (Figure 3). There are no other known buried water-carrying services in the vicinity.

3. THE 21 AUGUST 2005 LANDSLIDE

According to GEO's incident report, the landslide occurred at about 9:30 a.m. on 21 August 2005 on slopes Nos. 6SE-B/CR193, 6SE-B/CR212, 6SE-B/F69 and 6SE-B/DT15 along the Shing Mun Catchwater between chainage 7010 and chainage 7050, Tso Kung Tam, Tsuen Wan after a Landslip Warning had been in effect for about 36 hours.

The landslide incident initially involved the failure of the soil cut portions of slopes Nos. 6SE-B/CR193 and 6SE-B/CR212 located above the catchwater (Figure 2). The failure at slope No. 6SE-B/CR193 was relatively minor with a failure volume of about 6 m^3 (Scar 1, see Figure 2). The debris did not cause any subsequent blockage to the catchwater below. The failure at slope No. 6SE-B/CR212 involved a larger volume of about 26 m^3 (Scar 2). The landslide debris caused blockage to the open catchwater channel, resulting in uncontrolled overbank flow and subsequent washout failure of slope No. 6SE-B/F69 below the catchwater with the failure scar extending further downhill to slope No. 6SE-B/DT15 (Scar 3). The failure volume was about 100 m^3. Two other landslides occurred on slope No. 6SE-B/DT15 at some 30 m to the south (Scars 4 and 5). The two landslides were about 5 m apart comprising a small and a large failure with a failure volume of 100 m^3 and 900 m^3 respectively, and located near a broad local depression. The concrete access road alongside the catchwater channel above slopes Nos. 6SE-B/F69 and 6SE-B/DT15 was severely undermined and a 15 m long section of the catchwater channel collapsed. No casualties were reported.

4. MAINTENANCE RESPONSIBILITY

Slopes Nos. 6SE-B/CR193, 6SE-B/CR212 and 6SE-B/F69 are maintained by Water Supplies Department (WSD). Slope No. 6SE-B/DT15 is of mixed responsibility with two sub-divisions. Sub-division No. 1 is under the maintenance responsibility of the licensee of Licence 9402 while Sub-division No. 2 is under the maintenance responsibility of Lands Department (LandsD) (Figure 2).

The Shing Mun Catchwater and its associated access road are maintained by WSD.

5. SITE HISTORY AND PAST SLOPE INSTABILITIES

5.1 Site History

The development history of the site has been established from a review of aerial

photographs and available documentary records (Figures A1 and A2). A detailed account of the aerial photograph interpretation (API) is presented in Appendix A. Salient aspects of the key observations are summarised below.

In the earliest available aerial photographs taken in 1945, the four slopes involved in the 21 August 2005 landslide incident appeared to be covered with vegetation. Possible fill material is visible at the southwestern end of slope No. 6SE-B/DT15, extending southward along the downhill side of the Shing Mun Catchwater (Figure A2 and Plate A1).

In the 1963 aerial photographs, little change to the subject slopes is observed. However, a northwest-southeast trending drainage line is visible at the northern end of slope No. 6SE-B/DT15, while another west-east trending drainage line is seen to run across the southern end of slope No. 6SE-B/CR193 and the northern end of slope No. 6SE-B/F69 (Figure A2 and Plate A2). Multiple failures are observed on the natural hillside to the west of the 21 August 2005 landslide location (Section 5.2).

By 1973, little change to the subject slopes is observed other than the formation of terraces on the hillside near the northeastern portion of slope No. 6SE-B/DT15 (Plate A3). Between 1974 and 1982, little change to the subject slopes and the surrounding area is observed.

By 1983, vegetation clearance is visible at slope No. 6SE-B/F69 and boulders are seen on the slope surface at the northern end (Figure A2). By 1984, cultivation is visible in the area to the north of the vegetation clearance as observed in the 1983 aerial photographs (Plate A3).

Between 1985 and 1999, little change to the subject slopes and the surrounding area is observed, other than the formation of terraces at the southern portion of slope No. 6SE-B/DT15 (Plate A4).

By 2001, a strip of bare soil at the northern end of slope No. 6SE-B/F69 is observed near a drainage line, suggesting that a possible landslide might have occurred at this location (Figure A2 and Plate A5). A patch of bare soil is also visible at the southern end of slope No. 6SE-B/DT15 and appears to be the result of vegetation clearance possibly for agricultural use, which was observed in the aerial photographs of subsequent years. Between 2002 and 2004, little change to the subject slopes is observed other than a general increase in vegetation density. The November 2005 aerial photographs show the landslide scars of the 21 August 2005 incident (Figure A2 and Plate A6).

5.2 Past Slope Instabilities

There are no records of any previous landslides reported to the GEO on the subject slopes, but seven landslide incidents were noted to have occurred in the vicinity of the 2005 landslide site from other sources of information. The approximate locations of these incidents are shown in Figure 3 and Figure A2.

The first of the seven landslide incidents (WSD Incident No. WSD/2003/6/3/NTW) was a minor failure and occurred on a cut slope (No. 6SE-B/CR195) on 18 June 2003, about

75 m south of the 21 August 2005 landslide site (Figure 3). The failure involved a soil cut portion and a section of the catchwater lining at the slope toe, with a failure volume of about 10 m^3. There was no major impact on the catchwater.

The second landslide incident is inferred from the 2001 aerial photograph and is located at the northern end of slope No. 6SE-B/F69, on a west-east trending drainage line (Section 5.1 and Figure A2). This landslide appears to be on the downhill side of the catchwater, directly opposite one of the locations of 2005 landslide on slope No. 6SE-B/CR193 as shown in Figure 3.

Another four incidents are relict landslides registered in the GEO's Enhanced Natural Terrain Landslide Inventory (ENTLI Nos. 06SEB0315E to 06SEB0318E as shown in Figure 3). These landslides are visible in the 1963 aerial photographs, which appear to be part of a large relict open hillslope landslide, about 30 m to the west of the 21 August 2005 landslide location (Section 5.1 and Figure A2). This large relict landslide appears to be approximately 100 m wide, with the backscarp located along the northwest-southeast trending spur line above the catchwater. The landslide scar is seen to be a hummocky vegetated hillside.

The last relict landslide scar was relatively small and located at the southern end of slope No. 6SE-B/DT15. Its location coincided with that of the largest failure that occurred on 21 August 2005 (Figure 3 and Figure A2).

6. PREVIOUS ASSESSMENTS AND SLOPE MAINTENANCE

6.1 Catchwater Studies

In 1979, WSD and the Geotechnical Control Office (renamed as Geotechnical Engineering Office in 1991) commenced a joint study to investigate the stability of catchwaters (including the Shing Mun Catchwater) and associated slopes. The study concluded, among others, that "in terms of both cut slope condition and failure consequences, the Shing Mun Catchwater is potentially the most dangerous in the territory". Subsequently, improvement works to the Shing Mun Catchwater were carried out by WSD in the 1980s. However, the works did not cover the section of the Shing Mun Catchwater involved in the 2005 landslide incident. Also, no additional overflow weirs had been constructed along this section since the catchwater studies.

6.2 Stage 1 Study

In January 1997, slopes Nos. 6SE-B/CR193 and 6SE-B/CR212 were inspected by the GEO for a Stage 1 Study. According to the study report for slope No. 6SE-B/CR193, "reasonable" signs of distress were noted on the chunam cover near the crest, the mid-portion and at the toe of the slope. For slope No. 6SE-B/CR212, signs of seepage were observed on both the slope and wall portions, and minor cracks were also noted on the toe wall. It was recommended that further study be carried out.

6.3 SIFT and SIRST Studies

In 1992, the GEO initiated a project entitled "Systematic Inspection of Features in the Territory" (SIFT) to identify sizeable man-made slopes not previously registered in the 1977/78 Slope Catalogue and to update information on existing registered slopes based on studies of aerial photographs. According to the SIFT results, slopes Nos. 6SE-B/CR193, 6SE-B/CR212 and 6SE-B/DT15 were classified as SIFT Class 'C1' (i.e. cut slopes that have been formed or substantially modified before 30 June 1978); slope No. 6SE-B/F69 was classified as SIFT Class 'B1' (i.e. fill slopes that have been formed or substantially modified before 30 June 1978).

In 1997, slopes Nos. 6SE-B/CR193, 6SE-B/CR212 and 6SE-B/F69 were inspected by the consultants of GEO's project entitled "Systematic Identification and Registration of Slopes in the Territory" (SIRST). Minor cracks were observed at the toe wall of slope No. 6SE-B/CR212. Erosion was also noted on the surface of slope No. 6SE-B/F69.

There is no record of the SIRST study for slope No. 6SE-B/DT15.

6.4 Engineer Inspections and Routine Maintenance

Engineer Inspection (EI) of slopes Nos. 6SE-B/CR193, 6SE-B/CR212 and 6SE-B/F69 were undertaken by consultants engaged by WSD in 2001. For slope No. 6SE-B/DT15, the EI was carried out by LandsD's consultant in 2002. The salient observations made are given in Appendix B. Surface erosion and a local failure, and the collapse of a 10 m long section of the toe wall at the southern portion of slope No. 6SE-B/CR193 were noted during the EI in 2001 (BAL, 2001a). The exact location of the collapsed toe wall was unknown.

Routine Maintenance Inspection (RMI) of slopes Nos. 6SE-B/CR193, 6SE-B/CR212 and 6SE-B/F69 were undertaken by WSD's consultants in 2002 and 2003. For slope No. 6SE-B/DT15, the RMI was carried out by LandsD's consultants in 2004. The salient observations are given in Appendix B. No signs of distress were noted in the RMI.

It is also noted that there was no record to indicate the routine maintenance works recommended in the annual maintenance inspections in 2002 and 2003 had been completed for slopes Nos. 6SE-B/CR193 and 6SE-B/CR212.

7. POST-FAILURE OBSERVATIONS OF THE LANDSLIDE SITE BY MGSL

Maunsell Geotechnical Services Limited (MGSL), the 2005 Landslide Investigation Consultants for Kowloon and the New Territories, first inspected the landslide site at about 4:00 p.m. on 22 August 2005 and subsequently made several visits to the site between September and October 2005. Key observations made by MGSL are presented below and in Figure 4.

The landslide involved a total of five failure scars (Figure 4). Scar 1 was located at the middle portion of slope No. 6SE-B/CR193 just above its concrete toe wall. The failure volume was about 6 m^3 (Plate 2). The landslide debris was deposited in the catchwater

below, without causing significant blockage to the catchwater.

Scar 2 was located at the southern end of slope No. 6SE-B/CR212, about 30 m to the south of Scar 1. An approximately 7.8 m long section of the concrete toe wall collapsed. The landslide debris, with an estimated volume of about 26 m^3, was deposited in the catchwater channel below and completely blocked the channel (Plate 3), resulting in uncontrolled overbank flow.

Across the catchwater channel on the downhill side of Scar 2 was Scar 3 which was located at the crest of slope No. 6SE-B/F69. The scar was probably the result of a washout failure due to uncontrolled overbank flow from the blocked catchwater channel. The failure volume was about 100 m^3. A section of the concrete road above the backscarp was severely undermined. A fresh watermain of about 80 mm in diameter was also exposed (Figure 5 and Plate 4).

Located about 30 m to the southeast of Scar 3, at the southern end of slope No. 6SE-B/F69, was a tension crack which ran along the crest of the slope. The tension crack measured about 10 m long and 20 mm to 200 mm wide (Figure 4 and Plate 5). About 20 m to the east (downhill) of the tension crack was another washout scar (Scar 4). Scar 4 was located at the southern portion of slope No. 6SE-B/DT15 (Plate 6). The failure volume was about 100 m^3.

Adjacent to the south of the tension crack was the largest landslide scar (Scar 5), which was located at the southern end of slope No. 6SE-B/DT15 (Figure 4). The failure volume was about 900 m^3. The base of the scar dipped at about 15^o to 20^o. The average depth of the main scarp was about 12 m (Figure 6 and Plate 7). A section of about 15 m long catchwater sidewall together with a section of adjoining concrete access road above the back scarp had been washed away (Plate 7). The catchwater channel at this location was also undermined and the scar was flanked by cultivated land near the slope crest (Plates 6 and 8). At the time of inspection, a large quantity of water was still cascading over the collapsed section of the catchwater channel into the failure scar (Plate 8) and most of the debris from the scar had been washed away. A fresh watermain of about 80 mm in diameter (possibly the same as that exposed in Scar 3) was uncovered. The watermain was broken, probably due to the landslide.

The materials exposed within the flanks of Scar 5 (Plate 9) generally comprised thin localised fill and colluvium overlying residual soil and decomposed medium-grained granodiorite (generally Grade IV/V with occasional Grade II/III). The colluvium which formed most of the soil portion of the main scarp generally comprised stiff to hard, friable yellowish and reddish brown, slightly sandy to sandy clayey silt with some angular to sub-angular gravel cobbles and occasional boulders of decomposed granodiorite. According to Sheet 6 of the Hong Kong Geological Survey (HKGS) 1:20 000 scale map series HGM20 (GCO, 1988), the solid geology at the landslide site comprises dacite (Figure 7).

8. INSPECTION OF THE LANDSLIDE SITE BY HCL

HCL inspected the landslide site on 28 November 2007. At the time of inspection, the scars at slope No. 6SE-B/CR193 and slope No. 6SE-B/CR212 had been covered by

chunam with weepholes (Plates 10 and 11). The collapsed section of the catchwater channel and its adjoining concrete access road had been reinstated. The failure scars at slopes Nos. 6SE-B/DT15 and 6SE-B/F69 had been stabilized with no-fines concrete (Plates 12 and 13).

Along the catchwater channel, two overflow weirs were identified in the vicinity of the landslide site (Figure 2). Overflow weir OW1 is located at some 200 m upstream from Scar 2. The invert level of the weir opening was about 1.2 m above the channel bed (Plate 14) at about 208.8 mPD. The concrete access road runs along the catchwater channel from south (upstream) to north (downstream), in the same direction as the water flow in the catchwater channel. According to the as-built records of WSD, the level of the road section along the crest of slope No. 6SE-B/F69 ranged from about 208.4 mPD to 208.6 mPD, i.e. lower than the invert of the overflow weir OW1.

9. ANALYSIS OF RAINFALL RECORDS

Rainfall data were obtained from the nearest GEO automatic raingauge (No. N38), which is located at Po Leung Kuk Lee Shing Pik College, about 1.3 km to the south of the landslide site (Figure 1). This raingauge records and transmits rainfall data at 5-minute intervals via a telephone line to the Hong Kong Observatory and the GEO. According to the landslide incident report prepared by the GEO, the landslide incident occurred at about 9:30 a.m. on 21 August 2005.

The daily rainfall for the period of 31 days before the incident and the hourly rainfall between 20 and 21 August 2005 are presented in Figure 8. Daily rainfall of 405 mm and 22.5 mm of rainfall was recorded on 20 and 21 August 2005 respectively. On the day of the incident, only 5 mm of rainfall was recorded between 4:00 a.m. and 7:00 a.m., some 2.5 hours before the reported time of the landslide.

The return period for the rainfall recorded at raingauge No. N38 preceding the landslide was estimated based on historical rainfall data at the Hong Kong Observatory (Lam & Leung, 1994). The maximum rolling rainfall for various durations was derived and is given in Table 1. The result shows that for rainfall durations less than 24 hours, the corresponding return periods was up to 29 years. Return periods for rainfall durations less than 4 hours are less than 3 years. The return period of the 15-day and 31-day rolling rainfall before the landslide incident was very long. This may not have much significance for the two shallow failures (Scars 1 and 2) in the two cut slopes. However, the water flow in the catchwater would have increased due to the prolonged rainfall.

The return periods were also assessed based on the statistical parameters derived by Evans & Yu (2001) for rainfall data recorded by raingauge No. N38. It is noted that the estimated return periods of the 20-21 August 2005 rainstorm are generally similar to those estimated by the historical rainfall data at the Hong Kong Observatory, except for the long duration rainfall.

The maximum rolling rainfall of the 20-21 August 2005 rainstorm has been compared with those of the past major rainstorms recorded by raingauges Nos. N38 and N03 (the next nearest GEO automatic raingauge to the landslide site) between 1992 and 2005 (Figure 9).

The maximum rolling rainfall of the 20-21 August 2005 rainstorm is the most severe for rainfall durations more than 2 days.

10. DISCUSSION

The 21 August 2005 incident involved the failure of two pre-1978 soil cut slopes Nos. 6SE-B/CR193 and 6SE-B/CR212 above the Shing Mun Catchwater, and two other slopes Nos. 6SE-B/F69 and 6SE-B/DT15 below.

The relatively shallow landslides that occurred on the two old, steep soil cut slopes Nos. 6SE-B/CR193 and 6SE-B/CR212 (Scars 1 and 2) were likely triggered by slope saturation and transient build-up of water pressure as a result of infiltration and possible subsurface flow due to water ingress from the drainage lines in the proximity under heavy rainfall (Section 5.1). This would have led to a subsequent reduction in the shear strength of the groundmass. Post-failure site inspection revealed that both failures occurred immediately below the junctions of the slope crest U-channels where there was no provision of catchpits (Figure 2). Overspilling at these particular locations could have occurred during prolonged heavy rainfall, resulting in additional water ingress in the groundmass below.

The landslide debris from Scar 2 at slope No. 6SE-B/CR212 was deposited in the catchwater below and blocked the water flow. As the catchwater might have reached its full capacity due to the prolonged rainfall, the blockage would have led to an uncontrolled overbank flow across the adjacent concrete access road, where the elevation is lower than the outlet invert level (208.8 mPD) of the overflow weir, OW1, upstream. The uncontrolled overflow would have caused severe erosion on the vegetated surface of slope No. 6SE-B/F69 below the access road (i.e. Scar 3), undermining the road in the process and resulting in the formation of a deep scar and a tension crack in the slope crest (Plates 4 and 5).

The August 2005 incident involved 2 failure locations (Scars 4 and 5) on slope No. 6SE-B/DT15. Both failures were located on a relatively steep part of the DT feature with a history of instability and where unauthorised cultivation had taken place prior to the failure. The cultivation could have made the slope more vulnerable to water ingress under heavy rainfall. The landslides were also located near a broad local depression with possible subsurface flow towards the landslide location. Given the adverse site setting, the failure at this location is not unexpected under the severe rainfall. The 'initial' failure at Scar 5 could have severed the 80 mm diameter fresh watermain at the crest of the landslide scar, discharging water onto the failed area and subsequently undermined a section of the adjacent catchwater channel. This might have eventually led to the collapse of the catchwater sidewall. The damaged catchwater would have released a large amount of water onto the failed area, resulting in extensive erosion and formation of a large failure scar.

Although the landslides on the cut slopes had negligible direct consequence-to-life, their knock-on effects had resulted in a major washout failure of the slopes below the catchwater channel and severe damage to the catchment channel and access road. It was fortuitous that there were no other facilities affected by the incident and no casualties were involved.

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LIST OF TABLES

Table 1 - Maximum Rolling Rainfall at GEO Raingauge No. N38 for Selected Durations Preceding the Landslide on 21 August 2005 and Estimated Return Periods

Duration	Maximum Rolling Rainfall (mm)	End of Period (Hours) (see Note 4)	Estimated Return Period (Years) (see Note 3)	
			A	B
5 minutes	7.5	09:15 hours on 20 August 2005	1	1
15 minutes	18.0	10:55 hours on 20 August 2005	1	1
1 hour	47.0	09:50 hours on 20 August 2005	< 2	< 2
2 hours	85.5	11:00 hours on 20 August 2005	2	< 2
4 hours	135.5	11:45 hours on 20 August 2005	< 3	< 4
12 hours	297.0	18:40 hours on 20 August 2005	12	26
24 hours	460.0	18:50 hours on 20 August 2005	29	37
2 days	631.0	21:45 hours on 20 August 2005	73	71
4 days	765.5	21:10 hours on 20 August 2005	82	57
7 days	874.5	20:45 hours on 20 August 2005	113	90
15 days	1252.5	09:30 hours on 21 August 2005	385	89
31 days	1646.0	09:30 hours on 21 August 2005	888	43

Notes:
(1) Maximum rolling rainfall was calculated from 5-minute rainfall data.
(2) The nearest GEO raingauge to the landslide site is raingauge No. N38 located at Po Leung Kuk Lee Shing Pik College, about 1.3 km to the south of the landslide site.
(3) Return periods were derived from Table 3 of Lam & Leung (1994) (Column A refers) and using data of raingauge No. N38 from Evans & Yu (2000) (Column B refers).
(4) The landslide occurred at about 09:30 hours on 21 August 2005 when a Landslip Warning was in effect.

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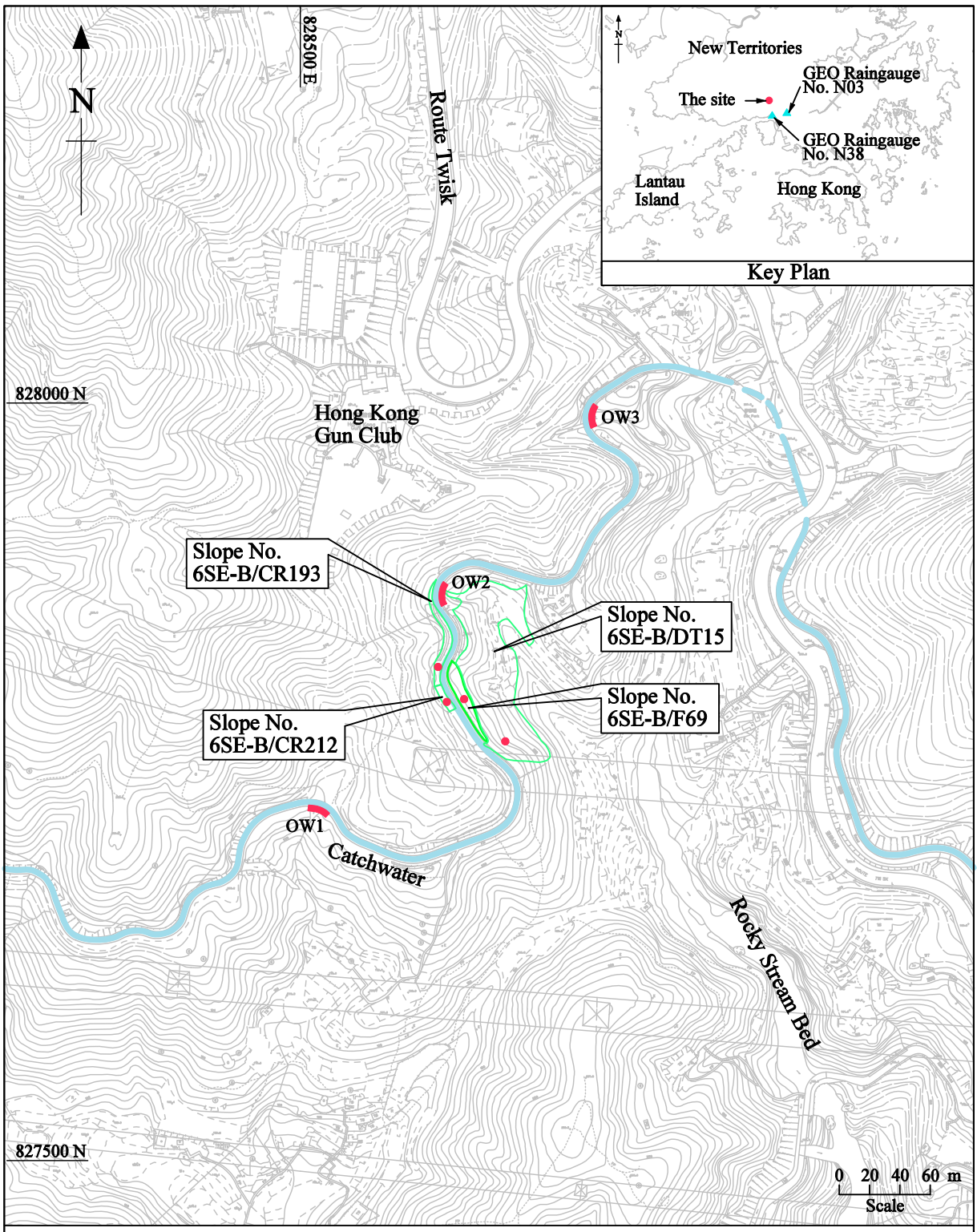

Figure 1 - Location Plan

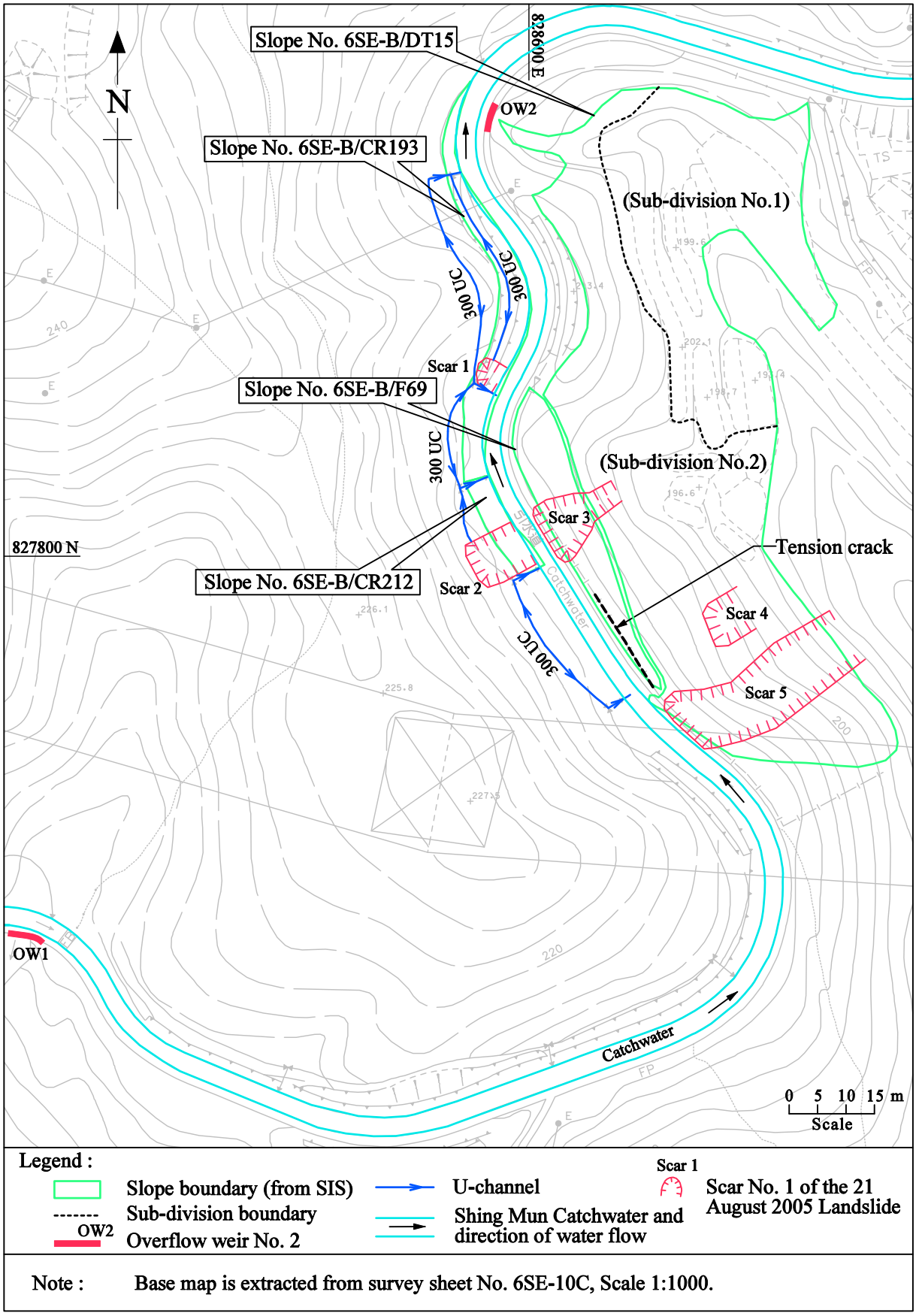

Figure 2 - Site Layout Plan

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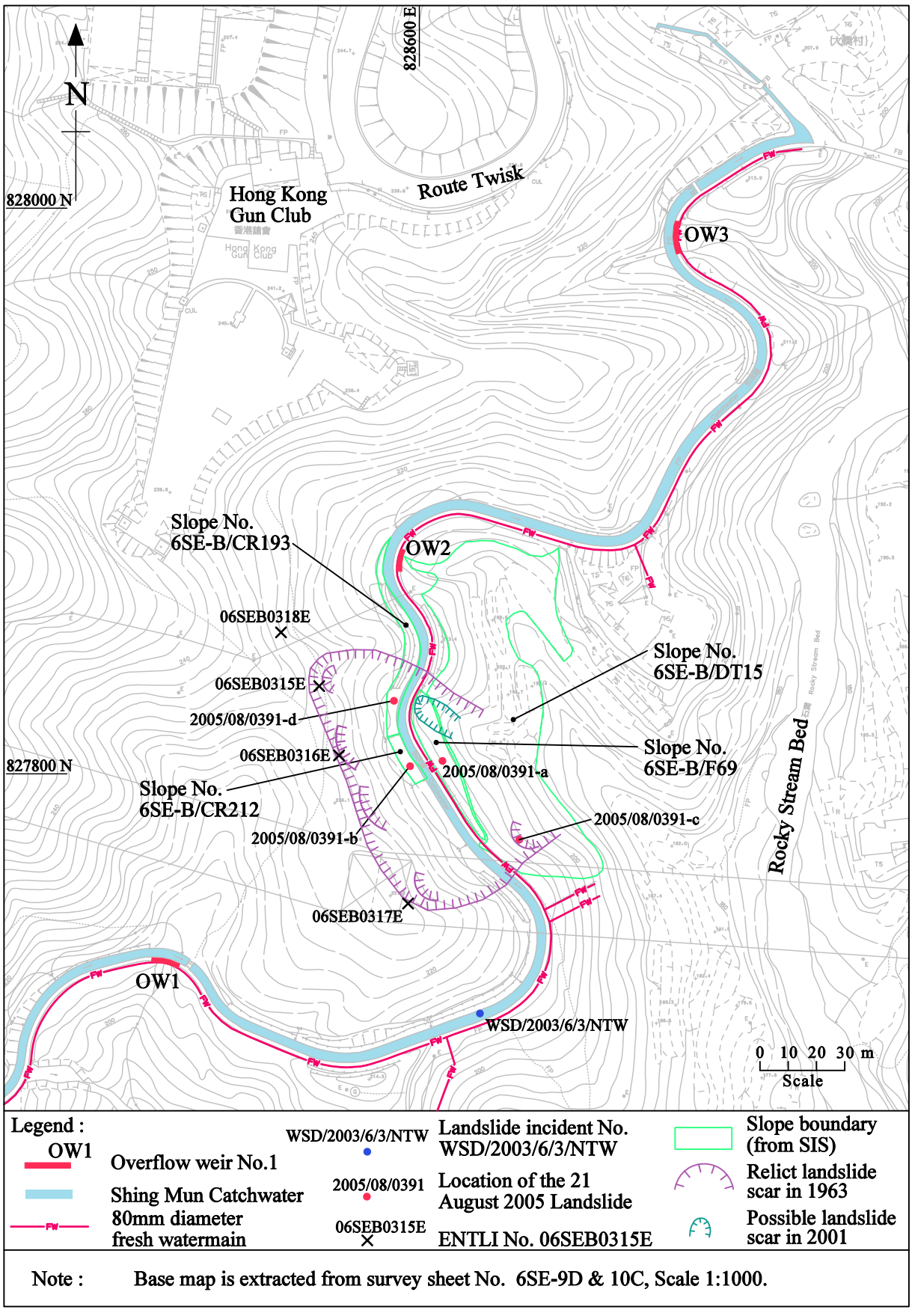

Figure 3 - Location of Water-carrying Services and Past Instabilities

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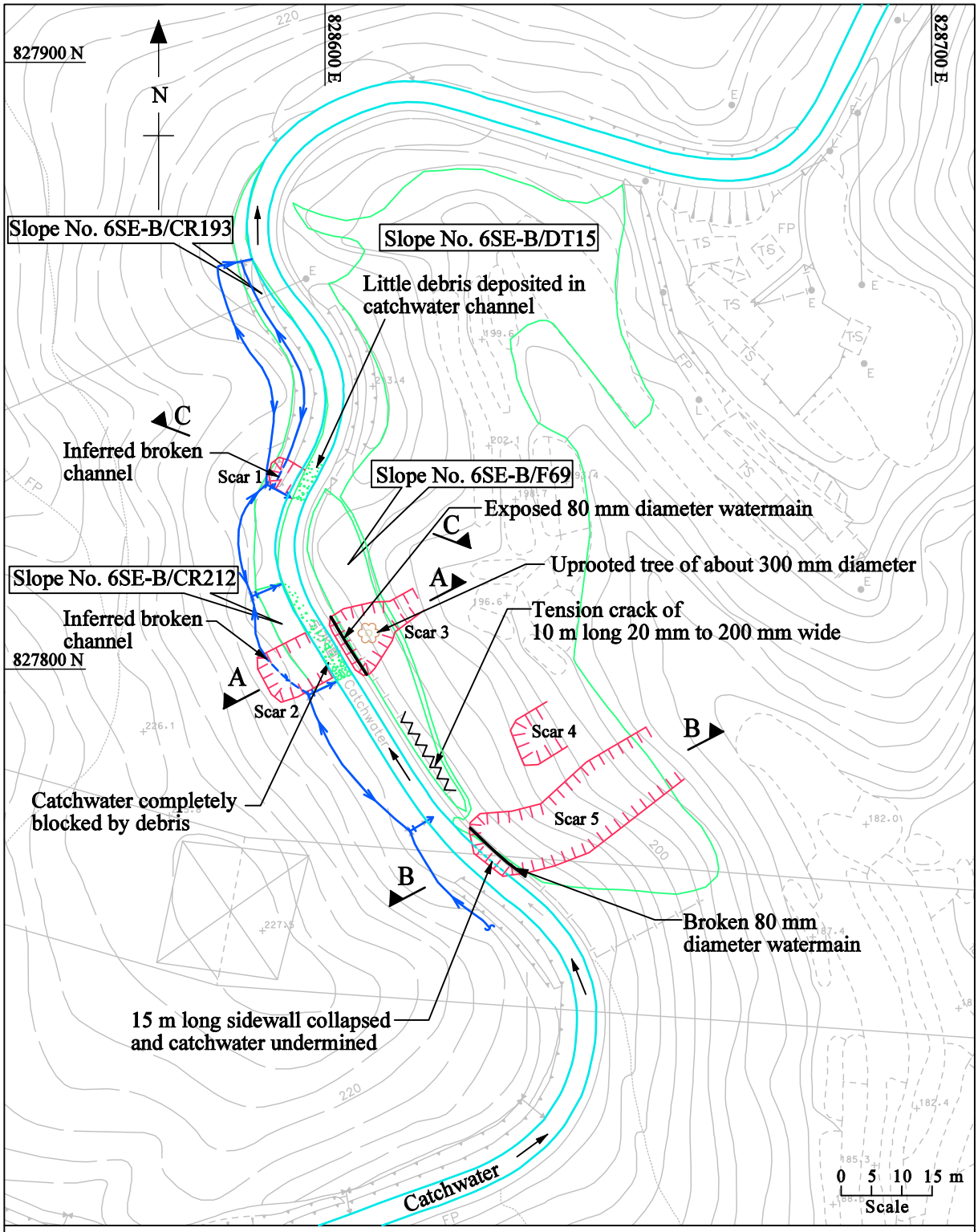

Figure 4 - Site Observations in the Vicinity of the 21 August 2005 Landslide Site

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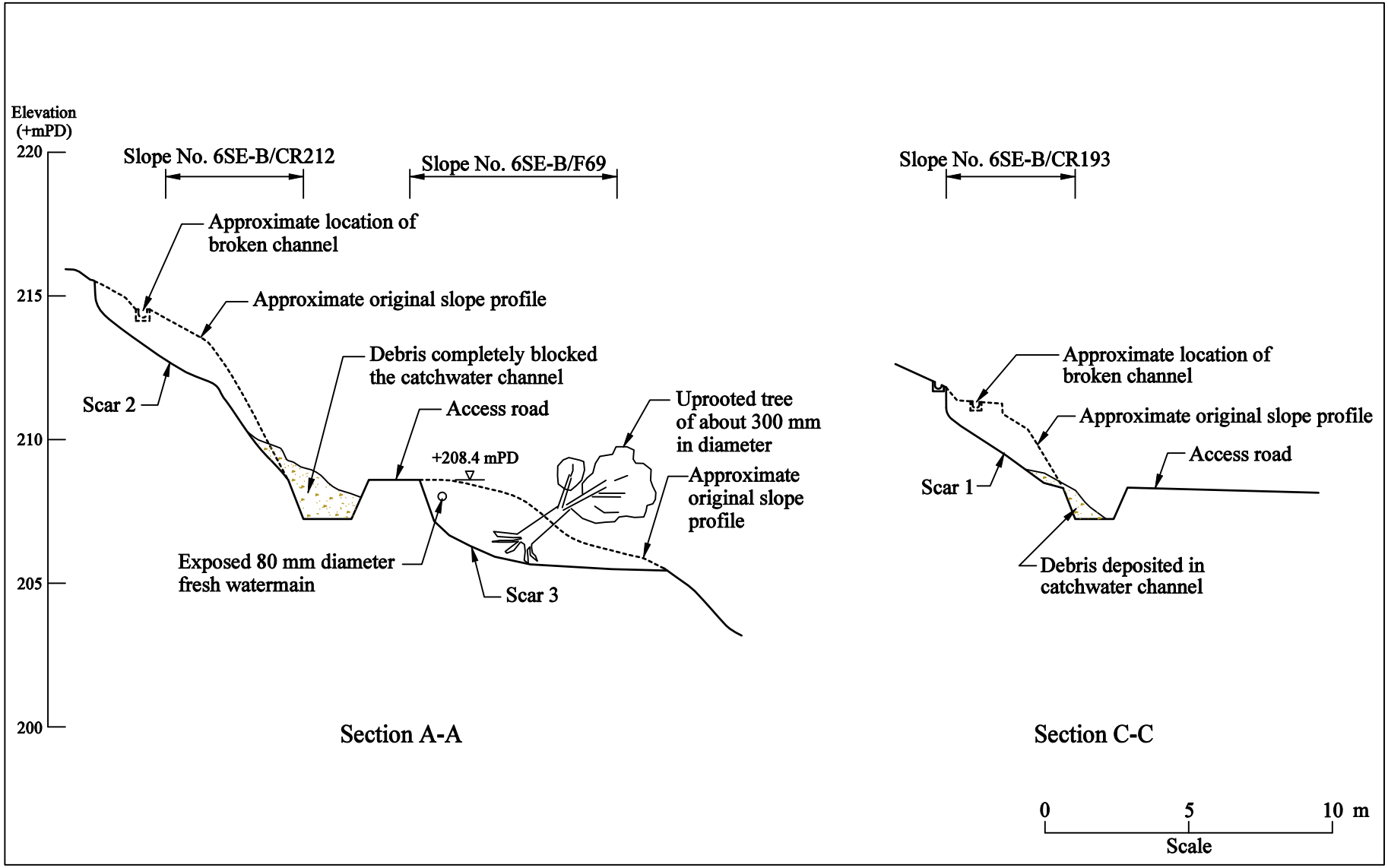


Figure 5 - Sections A-A and C-C through Landslide Scars 1, 2 and 3

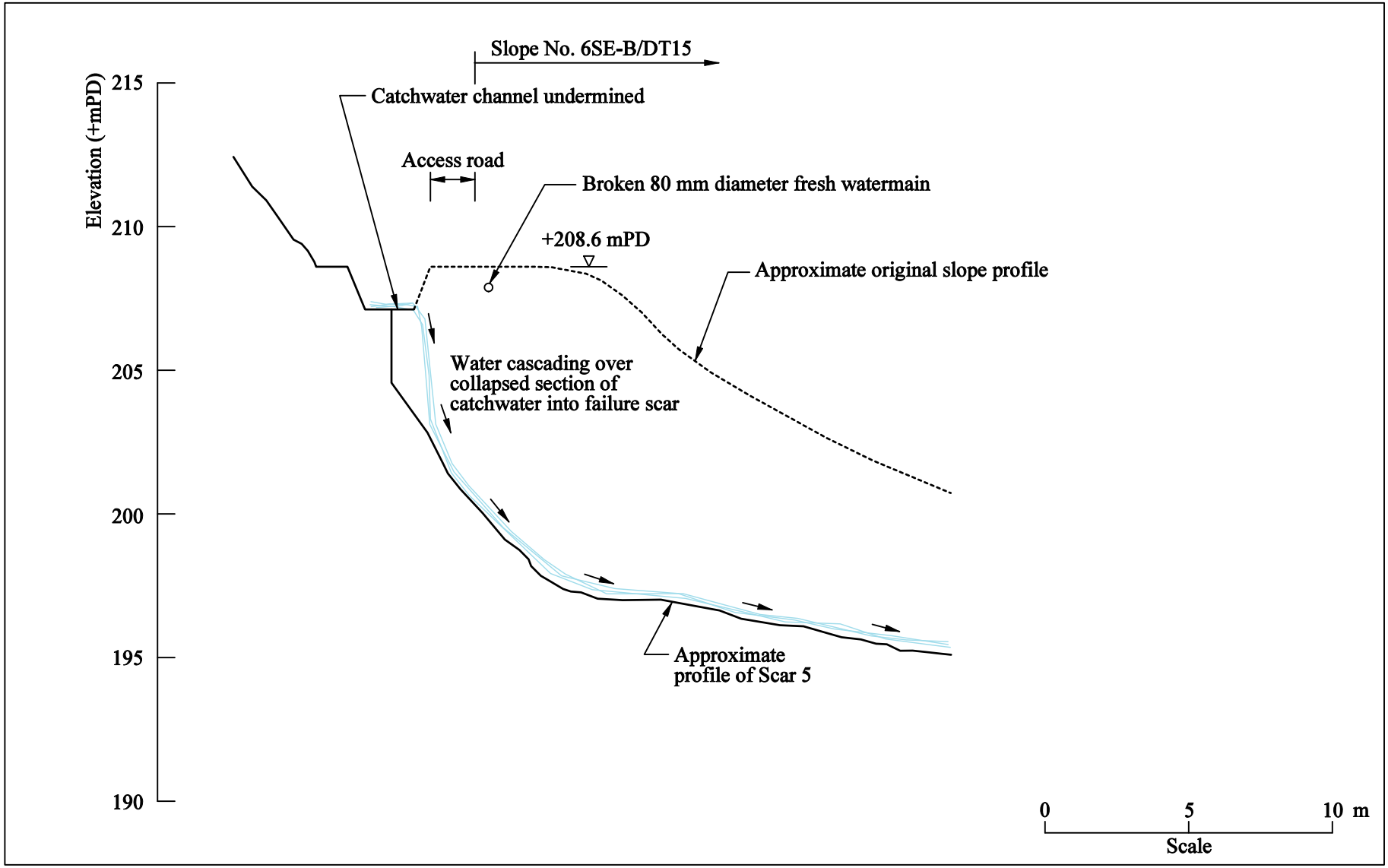
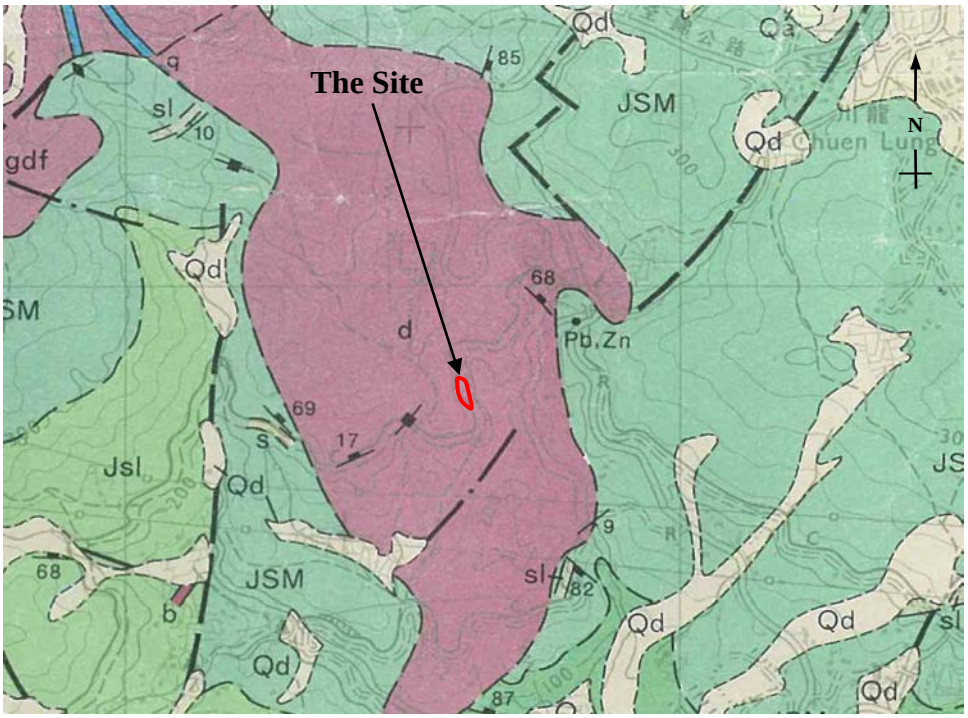


Figure 6 - Section B-B through Landslide Scar 5



LEGEND:

SUPERFICIAL DEPOSITS

Qa Alluvium

Qd Debris flow deposits

SOLID GEOLOGY

JSM Shing Mun Formation, undivided

Jsl Shing Mun Formation (Shek Lung Kung Member)

d Dacite

gdf Fine-grained granodiorite

b Basalt

q Quartz vein

s Sandstone

sl Siltstone and mudstone

GEOLOGICAL LINES

Geological boundary, superficial deposit

Geological boundary, solid rock (* Broken line denote uncertainty)

Fault (* Broken line denote uncertainty)

Photogeological lineament

STRUCTURAL SYMBOLS

Bedding Inclined 20

Jointing Inclined 20 Vertical 20

Foliation Vertical 20

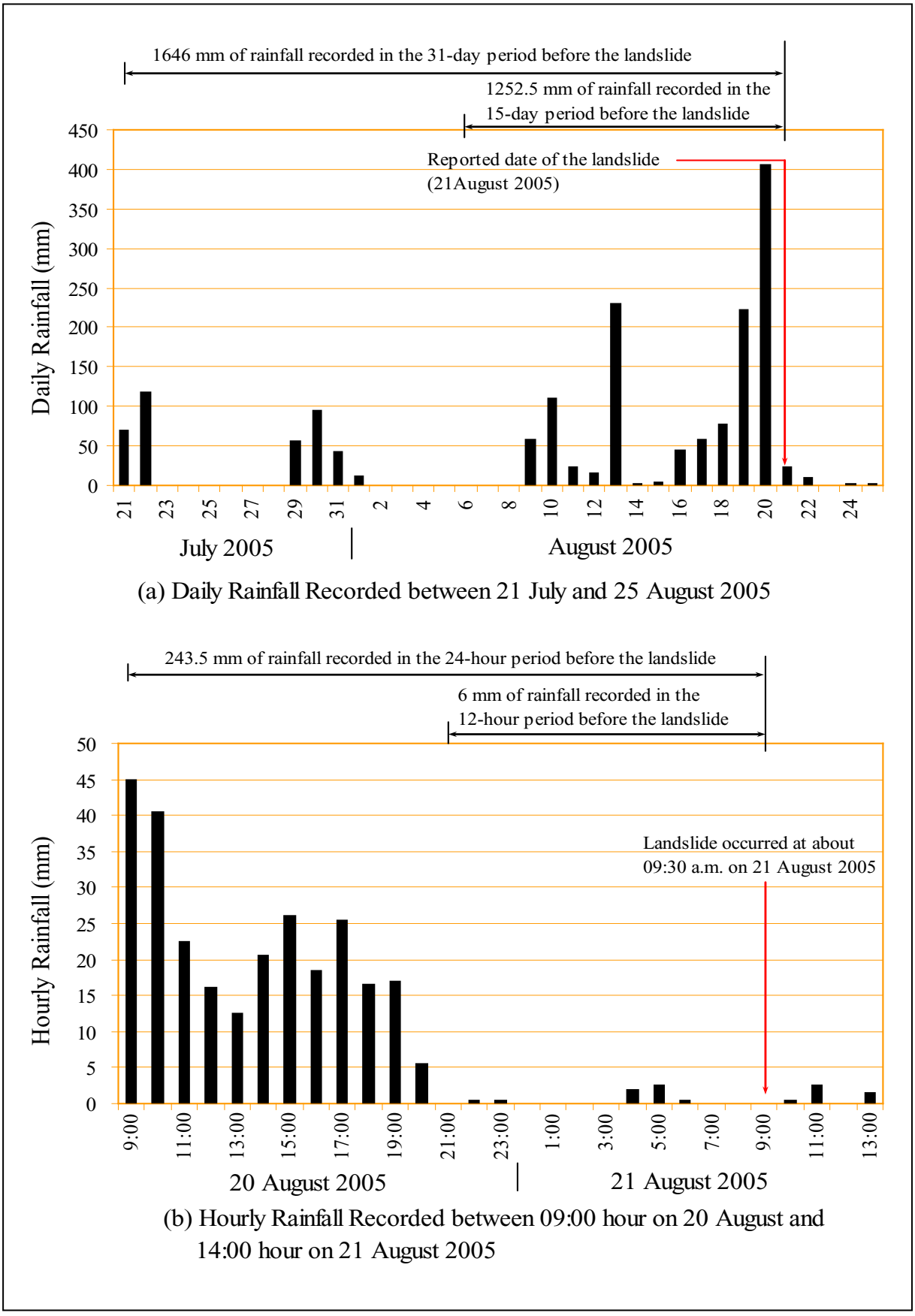
MINERAL OCCURRENCE

Pb Galena

Zn Zinc

Note: Extracted from Hong Kong Geological Survey Map Series HGM20, Sheet No. 6, 1:20,000 scale (GCO, 1986).

Figure 7 - Regional Geology



(a) Daily Rainfall Recorded between 21 July and 25 August 2005

(b) Hourly Rainfall Recorded between 09:00 hour on 20 August and 14:00 hour on 21 August 2005

Figure 8 - Daily and Hourly Rainfall Recorded at GEO Raingauge No. N38

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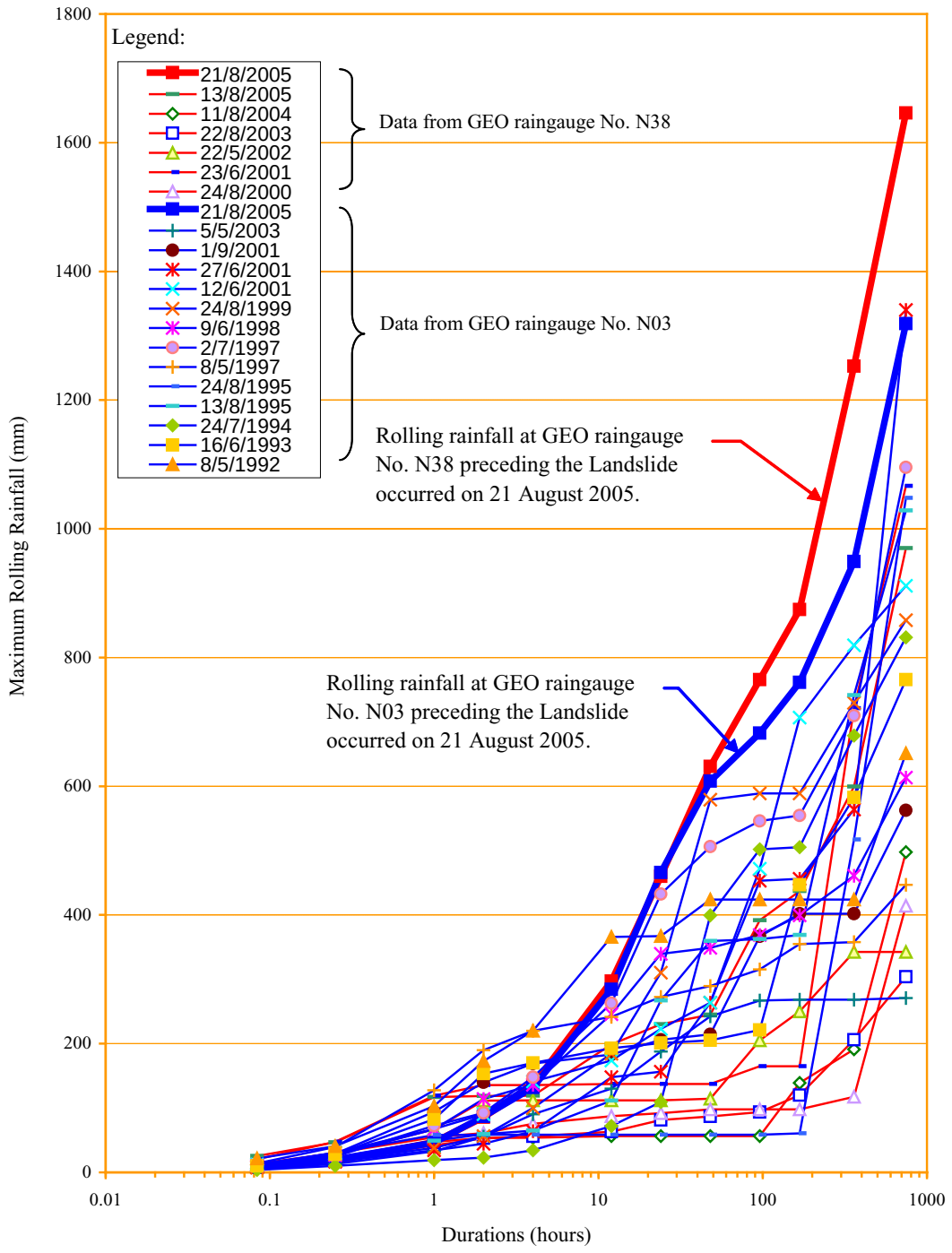

Notes:
(1) Rainfall data are 5-minute statistics from GEO raingauge No. N03 (about 1.9 km to the southeast of the site) and GEO raingauge No. N38 (about 1.3 km to the south of the site).
(2) Rolling rainfall of previous rainstorms calculated at GEO raingauge No. N03 since June 1983 and at GEO raingauge No. N38 since November 1999 when the raingauges became operational.

Figure 9 - Maximum Rolling Rainfall for Previous Major Rainstorms at GEO Raingauges Nos. N03 and N38

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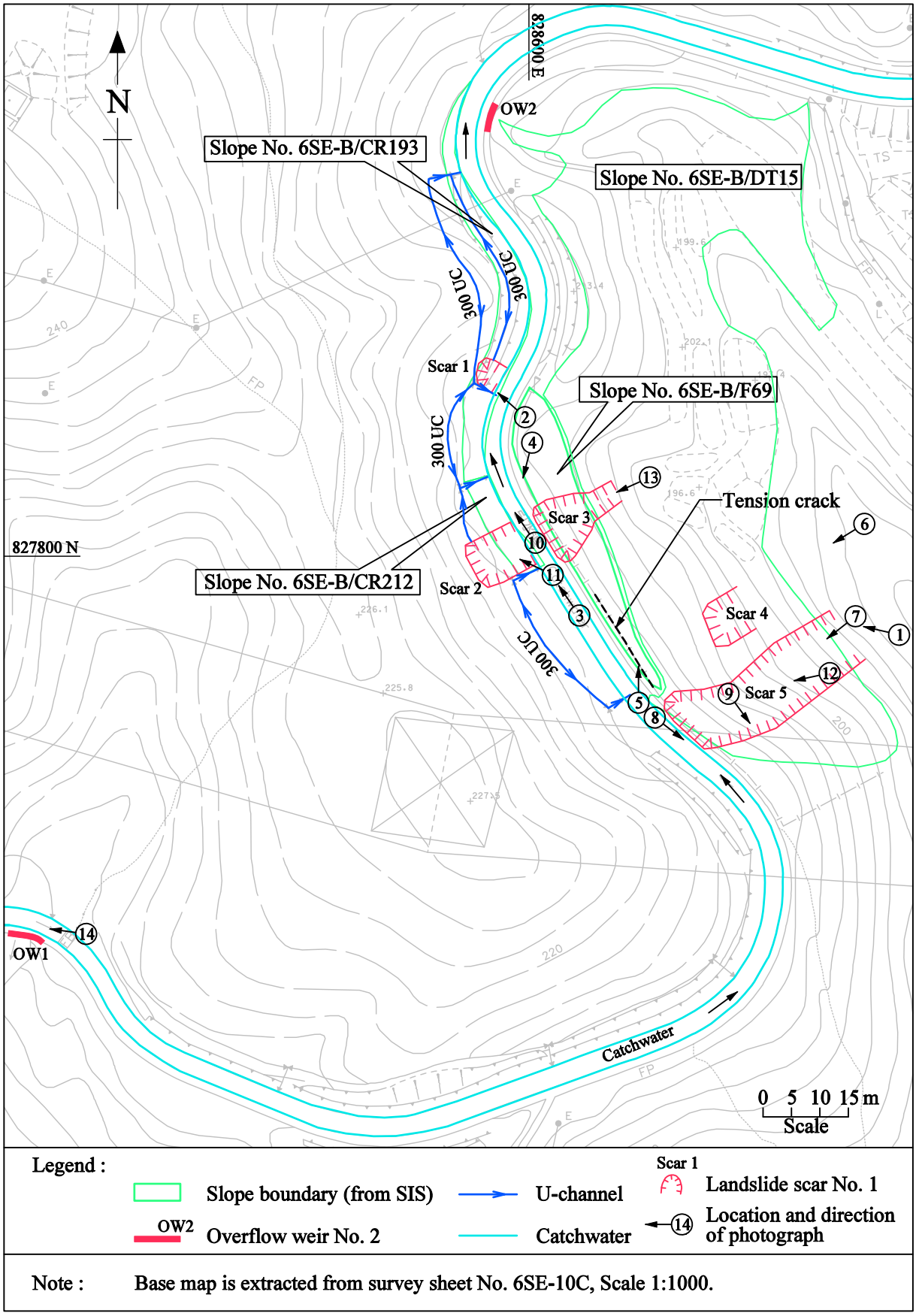

Figure 10 - Locations and Directions of Photographs Taken

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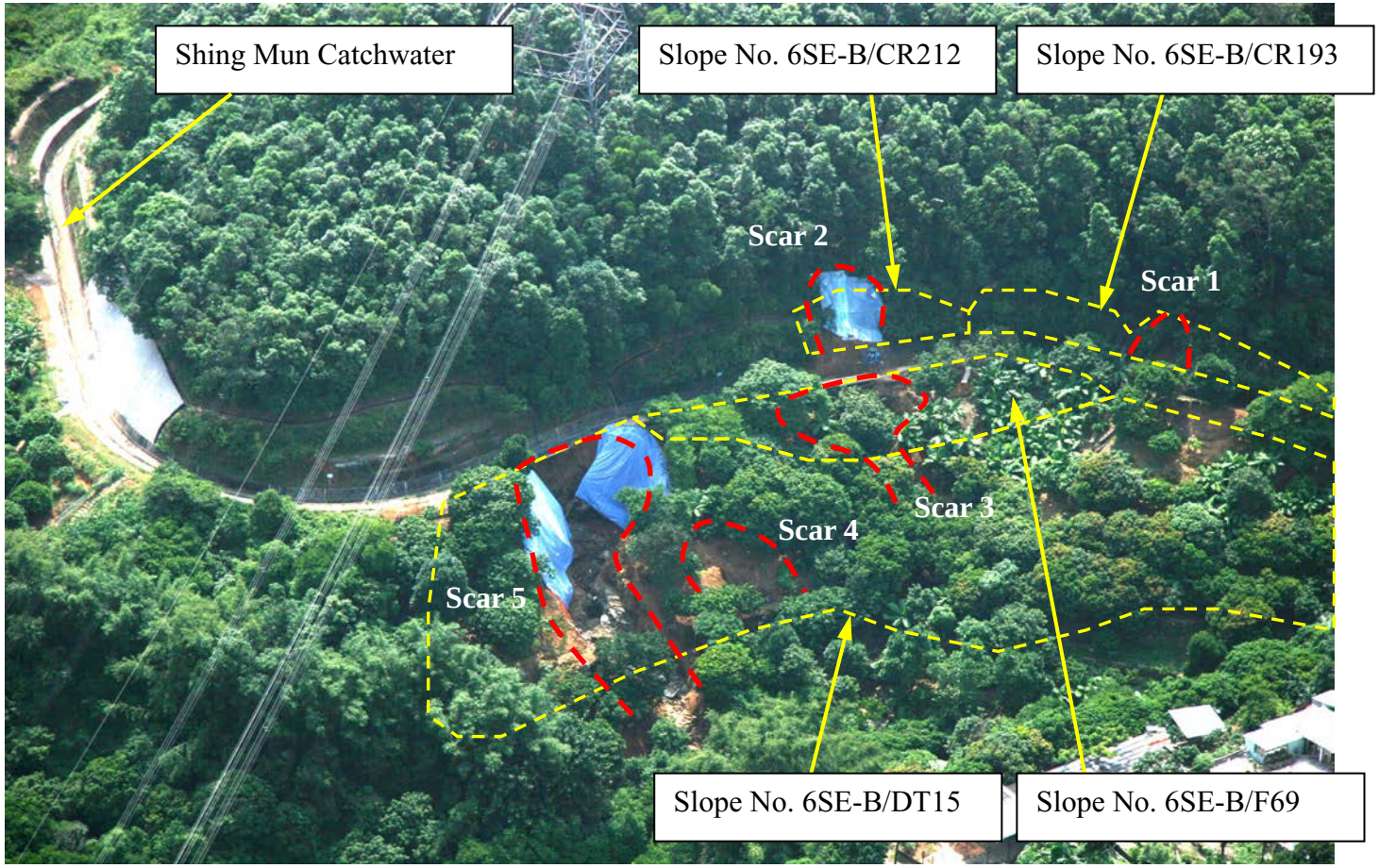

Plate 1 - Oblique Aerial View of Shing Mun Catchwater and Landslide Scars (Photograph taken on 7 September 2005 by MGSL)

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

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Plate 2 - Landslide Scar 1 on Slope No. 6SE-B/CR193 (Photograph taken on 22 August 2005 by MGSL)

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

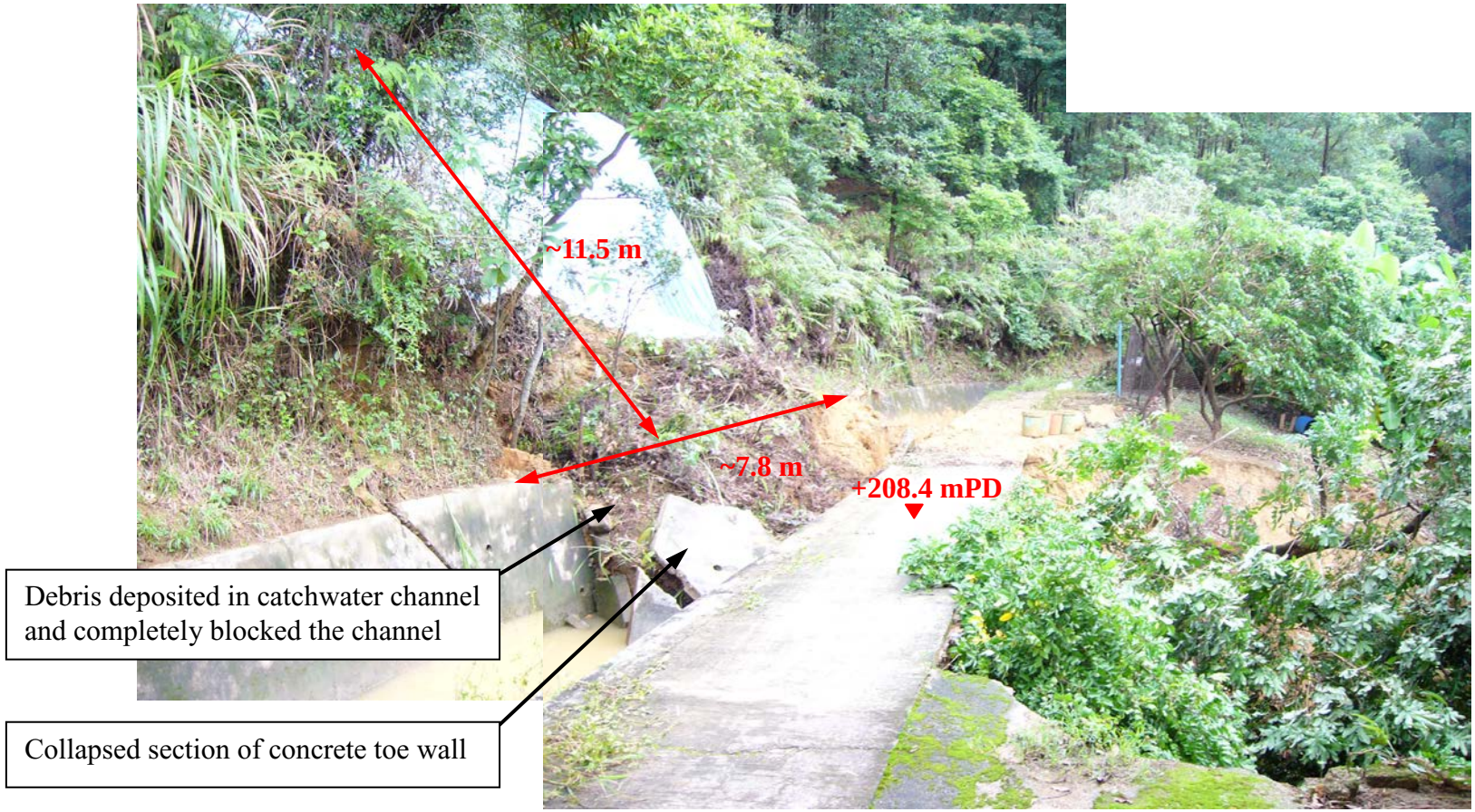

Plate 3 - Landslide Scar 2 on Slope No. 6SE-B/CR212 (Photograph taken on 22 August 2005 by MGSL)

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

Plate 4 - Washout Scar 3 on Slope No. 6SE-B/F69 (Photograph taken on 21 August 2005 by HyD)

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

Plate 5 - Tension Crack at Crest of Slope No. 6SE-B/F69 (Photograph taken on 21 August 2005 by MGSL)

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

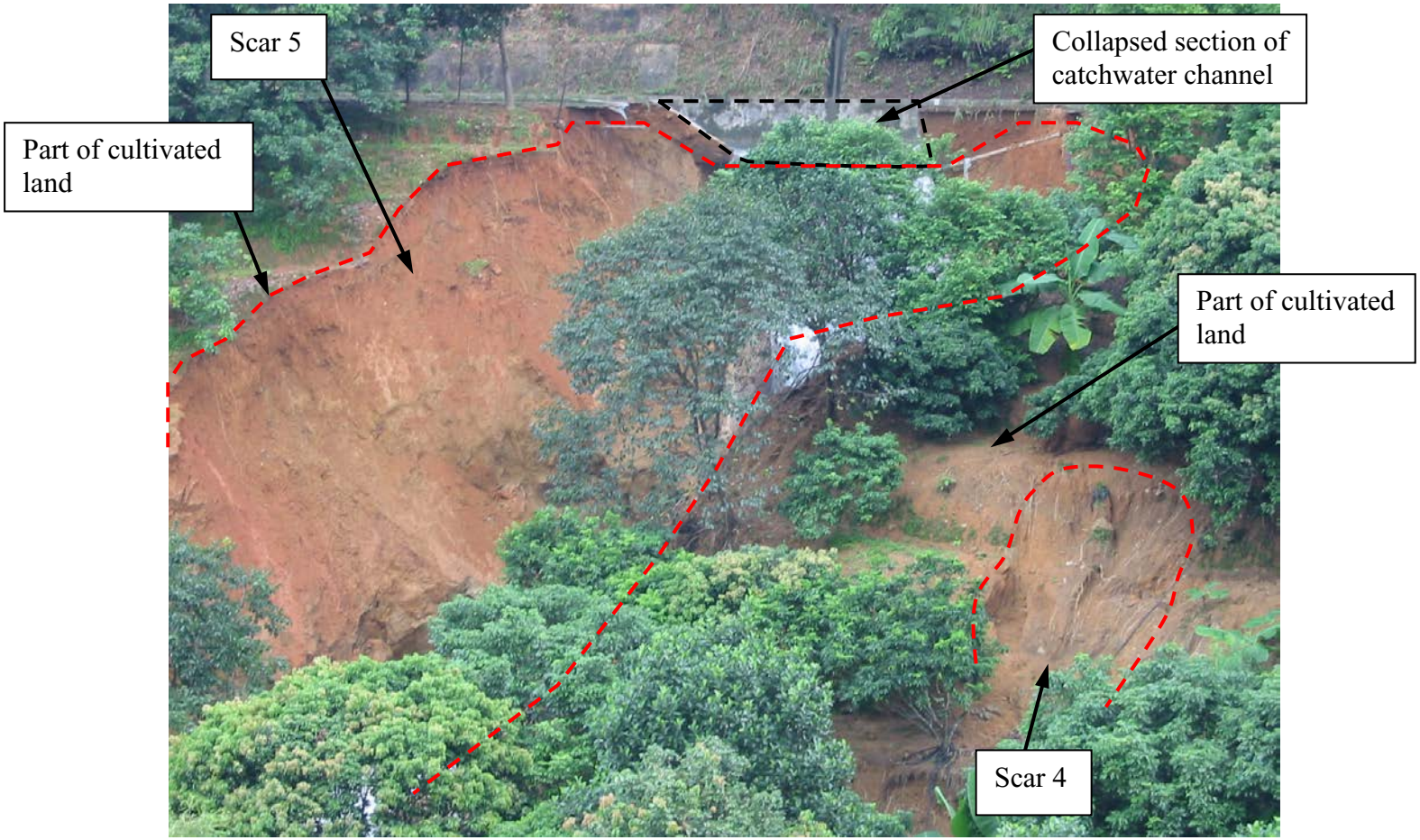

Plate 6 - Scar 4 and Scar 5 on Slope No. 6SE-B/DT15 (Photograph taken on 21 August 2005 by MGSL)

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

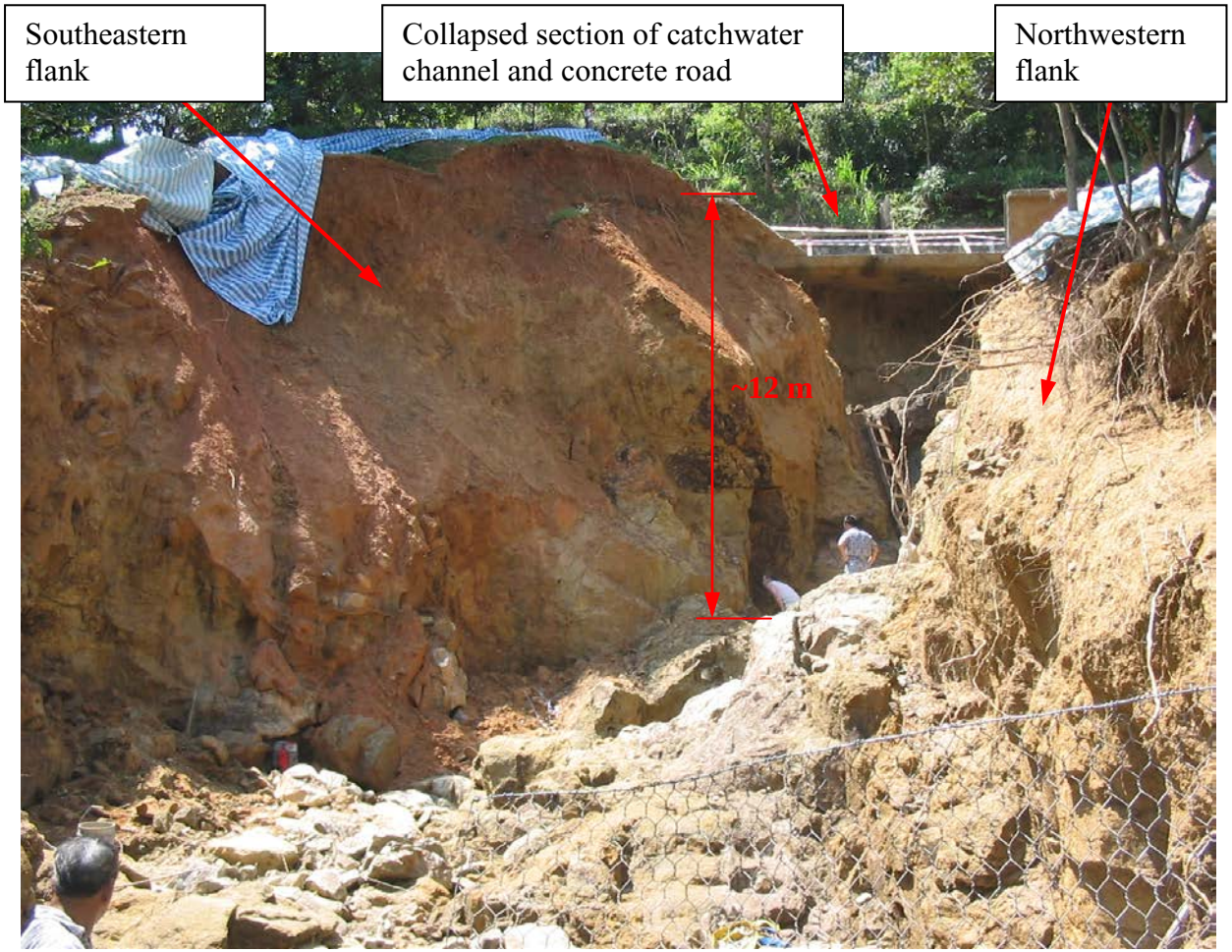

Plate 7 - General View of Scar 5 from Toe (Photograph taken on 16 September 2005 by MGSL)

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

Plate 8 - Water Cascading Over Collapsed Section of Catchwater (Photograph taken on 21 August 2005 by MGSL)

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

Plate 9 - General View of Southeastern Flank of Scar 5 (Photograph taken on 16 September 2005 by MGSL)

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

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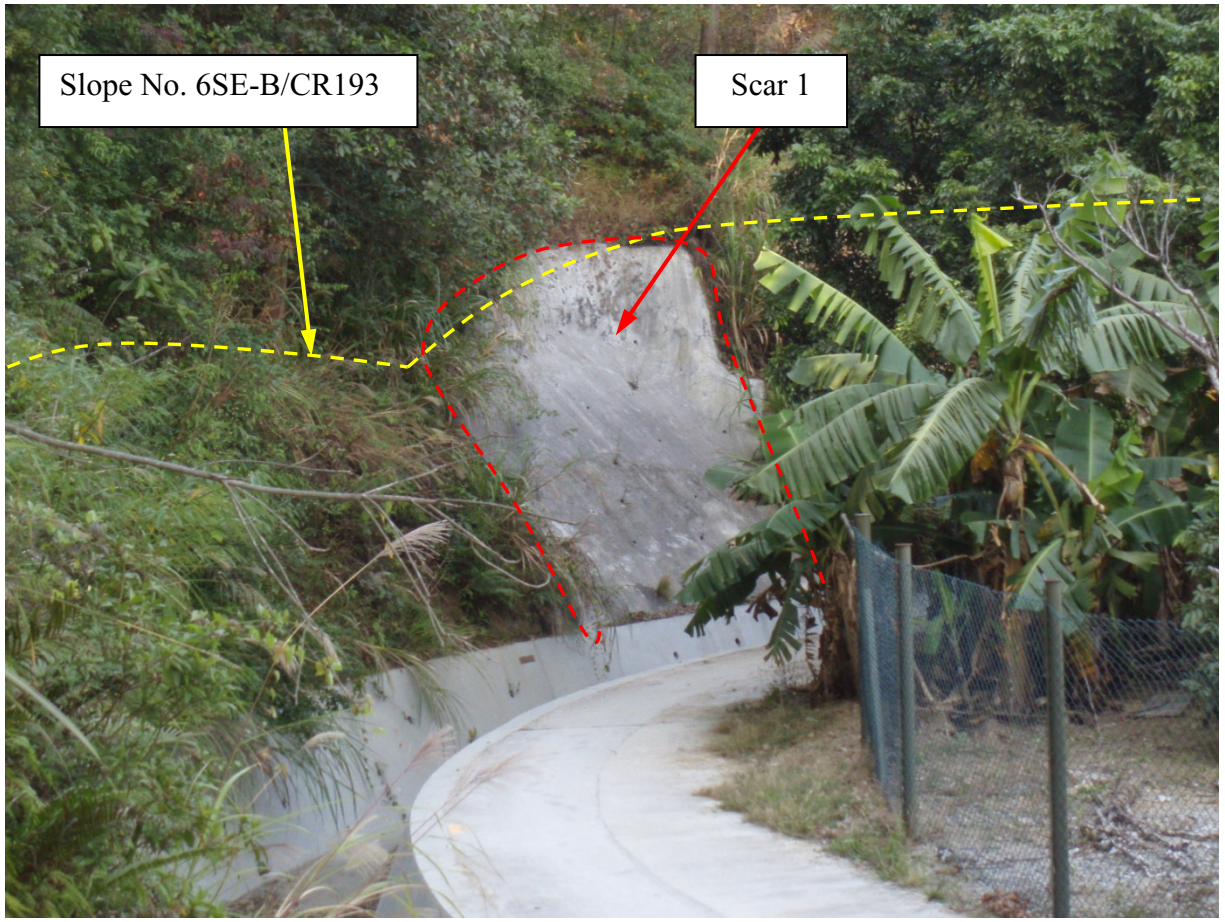

Plate 10 - General View of Scar 1 on Slope No. 6SE-B/CR193 in 2007 (Photograph taken on 28 November 2007 by HCL)

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

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Plate 11 - General View of Scar 2 on Slope No. 6SE-B/CR212 in 2007 (Photograph taken on 28 November 2007 by HCL)

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

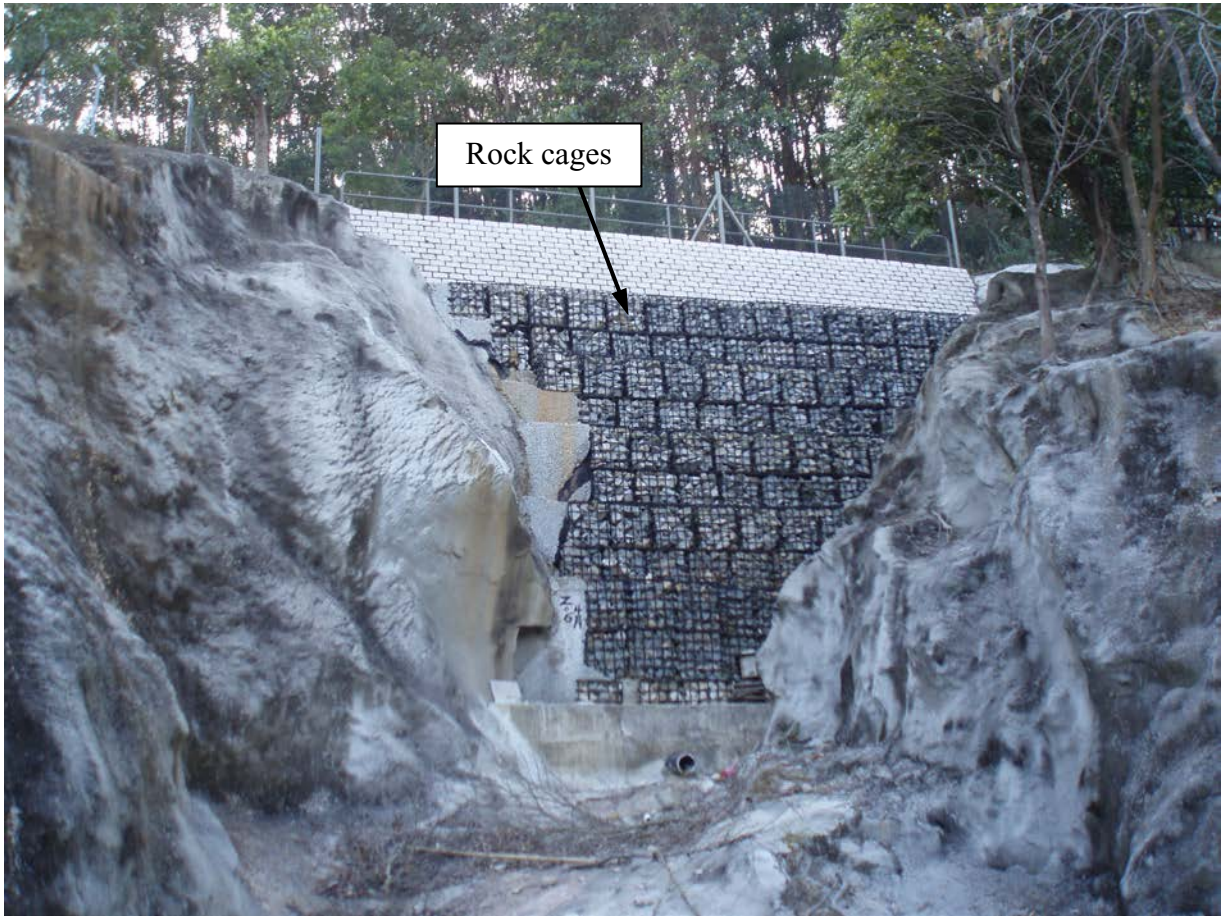

Plate 12 - General View of Remedial Works to Scar 5 on Slope No. 6SE-B/DT15 (Photograph taken on 28 November 2007 by HCL)

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

Plate 13 - General View of Remedial Works to Scar 3 on Slope No. 6SE-B/F69 (Photograph taken on 28 November 2007 by HCL)

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

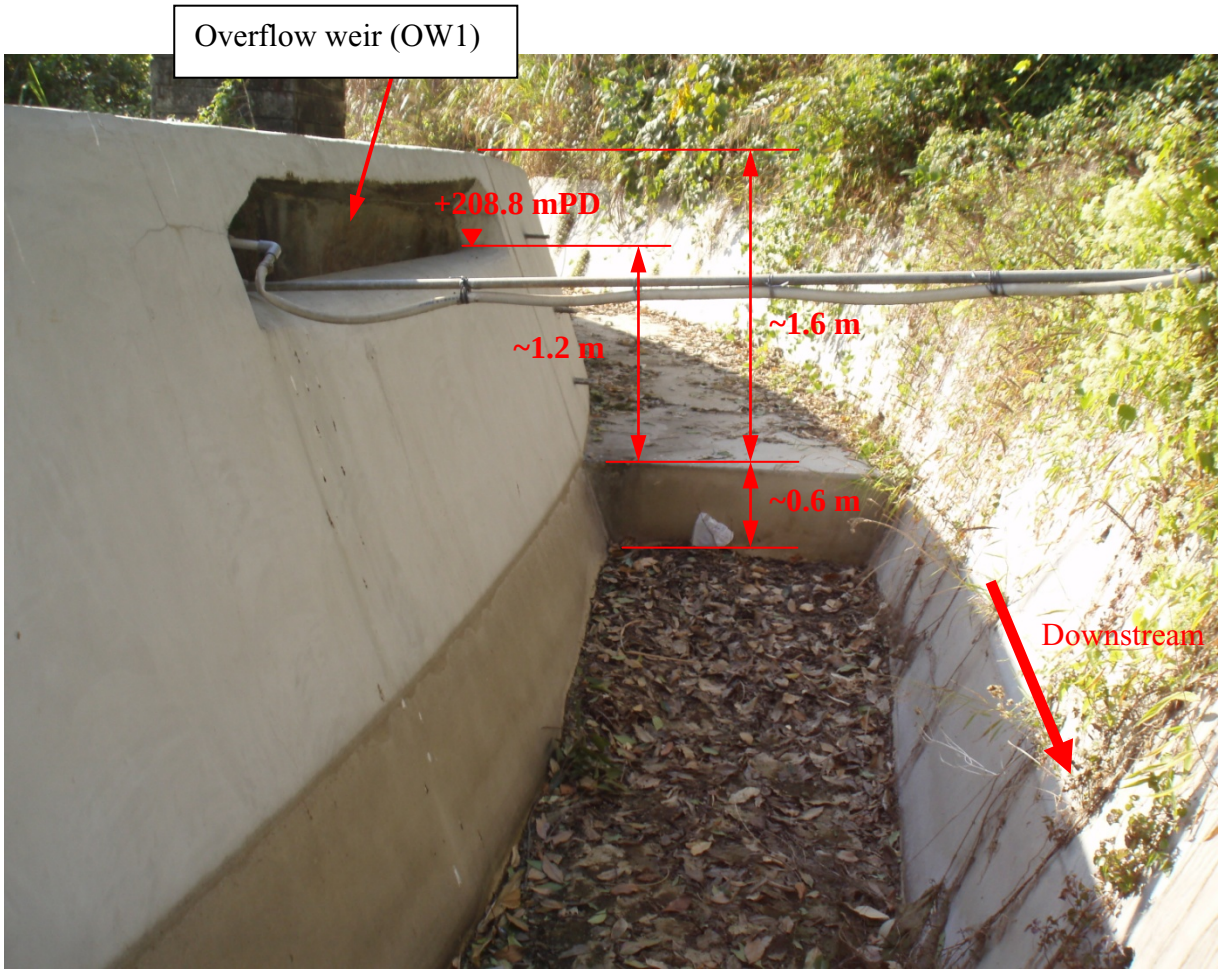

Plate 14 - Overflow Weir (OW1) at Upstream of the Landslide Site (Photograph taken on 28 November 2007 by HCL)

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

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APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

CONTENTS

A1. DETAILED OBSERVATIONS

This report presents the findings of an aerial photograph interpretation (API) of the 21 August 2005 landslide site and the surrounding area. The primary aims of the API were to identify the former topographical setting of the 21 August 2005 landslide location, and to establish the development history of the concerned area

A list of aerial photographs examined in this landslide review is presented in Table A1 and the key observations from the aerial photographs are shown in Figures A1 to A2, and Plates A1 to A6.

YEAR	OBSERVATIONS
1945	High altitude and medium resolution single photograph. The four slopes (viz. slope No. 6SE-B/CR193, slope No. 6SE-B/CR212, slope No. 6SE-B/F69 and slope No. 6SE-B/DT15) involved in the 21 August 2005 landslide (Incident No. 2005/08/0391) were formed. The Shing Mun Catchwater was also formed (Figures A1 and A2). The slopes were predominantly covered by vegetation. Soil fill is observed in the southwestern end of slope No. 6SE-B/DT15 immediately below the catchwater (Figure A2 and Plate A1). Terraces are seen to have been formed on the hillside below the southern end of slope No. 6SE-B/DT15 (Figure A1 and Plate A1).
1963	High altitude and high resolution stereo pairs. No significant change to the subject slopes and the surroundings. A northwest-southeast trending drainage concentration is identifiable at the northern end of slope No. 6SE-B/DT15, while another east-west trending drainage concentration is seen to run across the southern end of slope No. 6SE-B/CR193 and the northern end of slope No. 6SE-B/F69. A north-south trending natural stream course with rocky bed is also identifiable about 130 m east of the 21 August 2005 landslide location (Figure A2 and Plate A2). Multiple failures are observed on the natural hillside to the west of the 21 August 2005 landslide location. A large relict open hillside landslide of approximately 100 m in width is observed, with the backscarp along the northwest-southeast trending spur line above (to the west of) the catchwater. The landslide scar is seen to be a hummocky vegetated hillside. Within this landslide scar, four small relict landslide scars comprising predominately open hillside failure are noted along the crest. One small relict landslide scar is identifiable on the hillside about 20 m above (to the west of) slope No. 6SE-B/CR193 near the drainage concentration line. At the southern end of slope No. 6SE-B/DT15, a small relict landslide scar is also observed. All the landslide scars are observed to be covered by vegetation (Figure A2 and Plate A2).

YEAR	OBSERVATIONS
1964	High altitude and high resolution stereo pairs.
	No significant change to the subject slopes and the surroundings.
1973	Low altitude and high altitude, and high resolution single photograph.
	No significant change to the subject slopes.
	The formation of terraces on the hillside near the northeastern portion of slope No. 6SE-B/DT15 is identifiable. A footpath is seen to have been formed south of slope No. 6SE-B/DT15 (Figure A1 and Plate A3).
1974	High altitude and high resolution stereo pairs.
	No significant change to the subject slopes and the surroundings.
1975	High altitude and high resolution stereo pairs.
	No significant change to the subject slopes and the surroundings.
1976	High altitude and high resolution single photographs.
	No significant change to the subject slopes and the surroundings.
1978	High altitude and high resolution stereo pairs.
	View of the subject slopes was obscured by cloud. It appears that there was no significant change to the subject slopes and the surroundings.
1979	High altitude and high resolution, and low altitude high resolution single photograph.
	No significant change to the subject slopes and the surroundings.
1981	High altitude and medium resolution stereo pairs.
	No significant change to the subject slopes and the surroundings.
1982	High altitude and medium resolution stereo pairs, and low altitude high resolution single photograph.
	No significant change to the subject slopes and the surroundings.

YEAR	OBSERVATIONS
1983	High altitude and high resolution single photograph. Vegetation clearance is visible at slope No. 6SE-B/F69 and boulders are identifiable on the slope surface. No other significant changes are observed.
1984	Low altitude and high resolution single photograph. No significant change to the subject slopes and the surroundings. Planned vegetation is visible in the area of vegetation clearance observed in the 1983 aerial photographs (Plate A3).
1985	High altitude and high resolution, stereo pairs and single photograph. No significant change to the subject slopes and the surroundings.
1986	High altitude and high resolution stereo pairs. Vegetation clearance at the southern portion of slope No. 6SE-B/DT15 is observed.
1988	High altitude and high resolution stereo pairs, and low altitude high resolution single photograph. Terraces are observed to have been formed at the cleared area at the southern portion of slope No. 6SE-B/DT15 as observed in the 1986 aerial photographs.
1989	Low altitude and medium resolution single photograph. No significant change to the subject slopes and the surroundings.
1990	High altitude and high resolution single photograph. No significant change to the subject slopes. Overhead cables and towers are visible above the southern end of slope No. 6SE-B/DT15.
1991	High altitude and high resolution single photograph. No significant change to the subject slopes and the surroundings.

YEAR	OBSERVATIONS
1992	Low altitude and high resolution stereo pairs, and high altitude medium resolution single photograph. No significant change to the subject slopes and the surroundings. Details of the subject slopes are visible, terraces are observed on slope No. 6SE-B/DT15 (Figure A1 and Plate A4). The terraces are seen to have about 10 steps of each about 1 m to 2 m high.
1993	High altitude and medium resolution, stereo pairs and single photograph. No significant change to the subject slopes and the surroundings.
1994	High altitude and medium resolution stereo pairs. No significant change to the subject slopes and the surroundings.
1995	High altitude and low altitude, medium resolution; single photographs. No significant change to the subject slopes and the surroundings.
1997	Low altitude and medium resolution single photograph. No significant change to the subject slopes and the surroundings.
1998	Low altitude and high resolution stereo pairs. No significant change to the subject slopes and the surroundings.
1999	Low altitude, high resolution stereo pairs; and low altitude, medium resolution single photograph. No significant change to the subject slopes and the surroundings.
2001	High altitude and medium resolution stereo pairs and single photograph. High altitude and medium resolution single photograph. A strip of bare soil in the northern end of slope No. 6SE-B/F69 is observed in the 18 June 2001 aerial photograph (single photograph), suggesting a possible landslide has occurred at this location (Figure A2 and Plate A5). The soil strip appears to be covered with vegetation in the stereo pairs of 20 November 2001. A patch of bare soil is also visible in the southern end of slope No. 6SE-B/DT15 in the 18 June 2001 aerial photograph. This is likely the result of vegetation clearance based on the size of the patch (Figure A2 and Plate A5).

YEAR	OBSERVATIONS
2002	Low altitude and high resolution, stereo pairs and single photograph.
	No significant change to the subject slopes and the surroundings.
2003	High altitude and medium resolution stereo pairs.
	No significant change to the subject slopes and the surroundings.
2004	Low altitude and high resolution stereo pairs. High altitude and medium resolution single photograph.
	No significant change to the subject slopes and the surroundings.
	The subject slopes were covered by vegetation.
2005	High altitude and high resolution stereo pairs.
	Landslide scars of the 21 August 2005 incident are visible on the four subject slopes. The scars are seen to have been covered by hard surface cover (Figure A2 and Plate A6).

LIST OF TABLES

Table A1 - List of Aerial Photographs (Sheet 1 of 2)

Date Taken	Altitude (ft)	Photograph Number
10 November 1945	20,000	Y00688
26 February 1963	8,000	Y09119-Y09120
13 December 1964	12,500	Y13004-Y13005
20 February 1973	5,000	3266
20 December 1973	12,500	7967
25 November 1974	12,500	10071-10072
19 December 1975	12,500	11749-11750
04 November 1976	12,500	15993
23 November 1976	12,500	16519
10 January 1978	12,500	20705-20706
01 August 1979	4,000	26361
29 November 1979	10,000	28170
13 January 1981	10,000	35679-35680
28 July 1982	3,000	43092
10 October 1982	10,000	44595, 44621
22 December 1983	10,000	52179
20 October 1984	4,000	56551
01 October 1985	10,000	67246
04 October 1985	15,000	A02709-A02711
21 December 1986	10,000	A08128-A08129
10 October 1988	4,000	70354
03 November 1988	10,000	A15128-A15129
09 September 1989	4,000	A18381
03 December 1990	10,000	A24345
29 October 1991	10,000	A28779
13 May 1992	4,000	A31163-A31164
20 October 1992	4,000	A32655
17 December 1992	20,000	A33626

Table A1 - List of Aerial Photographs (Sheet 2 of 2)

Date Taken	Altitude (ft)	Photograph Number
04 October 1993	20,000	CN4423
06 December 1993	10,000	CN5648-CN5649
21 October 1994	10,000	A39459-A39460
26 September 1995	3,500	CN11199
21 December 1995	20,000	CN13228
24 September 1997	Unknown	A46336
25 August 1998	4,000	A48360-A48361
29 October 1999	5,000	A50533
24 November 1999	5,500	CN24758-CN24759
15 February 2001	8,000	CN29822
18 June 2001	7,000	CW31690
20 November 2001	8,000	CW35604-CW35605
15 August 2002	4,000	CW42655
25 October 2002	4,000	RW01404-RW01470
12 December 2002	4,000	RW02197-RW02198
25 September 2003	8,000	CW49673-CW49674
10 February 2004	8,000	CW55477
05 October 2004	4,000	CW60624-CW60625
21 November 2005	8,000	CW69018-CW69019
Note: All aerial photographs are in black and white except for those prefixed with CN, CW or RW.		

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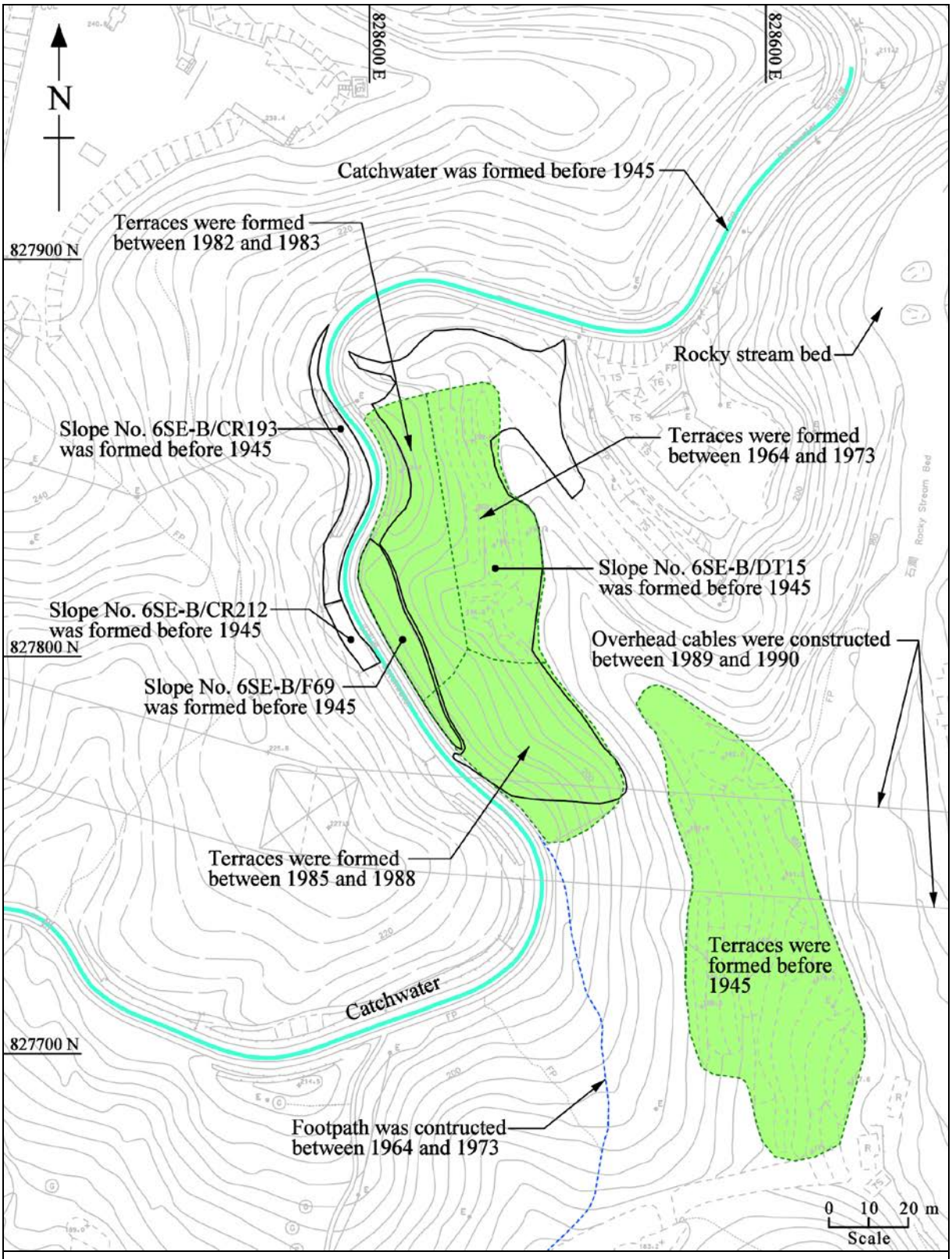

Figure A1 - Site Development History

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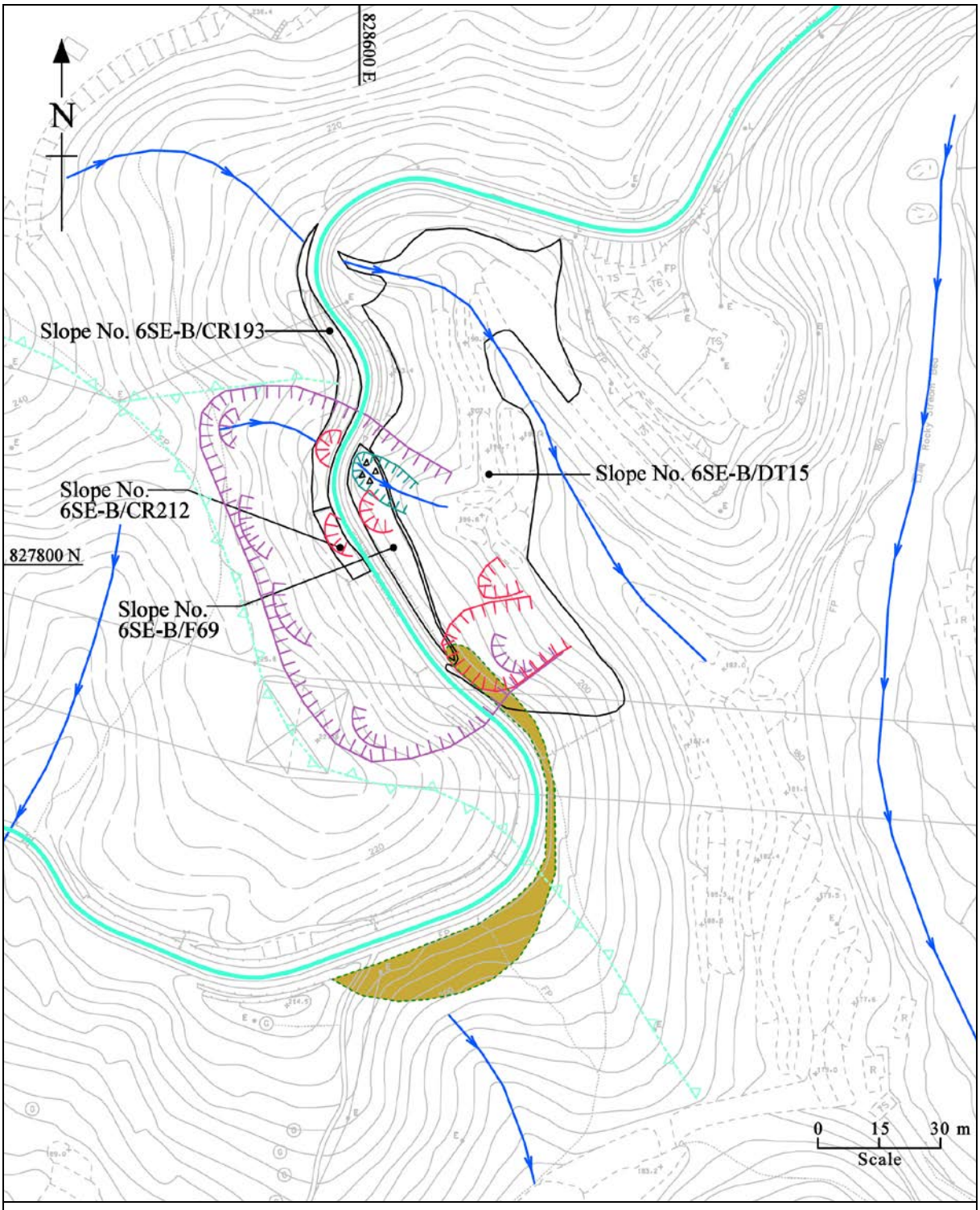

Note: Base map is extracted from survey sheet No. 6SE-10C, Scale 1:1000.

Figure A2 - API Findings

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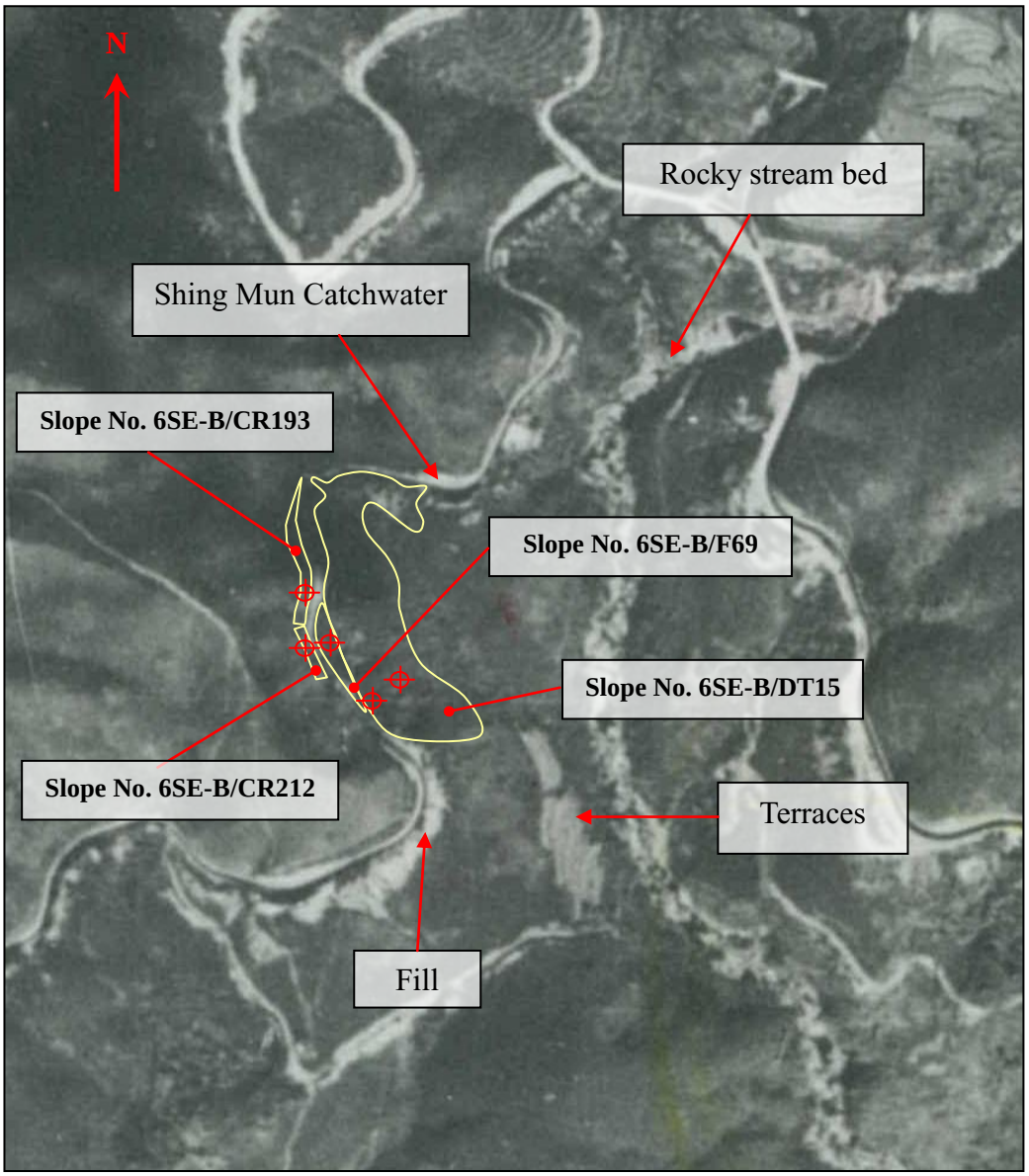

Plate A1 - Extract from 1945 Aerial Photograph (Photograph Y00688 taken on 10 November 1945)

Legend:

Incident No. 2005/08/0391

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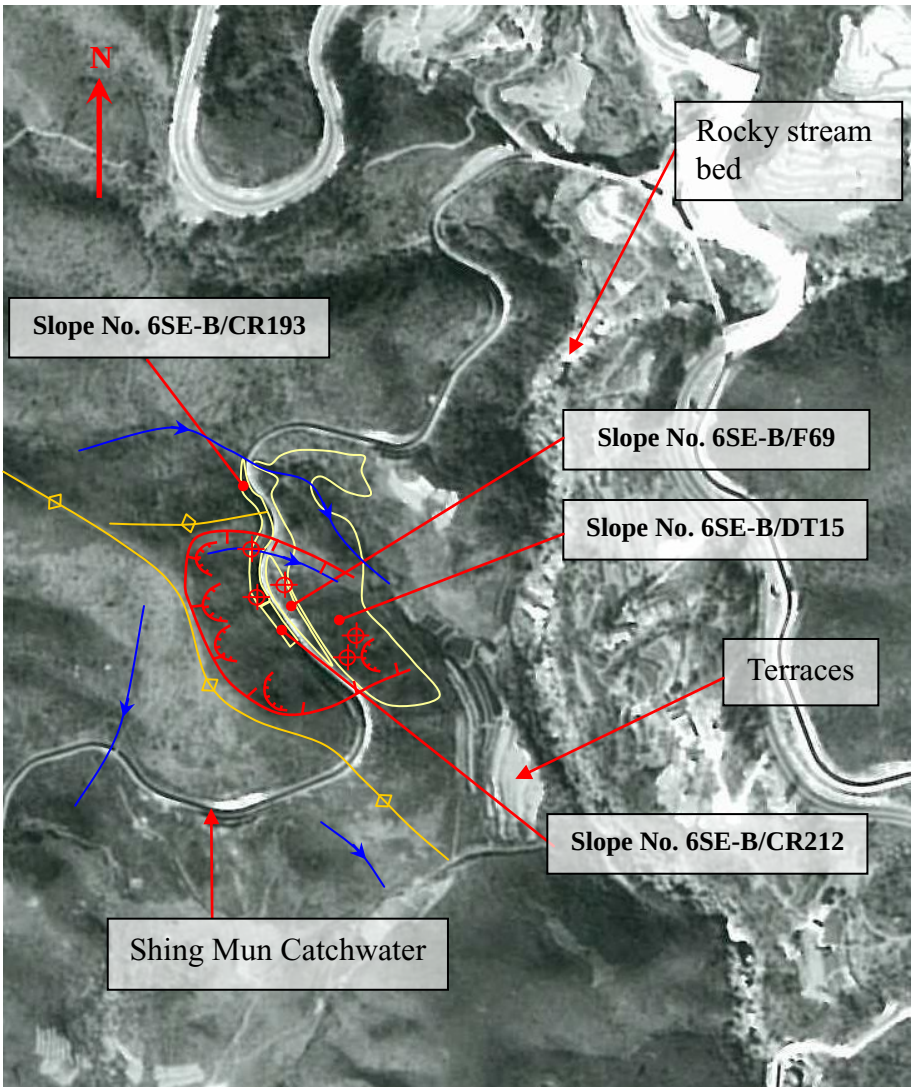

Plate A2 - Extract from 1963 Aerial Photograph (Photograph Y09120 taken on 26 February 1963)

Legend:

Drainage concentration

Ridge line / Spur line

Relict landslide

Incident No. 2005/08/0391

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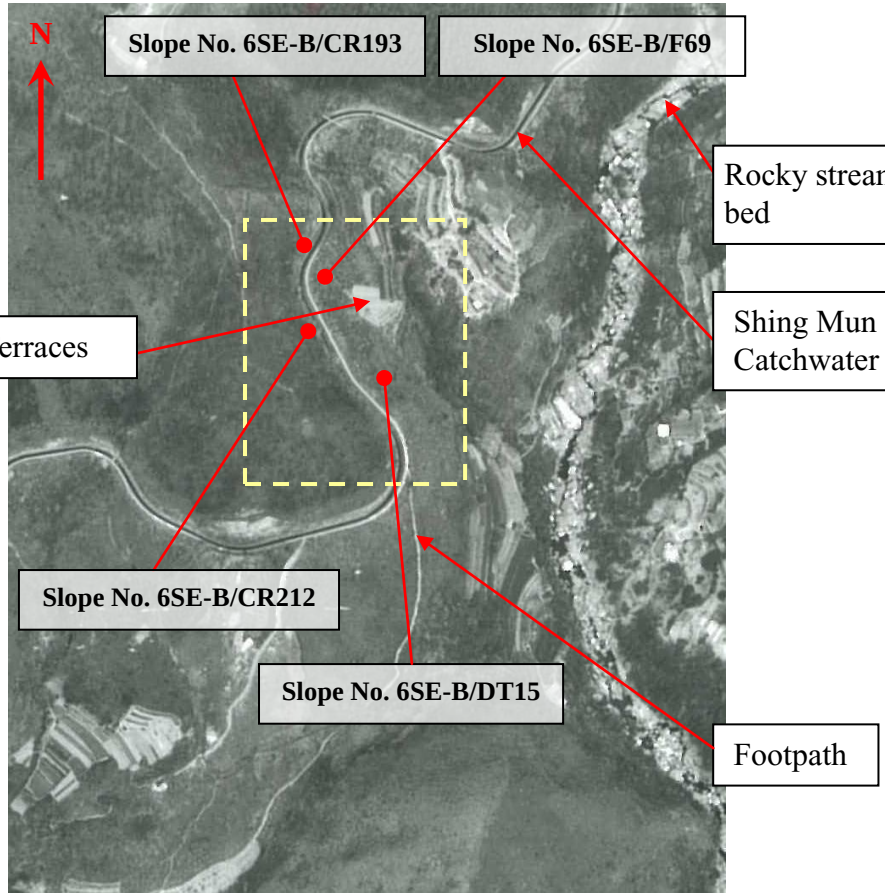
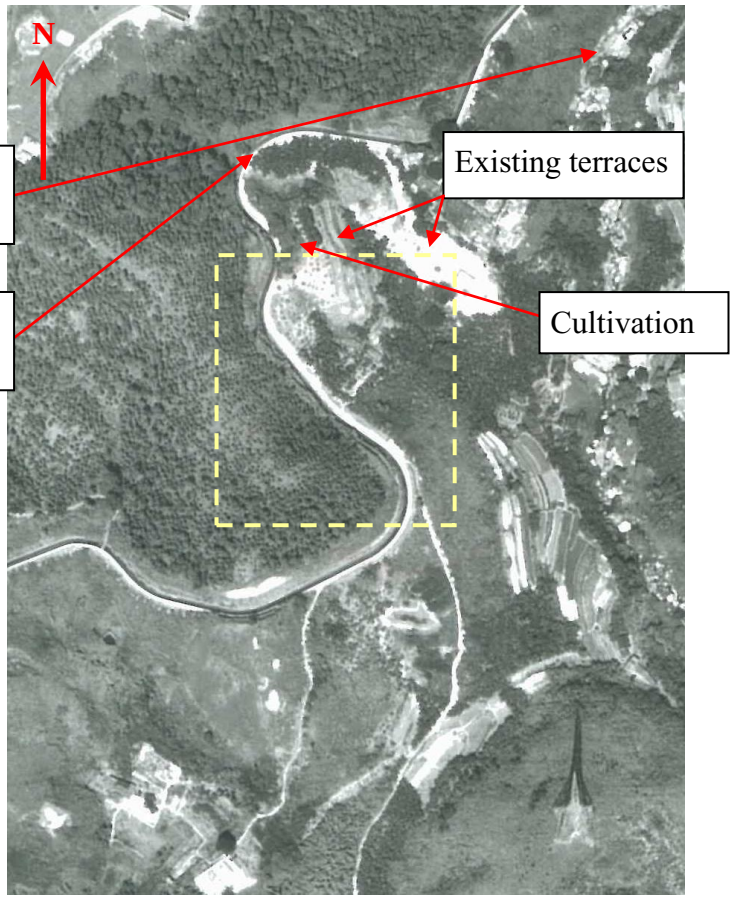


(Photograph 3266 taken on 20 February 1973)



(Photograph 56551 taken on 20 October 1984)

Plate A3 - Extract from 1973 and 1984 Aerial Photographs

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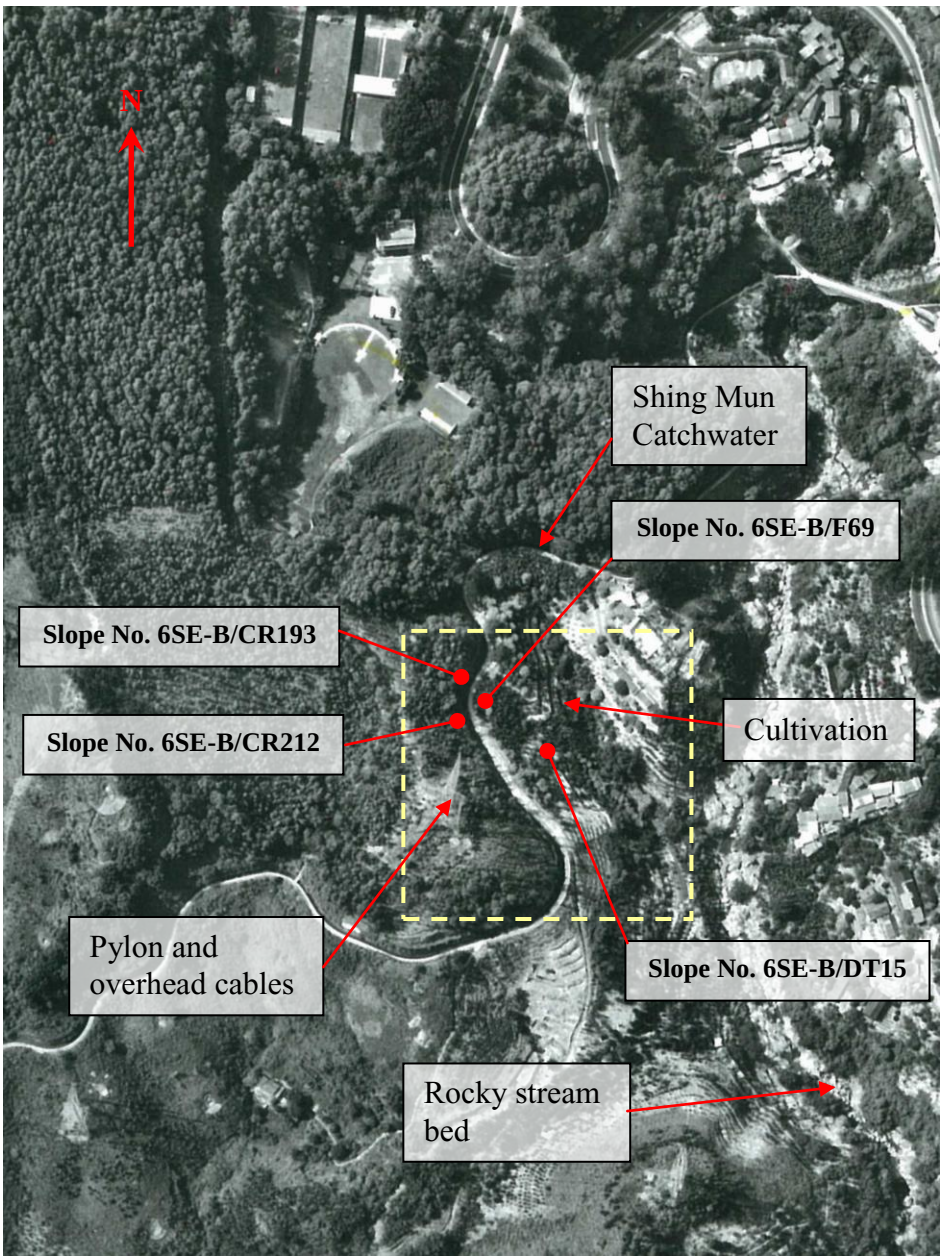
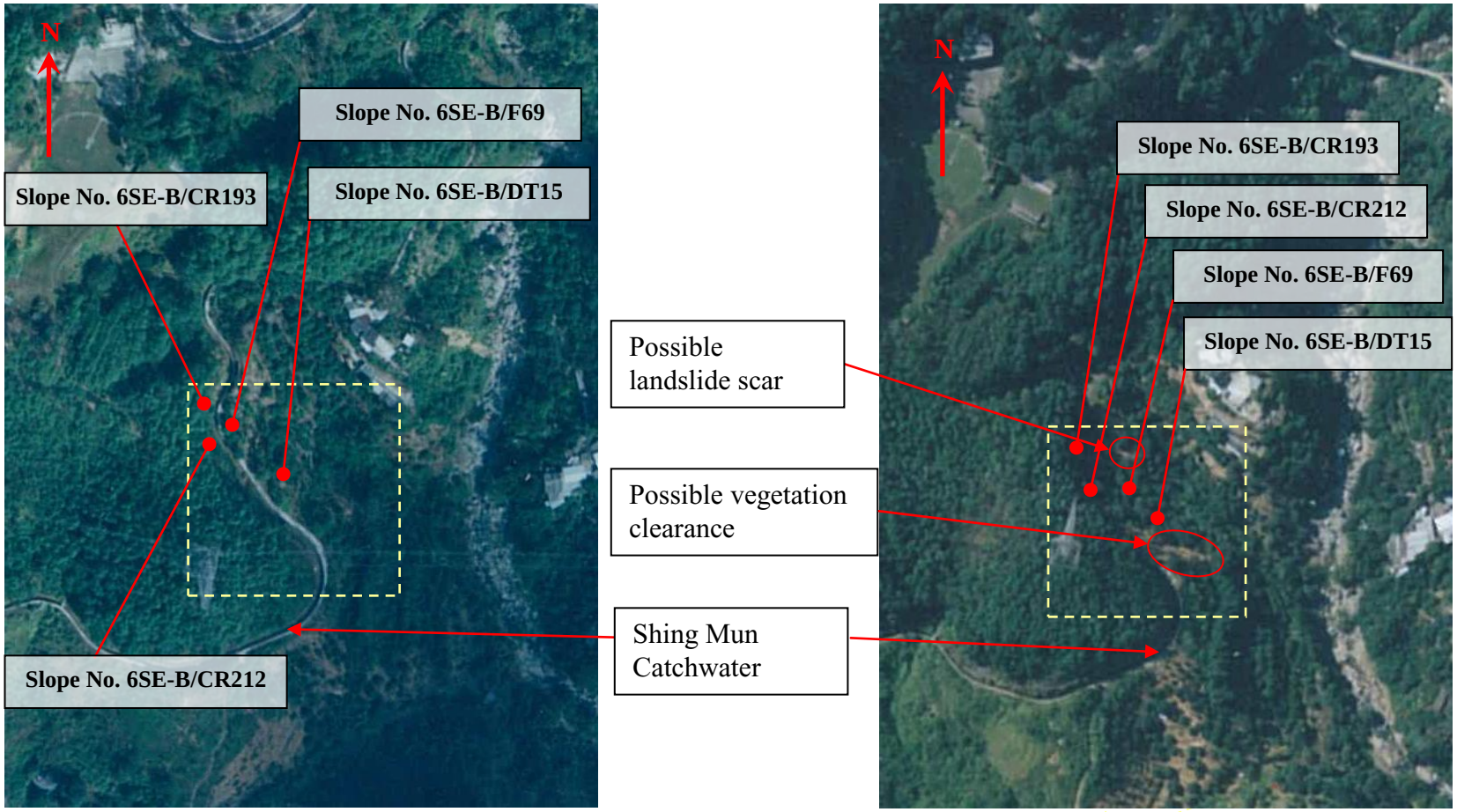


Plate A4 - Extract from 1992 Aerial Photograph (Photograph A31163 taken on 13 May 1992)



(Photograph CN24759 taken on 24 November 1999)

(Photograph CW31690 taken on 18 June 2001)

Plate A5 - Extract from 1999 and 2001 Aerial Photographs

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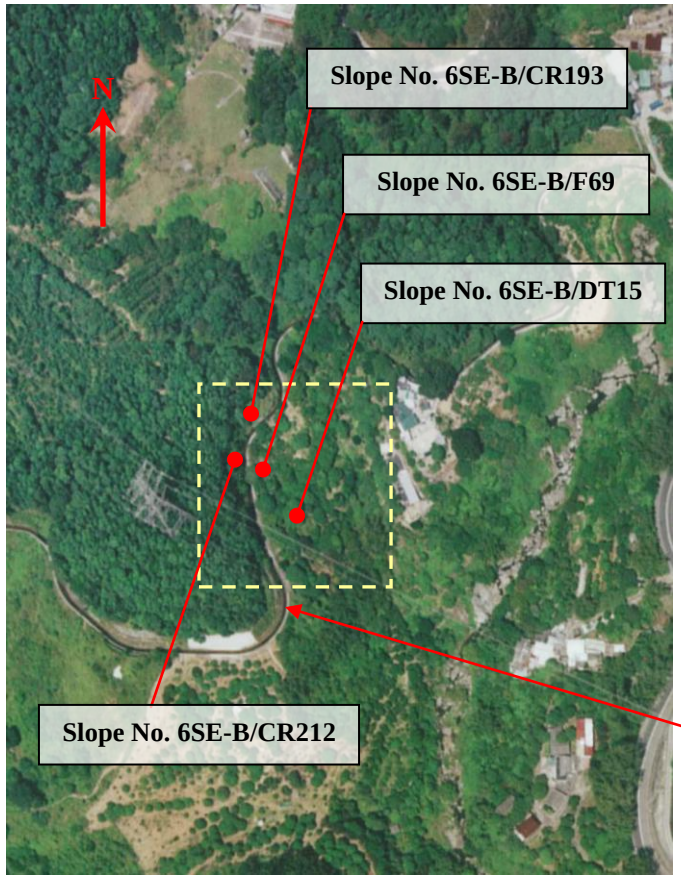
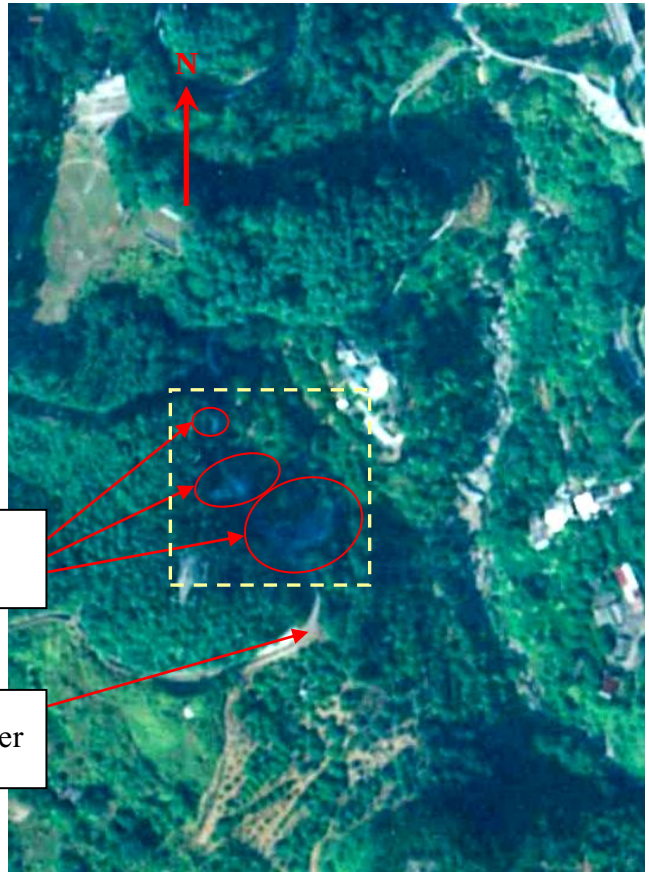


(Photograph CW60624 taken on 5 October 2004)



(Photograph CW69019 taken on 21 November 2005)

Plate A6 - Extract from 2004 and 2005 Aerial Photographs

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APPENDIX B

SUMMARY OF ENGINEER INSPECTIONS AND ROUTINE MAINTENANCE INSPECTIONS

CONTENTS

B1. ENGINEER INSPECTIONS AND ROUTINE MAINTENANCE INSPECTIONS

B1.1 Slope No. 6SE-B/CR193

An Engineer Inspection (EI) of the slope was carried out by Babtie Asia Ltd (BAL) for WSD on 11 July 2001 (BAL, 2001a). The overall condition of the slope was classified as "Fair". According to the EI record, surface erosion and a local failure were observed on the slope portion, while minor cracking and the collapse of a 10 m long section of the toe wall portion were identified. BAL recommended routine maintenance works (RMW), including removal of undesirable vegetation on slope surface, repair to the cracked wall surface and clearance of weepholes. BAL also recommended preventive maintenance works (PMW), including re-construction of the failed toe wall portion and improvement to the slope surface protection by hydroseeding with erosion control mat.

Routine Maintenance Inspections (RMIs) were carried out by WSD on 20 June 2002 and 29 May 2003 respectively before the August 2005 incident. In both the 2002 and 2003 RMI records (WSD, 2002a & 2003a), similar RMW including clearance of accumulated debris in the surface channels, removal of vegetation that might have caused severe cracking of the slope surface cover and drainage channels, and unblocking of weepholes, were recommended. However, there is no record to indicate that the recommended RMW had been completed prior to the August 2005 incident.

A record photograph of the 2003 RMI shows a general view of the slope in May 2003, from which signs of recent repair to a section of the wall in the middle portion of the slope can be seen. This repaired wall section appears to be the collapsed wall identified in the 2001 EI. However, there is no record to indicate the completion dates of the repair works and whether other PMW recommended in the 2001 EI were carried out.

B1.2 Slope No. 6SE-B/CR212

An EI was carried out by WSD's consultants, BAL, on 11 July 2001 (BAL, 2001b). The overall condition of the slope was classified as "Fair". No signs of distress were identified in the EI.

RMIs of this slope were carried out by WSD in 2002 and 2003, in conjunction with slope No. 6SE-B/CR193. According to the 2002 and 2003 RMI records (WSD, 2002b & 2003b), WSD recommended the same RMW as for slope No. 6SE-B/CR193. Again, there is no record to indicate that the recommended RMW had been completed prior to the August 2005 incident.

B1.3 Slope No. 6SE-B/F69

An EI was carried out by WSD's consultants, BAL, on 13 July 2001 (BAL, 2001c). The overall condition of the slope was classified as "Fair". According to the EI record, BAL reported no sign of distress but "debris and obstructions on the slope surface". The 'debris and obstruction' might have originated from the landslide identified in the June 2001 aerial photograph at the northern end of the slope (Section 3.2). According to the EI record, BAL recommended to remove the debris from the slope and to improve the slope drainage with the

provision of surface channels.

RMIs were carried out by WSD in 2002 and 2003, in conjunction with slopes Nos. 6SE-B/CR193 and 6SE-B/CR212. According to the 2002 RMI records (WSD, 2002c), no RMW were recommended. In the 2003 RMI record (WSD, 2003c), removal of surface debris was recommended and was completed on 22 March 2004. However, there is no record to indicate that the drainage works recommended in the 2001 EI were carried out.

B1.4 Slope No. 6SE-B/DT15

An EI was carried out by Maunsell Fugro Joint Venture (MFJV) for the LandsD on 24 January 2002 (MFJV, 2002). The overall condition of the slope was classified as "Good" and no signs of distress were observed.

On 18 October 2004, MGSL carried out an RMI of the slope for the LandsD (MGSL, 2004). The RMI recommended removal of debris and withered vegetation from the slope surface and the works were completed in June 2005.

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土力工程處刊物及訂購資料

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

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MAJOR GEOTECHNICAL ENGINEERING OFFICE PUBLICATIONS
土力工程處之主要刊物

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.

GEOGUIDES

Geoguide 1	Guide to Retaining Wall Design, 2nd Edition (1993), 258 p. (Reprinted, 2007).
Geoguide 2	Guide to Site Investigation (1987), 359 p. (Reprinted, 2000).
Geoguide 3	Guide to Rock and Soil Descriptions (1988), 186 p. (Reprinted, 2000).
Geoguide 4	Guide to Cavern Engineering (1992), 148 p. (Reprinted, 1998).
Geoguide 5	Guide to Slope Maintenance, 3rd Edition (2003), 132 p. (English Version).
岩土指南第五冊	斜坡維修指南，第三版(2003)，120頁(中文版)。
Geoguide 6	Guide to Reinforced Fill Structure and Slope Design (2002), 236 p.
Geoguide 7	Guide to Soil Nail Design and Construction (2008), 97 p.

GEOSPECS

Geospec 1	Model Specification for Prestressed Ground Anchors, 2nd Edition (1989), 164 p. (Reprinted, 1997).
Geospec 3	Model Specification for Soil Testing (2001), 340 p.

GEO PUBLICATIONS

GCO Publication No. 1/90	Review of Design Methods for Excavations (1990), 187 p. (Reprinted, 2002).
GEO Publication No. 1/93	Review of Granular and Geotextile Filters (1993), 141 p.
GEO Publication No. 1/2006	Foundation Design and Construction (2006), 376 p.
GEO Publication No. 1/2007	Engineering Geological Practice in Hong Kong (2007), 278 p.
GEO Publication No. 1/2009	Prescriptive Measures for Man-Made Slopes and Retaining Walls (2009), 76 p.
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.

TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents