DETAILED STUDY OF THE 20 AUGUST 2005 DEBRIS FLOOD AT ROUTE TWISK, TSUEN WAN

GEO REPORT No. 240

Maunsell Geotechnical Services Limited

GEOTECHNICAL ENGINEERING OFFICE

CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT

THE GOVERNMENT OF THE HONG KONG SPECIAL ADMINISTRATIVE REGION

DETAILED STUDY OF THE 20 AUGUST 2005 DEBRIS FLOOD AT ROUTE TWISK, TSUEN WAN

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This report is largely based on GEO Landslide Study Report No. LSR 6/2007 produced in July 2007

First published, March 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. These include guidance documents and results of comprehensive reviews. These publications and the printed GEO Reports may be obtained from the Government's Information Services Department. Information on how to purchase these documents is given on the second last page of this report.

R.K.S. Chan
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March 2009

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FOREWORD

This report presents the findings of a detailed study of the debris flood (Incident No. 2005/08/0351a) that occurred at about 6:00 p.m. at Route Twisk, Tsuen Wan on 20 August 2005. The debris flood was probably triggered by a major landslide (Incident No. 2005/08/0480) on slope No. 6SE-B/CR249, involving a failure volume of about 50 m^3. The slope is situated immediately above the section of the Shing Mun Catchwater northeast of Route Twisk near Kwong Pan Tin San Tsuen, Tsuen Wan. Another slope No. 6SE-D/FR98 located along the debris trail and on the downhill side of Route Twisk was also severely eroded (Incident No. 2005/08/0351b). A section of Route Twisk was temporarily closed.

The key objectives of the study were to document the facts about the debris flood and the associated landslides, present relevant background information and establish the probable causes of the debris flood and associated landslides. The scope of the study comprised desk study, site reconnaissance, detailed field mapping and theoretical hydraulic assessment of the catchwater channel. Recommendations for follow-up actions are presented separately.

The report was prepared as part of the 2006 Landslide Investigation Consultancy for landslides occurring in Kowloon and the New Territories in 2006, for the Geotechnical Engineering Office, Civil Engineering and Development Department, under Agreement No. CE 50/2005 (GE). This is one of a series of reports produced during the consultancy by Maunsell Geotechnical Services Limited.

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Agreement No. CE 50/2005 (GE)
Study of Landslides Occurring in Kowloon and the New Territories in 2006 - Feasibility Study

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1. INTRODUCTION

At about 6:00 p.m. on 20 August 2005 when the Landslip Warning and Amber Rainstorm Warning had been in effect for about 21 hours and 9½ hours respectively, a landslide (Incident No. 2005/08/0480) occurred on slope No. 6SE-B/CR249, involving a failure volume of about 50 m³. The slope is situated immediately above a section of the Shing Mun Catchwater, to the northeast of Route Twisk near Kwong Pan Tin San Tsuen, Tsuen Wan (Figure 1). The landslide debris blocked the catchwater channel and caused the water to back up. Consequently, large quantities of water discharged via the overflow weirs upstream of the landslide into a natural streamcourse intersecting the catchwater (Figure 2).

As the flow travelled downstream, it undercut the stream bed and side slopes of the streamcourse and entrained loose materials (Figure 3). The flow, that entrained significant amounts of debris, developed into a debris flood (Incident No. 2005/08/0351a).

At the time of the incident, the debris flood overtopped at a sharp bend of the streamcourse and travelled across Route Twisk (Figure 3) where a large amount of debris was deposited (Plates 1 and 2). Slope No. 6SE-D/FR98 situated on the opposite side of Route Twisk was also significantly eroded (Incident No. 2005/08/0351b) (Plate 3).

As a result of the incident, one registered squatter structure was undermined (Plate 4) and subsequently recommended for permanent evacuation.

Following the incident, Maunsell Geotechnical Services Limited (MGSL), the 2006 Landslide Investigation Consultant for Kowloon and the New Territories, carried out a detailed study of the landslide incident for the Geotechnical Engineering Office (GEO), Civil Engineering and Development Department (CEDD), under Agreement No. CE 50/2005 (GE).

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

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

(a) review of all relevant documents relating to the study area,

(b) aerial photograph interpretation (API),

(c) detailed field observations and measurements,

(d) analysis of rainfall records,

(e) theoretical hydraulic assessment, and

(f) diagnosis of the probable causes of the debris flood and associated landslides.

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2. THE SITE

2.1 Site Description

2.1.1 General

The landslide site is situated above a section of the Shing Mun Catchwater, approximately 220 m northeast of Route Twisk near Kwong Pan Tin San Tsuen (Figure 1), at an elevation of about 206 mPD. The overflow weir (SMOF-28), which allowed a large amount of discharge into a natural streamcourse during the 20 August 2005 debris flood incident, is located within this section of the catchwater and about 120 m upstream of the landslide location (Figure 2).

The streamcourse below the catchwater runs in a south-westerly direction through a natural hillside and a registered disturbed terrain (No. 6SE-D/DT14) in the Government's Slope Catalogue. The streamcourse turns sharply at an elevation of about 123 mPD and it continues for another 30 m along the eastern side of Route Twisk, before discharging into a cross-road culvert beneath the road at an elevation of about 117 mPD. An area of agricultural land is located below the western side of this section of Route Twisk.

Kwong Pan Tin San Tsuen is situated about 160 m to the south of the streamcourse and bounded by Route Twisk to the west (Figure 2). Two private developments, the Cliveden and the Cairnhill, are located about 350 m and 280 m respectively to the northwest of the streamcourse (Figure 2).

2.1.2 Shing Mun Catchwater

According to the records from the Water Supplies Department (WSD), the entire Shing Mun Catchwater is about 9 km long and is located on the hillside of Tai Mo Shan. It runs from Ha Fa Shan to the west to the Shing Mun Reservoir to the east. It collects storm water from Tai Mo Shan through direct runoff or by intercepting natural streamcourses above the catchwater. Controlled intake dams are located at the interception points of the major natural streamcourses to control the amount of water entering the catchwater. Overflow weirs are located along the catchwater. The size of the catchwater channel varies. At chainage M6500 (i.e. about 6.5 km from the Shing Mun Reservoir) near Route Twisk, the cross-sectional area of the catchwater channel is about 11 m^2 while at the outfall to the Shing Mun Reservoir the cross-sectional area of the catchwater channel is approximately 16 m^2. A 3.5 m wide road runs beside the catchwater to provide vehicular access.

Slope No. 6SE-B/CR249 is situated immediately above the section of the Shing Mun Catchwater, which is about 5 km from the Shing Mun Reservoir. The slope is about 135 m long, with a soil cut portion above the catchwater channel wall (Plate 5). The maximum height of the soil cut portion is about 16 m. The soil cut portion is inclined at about 50° and is covered with vegetation. The sidewall of the catchwater channel is about 2.7 m high and inclined at approximately 70°. The natural terrain above the soil cut is inclined at about 28° and covered with dense vegetation, comprising grass and shrubs.

Overflow weir SMOF-28 is located at chainage M5133, upstream of slope No. 6SE-B/CR249. The weir opening is about 6.3 m wide and 0.6 m high, located on the

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downhill side of the catchwater (Plate 6). The catchwater channel between the overflow weir and slope No. 6SE-B/CR249 has a trapezoidal section, with a depth of 2.7 m and top and base widths of 5 m and 2.9 m respectively.

Three controlled intake dams are located upstream of slope No. 6SE-B/CR249, at chainages M6557, M6664 and M6704.

2.1.3 Streamcourse

The upper part of the streamcourse is almost straight and runs southwesterly through the natural hillside below the Shing Mun Catchwater (Figure 2). This part of the streamcourse, up to about 86 m from the overflow weir, is typically about 3 m to 6 m wide and has an overall gradient of about 35°. The lower part of the streamcourse runs through slope No. 6SE-D/DT14 and turns slightly, towards south-southwest. The overall gradient reduces to about 20°. The entire slope No. 6SE-D/DT14 is about 346 m long and 58 m high, with an average gradient of about 26°. The part of the streamcourse located within slope No. 6SE-D/DT14 has no obvious signs of human disturbance. This part of the streamcourse is typically 1 m to 3 m wide. A registered squatter structure (No. RTW/4D/296) and a man-made slope No. 6SE-B/C236 are situated adjacent to the streamcourse on its northern side (Figure 2).

There is a sharp bend in the streamcourse about 160 m downstream from the overflow weir, beyond which the streamcourse runs due south along the eastern side of Route Twisk. The streamcourse discharges into a cross-road culvert beneath Route Twisk. This section of the streamcourse is about 30 m long, 2 m to 3 m wide and has a gradient of 8° (Plate 7). Isolated brick/rubble walls are present on the sides of this section of the streamcourse. A covered 300 mm wide U-channel, originating at the toe of slope No. 6SE-B/C236, also runs beside the eastern side of Route Twisk and discharges to the cross-road culvert.

2.1.4 Route Twisk and Cross-road Culvert

Route Twisk runs between Tsuen Wan and Shek Kong and the section of concern is an approximately 9 m wide, 2-lane carriageway, which is aligned approximately northwest to southeast. An approximately 1.9 m wide footpath is present on the western side of the carriageway. The gradient of this section of the road is about 5°. Slope No. 6SE-D/FR98 is situated on the western side of Route Twisk, opposite the sharp bend of the streamcourse (Figure 2). The fill slope is about 135 m long, 7 m high and is inclined at an angle of about 40°. A wall, which is about 40 m long, 3 m high and inclined at approximately 80°, is located at the toe of the slope about 20 m from the August 2005 landslide scar. An area of agricultural land, about 320 m^2, is situated below slope No. 6SE-D/FR98.

The cross-road culvert beneath Route Twisk, is rectangular in section and is about 15 m long, 1.4 m wide by 1.4 m high (Plate 8).

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2.2 Regional Geology

According to Hong Kong Geological Survey 1:20,000 Solid and Superficial Geology Map Sheet 6 – Yuen Long (GCO, 1986), slope No. 6SE-B/CR249 and the streamcourse situated above and below the Shing Mun Catchwater respectively are underlain by coarse ash crystal tuff. Areas of debris flow deposits are present on both sides of the streamcourse. Slope No. 6SE-D/FR98 is underlain by feldsparphyric rhyolite. There is a photogeological lineament located about 180 m southeast of the streamcourse (Figure 4).

3. MAINTENANCE RESPONSIBILITY AND LAND STATUS

3.1 Slopes

According to the Slope Maintenance Responsibility Information System (SMRIS) of the Lands Department (Lands D), WSD is responsible for the maintenance of slope No. 6SE-B/CR249 whilst the Highways Department (HyD) is responsible for the maintenance of slope No. 6SE-D/FR98. Slope No. 6SE-D/DT14 is jointly maintained by the Lands D and the owners of private lots DD432 Lot 105 and CLL 9505, but the sub-divisions under the different maintenance responsibility (MR) are yet to be assigned.

3.2 Streamcourse

The Environment, Transport and Works Bureau Technical Circular (Works) No. 14/2004, states that "since most natural watercourses are self cleaning, full scale maintenance to all the natural watercourses would not be necessary" and "*ad hoc* maintenance should be carried out when necessary". The maintenance of the streamcourse is under the purview of the Drainage Services Department (DSD) in accordance with the Circular.

3.3 Cross-road Culvert

At the time of preparing this report, the maintenance responsibility of the cross-road culvert is being discussed between DSD and HyD.

4. SITE HISTORY AND PAST INSTABILITY

4.1 Site History

The history of site development has been determined from an interpretation of the available aerial photographs, together with a review of the relevant documentary information (including old topographical survey maps) and site observations. Detailed observations from aerial photograph interpretation (API) are summarized in Appendix A.

According to WSD's record, construction of Shing Mun Catchwater was completed in 1936 and the associated slopes, including slope No. 6SE-B/CR249, were probably formed at around the same time. Based on API, slope No. 6SE-B/CR249 was modified between 1987

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and 1988 with surface drainage channels constructed on the slope surface and at the crest (Figure 5).

Prior to 1955, agricultural areas were present on either side of the streamcourse (Figure 5). An agricultural area was located adjacent to the northern side of the streamcourse while some larger agricultural areas were located at the present-day Kwong Pan Tin San Tsuen, to the south of the streamcourse. Between 1963 and 2003, there were changes to the extent of these agricultural areas. A squatter structure (labelled 'A' in Figure 5) is visible in the 1963 aerial photographs, and was located about 30 m north of the streamcourse. The squatter structure appeared to have been cleared between 1977 and 1979. Another squatter structure (labelled 'C' in Figure 5), which appeared at the previous location of the demolished squatter structure 'A', can be observed in the 1979 aerial photographs. In 1982, the platform of squatter structure 'C' had been extended and another squatter structure 'E' was erected. Squatter structures 'C' and 'E' were subsequently demolished between 1992 and 1993 and between 1983 and 1984 respectively.

Another two squatter structures ('B' and 'F'), which are visible in the 1977 and 1982 aerial photographs respectively, were located adjacent to the streamcourse and at the crest of slope No. 6SE-B/C236 (Figure 5). Based on the locations of these two squatter structures, they were probably squatter structures Nos. XRTW/4D/3 and RTW/4D/270, as registered by the Housing Department (HD) under their 1982 Squatter Structure Survey (Figure 5). Squatter structures 'B' and 'F' were subsequently demolished between 1994 and 1998 and between 1992 and 1993 respectively. In the 1977 aerial photographs, the platform in front of the squatter structure 'B' was extended. By 1981, squatter structure 'D' was erected, which is probably registered squatter structure No. RTW/4D/296. There were no obvious changes to this squatter structure since then.

Route Twisk and the associated cross-road culvert were constructed between 1924 and 1955 (Figure 5). The section of the streamcourse crossing the present-day location of Route Twisk was also realigned between 1924 and 1955, probably associated with the construction of Route Twisk. The realigned streamcourse runs along the eastern side of Route Twisk towards the cross-road culvert. There have been no obvious changes to this section of Route Twisk since then. Construction of the private developments, the Cliveden and the Cairnhill, northwest of the streamcourse, commenced in 2001.

4.2 Squatter Clearance

As a result of the August 2005 debris flood, registered squatter structure (No. RTW/4D/296) was recommended for permanent evacuation (*viz.* Category I NDC) by the GEO (Figure 6). This squatter structure, which is situated adjacent to the streamcourse, was undermined in the incident. Based on GEO records, squatter structure No. RTW/4D/296 was previously recommended for clearance (Category 2 NDC recommendations) by the GEO under the 1992 Non-Development Clearance (NDC) Re-inspection Programme (Figure 6). The squatter structure was still occupied at the time of the incident.

There were previously two other registered squatter structures (*viz.* Nos. RTW/4D/270 and XRTW/4D/3) situated near the streamcourse (Figure 6). According to the GEO's records, these two structures had been recommended for clearance (Category 2 NDC

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recommendations) by the GEO. In the post-failure site inspection, it was observed that these two squatter structures had already been cleared, probably prior to the incident.

4.3 Past Instability

4.3.1 Natural Terrain Landslide Inventory and Large Landslide Database

In 1995, GEO compiled the Natural Terrain Landslide Inventory (NTLI), from the interpretation of high-level aerial photographs dating from 1945 to 1994 (Evans *et al*, 1997 and King, 1997). The NTLI has since been updated to 2003. According to the GEO's NTLI, there are two natural terrain landslides (tag Nos. 06SEB0083 and 06SEB0084), which are situated at about 290 m and 300 m northwest of slope No. 6SE-B/CR249 respectively (Figure 7).

In 2004, GEO commenced a project to enhance the NTLI using low-altitude aerial photographs and produced an Enhanced Natural Terrain Landslide Inventory (ENTLI). The ENTLI database records five natural terrain landslides (tag Nos. 06SEB0348E, 06SEB0349E, 06SEB0350E, 06SED0428E and 06SED0432E) in the vicinity of the streamcourse. The landslide nearest to the streamcourse was about 80 m to the southeast (tag No. 06SEB0348E). However, the two NTLI landslides (tag Nos. 06SEB0083 and 06SEB0084) do not appear to correspond to any of these ENTLI landslides.

The GEO's Large Landslide Database contains no records of any large landslides in the immediate vicinity of slope No. 6SE-B/CR249 and the streamcourse.

4.3.2 Aerial Photograph Interpretation

The aerial photographic record of the site indicates that previous instability has occurred at several locations, including slope No. 6SE-B/CR249, the adjoining man-made slope No. 6SE-B/CR248 to the northwest, the natural hillside in the vicinity of the streamcourse and slope No. 6SE-B/C236 (Figure 7).

On slope No. 6SE-B/CR249, the 1963 aerial photographs show a reflective appearance in the northwest portion of the slope, suggesting a failure. Another area of high reflectivity was visible in the 1982 aerial photographs, which is about 40 m northwest of the August 2005 landslide scar on slope No. 6SE-B/CR249. This area was probably associated with the reported landslide, Incident No. NT82/241. A probable landslide on the adjoining slope No. 6SE-B/CR248 is evident in the 1969 aerial photographs.

In the 1963 aerial photographs, a shallow depression which is defined by a rounded concave break in slope, is visible in the natural hillside below the catchwater, about 30 m northwest of the streamcourse. The depression probably suggests past instability. An area of erosion in the natural hillside is also evident in the 1963 aerial photographs, which is about 20 m southeast of the streamcourse. In the 1967 aerial photographs, a landslide scar is visible on the natural hillside immediately to the north of the streamcourse. The landslide appeared to be an open hillside failure with a relatively short run-out distance of about 20 m.

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An area of high reflectivity on slope No. 6SE-B/C236, which was probably associated with Incident No. MW97/7/4, is visible in the 1988 aerial photographs.

4.3.3 GEO's Landslide Database

According to the GEO's landslide database, a landslide occurred on slope No. 6SE-B/CR249 in 1982 (Incident No. NT82/241). The landslide occurred on a section of the slope with an angle of "80°" and the scar measured approximately 15 m wide by 6 m high and 0.7 m deep (measured normal to the slope face), extending to 0.5 m above the base of the catchwater channel. No failure volume was provided in the incident report, but it is estimated to be about 30 m^3 based on the scar dimensions. This landslide is about 40 m northwest of the August 2005 landslide.

Some landslides occurred along or near the concerned section of Route Twisk (Figure 7), involving failure volumes from about 1 m^3 to 30 m^3.

5. PREVIOUS ASSESSMENTS AND SLOPE WORKS

5.1 GCO Catchwater Studies

In 1979, WSD and GCO commenced a joint study to investigate the stability of catchwaters and their associated slopes and recommend measures to reduce the potential risk to downhill developments. The first study report (GCO, 1980) summarized the available information and recommended a phased study of all catchwaters.

In the second study report (GCO, 1982), data for 48 catchwaters were collated and after screening, walkover surveys of 19 catchwaters were carried out. API and mapping were carried out on six catchwaters that were considered to present the greatest potential risks. Four catchwaters, including the Shing Mun Catchwater, were considered to have generally high failure consequences at several sections and were studied in detail over their entire lengths.

The second catchwater study report also concluded that there were a few catchwaters which were of concern throughout their lengths, and "in terms of both cut slope condition and failure consequences, the Shing Mun catchwater is potentially the most dangerous in the territory."

As follow-up actions, WSD carried out flooding studies of selected catchwaters and subsequently nominated some slopes for inclusion into the Landslip Preventive Measures (LPM) Programme managed by the GEO. Improvement works to the Shing Mun catchwater were also carried out by WSD in the 1980s. In particular, based on WSD's record drawings, an additional overflow weir at chainage M5352 (i.e. about 270 m upstream of slope No. 6SE-B/CR249) was constructed in 1985.

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5.2 SIFT and SIRST Studies

In 1992, the GEO initiated a project entitled "Systematic Inspection of Features in the Territory" (SIFT). This project aimed to search systematically for slopes not included in the 1977/78 Slope Catalogue and to update information on previously registered features by studying aerial photographs together with limited site inspections.

In 1996, slope No. 6SE-B/CR249 was classified as SIFT Class ‘C2’, i.e. a slope that had “been formed or substantially modified after 30.6.78”. In the SIFT report, it was also stated that the slope was “originally cut pre 1963 during catchwater construction” and “substantially modified between 1987 and 1988”. In 1996, slope No. 6SE-D/FR98 was classified as SIFT Class ‘B1’, i.e. a slope that had “been formed or substantially modified before 30.6.78”.

In July 1994, the GEO commenced a project entitled “Systematic Identification and Registration of Slopes in the Territory” (SIRST), to update the 1977/78 Slope Catalogue. The SIRST results are summarised below.

On 29 November 1996, slope No. 6SE-B/CR249 was inspected by the SIRST consultants, MGSL. The slope surface was 75% vegetated and 25% bare. The slope surface condition was assessed as “fair”. Sign of distress was assessed as “reasonable” and no sign of seepage was noted. The consequence-to-life category was assessed to be “3”. The CNPCS score (which reflects the direct risk-to-life) of the slope was revised from “0” to “1.049” in 2001 (Section 5.3).

The SIRST consultants, MGSL, inspected slope No. 6SE-D/FR98 on 6 December 1996 and recorded that 90% of the slope surface was vegetated and the rest of the surface being bare or sealed with stone pitching. The slope surface condition was assessed as “fair”. No sign of distress or seepage were noted. The consequence-to-life category was assessed to be “2”. The slope has a CNPCS score of 0.74.

5.3 Engineer Inspections and Routine Maintenance Inspections

An Engineer Inspection (EI) was carried out on slope No. 6SE-B/CR249 by MGSL (consultants to WSD) in February 2001. The condition of the vegetated surface was assessed as “Good” and no signs of distress were noted. Cracking on the channel wall was noted, the location of which is within the August 2005 landslide scar (Plate 9). No previous stability assessment could be located during the desk study of the EI. However, stability assessment was not recommended as “no past record of instability was noted”, and that “no sign of distress/seepage was observed” and the “Consequence-to-life category of the features is ‘3’”. The classification of the overall state of maintenance of the slope was assessed as “Fair”. Minor routine maintenance works including clearance of obstructions in weepholes, repair of cracking on the channel wall, and clearance of debris, undesirable vegetation and other obstructions from surface drainage systems, were recommended in the EI report. The EI report also recommended the type of facility at the toe to be changed from “Road with very low traffic” to “Catchwater”, updating the CNPCS from “0” to “1.049”. The slope angle in the SIS record was recommended to be revised to “50°”.

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Routine Maintenance Inspection (RMI) of slope No. 6SE-B/CR249 was carried out by WSD in January 2001. Minor maintenance works including clearance of drainage channels, removal of surface debris and vegetation, and clearance of blocked weepholes, were recommended.

RMIs of slope No. 6SE-D/FR98 were carried out by the HyD's consultant, Black & Veatch Hong Kong Limited in June 2003 and April 2004. In both RMIs, minor maintenance works including clearance of drainage channels and blocked weepholes, removal of debris on slope and broken tree branches, and trimming of undesirable and overgrown vegetations, were recommended. In July 2005, another RMI was carried out by the HyD's contractor, Chiu Hing Construction and Transportation Co. Ltd. Maintenance works including clearance of vegetation from slope and wall surface, removal of debris on slope surface and fallen trees, and clearance of blocked weepholes, drainage channels and catchpits, were recommended.

An EI was carried out on slope No. 6SE-D/FR98 by MGSL (consultants to HyD) in November 2005. The conditions of both the rigid surface cover and vegetated surface were assessed as "Fair" and no signs of instability were noted. Routine maintenance, including clearance of debris, undesirable vegetation and other obstructions from surface drainage systems, sealing up of cracks in surface drainage system, clearance of obstructions from weepholes, removal of undesirable vegetation on the rigid surface, repair of the rigid surface and regrading of eroded areas, was recommended. The EI report also recommended preventive maintenance works, which included provision of a 300 mm U-channel and extension of an existing upstand at the crest of the slope to cover the August 2005 landslide area.

5.4 Drainage Maintenance Works

No records on the maintenance of the streamcourse were available from DSD and the Home Affairs Department. No records on the construction or maintenance of the cross-road culvert beneath Route Twisk were available from DSD and HyD.

6. THE 20 AUGUST 2005 DEBRIS FLOOD AND POST-FAILURE OBSERVATIONS

6.1 The 20 August 2005 Debris Flood and Associated Landslides

The debris flood incident (No. 2005/08/0351a) occurred at about 6:00 p.m. on 20 August 2005, when the Landslip Warning and Amber Rainstorm Warning had been in effect for about 21 hours and 9½ hours respectively. A landslide occurred at slope No. 6SE-B/CR249 (Plate 10), which is situated directly above the catchwater (Incident No. 2005/08/0480). The resulting blockage of the catchwater triggered the incident.

The landslide debris from slope No. 6SE-B/CR249, with an estimated total volume of about 50 m³, was deposited in the open catchwater channel, partially blocking it. This led to back up of water in the catchwater channel and caused a large quantity of discharge at overflow weir SMOF-28.

The overflow entered the streamcourse and washed out some of the refuse (synthetic fabric) placed below the overflow weir, into the streamcourse. Little erosion and entrainment

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of the streamcourse occurred along the upper 80 m of the streamcourse where intact rock is present near the surface. Further downstream, the water flow entrained colluvium from the sides of the streamcourse and increased its erosive power. The flood water turned into a debris flood and undercut the side of a former squatter platform, which was situated about 130 m downstream of the overflow weir.

Registered squatter structure No. RTW/4D/296, about 140 m from the overflow weir, was undermined. The debris flood continued to the sharp bend of the streamcourse where it overtopped and deposited about 60 m^3 of debris onto Route Twisk. Slope No. 6SE-D/FR98 situated on the opposite side of Route Twisk was also significantly eroded by the debris flood. The volume of the landslide debris from slope No. 6SE-D/FR98 was about 130 m^3. The debris deposited on Route Twisk was subsequently washed out and generated an outwash trail of about 1 km long along Route Twisk, towards Tsuen Wan.

As a result of the incident, registered squatter structure No. RTW/4D/296 was recommended for permanent evacuation. A section of Route Twisk was completely closed (except for pedestrians) between 20 August 2005 and 24 August 2005.

6.2 Observations Made and Actions Taken by Water Supplies Department on 20 August 2005

According to WSD's records, WSD inspected the Shing Mun Catchwater on the afternoon of 20 August 2005. The inspection team passed the section of Shing Mun Catchwater above Lo Wai twice between 3:00 p.m. and 4:35 p.m. on 20 August 2005. No landslide or irregularity along this section of the catchwater was noted.

At that time, the three controlled intake dams along the Shing Mun Catchwater and upstream of the overflow weirs (at chainages M6704, M6664, and M6557 respectively) were functioning properly (i.e. allowing water to enter the catchwater).

At 10:20 p.m. on 20 August 2005, WSD closed off the controlled intake dams at chainages M6557 and M6664 (i.e. about 1480 m and 1590 m upstream of the landslide at slope No. 6SE-B/CR249 respectively) to prevent water from entering the Shing Mun Catchwater.

6.3 Post-failure Observations

Following the incident, several site inspections were carried out by MGSL between 26 August 2005 and 22 February 2006. Figure 3 shows the observations along the debris flood trail with a reference chainage (CH) starting from the overflow weir. The longitudinal and cross sections of the debris trail are presented in Figures 8 and 9.

Source Area

At the time of the inspection on 26 August 2005, the landslide scar at slope No. 6SE-B/CR249 was mostly covered and detailed mapping of the scar was not possible (Plate 10). The landslide measured approximately 18 m wide by 8 m high by up to 1.5 m

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deep with a failure volume of about 50 m³. A surface drainage channel located on mid-slope also collapsed. The toe of the scar was at the base level of the catchwater channel, and the channel wall had collapsed (Plate 10). With limited exposure of the scar, the scar materials appeared to comprise yellowish brown, sandy clayey silt (completely decomposed tuff). A small area of Grade IV/III rock was observed at the toe of the scar (Plate 10). Sealed cracks on the catchwater channel wall immediately adjacent to and northwest of the landslide scar were observed (Plate 11). At the time of inspection, urgent repair works, including the removal of the debris and placement of some gabion cages in the catchwater channel were on-going. Plate 12, provided by WSD, shows the general view of the landslide just before the slope surface was covered with shotcrete.

The section of catchwater between slope No. 6SE-B/CR249 and the upstream overflow weir (SMOF-28) was also inspected. No clear flow marks within the catchwater channel and no signs of overtopping were observed.

Upper Trail (chainages CH 0 to CH 86)

For ease of reference, a chainage line has been established along the debris flood trail with the outlet of the overflow weir being designated as chainage 0 (CH 0, see Figure 3). The hillside alongside the upper section of the trail is covered with dense vegetation. An area of erosion (Figure 3 and Plate 13), about 6 m wide by 5 m long by 0.6 m deep with a volume of about 5 m³, was observed on the northern side of the streamcourse immediately below the overflow weir. Colluvium comprising reddish brown and brown, sandy clayey silt with some fine to coarse gravel, was exposed on the erosion scar. Some refuse comprising synthetic fabric was observed on the southern side, which suggests that fill was probably placed on the downslope side of catchwater (Plate 13). Further downstream (chainage CH 23), rock was exposed at the stream bed, which comprised grey, moderately decomposed coarse ash tuff (Plate 14).

From chainage CH 10 to chainage CH 32, moderately decomposed tuff (MDT) was exposed in the bed of the streamcourse, which undulated in steps. In this section, the streamcourse is about 3 m to 4 m wide and has a gradient of about 30° (Figure 8 and Plate 15). Apart from some minor erosion on the sides of the streamcourse at chainages CH 10, CH 23 and CH 30 (each with less than 1 m³ in volume), there was no other evidence of erosion and deposition of debris along this section of the streamcourse (Figure 3).

The streamcourse widens to about 5 m to 6 m between CH 32 and CH 57 (Figure 3 and Plate 15). The gradient of the streamcourse increases locally to about 45° between chainages CH 49 and CH 57 (Figure 8 and Plate 16). MDT was exposed in the bed of the streamcourse with moss and vegetation, which suggests little erosion along the bed in this section. Minor erosion (with a depth of about 0.2 m to 0.3 m and a total volume of about 5 m³) was observed on the sides of this steep section of the streamcourse (Figure 3 and Plate 17).

From chainage CH 57 to chainage CH 86, the streamcourse narrows to a width of about 3 m to 4 m with MDT exposed in the bed and both sides of the streamcourse. There is a series of steps of about 1 m to 2 m drop along the bed of the streamcourse, giving an overall gradient of about 35° (Figure 8). There was little erosion and deposition along this section of the streamcourse (Figure 3 and Plate 18).

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Middle Trail (chainages CH 86 to CH 130)

The gradient of the streamcourse at the middle portion of the trail reduces significantly to about 10° to 20° with some small drops of about 1.5 m high at chainage CH 108 and 2.5 m high at chainage CH 116 respectively (Figure 8). The bed of the streamcourse comprises mostly highly to moderately decomposed tuff (H/MDT) with colluvium present on both sides of the streamcourse (Plate 19). The width of the streamcourse is typically about 2 m to 3 m wide with a local narrower width of about 1 m at chainages CH 88 and CH 100 (Plates 19 and 20). The streamcourse widens downstream of chainage CH 116.

Erosion at the sides (about 1 m deep) and base of the streamcourse (about 0.3 m deep) was observed between chainages CH 88 and CH 108. In total, about 20 m^3 of materials was eroded (Figures 3 and 9). Colluvium, which comprised brown and reddish brown, sandy clayey silt, was exposed on both sides of the streamcourse (Plate 21). HDT, comprising reddish brown to yellowish brown sandy silt, was also observed just above the eroded bed of the streamcourse. In this section of the streamcourse, deposition of angular rock fragments was observed on the stream bed (Plate 20). However, it was difficult to determine whether or not these rock fragments were deposited as a result of the August 2005 incident.

Between chainages CH 108 and CH 116, both sides of the streamcourse are relatively steep (about 60° to 70° with no access for close inspection) but no signs of recent erosion were apparent (Plate 22). Fine deposit of about 2 m^3 was observed at chainage CH 110. The streamcourse drops by 2.5 m at chainage CH 116 (Plate 23) and between chainages CH 116 and CH 130, the gradient of the streamcourse is about 10° (Figure 8). Significant erosion was observed near chainage CH 126 (Figure 3 and Plate 24) on the southern side of the streamcourse where an erosion scar, about 3 m high by 6 m wide, was observed. Colluvium, which comprised yellowish brown sandy silt with many sub-angular to sub-rounded, cobble-sized rock fragments, was observed in the erosion scar (Plate 24). Minor erosion was noted on the northern side and along the bed of the streamcourse along this section. The volume of eroded materials was about 20 m^3.

Lower Trail (chainages CH 130 to CH 165)

A 2.5 m high fill platform with a masonry facing was observed on the western side of the streamcourse, from CH 130 to CH 136 (Figure 3 and Plate 25). The platform was probably occupied by a squatter structure previously. A registered squatter structure (No. RTW/4D/296) (Plate 26) is located on the west side of the streamcourse, between chainages CH 140 and CH 146 (Figure 3). The streamcourse near the fill platform is about 1 m to 2 m wide and it widens to about 3 m wide near the sharp bend of the streamcourse (Figure 3). The streamcourse in this section has an overall gradient of about 10° to 15° with some small drops of about 1 m high at chainage CH 140 and 2 m high at chainage CH 146, beside registered squatter structure No. RTW/4D/296.

The fill platform was undercut by the debris flood and created a scar of about 5.5 m wide by 1.5 m high, with a maximum depth of about 0.8 m (with a volume of about 5 m^3, see Figure 9 and Plate 25). Colluvium was exposed behind the masonry facing, which provided some protection to the side slope of the streamcourse. Further downstream, the soil underneath the poles supporting the squatter structure was eroded. The erosion area was

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about 4 m long by 1 m wide by maximum 2 m high, with a volume of about 5 m^3 (Plate 26). The remaining section of the lower trail has no significant erosion.

It is estimated that a total of about 60 m^3 of material was entrained from the streamcourse between CH 0 and CH 165 by the debris flood. It is noteworthy that the debris deposited beyond the sharp bend of the streamcourse at chainage CH 160 contained a significant amount of refuse (synthetic fabric), alluvial boulders and domestic refuse (estimated to be about 40 m^3 in volume). These materials might have been washed down from the upstream end near the overflow weir and from the lower trail (near the squatter structure), contributing to the volume of the debris.

Deposition (chainages CH 165 to CH 186)

Debris, comprising boulders, tree branches, domestic refuse, fragments of synthetic fabric, silt and detritus, was observed to have accumulated beyond the sharp bend of the streamcourse, extending onto Route Twisk (Plates 1 and 2). The thickness of the debris was at up to 1 m near the sharp bend and diminished across Route Twisk. Some outwash fines and debris were also observed along Route Twisk towards Tsuen Wan (Plate 27). Based on the photograph provided by HyD (Plate 28), debris was also deposited in the vicinity of the inlet of the cross-road culvert. However, it appears that the debris might not have fully blocked the inlet of the cross-road culvert.

Slope No. 6SE-D/FR98, which is situated on the western side of Route Twisk and opposite the sharp bend of the streamcourse, also failed in this incident (Figure 3). The landslide measured approximately 10 m wide by 7 m high and up to 4 m deep, with a failure volume of about 130 m^3. The landslide debris was deposited near the toe of the landslide scar and comprised mainly brown, silty sand with boulders. Utilities in the footpath located at the crest of the slope were also damaged (Plate 3).

7. ANALYSIS OF RAINFALL RECORDS

Rainfall data were obtained from the nearest GEO automatic raingauge No. N38, which is located about 1 km to the southwest of the August 2005 landslide at Po Leung Kuk Lee Shing Pik College at On Yin Street, Chai Wan Kok, Tsuen Wan (Figure 1). The raingauge records and transmits rainfall data at 5-minute intervals to the GEO and the Hong Kong Observatory (HKO). The daily rainfall recorded by raingauge No. N38 over the month preceding the debris flood and associated landslides, together with the hourly rainfall readings for the period between 18 and 21 August 2005, are presented in Figure 10. Records from another nearby GEO automatic raingauge No. N03, which is about 1.9 km to the southeast of the August 2005 landslides, were also examined. The pattern of rainfall recorded at this raingauge was broadly similar to that recorded at raingauge No. N38, although the rainfall was slightly less intense at raingauge No. N03.

The rainstorm preceding the debris flood and associated landslides commenced on the evening of 18 August 2005 and continued until the evening of 20 August 2005. Amber Rainstorm Warnings were issued from 7:25 a.m. on 19 August 2005 to 12:55 a.m. on 20 August 2005, and from 8:35 a.m. to 9:10 p.m. on 20 August 2005. According to the

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Incident Report No. 2005/08/0351a, the debris flood occurred at approximately 6:00 p.m. on 20 August 2005. The landslide on slope No. 6SE-B/CR249 probably occurred around the same time (no time was given in the Incident Report No. 2005/08/0480). The maximum 24-hour and 48-hour rainfall before the landslide was 456 mm and 598.5 mm respectively. The maximum 1-hour rolling rainfall was recorded as 47 mm between 8:50 a.m. and 9:50 a.m. on 20 August 2005 (Table 1).

An analysis of the return periods for various durations of maximum rolling rainfall recorded at raingauge No. N38, with reference to the historical rainfall data at the HKO at Tsim Sha Tsui where records began in 1884 (Lam & Leung, 1994), shows that a rainfall duration of 10 days or more before the landslide was the most critical, with a corresponding return period of more than 100 years (Table 1).

The return periods were also assessed based on the statistical parameters derived by Evans & Yu (2001) from rainfall data recorded by local raingauge No. N03 between 1984 and 1997. The return periods of the 10-day and 12-day rainfall at raingauge No. N03 were the most critical with a return period of more than 100 years (Table 1).

The maximum rolling rainfall for the August 2005 rainstorm has been compared with the past significant rainstorms recorded by raingauges Nos. N03 and N38 between 1983 and 2004 (Figure 11). The August 2005 rainstorm is the most severe for rainfall durations between 12 hours and 31 days.

8. DIAGNOSIS OF THE PROBABLE CAUSES OF THE 20 AUGUST 2005 DEBRIS FLOOD AND ASSOCIATED LANDSLIDES

8.1 Site Setting

At the time of the incident, the three controlled intake dams upstream of the overflow weirs at chainages M6557, M6664 and M6704 were operating normally, allowing water to enter the catchwater.

The results of the rainfall analysis show that the return period of a rainfall duration of 10 days or more before the incident was more than 100 years. This could suggest that the catchwater might have reached its design capacity at the time of the incident.

Slope No. 6SE-B/CR249, located directly above the catchwater, comprised an old (pre-1977) cut that was formed without any geotechnical input. This feature had a record of past instability (Incident No. NT82/241). The EI of the slope carried out in 2001 also identified some cracking on the channel wall within the August 2005 landslide source area.

The streamcourse below the catchwater connects to the overflow weir SMOF-28. Based on WSD’s record, this overflow weir has a discharge capacity of 4.8 m^3/s.

Part of the streamcourse was realigned as a result of the construction of Route Twisk between 1924 and 1955, introducing a sharp bend in the streamcourse where it runs further downstream along the eastern side of Route Twisk before discharging into a cross-road culvert. This realigned section of the streamcourse is relatively shallow and its western side is

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mostly unconstrained (Plate 7). The longitudinal gradient of this section of the streamcourse is also relatively gentle (about 8°).

8.2 Probable Causes of the Debris Flood and Associated Landslides

The failure at slope No. 6SE-B/CR249 was probably caused by water ingress through direct infiltration and subsurface recharge from the uphill area, due to heavy and prolonged rainfall, leading to wetting up of the ground mass, reduction of soil suction and development of positive groundwater pressure. Based on API, there is a slight local topographic depression in the natural hillside located above slope No. 6SE-B/CR249 and adjacent to the August 2005 landslide scar. This depression might have allowed localised concentration of surface runoff and in turn, promoted concentrated infiltration.

The large amount of discharge at overflow weir SMOF-28 was likely to have resulted from the partial blockage of the catchwater channel by landslide debris from the failure of slope No. 6SE-B/CR249. Landslide debris reduced the water-carrying capacity of the catchwater, which might have been close to its design capacity, causing the water to back up along the channel and overflow. Based on the estimated volume of the debris and the measurements of the channel size below the landslide, it was estimated that the debris blocked about 40% of the channel cross-sectional area. However, it is not known whether spillage at the overflow weir occurred prior to the blockage.

To assess whether there was uncontrolled overtopping of the catchwater channel after it had been partially blocked by the landslide debris, a theoretical hydraulic assessment of the flow condition of the catchwater channel with partial blockage was carried out. The assessment assumed that the catchwater had reached its design capacity of 32.3 m^3/s (based on WSD's record) at the time of the incident. Details of the assessment are given in Appendix B. The results of the assessment show that at the time of the incident, the water level within the catchwater channel might have risen to just below the crest line of the channel, causing the discharge at overflow weirs SMOF-28 and SMOF-29 but without any overtopping of the catchwater. This is consistent with the field observations made on 26 August 2005 by MGSL that there were no signs of overtopping of the catchwater. The hydraulic assessment also revealed that overflow might have also occurred at overflow weir SMOF-29 which is further upstream of SMOF-28 (Figure B1).

The heavy flow from the overflow weir into the streamcourse probably built up a large momentum as it travelled downstream. Refuse, which was probably dumped immediately below the catchwater, was eroded and transported downstream by the water flow. The lower part of the streamcourse (chainages CH 86 to CH 165) comprising loose colluvium was susceptible to entrainment and undercutting by the flow (Section 6.2.2). The entrained materials probably increased the erosive power of the stream flow and allowed it to develop into a debris flood.

As the debris flood reached the sharp bend of the streamcourse at CH 160 near Route Twisk, it probably overshot due to its high momentum and the lack of restraint at the bend. The debris flood spread out as it spilled onto Route Twisk, depositing a large amount of debris (Plate 2). Some of the debris flood probably spilled over onto slope No. 6SE-D/FR98 and contributed to the slope failure through erosion by concentrated surface runoff. It is

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possible that as the deposition began, it piled up beyond the sharp bend of the streamcourse. This provided some restraints to the debris flood and probably forced some of the debris flood to travel along the downstream section of the streamcourse towards the cross-road culvert. As a result, some debris might have partially blocked the cross-road culvert.

9. DISCUSSION

The major failure at the source area on slope No. 6SE-B/CR249 had negligible direct consequence-to-life but due to the knock-on effects triggered by the slope failure, a debris flood was developed and it undermined a squatter structure and caused significant damages to Route Twisk and slope No. 6SE-D/FR98. The indirect consequence-to-life as well as the social and economic consequences were therefore more serious. The incident occurred under the normal operating conditions of the catchwater whereby large quantities of discharge were released through the overflow weirs into the natural streamcourse below, pursuant to the design intent.

The debris flood was probably the result of a series of related events:

(a) a major landslide with a failure volume of about 50 m^3 at slope No. 6SE-B/CR249 immediately above the catchwater during heavy rainfall;

(b) partial blockage of the catchwater flow by the landslide debris, causing a large amount of discharge at the upstream overflow weir SMOF-28;

(c) entrainment and erosion of the connecting streamcourse, providing the source of materials to the debris flood; and

(d) overtopping at the sharp bend of the streamcourse near Route Twisk where a large amount of debris was deposited.

The following are the key contributory factors to the above events:

(a) the severe and prolonged rainfall, with critical return periods of greater than 1 in 100 years for long-duration rainfalls, triggered the landslide at slope No. 6SE-B/CR249, which has a history of instability (Section 3.3.2);

(b) the landslide at slope No. 6SE-B/CR249 might have occurred with little warning (WSD carried out their inspection between 3:00 p.m. and 4:35 p.m. on 20 August 2005, i.e. 1½ hr to 3 hr before the incident and no landslide or irregularity was reported);

(c) the EI of slope No. 6SE-B/CR249 carried out in 2001 identified cracking of the channel wall, which might have provided an indication of slope distress. Sealed cracks on the channel wall (adjacent to the landslide scar) were

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observed in the post-failure site inspection, suggesting some sealing of cracks might have been carried out following the EI. However, no relevant records could be found;

(d) despite its considerable cross-sectional area (11 m^2), the open catchwater channel was vulnerable to blockage by debris from a landslide occurring above it (it was estimated that about 40% of the catchwater channel cross-section area was blocked by the debris from the landslide on slope No. 6SE-B/CR249);

(e) the lower part of the streamcourse which connects to the overflow weir SMOF-28, comprised colluvium overlying decomposed tuff. The colluvium is relatively thick in places and susceptible to scouring. The eroded materials from the streamcourse probably increased the erosive power of the floodwater which turned into a debris flood;

(f) the refuse (comprising synthetic fabric), which was probably illegally dumped immediately below the catchwater, provided an additional source of entrained material to the debris flood;

(g) the construction of Route Twisk between 1924 and 1955 probably involved the re-alignment of part of the streamcourse, resulting in the formation of a sharp bend along the streamcourse near Route Twisk. The relatively shallow depth of this re-aligned section of the streamcourse and the sharp bend were susceptible to overtopping when a large amount of water flow was discharged from the overflow weir; and

(h) it is unlikely that the cross-road culvert would have been able to cope if the large amount of discharge from the overflow weirs was all channelled to the cross-road culvert (i.e. without overtopping occurring near the sharp bend of the streamcourse). No preventive or mitigation measures against blockage, such as gratings, were provided for the cross-road culvert and it is also susceptible to blockage.

10. CONCLUSIONS

It is concluded that the debris flood that occurred at Route Twisk on 20 August 2005 was the result of a series of events at the concerned section of Shing Mun Catchwater and along the streamcourse below the catchwater overflow weir, which were a result following the occurrence of a major landslide on a cut slope (No. 6SE-B/CR249) uphill of the catchwater.

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The major landslide at slope No. 6SE-B/CR249, with a failure volume of about 50 m^3, was probably triggered by prolonged and intense rainfall, with a return period of over 100 years, that preceded the landslide. The resulting blockage of the catchwater channel by the landslide debris caused the water in the catchwater to back up, resulting in large amount of discharge at the upstream overflow weir. The large amount of discharge through the catchwater overflow weirs caused significant scouring of a streamcourse and led to the development of a debris flood. The realigned section of the shallow streamcourse, together with the sharp bend, was vulnerable to overtopping when large amounts of discharge emanated from the catchwater via the overflow weir.

The overall site setting was adverse in that a slope failure of 50 m^3 in volume, some 160 m above Route Twisk could, through a series of knock-on effects, lead to notable social and economic consequences.

Three squatter structures located along the streamcourse were all subject to previous Category 2 NDC recommendations. Two of the squatter structures had been cleared prior to the incident. The remaining squatter structure had not been cleared at the time of the incident and was affected by the debris flood. This squatter structure was recommended for permanent evacuation after the incident.

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Table 1 - Maximum Rolling Rainfall at GEO Raingauge No. N38 for Selected Durations Preceding the 20 August 2005 Landslide and the Estimated Return Periods

Duration	Maximum Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years)	
			By Lam & Leung (1994)	By Data of N03 from Evans & Yu (2001)
5 Minutes	12.0	7:55 a.m. on 19 August 2005	< 2	2
15 Minutes	23.0	1:00 a.m. on 19 August 2005	< 2	< 2
1 Hour	47.0	9:50 a.m. on 20 August 2005	< 2	< 2
2 Hours	85.5	11:00 a.m. on 20 August 2005	< 2	< 2
4 Hours	135.5	11:45 a.m. on 20 August 2005	3	3
12 Hours	290.0	6:00 p.m. on 20 August 2005	10	22
24 Hours	456.0	6:00 p.m. on 20 August 2005	27	35
48 Hours	598.5	6:00 p.m. on 20 August 2005	52	50
4 Days	728.0	6:00 p.m. on 20 August 2005	59	42
7 Days	836.5	6:00 p.m. on 20 August 2005	82	67
10 Days	1075.5	6:00 p.m. on 20 August 2005	298	> 100
12 Days	1207.5	6:00 p.m. on 20 August 2005	528	> 100
15 Days	1207.5	6:00 p.m. on 20 August 2005	278	70
31 Days	1740.0	6:00 p.m. on 20 August 2005	> 1000	59

Notes : (1) Maximum rolling rainfall was calculated from 5-minute rainfall data.

(2) Return periods were derived from Table 3 of Lam & Leung (1994) and using data from Evans & Yu (2001) for raingage No. N03 with interpolation of rainfall parameters for 10 days and 12 days.

(3) According to GEO records, the landslide occurred at about 6:00 p.m. on 20 August 2005.

(4) The nearest GEO raingauge to the landslide site is raingauge No. N38, located at about 1 km to the southwest of the landslide. GEO raingauge No. N03 is located at about 1.9 km to the southeast of the landslide.

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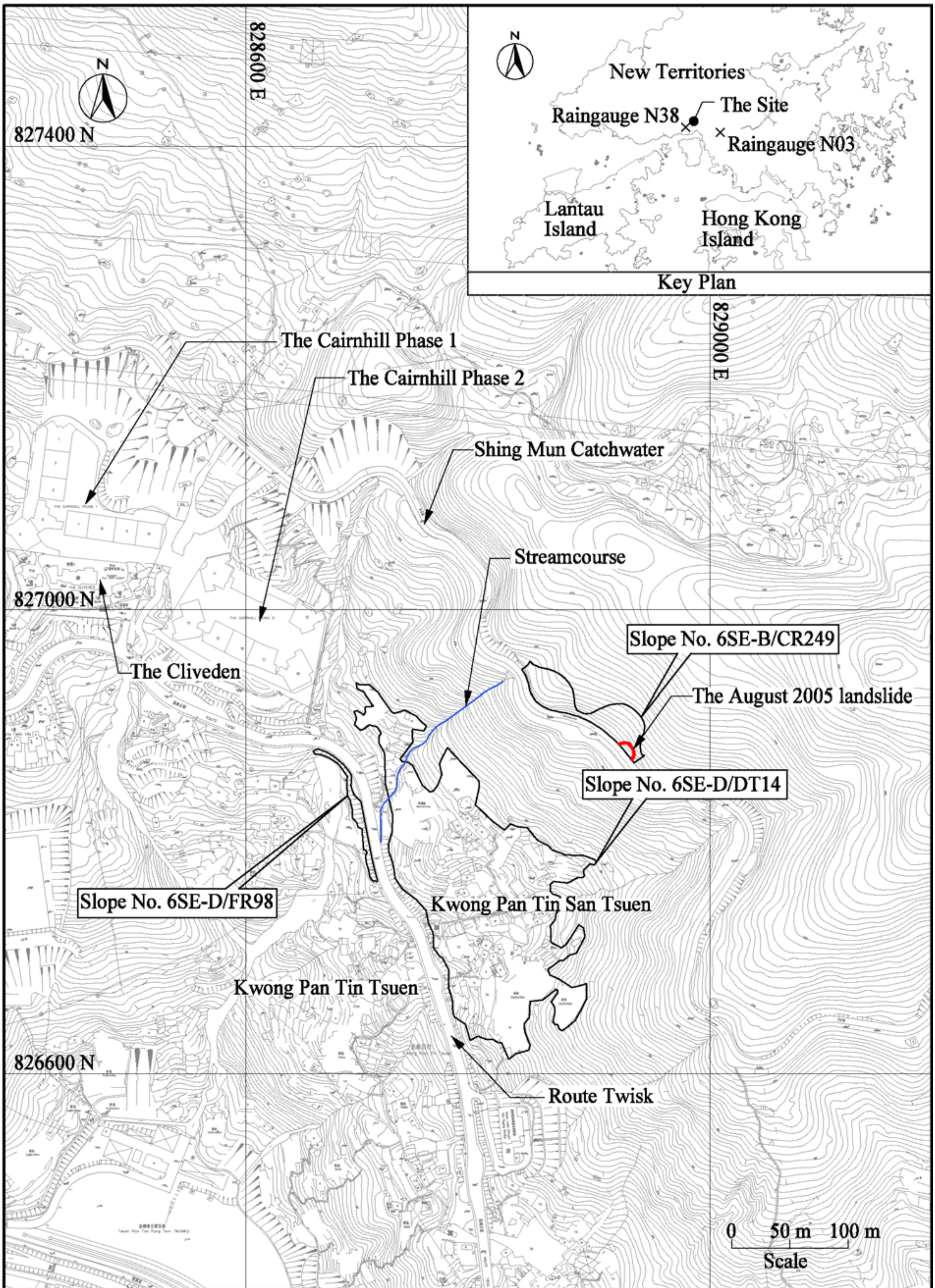
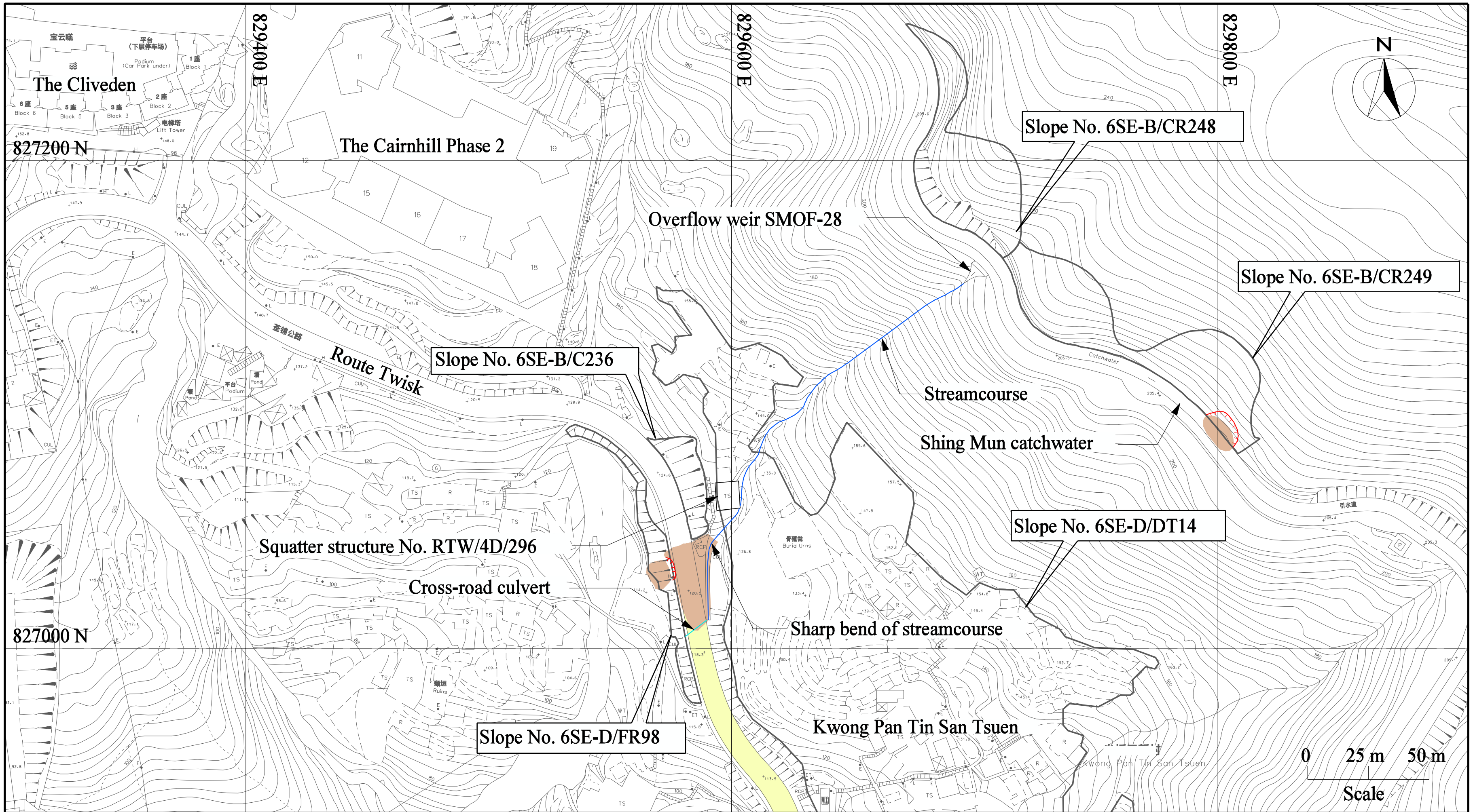


Note : Base plan is extracted from 1 : 1000 survey sheets Nos. 6SE-10D, 6SE-15B, 6SE-15D and 7SW-11C dated March 2004.



Legend : The August 2005 Landslides — Cross-road drain — Streamcourse — Landslide debris — Washout debris

Note : Base plan is extracted from 1 : 1000 survey sheets Nos. 6SE-15B and 6SE-15D dated March 2004.

Figure 2 - Site Layout Plan

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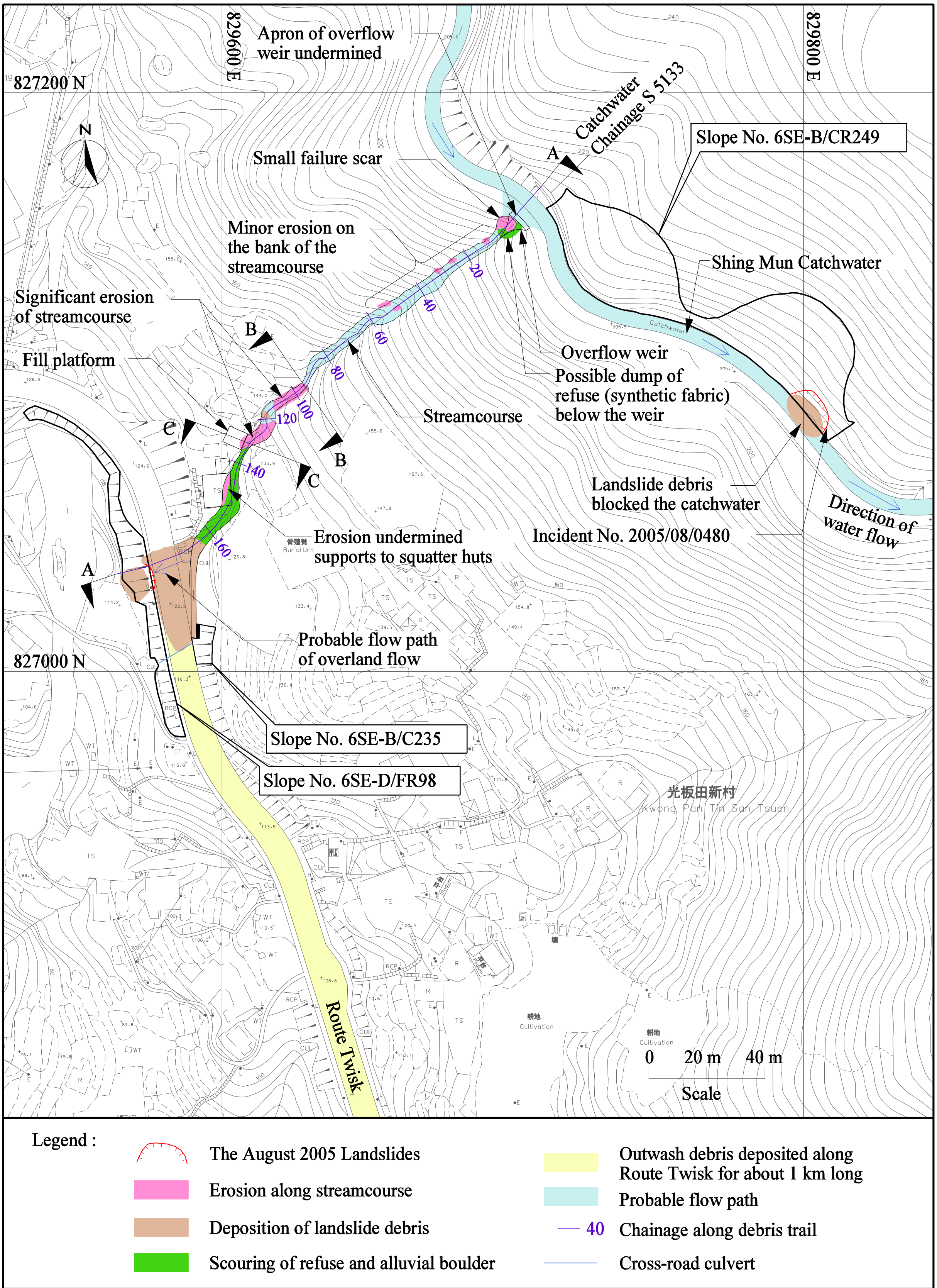

Note : Base plan is extracted from 1 : 1000 survey sheets Nos. 6SE-15B and 6SE-15D dated March 2004.

Figure 3 - Debris Flood Trail

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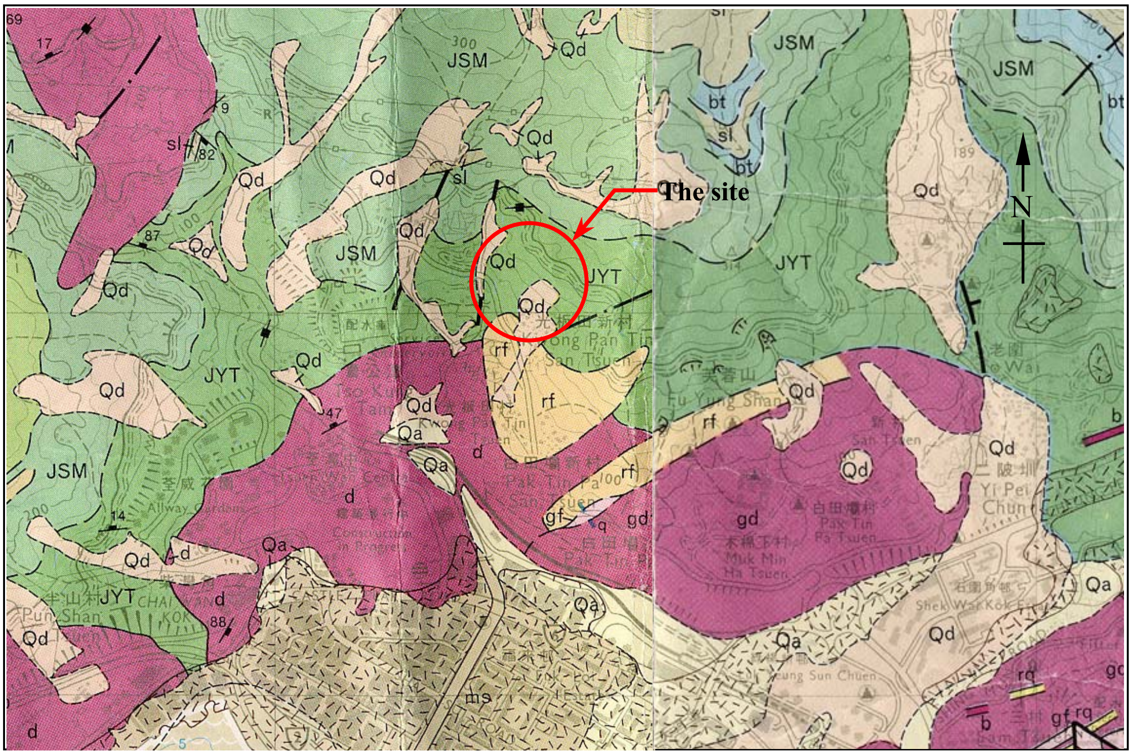

0m 1000 m

Scale

LEGEND:

SUPERFICIAL DEPOSITS

Qa	Clay/silt, sand and gravel well-sorted to semi-sorted (Alluvium)
Qd	Unsorted sand, gravel, cobbles and boulders; clay/silt matrix (Debris flow deposits)
(Fill pattern)	Fill

SOLID GEOLOGY

gd	Granodiorite
d	Dacite
rf	Feldsparphyric rhyolite
bt	Block-bearing tuff and tuffite
JYT	Coarse ash crystal tuff
JSM	Fine ash to coarse ash tuffs, tuff-breccia and tuffite
sl	Siltstone and mudstone

GEOLOGICAL LINES

- Geological boundary, superficial deposits
- Geological boundary, solid rock (* Broken lines denote uncertainty)
- Fault (crossmark indicates downthrow side)
- Mineral vein
- Photogeological lineament

STRUCTURAL SYMBOLS

- 22 Intrusive contact
- 20 Jointing - inclined
- Jointing - vertical

Note: Extracted from Hong Kong Geological Survey, Map Series HGM20, Sheets Nos. 6 and 7, 1:20 000 scale (GCO, 1986)

Figure 4 - Regional Geology

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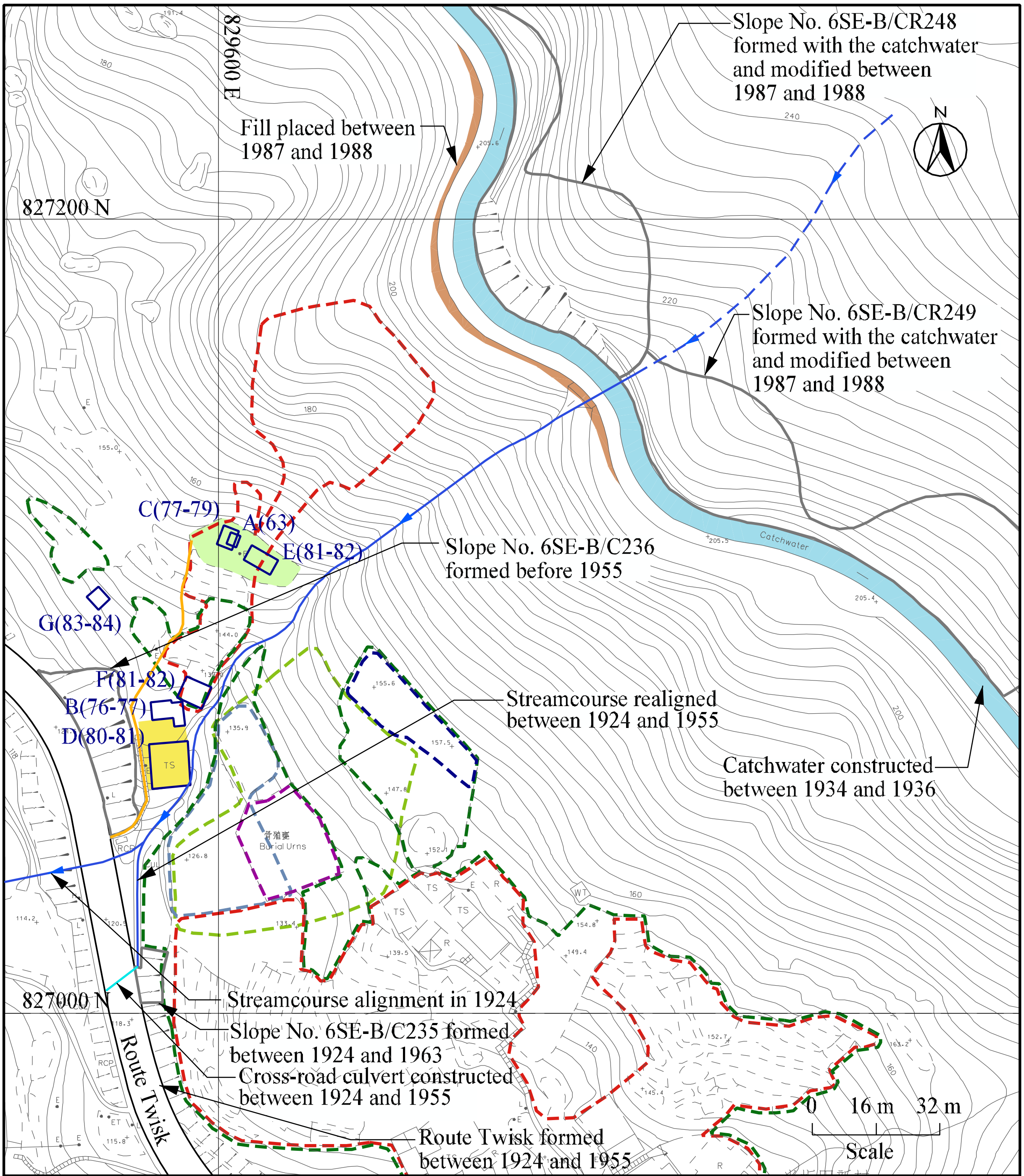

Legend :

- Abandoned cultivation terraces observed in 1963
- Cultivation terraces observed in 1963
- Extented cultivation terraces observed in 1969
- Cultivation terraces observed in 1976
- Cultivation terraces observed in 2003
- Burial urns observed in 2002
- Platform formed between 1976 and 1977
- Platform formed between 1981 and 1982
- D(80-81) Squatter structure D first observed in 1981
- Access track formed before 1963

Notes :

(1) Base plan is extracted from 1 : 1000 survey sheets Nos. 6SE-15B and 6SE-15D dated March 2004.

(2) The periods or years shown above are based on aerial photograph interpretation and old topographical survey maps.

Figure 5 - Site History

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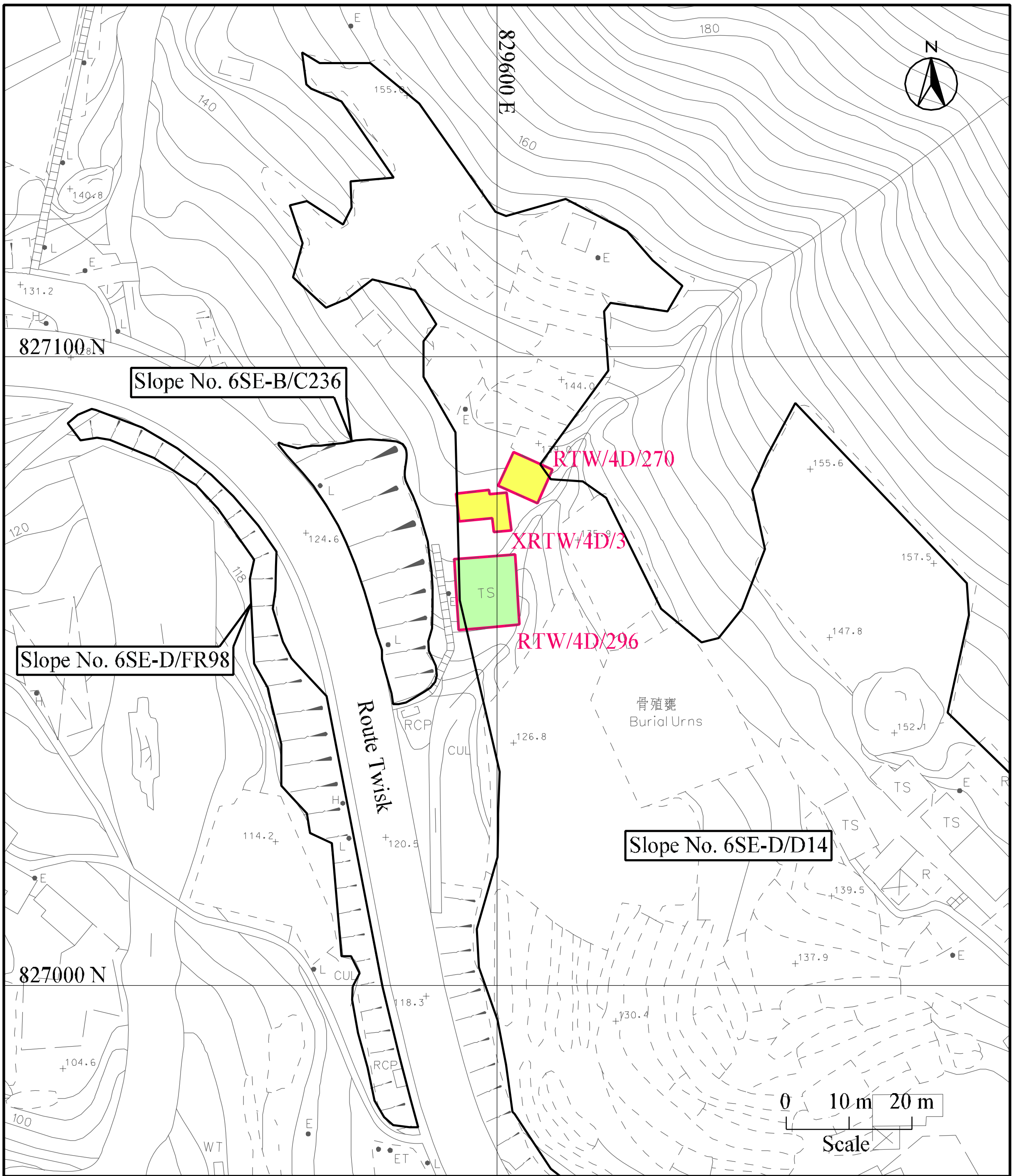

Legend :

- (green) Squatter structures recommended for Cat. 1 NDC after the 20 August 2005 debris flood incident
- (yellow) Squatter structures cleared prior to the August 2005 debris flood incident
- (red outline) Squatter structures recommended for Cat. 2 NDC under 1992 NDC Re-inspection Programme

Notes :

(1) Base plan is extracted from 1 : 1000 survey sheets Nos. 6SE-15B and 6SE-15D dated March 2004.
(2) For clarity, only the NDC status of the squatter structures along the debris trail was shown.

Figure 6 - Registered Squatter Structures along the Debris Flood Trail and Recommendations for Non-Development Clearance

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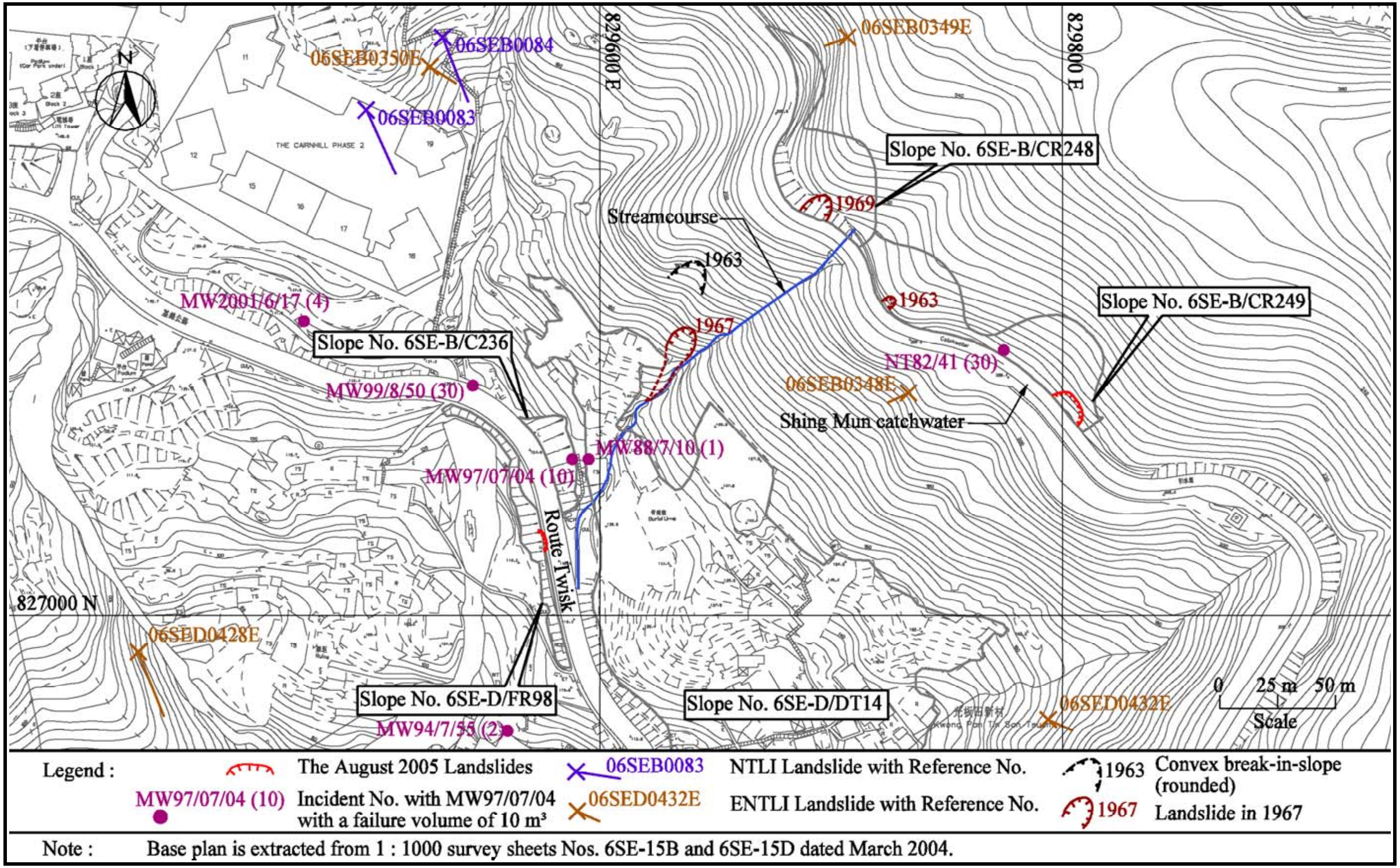

Figure 7 - Past Instabilities

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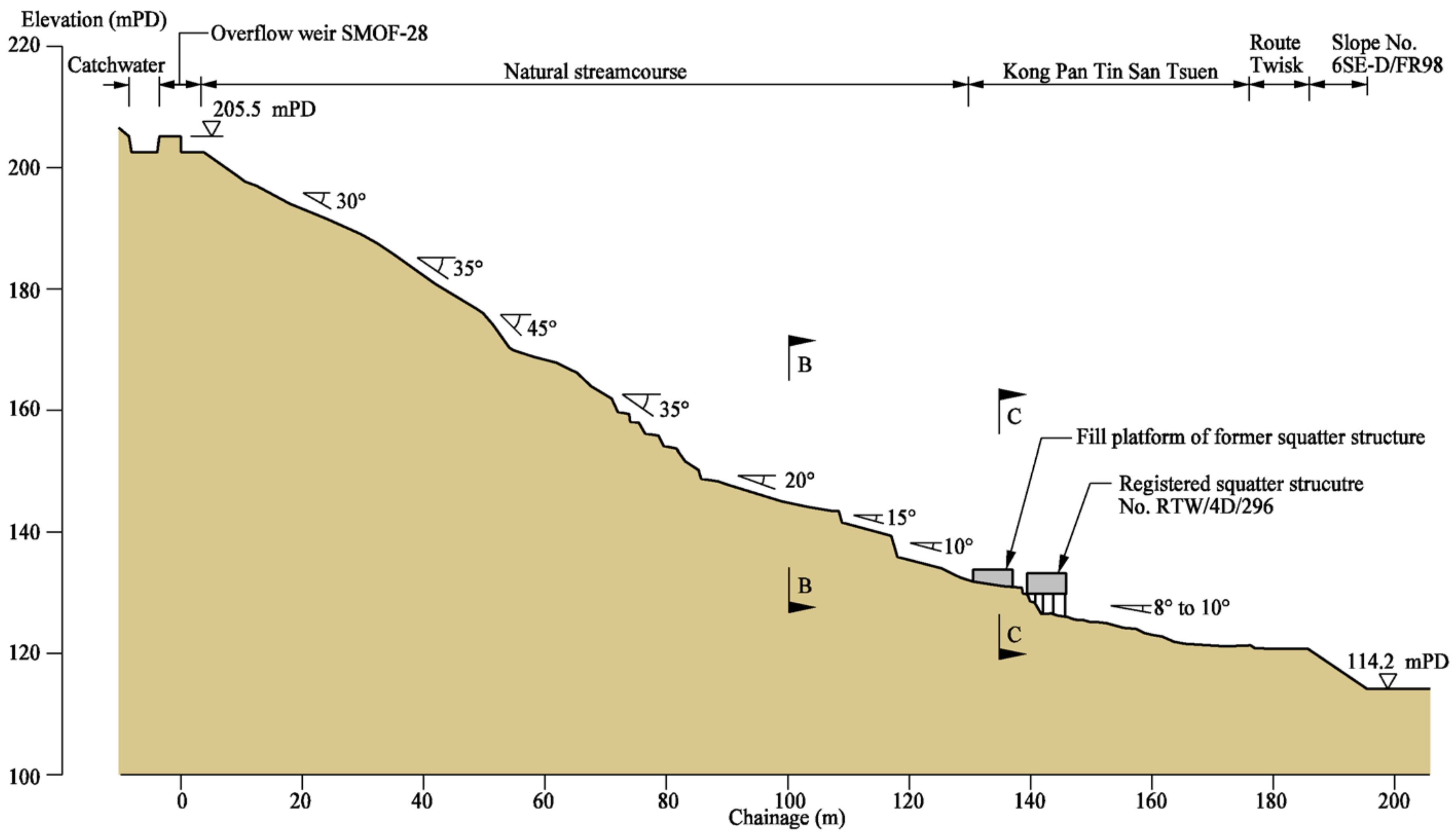

Notes : (1) See Figure 3 for location of Section A-A
(2) Longitudinal section based on 1 : 1000 survey sheet Nos. 6SE-15B and 6SE-15D dated March 2004.

Figure 8 - Longitudinal Section of Streamcourse

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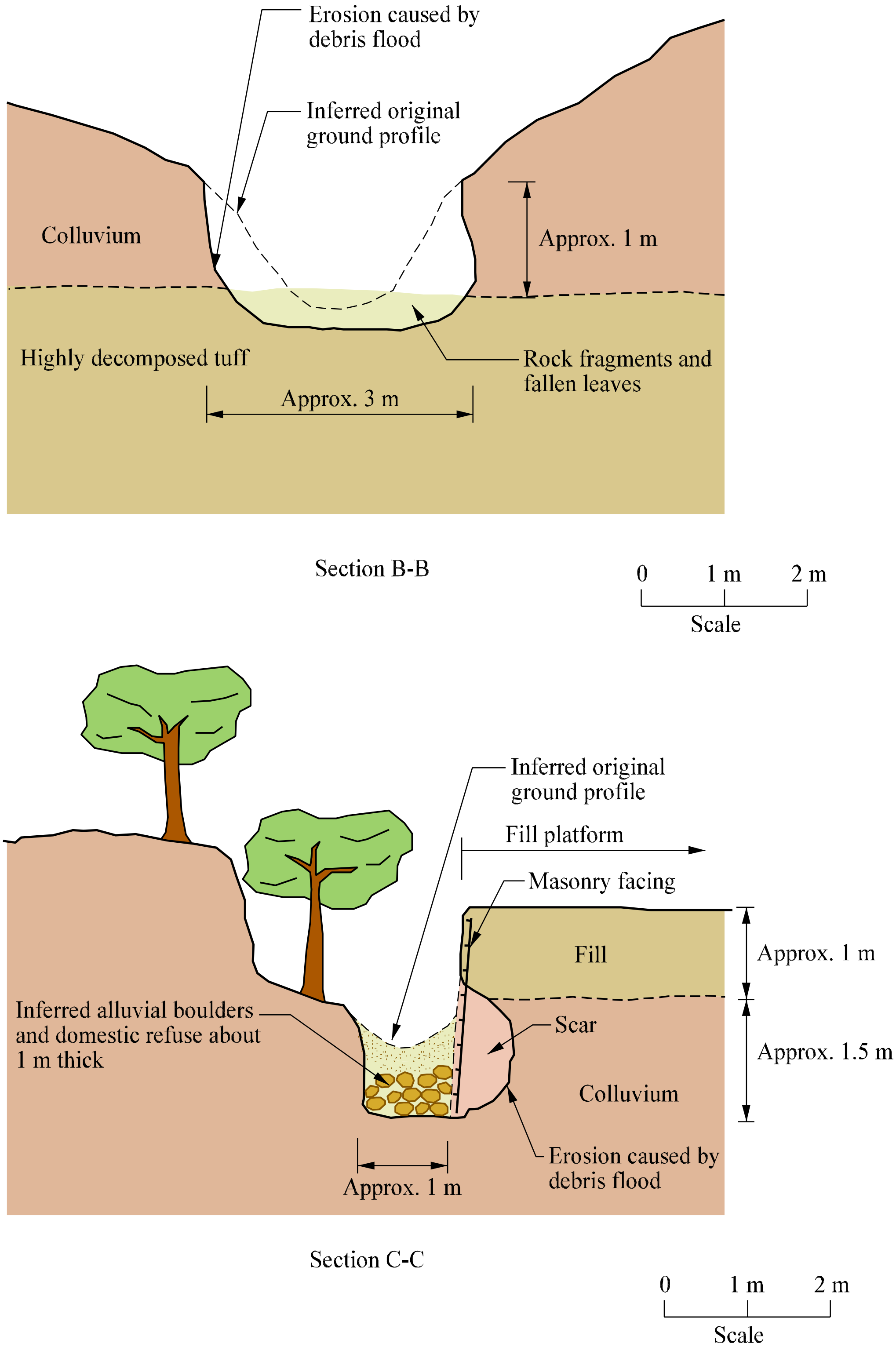

Note : See Figure 3 for locations of Sections B-B and C-C.

Figure 9 - Cross-sections B-B and C-C of Streamcourse

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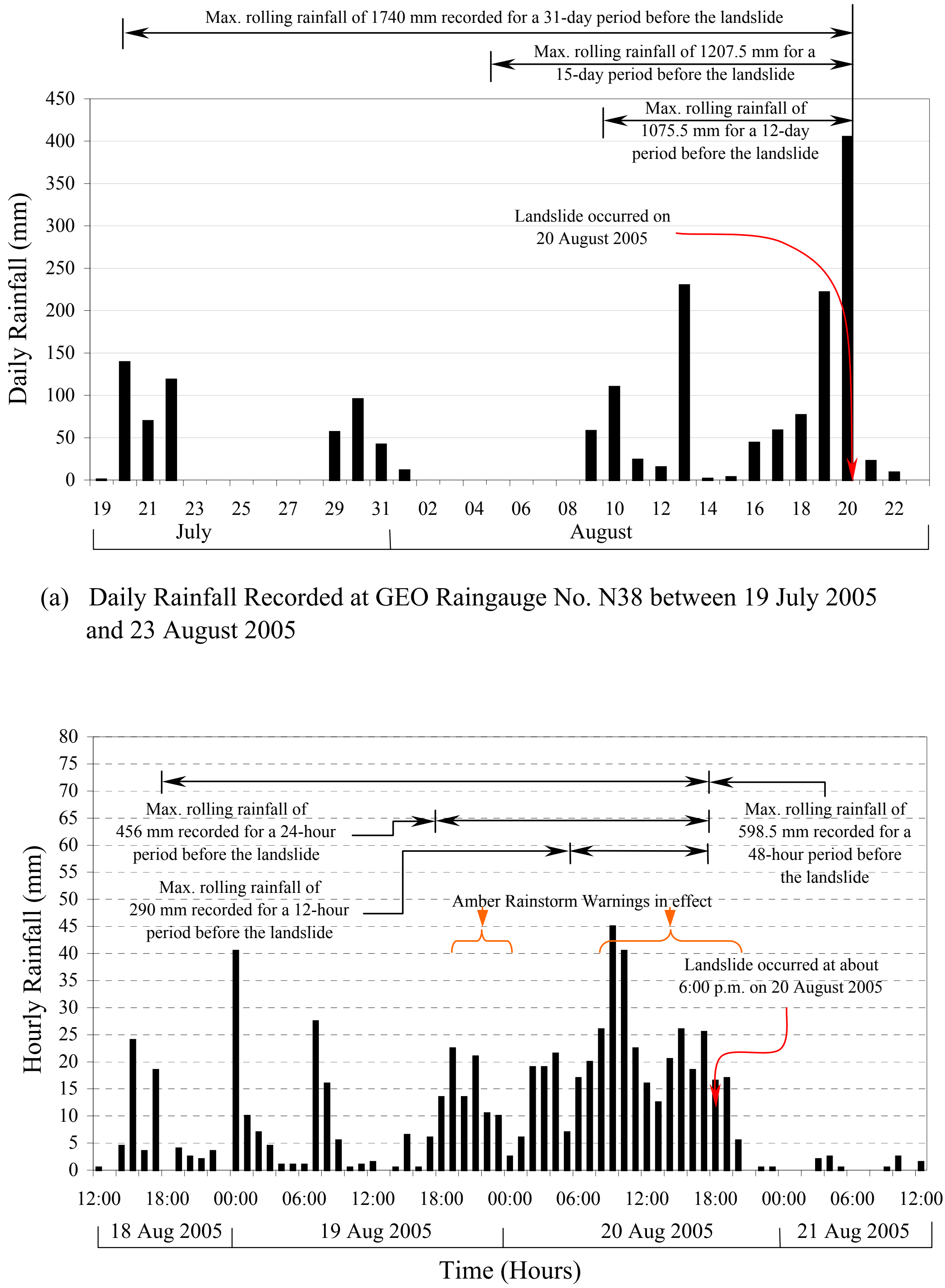

(a) Daily Rainfall Recorded at GEO Raingauge No. N38 between 19 July 2005 and 23 August 2005

(b) Hourly Rainfall Recorded at GEO Raingauge No. N38 between 18 August 2005 and 21 August 2005

Figure 10 - Daily and Hourly Rainfall Recorded at GEO Raingauge No. N38

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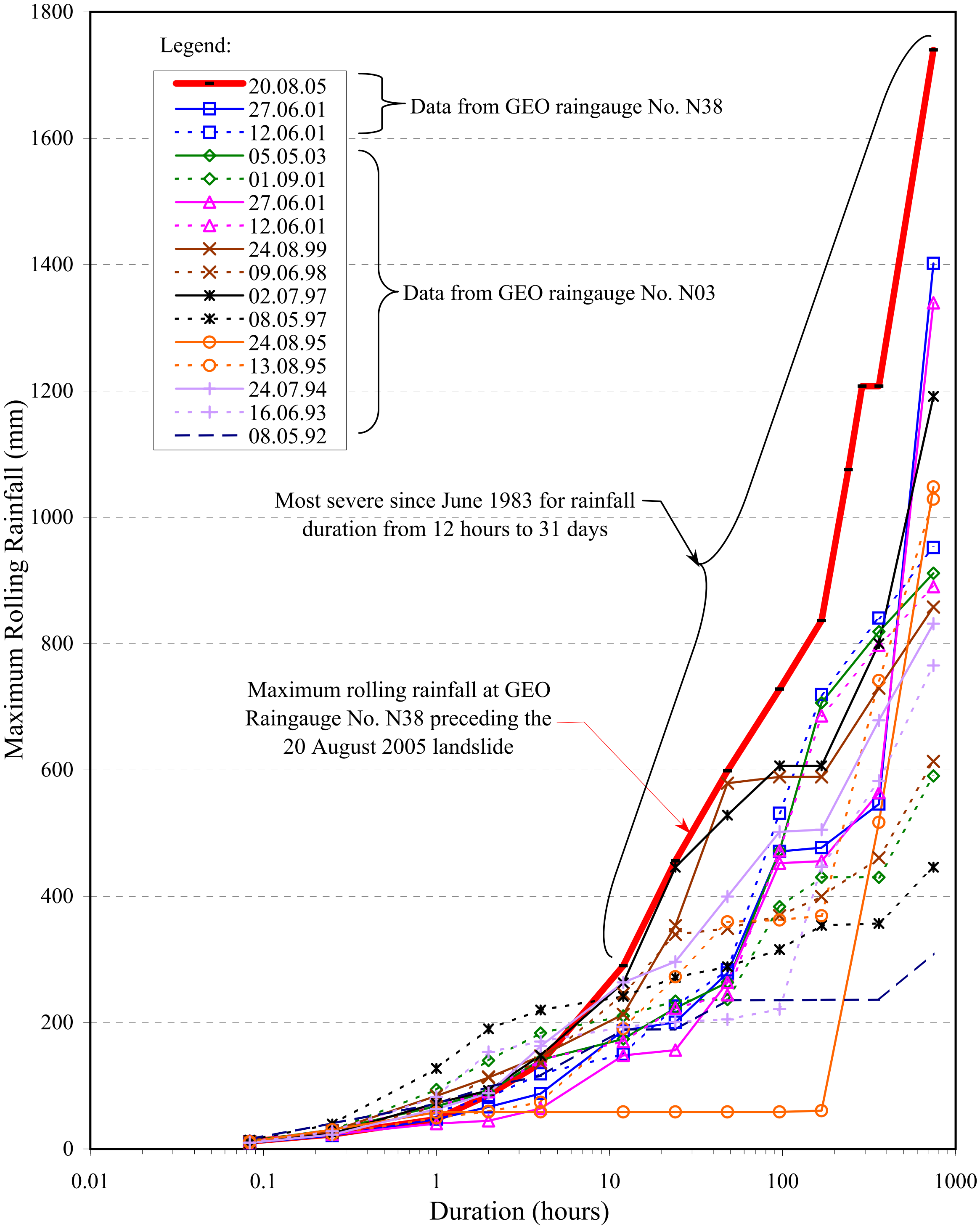

Notes: (1) Maximum rolling rainfall are evaluated from 5-minute readings from GEO raingauge No. N38, about 1 km to the southwest of the site and GEO raingauge No. N03, about 1.9 km to the southeast of the site .

(2) Rolling rainfall of previous rainstorms calculated at GEO raingauge No. N03 since June 1983 and at GEO raingauge No. N38 since October 1999 when the raingauges became operational.

Figure 11 - Maximum Rolling Rainfall for Previous Major Rainstorms at GEO Raingauges Nos. N03 and N38

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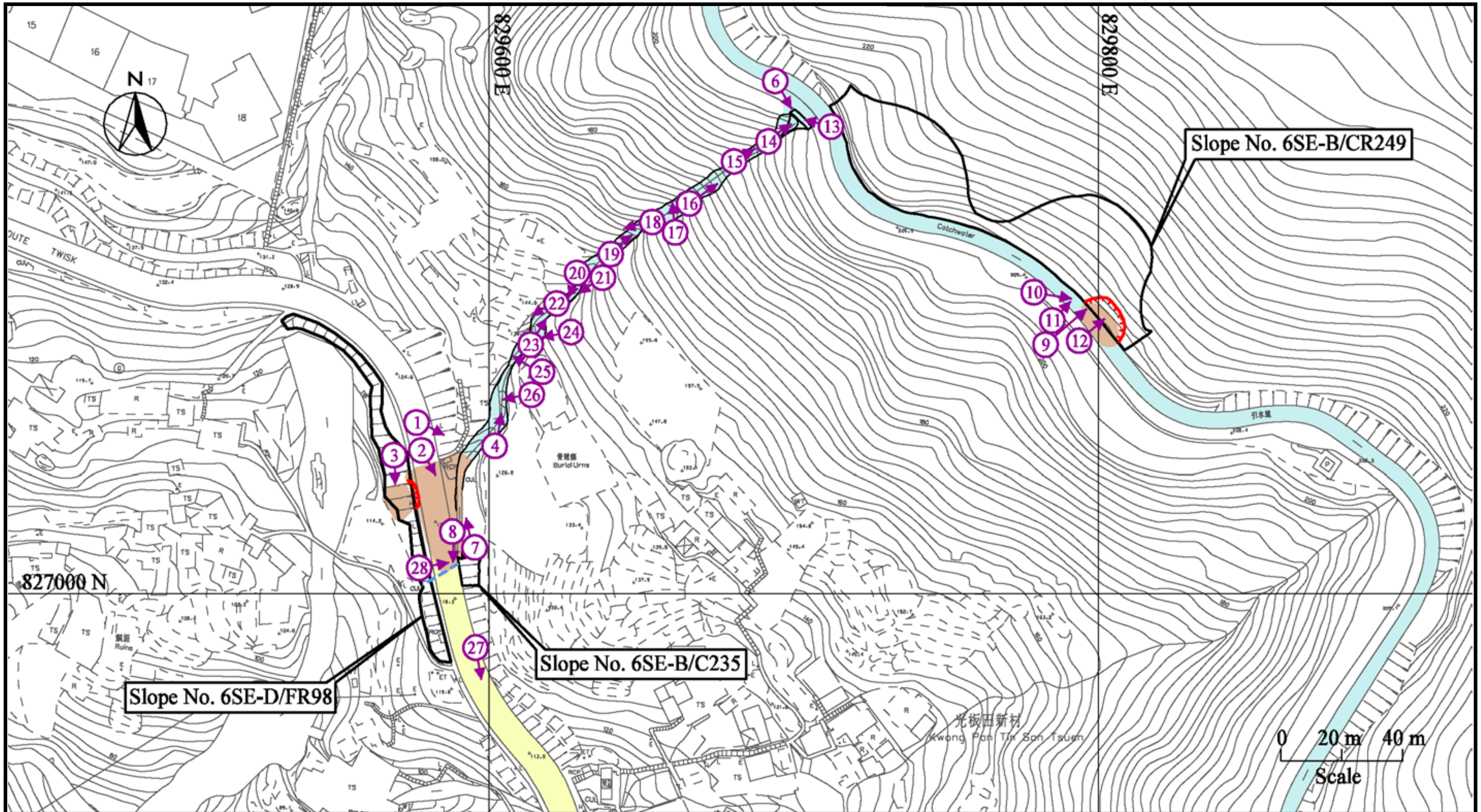

Legend : The August 2005 Landslides; Location and direction of photograph

Note : Base plan is extracted from 1 : 1000 survey sheets Nos. 6SE-15B and 6SE-15D dated March 2004.

Figure 12 - Locations and Directions of Photographs Taken

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Plate 1 - Debris Deposited on Route Twisk Looking East
(Photograph taken by HyD on 21 August 2005)

Plate 2 - Debris Deposited on Route Twisk Looking Southeast
(Photograph taken by HyD on 21 August 2005)

Note : See Figure 12 for locations and directions of photographs.

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Plate 3 - View of Landslide at Slope No. 6SE-D/FR98
(Photograph taken on 21 August 2005)

Plate 4 - View of Undermining of Registered Squatter Structure No. RTW/4D/296 along Streamcourse
(Photograph taken on 26 August 2005)

Note : See Figure 12 for locations and directions of photographs.

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Plate 5 - General View of Slope No. 6SE-B/CR249 before the Landslide
(Photograph taken on 7 December 2000)

Plate 6 - View of Overflow Weir SMOF-28
(Photograph taken on 26 August 2005)

Note : See Figure 12 for locations and directions of photographs.

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Plate 7 - View of Streamcourse between the Sharp Bend and Cross-road Culvert (Photograph taken on 21 August 2005)

Plate 8 - Inlet of 1.4 m x 1.4 m Cross-road Culvert (Photograph taken on 26 August 2005)

Note : See Figure 12 for locations and directions of photographs.

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Plate 9 - Cracking of Catchwater Channel before the Landslide on Slope No. 6SE-B/CR249
(Photograph taken on 7 December 2000)

Plate 10 - General View of the Landslide on Slope No. 6SE-B/CR249
(Photograph taken on 26 August 2005)

Note : See Figure 12 for locations and directions of photographs.

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Plate 11 - Sealed Cracks on Catchwater Channel adjacent to Landslide Scar of Slope No. 6SE-B/CR249
(Photograph taken on 26 August 2005)

Plate 12 - General View of the Landslide on Slope No. 6SE-B/CR249
(Photograph taken by WSD on 31 August 2005)

Note : See Figure 12 for locations and directions of photographs.

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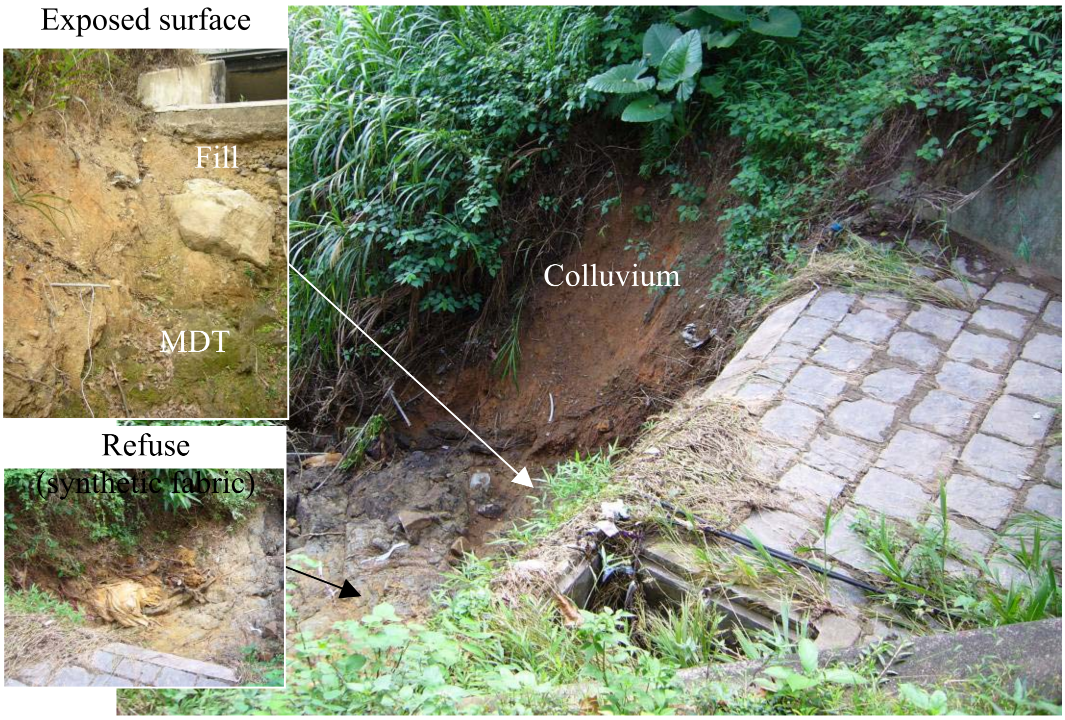

Plate 13 - Erosion below Overflow Weir SMOF-28
(Photograph taken on 26 August 2005)

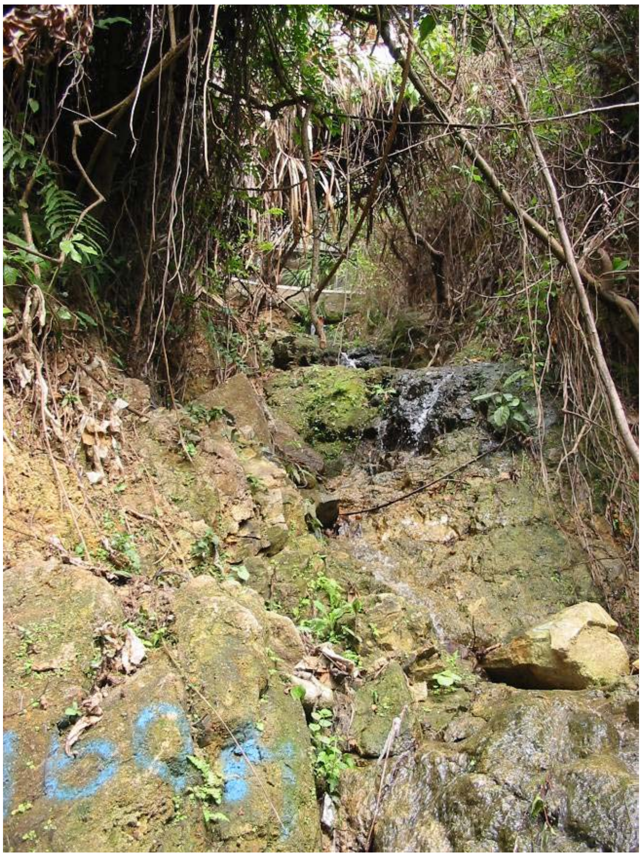

Plate 14 - View of the Upper Portion of the Debris Flood Trail at CH 23 (Photograph taken on 22 February 2006)

Note : See Figure 12 for locations and directions of photographs.

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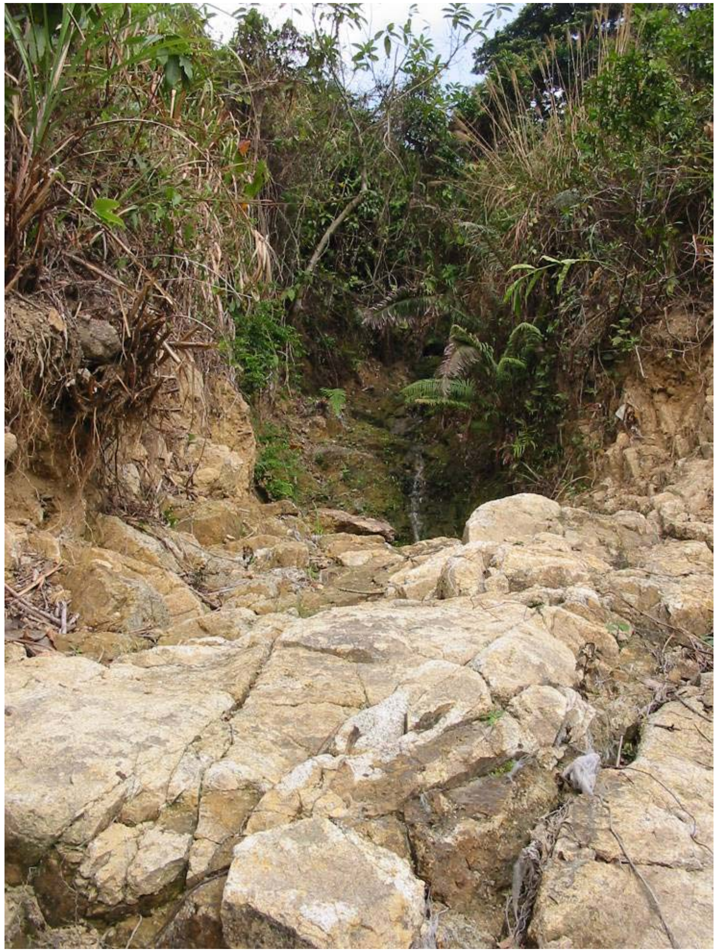

Plate 15 - View of the Upper Portion of the Debris Flood Trail at CH 32
(Photograph taken on 22 February 2006)

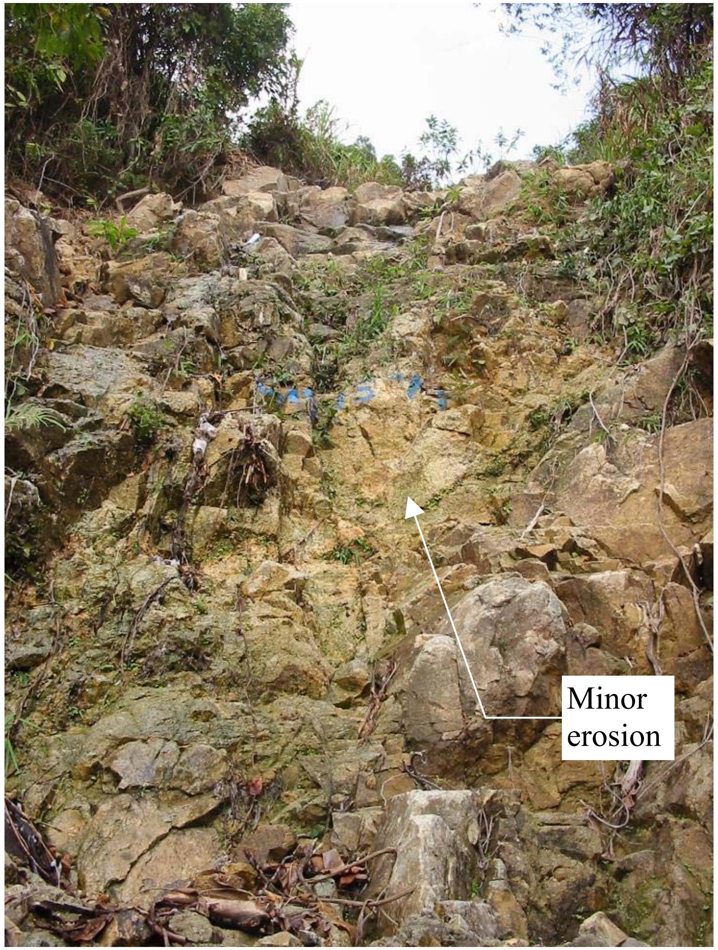

Plate 16 - View of the Steeper Section of the Debris Flood Trail between CH 49 and CH 57
(Photograph taken on 22 February 2006)

Note : See Figure 12 for locations and directions of photographs.

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Plate 17 - Erosion along the Northern Bank of the Streamcourse at CH 57
(Photograph taken on 22 February 2006)

Plate 18 - View of the Upper Portion of the Debris Flood Trail at CH 73
(Photograph taken on 22 February 2006)

Note : See Figure 12 for locations and directions of photographs.

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Plate 19 - View of Middle Portion of the Debris Flood Trail at CH 88
(Photograph taken on 22 February 2006)

Note : See Figure 12 for location and direction of photograph.

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Plate 20 - View of Middle Portion of the Debris Flood Trail at CH 100
(Photograph taken on 22 February 2006)

Plate 21 - View of the Erosion between CH 88 and CH 108
(Photograph taken on 22 February 2006)

Note : See Figure 12 for locations and directions of photographs.

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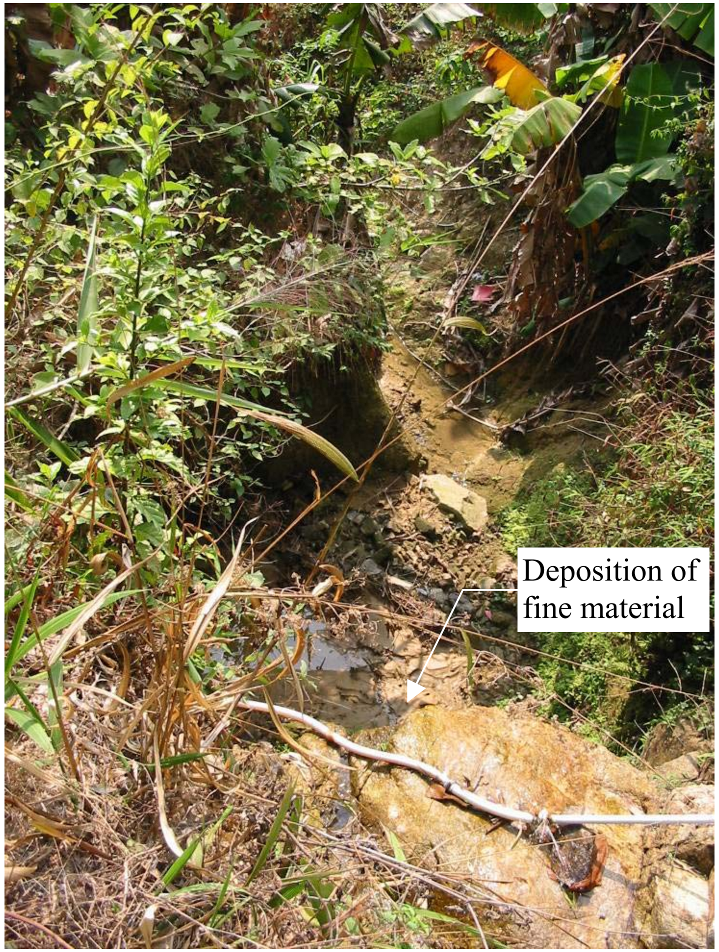

Plate 22 - View of Middle Portion of the Debris Flood Trail at CH 108
(Photograph taken on 22 February 2006)

Plate 23 - View of the Steeper Section of the Debris Flood Trail at CH 116
(Photograph taken on 22 February 2006)

Note : See Figure 12 for locations and directions of photographs.

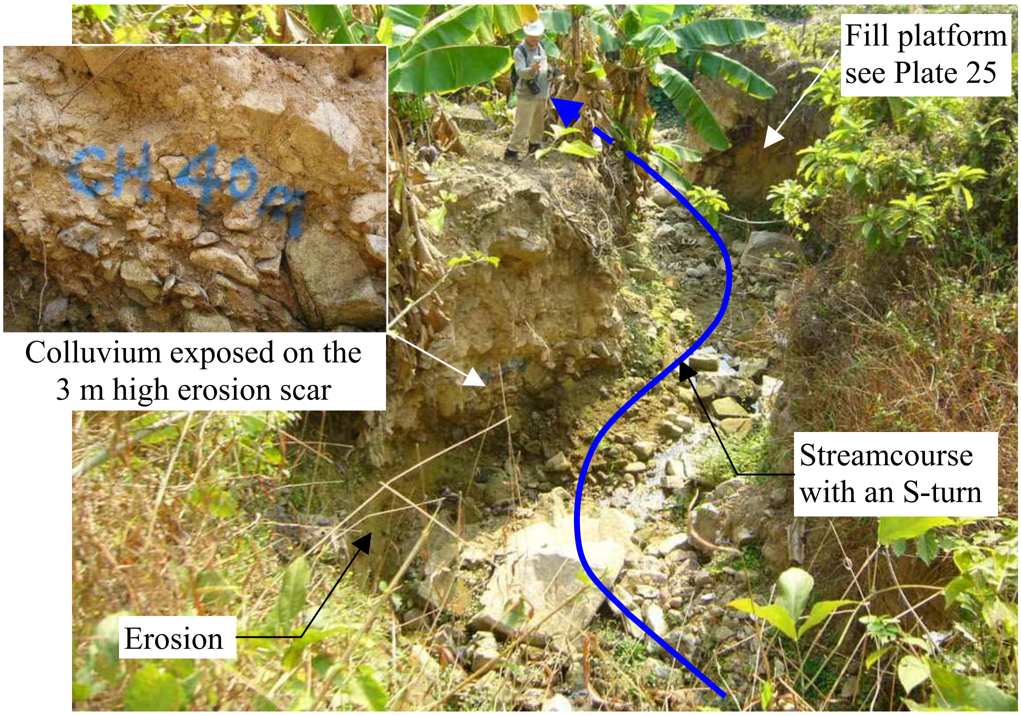

Plate 24 - View of the Significant Erosion at Middle Portion of the Debris Flood Trail at CH 126
(Photograph taken on 22 February 2006)

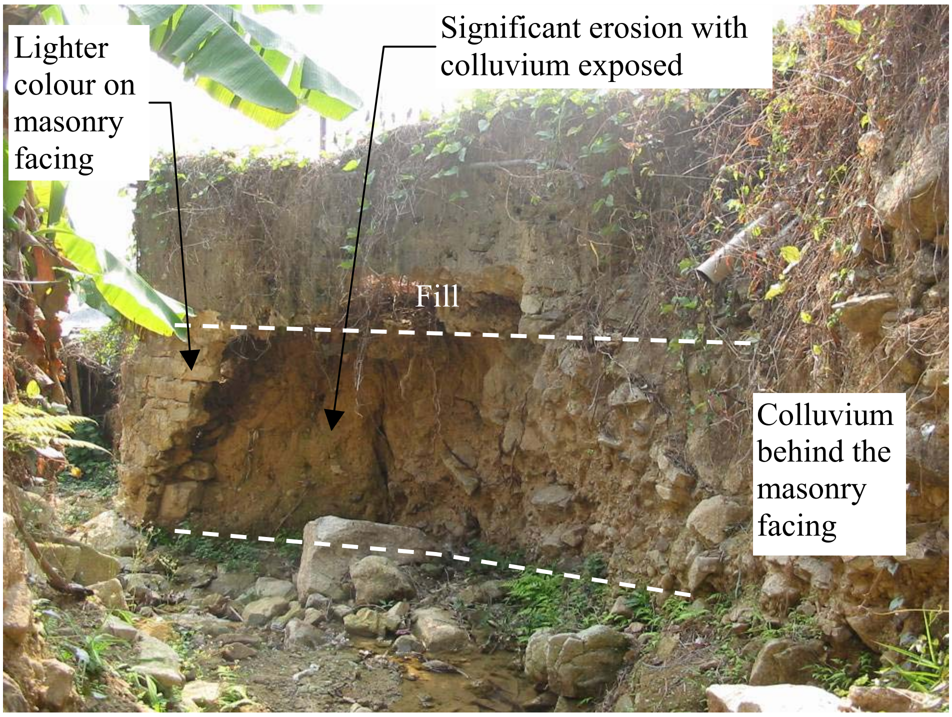

Plate 25 - View of the Masonry Facing and the Fill Platform
(Photograph taken on 22 February 2006)

Note : See Figure 12 for locations and directions of photographs.

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Plate 26 - Erosion underneath Registered Squatter Structure No. RTW/4D/296
(Photograph taken on 22 February 2006)

Plate 27 - Washout Debris along Route Twisk
(Photograph taken by HyD on 21 August 2005)

Note : See Figure 12 for location and direction of photograph.

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Plate 28 - Area in the Vicinity of Inlet of the Cross-road Culvert (Photograph taken by HyD on 21 August 2005)

Note : See Figure 12 for location and direction of photograph.

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APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

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A1. DETAILED OBSERVATIONS

This appendix sets out the detailed observations made from an interpretation of aerial photographs taken between 1924 and 2004. A list of the aerial photographs studied is presented in Table A1 and a location plan (Figure A1) is also attached.

YEAR	OBSERVATIONS
1924	This single, high-level photograph is of poor resolution. The study area is a natural hillside and it is drained by a main southwest-draining streamcourse. There is evidence of an unpaved track with a section generally follows the present-day alignment of Shing Mun Catchwater in the vicinity of the study area.
1963	High-flight, excellent resolution aerial photographs. The study area is located on the southwest-facing hillslopes of a northwest-southeast trending ridge and the hillslope is generally planar in profile. The hillside is generally sparsely vegetated comprising grass and scattered small trees. Shing Mun Catchwater and its associated slopes, including slopes Nos. 6SE-B/CR248 and 6SE-B/CR249 have been constructed near the crest of the study area. Route Twisk has been constructed and is in its present-day alignment. Slopes Nos. 6SE-B/C235 and 6SE-B/C236 have been formed by cutting into the natural hillside and appear to be covered with sparse vegetation. Slope No. 6SE-D/FR98 has also been formed on the downhill side of Route Twisk. An incised, southwest-draining main streamcourse drains the upper and middle portion of the study area while the lower portion turns a bend draining south alongside Route Twisk. It appears that the drainage section alongside Route Twisk has been affected by anthropogenic activities which shows a linear alignment with a flat platform in between. The cross-road culvert has been constructed on the downhill side of Route Twisk connecting to a main drainage line. A trail of bouldery colluvium is present along the lower portion of the drainage line. Scattered boulders are present on the spur and mid-slope in the vicinity of the landslide area. A recent landslide can be identified on slope No. 6SE-B/CR249 with a reflective appearance.

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YEAR	OBSERVATIONS
1963 (Cond't)	A shallow depression (defined by a rounded convex break-in-slope) is visible on the mid-slope west of the main drainage line, probably indicating past instability. Another area of erosion is evident east of the drainage line, approximate 30 m downslope from the catchwater. Cultivated terraces, with a squatter structure A, are visible on the hillslope to the west of the study area. An unpaved track can be seen providing a connection between the cultivation terraces and Route Twist. There is an area of abandoned cultivation terraces evident south of the lower portion of the study area. The adjacent hillside areas south of the study area comprise cultivation terraces and isolated village structures, which are probably the squatter units at the present-day location of Kong Pan Tin San Tsuen.
1964	No observable changes can be observed.
1967	A recent landslide scar can be seen on the mid-slope of the study area. The landslide is an open hillslope failure on the western side of the main drainage line and the debris did not appear to be channelised. The cultivation terraces west of main drainage line mentioned in 1963 have been abandoned.
1969	A probable recent landslide is evident on slope No. 6SE-B/CR248 about 25 m west of the main drainage line. The source area of landslide scar mentioned in 1967 was still bare. There is an increase in cultivation area south of the lower portion of the drainage line.
1976	The recent landslide observed in the 1967 aerial photograph has been re-vegetated. There is evidence showing that the abandoned cultivation terraces reactivated again. There is also an increase in the extent of the cultivation terraces in the adjacent terrain, including the area adjacent to the end of the main drainage line.
1977	Squatter structure B has been constructed on the western side of the main drainage line above slope No. 6SE-B/C236. An area of highly reflectivity area is evident in front of squatter structure B, probably comprising a minor cut and fill platform. Some boulder fill materials appear to have been placed at the end of the drainage line adjacent to Route Twisk.

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YEAR	OBSERVATIONS
1979	Some of the cultivation terraces were abandoned and covered with light vegetation. Squatter structure A appears to have been demolished and a new squatter structure C has been constructed on the platform.
1980	No observable changes.
1981	The affected squatter structure D has been constructed on the platform mentioned in 1977.
1982	The platform of squatter structure C has been further extended eastward and squatter structure E has been constructed. Another squatter structure F has also been constructed adjacent to squatter structure B next to the drainage line. An area of highly reflectivity can be seen on slope No. 6SE-B/C249, located 40 m northwest of landslide incident No. 2005/08/0480, which is probably associated with the minor instability or surface erosion reported in Incident No. NT82/241.
1983	No observable changes.
1984	Squatter structure E appears to have been demolished. Squatter structure G has been constructed further northwest of squatter structure F.
1986	No observable changes.
1987	A small structure is evident downslope from the affected squatter structure D, probably an electric plant. Squatter structure E appears to have been demolished. The density of vegetation on the natural hillside has increased.
1988	Slopes Nos. 6SE-B/CR248 and 6SE-B/CR249 have been modified with highly reflective appearances and surface drainage channels can be seen along the crests and mid-slopes. Fill material can be seen on the downhill side along the catchwater.
1991	No observable changes.
1992	No observable changes, except the density of vegetation on the natural hillside has increased.
1993	Squatter structures C and F appear to be demolished.
1994	Light vegetation has re-established itself on slopes Nos. 6SE-B/CR248 and 6SE-B/CR249.

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YEAR	**OBSERVATIONS**
1998	An area of high reflectivity can be seen near the crest of slope No. 6SE-B/C236. This is inferred as an area of instability (Incident No. MW97/7/4) Squatter structure B appears to have been demolished.
1999	No observable changes.
2000	Most of the cultivation terraces appear to have been abandoned.
2001	Extensive site formation work is evident northwest of the drainage line, probably associated with the construction of two private developments, the Cairnhill and the Cliveden.
2002	An area of high reflectivity, probably associated with anthropogenic activity (burial urns), is evident south of the drainage line. Construction of the Cairnhill and the Cliveden residential buildings is in progress.
2003	No observable changes. The construction of the Cairnhill and the Cliveden residential buildings is in progress.
2004	No observable changes.

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Table A1 - List of Aerial Photographs

Date Taken	Altitude (ft)	Photograph Number
1924	Unknown	Y00124
29 January 1963	3900	Y09036-37
31 December 1964	1800	Y11313
13 May 1967	3900	Y13483-84
1969	Unknown	Y15415-16
29 January 1976	4000	13272
23 August 1977	2000	18885
1 August 1979	4000	26384
13 November 1980	4000	32967
27 October 1981	10000	39186
28 July 1982	3000	43089-90
22 December 1983	10000	52182
20 October 1984	4000	56549
17 September 1986	4000	A05703
4 October 1987	4000	A10493-94
10 October 1988	4000	70353
3 November 1988	10000	A15096-97
1 October 1991	4000	A27542
13 May 1992	4000	A31164-65
9 July 1993	4000	A35375
6 May 1994	5000	A38141
19 May 1994	4500	CN6622
25 August 1998	4000	A48360
8 February 1999	4000	CN22691
9 December 1999	8000	CN25101-02
14 July 2000	5500	CN28066-67
13 September 2001	4000	CW32753-54
15 August 2002	4000	CW42646-47
25 November 2003	4000	CW52800-01
5 November 2004	4000	CW60176-77

Notes:
(1) Aerial photographs are in black and white except for those prefixed with CN or CW.
(2) Aerial photographs taken in 1949 have been borrowed by other parties.

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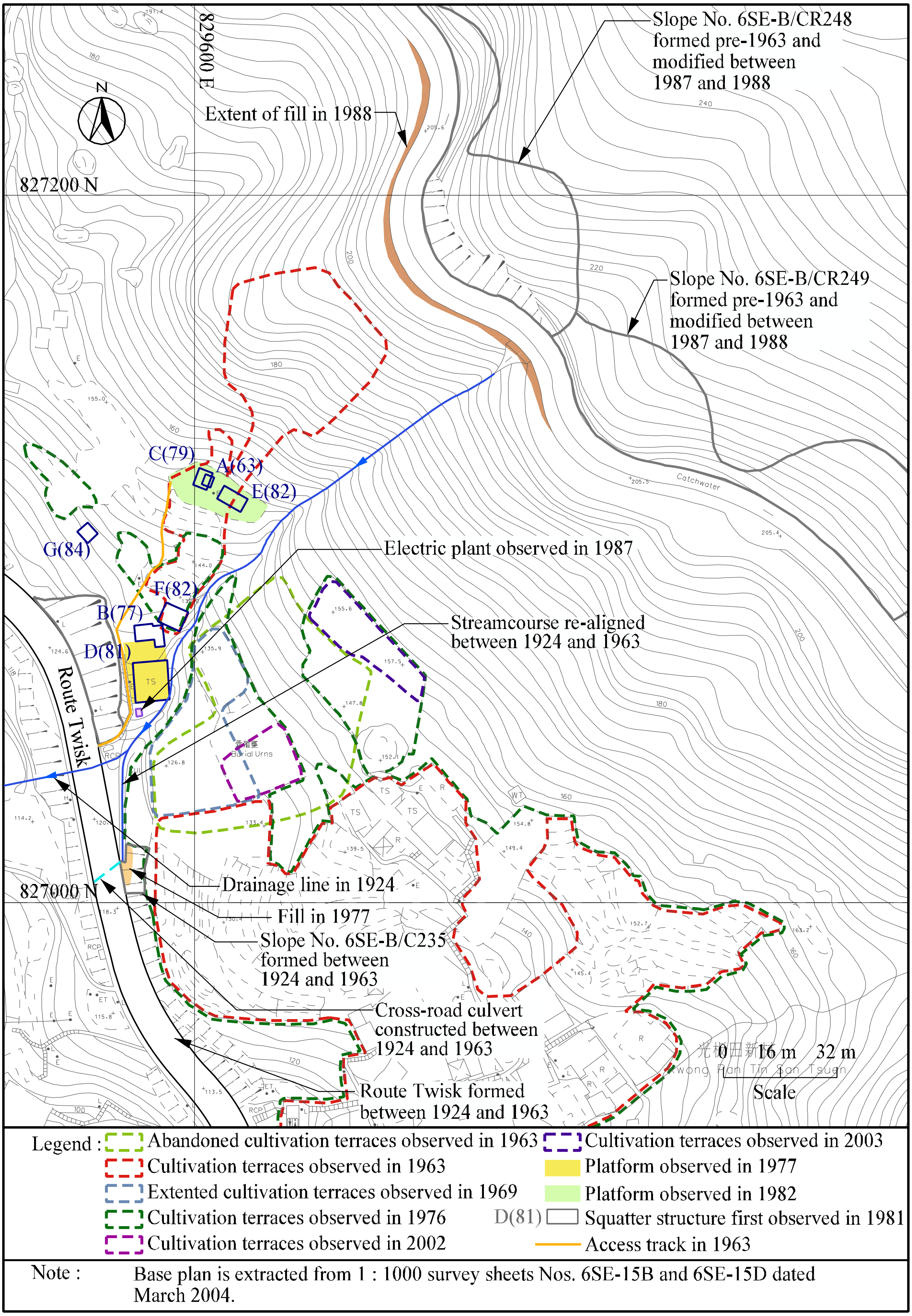

Figure A1 - Site Development

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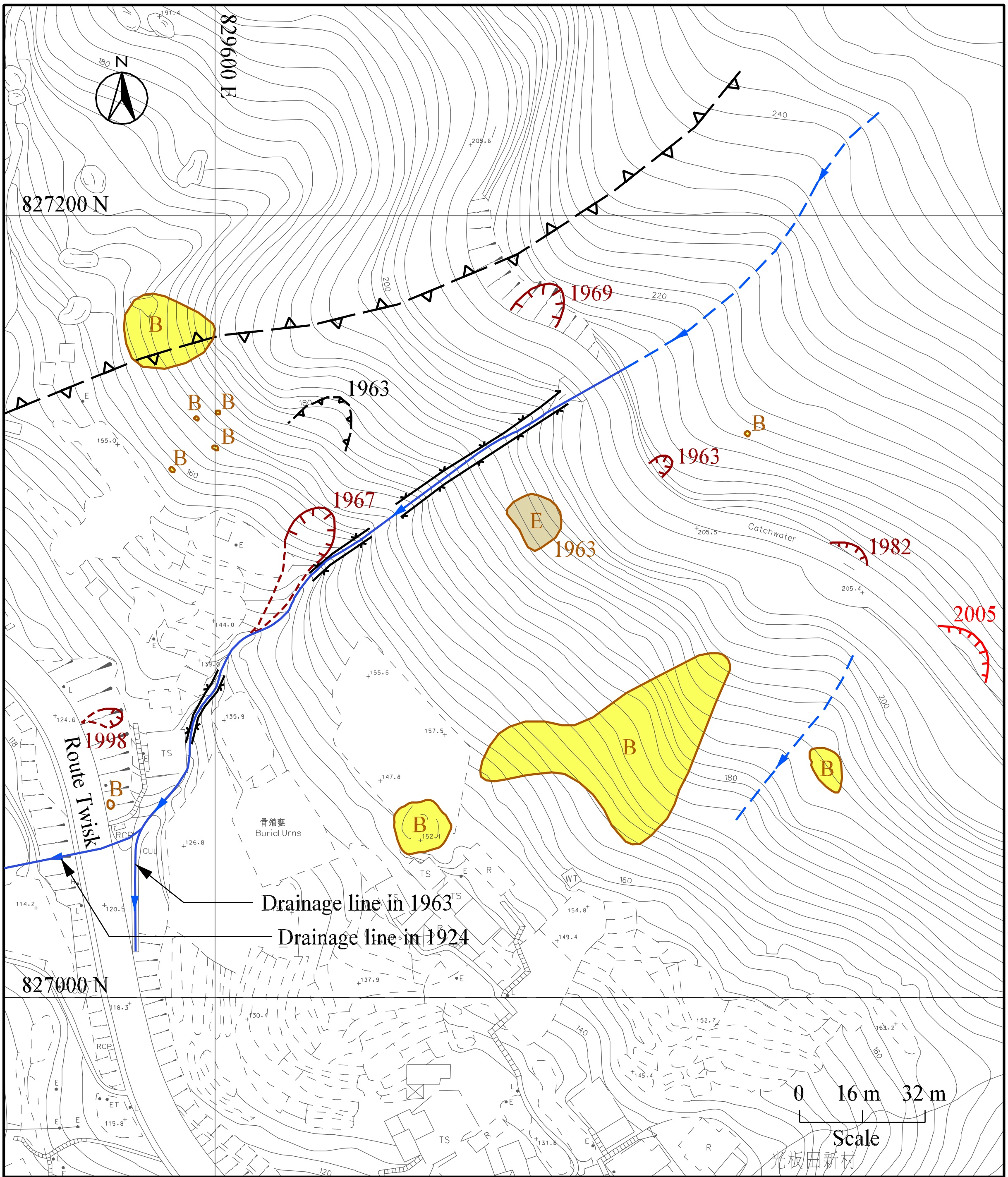

Legend :

- 2005 The 2005 landslide scar
- Spurline (rounded)
- Convex break-in-slope (rounded)
- Concave break-in-slope (sharp)
- Main drainage line
- Ephemeral drainage line
- 1963 E Area of erosion with year first observed
- B Isolated boulder / boulder group
- 1963 Landslide scar with year first observed
- Landslide debris trail

Note : Base plan is extracted from 1 : 1000 survey sheets Nos. 6SE-15B and 6SE-15D dated March 2004.

Figure A2 - Geomorphology Plan

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APPENDIX B

HYDRAULIC ASSESSMENT OF CATCHWATER OVERTOPPING

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B1. GENERAL

A hydraulic assessment was carried out to investigate the likelihood of overtopping at the Shing Mun Catchwater due to blockage by the landslide debris from slope No. 6SE-B/CR249 on 20 August 2005.

The likelihood of overtopping is assessed by investigating the remaining flow capacity of the catchwater channel after it was partially blocked, and the capacity of the upstream overflow weirs for coping with the rise in the water level within the catchwater channel.

Figure B1 shows the general layout of the section of the catchwater concerned and the relative positions of the landslide site and overflow weirs.

B2. METHODOLOGY AND ASSUMPTIONS

As the landslide debris partially blocked the catchwater channel, the water in the channel probably backed up, resulting in discharge at the upstream overflow weirs (*viz.* SMOF-28, SMOF-29, etc.). The quantities of discharge at the overflow weirs would also increase as the water level rose. It is assumed that overtopping near the blockage would have occurred if the total capacity of the partially blocked catchwater channel and the overflow weirs was less than the original flow in the channel with the water level reaching the top of the channel wall.

The other assumptions made in the hydraulic assessment are as follows:

(a) the original water flow within the catchwater channel (near the blockage and just before the incident) was at the channel design capacity of 32.3 m^3 (which is based on WSD's record);

(b) the partially blocked catchwater behaved hydraulically as a V-shaped notch and its dimensions are based on the volume of the landslide debris and photographic records (Table B1); and

(c) the water level in the catchwater channel between the blockage and discharging overflow weirs remained constant. As there might still be water flowing through the partially blocked section of the catchwater channel, a hydraulic gradient could exist and the water levels at the upstream overflow weirs would have been under-estimated. This assumption will in turn be conservative in estimating the discharge at the overflow weirs.

In the assessment, a trial and error approach is adopted where different water levels in the catchwater channel are assumed. For each assumed water level, the amount of discharge from these overflow weirs is calculated and added to the quantity of flow through the partially blocked channel. If the total flow quantity is equal to the original flow quantity, an approximate water level in the channel is found.

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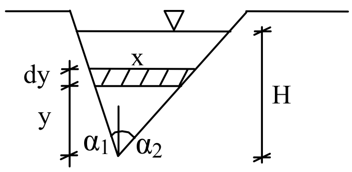
B3. ANALYSIS AND RESULTS

The amount of flow through the partially blocked catchwater channel is calculated assuming it behaves as a V-shaped notch. The derivation of the flow is as follows:



$$dQ = \text{area} \cdot \text{velocity} = x\, dy\, [2g\,(H-y)]^{1/2}$$

where $x = y\,(\tan\alpha_1 + \tan\alpha_2) = y\,\tan(\alpha_1 + \alpha_2)\,(1 - \tan\alpha_1 \tan\alpha_2)$

Substitute x and integrate,

$$Q = \int_0^H y\,\tan(\alpha_1 + \alpha_2)\,(1 - \tan\alpha_1 \tan\alpha_2)\,[2g\,(H-y)]^{1/2}\,dy$$

Rearrange and incorporate the coefficient of discharge C_d,

$$Q = C_d\,\frac{4}{15}\sqrt{(2g)}\,\tan(\alpha_1 + \alpha_2)(1 - \tan\alpha_1 \tan\alpha_2)\,H^{5/2}$$

Notation:
- Q is the amount of flow (in m^3/s)
- C_d is the coefficient of discharge
- g is the acceleration due to gravity (in m/s^2)
- α_1 and α_2 are the angles of the V-shaped notch (see Table B1)
- H is the water height above bottom of the notch (in m)

The amount of discharge at the overflow weirs (which are rectangular in shape) can be calculated as follows (Douglas, 1975):

$$Q = C_d\,\frac{2}{3}\,B\,\sqrt{(2g)}\,H^{3/2}$$

where B is the width of the overflow weir (in m)

The coefficients of discharge C_d for the partially blocked catchwater channel and the overflow weirs are less than unity. The value of C_d for the overflow weirs is back calculated based on their design capacities as given in WSD's records. A value of 0.6 provides a reasonable fit (see Table B1). However, the value of C_d for the partially blocked catchwater channel cannot be explicitly determined and the assessment has been carried out assuming C_d varying from 0.6 to 0.9.

Table B2 tabulates the assumed water levels in the catchwater channel and the calculated amount of flow in the partially blocked channel and the discharges at the overflow weirs. The results suggest that the water level at the time of the incident may be very close to the crest level of the catchwater channel near the blockage (205.4 mPD) and overtopping was unlikely to have occurred at the time of the incident. The results also show that the estimated water level in the catchwater channel is not sensitive to the C_d value assumed for the partially blocked channel.

References

Douglas J.F. (1975). Solution of Problems in Fluid Mechanics Part 1. Pitman, London.

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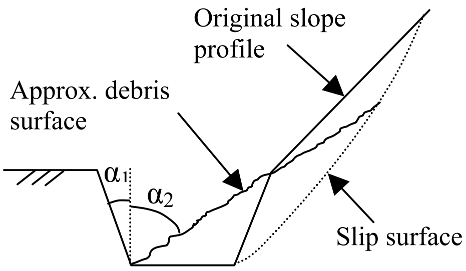
Table B1 – Partially Blocked Catchwater Channel and Overflow Weirs

Partially Blocked Catchwater Channel

Chainage (m)	Invert Level (mPD)	Top Level of Catchwater Channel (mPD)	Top Width (m)	Bottom Width (m)	Height (m)	Angle of Notch, α_1 (degree)	Angle of Notch, α_2 (degree)
5260	202.7	205.4	5.0	2.9	2.7	21	55



Cross-section


Photograph taken on 21 August 2005

Overflow Weirs

Overflow Weir No.	Chainage (m)	Invert Level (mPD)	Top Level of Adjacent Catchwater Channel (mPD)	Total Width (m)	Height (m)	Calculated Capacity (m^3/s) (Note 1)	Design Capacity (m^3/s) (Note 2)
SMOF-28	5133	204.81	205.60	6	0.57	4.574	4.786
SMOF-29	5352	205.05	205.90	36	0.58	28.171	26.631

Notes

1. Section B3 refers. C_d is taken as 0.6.
2. Based on WSD records.

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Table B2 – Flow Quantities

Coefficient of Discharge for Partically Blocked Catchwater Channel = 0.6
Coefficient of Discharge for Overflow Wier = 0.6

Assumed Water Level in Catchwater Channel (at Blockage) (mpD)	Water Height in Catchwater Channel (at Blockage) (m)	Flow Capacity of Partially Blocked Catchwater Channel (m^3/s) (1)	Overflow Weir SMOF-28			Overflow Weir SMOF-29			Total Flow Quantity (m^3/s) (1)+(2)+(3)	Original Flow Quantity in Catchwater Channel (m^3/s)	Remark
			Invert Level (mPD)	Water Height Above Invert Level (m)	Quantity of Discharge at Overflow Weir (m^3/s) (2)	Invert Level (mPD)	Water Height Above Invert Level (m)	Quantity of Discharge at Overflow Weir (m^3/s) (3)			
204.7	2.00	7.27	204.81	0	0.00	205.05	0	0.00	7.27	32.3	
204.8	2.10	8.21	204.81	0	0.00	205.05	0	0.00	8.21	32.3	
204.9	2.20	9.22	204.81	0.09	0.29	205.05	0	0.00	9.51	32.3	
205.0	2.30	10.30	204.81	0.19	0.88	205.05	0	0.00	11.18	32.3	
205.1	2.40	11.46	204.81	0.29	1.66	205.05	0.05	0.71	13.83	32.3	
205.2	2.50	12.69	204.81	0.39	2.59	205.05	0.15	3.71	18.99	32.3	
205.3	2.60	14.00	204.81	0.49	3.65	205.05	0.25	7.97	25.62	32.3	See note
205.4	2.70	15.38	204.81	0.59	4.82	205.05	0.35	13.21	33.41	32.3	below

Coefficient of Discharge for Partically Blocked Catchwater Channel = 0.7
Coefficient of Discharge for Overflow Wier = 0.6

Assumed Water Level in Catchwater Channel (at Blockage) (mpD)	Water Height in Catchwater Channel (at Blockage) (m)	Flow Capacity of Partially Blocked Catchwater Channel (m^3/s) (1)	Overflow Weir SMOF-28			Overflow Weir SMOF-29			Total Flow Quantity (m^3/s) (1)+(2)+(3)	Original Flow Quantity in Catchwater Channel (m^3/s)	Remark
			Invert Level (mPD)	Water Height Above Invert Level (m)	Quantity of Discharge at Overflow Weir (m^3/s) (2)	Invert Level (mPD)	Water Height Above Invert Level (m)	Quantity of Discharge at Overflow Weir (m^3/s) (3)			
204.7	2.00	8.48	204.81	0	0.00	205.05	0	0.00	8.48	32.3	
204.8	2.10	9.58	204.81	0	0.00	205.05	0	0.00	9.58	32.3	
204.9	2.20	10.76	204.81	0.09	0.29	205.05	0	0.00	11.04	32.3	
205.0	2.30	12.02	204.81	0.19	0.88	205.05	0	0.00	12.90	32.3	
205.1	2.40	13.37	204.81	0.29	1.66	205.05	0.05	0.71	15.74	32.3	
205.2	2.50	14.81	204.81	0.39	2.59	205.05	0.15	3.71	21.10	32.3	
205.3	2.60	16.33	204.81	0.49	3.65	205.05	0.25	7.97	27.95	32.3	See note
205.4	2.70	17.95	204.81	0.59	4.82	205.05	0.35	13.21	35.97	32.3	below

Coefficient of Discharge for Partically Blocked Catchwater Channel = 0.8
Coefficient of Discharge for Overflow Wier = 0.6

Assumed Water Level in Catchwater Channel (at Blockage) (mpD)	Water Height in Catchwater Channel (at Blockage) (m)	Flow Capacity of Partially Blocked Catchwater Channel (m^3/s) (1)	Overflow Weir SMOF-28			Overflow Weir SMOF-29			Total Flow Quantity (m^3/s) (1)+(2)+(3)	Original Flow Quantity in Catchwater Channel (m^3/s)	Remark
			Invert Level (mPD)	Water Height Above Invert Level (m)	Quantity of Discharge at Overflow Weir (m^3/s) (2)	Invert Level (mPD)	Water Height Above Invert Level (m)	Quantity of Discharge at Overflow Weir (m^3/s) (3)			
204.7	2.00	9.69	204.81	0	0.00	205.05	0	0.00	9.69	32.3	
204.8	2.10	10.94	204.81	0	0.00	205.05	0	0.00	10.94	32.3	
204.9	2.20	12.29	204.81	0.09	0.29	205.05	0	0.00	12.58	32.3	
205.0	2.30	13.74	204.81	0.19	0.88	205.05	0	0.00	14.62	32.3	
205.1	2.40	15.28	204.81	0.29	1.66	205.05	0.05	0.71	17.65	32.3	
205.2	2.50	16.92	204.81	0.39	2.59	205.05	0.15	3.71	23.22	32.3	
205.3	2.60	18.67	204.81	0.49	3.65	205.05	0.25	7.97	30.28	32.3	See note
205.4	2.70	20.51	204.81	0.59	4.82	205.05	0.35	13.21	38.54	32.3	below

Coefficient of Discharge for Partically Blocked Catchwater Channel = 0.9
Coefficient of Discharge for Overflow Wier = 0.6

Assumed Water Level in Catchwater Channel (at Blockage) (mpD)	Water Height in Catchwater Channel (at Blockage) (m)	Flow Capacity of Partially Blocked Catchwater Channel (m^3/s) (1)	Overflow Weir SMOF-28			Overflow Weir SMOF-29			Total Flow Quantity (m^3/s) (1)+(2)+(3)	Original Flow Quantity in Catchwater Channel (m^3/s)	Remark
			Invert Level (mPD)	Water Height Above Invert Level (m)	Quantity of Discharge at Overflow Weir (m^3/s) (2)	Invert Level (mPD)	Water Height Above Invert Level (m)	Quantity of Discharge at Overflow Weir (m^3/s) (3)			
204.7	2.00	10.90	204.81	0	0.00	205.05	0	0.00	10.90	32.3	
204.8	2.10	12.31	204.81	0	0.00	205.05	0	0.00	12.31	32.3	
204.9	2.20	13.83	204.81	0.09	0.29	205.05	0	0.00	14.12	32.3	
205.0	2.30	15.46	204.81	0.19	0.88	205.05	0	0.00	16.34	32.3	
205.1	2.40	17.19	204.81	0.29	1.66	205.05	0.05	0.71	19.56	32.3	
205.2	2.50	19.04	204.81	0.39	2.59	205.05	0.15	3.71	25.33	32.3	See note
205.3	2.60	21.00	204.81	0.49	3.65	205.05	0.25	7.97	32.62	32.3	below

Note - Approximate range of water level in the catchwater channel at the time of the incident

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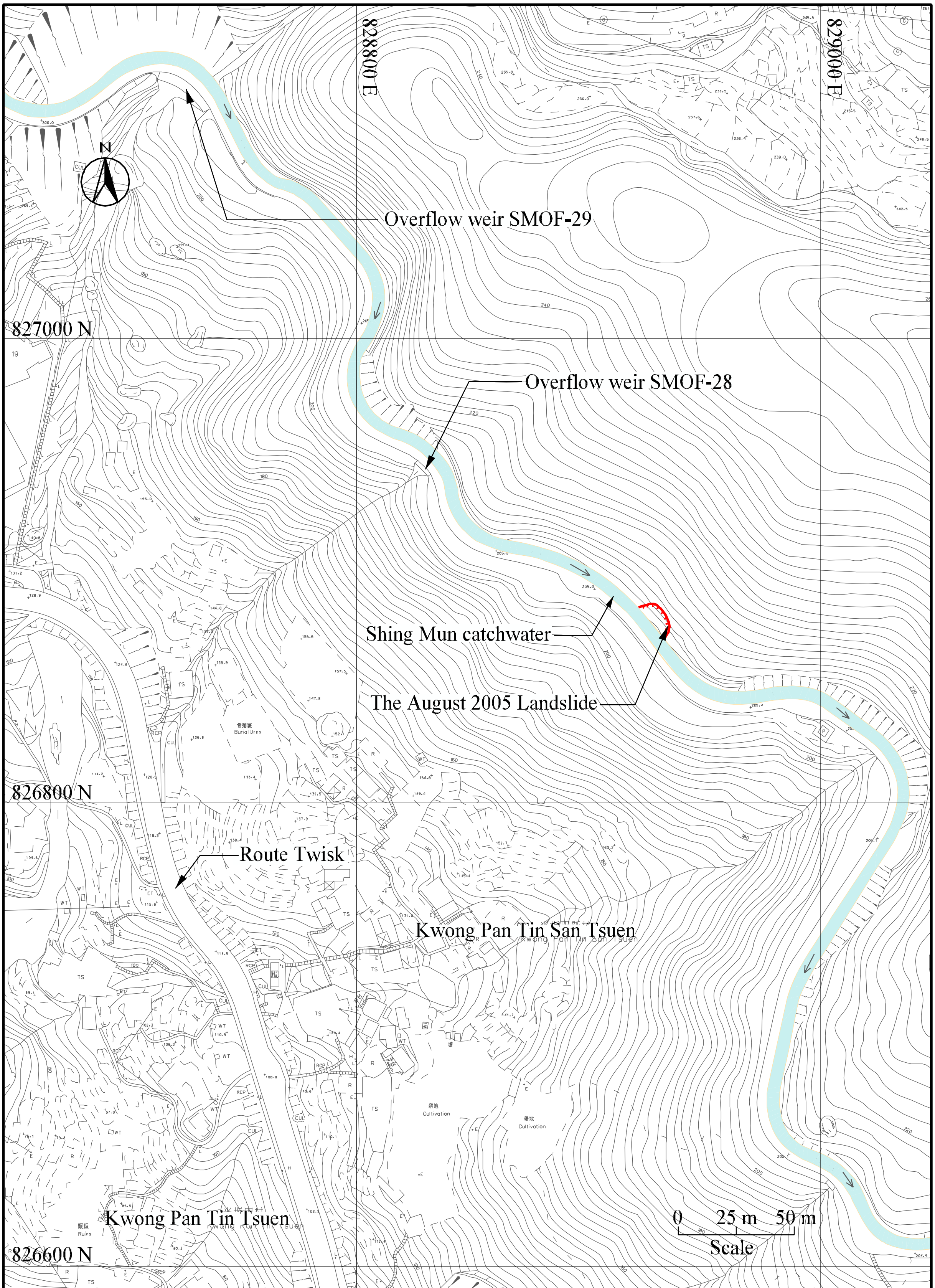

Note : Base plan is extracted from 1 : 1000 survey sheets Nos. 6SE-15B and 6SE-15D dated March 2004.

Figure B1 - Shing Mun Catchwater Above Route Twisk

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

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

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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)。
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GEO Publication No. 1/2000	Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls (2000), 146 p.
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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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