DETAILED STUDY OF THE 7 JUNE 2008 LANDSLIDES ON THE HILLSIDE ABOVE YU TUNG ROAD, TUNG CHUNG

GEO REPORT No. 271

AECOM Asia Company Limited

GEOTECHNICAL ENGINEERING OFFICE

CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT

THE GOVERNMENT OF THE HONG KONG

SPECIAL ADMINISTRATIVE REGION

DETAILED STUDY OF THE 7 JUNE 2008 LANDSLIDES ON THE HILLSIDE ABOVE YU TUNG ROAD, TUNG CHUNG

GEO REPORT No. 271

AECOM Asia Company Limited

This report is largely based on GEO Landslide Study Report No. LSR 14/2009 produced in March 2010

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

© The Government of the Hong Kong Special Administrative Region

First published, October 2012

Prepared by:

Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon,
Hong Kong.

Table of Contents
Table of Contents
Table of Contents

PREFACE

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. The GEO Reports can be downloaded from the website of the Civil Engineering and Development Department (http://www.cedd.gov.hk) on the Internet. Printed copies are also available for some GEO Reports. For printed copies, a charge is made to cover the cost of printing.

The Geotechnical Engineering Office also produces documents specifically for publication in print. These include guidance documents and results of comprehensive reviews. They can also be downloaded from the above website.

The publications and the printed GEO Reports may be obtained from the Government's Information Services Department. Information on how to purchase these documents is given on the second last page of this report.

Y.C. Chan
Head, Geotechnical Engineering Office
29 October 2012

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

FOREWORD

This report presents the findings of a detailed study of the natural terrain landslides that occurred on the hillside above Yu Tung Road, Tung Chung Northern Lantau, on 7 June 2008 during a Black Rainstorm.

Yu Tung Road was affected directly by two major channelised debris flows that occurred in catchments Nos. 24 and 30 at the northern and southern end of the northwest facing hillside above the road respectively. The largest channelised debris flow from catchment No. 30 resulted in about 3,500 m^3 of debris reaching Yu Tung Road. Both westbound lanes of Yu Tung Road were closed for more than two months. The other channelised debris flow from catchment No. 24 resulted in about 250 m^3 of debris being deposited alongside the road. In addition, minor quantities of fine material were washed onto the road from other drainage lines within the central portion of the hillside from catchments Nos. 25, 26 and 29. Subsequent outwash resulted in debris being carried onto the Tung Chung Eastern Interchange and flooding of Cheung Tung Road below. No casualties were reported as a result of the landslide.

The key objectives of the study were to document the facts about the landslides, present relevant background information, summarise the detailed landslide debris trail mapping reports for selected landslides and establish the probable causes of the landslides and debris movement processes. The scope of the study comprised desk study, site reconnaissance, detailed field mapping, and engineering geological mapping. Recommendations for follow-up actions are presented separately.

The report was prepared as part of the Landslide Investigation Consultancy for landslides occurring in Kowloon and the New Territories in 2008 and 2009, for the Geotechnical Engineering Office, Civil Engineering and Development Department, under Agreement No. CE 41/2007 (GE). This is one of a series of reports produced during the consultancy by AECOM Asia Company Limited.

Mr. Fred H.Y. Ng
Project Director
AECOM Asia Company Limited

Agreement No. CE 41/2007 (GE)
Study of Landslides Occurring in Kowloon and the New Territories in 2008 and 2009 - Feasibility Study

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

CONTENTS

Page No.

Table of Contents

Table of Contents

Table of Contents

Table of Contents

Page No.

1. INTRODUCTION

As a result of intense rainfall in the early morning of 7 June 2008, 19 landslides occurred on the hillside above Yu Tung Road, Tung Chung, Northern Lantau (Figure 1 and Plate 1).

Of the 19 landslides, four subsequently developed into three channelised debris flows (CDF) in hillside catchments Nos. 24, 25 and 30 (Figure 1). The CDF in catchments Nos. 24 and 30 each involved a single landslide source area, while that in catchment No. 25 involved two source areas. Debris from the two CDFs in catchments Nos. 24 and 30 reached Yu Tung Road, resulting in blockage of both westbound lanes (Plate 2) and flooding of the adjacent Cheung Tung Road (Figure 2, Plate 3) respectively. The other CDF occurred within catchment No. 25 with the debris coming to rest at the mid-portion of the hillside. Minor quantities of fine debris were also washed onto Yu Tung Road from five landslides that occurred in catchments Nos. 26 and 29 (Figure 2, Plates 4 and 5). No casualties were reported as a result of the landslides.

Following the incidents, AECOM Asia Company Limited (AECOM), the Landslide Investigation Consultant for Kowloon and the New Territories, carried out a detailed study for the Geotechnical Engineering Office (GEO), Civil Engineering and Development Department (CEDD), under Agreement No. CE 41/2007 (GE).

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

(a) Review of all known relevant documents relating to the study area and the sequence of events leading up to the landslides,

(b) Topographical surveys, engineering geological mapping and detailed field observations and measurements,

(c) Aerial photograph interpretation,

(d) Analysis of rainfall records,

(e) Diagnosis of the probable causes of the landslides, and

(f) Discussion on the process of the debris movement.

2. DESCRIPTION OF THE SITE

2.1 General

The study area comprises the hillside above Yu Tung Road, located to the southeast of Tung Chung New Town, Lantau (Figures 1 and 2). To facilitate the investigation, the hillside within the study area is subdivided into ten (10) drainage catchments, the numbers of which follow that of a previous Natural Terrain Hazard Study (OAP, 2005). Catchments within the study area are numbered 22 to 31. Landslides on the hillside in catchments Nos. 1

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

to 21, are located above the North Lantau Highway and Cheung Tung Road and are reported separately (AECOM, 2010).

The study area comprises the northwest facing hillside above Yu Tung Road, and extends from the road with a toe elevation of between 17 mPD and 27 mPD and reaches a maximum elevation of 482 mPD (Figure 1). The hillside is generally densely vegetated with shrubs and bushes, particularly along the well-defined northwest-trending drainage lines and streamcourses.

The upper portion of the hillside within the study area is inclined at between 30° and 45° and locally steeper than 45° (Figure 11), where there are large areas of rock exposure. In the mid-slope area, the hillside gradient is generally between 15° and 30°, with the gradient decreasing to less than 15° towards the toe-slope area. Prominent rock exposures are present in the mid to upper portions of catchments Nos. 24 and 25 and colluvial boulder fields and areas of rock exposure are present locally within the upper portion of catchment No. 30.

Several footpaths cross the hillside and an electricity cable crosses the hillside within the toe-slope area (Figure 2).

2.2 Regional Geology and Geotechnical Area Studies Programme

According to the Hong Kong Geological Survey (HKGS) 1:20 000 scale Solid and Superficial Geology Map Sheet No. 9 (GEO, 1994), the site is underlain by metamorphosed rhyolite lava and tuff of the undivided Lantau Formation (Langford et al, 1995), which was reassigned later as the Lantau Volcanic Group (Sewell et al, 2000), and locally mantled by debris flow deposits (Figure 3). Feldspharphyric rhyolite, banded lava, granite porphyry and tuff are present near the toe of the hillside.

The Regional Fault Plan (Ding & Lai, 1997) indicates that two regional faults are present in the vicinity of the study area. One is located within 50 m from the toe of the study area, trending northeast-southwest beneath the North Lantau Highway and Yu Tung Road. Another one is located at about 150 m on the southwestern side of catchment No. 30, trending southeast-northwest and running parallel to sub-parallel to the drainage lines in the study area (Figure 3).

Based on the Geotechnical Area Studies Programme (GASP) Report No. VI, North Lantau (GCO, 1988) carried out by the Geotechnical Control Office (GCO, renamed GEO in 1991), the study area is a zone of general instability associated with predominantly insitu terrain and colluvial terrain.

3. DESCRIPTION OF THE LANDSLIDES

The 19 landslides that occurred in the hillside above Yu Tung Road involved displaced volumes (terminology after Cruden & Varnes, 1996) that ranged between less than 5 m^3 and 2,350 m^3 (Figure 2). Debris from two of the landslide source areas Nos. L3 and L25 in catchments Nos. 24 and 30 respectively developed into CDFs and affected Yu Tung Road. According to the incident records and information from the Police, the landslides that affected

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

Yu Tung Road occurred at around 9:00 a.m. on 7 June 2008. Debris from another CDF initiated from landslide source areas Nos. L1 and L2 in catchment No. 25 came to rest at the mid-portion of the hillside. Secondary outwash action carried more than 50 m^3 fines from the debris, including those from other catchments Nos. 26 and 29, onto Yu Tung Road (Figure 2).

The largest CDF occurred in catchment No. 30 (Incident No. 2008/06/0344). About 2,350 m^3 of debris from the landslide source No. L25 entered into an adjacent drainage line and through material entrainment developed into a CDF with a maximum active volume of about 3,400 m^3, and a runout distance of about 600 m (Figure 9). All the debris reached Yu Tung Road and completely blocked the westbound lanes of Yu Tung Road with a minor quantity, less than 5 m^3, of debris spilling over onto the eastbound carriageways.

Another CDF (Incident No. LI/2008/06/2005) occurred in catchment No. 24. About 150 m^3 from landslide source No. L3 together with about 230 m^3 of material from local entrainment at the base of the source area entered into a drainage line and developed into a 450 m^3 CDF. The debris travelled a horizontal distance of about 550 m and deposited about 250 m^3 of debris on the roadside verge alongside Yu Tung Road (Figure 7). Subsequent surface runoff from the hillside washed some of the debris onto Tung Chung Eastern Interchange causing overspilling onto Cheung Tung Road below resulting severe flooding.

The remaining CDF occurred in catchment No. 25 (Incident No. LI/2008/06/2016). Debris from the landslide source areas Nos. L1 and L2, with a source volume less than 100 m^3 each, together with about 290 m^3 of material from a side-slope failure, entered into a drainage line and developed into a 600 m^3 CDF that travelled for a horizontal distance of about 450 m (Figure 8). Although the debris largely spread and remained on the hillside, subsequent outwash action carried a small amount of fines for a distance of over 200 m to the toe of the catchment.

4. SITE HISTORY AND PAST INSTABILITIES

4.1 General

The history of the study area has been determined from an interpretation of the available aerial photographs, together with a review of relevant documentary information (Figure 4). Detailed observations from the aerial photograph interpretation (API) are summarised in Appendix A, and the salient observations are given below.

4.2 Site History

Based on a review of the earliest aerial photograph taken in 1945, the study area comprises northwest facing natural hillside, characterised by well-defined drainage catchments separated by rounded spurlines. The catchments are dissected by several drainage lines that typically drain towards the northwest direction (Figure 4).

In the 1945 aerial photographs, anthropogenic disturbance of the hillside, which primarily comprises footpaths and some agricultural terracing of the lower reaches of colluvial fans, are observed to extend north-westwards from the hillside towards the sea.

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

In 1975 small dwellings were present near the outlet of catchment No. 30, with one small dwelling being situated centrally within the outlet of the catchment adjacent to the perennial streamcourse (S1 in Figure 4), along which the June 2008 CDF travelled. The dwelling was demolished in 1995 during the site formation for Yu Tung Road. A cable supported on poles was installed across the lower portion of the hillside before 1975. To the north of catchment No. 30, the Buddhist Youth camp at the toe of catchment No. 23 was built between 1975 and 1977.

Eight man-made features (Figure 1) were formed at the toe of the study area, in association with the construction of Yu Tung Road between 1992 and 1996. Reclamation for Tung Chung New Town northwest of the study area was carried out between 1992 and 1996 with development on the newly reclaimed area taking place from 1996 onwards.

In 1981 and 1993 part of the hillside in the southern portion of the study area appears to have been affected by hillfires (Figure A1). In 2003, some localised vegetation clearance was being carried out along the upper northern spurline of catchment No. 30, as well as across the crest of the catchment (Figure 4).

4.3 Past Instabilities

4.3.1 Historical Landslide Catchment Inventory

Three historical landslide catchments (HLC), i.e. a catchment with a history of landslides that occurred close to existing buildings and important transport corridors (Wong et al, 2006), have been identified within the study area (Figure 5). These include open hillslope catchments Nos. 09SEB-O7 and 09SEB-O8, in catchments Nos. 22 and 27 respectively, and a debris flow catchment No. 09SEB-C04 in catchment No. 29. The HLCs in catchments Nos. 22 and 27 were assigned based on the ENTLI features being within 100 m of an important facility (Figure 5), and catchment No. 29 was included as a HLC following the occurrence of the 1993 channelised debris flow within the catchment, which had a long debris runout reaching Yu Tung Road (see Section 4.3.3).

4.3.2 Enhanced Natural Terrain Landslide Inventory and Large Landslide Database

In 2004, GEO produced an Enhanced Natural Terrain Landslide Inventory (ENTLI). A total of 141 landslides were identified within the study area under the ENTLI. Of the 141 landslides, 39 landslides were classified as recent[1] landslides while 102 landslides as relict[1] landslides (Figure 5). All the relict landslides were identified in the 1963 aerial photographs.

The ENTLI records one recent landslide and three relict landslides in catchment No. 24. One of them, ENLTI landslide No. 09SEB0745E, coincides with the location of

---

[1] Recent landslides are those that can be identified distinctly on aerial photographs and the time period in which the landslides occurred can also be confirmed by available aerial photographs. Relict landslides are those that occurred earlier than the time-scale of the available aerial photographs (i.e. pre-1945).

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

landslide No. L3 in catchment No. 24 (Figure 5), and is indicated as a minor depression measuring about 12 m wide by 9 m long.

The ENTLI records nine relict landslides in catchment No. 25. Two of them, ENTLI relict landslides Nos. 09SEB0741E and 09SEB07043E, were located above the sources of L1 and L2 respectively. Landslide No. 09SEB0741E appeared to be a failure involving rock outcrop with approximate source dimensions of 24 m in width and 9 m in length while landslide No. 09SEB0713E appeared as a shallow depression, with approximate source dimensions of 16 m in width and 8 m in length (Figure 5).

In catchment No. 30, two relatively prominent, relict landslide scars (ENTLI Nos. 09SEB0146E and 09SEB0147E) are located at the same location as the 7 June 2008 source area (L25). These two relict landslide scars are indicated as minor depressions, approximately 14 m wide by 7 m long and 16 m wide by 11 m long respectively (Figure 5). The relict landslides were separated by a minor local spur in which a recent landslide (ENTLI No. 09SEB1602E) was present. It is apparent that the debris from landslide No. 09SEB0147E might have formed a minor debris lobe on the hillside below the relict scar. (Figure A4).

GEO's large landslide database (Scott Wilson, 1999) contains records of five large landslides within the study area (Figure 6). A large landslide No. 09SEBL005 was located near the crest of catchment No. 30, immediately above the 7 June 2008 landslide source area (L25). The large landslide scar is likely not a single event but comprised several past events. Further supporting details is obtained from the API, as detailed in the following section.

4.3.3 Aerial Photograph Interpretation

The 1945 aerial photographs show that most of the study area has a surface cover of colluvium and in places talluvium (a matrix supported bouldery colluvium). Relict, large scale (several hundred metres across) colluvial debris fans are present at the toe of catchments Nos. 24, 25 and 30 (Figures 4 and A2). Smaller, relatively more recent colluvial debris lobes are present at the outlets of the drainage lines in catchments Nos. 24 and 30. A debris lobe is also located at the drainage line outlet in catchment No. 26.

The 1945 and 1963 aerial photographs (Figures 4 and A3) show a large debris lobe emerging at the lower section of catchment No. 30. The debris lobe is likely related to the landslide scar No. 09SEBL005 recorded in the GEO's large landslide database. The large landslide scar is located immediately above source area No. L25 that occurred on 7 June 2008. The aerial photographs indicate that the large debris lobe was probably the result of several past landslide events, as it comprised an older and younger colluvial debris fans. Furthermore, the past landslide events could have resulted in the formation of a deeply incised drainage line that traversed the catchment.

The 1963 aerial photographs also indicate in catchment No. 30 signs of erosion on the south-western flank of the drainage line some 50 m downhill from the source area No. L25. Several relict and recent landslide scars are evident on the north-facing flank of the drainage line. In addition, intermittent rock outcrop and a cluster of boulders can be seen on the hillside immediately above the source area in question. A portion of the pre-failure hillside

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

at the source area was located within an area of bouldery deposits, where were probably resulted from previous landslides and general mass wasting (Figures 4, 6 and A4).

Based on the 1963 aerial photographs, well-defined topographic depressions encircled by distinct convex breaks-in-slope can be seen at the head of catchments Nos. 24 and 25, at the locations of the source areas (L1 to L3) of the 7 June 2008 landslides in these catchments. The topographic depressions appear to correspond to relict landslide scars, which are likely to be susceptible to retrogressive landslide action at locations prone to concentrated surface runoff. The drainage lines at the lower part of the catchments Nos. 24 and 25 appear to be the result of fluvial erosion over the surface of the colluvial debris fan. The drainage lines in these catchments are therefore relatively poorly defined as compared with that in catchment No. 30.

In 1993, about 20 landslides occurred on the hillside following the 5 November 1993 Rainstorm (Figure A7). Among these, a 2,300 m^3 channelised debris flow with a runout distance of about 450 m occurred in catchment No. 29. Several of the landslides are documented in GEO Report No. 57 (Franks, 1998), and the mobility of the channelised debris flow from catchment No. 29 (labelled landslide No. 5/A2 in GEO Report No. 57) was back-analysed by Ayotte & Hungr (1998). Most of the landslides occurred in catchment No. 30 with one small-scale failure immediately below the toe of the 7 June 2008 landslide source No. L25. Few landslides are observed from the aerial photographs on the hillside in other catchments within the study area.

4.3.4 GEO's Landslide Database

No landslide incidents were recorded in the GEO's landslide database, in the immediate vicinity of the study area.

4.3.5 Summary

The hillside above Yu Tung Road has been affected by many relict and recent landslides, many of them tend to cluster at the relatively steep, upper parts of the hillside. The 7 June 2008 landslides also appeared to occur within or close to these clustered zones.

The past landslide events could have contributed to the development of deeply incised drainage lines that traverse catchments Nos. 26, 29 and 30 as well as formation of debris lobes near the drainage outlets in the catchments. Signs of erosion on the flanks of the drainage lines as well as topographic depressions encircled by sharp convex breaks-in-slopes are not uncommon within the study area. They are probably due to retrogressive landslide action in the past. In addition, intermittent rock outcrop and clusters of bouldery deposits can be seen immediately above some of the past landslide scars in catchment No. 30.

5. FIELD OBSERVATIONS AND LANDSLIDE PROCESS

5.1 General

Detailed field mapping was carried out within the study area for landslide No. L3 in catchment No. 24, landslides Nos. L1 and L2 in catchment No. 25 and landslide No. L25 in

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

catchment No. 30. These landslides had developed into CDFs. The field mapping also covered the debris trails. Salient observations from the detailed mapping are discussed below and further details are presented in Appendix B. The detailed mapping reports are given separately in file ref. No.: GCLI/2/A2/54-9.

Other landslide sources in the study area not selected for detailed mapping were inspected through reconnaissance field inspection, which comprised a walkover survey and preliminary inspection. Details are given separately in file ref. No.: GCLI/2/A2/54-9. A summary of the characteristics of all the landslides inspected within the study area is presented in Table 3.

5.2 Landslide No. L3 in Catchment No. 24

The crown of landslide source No. L3 is situated at 226 mPD near the head of an ephemeral drainage line within a broad concave depression in catchment No. 24 (Figure 2, Plates 6 and 7). A longitudinal section through the landslide and the debris trail, together with the estimated volume of material entrainment and deposition is presented in Figure 7.

The landslide source area involved a displaced volume of about 150 m^3 of colluvium, which comprised angular to subrounded cobbles with much gravel and occasional boulders in a silty sandy matrix. The failure scar measured about 15 m wide, 15 m long and about 1 m deep. The surface of rupture was inclined between 35° and 50° and ran primarily along the interface between the colluvium and underlying moderately to slightly decomposed tuff (Plate 8). Soil pipes and voids were observed in the backscarp (Plate 9) at the colluvium/rock interface.

Landslide debris from the failure source area travelled as an avalanche over a steep rockface, inclined between 40° and 45°. Owing to a slight transverse dip of the rockface towards the east, the debris movement entrained about 230 m^3 of colluvial material locally from the eastern flank between chainage CH15 and CH94. The debris active volume increased to about 400 m^3 at CH94 before the debris entered into the drainage line (Plate 10) and developed into a CDF.

The debris flow path generally comprised a transport zone between CH94 and CH420 where erosion and entrainment predominated, and a deposition zone between CH420 and CH605 downhill where debris deposition was predominant (Figure 7).

In the transport zone, the drainage line was not particularly steep but relatively confined (compared to catchment No. 25). The gradient decreased from about 35° near the crest at CH94, where the drainage line traversed over exposed rock, to about 15° near the toe of the transport zone at CH420. The channelisation ratio[2] (CR) along the drainage line was typically about 6 - 7 indicating that the degree of channelisation was not particularly high (Plate 11). However, the debris was able maintain a relatively high velocity of about 10 m/s based on the superelevation data at CH250. Between CH94 and CH420 about 160 m^3 (about

[2] Channelisation ratio is defined as the width to depth ratio of the cross section area in a channel occupied by a pulse of landslide debris (Ng et al, 2002).

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

0.5 m^3/m) of material were entrained and 90 m^3 of material were deposited, resulting in a maximum active volume about 450 m^3 near the toe of the transport zone. Debris levees were observed along the side of the debris trails at CH240 and CH343, which contained large boulders of up to 2 m diameter (Plate 12).

Further downstream from CH420 is the deposition zone, where the drainage line becomes increasingly broader with a gradient generally less than 15°. About 150 m^3 of debris were deposited along the southern side of the drainage line between CH550 and CH605 (Plate 13). Another 255 m^3 travelled downstream beyond the outlet of the drainage line and over the top of the adjoining slope No. 9SE-B/C52, reaching the safety barrier alongside Yu Tung Road below (Plate 14). The debris deposited behind the safety barrier contained large boulders up to about 1 m in diameter. It is apparent that the debris travelled over the slope at a low velocity, as evidenced by an absence of signs of significant impact on the safety barrier.

Subsequent flow of surface water caused further erosion of the debris deposits and washed out about 50 m^3 of fines onto Yu Tung Road (Plate 15). Some outwash debris continued along Yu Tung Road, and reached the Tung Chung Eastern Interchange some 300 m away as well as part of the Cheung Tung Road below. This resulted in severe flooding along the affected road sections (Plates 3 and 16).

5.3 Landslides Nos. L1 and L2 in Catchment No. 25

The crown of landslide sources No. L1 and No. L2 are situated at an elevation of about 340 mPD and 296 mPD respectively (Figure 2, Plates 1 and 17). A longitudinal section through the landslide and the debris trail, together with the estimated volume of material entrainment and deposition is presented in Figure 8.

The landslide sources Nos. L1 and L2 involved displaced volumes of about 75 m^3 and 60 m^3 respectively. The failed material comprised mainly colluvium, with angular to subrounded cobbles and much gravel and occasional boulders in a silty sandy matrix. The failure scar at landslide No. L1 measured about 8.7 m wide by 11 m long with a maximum depth of about 1.5 m. The scar at landslide No. L2 measured about 8 m wide by 13 m long with a maximum depth of about 1.2 m. The rupture surfaces were inclined at about 30° to 40° and ran primarily along the interface between the colluvium and underlying moderately to slightly decomposed tuff. Soil pipes and voids were observed in the backscarps at the colluvium/rock interfaces.

Landslide debris from the two sources probably failed as translational slides initially before breaking up and travelling as debris avalanches over steep rockfaces, inclined at about 40° to 50°. The debris trails then confluenced at an elevation of about 246 mPD (Plates 17 and 18). Evidence from field mapping suggested that the landslide at source No. L1 might have occurred before L2 (Plate 19), since the deposited debris and flattened vegetation across the mouth of the landslide No. L1 tributary was likely caused by the subsequent passage of debris from landslide No. L2. For the purposes of estimating the maximum active volume of the CDF, the failures at landslides Nos. L1 and L2 were assumed to have occurred simultaneously.

There was a minor local entrainment of about 35 m^3 at the base of the landslide sources. In addition, just above the confluence point of the debris trails, the northern side slope at the

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

landslide No. L2 tributary failed and released about 290 m³ of debris (Plate 20). The side slope may have failed as a result of impact or undermining action from the debris arising from landslide source No. L2. The slight transverse dip in the rocky stream bed might have directed the passage of debris towards the side slope causing direct impact or undermining of the colluvial material, and resulting in the failure (Plate 20). This gave rise to a total active volume of about 460 m³ at the confluence point. The debris then entered into the drainage line at CH176 and developed into a CDF.

The debris flow path below the confluence point generally comprised a transport zone between CH176 and about CH414 (Figure 8), with a deposition zone further downhill between CH414 and CH562. Near the crest of the transport zone at CH176, the drainage line is relatively steep with a gradient of about 50° where it traverses over exposed rock. The gradient then reduces rapidly to about 15° (Figure 8). The drainage channel is relatively open with a channelisation ratio over 8. About 100 m³ (0.45 m³/m) of material were entrained in the transport zone, increasing the active volume of the CDF to the maximum (about 560 m³) near the toe of the transport zone. At CH414, a concave break-in-slope marks the transition between the upper transport zone and the lower deposition zone. Below CH414, the drainage line becomes increasingly broader and gentler with a gradient generally less than 15° in the deposition zone.

Field evidence indicates a "transition zone" from a debris flow to outwash action exists between CH414 and CH562. About 490 m^3 of debris were deposited as an elongated body along the northern side of the drainage line between CH414 and CH562 (Plate 21), though some several sizable boulders (up to 1.5 m in diameter) and wood debris could still be observed on the surface of the debris deposit that were clast and matrix supported, comprising gravel, cobbles and boulders in a silty sandy matrix. This marked the end of the main debris lobe. However, some parts of the deposits also contained "sorted" boulders with sizes decreasing toward CH562, as result of outwash action.

Beyond CH562, the drainage line virtually disappears and the outwash action appeared to be predominant, and the deposits comprised mainly outwash materials containing cobbles and gravel. At CH562, some 50 m^3 of debris bifurcated to travel along a minor ephemeral drainage line towards catchment No. 24 (Plate 22). The outwash action also pushed forwards some 200 m^3 of debris along the direction of the main pulse (i.e. the water flow action) and carried a small volume (less than 5 m^3) of material down to the footpath at the toe of the catchment (Plate 23).

5.4 <u>Landslide No. L25 in Catchment No. 30</u>

The crown of landslide source area No. L25 is situated at 202 mPD on the southwest-facing flank of a drainage line below a rock outcrop in catchment No. 30 (Figure 2, Plates 24 to 28). A longitudinal section through the landslide and debris trail, together with the estimated volume of material entrainment and deposition is presented in Figure 9. The lower portion of the CDF was captured on video by a member of the public and uploaded to the "You Tube" although the exact time of failure could not be determined from the video.

Based on the post-landslide topographic survey, the landslide source involved a displaced volume of about 2,350 m³ of bouldery colluvium/talluvium (a matrix supported

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

boulder rich colluvium, Plates 29 and 30), which comprised subangular to subrounded cobbles with many gravels and occasional boulders in a silty/clayey sandy matrix. The failure scar measured about 32 m by 50 m long with a maximum thickness of about 3 m. The gradient of the rupture surface varies between 35° and 50° at the backscarp and down to about 30° near the toe. Part of the rupture surface appears to have been through the upper portion of the underlying completely and highly decomposed fine ash tuff. A planar adversely orientated joint surface (30/258) in moderately decomposed tuff was exposed in the base of the landslide near the northeastern portion of the landslide source area (Plate 31). Landslide debris from the source travelled over a short section of open hillside into the drainage line below at about CH65 and developed into a CDF.

The debris flow path generally comprised a transport zone between about CH65 and CH510, with a deposition zone between CH510 and CH625. Based on the super-elevation data measured (Hungr et al, 1984) the velocity of the debris was estimated to be about 12 m/s at CH100. The drainage line in the transport zone is sinuous, deeply incised and moderately steep with a gradient of about 30° at CH90, decreasing to about 15° at CH340. Debris filled the narrow channel near the crest of the transport zone with an average entrainment rate of about 3.5 m^3/m and a high degree of channelisation with a CR of about 3 to 4. The side slopes of the drainage line were scoured but the depth of erosion from the flanks was typically less than 200 mm. The active volume of the CDF through material entrainment increased to about 3,350 m^3 by CH340. It is apparent that most of the perched materials in the drainage line were entrained with few boulders remaining in the drainage line after the passage of the debris flow.

Between CH340 and CH510 at the lower part of the transport zone, the drainage line becomes less channelised (Plate 32). The gradient decreased to less than 15° with intermittent rock steps in the channel but the debris was still travelling at a high speed with limited deposition taking place. Field evidence suggested that there was little change in the active volume along this part of the drainage line, with a maximum active volume of about 3,400 m^3 by CH510. Measured super-elevation (Plate 35) and the "You Tube" video gave consistent velocity of about 10 m/s at CH439 near the base of the transport zone.

In the deposition zone (CH510 to CH625), the drainage line gradient decreased further to about 12° and opened out, where significant debris deposition occurred along the flanks of the drainage line (Plates 33 and 34). Estimation based on both super-elevation data and the "You Tube" video show that the debris was still travelling at a high velocity of about 10 m/s at around this location. The video also indicated that the main pulse of debris continued at a high velocity towards the crest of the cut slope No. 9SE-B/C27 at the drainage outlet adjacent to Yu Tung Road. This resulted in a large proportion of debris (about 3,100 m^3) including many large boulders discharging at a high velocity over slope No. 9SE-B/C27 at CH550, toppling and ripping trees from the surface of the cut slope (Plate 36). All 3,100 m^3 of debris finally deposited on the two westbound lanes of Yu Tung Road, at an elevation of about 17 mPD (Plate 37). Some debris also reached the eastbound lanes of Yu Tung Road at CH625 (Plates 37 and 38). The debris contained a significant proportion of boulders (possibly up to 40% boulder content), and some up to 2.5 m in size (Plate 39). Boulder impact during the CDF severely damaged the concrete drainage channel at the western side of slope No. 9SE-B/C27 (Plates 40 and 41).

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

6. EMERGENCY REMEDIAL WORKS IN CATCHMENTS NOS. 24 AND 30

Following the clearance of the debris from Yu Tung Road, temporary barriers were erected directly above the crest of slope No. 9SE-B/C52 in catchment No. 24 (Plate 42) and on one of the westbound carriageways at the toe of slope No. 9SE-B/C27 below catchment No. 30 (Plate 43), as the emergency works. Short-term remedial works comprising installation of soil nails at 2 m centres were carried out at the landslide source areas in catchment No. 30. Both westbound lanes of Yu Tung Road were closed for 2 months following the incident.

7. PREVIOUS STUDIES

7.1 General

The hillside within the study area had previously been studied under three occasions. In 2005, a Natural Terrain Hazard Study (NTHS) was conducted to assess the hillsides above North Lantau Highway and Yu Tung Road (OAP, 2005). In 2006, another NTHS was carried out for catchments Nos. 29 and 30 for the proposed Tung Chung Hospital (MGSL, 2006). Lastly, the natural terrain landslide hazards identified in the earlier NTHS (OAP, 2005) were reviewed in 2008 for the design of the mitigation works at North Lantau Highway and Yu Tung Road (MGSL, 2008). A summary of the key findings from the three NTHS are presented in the following sections. In addition, a study was carried out in 1996 with an aim to document the landslides triggered by the November 1993 rainstorm. The findings are given in GEO Report No. 57 (Franks, 1998).

7.2 Natural Terrain Hazard Study in 2005

A NTHS at North Lantau Highway was carried out by Ove Arup & Partners Hong Kong Ltd. in 2005 (OAP, 2005), covering the study area under this investigation. Both Quantitative Risk Assessment (QRA) and Design Event approaches were adopted to assess the natural terrain hazards associated with CDF events. The study concluded that based on aerial photograph interpretation and field verification, the worst credible event (Ng et al, 2002) with a source volume of 2,600 m³ be adopted for the whole study area (i.e. both North Lantau Highway and Yu Tung Road). With this, a hypothetical CDF was stimulated using the mass balance approach for each catchment. The results showed that an active debris volume of 1,660 m³, 185 m³ and 747 m³ would reach Yu Tung Road for CDFs occurring at catchments Nos. 26, 29 and 30 respectively (Table 1). For the other catchments, the results indicated that the landslide debris would unlikely reach Yu Tung Road.

7.3 Preliminary Natural Terrain Hazard Study for the Proposed North Lantau Hospital at Tung Chung in 2006

Maunsell Geotechnical Services Ltd. (MGSL) carried out a preliminary NTHS in 2006 for a proposed North Lantau Hospital, which was tentatively to be located at the toe of catchments Nos. 29 and 30. The study recommended that, based on the results of the 2005 NTHS (OAP, 2005), a flexible debris barrier together with concrete baffles and a gabion check dam should be erected at the outlet of catchment No. 30 and 29 respectively.

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

7.4 Natural Terrain Hazard Mitigation Works at North Lantau Highway and Yu Tung Road near Tung Chung Eastern Interchange in 2007

In August 2007, MGSL was appointed to carry out a Design and Construction Assignment for the Natural Terrain Hazard Mitigation Works at North Lantau Highway and Yu Tung Road near Tung Chung Eastern Interchange (MGSL, 2008). The study included a review of the previous 2005 NTHS (OAP, 2005) and carrying out the design of hazard mitigation measures for each catchment.

After reviewing the previous 2005 NTHS, the design event of 2,600 m^3 (worst credible event) for the whole hillside was generally adopted. Dynamic mobility modelling, in contrast to the mass balance approach adopted in the 2005 NTHS, was then carried out based on the design event using GEO's DMM program (GEO, 2004) as well as MGSL's DEBRIFLO program (Sun et al, 2005). The Voellmy rheological model (Lo, 2000) and typical debris parameters (Table 2) were adopted. The results indicated that debris from catchments Nos. 26, 29 and 30, where the drainage lines appeared to be more confined and deeply incised with a CR $\leq$ 4, would likely reach the toe of the catchments. Debris barriers with designed retention capacities of 250 m^3, 1,200 m^3 and 250 m^3 were subsequently proposed at the toe of catchments Nos. 26, 29 and 30 respectively (Table 1). It is noted that no CDF occurred in catchments Nos. 26 and 29 during the 7 June 2008 rainstorm.

After the 7 June 2008 landslides, a review of the previously proposed mitigation measures was carried out in light of the new information provided by the June 2008 events. The design retention capacities of the debris barriers for catchments Nos. 24, 25, 26, 29 and 30 were subsequently revised and details are given in Table 1.

7.5 Previous Ground Investigation

No ground investigation (GI) was carried out as part of this study. However, records of previous GI carried out within and in the vicinity of the study area in 1978, 1982, 1991 and 2002 were collated and reviewed. Most of the previous GI were located at the toe of the study area (Figure 10) and a summary is shown in Appendix C. The findings have been used to develop the geological model as detailed in Section 8 below.

8. GEOLOGICAL AND GEOMORPHOLOGICAL MODEL

The solid geology of the study area comprises a complex sequence of porphyritic rhyolitic lavas and rhyolitic fine ash crystal tuffs (Sewell et al, 2000 & 2002). The drainage lines in the study area trend parallel to sub-parallel to the alignment of the regional fault, as shown in the Regional Fault Plan (Figure 3). This indicates that the orientation of the drainage lines may be fault related.

The upper portion of the study area is located above prominent concave breaks-in-slope and is relatively steep with a slope angle exceeding 40° (Figure 11), and coincides with large areas of rock exposure. The nature of the rock at this location appears less jointed than typical volcanic rocks. As a result, bouldery deposits (with boulders over 2 m in size) are present on the steep rocky hillside. The steep volcanic terrain with prominent breaks-in-

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

slope is generally more susceptible to landslides than the predominantly granitic terrain present to the east above North Lantau Highway (AECOM, 2010).

The lower portion of the hillside is characterised by an open hillside landform. Debris fans from older and younger phases of landslide events present at the outlets of a number of drainage lines that extend to the pre-reclamation shoreline (Section 4.3.3 and Appendix A). The older and more widespread debris fans are evident across the lower reaches of catchments Nos. 24 to 26 and 30. Relatively younger debris fans are also evident at the outlets of catchments Nos. 26, 29 and 30 which may indicate potentially problematic drainage lines with respect to debris flow events. Possible layering of the debris fan deposits, indicating several landslide events, was observed during field mapping in areas along the flanks of drainage lines. The same was also observed in the trial pits done for the previous NTHS (OAP, 2005).

Colluvial layers typically 1 m to 2 m thick are present on the upper parts of the hillside, although some layers could be up to 4 m thick. The thickness of the colluvium generally increases towards the toe of the hillside. Previous ground investigation indicated that up to 16 m of colluvium was encountered on the lower portion of the hillside in catchments Nos. 24 and 25 (Table C1).

9. ANALYSIS OF RAINFALL RECORDS

Rainfall data were obtained from the nearest GEO automatic raingauge No. N17, located at about 1.3 km west of the study area. The raingauge records and transmits rainfall data at 5-minute intervals to the GEO and the Hong Kong Observatory (HKO). Rainfall data from another local raingauge, which was installed under Agreement No. CE 4/2005 (GE), located near the boundary of catchments Nos. 19 and 20 at about 90 mPD (referred as NLH raingauge hereinafter), is also reviewed.

Based on records provided by the Police, landslide No. L25 in Catchment No. 30 likely occurred at around 9:00 a.m. on 7 June 2008 when the Black Rainstorm Warning was in force. The other landslides in the study area were therefore assumed to have occurred at about the same time for the purpose of rainfall analysis. The daily rainfall recorded by raingauges Nos. N17 and the NLH raingauge over the month preceding the 7 June 2008 rainstorm, together with the hourly rainfall readings for the period between 5 and 7 June 2008, are presented in Figures 12 and 13.

The rainstorm started at about 8:00 a.m. on 6 June 2008 and continued until noon on 7 June 2008. The intensity of rainfall recorded in both raingauges during 7 June 2008 was similar. During the period between 6 and 23 May 2008, raingauge No. N17 was not in operation. A review of a nearby raingauge No. 21 located about 1.6 km east from raingauge No. N17 revealed that only about 100 mm rainfall was recorded throughout this 15-day period. The missing data in raingauge No. N17 within this period were taken to be the same as those from the nearby raingauge No. 21.

The maximum 1-hour rolling rainfall recorded preceding the landslide at raingauges Nos. N17 and the NLH raingauge was 140.5 mm and 133 mm respectively (Tables 4 and 5). An analysis of the return periods for various durations of rolling rainfall recorded by raingauge Nos. N17 and the NLH raingauge has been carried out, with reference made to

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

historical rainfall data at the HKO in Tsim Sha Tsui where records began in 1884 (Lam & Leung, 1994). The results show that a rainfall duration of 4 hours was the most severe at raingauge No. N17 and the NLH raingauge, with a corresponding return period of about 570 years and 246 years respectively (Tables 4 and 5).

The maximum rolling rainfall for the 7 June 2008 rainstorm has been compared with previous major rainstorms recorded by raingauge No. N17, which came into operation in April 1991 (Figure 14). The 7 June 2008 rainstorm is more severe than the previous major rainstorms for rainfall durations between 1 hour and 4 hours.

10. DEBRIS MOBILITY

10.1 General

Assessment has been made on the mobility of the three CDFs in catchments Nos. 24, 25 and 30, as shown below.

10.2 Travel Angle and Distance

Debris from landslide source No. L25 in catchment No. 30 developed into a CDF and travelled a total horizontal distance of about 600 m, with about 300 m in the downhill area where the overall gradient was 15° or less. The travel angle[3] of the CDF was about 17°. The debris mobility is classified as "Zone 7" (Figure 16) based on the classification system of Wong (2006). The CDF in catchment No. 30, with a maximum active volume of 3,400 m^3, was highly mobile compared with previous events of similar scale in Hong Kong (Figure 17).

Debris from landslide source No. L3 in catchment No. 24 developed into a CDF and travelled a total horizontal distance of about 550 m, with about 190 m in the downhill area where the overall gradient was 15° or less. The travel angle of the CDF was about 22°. The debris mobility is classified as "Zone 6" (Figure 16). The CDF in catchment No. 24, with a maximum active volume of 450 m^3, was fairly mobile compared with previous events of similar scale in Hong Kong (Figure 17).

Debris from landslide sources in catchment No. 25 developed into a CDF, and travelled a total horizontal distance of about 450 m, with about 150 m in the downhill area where the overall gradient was 15° or less. The travel angle of the CDF was about 29°. The debris mobility is classified as "Zone 5" (Figure 16). The CDF in catchment No. 25, with a maximum active volume of 560 m^3, was not particularly mobile compared with previous events of similar scale in Hong Kong (Figure 17).

For comparison, the 1993 channelised debris flow (2,300 m^3) from catchment No. 29 travelled a total horizontal distance of about 450 m with about 120 m in the downhill area where the overall gradient was 15° or less. The travel angle of the channelised debris flow was about 18° (Figures 16 and 17).

---

[3] Travel angle is the angle of a line connecting the head of the landslide source to the distal end of the displaced mass (Cruden & Varnes, 1996).

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

In summary, the June 2008 CDF in catchment No. 30 was more mobile than the other two that occurred in the nearby catchments Nos. 24 and 25. The mobility of the CDF in catchment No. 30 also exceeded that of the 1993 channelised debris flow event in the adjoining catchment No. 29. Factors including the drainage line morphology and catchment size that may contribute to the debris mobility and runout distance are discussed further in Section 12.2.

10.3 Theoretical Modelling of Debris Runout

Dynamic mobility modelling was carried out using AECOM's Debriflo program (Sun et al, 2005), under the NTHS carried out by MGSL (2008). A summary of the key findings and observations from the debris mobility modelling is given below.

Back analysis of the CDF in catchment No. 30 was carried out based on the results of detailed field mapping (e.g. measured debris heights, mass balance and super-elevation data) and the "You Tube" video to ascertain the velocity of the main pulse. The model successfully simulated the CDF. The results indicated that the landslide was particularly mobile, with a low apparent angle of friction (ϕ_a) of about 6° and a turbulence coefficient (ζ) of about 300 ms^{-2} for the debris (Table 2). The two parameters are comparable with those derived from the back analyses of the 1993 channelised debris flow (Ayotte & Hungr, 1998) at catchment No. 29.

However, the model failed to simulate the June 2008 CDF in catchment No. 24. The results from mobility modelling indicated that the debris in catchment No. 24 would have stopped at CH600, some 25 m before reaching Yu Tung Road, using the debris mobility parameters back-analysed from the June 2008 CDF in catchment No. 30. This suggests that ϕ_a in catchment No. 24 may have been lower, or that the debris may have been remobilised by subsequent pulses and pushed downstream. Field observations indicate that a portion of the debris, mainly comprising large boulders (Plate 14), continued to travel over the cut slope at CH625, though at a fairly low velocity (Section 5.2).

As for the CDF in catchment No. 25, the model successfully simulated the June 2008 event with the debris stopping at the mid-portion of the hillside, using ϕ_a of around 11° and ζ of about 500 ms^{-2} for the debris. This was in-line with the findings discussed in Section 10.2 above, where the CDF in catchment No. 25 exhibited a relatively low mobility compared to that in catchments Nos. 24 and 30.

11. DIAGNONSIS OF THE PROBABLE CAUSES OF THE LANDLSIDES

The 7 June 2008 landslides that occurred on the hillside above Yu Tung Road involved typically the top 2 to 3 m of surface mantle of colluvium/talluvium on steeply inclined hillside. The shallow nature of the 7 June 2008 landslides and close correlation between the landslides and preceding intense heavy rainstorm (Section 9) suggests that the failures were probably triggered by intense rainfall as a result of slope saturation and transient build-up of water pressures due to infiltration and sub-surface flows as evidenced by the presence of soil pipes.

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

Several of the landslides, including those occurred in catchments Nos. 24, 25 and 30, were located at or close to the locations of past failures. As such, the possibility of reactivation or retrogression of previous failures could not be ruled out. In addition, the failure at the source area in catchment No. 30 may have been partly influenced by adversely orientated joints in the upper portion of the weathered rock underlying the colluvium.

12. DISCUSSION

12.1 Landslide Density

The 7 June 2008 rainstorm triggered 19 shallow landslides on the hillside catchments within the study area. The rainfall-landslide correlation in terms of the landslide density (number of landslides per km²) against the normalized 24-hour rolling rainfall derived by Ko (2003) is shown in Figure 15. The average landslide density for natural terrain landslides in Hong Kong is about 2, for a normalized maximum 24-hour rolling rainfall of 20% to 25%. The corresponding landslide density for the 7 June 2008 rainstorm is about 45 landslides per km², which is considerably higher than the average value presented by Ko (2003) but comparable to the landslide density of the 1993 rainstorm (Figure 15). The high landslide density within the study area may have been influenced by the high landslide susceptibility of the hillside in additional to the rainfall characteristics (Figure 14).

12.2 Debris Mobility

12.2.1 General

Past observations indicated that debris flows in an intense rainstorm could become more mobile and that high debris mobility could be related to increase in the volume of debris (Wong, 2009). Field observations from the CDFs above Yu Tung Road show that debris mobility may also be influenced by the drainage line characteristics and morphology, as well as the water content of the debris.

12.2.2 Drainage Line Characteristics and Morphology

The drainage line characteristics have contributed to the high mobility of the CDF in catchment No. 30. The upper portion of the drainage line is relatively steep at about 30° and deeply incised with a CR of about 3 to 4. This would have resulted in a high debris velocity as evidenced by the super-elevation data (Section 5.4). While the drainage line gradient decreased to less than 15° near the drainage line outlet, the channel remained sufficiently confined thus enabling the CDF to sustain a relatively high velocity, resulting in a long runout distance of 600 m.

In contrast to catchment No. 30, the drainage line in catchment No. 24 is generally more open, having a lower degree of channelisation with a typical CR of 6 -7. The debris was largely deposited at the distal end of the relatively older colluvial debris fan (Figures 4 and 6) where the channel opened out and the gradient decreased to about 15°. Parts of the channel in the depositional zone remain relatively confined. This may have enhanced the mobility of the debris, resulting in a deposition zone stretching over a distance of about 200 m.

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

Comparing the debris mobility with previous CDF events of similar scale (Figure 17), the CDF in catchment No. 24 is relatively mobile, with a long runout distance of about 550 m.

In catchment No. 25, the main body of the debris was deposited where the drainage line became more open with a CR over 8, and the gradient decreased to less than about 15°. The deposition zone corresponded to the head of an old colluvial debris fan and was therefore not a surprise. Comparing the debris mobility with previous CDF events of similar scale (Figure 17), the CDF in catchment No. 25 is not particularly mobile.

12.2.3 Water Content

The high mobility of the CDF in catchment No. 30 may be related to the increased water content of debris. The relatively large area of catchment No. 30 (about 100,000 m^2), compared with catchments Nos. 24 (32,000 m^2) and 25 (62,000 m^2), together with the presence of streamcourse tributaries, could have brought additional water into the main drainage line in catchment No. 30. This would increase significantly the bulked volume of the debris and its water content, turning the material into "watery" debris as observed in the "You Tube" video. Consequently the main pulse of the CDF in catchment No. 30 may have been able to maintain a high velocity up to and beyond the drainage outlet, where the debris was discharged over a 9 m high cut slope before landing on Yu Tung Road.

12.2.4 Implications

Results of the back-analysis show that the apparent frictional angle of the CDF in catchment No. 30 is about 6^{o} with ζ of around 300 m/s^2, which are lower than that ($\phi_a = 11^{o}$, $\zeta = 500$ m/s^2) recommended for the design of debris-resisting barrier in GEO Report No. 104 (Lo, 2000).

In addition, the local practice in the design of rigid or flexible barriers may not be very effective in retaining "watery" debris.

12.3 Scale of Debris Flow

12.3.1 General

Of the three CDFs examined, the one in catchment No. 30 attained the largest active volume of about 3,300 m^3, while that in catchments Nos. 24 and 25 were of medium-scale with an estimated maximum active volume of about 450 m^3 and 560 m^3 respectively. The scale of debris flows is influenced by a number of factors including the volume of the failure at source and the amount of entrainment.

12.3.2 Failure Source

The failures at source areas Nos. L1 and L2 in catchment No. 25, and source area No. L3 in catchment No. 24 were relatively small in scale, with a failure volume less than

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

150 m³. However, additional materials from the local entrainment that occurred immediately below the source area at L3 in catchment No. 24 would have increased considerably the active volume of the debris before the debris entered into the drainage lines and developed into CDF. Similarly in catchment No. 25, the debris active volume would have been increased significantly due to the additional materials released from the side-slope failure that occurred along the drainage line before the debris trails from sources Nos. L1 and L2 confluenced.

The failure at the source area of landslide No. L25 in catchment No. 30 was shallow but relatively spatially extensive. It occurred on a relatively steep portion of the hillside below a prominent rock outcrop, where a large area of boulderly deposits had accumulated probably as a result of a combination of landsliding activity, boulder fall and general mass wasting. The spatial extent of the failure at the source area appears to have been influenced by the presence of a concave break-in-slope within the accumulated deposits, marking the boundary between talus and talluvium (Figure 18). The rock outcrop above might have directed surface and subsurface water flow to the boulder deposits above and below the concave break-in-slope. While the permeability of the clast supported "talus" above the concave break-in-slope was large enough to dissipate the pore water pressure, the matrix supported talluvium could not. On the other hand, the talluvium was likely more permeable than the underlying insitu decomposed tuff. As a result of the permeability contrast, transient elevated water pressures possibly developed in the talluvium giving rise to the large scale failure.

12.3.3 Entrainment

The quantity of pre-existing "entrainable" material within the drainage line has a major bearing on the scale of a CDF event. Detailed field mapping of the landslides indicated that there was likely a limited amount of perched or entrainable material in the drainage lines in catchments Nos. 24 and 25, prior to the June 2008 event. In catchment No. 30, however, a significant amount of perched material was present in the drainage line prior to the June 2008 event, as observed in the 1963 aerial photographs (Figure A5) and field observations. Mapping results also indicate that the entrainment mainly involved the materials pre-existing on the drainage line. The extent of depletion into the existing side slopes and bed of the drainage line was limited, probably due to the dense nature of the colluvium present in the channel bed and side slopes. The nature of the colluvium also gives an indication of the maturity of the drainage line. In addition, the amount of pre-existing "entrainable" materials present in the drainage line is dynamic and may change significantly after a rainstorm.

12.4 Presence of Relatively Recent Debris Fans

Based on the review of aerial photographs, distinct older and younger colluvial debris fans can be identified with the relatively younger debris lobes at the outlets of catchments Nos. 26, 29 and 30.

The 1945 and 1963 aerial photographs show a distinct and relatively more recent debris fan at the outlet of the main drainage line in catchments Nos. 26, 29 and 30 (Figures 4, 6, A2 and A3), as evidenced by the hummocky surface and different vegetation type compared with other parts of the debris fan. The more recent debris fan in catchment No. 30 had possibly been formed as a result of a single large failure, with an estimated volume in the

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

order of about 3,000 m³, comparable with the scale of the June 2008 failure from the same catchment. Such a debris fan could be a "tell-tale" sign of a potentially "active" drainage line with respect to a CDF event. However, the debris fan does not provide any indication of the likely frequency of a significant CDF event, as evidenced by the fact that no CDF occurred in catchments Nos. 26 and 29 on 7 June 2008. Moreover, the identification of such debris fans in urban areas from aerial photographs may be difficult, as the debris deposits would likely have been removed or substantially disturbed by the developments prior to any aerial photograph records. Further, the presence of debris fans may be related to fluvial deposition instead of past failures.

12.5 Impact of Boulders and Secondary Outwash Action

The debris from catchments Nos. 24 and 30 appeared to contain a large proportion of boulders (Plates 14 and 39), with possibly up to 40% boulder content (some as large as 2.5 m in diameter) in catchment No. 30. The boulder impact had caused significant damage to the concrete drainage channel in catchment No. 30 (Plates 40 and 41). The implication of boulder impact to mitigation measures should not be overlooked.

Apart from the direct consequence-to-life of a CDF, the effect of secondary outwash due to continuous surface water flow after the passage of the main pulse of the CDF could result in severe erosion and washing out of fines from the debris deposits. The debris outwash from catchments Nos. 24 and 25 amounted to about 100 m³, which had contributed to flooding of Yu Tung Road and the adjoining Cheung Tung Road causing traffic disruption at Tung Chung Eastern Interchange of the North Lantau Highway.

12.6 Historical Landslide Catchments

The 7 June 2008 rainstorm triggered a large-scale CDF in catchment No. 30, resulting in closure of both westbound lanes of Yu Tung Road. However, based on the current definition of a HLC (Wong et al, 2006), this catchment does not satisfy the criteria before the June event despite the presence of numerous historical landslides. Therefore, it may be timely to identify new HLCs in the light of the data obtained from the June 2008 landslides.

13. CONCLUSION

The severe 7 June 2008 rainstorm triggered 19 landslides on the hillside above Yu Tung Road. The hillside had a high density of past landslides and was susceptive to failure.

Of the 19 landslides, the largest one occurred in catchment No. 30 with a failure volume of 2,350 m^3. The landslide was shallow but spatially extensive, which is uncommon for natural terrain landslides in Hong Kong. The failure involved a large area of bouldery deposits within a topographical depression. This may have influenced the extent of the landslide and be a potential geomorphological sign of possible large-scale landslide.

The CDFs in catchments Nos. 24 and 30 were very mobile. The back-analysed debris mobility parameters for catchment No. 30 were less than those recommended in GEO Report

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

No. 104. This implies that the existing guideline would have underestimated the debris mobility in catchment No. 30. The high debris mobility may be influenced by the volume of debris, drainage line characteristics and morphology, water content of the debris and rainfall characteristics. Also, the CDF in catchment No. 30 appeared to be more “watery” than those commonly observed in Hong Kong, probably due to the large catchment size and presence of tributaries.

Field observations from the CDF in catchment No. 30 indicated that the entrainment mainly involved loose materials previously perched on the drainage line. The depletion into the existing side slopes and beds of the drainage line was limited, probably due to the dense nature of the groundmass in the channel bed and side slopes. It is also noted that the amount of perched material present along a drainage line is dynamic and may change significantly after a rainstorm.

The large landslide in catchment No. 30 was not a surprise, given the presence of a relatively young debris fan (in the order of about 3,000 m^3) at the outlet of the drainage line as shown in the 1963 aerial photographs. However, the debris fan does not provide any indication of the likely frequency of a significant CDF event.

The CDFs from catchments Nos. 24 and 30 inundated the Yu Tung Road, resulting in closure of both westbound lanes for over two months. Subsequent outwash from the debris deposits in catchments Nos. 24, 25 and 30 brought further debris onto the road, contributing to the flooding and traffic disruption of the adjacent Cheung Tung Road. Therefore, the impact of a CDF together with the subsequent outwash action should be considered in a holistic manner in the design of the mitigation measures.

14. REFERENCES

AECOM (2010). Detailed Study of the 7 June 2008 Landslides on the Hillside above the North Highway Highway and Cheung Tung Road, North Lantau (LSR Report No. 7/2010). Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong, 113 p.

Ayotte, D. & Hungr, O. (1998). Runout Analysis of Debris Flows and Debris Avalanches in Hong Kong. Report prepared for the Geotechnical Engineering Office, Hong Kong, 90 p.

Cruden, D.N. & Varnes, D.J. (1996). Landslide Types and Processes. Landslides: Investigation and Mitigation (Ed. Turner, A.K. and Schuster, R.L.), Special Report 247 of the Transport Research Board, National Research Council, National Academy press, Washington D.C. Chapter 3, pp 36-75.

Ding, Y.Z. & Lai, K.W. (1997). Neotectonic fault activity in Hong Kong: evidence from seismic events and thermoluminescence dating of fault gouge. Journal of the Geological Society, vol. 154, pp 1001–1008.

Franks. C.A.M. (1998). Study of Rainfall Induced Landslides on Natural Slopes in the Vicinity of Tung Chung New Town, Lantau Island (GEO Report No. 57). Geotechnical Engineering Office, Hong Kong, 102 p.

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

Geotechnical Control Office (1988). Geotechnical Area Studies Programme - North Lantau, GASP Report No. VI. Geotechnical Control Office, Hong Kong, 124 p. plus 4 maps.

Geotechnical Engineering Office (1994). Tung Chung: Solid and Superficial Geology. 1:20,000 Series HGM20 Hong Kong Geological Survey Sheet 9. Geotechnical Engineering Office, Hong Kong.

Geotechnical Engineering Office (2004). User Manual for Computer Program "DMM" – Debris Mobility Model (Spreadsheet Version 1.0). Geotechnical Engineering Office, Hong Kong.

Hungr, O. (1998). Mobility of Landslide Debris in Hong Kong: Pilot Back Analyses Using a Numerical Model. Report prepared for the Geotechnical Engineering Office, Hong Kong, 50 p.

Hungr, O., Morgan, G.C. & Kellerhals, R. (1984). Quantitative analysis of debris torrent hazards for design of remedial measures. Canadian Geotechnical Journal, vol. 21, pp 663-677.

Iverson, R.M. (1997). The Physics of Debris Flows. Reviews of Geophysics, American Geophysical Union, vol 35, pt 3, pp 245-296.

King, J.P. (1996). The Tsing Shan Debris Flow. Special Project Report No. SPR 6/96. Geotechnical Engineering Office, Hong Kong, 3 volumes.

Ko, F.W.Y. (2003). Correlation between Rainfall and Natural Terrain Landslide Occurrence in Hong Kong (GEO Report No. 168). Geotechnical Engineering Office, Hong Kong, 77 p.

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

Langford, R.L., James, J.W.C., Shaw, R., Campbell, S.D.G., Kirk, P.A. & Sewell, R.J. (1995). Geology of Lantau District. Hong Kong Geological Survey Memoir No. 6, Geotechnical Engineering Office, Hong Kong, 173 p.

Lo, D.O.K. (2000). Review of Natural Terrain Landslide Debris-resisting Barrier Design (GEO Report No. 104). Geotechnical Engineering Office, Hong Kong, 91 p.

Maunsell Geotechnical Services Ltd. (2006). Preliminary Natural Terrain Hazard Study for Proposed North Lantau Hospital at Tung Chung. Report for Architectural Services Department, Hong Kong, 50 p.

Maunsell Geotechnical Services Ltd. (2008). Natural Terrain Hazard Mitigation Works at North Lantau Expressway and Yu Tung Road near Tung Chung Eastern Interchange – Design and Construction, Review Report. Report to Geotechnical Engineering Office, Civil Engineering and Development Department, Government of the Hong Kong SAR.

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

Ng, K.C., King, J.P., Franks, C.A.M. & Shaw, R. (2002). Guidelines for Natural Terrain Hazard Studies (GEO Report No. 138). Geotechnical Engineering Office, Hong Kong, 136 p.

Ove Arup & Partners Hong Kong Limited (2005). Natural Terrain Hazard Study at North Lantau Expressway - Final Report. Report Prepared for the Geotechnical Engineering Office, Hong Kong, 5 vols.

Scott Wilson (Hong Kong) Ltd. (1999). Specialist API Services for the Natural Terrain Landslide Study - Task B Final Report. Report to Geotechnical Engineering Office, Hong Kong, 9 p. plus 4 maps.

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

Sewell, R.J. & Kirk, P.A. (2002). Geology of Tung Chung and the Northshore Lantau Island. Hong Kong Geological Survey Sheet Report No. 6. Geotechnical Engineering Office, Hong Kong, 90 p.

Sun, H.W., Lam T.T.M. and Tsui, H.M. (2005). Design Basis for Standardized modules of Landslide Debris-Resisting Barriers (GEO Report No. 174). Geotechnical Engineering Office, Hong Kong, 161 p.

Tattersall, J.W., Devonald, D.M. & McDougall, S. (2009b). Modelling of debris flows for the North Lantau Expressway and Yu Tung Road Study Area. Proceedings of the 29th Annual Seminar, The Hong Kong Institution of Engineers, Geotechnical Division, pp 163-169.

Wong, H.N. (2005). Landslide risk assessment for individual facilities. Proceedings of the International Conference on Landslide Risk Management, Vancouver, Canada, pp 237-296.

Wong, H.N., Ko, F.W.Y. & Hui, T.H.H. (2006). Assessment of Landslide Risk of Natural Hillsides in Hong Kong (GEO Report No. 191). Geotechnical Engineering Office, Hong Kong, 117 p.

Wong, H.N., Lam, K.C. & Ho, K.K.S. (1998). Diagnostic Report on the November 1993 Natural Terrain Landslides on Lantau Island (GEO Report No. 69). Geotechnical Engineering Office, Hong Kong, 98 p.

Wong, H.N. (2009). Rising to the Challenges of Natural Terrain Landslides. Proceedings of the 29th Annual Seminar, The Hong Kong Institution of Engineers, Geotechnical Division, pp 15-53.

Woods, N.W. (1992). Engineering Geology of North Lantau: Tung Chung, Vol I & II. Special Project Report SPR 1/93, Geotechnical Engineering Office, Hong Kong, 94 p. plus 8 drgs.

Table of Contents
Table of Contents
Table of Contents

LIST OF TABLES

Table 1 - Previous Hazard Assessments and Design Events

Author of NTHS	Catchment (Design Source Volume)		Catchment (Design Barrier Retention Capacity)	
OAP in 2005	• C26 (2,600 m^3) • C29 (2,600 m^3) • C30 (2,600 m^3)	based on NTLI and API using both QRA and Design Event approaches	• C26 (1,660 m^3)* • C29 (185 m^3)* • C30 (747 m^3)*	Simulating the debris flow event using mass balance approach
MGSL in 2006 (for Tung Chung hospital)	Not reviewed, followed CE89/2002		Not reviewed, followed CE89/2002	
MGSL before 7 June 2008	2,600 m^3 in all catchments within the study area	based on CE89/2002, and counterchecked with ENTLI	• C26 (250 m^3) • C29 (1,200 m^3) • C30 (250 m^3) Nil in other catchments	Simulating the debris flow event with typical debris parameters given in Table 2 for the pre- 7 June 2008 parameters
MGSL after 7 June 2008	• C22 (611 m^3) • C23 (- m^3)⁺ • C24 (452 m^3) • C25 (729 m^3) • C26 (564 m^3) • C27 (388 m^3) • C28 (388 m^3) • C29 (653 m^3) • C30 (2,400 m^3)	based on a reassessment of design event using Magnitude, Cumulative Frequency analysis (Tattersall *et al* , 2009a)	• C22 (0 m^3) • C23 (- m^3) • C24&25 (820 m^3) • C26 (1,490 m^3) • C27 (0 m^3) • C28 (0 m^3) • C29 (806 m^3) • C30 (2,900 m^3)	Simulating the debris flow event with debris parameters obtained from back-analysis of the 7 June 2008 landslide event that occurred in catchment No. 30 (see Table 2 for the post- 7 June 2008 parameters)

Note : * Estimated active volume at site boundary

$^{+}$ Insufficient data to determine a design event for catchment No. C23

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

Table 2 – Parameters Adopted in Debris Mobility Modelling

	Landslide Type	Apparent Friction ϕ (deg)	Turbulence Coefficient ξ (m/s^2)
Typical Parameters adopted before 7 June 2008	Channelised debris flow in all catchments	11 - 15	500
Parameters adopted after 7 June 2008	Channelised debris flow in catchments Nos. 26 and 29 with incised (i.e. CR $\leq$ 4) channels	5-8	500
	Channelised debris flow in catchment No. 30 with incised (i.e. CR $\leq$ 4) channels	6	300
	Channelised debris flow in the other catchments	11	500

Note: Parameters are used with the Voellmy rheological model in debris mobility modelling.

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

Table 3 - Summary of Landslide Characteristics of the 7 June 2008 Landslides above Yu Tung Road (Sheet 1 of 2)

Landslide No.	Catchment No.	Crown Elevation (mPD)	Gradient (°)	Slope Aspect (°)	Length L (m)	Width W (m)	Depth D (m)	Source Volume V (m^3)	Runout [(1)] (m)	Travel Angle (°)	Landslide Type and Process [(2), (3)]	Remarks
L1	25	340	45-60	330	11	8.7	0.9, max 1.5	135	188	35-45	OHF → CDF	Detailed mapping report No. LS08-0213
L2	25	296	45-60	350	13	8	0.4, max 1		450	13-45	OHF → CDF → O Action	Detailed mapping report No. LS08-0243
L3	24	226	45-50	330	15	15	0.7, max 1.5	150	550	15-45	OHF → CDF	Detailed mapping report No. LS08-0214
L5	22	120.2	34	310	11	8	0.3	13	-	-	OHF	
L25	30	202	35	250-260	55	32.5	3, max 5.5	2,352	600	19	OHF → CDF	Detailed mapping report No. LS08-0241
L26	30	228	35	310	10	6	0.4, max 0.8	30	10	32	OHF	Some debris ran into drainage line below
L27	30	213	34	324	18.3	9.2	1.5	130	90	40	OHF	
L28	30	172	36	318	15	11.5	<1	90	18-19	~32	OHF	
L29	30	140	38	335	9	4	1.5	27	12	50	OHF	
L30	30	92	40	330	4	3.5	1	7	22	45	OHF	
L31	26	59	50	50	7	6.2	0.5	11	19.9	58	OHF	Flank of drainage line in Catchment No. 26
L32	24	192	30	275	12	10	0.6	36	-	-	OHF	No access through dense vegetation
L48	30	152	30	300	12	10.5	max 1	126	30		OHF	
L49	30	157-160	30-32	340	15	12.5	1.6	150	50	28	OHF	
L50a	29	181	60	295	4.5	3.5	0.6	4	-	-	OHF	Minor erosion of 1993 landslide

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

Table 3 - Summary of Landslide Characteristics of the 7 June 2008 Landslides above Yu Tung Road (Sheet 2 of 2)

Landslide No.	Catchment No.	Crown Elevation (mPD)	Gradient (°)	Slope Aspect (°)	Length L (m)	Width W (m)	Depth D (m)	Source Volume V (m^3)	Runout [1] (m)	Travel Angle (°)	Landslide Type and Process [2], [3]	Remarks
L50b	29	181	40	290	16.3	9.5	0.3-0.4	30	12	30	OHF	Minor retrogression of previous failure in 1993
L51	29	178	35-40	282	9.2	8.3	0.6, max 1.2	30	10	45	OHF	Minor retrogression of previous failure in 1993
L52	29	113	45	260	13	8	0.5, max 1	52	-	-	OHF	

Note: [1] Runout distance is the horizontal distance measured from the crown of a landslide to the distal end of the debris in the context of this report.

[2] Landslide Type and Process:

OHF - Open Hillside Failure

CDF - Channelised Debris Flow

O Action - Outwash Action

[3] Four landslides (i.e. L1-L3 and L25) developed into CDFs. The other landslides did not develop into CDFs primarily because the landslide source areas were located a long distance away from the main drainage line in the catchment (Figure 2 refers).

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

Table 4 - Maximum Rolling Rainfall at NLH Local Raingauge for Selected Durations Preceding the 7 June 2008 Landslides and the Estimated Return Periods

Duration	Maximum [(1)] Rolling Rainfall (mm)	End of Period	Estimated Return Period [(2)] (Years)
5 Minutes	-	-	-
15 Minutes	42	8:45 a.m. on 7 June 2008	22
1 Hour	133	9:00 a.m. on 7 June 2008	54
2 Hours	221	9:00 a.m. on 7 June 2008	150
4 Hours	324	9:00 a.m. on 7 June 2008	246
12 Hours	375	9:00 a.m. on 7 June 2008	38
24 Hours	481	9:00 a.m. on 7 June 2008	36
48 Hours	490	9:00 a.m. on 7 June 2008	17
4 Days	535	9:00 a.m. on 7 June 2008	11
7 Days	551	9:00 a.m. on 7 June 2008	8
15 Days	614	9:00 a.m. on 7 June 2008	4
31 Days	715	9:00 a.m. on 7 June 2008	3

Notes :

(1) Maximum rolling rainfall was calculated from 15-minute rainfall data.

(2) Return periods were derived from the statistical parameters extracted from Table 3 of Lam & Leung (1994).

(3) Historical rainfall records for Lantau Island do not cover sufficiently long period for calculating the return periods, return periods can only be estimated based on rainfall records of the HKO raingauge at Tsim Sha Tsui.

(4) According to the eyewitness ' s account, the landslide occurred between 8:45 a.m. to 9:00 a.m. on 7 June 2008. For the purpose of rainfall analysis, the landslide was assumed to have occurred at 9:00 a.m. on 7 June 2008.

(5) The local raingauge within the NLH study area was installed under Agreement No. CE 4/2005 (GE) which is situated near the boundary of catchments Nos. 19 and 20 at a level of about 90 mPD.

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

Table 5 - Maximum Rolling Rainfall at GEO Raingauge No. N17 for Selected Durations Preceding the 7 June 2008 Landslides and the Estimated Return Periods

Duration	Maximum [(1)] Rolling Rainfall (mm)	End of Period	Estimated Return Period [(2)] (Years)
5 Minutes	16.5	7:25 a.m. on 7 June 2008	7
15 Minutes	44.5	7:25 a.m. on 7 June 2008	34
1 Hour	141.0	8:15 a.m. on 7 June 2008	84
2 Hours	236.5	8:35 a.m. on 7 June 2008	269
4 Hours	357.5	8:40 a.m. on 7 June 2008	570
12 Hours	429.5	9:00 a.m. on 7 June 2008	90
24 Hours	571.5	9:00 a.m. on 7 June 2008	108
48 Hours	585.0	9:00 a.m. on 7 June 2008	45
4 Days	632.5	9:00 a.m. on 7 June 2008	26
7 Days	648.5	9:00 a.m. on 7 June 2008	17
15 Days	710.0	9:00 a.m. on 7 June 2008	8
31 Days	810.0	9:00 a.m. on 7 June 2008	4

Notes :
(1) Maximum rolling rainfall was calculated from 5-minute rainfall data.
(2) Return periods were derived from the statistical parameters extracted from Table 3 of Lam & Leung (1994).
(3) Historical rainfall records for Lantau Island do not cover sufficiently long period for calculating the return periods, return periods can only be estimated based on rainfall records of the HKO raingauge at Tsim Sha Tsui.
(4) Accorting to the eyewitness ' s account, the landslide occurred between 8:45 a.m. to 9:00 a.m. on 7 June 2008. For the purpose of rainfall analysis, the landslide was assumed to have occurred at 9:00 a.m. on 7 June 2008.
(5) The nearest GEO raingauge to the landslide site is raingauge No. N17 situated at about 1.3 km to the west of the landslide site. Raingauge No. N21 situated at about 2.4 km to the southwest of the landslide site.
(6) GEO raingauge No. N17 has no rainfall data recorded between 6 May and 23 May 2008. During this period, about 100 mm rainfall was recorded in nearby raingauges. For the purpose of this analysis, the missing rainfall data within this period with was inferred from raingauge No. N21.

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

LIST OF FIGURES

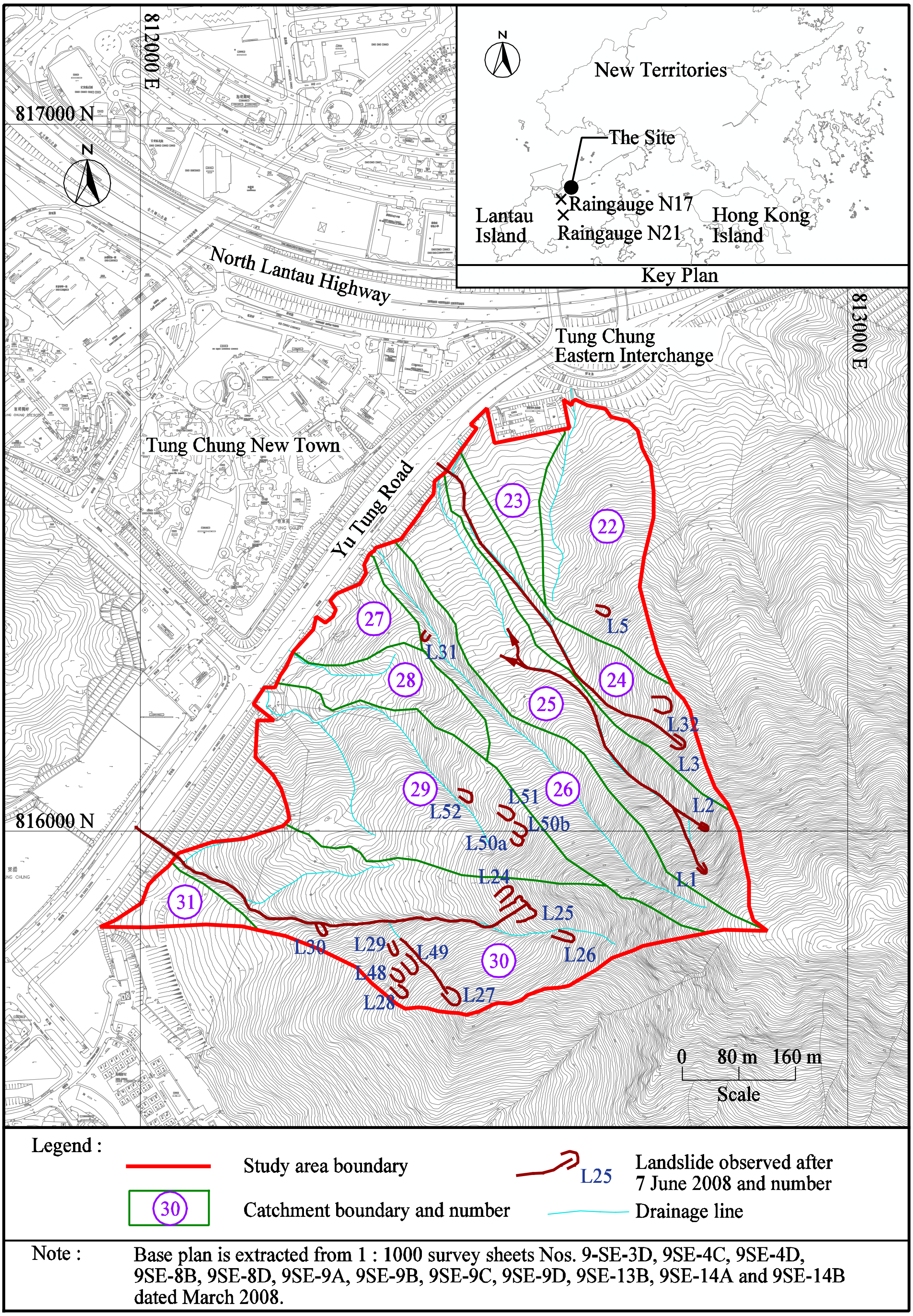
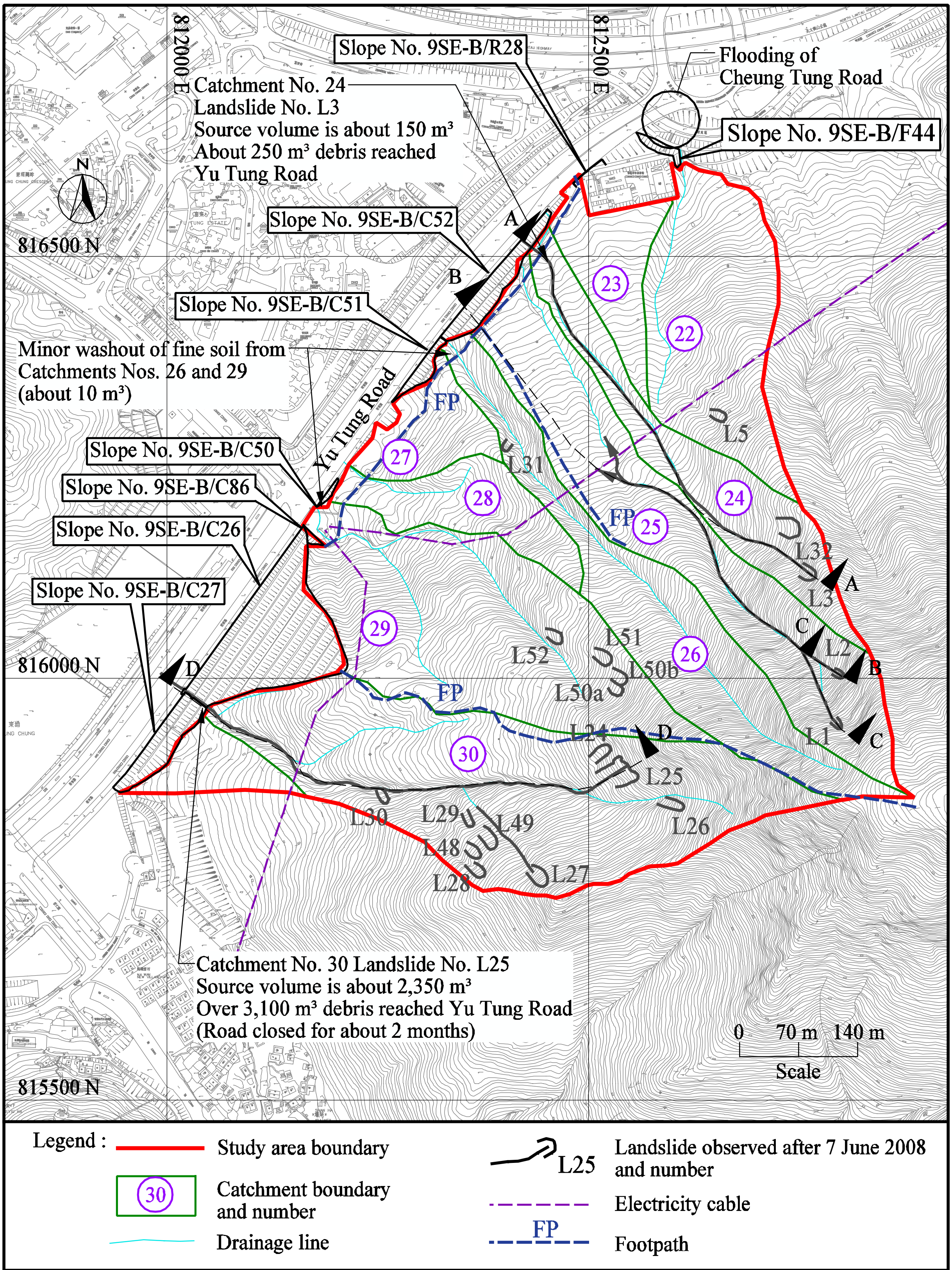


Figure 1 - Location Plan

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



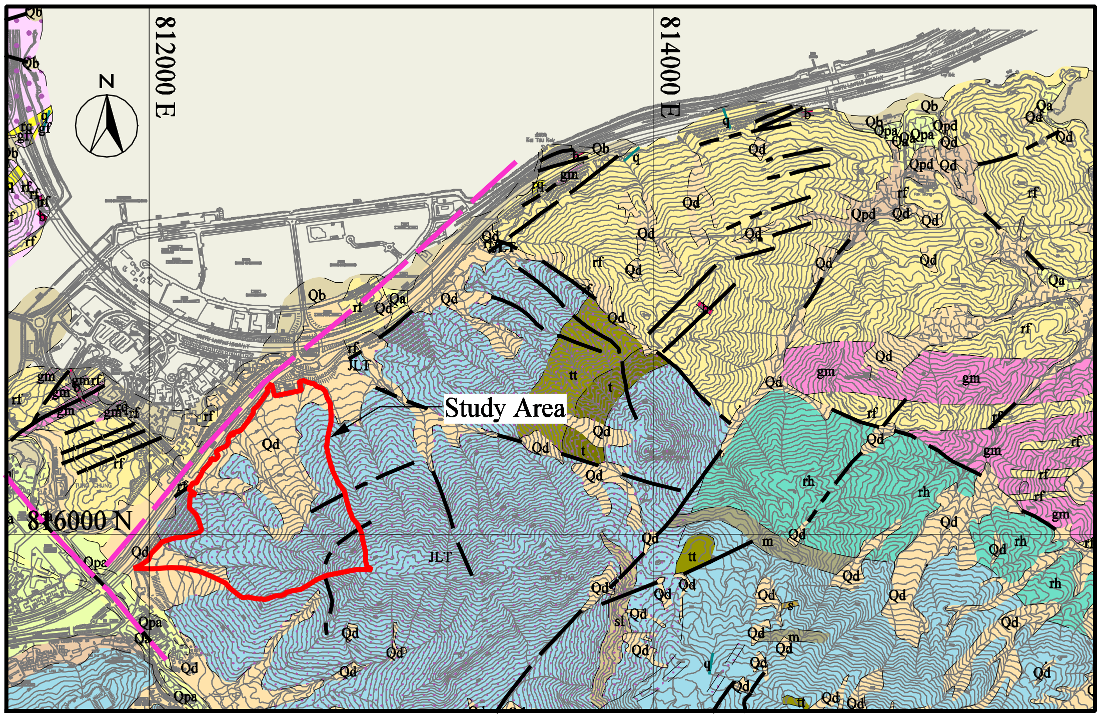
Notes :

(1) Base plan is extracted from 1 : 1000 survey sheets Nos. 9-SE-3D, 9SE-4C, 9SE-4D, 9SE-8B, 9SE-8D, 9SE-9A, 9SE-9B, 9SE-9C, 9SE-9D, 9SE-13B, 9SE-14A and 9SE-14B dated March 2008.

(2) See Figures Nos. 7, 8 and 9 for Sections A-A, B-B, C-C and D-D respectively.

Figure 2 - Site Layout Plan

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



Legend :

Superficial deposits

Qa	Alluvium	Clay/silt, sand and gravel; well-sorted to semi-sorted
Qd	Debris flow deposits	Unsorted sand, gravel, cobbles and boulders; clay/silt matrix
Qpa	Terraced alluvium	Clay/silt, gravelly sandy, well-sorted to semi-sorted
ms	Marine sand	Sand, part silty

0 300 m 600 m

Scale

Solid geology

JTL	Tuff and lava	gm	Medium-grained granite, 2 - 6 mm
rf	Feldsparphyric rhyolite	b	Basalt
tt	Tuff and tuffite	rq	Quartzphyric rhyolite
t	Crystal tuff		

Metamorphic Rocks

Metamorphosed

Geological lines

Photogeological lineament

Fault

Geological boundary, superficial deposits

Dyke to dyke contact

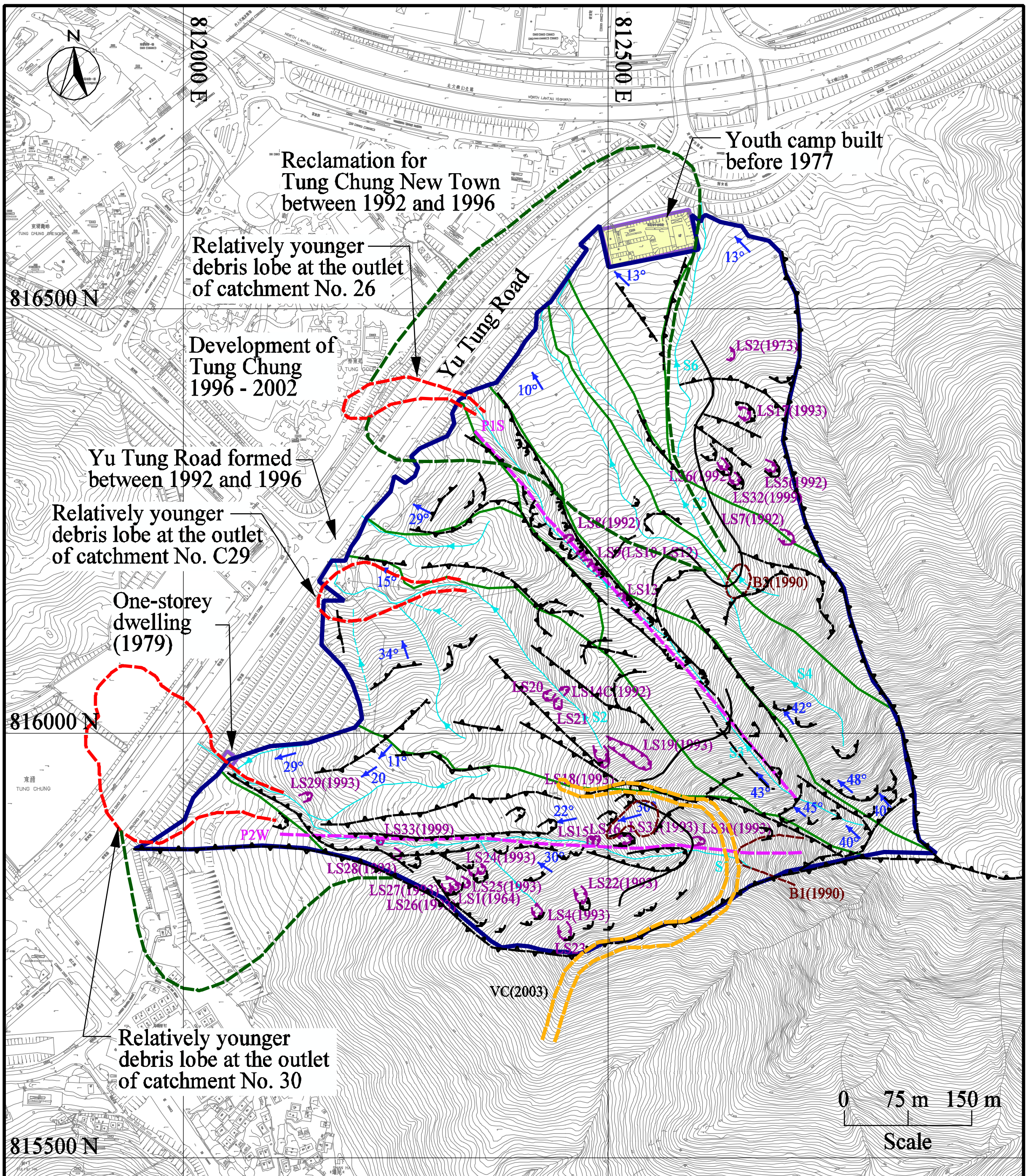
Inferred fault from the Regional Fault Plan (Sewell *et al.*, 2000)

Note : Extracted from Hong Kong Geolgical Survey, Map Series HGM 20, Sheet 9 and 10. 1:20 000 scale (GCO, 1994).

Figure 3 - Regional Geology

et al

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

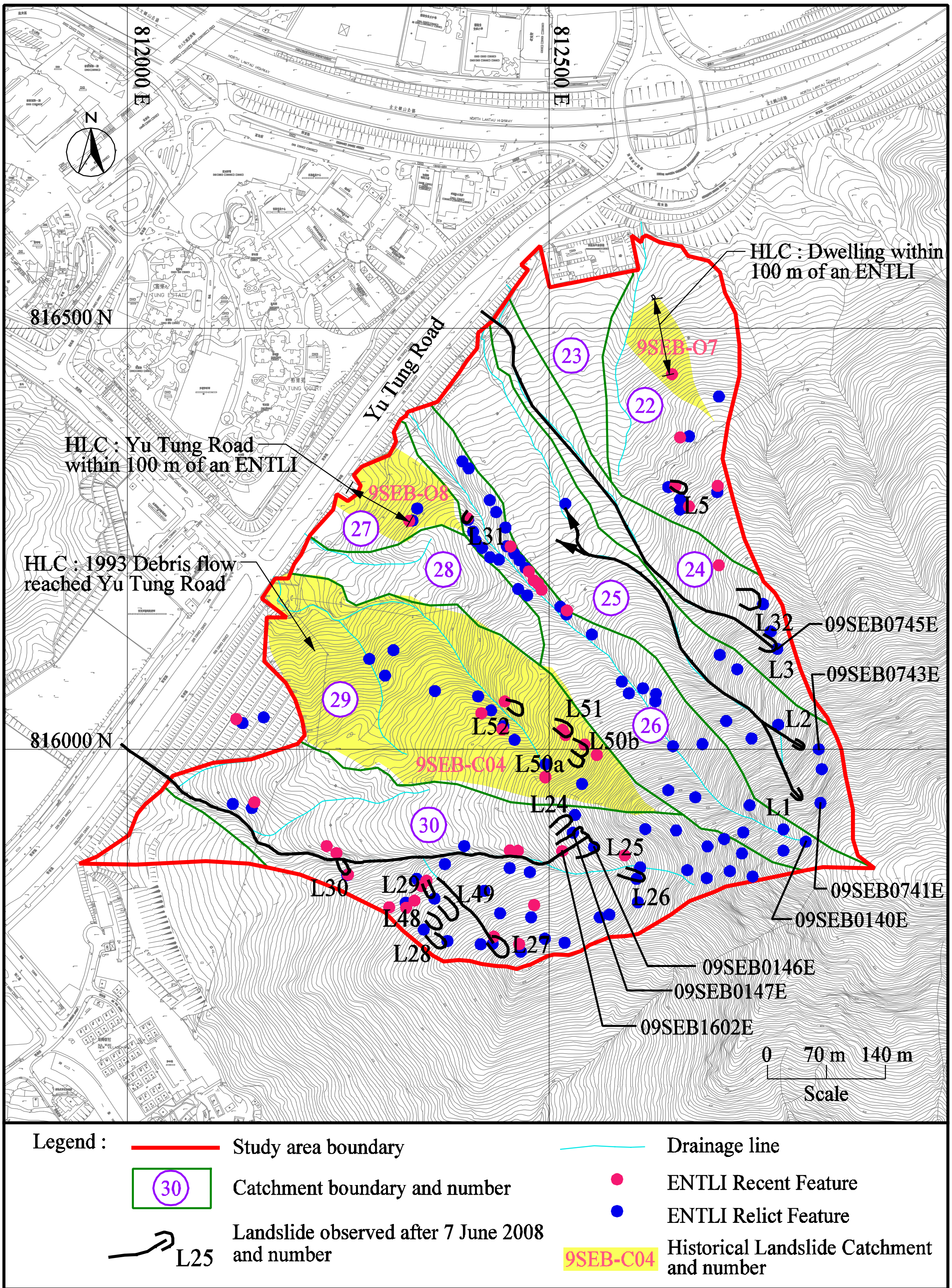


Legend :			
	Study area boundary	B2(1990)	Boulder field / corestones
	Catchment boundary		Convex break-in-slope
	Perennial drainage line	P2W	Photolineament
	Ephemeral drainage line		Concave break-in-slope
	Vegetation clearance		Relatively younger colluvial lobe
LS23	Recent landslide with number		Relatively older colluvial fan

Note : Base plan is extracted from 1 : 1000 survey sheets Nos. 9-SE-3D, 9SE-4C, 9SE-4D, 9SE-8B, 9SE-8D, 9SE-9A, 9SE-9B, 9SE-9C, 9SE-9D, 9SE-13B, 9SE-14A and 9SE-14B dated March 2008.

Figure 4 - Site History and Geomorphology

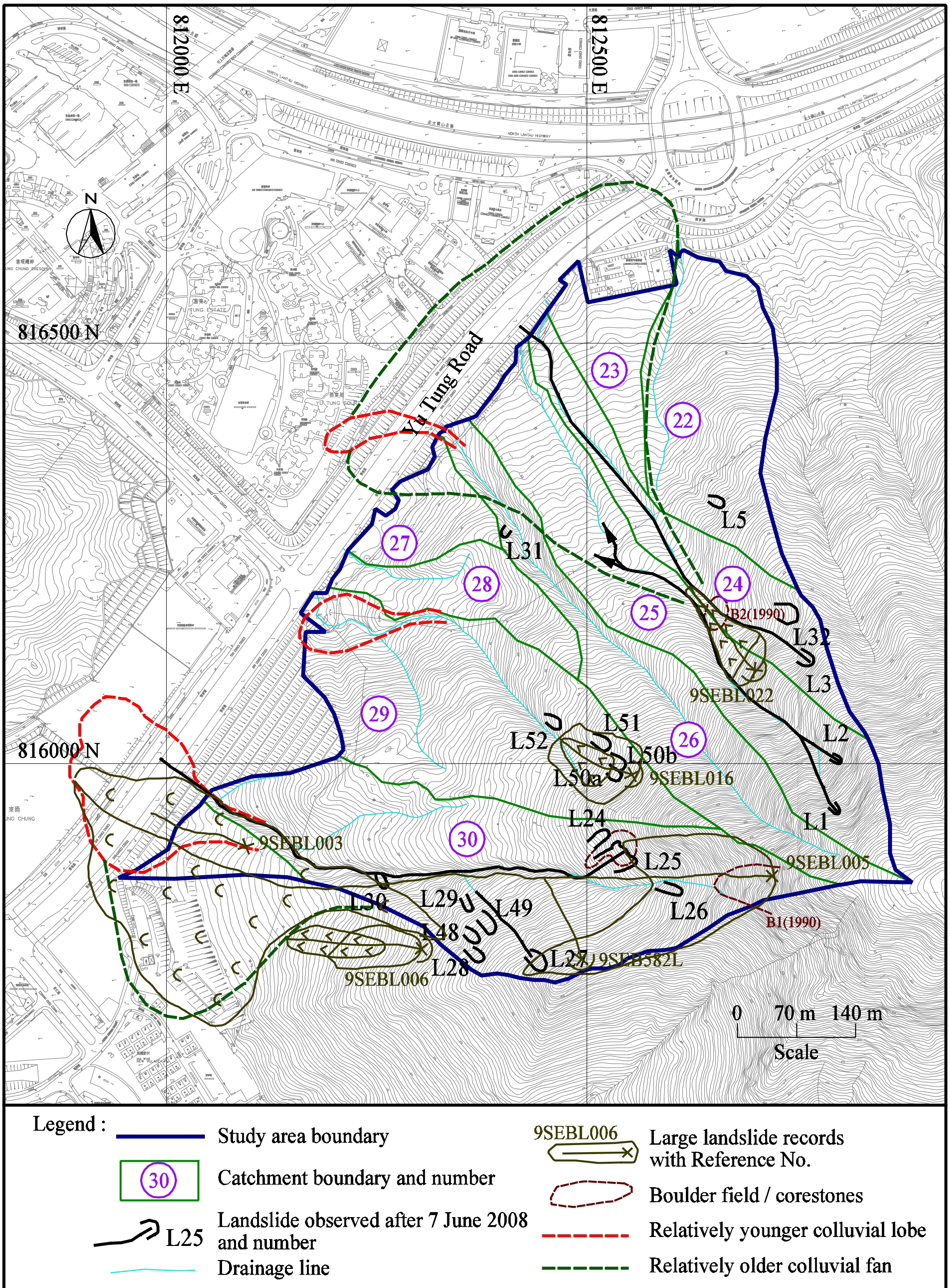
Table of Contents
Table of Contents
Table of Contents
Table of Contents



Note : Base plan is extracted from 1 : 1000 survey sheets Nos. 9-SE-3D, 9SE-4C, 9SE-4D, 9SE-8B, 9SE-8D, 9SE-9A, 9SE-9B, 9SE-9C, 9SE-9D, 9SE-13B, 9SE-14A and 9SE-14B dated March 2008.

Figure 5 - Past Instability and Historical Landslide Catchments

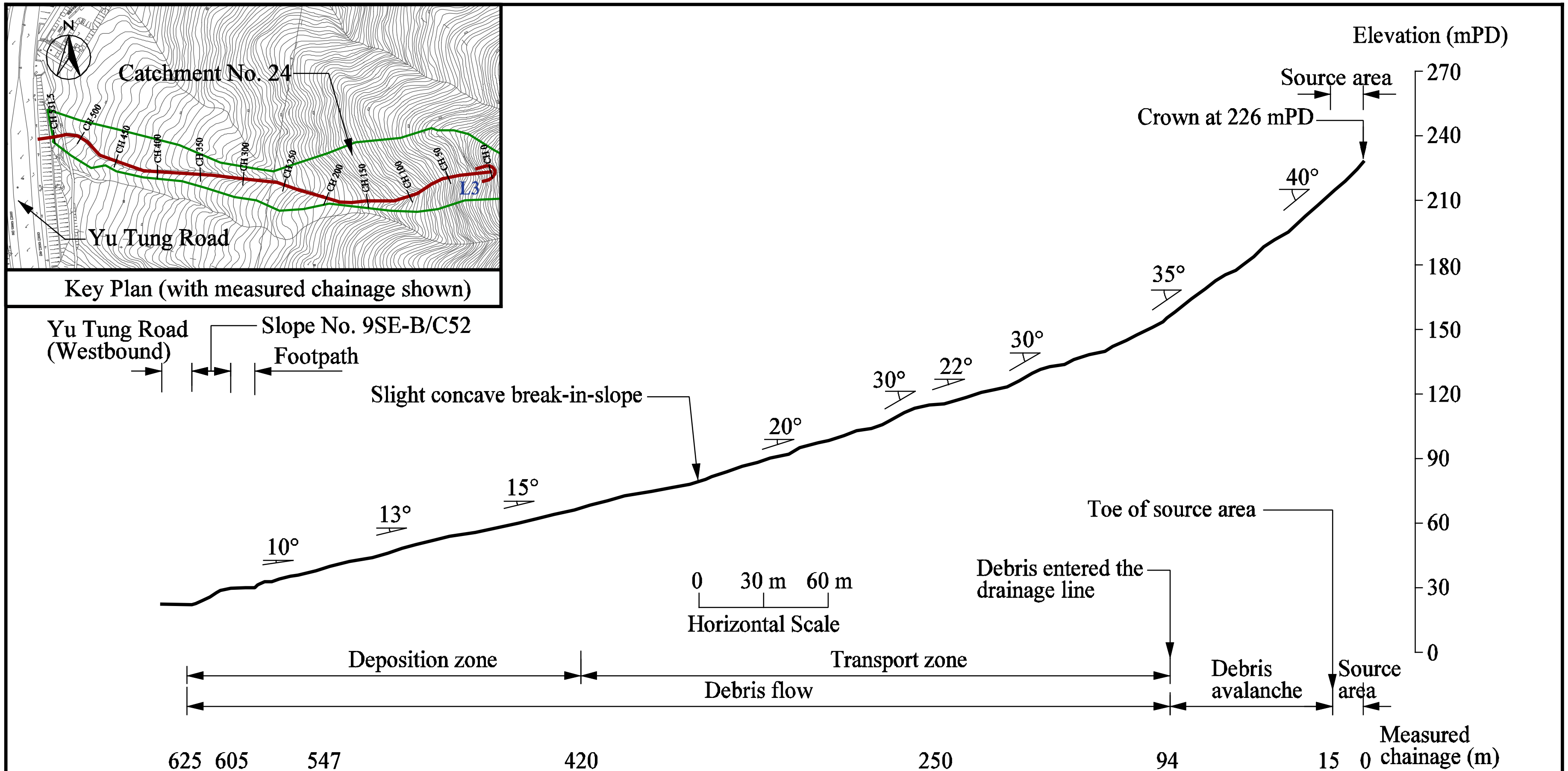
Table of Contents
Table of Contents
Table of Contents
Table of Contents



Note : Base plan is extracted from 1 : 1000 survey sheets Nos. 9-SE-3D, 9SE-4C, 9SE-4D, 9SE-8B, 9SE-8D, 9SE-9A, 9SE-9B, 9SE-9C, 9SE-9D, 9SE-13B, 9SE-14A and 9SE-14B dated March 2008.

Figure 6 - Large Landslides

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

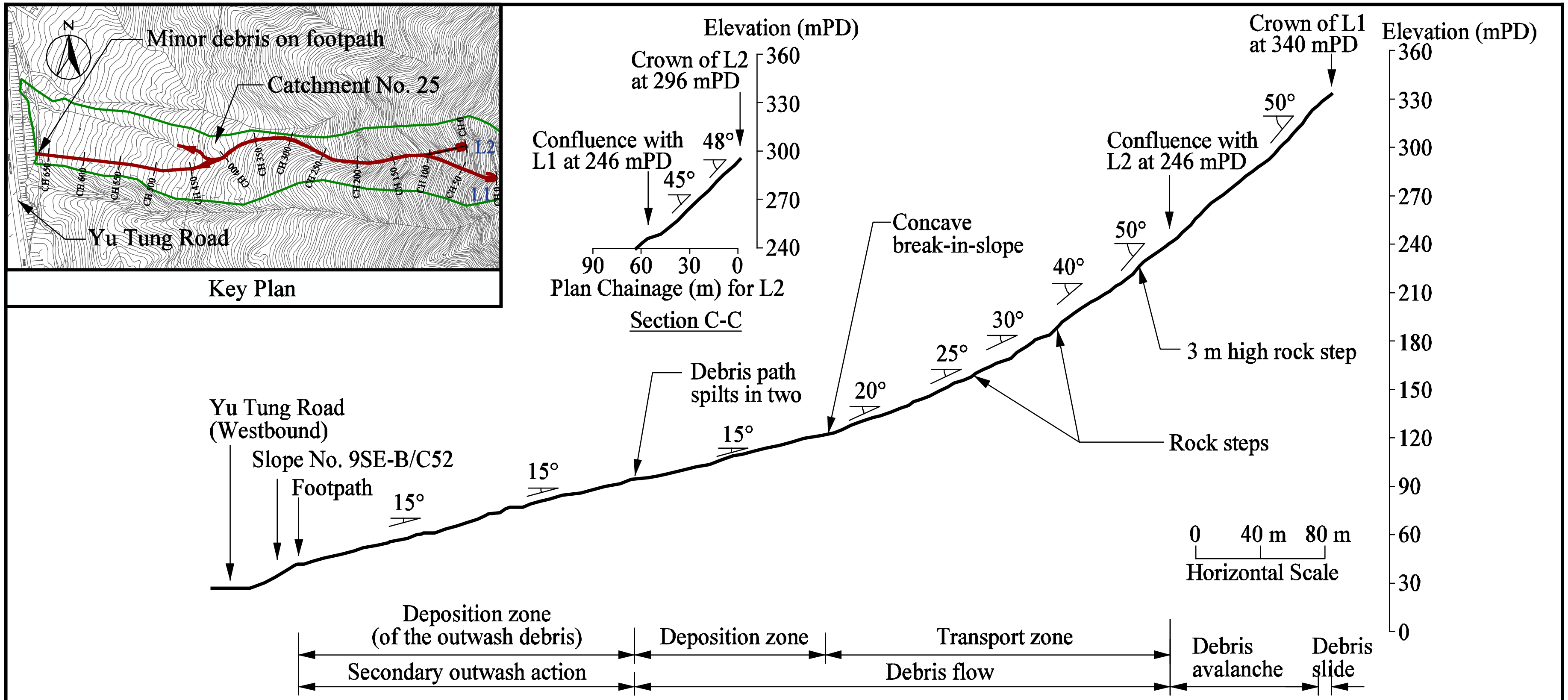


625–605	605–547	547–420	420–250	250–94	94–15	15–0	
0	10	30	140	20	230	150	Erosion (m³)
255	170	65	70	20	0	0	Deposition (m³)
0	255	415	450	380	380	150	Mass Balance (m³)

Note : See Figure 2 for location of Section.

Figure 7 - Section A-A through Landslide No. L3 in Catchment No. 24

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

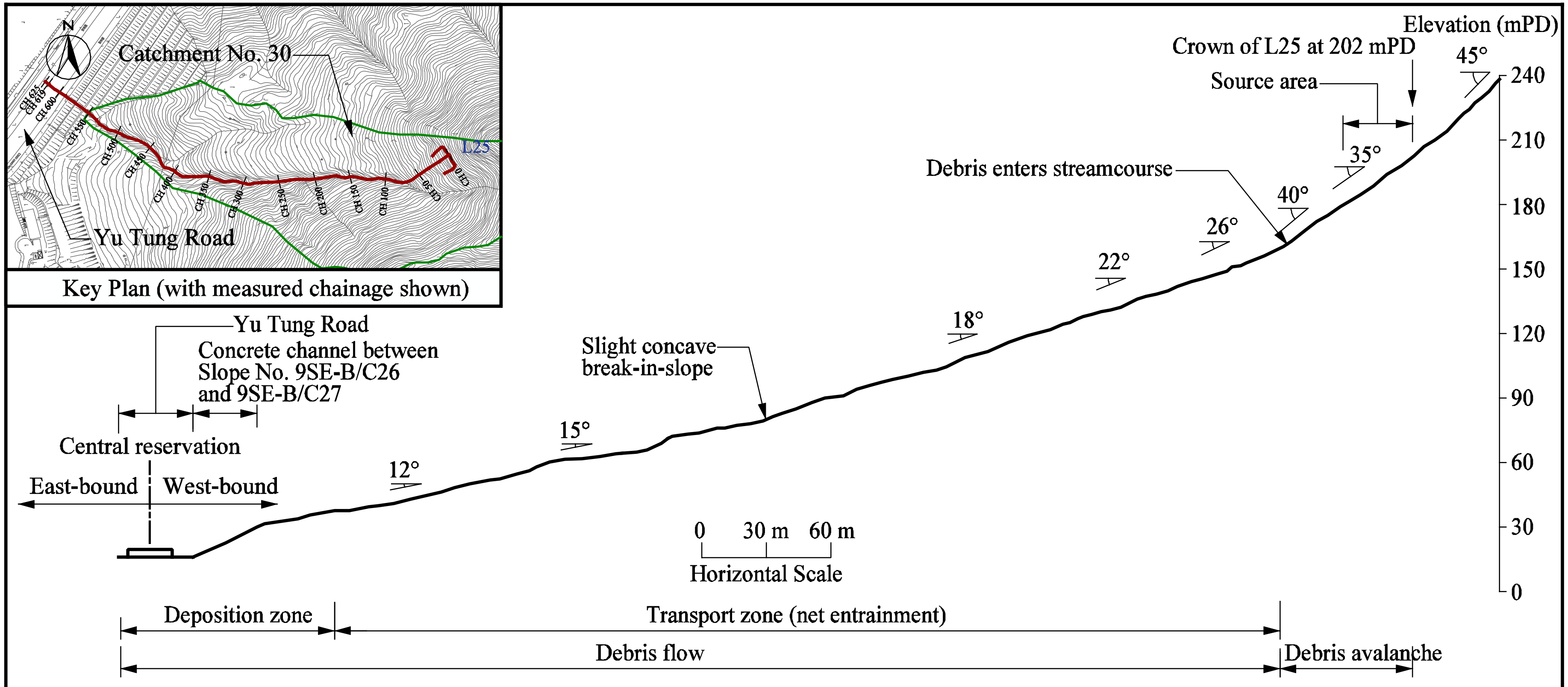


Measured chainage (m)	826–614	614–562	562–414	414–199	199–176	176–11	11–0
Erosion (m³)	26	35	110	100	0	35	75
Deposition (m³)	101	26	490	0	0	0	0
Mass Balance (m³)	114	189	180	560	460 (2)	110	75

Notes : (1) See Figure 2 for location of Sections.
(2) Includes 290 m³ from slope failure and 60 m³ from Landslide No. L2.

Figure 8 - Section B-B and C-C through Landslides Nos. L1 and L2 in Catchment No. 25

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

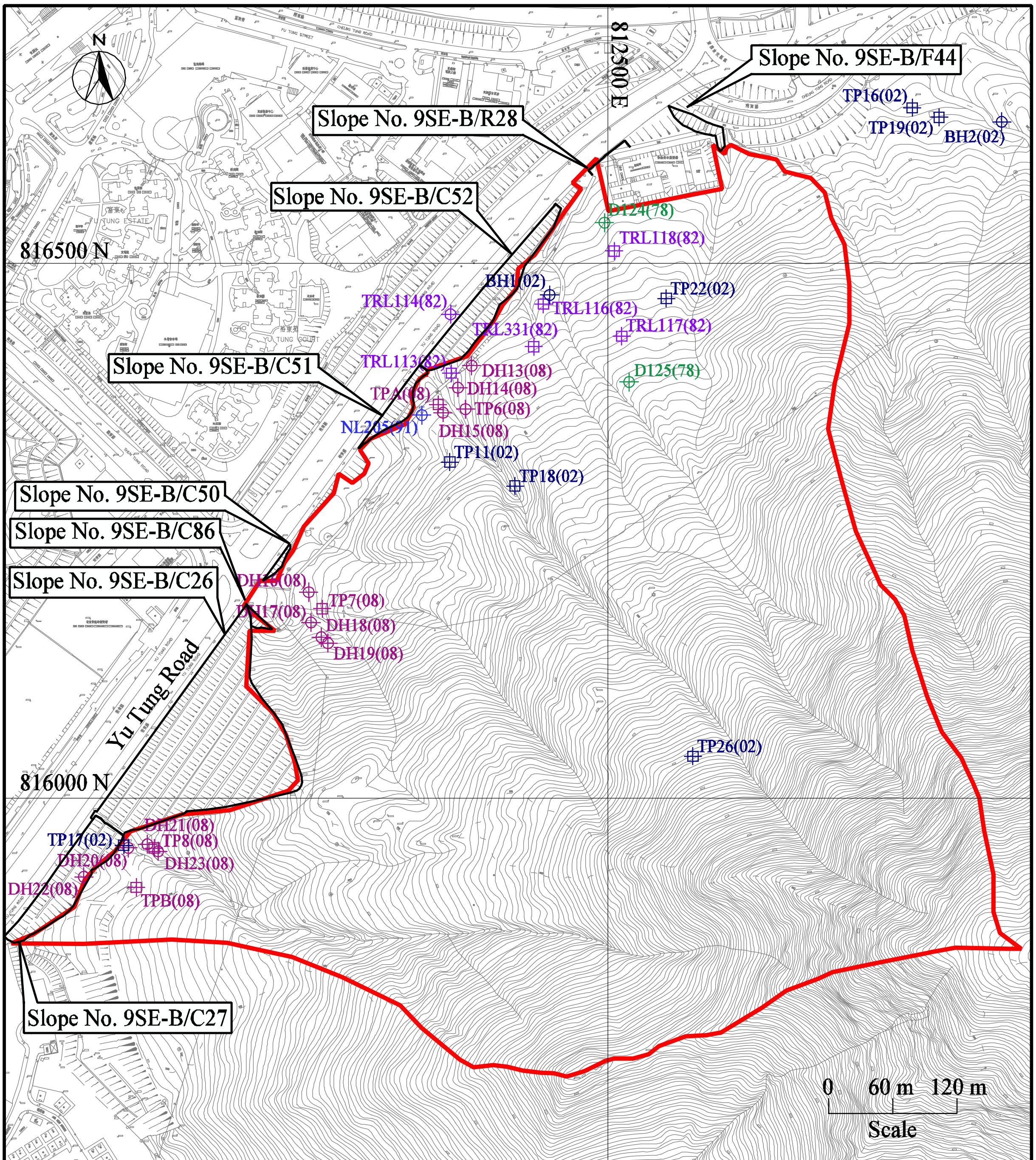


Measured chainage (m)	Erosion (m^3)	Deposition (m^3)	Mass Balance (m^3)
625–545	0	3115	0
545–510	70	355	3115
510–470	110	65	3400
470–455	25	5	3355
455–435	75	10	3335
435–415	75	0	3270
415–390	70	130	3195
390–340	85	175	3255
340–330	40	15	3345
330–310	70	25	3320
310–300	30	10	3275
300–285	45	5	3255
285–270	60	15	3215
270–255	60	10	3170
255–230	80	20	3120
230–220	40	5	3060
220–200	70	10	3025
200–180	75	15	2965
180–175	30	5	2905
175–150	130	10	2880
150–140	45	20	2760
140–125	65	0	2735
125–105	50	10	2670
105–90	85	20	2630
90–65	140	5	2565
65–55	100	70	2430
55–40	180	130	2400
40–0	2350	0	2350

Note : See Figure 2 for location of Section.

Figure 9 - Section D-D through Landslide No. L25 in Catchment No. 30

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



Legend :

(red line)	Study area boundary	BH1(02)	Drillhole in 2002 for Natural Terrain Hazard Studies at North Lantau Expressway (CE 89/2002)
D125(78)	Drillhole in 1978 for PWD Contract No. 682/77	TP26(02)	Trial pit in 2002 for Natural Terrain Hazard Studies at North Lantau Expressway (CE 89/2002)
TRL117(82)	Trial pit in 1982 for Trunk Road to Replacement Airport at Chek Lap Kok Phase I	DH22(08)	Drillhole in 2008 for mitigation measures design (CE 9/2007)
NL205(91)	Drillhole in 1991 for North Lantau Development Phase I	TPB(08)	Trial pit in 2008 for mitigation measures design (CE 9/2007)

Note : Base plan is extracted from 1 : 1000 survey sheets Nos. 9-SE-3D, 9SE-4C, 9SE-4D, 9SE-8B, 9SE-8D, 9SE-9A, 9SE-9B, 9SE-9C, 9SE-9D, 9SE-13B, 9SE-14A and 9SE-14B dated March 2008.

Figure 10 - Previous Ground Investigation

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

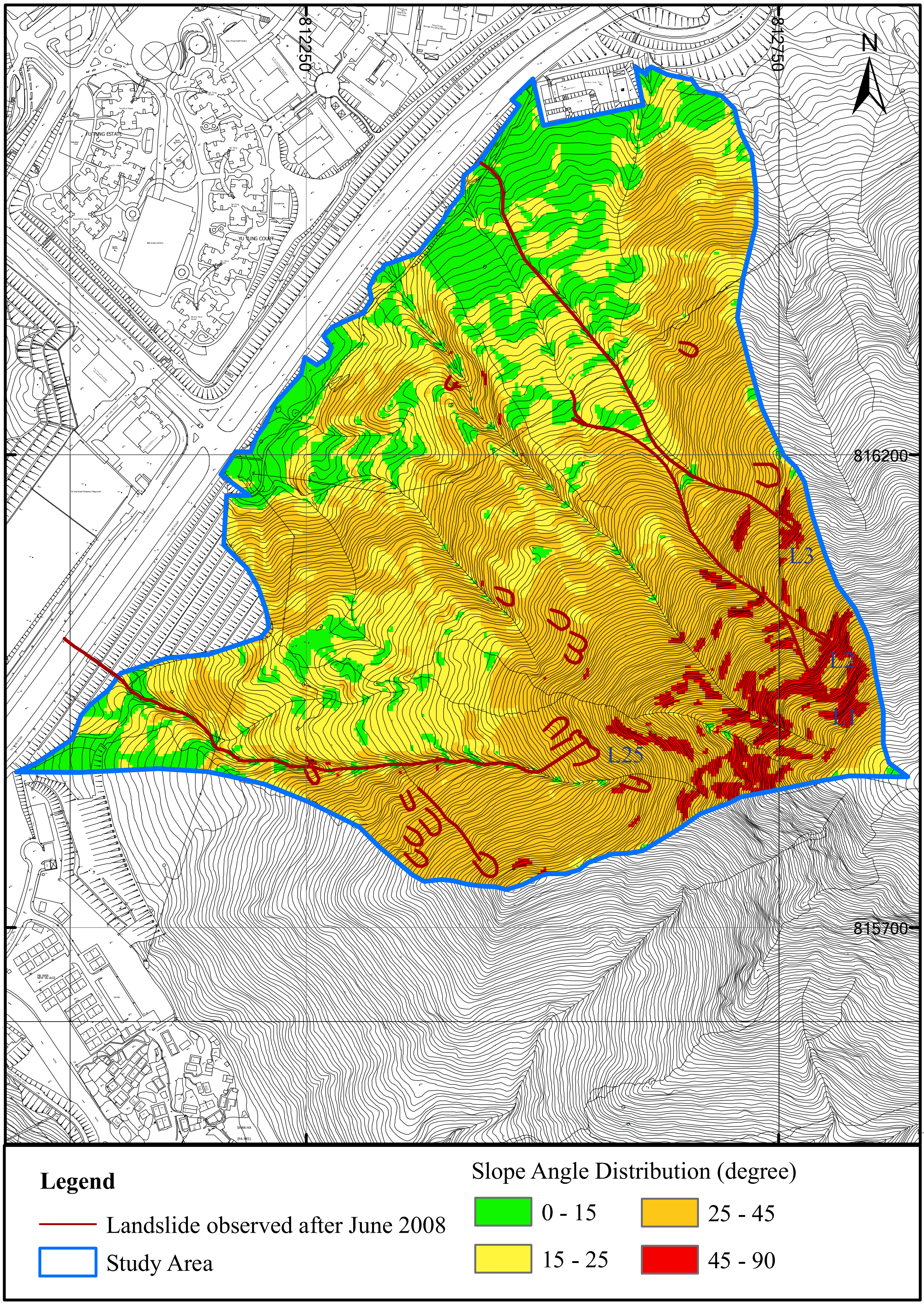
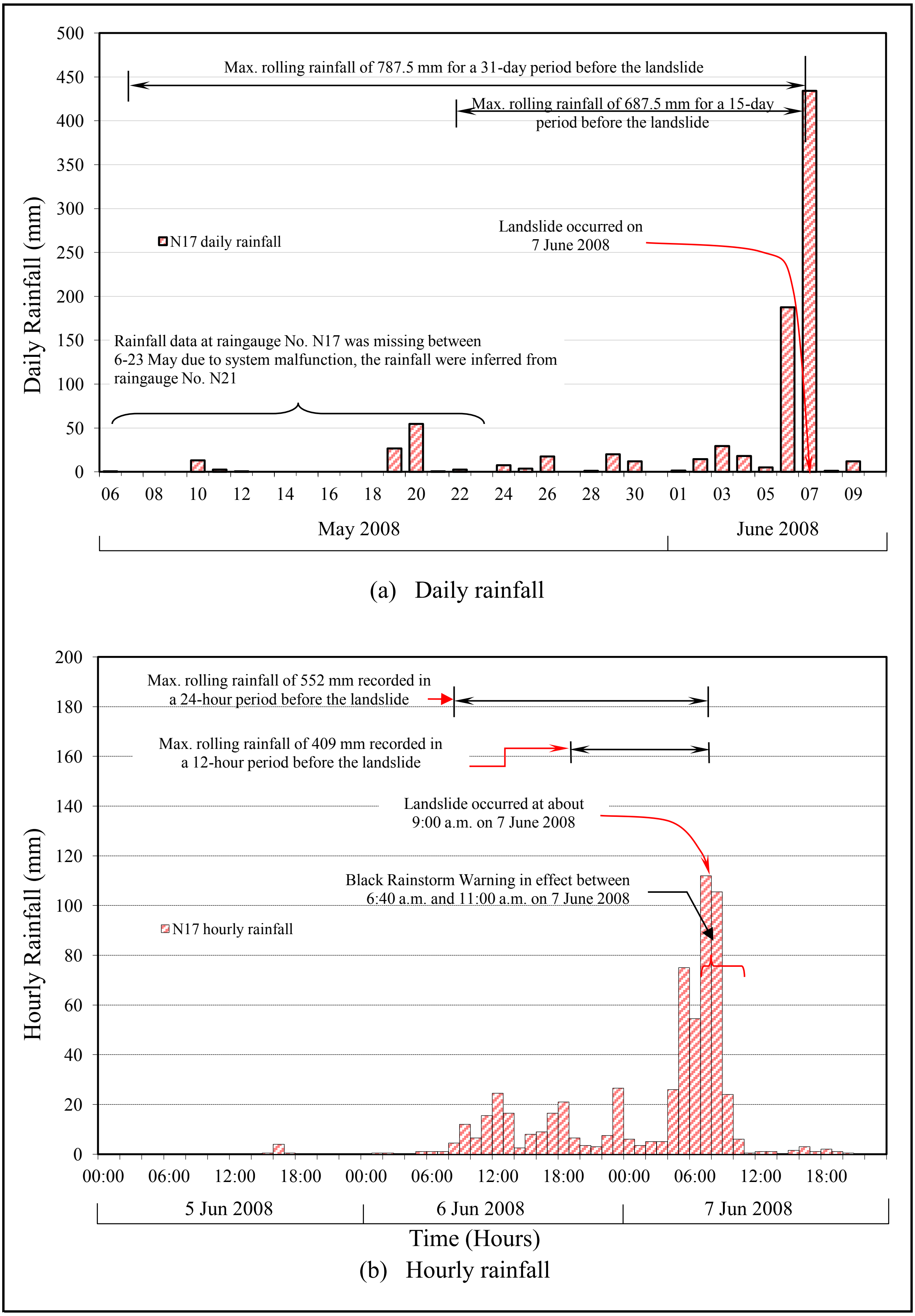


Figure 11 - Slope Angle Distribution Plan

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

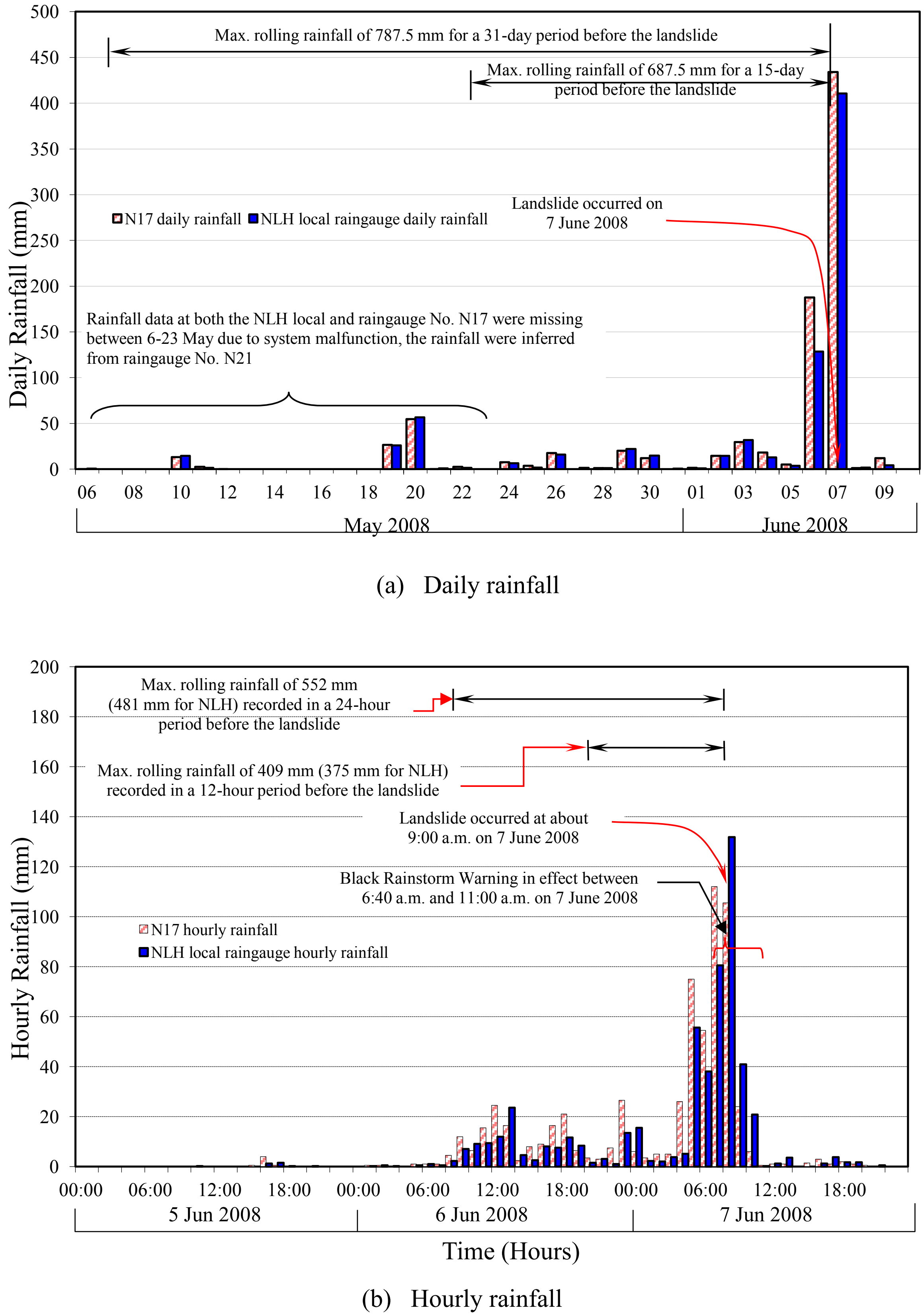


(a) Daily rainfall

(b) Hourly rainfall

Figure 12 - Daily and Hourly Rainfall Records at GEO Raingauge No. N17

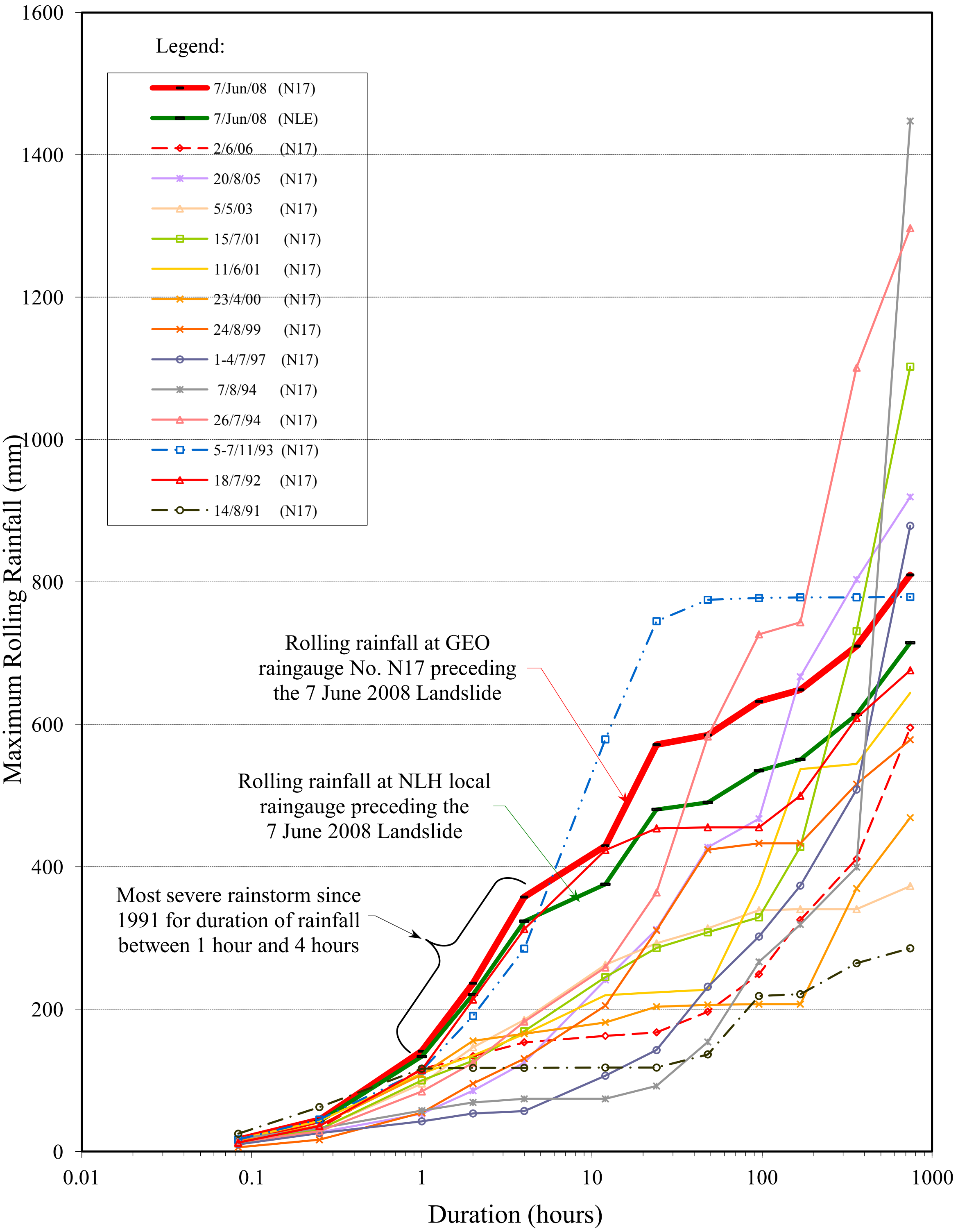
Table of Contents
Table of Contents
Table of Contents
Table of Contents



Note: Raingauge installed at Catchment No. 20 under agreement No. CE4/2005 (GE)

Figure 13 - Daily and Hourly Rainfall Records at NLH Local Raingauge

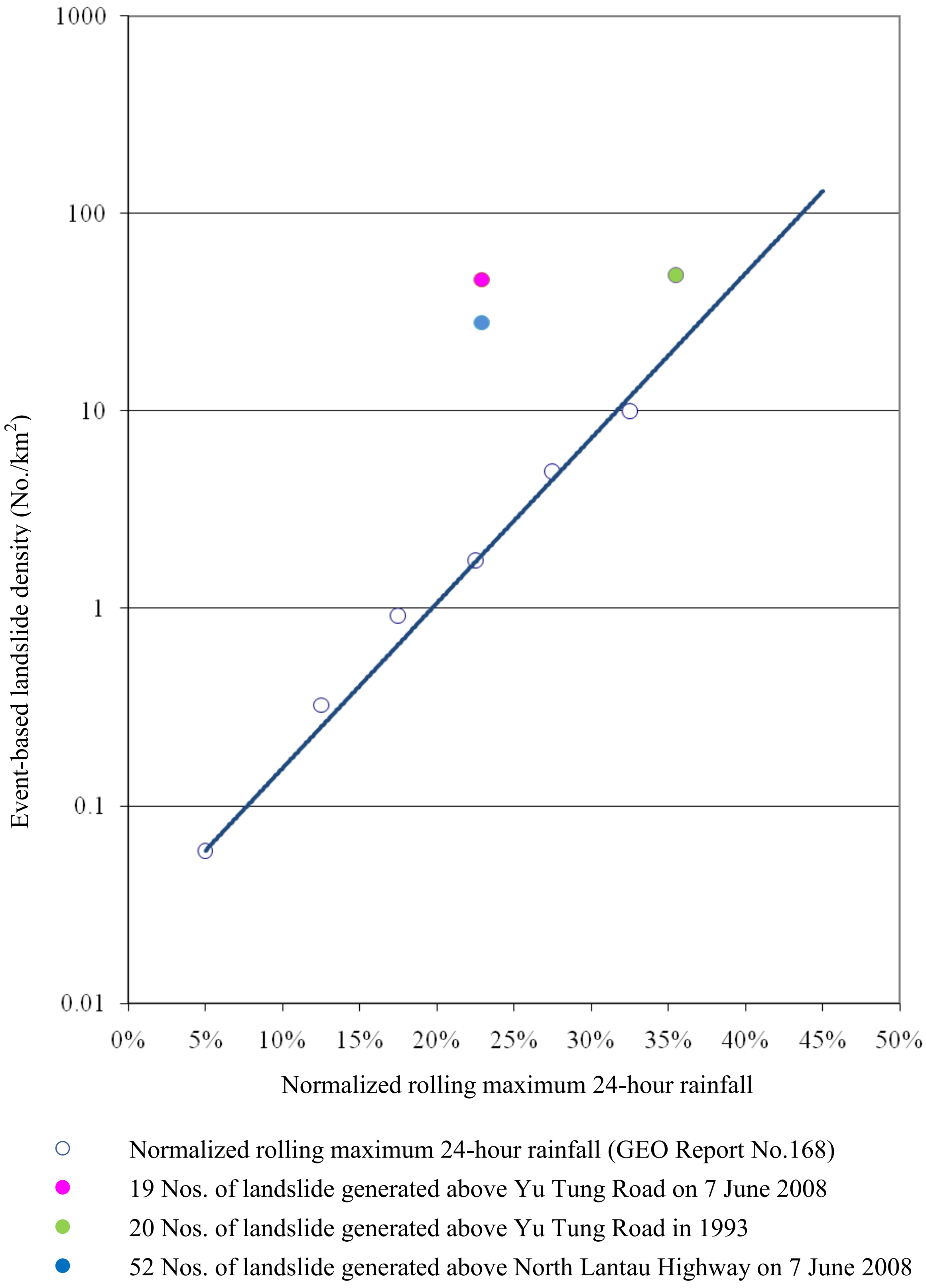
Table of Contents
Table of Contents
Table of Contents
Table of Contents



Notes: (1) Rainfall data evaluated from 5-minute readings from GEO raingauges No. N17 (about 1.3 km to the west of the site).
(2) Rolling rainfall of previous rainstorms calculated at GEO raingauge No. N17 since April 1991 when the raingauge became operational.

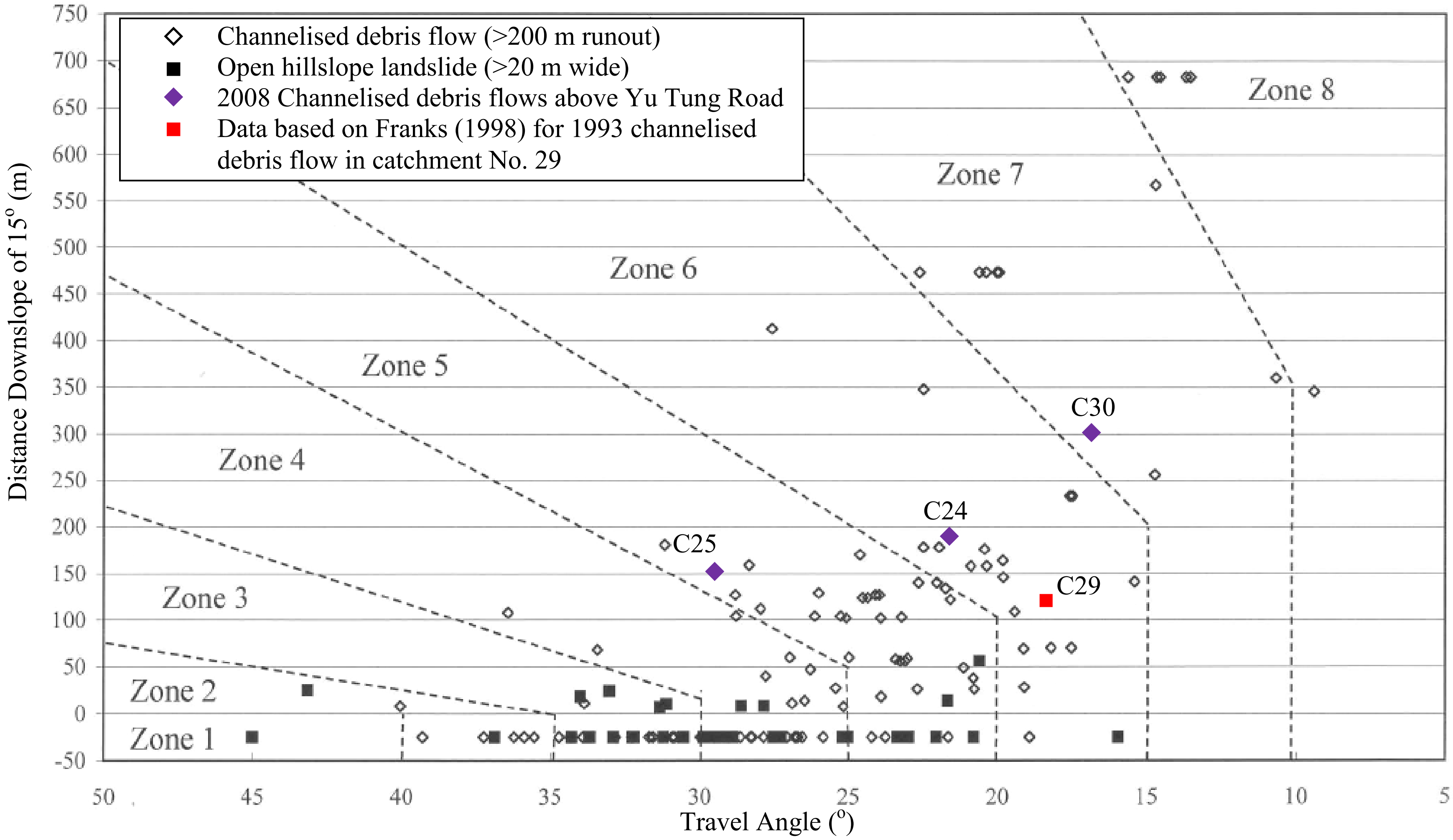
Figure 14 - Maximum Rolling Rainfall for Previous Major Rainstorms at GEO Raingauge No. N17

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



[Note: Normalised rainfall = rainfall intensity / mean annual rainfall]

Figure 15 – Rainfall-Natural Terrain Landslide Correlation



Note : Original Chart extracted from Wong et al (2006).

Figure 16 – Proximity Zones and Debris Runout Data from the 2008 Landslides

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

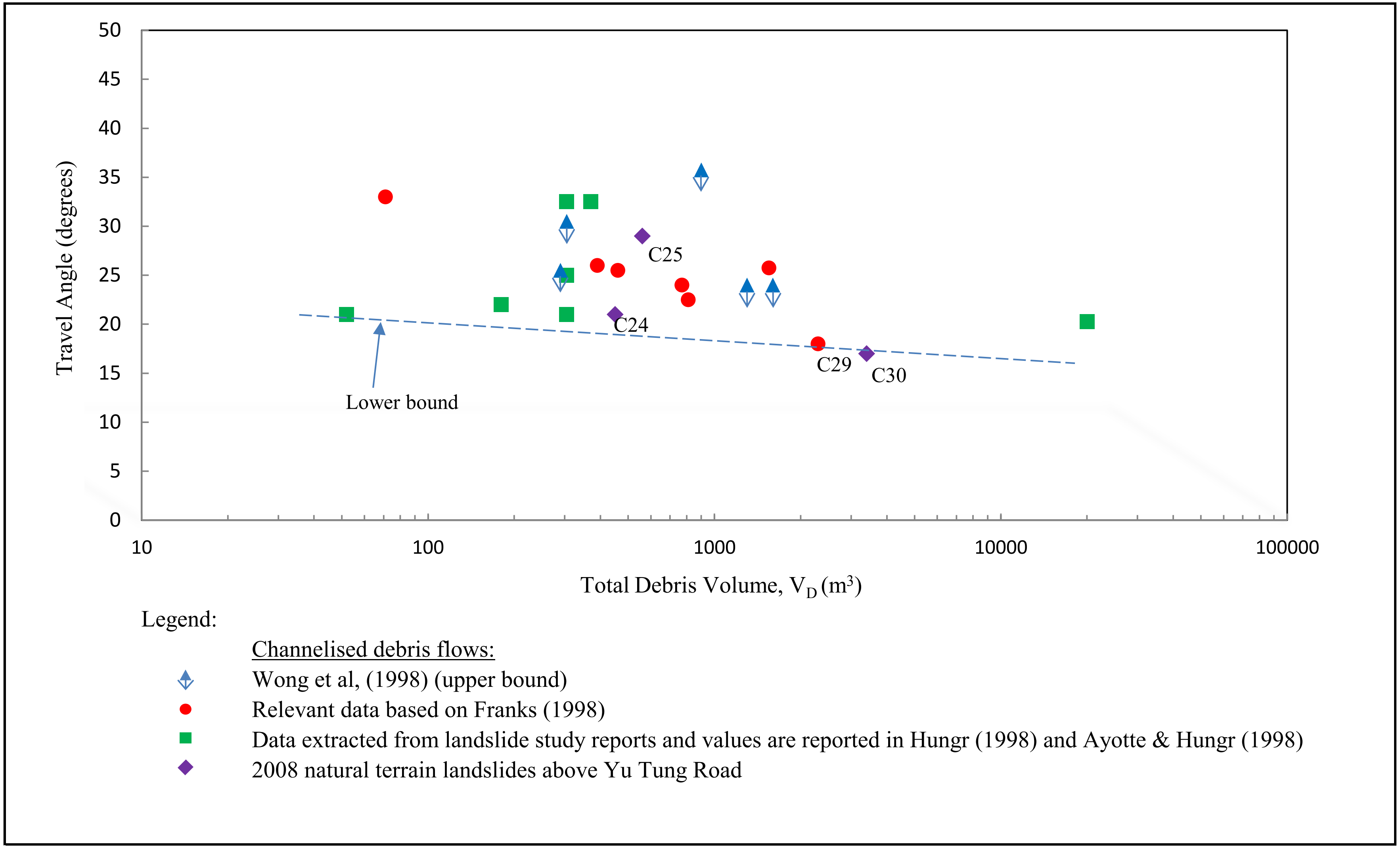


Figure 17 - Data on Debris Mobility for Channelised Debris Flows of Different Scale in Hong Kong

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

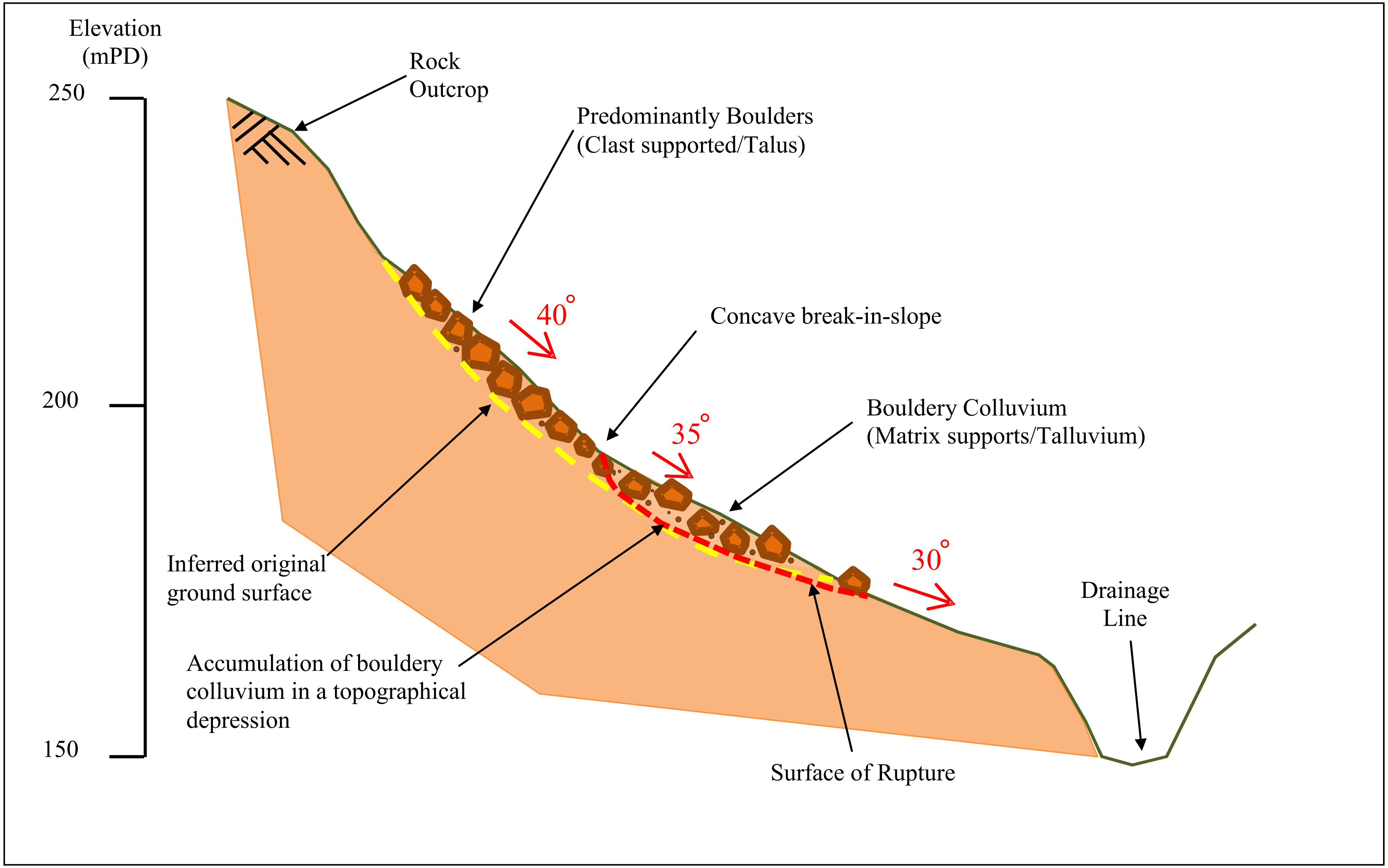


Figure 18 – Diagrammatic Section through Landslide Source in Catchment No. 30

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

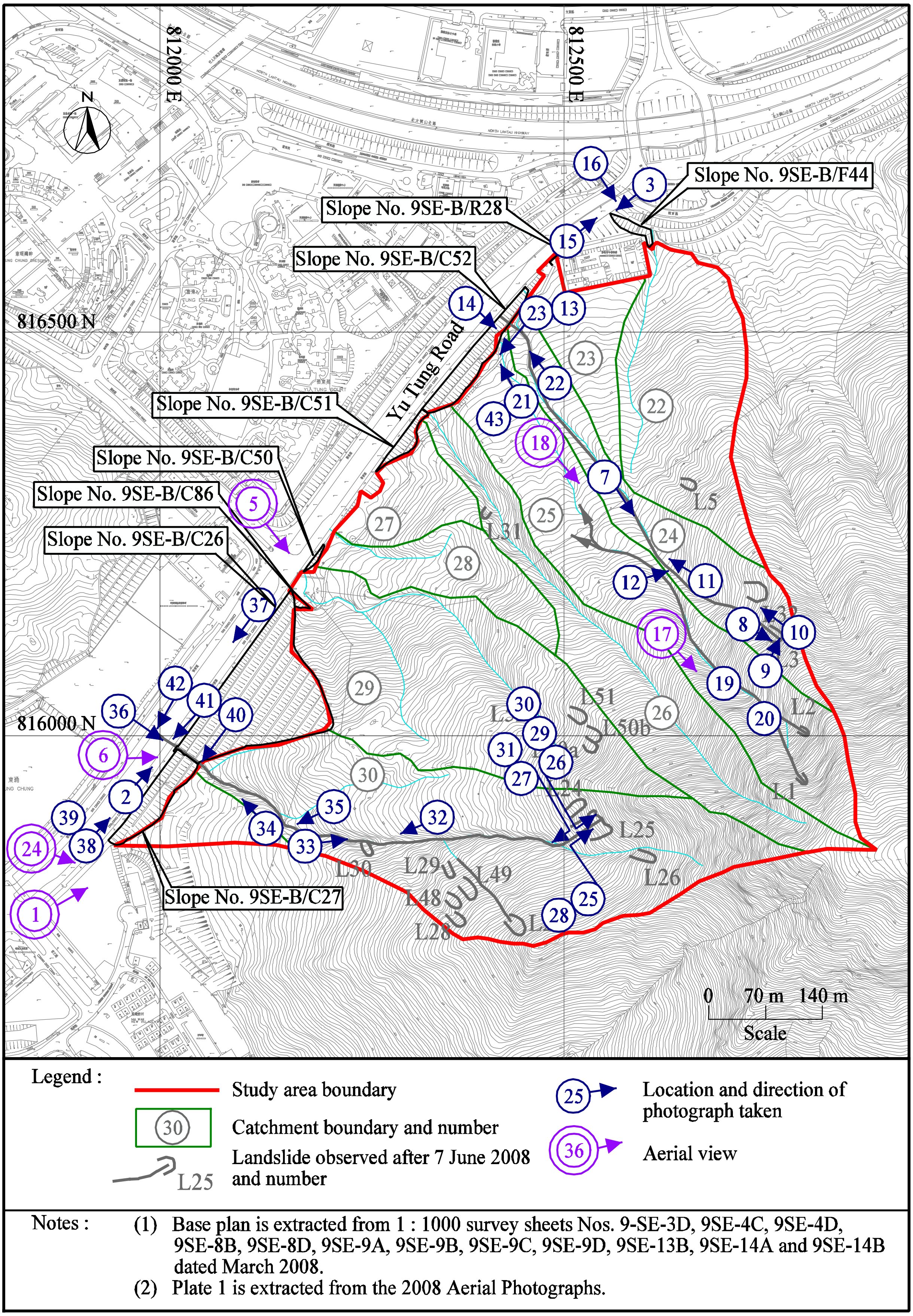


Figure 19 - Locations and Directions of Photographs

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

LIST OF PLATES

Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents

(Photograph No. CS13674, 6000 ft)

Plate 1 - 2008 Aerial Photograph of the Study Area
(Photograph taken on 25 July 2008)

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

Plate 2 – View of Watery Debris on Yu Tung Road from Catchment No. 30 (Photograph taken on 7 June 2008)

Plate 3 - Outwash from Landslide No. L3 in Catchment No. 24 and Flooding of Cheung Tung Road (Photograph taken on 7 June 2008)

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

Plate 4 – View of Fine Debris from Catchment No. 26 (Photograph taken on 7 June 2008)

Plate 5 – View of Fine Debris from Catchment No. 29 (Photograph taken on 7 June 2008)

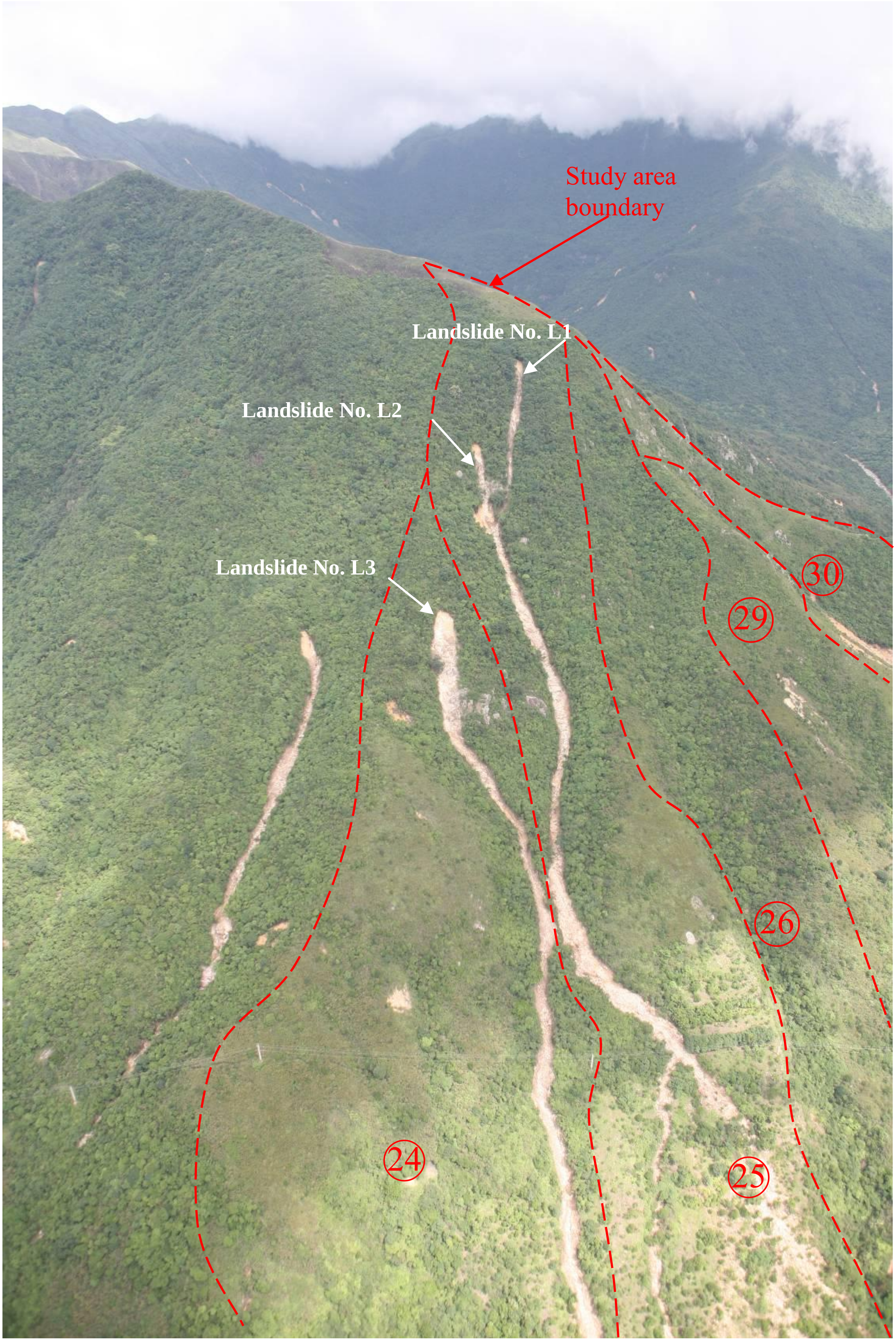


Plate 6 - Aerial View of Catchments Nos. 24 and 25 and Landslides Nos. L1, L2 and L3 (Photograph taken on 13 June 2008)

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

Plate 7 - View of Landslide No. L3 in Catchment No. 24 (Photograph taken on 15 June 2008)

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

Plate 8 - Source of Landslide No. L3 in Catchment No. 24 (Photograph taken on 15 June 2008)

Plate 9 - Voids in Colluvium at Landslide No. L3 in Catchment No. 24 (Photograph taken on 15 June 2008)

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

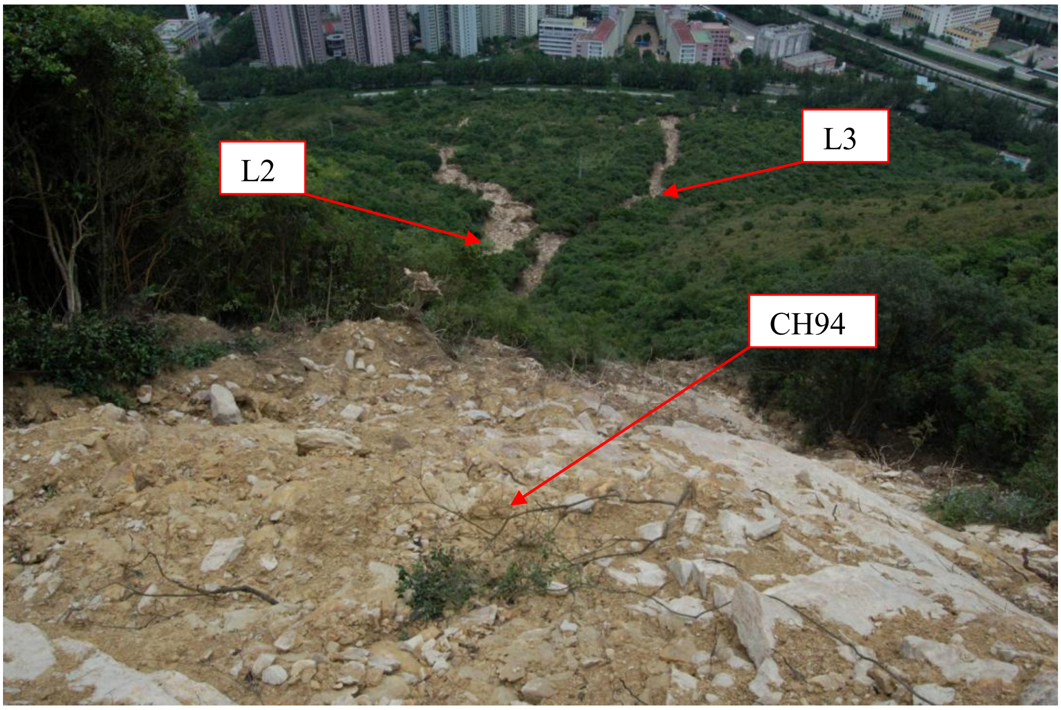


Plate 10 – View of the Landslide Occurred in Catchment No. 24 at CH94 before the Debris Entered the Drainage Line (Photograph taken on 15 June 2008)

Plate 11 – View of Drainage Line in Catchment No. 24 between CH240 and CH250 Looking Downhill (Photograph taken on 15 June 2009)

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

Plate 12 – Debris Levees with Large Boulders of up to 2 m Diameter along the Side of the Debris Trail at about CH255 in Catchment No. 24 (Photograph taken on 7 June 2008)

Plate 13 – Debris Deposited along the Southern Side of the Drainage Line between CH547 and CH605 in Catchment No. 24 (Photograph taken on 7 June 2008)

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

Plate 14 – Bouldery Debris from Landslide No. L3 in Catchment No. 24 (Photograph taken on 7 June 2008)

Plate 15 – Outwash from Landslide No. L3 in Catchment No. 24 on Yu Tung Road and Tung Chung Eastern Interchange (Photograph taken on 7 June 2008)

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

Plate 16 – Flooding of Cheung Tung Road below Yu Ting Road and Tung Chung Eastern Interchange (Photograph taken on 7 June 2008)

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

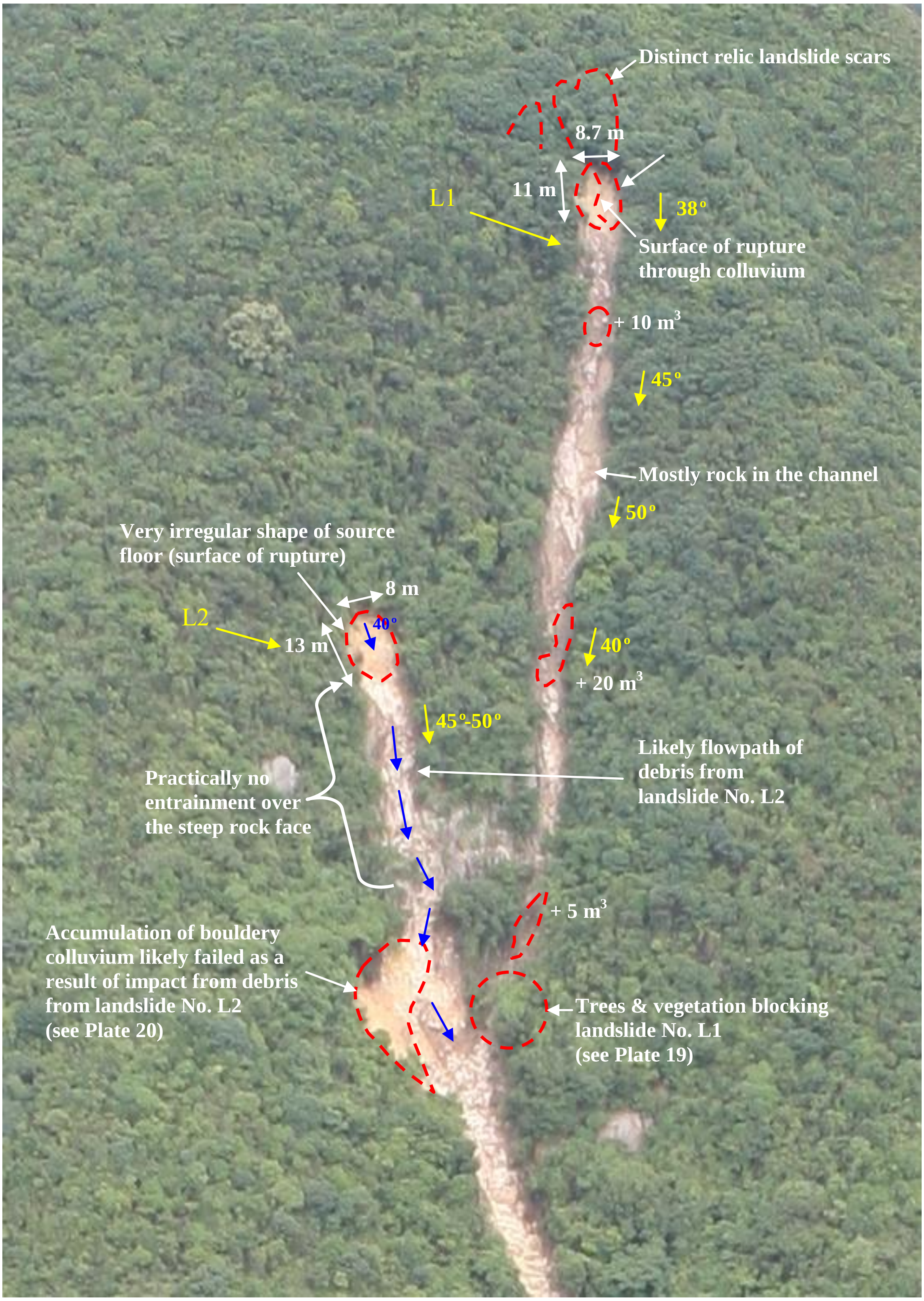


Plate 17 – Close-up Aerial View of Landslides Nos. L1 and L2 in Catchment No. 25 (Photograph taken on 13 June 2008)

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

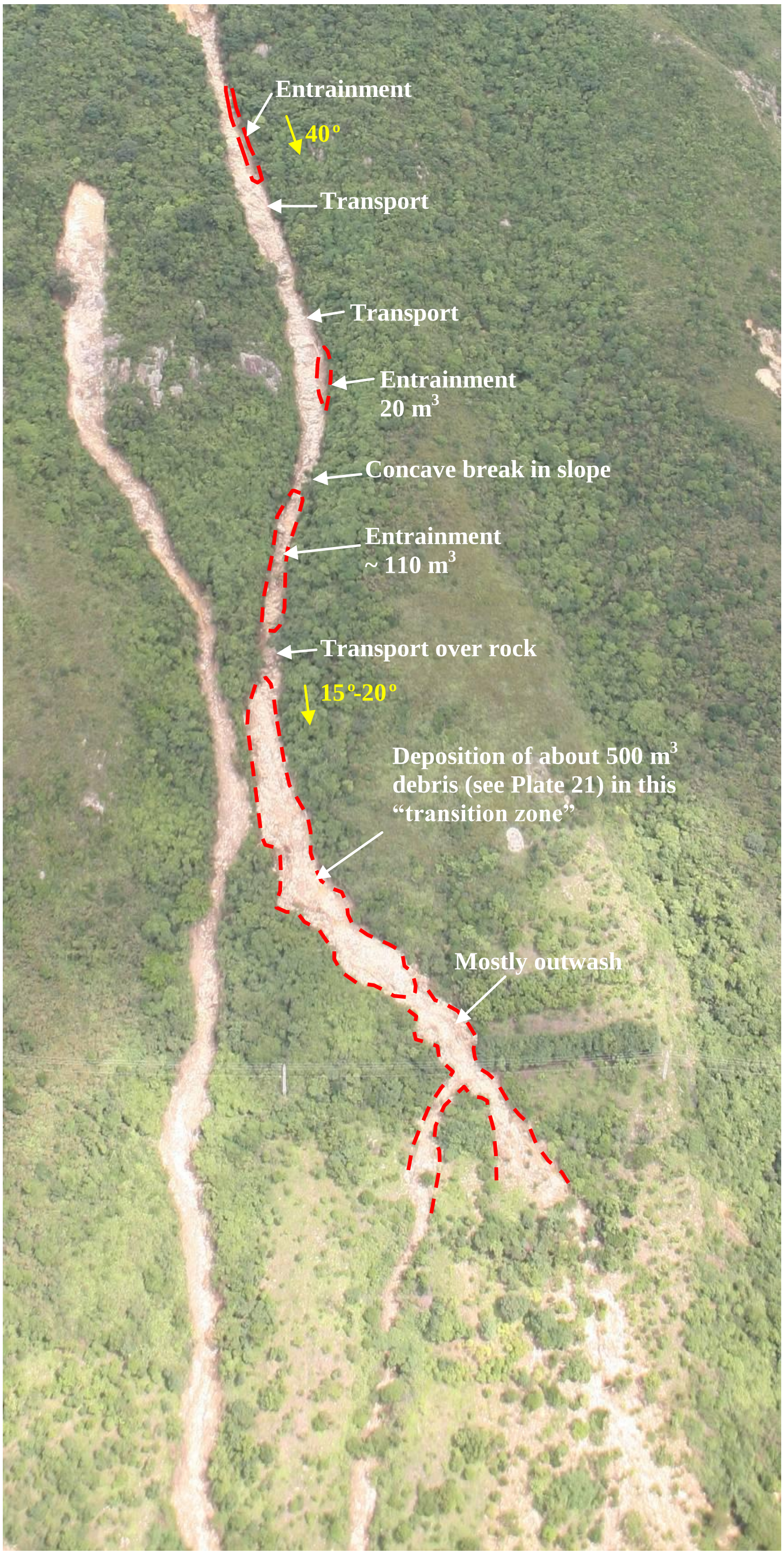


Plate 18 – Aerial View of Lower Portion of the Debris Trail in Catchment No. 25 (Photograph taken on 13 June 2008)

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

Plate 19 – Vegetation Partially Blocking Outlet of Drainage Line Affected by Landslide No. L1 in Catchment No. 25 (See Plate 17 for Location) (Photograph taken on 15 June 2008)

Plate 20 – Failed Side-slope at the Confluence of Landslides Nos. L1 and L2 in Catchment No. 25 (See Plate 17 for Location) (Photograph taken on 15 June 2008)

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

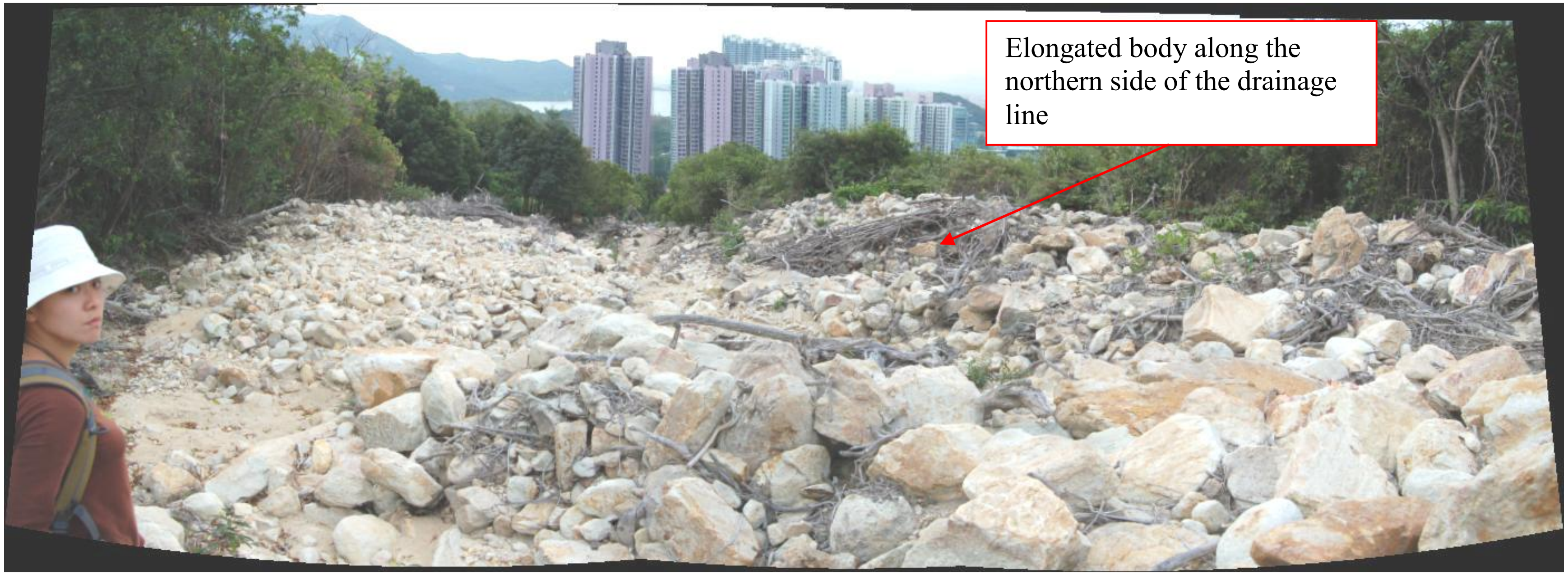


Plate 21 - Main Area of Debris Deposition in Catchment No. 25 (Photograph taken on 3 December 2008)

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

Plate 22 – View of Debris Outwash from Landslide No. L2 Spreading over Hillside and Travelling down Existing Drainage Line in Catchment No. 25 (Photograph taken on 15 June 2008)

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

Plate 23 – Small Volume of Outwash from Landslide No. L2 in Catchment No. 25 Deposited on Concrete Path above Crest of Slope No. 9SE-B/C52 (Photograph taken on 7 June 2008)

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

Plate 24 – Aerial View of Catchment No. 30 and Landslide No. L25 (Photograph taken on 9 June 2008)

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

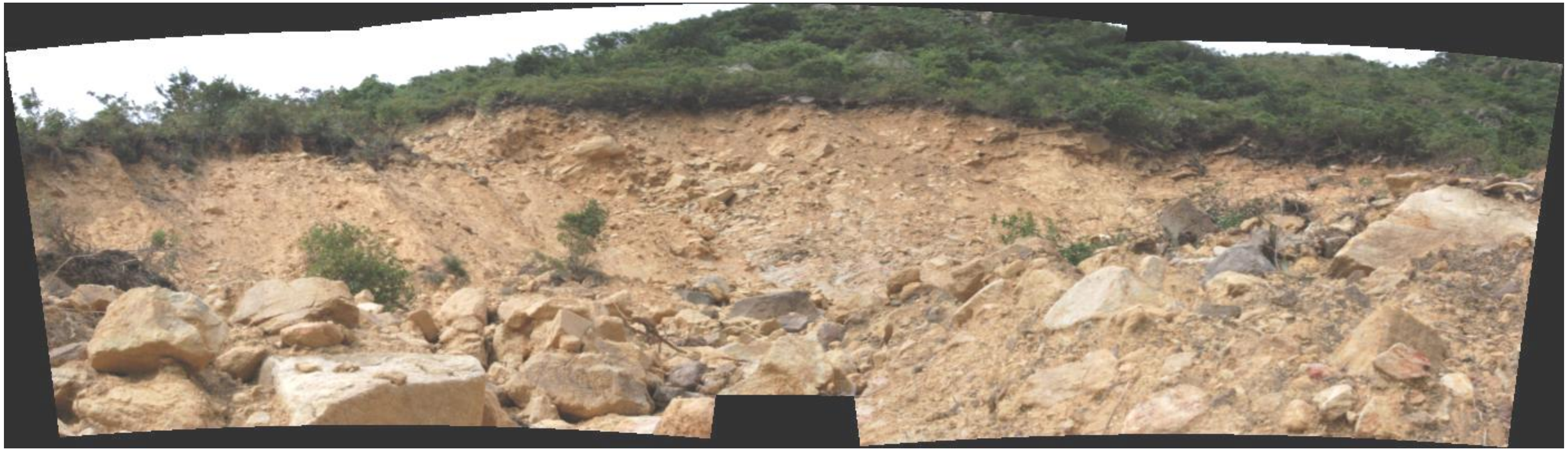


Plate 25 – General View of Source of Landslide No. L25 in Catchment No. 30 (Photograph taken on 14 June 2008)

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

Plate 26 – General View of Western Flank of Drainage Line in Catchment No. 30 below Source of Landslide No. L25
(Photograph taken on 14 June 2008)

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

Plate 27 – View down Drainage Line below Toe of Source of Landslide No. L25 in Catchment No. 30 (Photograph taken on 14 June 2008)

Plate 28 – General View of Source of Landslide No. L25 in Catchment No. 30 (Photograph taken on 8 June 2008)

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

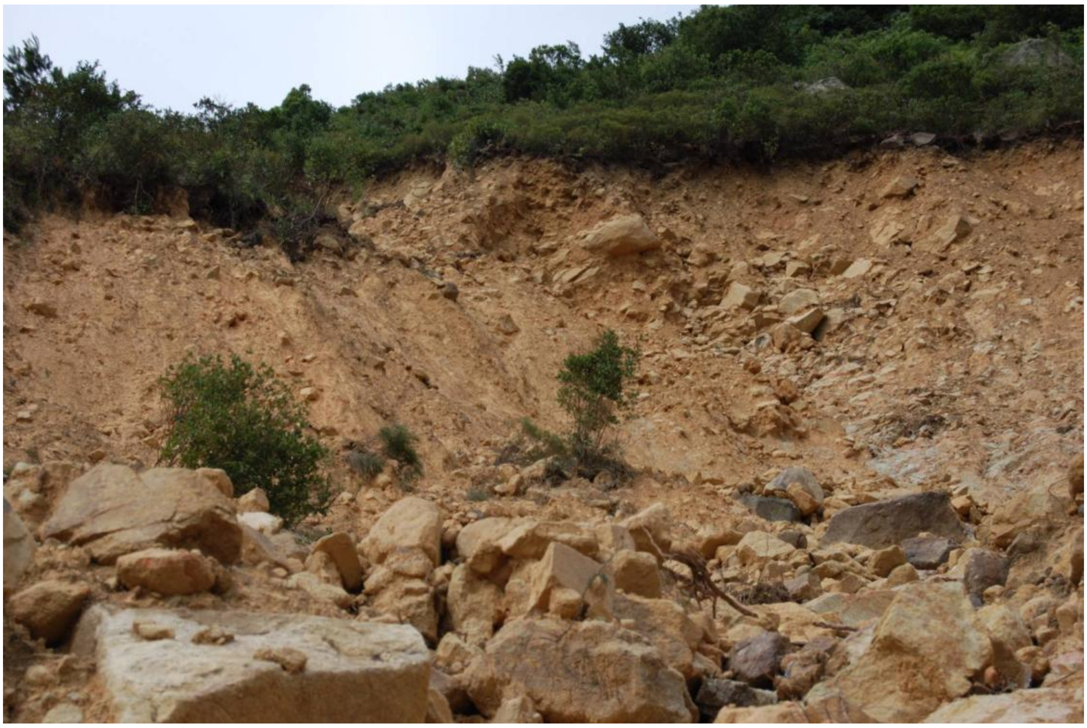


Plate 29 – Talluvium Exposed in Backscarp of Source of Landslide No. L25 in Catchment No. 30 (Photograph taken on 14 June 2008)

Plate 30 – Close-up of Talluvium in Backscarp of Landslide No. L25 in Catchment No. 30 (Photograph taken on 21 July 2008)

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

Plate 31 – Planar Joint Moderately Decomposed Tuff in Base of Landslide Scar at Landslide No. L25 in Catchment No. 30 (Photograph taken on 21 July 2008)

Plate 32 – Broadening of Drainage Line below CH310 in Catchment No. 30 (Photograph taken on 13 June 2008)

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

Plate 33 – View of Lower Portion of Drainage Line and Debris Trail in Catchment No. 30 (Photograph taken on 8 June 2008)

Plate 34 – View of Debris Trail Extending to Crest of Slope No. 9SE-B/C27 (Photograph taken on 8 June 2008)

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

Plate 35 – View of Western Flank of Drainage Line at CH413 Showing Superelevated Debris (Photograph taken on 25 July 2008)

Plate 36 – View of Debris Running over Slope No. 9SE-B/C27 and Deposited onto Yu Tung Road (Photograph taken on 7 June 2008)

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

Plate 37 – View of Debris on Yu Tung Road Extending onto Eastbound Carriageway (Photograph taken on 7 June 2008)

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

Plate 38 – Debris on Eastbound Carriageway (Photograph taken on 7 June 2008)

Plate 39 – Clearing Bouldery Debris from Yu Tung Road (Photograph taken on 8 June 2008)

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

Plate 40 – Damage to Concrete Drainage Channel at West of Slope No. 9SE-B/C27 in Catchment No. 30
(Photograph taken on 25 July 2008)

Table of Contents

Table of Contents

Table of Contents

Table of Contents

Plate 41 – Damage to Concrete Channel at Toe of Slope No. 9SE-B/C27 in Catchment No. 30
(Photograph taken on 11 November 2008)

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

Plate 42 – Temporary Barrier above Slope No. 9SE-B/C52 in Catchment No. 24 (Photograph taken on 15 June 2009)

Plate 43 – Temporary Barrier along Yu Tung Road below Catchment No. 30 (Photograph taken on 28 November 2008)

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

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

APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

CONTENTS

A1. INTRODUCTION

An Aerial Photograph Interpretation (API) has been carried out as part of the study to identify any possible signs or evidence that may relate or contribute to the landslides that occurred on 7 June 2008, through identification of the geological and geomorphological characteristics of the site. A site history has also been established. A review of available aerial photographs taken between 1945 and 2008 was undertaken and are listed in Table A1. Relevant observations relating to the morphology and hydrology as well as site history are shown on Figure A1. Pertinent observations from the 1945, 1963 and 1993 aerial photographs are highlighted in Figures A2 to A7.

A2. SUMMARY

The hillside within the study area comprises northwest facing hillside which extends downhill from a relatively sharp ridgeline initially at a relatively steep gradient, with areas of steep rock exposure, which gradually becomes less steep as the hillside extends towards the sea which was formerly at the toe of the hillside prior to the Tung Chung Town reclamation works.

The locations within the catchments at which significant landslides occurred in early June 2008, coincide with the locations of pre-existing topographical depressions. These depressions, which consist of relatively steep terrain, appear to have formed as a result of past landslide events, and have become characterized by relatively sharp convex breaks-in-slopes. The morphology of the terrain is such that formation of ephemeral drainage channels occurs resulting in concentration of surface and sub-surface runoff and commonly the reactivation of landslides.

Rock exposure is found in the vicinity of most landslide scars, which reflect the presence of relatively shallow rockhead with thin regolith cover. The regolith generally consists of colluvium probably originated from landslide debris containing bouldery material, with boulders identified in the vicinity of all concerned landslide areas. The sparse vegetation, which covers the landslide areas, may promote direct infiltration into the thin regolith layer during intense rainstorms.

A3. MORPHOLOGY, HYDROLOGY AND SUPERFICIAL MATERIALS

In general, the upper catchment of the study area is delineated by a well-defined ridgeline, with heads of the catchments located immediately below. Extending downslope from the ridgeline are a series of rounded spurlines that from the catchment boundaries within the study area. The terrain immediately downslope from the ridgeline is typically very steep (approximately 40°) and comprises a transportational upper slope terrain morphology. The steepness of the terrain may be associated with the presence of shallow rockhead, as several areas of exposed rock are observed within the zone. The downslope terrain comprises shallower gradient midslope terrain (approximately 20°-36°). The lower slopes are predominantly colluvial with the several large debris fans observed. Boulders are observed to be scattered across the upslope and mid-slope area of the hillside. The general morphology and hydrology of the area is shown on Figure A1.

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

Three photogeological lineaments are apparent within the vicinity of the study area (Figure A1). Photogeological lineament P1s is a strong feature while P2w and P3w are relatively ill-defined weak lineaments. Both P1s and P2w trend northwest to southeast and west-northwest to east-southeast respectively and run parallel to the main natural drainage lines that drain towards northwest and west-northwest. P3w strikes east-northeast to west-southwest.

There are total 6 perennial streamcourses (S1 to S6) meandering generally towards northwest within the study catchments. A west-northwest-trending perennial streamcourse (S1) with some ill-defined ephemeral branches drains catchment No. 30 while a northwest-trending streamcourse (S2) drains the catchment No. 26 of the study area (Figure A1).

A4. DETAILED OBSERVATIONS

Detailed observations from an examination of the aerial photographs for the period between 1945 and 2008 are presented below. Key observations are shown in Figures A1 to A7. A list of the aerial photographs examined is presented in Table A1.

YEAR	**OBSERVATIONS**
1945	High flight, moderate resolution aerial photographs. The hillside within the study area comprises northwest facing terrain which extends downhill from a relatively sharp ridgeline initially at a relatively steep gradient (which cannot be quantified but is estimated at over 35°) which gradually becomes less steep as the hillside extends to the sea at the toe of the hillside. A defined concave break-in-slope between the steeper upslope area and the more gently inclined toe slopes is evident in catchment No. 30 and extends into the upper portion of catchment No, 29 but cannot clearly identified in catchments Nos. 22 to 25, although a rounded concave break-in-slope at about the mid-slope portion of the hillside in those catchments is inferred. The vegetation cover over the entire hillside appears sparse with a marginally increased density along the central portion of the drainage lines. There appears to be no evidence of recent or fresh landslides on the hillside within the study area. Catchment No. 22 appears to be a rounded open drainage line that is weakly channelised. A photogeological lineament is observed to cut across the spurline between catchment No. 22 and the study area boundary at the lower portion of hillside (Figure A1). The lineament trends east-northeast/west-southwest and in places coincides with a narrow ridge of raised ground which may indicate a dyke or more resistant geological feature. A footpath is observed to cross diagonally over the hillside at the lower portion of catchments Nos. 24 and 25 (i.e. the lower portion of a colluvial debris fan) the alignment of which appears to continue to follow the trend of the photogeological lineament. Material eroded from catchment No. 22 appears to have been transported to the sea at the toe of the drainage line with a proportion of the material deposited on the alluvial fan at the

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

YEAR **OBSERVATIONS**

outlet of the catchment. Agricultural terracing of the surface of the alluvial fan appears to be ongoing (Figure A2).

The uppermost portions of Catchments Nos. 24 and 25 are obscured by shadow although the lower reaches are visible and a continuous colluvial fan appears to extend over the hillside across the lower portions of both catchments. Weakly defined ephemeral drainage lines, probably initiated through landsliding and subsequently eroded further through ephemeral fluvial action, are observed to cut through the central portion of the colluvial fan. These ephemeral drainage lines correspond to the central drainage lines with catchments Nos. 24 and 25. Ephemeral drainage lines are also observed either side of the fan that correspond to catchments Nos. 22 and 26 on the east and west sides respectively.

Catchment No. 26 is linear with a relatively confined central ephemeral streamcourse channel, though the drainage line is observed to turn towards the west as it approaches the sea. There is evidence of several relic landslides having occurred along the steep flanks of the drainage, in the form of closely spaced arcuate convex breaks-in-slope (Figure A1). Areas of bare soil are observed on the hillside between catchments Nos. 26 and 29. Notably a small debris lobe is observed emerging from the outlet of the drainage line in catchment No. 26. The debris lobe is distinguished by the darker shade of vegetation and hummocky appearance. Debris from the lobe can also be seen to extend upslope along the drainage line for about 100 m. It is possible therefore that the lobe represents one event, with approximate volume of about 1000 m^3 (assuming an approximate scale of 1:20 000 the approximate dimensions of the lobe are a radius of 25 m and an assumed average depth of 1 m. Thus $½(\pi r^2 h)$, gives about 1960/2 = 980 m^3). A further possible small fan of colluvium is also observed on the coast directly downslope of the linear portion of the drainage line in catchment No. 26 which may correspond to debris from a landslide that has overrun the sides of the drainage line and travelled directly to the sea (Figure A2).

Catchment No. 29 is an open catchment with the flanks of the catchment comprising an undulating morphology in the form of several east-west trending spur lines and hollows in the hillside either side of a central ephemeral drainage line. Bare areas on the minor ridges within the hummocky hillside suggest surface erosion.

On the hillside at the south-western portion of the catchment a series of narrow discontinuous ridges are observed (Figure A2). These features may represent the surface expression of a geological feature, such as a dyke or quartz vein, or possibly man-made features such as exploratory mining activities. A probable lobe of debris is observed at the outlet of the catchment where the drainage line runs onto a terraced area of colluvial deposits.

The hillside at the toe of the study area between catchments Nos. 29 and 30 is occupied by agricultural terraces. It is possible that the terraced land between

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

YEAR **OBSERVATIONS**

the hillside of the study area and an area of raised hillside to the north was previously under sea. This would correspond to a sea level about 5 m higher than present day.

The upper portion of catchment No. 30 is visible. Overall the catchment is defined by rounded open terrain with a defined channel that cuts though the hillside and along which a central streamcourse runs. On the hillside below the prominent northwest-trending spurline that separates catchment No. 30 from catchment No. 29, a concave break-in-slope is observed above the approximate location of the crown of the source of the 7 June 2008 channelised debris flow. Well defined relict scars are present at about the locations of the sources of landslides Nos. L24 and L25 (Figure A4). The two well-defined relict landslide scars extend downslope to the central streamcourse channel. The landslide scars are defined by relatively sharp convex break-in-slopes, although debris associated with the landslide are not evident in the single aerial photograph.

A distinct colluvial lobe of about 40,000 m^3 in volume at the outlet of the drainage line (Figure A3). A possible previous single debris flow event is interpreted to have affected the drainage line (Figure A6), with the estimated volume of debris from the event exiting the drainage line at about 3,100 m^3.

Man-made disturbance is observed in the form of footpaths. Two narrow footpaths about 100 m up hill of the coastline, are observed to cross the lowest portion of the colluvial fan at catchments Nos. 24 and 25. Agricultural terraces are also observed on an alluvial fan area adjacent to the sea and the toe of the hillside below catchment No. 22.

1963 Low flight, good resolution aerial photographs.

The hillside within the study area appears more densely vegetated than in 1945 with the upper portions of catchments Nos. 24 and 25 appearing most vegetated. Although overall density of vegetation is not particularly high.

There is little observable change to catchments Nos. 22 to 25 apart from a perceived increase in vegetation density, comprising small shrubs and trees, along the drainage line. Footpaths are observed to cross up through the hillside in catchments Nos. 22 to 26 and a recent grave and possibly two to three older graves are visible on the hillside at the mid portion of catchment No. 25.

At the head of catchment No. 26 is a relatively well defined linear depression the limit of which is marked by a convex-break-in-slope. The depression may correspond to a single large-scale failure. A bare area of soil which has the appearance of a relatively recent landslide is observed on the eastern flank of the depression. The toe of the depression is marked by a sharp convex break-in-slope below which rock is exposed. The break-in-slope appears to correspond to a small scale failure.

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

YEAR **OBSERVATIONS**

At the upper portions of catchment No. 30, large areas of intermittent rock exposure are observed with numerous boulders and an large area of bouldery deposits observed downhill of the outcrop. The largest area of predominantly rock exposure is observed at the head of the catchment (Figures A3 and A4) where the gradient of the hillside appears relatively steep with the toe of the predominantly rocky area marked by a concave break-in-slope (Figure A1). The concave break-in-slope extends across the hillside to above the crown of the 7 June 2008 debris flow.

An estimate of the quantities of perched deposits along the drainage line in catchment No. 30 has been carried out and about 1,120 m^3 of perched material is estimated to be present in the drainage line (Figure A5).

1964 High flight, good resolution aerial photographs.

Catchments Nos. 24 and 25 are located near the crests of channelised catchments 24 and 25 respectively. They are also found at the heads of the northwest-trending streamcourse channels, where well-defined topographical depressions encircled by sharp convex break-in-slopes are identified. These topographical depressions correspond to catchment Nos. with relict landslide scars, which are probably subject to retrogressive actions and fluvial erosion. Catchment No. 25 exhibits rugged terrain, which may suggest the presence of exposed rock outcrops or shallow rockhead.

Catchment No. 30 is located on the relatively steep southwest-facing hillside consisting of two relatively sharp relict landslide scars that are separated by a minor, local spur. Both relict landslide features have re-vegetated and the associated debris are not apparent. It appears that the extent of the relict landslide scars reaches the major streamcourse channel downslope. A small cluster of boulders/rock outcrops is evident on the local spur immediately above catchment No. 30.

1973 A recent open hillside landslide (LS2) is apparent at the catchment No. 22. A pier is forming at the toe of the catchment No. 23.

Some incised erosions are visible both banks along the drainage line S3 in catchment No. 26.

Channelised debris flow (LS3) is evident at catchment No. 29 with the source of landslide located at the head of drainage channel (S2).

Another recent open hillside landslide (LS4) is visible at the catchment No. 30.

1974 High flight, good resolution with coverage for catchment Nos. 24, 25 and 30.

Catchments Nos. 24 and 25 are covered with moderately dense vegetation. No signs of distress or instability are evident.

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

YEAR	**OBSERVATIONS**
	For Catchment No. 30, no signs of distress or instability are observed, except that erosion remains visible on the general northwest-facing hillsides of catchment 30, downslope of Catchment No. 30.
1975	No changes of significance are observed except electricity cable (M1) is observed in the vicinity of toeslope area of the study catchments.
1976	No changes of significance are observed. There are no signs of distress or instability evident within the concerned catchments.
1977	Two non stereo-pair low flight, good resolution, aerial photographs coverage catchments Nos. 29, 30 and 31.
	Construction of Buddhist youth camp (M2) is evident at the toe of catchment No. 23.
1978	Low flight, good resolution, aerial photographs only covered catchment No. 31.
	No changes of significance are observed.
1979	Another dwelling (M3) is visible near the toe of catchment No. 30.
	No signs of distress or instability are evident within catchments Nos. 24, 25 and 30.
1980	No changes of significance are observed.
1981	The development of Buddhist youth camp (M1) is completed at the toe of catchment No. 23. Catchments Nos. 24 and 25 are overgrown with dense vegetation, and signs of instability are not evident.
	A cluster of large boulders (B1) is apparent on the hillsides immediately above catchment No. 30. The general hillsides of catchment No. 30 appear to be affected by a hillfire (HF1).
1982	No significant changes are observed. Erosions still evident at the bank of drainage line (S2) in catchment No. 26.
1983	No significant changes are observed.
1984	No significant changes are observed.
1985	No significant changes are observed.
1986	Low flight, single aerial photographs was reviewed.
	No significant changes are observed.

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

YEAR	OBSERVATIONS
1987	No changes of significance are observed.
1988	No significant changes to the study area are observed except vegetation clearance seems to have taken place in the areas of hillside directly adjacent to the electricity poles in catchments Nos. 28 and 29.
1989	No changes of significance are observed.
1990	No photo coverage for catchment No. 30. No changes of significance are observed. Rock outcrops (B2) are evident immediately below catchments Nos. 24 and 25.
1991	Single, low flight, good resolution, aerial photograph was reviewed. No changes of significance are observed.
1992	Excavation works and reclamation works are apparent along the toe slope area of the study catchments. Three recent landslides (LS5 to LS7) are evident at catchments Nos. 22 and 24. Some debris avalanches (LS8 to LS13) are evident along the bank of drainage line (S3) in catchment No. 26. Another debris avalanche (LS14) is evident at the bank of drainage line (S2) in catchment No. 29. Two debris avalanches (LS15 and LS16) are visible at the bank of drainage line (S1) in catchment No. 30.
1993	About 20 recent landslides are visible on the hillside (Figure A7) [as a result of the 5 November 1993 rainstorm]. Construction of North Lantau Highway and Yu Tung Road has commenced (Figure A7). A recent open hillside landslide (LS17) is observed on the hillsides further downslope of catchment No. 22. Hillfire (HF2) can be identified as affecting the toeslope areas of study catchment Nos. 23 to 25. Two channelised debris flows (LS18 and LS19) and two debris avalanches (LS20 and LS21) are evident at the drainage line in catchment No. 29. Two landslides (LS22 and LS23) are visible at the upslope to midslope of catchment No. 30 while eight recent landslides (LS24 to LS31) are also observed downslope from catchment No. 30.

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

YEAR	**OBSERVATIONS**
1994	No changes of significance are observed except tree planting is apparent in the vicinity of study catchments Nos. 23 to 31. Many man-made slopes are formed along Yu Tung Road.
1995	No changes of significance are observed except slope Nos. 9SE-B/C26, 9SE-B/C27 have been formed along the Yu Tung Road.
1997	No changes of significance are observed.
1998	No changes of significance are observed.
1999	A recent landslide (LS32) is apparent at the catchment No. 22. Another landslide (LS33) is visible at the bank of drainage line (S1) in catchment No. 30.
2000	No changes of significance are observed.
	The landslide scars previously identified downslope from catchment No. 30 have mostly re-vegetated and become less apparent.
2001	No changes of significance are observed.
2002	No changes of significance are observed.
2003	Some localized vegetation clearance is observed along the upper northern spurline of catchment 30, as well as traversing the crest of catchment No. 30.
2005	No changes of significance are observed.
2006	No changes of significance are observed.

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

LIST OF TABLES

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

Table A1 - List of Aerial Photographs Examined

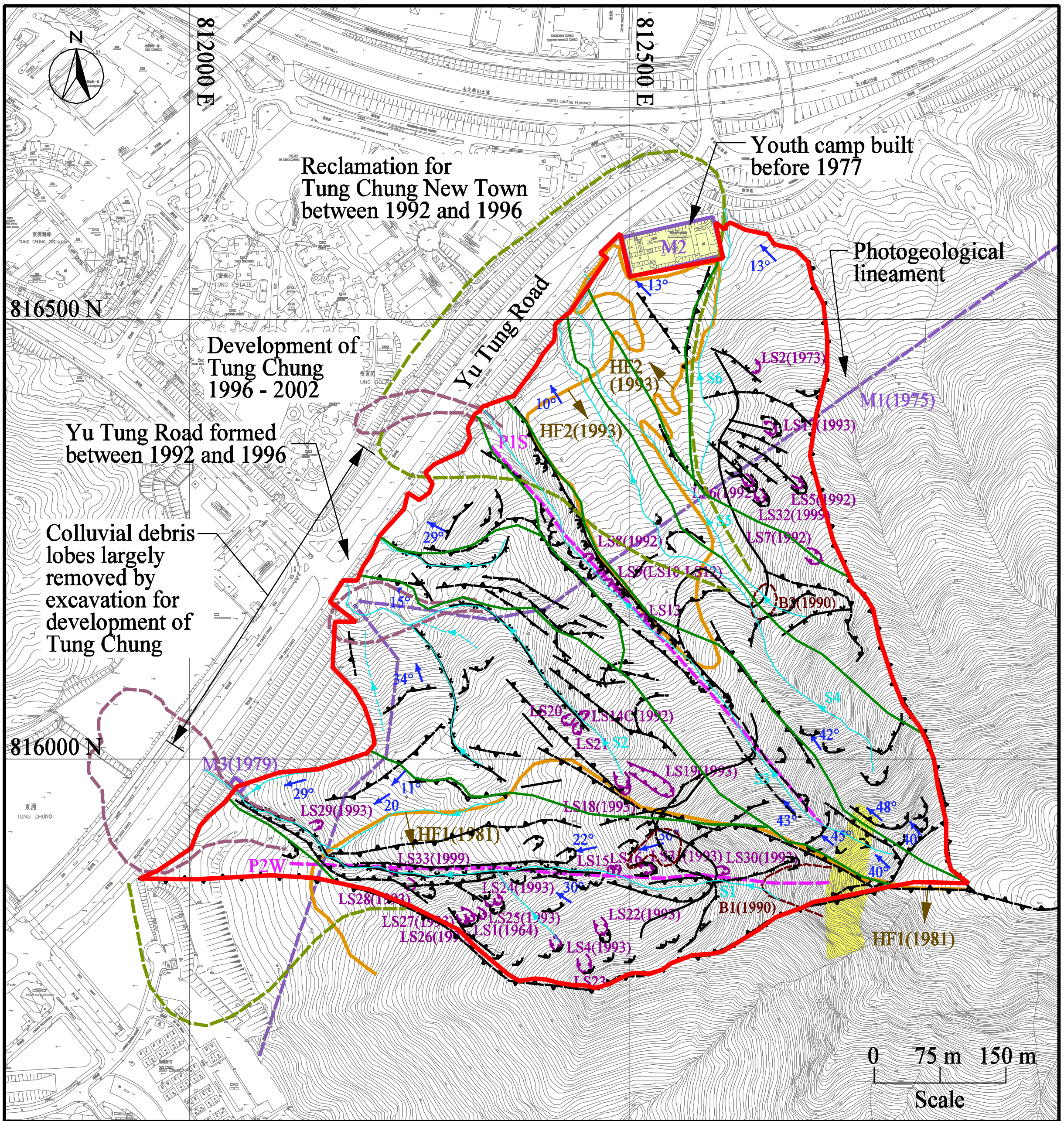
Date taken	Altitude (ft)	Photograph Number
11 November1945	20000	Y00404 – 7 Y00444- 8
25 January1963	3900	Y06358-9
24 January1963	3900	Y06280-1
14 December 1964	12500	Y12876-7
4 April1973	6000	3917-8
20 November1974	12500	9557-8
19 December1975	12500	11692-3
24 November1976	12500	16595-6
23 August1977	2500	18822
23 August1977	2500	18824
24 January1978	2500	21006-7
28 November1979	10000	27992-4
28 November1980	10000	33406-7
19 January1981	2000	36215-6
27 October1981	10000	39120-1
3 May1982	4000	41957-8
10 October1982	10000	44484-5
30 November1983	10000	51364-5
22 November1984	5000	57234-5
7 July1985	10000	A01742-3
19 December1986	3500	A07861
14 January1987	4000	A08717-8
25 October1988	4000	A14900
16 January1988	10000	A12230-1
20 November1989	10000	A19312-3
20 May1990	4000	CN2306-7,CN2309
6 December1990	4000	A24931
30 October1991	5000	A28955
8 December1992	3100	A33355-6
14 September1992	6000	CN3332-3
9 January1992	5000	CN2762-4
4 February1993	5500	A33909-10
5 December1993	6000	CN5205-6
28 March1994	6000	CN6258-60
20 December1994	5000	CN8933-4
31 October1995	5000	CN11631-2
11 November1996	5000	A43927-8

Table of Contents

Date taken	Altitude (ft)	Photograph Number
30 July1997	6000	CN17797-8
29 October1997	6000	CN18105-6
27 July1998	4000	CN20051-2
31 July1998	4000	CN20322
10 November1998	8000	CN22032-3
3 November1999	5500	CN24160
3 November1999	5500	CN24192-3
9 December1999	8000	CN25678-9
19 April2000	5000	CN26274-5
22 November2001	4000	CW36818-9
19 September2002	4000	CW43572-3
7 October2002	4000	RW01044
19 October2003	8000	CW50931-2
30 October2003	4000	CW51557-8
27 September2004	4000	CW59369
20 October2005	4000	CW65905-6
5 March2005	5000	RW05142
26 September2006	4000	CW72987-8
17 December2006	8000	CW75747-8
Note: All aerial photographs are in black and white apart from those with prefix CN and CW. RW refers to infrared.		

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

LIST OF FIGURES



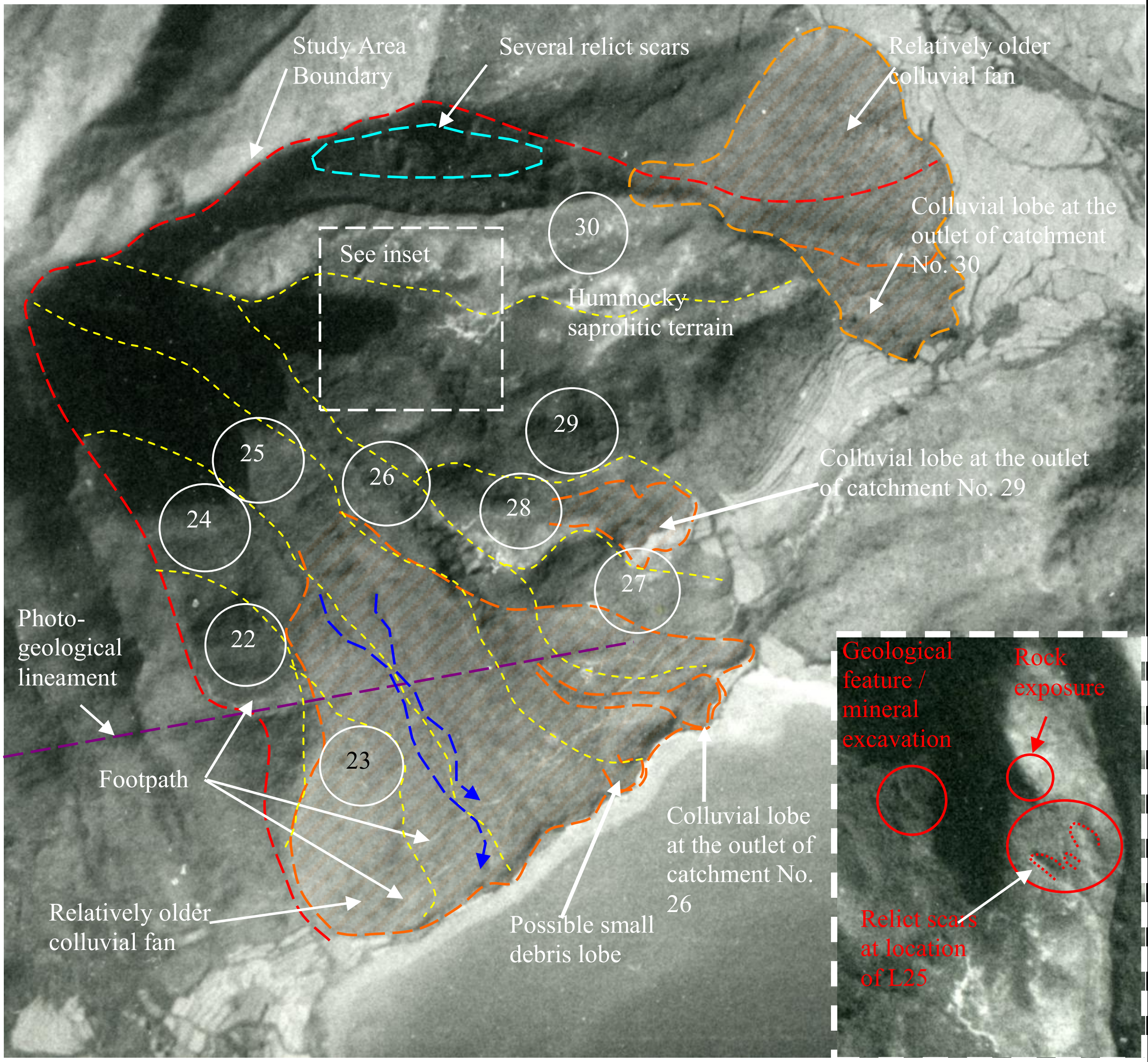
Legend :

Study area boundary	Rounded convex break-in-slope
Catchment boundary	Sharp convex break-in-slope
Perennial drainage line	Sharp concave break-in-slope
Ephemeral drainage line	Rounded concave break-in-slope
M1 Man-made feature with number	P2W Photolineament
LS23 Recent landslide with number	HF1(1981) Extent of hillside affected by hillfire and date
B2(1990) Boulder field / corestones	
Predominant rock	

Note : Base plan is extracted from 1 : 1000 survey sheets Nos. 9-SE-3D, 9SE-4C, 9SE-4D, 9SE-8B, 9SE-8D, 9SE-9A, 9SE-9B, 9SE-9C, 9SE-9D, 9SE-13B, 9SE-14A and 9SE-14B dated March 2008.

Figure A1 - Site History and Geomorphology

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



(Photograph Y00445 (20,000ft) taken on 11 November 1945)

Legend:

Study Area Boundary

Catchment boundary

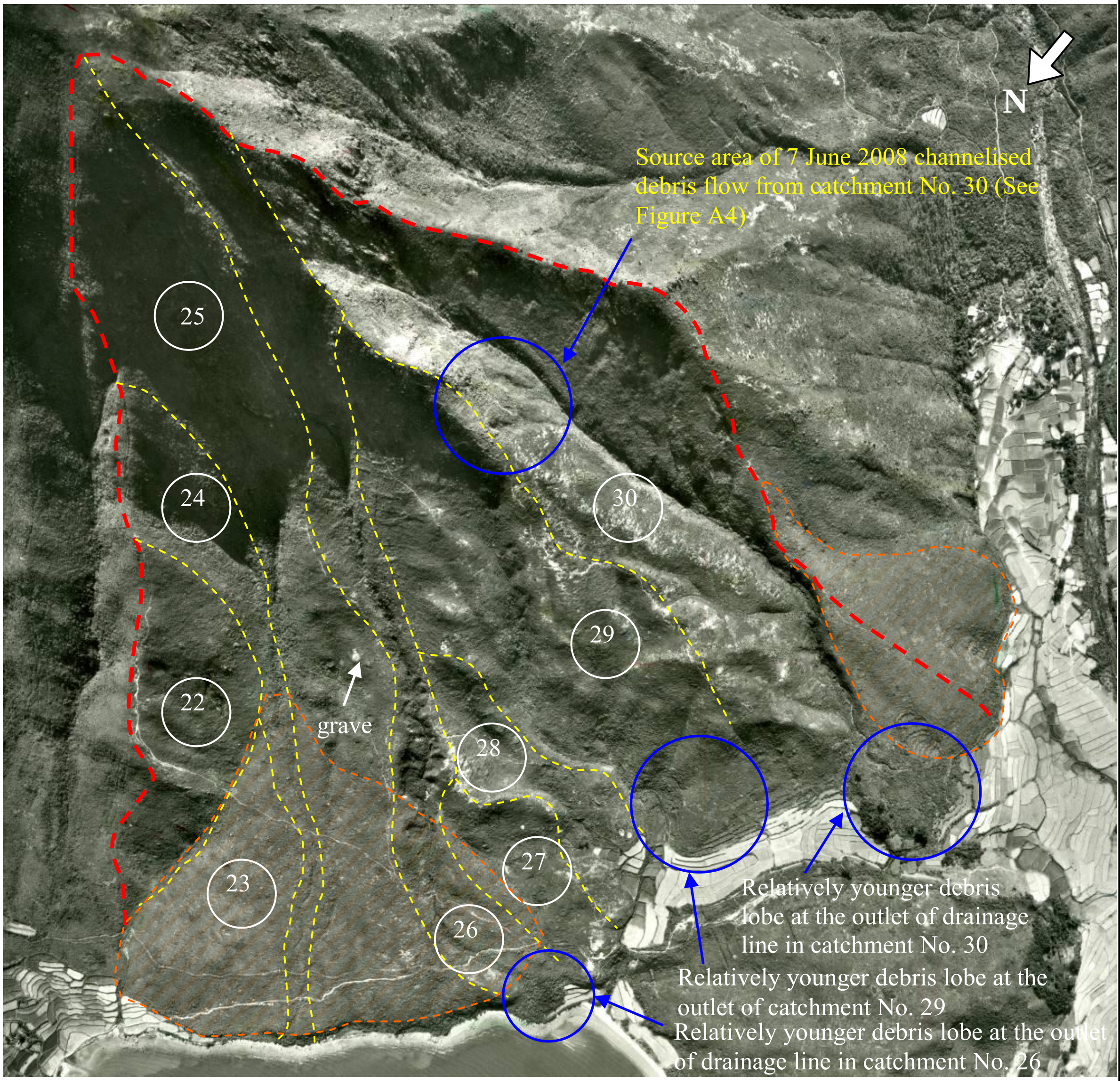
25 Catchment No.

Ephemeral drainage line

Relative older colluvial fans

Figure A2 - Interpretation of 1945 Aerial Photograph

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



(Photograph Y06358 (3,900ft) taken on 25 January, 1963)

Legend:

Study area boundary

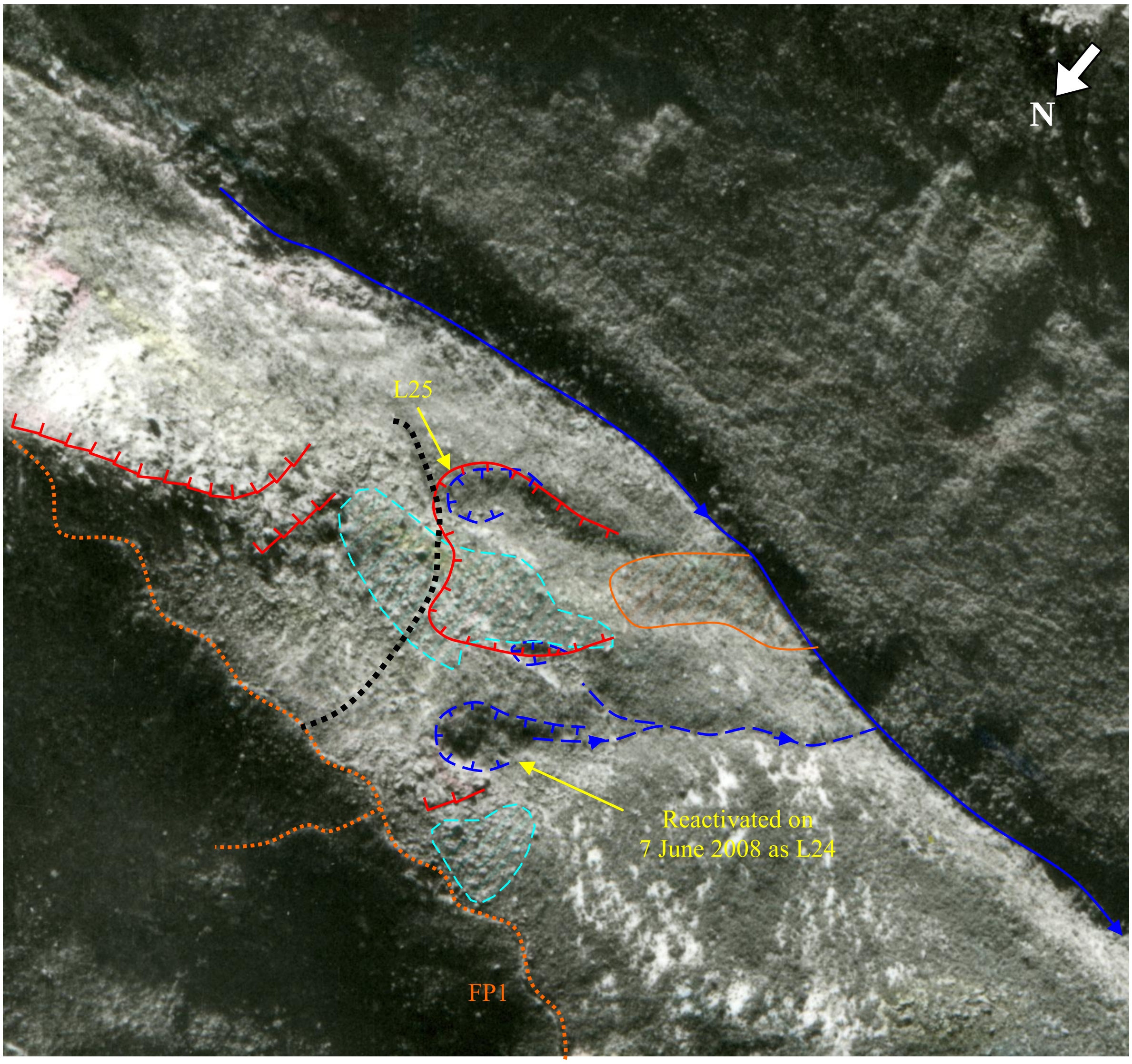
Relatively older colluvial fans

25 Catchment No.

Catchment boundary

Figure A3 - Interpretation of 1963 Aerial Photograph

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



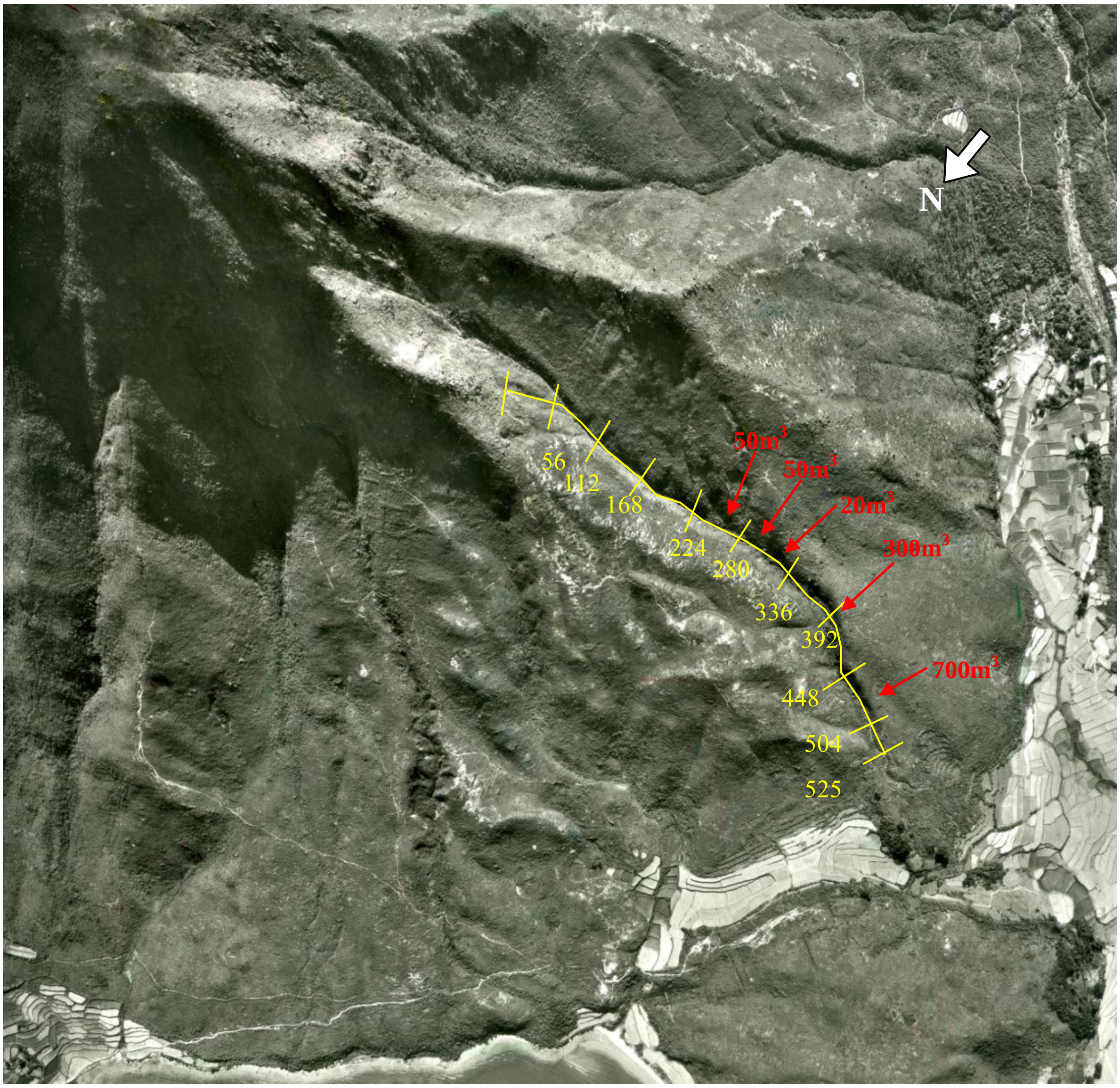
(Photograph Y06358 (3,900ft) taken on 25 January, 1963)

Legend:

- Ephemeral drainage line
- Streamcourse
- Relict failure scars
- Approximate extent of scar of 7 June 2008 source of CDF
- Concave break-in-slope above the landslide scar
- Debris lobe from previous failures
- FP1 Footpath and number
- Bouldery deposits
- Rock exposure

Figure A4 - Close-up of Source Area of the June 2008 Channelised Debris Flow in Catchment No. 30 Extracted from 1963 Aerial Photograph

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



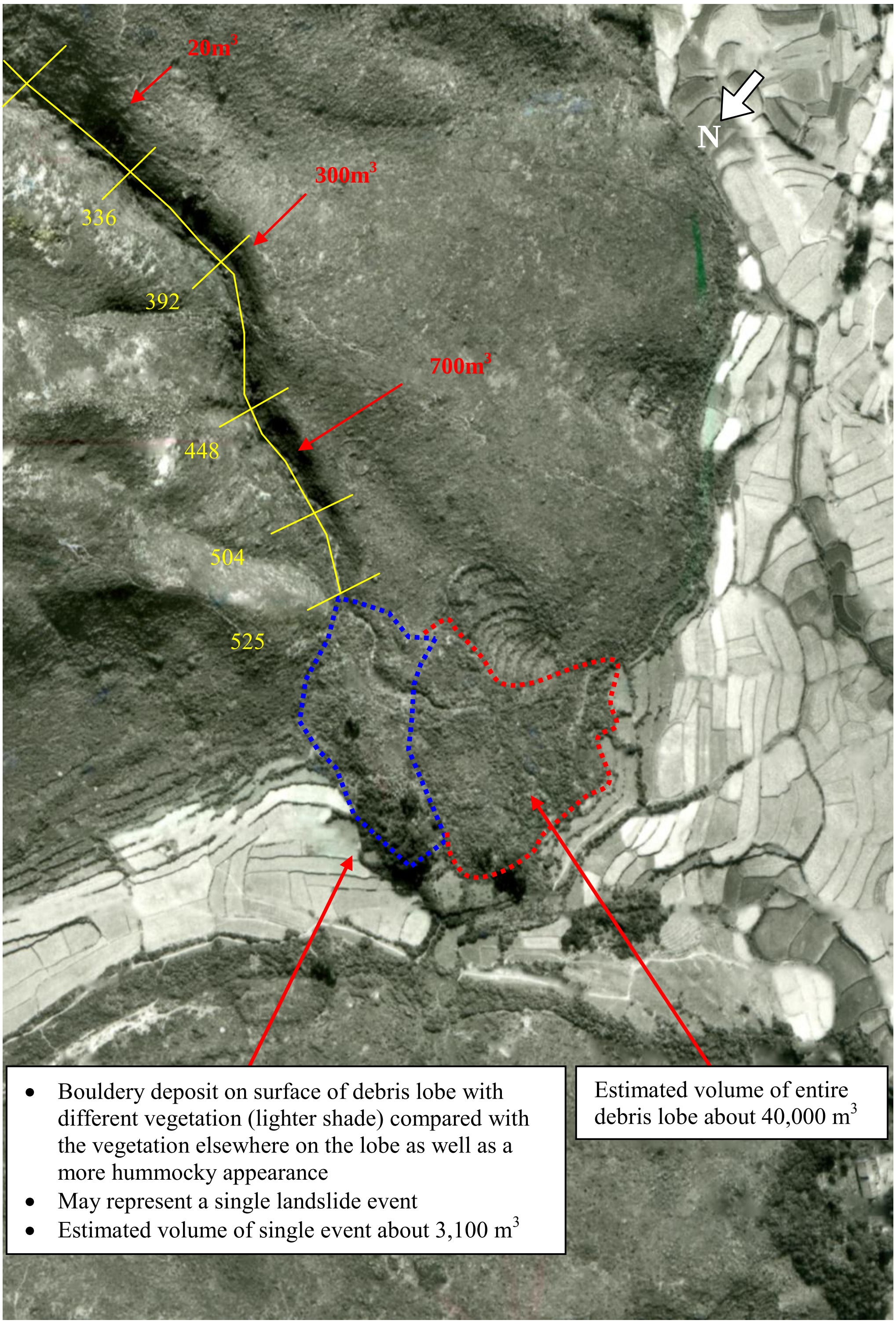
Chainage*	Estimated Volume (m^3)
235-252	50
258-291	50
302-325	20
336-414	300
448-525	700

Notes
* Chainage is approximate and refers to plan chainage along 2008 debris flow

(Photograph No. Y06358, (3900 ft), taken on 25 January 1963)

Figure A5 - Estimate of Perched Material along Drainage Line from 1963 Aerial Photograph

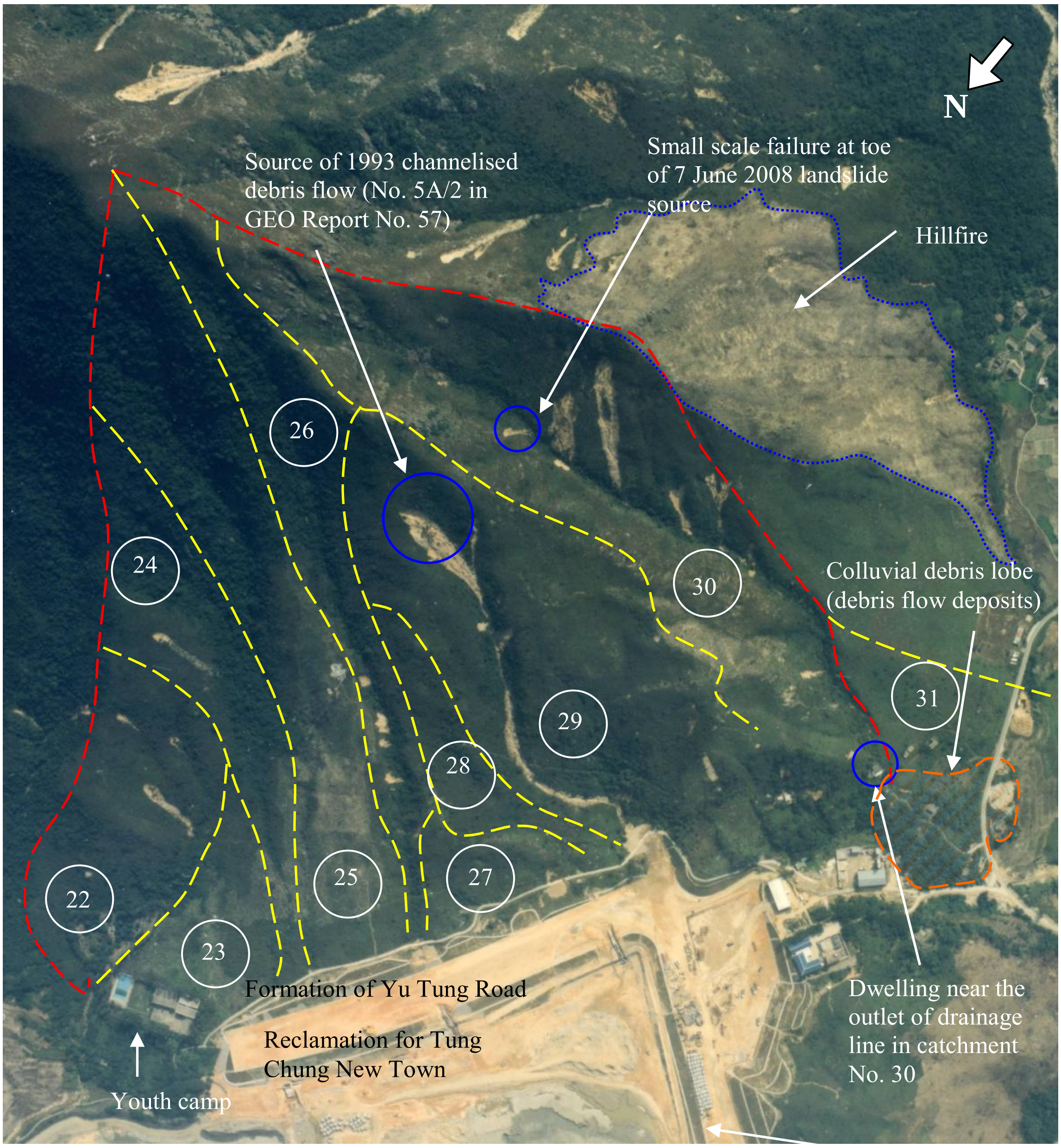
Table of Contents
Table of Contents
Table of Contents
Table of Contents



(Photograph No. Y06358, (3900 ft), taken on 25 January 1963)

Figure A6 - Extract from 1963 Aerial Photograph Showing Colluvial Debris Lobe at the Outlet of the Drainage Line in Catchment No. 30

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



(Photograph No. CN5205 (6,000 ft) taken on 5 December 1993)

Legend:

Catchment Boundary

Study Area Boundary

(22) Catchment Number

Figure A7 – Interpretation of 1993 Aerial Photograph

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

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

APPENDIX B

SUMMARY OF DETAILED MAPPING AT LANDSLIDES NOS. L1, L2, L3 AND L25

CONTENTS

Table of Contents
Table of Contents
Table of Contents

B1. THE JUNE 2008 LANDSLIDES AND POST-FAILURE OBSERVATIONS

B1.1 General

Three landslides within the study area were mapped in detail using mapping proformas and included Landslide No. L3 (also denoted as LS08-214) in catchment No. 24, landslides Nos. L1 and L2 (also denoted as LS08-0213 and 0243), mapped as one event, in catchment No. 25 and landslide No. L25 (also denoted as LS08-0241) in catchment No. 30. The detailed field mapping reports are presented separately (Ref. No.: GCLI 2/A2/54-9).

B1.2 Landslide No. L3 (LS08-0214)

B1.2.1 General

Landslide No. L3 is located in catchment No. 24 (Figure 2). According to Incident No. LI/2008/06/2005, the landslide occurred at 9:00 am on 7 June 2008. The exact time of failure is uncertain, however, based on the Police recorded time for the landslides that affected Yu Tung Road of 8:59 am, Landslide No. L3 is assumed to have occurred at about 9:00 am. An initial inspection of the landslide was carried out on 7 June 2008 with detailed field mapping carried out between 29 July 2008 and 30 October 2008.

The landslide involved a displaced volume of about 150 m^3, attained a maximum active volume of about 450 m^3 and deposited about 250 m^3 alongside Yu Tung Road. The crown of the landslide is situated at an elevation of 226 mPD and the toe of the landslide at Yu Tung Road is at about 22 mPD. The landslide travelled a horizontal distance of 550 m and the travel angle of the landslide is about 22° (Cruden & Varnes, 1996). A longitudinal section through the landslide, together with the estimated volumes of materials entrained and deposited is presented in Figure 7.

Debris from the landslide travelled over and caused damage to cut slope No. 9SE-B/C52 and came to rest behind the safety barrier alongside the westbound carriageway of Yu Tung Road. Much of the debris retained behind the safety barrier was a coarse bouldery material with boulders up to 1 m in size, with a small proportion of smaller boulders travelling over the barrier onto the carriageway. Fine debris was washed out onto the road and carried down to the Tung Chung Eastern Interchange and also spilled onto the North Lantau Highway below the roundabout temporarily causing flooding. Muddy water also spilled over slope No. 9SE-B/F44, which was locally eroded through washout, and travelled onto Cheung Tung Road which was flooded to a depth of over 1 m for several hours.

B1.2.2 Source

The landslide source is located near the head of an ephemeral drainage line within a broadly concave depression bounded by north-northwest to south-southeast trending spurlines. The source measured about 15 m wide by 15 m long with a maximum depth of about 1 m, and involved the failure of about 150 m^3 of colluvium. The colluvium comprised angular to subrounded cobbles with much gravel and occasional boulders with a silty sandy matrix. The surface of rupture was primarily along the colluvium/moderately to slightly decomposed tuff interface, and ran partially along a planar joint surface (50/325) that defines the rockface

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

at that location and partly over irregular rockface. The surface of rupture is inclined at between 35° and 50°. There was evidence of soil piping and voids were observed between cobbles and boulders above the colluvium/rock interface in the backscarp. The vegetation located immediately adjacent to the landslide scarp comprises shrubs and grasses and small trees, however to the northeast, the vegetation becomes sparse where there is rock exposed and likely near surface moderately to slightly decomposed rock.

The landslide probably initiated as a translational slide along the colluvium/moderately decomposed tuff interface but the debris is likely to have broken up immediately below the toe of the source and develop into a debris avalanche.

B1.2.3 <u>Debris Trail</u>

Below the toe of the landslide source the debris travelled over a steep exposed rockface, inclined at about 40°, and due to the slight transverse dip of the rockface towards the east, colluvial material from along the eastern edge of the exposed rock was entrained. Between the source toe at CH15 and CH94 about 380 m^3 of material from the eastern flank was entrained.

At CH94 there is a prominent concave break-in-slope where the debris enters a drainage line and is likely to have developed into a debris flow. Between CH94 and CH249 there is little evidence of significant entrainment with total entrainment estimated to be about 5 m^3 over the interval. Between CH94 and CH180 the base of the drainage line is predominantly moderately decomposed rock with colluvium in both flanks. A northwest-southeast trending fault is evident in the rock along the base of the drainage line and appears to be a structural influence on the alignment of the drainage line through the interval. From about CH180 onwards the ephemeral drainage line is entirely within colluvium.

At about CH249 the debris trail runs very close to the debris trail for landslide No. L2 in the adjacent catchment No. 25 (Figure 2) with a distance of less than 2 m between the two debris trails at the nearest point. About 40 m^3 of super-elevated debris was deposited at about CH249, at a minor bend in the ephemeral drainage line. However there is insufficient evidence of the a clear top of debris at that point in order to take a super-elevation reading and as such an estimate of the likely debris velocity at that location cannot be made.

The drainage line is inclined at about 25° at CH249 but a series of steps in the drainage line between CH249 and about CH320 with local inclination over 40° suggest the debris velocity may have increased through this portion of the drainage line with evidence of a large boulder deposited on near the top of the eastern flank of the drainage line.

Between CH249 and CH450 an estimated 140 m^3 is entrained and about 70 m^3 is deposited including a pocket of super-elevated debris at CH343. The observed landslide debris is a remoulded clast and matrix supported debris, comprising cobbles and boulders with a silty sand matrix.

Between CH450 and CH605, at the crest of slope No. 9SE-B/C52, the drainage line becomes more open with a low degree of channelisation (greater than 6) and is inclined at between 15° and 20° with inclination decreasing downhill. A further pocket of super-elevated

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

debris was deposited at CH520 of about 50 m³ in volume and a broad lobe of debris up to 30 m across comprising about 150 m³ of remoulded debris is deposited either side of a central drainage line between CH547 and CH605. Vegetation has been flattened and an electricity/telephone pole has been tilted by debris impact in the vicinity of the debris lobe.

B1.2.4 Terminal Debris Lobe

At CH605 at the crest of slope No. 9SE-B/C52, the active volume is estimated to be about 250 m³. From CH605 the debris travels over the crest of the slope flattening a mesh fence along the crest and over the slope face causing damage through erosion of the slope material and exposing filter drains near the crest. The debris subsequently travels to the slope toe and is arrested behind the roadside safety barrier along the southeastern side of Yu Tung Road. It is likely that the debris velocity was very low at this point as little damage is caused to the barrier by the bouldery debris. The accumulated debris is approximately 30 m in length by 5 m width and up to 1.5 m thick.

B1.2.5 Outwash

Some bouldery debris and a significant proportion (estimated to be more than 50 m³) of fine material (sands, silts and clays) was washed out from the debris onto the road and carried down to the Tung Chung Eastern Interchange and also spilled onto the North Lantau Highway below the roundabout temporarily causing flooding. Muddy water also spilled over slope number 9SE-B/F44, which was locally eroded through washout, and travelled onto Cheung Tung Road which was flooded to a depth of over 1 m for several hours.

B1.3 Landslides Nos. L1 (LS08-0213) and L2 (LS08-0243)

B1.3.1 General

Landslides Nos. L1 and L2 are located within catchment No. 25 (Figure 2). The two landslides sources are situated at the heads of two separate ephemeral drainage line tributaries with the debris trails from the two landslides merging at the confluence of the tributaries and subsequently travelling down along the main drainage line within the catchment. The relative timing of the landslides is discussed below; however the landslides were mapped as a single event.

According to the Incident Report No. LI/2008/06/2016 the landslide was reported at 9:00 am on 7 June 2008. The exact time of failure is uncertain. Based on the Police reported time of 8:59 am for the landslide incidents that affected Yu Tung Road, Landslides Nos. L1 and L2 are also assumed to have occurred at about 9:00 am. An initial inspection of the landslide was carried out on 7 June 2008 with detailed field mapping carried out between 22 July 2008 and 20 October 2008. To provide a reference for field mapping and fixing the position of features within the debris trail a chainage was established along the centreline of the landslide with the starting chainage (CH0) at the uppermost extremity of the crowns of the landslides. As the two landslides are of different distances from the confluence point the

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

chainage from the crown of landslide No. L1, which is at a higher elevation, is referenced in terms of total travel distance.

The landslide sources volumes were about 60 m^3 and 75 m^3 for landslides Nos. L2 and L1 respectively. A further 460 m^3 of material was entrained in the upper portion of the drainage line with the majority came from a single area at the confluence of the two landslides, where about 290 m^3 of material were failed from the northern flank of the drainage line. The landslide attained an estimated maximum active volume of about 600 m^3, with the main pulse of the debris coming to rest within the drainage line with subsequent outwash onto the hillside in the lower portion of the hillside as well as into the drainage lines in the catchments Nos. 24 and 26 either side. The crown of landslide No. L2 is situated at an elevation of 296 mPD and the crown of landslide No. L1 sits at an elevation of 340 mPD the confluence point of the drainage lines is at 246 mPD. The debris continued along the ephemeral drainage line with little evidence of deposition along the rocky upper portion of the trail and a significant deposition of a large body of debris (about 500 m^3) below a concave break-in-slope between elevations 129 mPD and 107 mPD. The landslide debris is clast and matrix supported, comprising gravel, cobbles and boulders with a silty sandy matrix. The landslide travelled a horizontal distance of 450 m and the travel angle of the landslide is about 29° (Cruden & Varnes, 1996), measured from the crown of landslide No. L2 to the distal end of the depositional fan of the main debris pulse at CH562. A longitudinal section through the landslide, together with the estimated volumes of materials entrained and deposited is presented in Figure 8.

Much of the bouldery debris from the landslide was deposited near the base of the steep rocky section of the drainage line at the head of an existing colluvial debris fan (Plate 18) within the mid-portion of the catchment. The transition from steep rocky section of the drainage line to the lower portion of the catchment is marked by a prominent concave break-in-slope (Figure 8). Subsequent outwash travelled over the hillside with a proportion of outwash material travelling into catchments Nos. 24 and 26 either side as well as spreading over hillside in the lower portion of the catchment No. 25. Debris from the landslide in catchment No. 25 did not reach Yu Tung Road directly.

B1.3.2 Source

The source of landslide No. L2 is located near the head of an ephemeral drainage line within a broadly concave depression. The source measured about 8 m wide by 13 m long with a maximum depth of about 1.2 m, and involved the failure of about 60 m^3 of colluvium. The colluvium comprised angular to subrounded cobbles with much gravel and occasional boulders and a silty sandy matrix. The surface of rupture is an irregular colluvium/moderately to slightly decomposed tuff interface irregular. The surface of rupture is inclined at about 40°. Voids were observed between cobbles and boulders above the colluvium/rock interface in the backscarp.

The source of landslide No. L2 is located near the head of an ephemeral drainage line within a more distinct concave depression. The source measured 8.7 m wide by 11 m long with a maximum depth of about 1.5 m, and involved the failure of about 75 m^3 of colluvium. The colluvium comprised angular to subrounded cobbles with much gravel and occasional boulders and a silty sandy matrix. The surface of rupture is along the colluvium/moderately

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

decomposed tuff interface and appears to be along an adversely orientated joint (38/342) in the tuff at the southern half of the source area. The surface of rupture is inclined at between 35° and 40°. Soil pipes were observed in the backscarp. Above the crown of the landslide No. L1 there is a distinct concave break-in slope, but no tension cracks, although the curved form and proximity of the concave break-in-slope suggests a larger area was affected by the 2008 landslide. Distinct relic landslide scarps were also observed in the hillside uphill of the landslide crown, which indicated that the 7 June 2008 failure probably comprised of landslide debris (colluvium) derived from earlier landslides.

The vegetation located immediately adjacent to both landslide scars comprises shrubs and small trees. Minor rafts of vegetation near the landslide backscarps of both landslide suggest that the failure initiated as a translational slide and likely developed into a debris flow immediately below the source toe along the ephemeral drainage line.

B1.3.3 Debris Trail

Debris from landslide No. L1, with a volume of about 75 m^3, travelled over a steep rock face inclined at between 40° and 50° and entrained about 35 m^3 of material resulting in an estimated active volume of about 110 m^3 at CH176 at an elevation of about 246 mPD.

Debris from landslide No. L2, with a volume of about 60 m^3, travelled over a steep rock face inclined at about 45° to 50° about 70 m, at which point the eastern side slope of the drainage line failed and released about 290 m^3 of debris. This increased the active volume of Landslide No. L2 to about 460 m^3 at about CH200.

Field inspection of landslide No. L1 indicated debris and fallen vegetation partially covering the lowest point of the ephemeral tributary where it confluences with the main drainage line. This indicates that landslide No. L1 has likely occurred before landslide No. L2 with debris and vegetation from landslide No. L2 depositing on the mouth of the tributary. It is also likely that the debris released from landslide No. L1 have travelled via the confluence point at CH176, and were deposited further downstream probably between CH414 and CH562. However, during detailed field mapping the source of the debris could not be distinguished easily hence a combined overall active landslide volume from both landslides Nos. L1 and L2 was adopted in the mass balance assessment from the confluence point onwards.

The main pulse of the debris flow was thought to have originated from the landslide at source No. L2. The debris travelled through the confluence point and probably developed into a debris flow and continued along the drainage line, entraining a further 100 m^3 between CH176 and CH414 through local scouring from the base of the drainage line as well as entrainment of any perched material within the drainage line. Though there did not appear to be any evidence of significant perched material along the mostly rocky streamcourse, with an estimated volume of perched material of only about 10 m^3 assumed to be entrained between CH156 and CH350 and a further 30 m^3 is estimated to have been entrained between CH350 and CH414. The active debris volume is therefore estimated to have attained a maximum of about 560 m^3 by CH414.

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

B1.3.4 Terminal Debris Lobe

Below a prominent concave break-in-slope below CH414 the drainage line opens and the gradient decreases significantly to about 15°, resulting in much of the debris, about 500 m^3, being deposited between CH414 and CH562 at around 110 mPD. The debris was deposited as an elongated super-elevation on the eastern outside edge of a bend in the drainage line. Several sizable boulders (up to 1.5 m across) and wood debris were present on the surface of the debris body.

A small portion of debris (about 100 m^3) continued beyond CH562. The debris was spread along the direction of the drainage line onto the hillside between CH562 and CH614. This part of the hillside below CH562 was relatively planar, where the debris was spread and deposited in a fan shape. At CH562, a proportion of the debris possibly travelled along the existing drainage line.

B1.3.5 Outwash

Outwash of debris deposited between CH414 and CH562 was eroded along the western side of the drainage line where the debris was thinner. The volume of debris eroded is estimated to be about 100 m^3. A small proportion of the debris outwash continued to travel down the drainage line beyond CH562, with the largest proportion of the outwash material making their way through the newly deposited debris between CH562 and CH614. Outwash below CH614 spread over the hillside in the lower portion of catchment No. 25 with a proportion of fine debris washing into catchments Nos. 24 and 26 either side. A small volume (less than 5 m^3) of outwash was carried to the footpath above the crest of slope No. 9SE-B/C51 at the toe of the catchment.

B1.4 Landslide No. L25 (LS08-0241)

B1.4.1 General

Landslide No. L25 is located in catchment No. 30 (Figure 2). According to the GEO Incident No. 2008/06/0344 the landslide was reported at 9:00 am on 7 June 2008. Although an exact time of failure is not known based on the Police record, the landslide incident was reported at 8:59 am on 7 June 2008 and is therefore assumed to have occurred at about 9:00 am. The lower portion of the debris flow was captured on video and uploaded to the internet, however an exact time of failure cannot be determined from the video nor has it been possible to trace the person who took the video. An initial inspection of the landslide was carried out on 7 June 2008 with detailed field mapping carried out between 21 and 25 July 2008.

The crown of the landslide is situated at an elevation of 200 mPD and the toe of the landslide at Yu Tung Road is at about 17 mPD. The landslide travelled a distance of 625 m with a travel angle of about 17° (Cruden & Varnes, 1996). A longitudinal section through the landslide, together with the estimated volumes of materials entrained and deposited is presented in Figure 9.

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

The landslide most likely failed as a debris avalanche developing into a debris flow which became channelised. The landslide involved a displaced volume of 2,352 m³, (Ref. No. GCLI 2/A2/54-9) attained a maximum active volume of about 3,400 m³ and over 3,100 m³ of the debris were deposited onto the westbound carriageway of Yu Tung Road (Figure 9). The two westbound lanes of Yu Tung Road affected by the landslide were subsequently closed for over two months, after which time a temporary debris barrier was erected and one westbound lane was reopened.

B1.4.2 Source

The landslide source is located on the southwest facing flank of a drainage line below a rock outcrop. The hillside above the landslide crown is inclined at about 35° and has a cover of angular to subangular boulders, up to 3 m across, that have travelled down from the rock outcrop. Boulders were also observed in the aerial photographs (Figure A4) to have been present on the hillside affected by the 7 June 2008 failure.

The source measured 32.5 m wide and 55 m long with a maximum thickness of about 3 m. The total estimated volume of failure based on post-failure detailed topographical survey is 2,352 m³. The gradient of the source varies from about 45° to 50° at the backscarp to about 30° near the toe. A minor tension crack was observed near the northern flank of the scar.

The failed material comprised a bouldery colluvium/talluvium (a matrix supported boulder rich colluvium) comprising subangular to subrounded cobbles with much gravel and occasional boulders and a silty/clayey sandy matrix. The failure mainly involved the colluvium/talluvium over saprolite with part of the surface of rupture through the upper portion of the underlying completely and highly decomposed fine ash tuff. With a planar adversely orientated joint surface (30/258) in moderately decomposed tuff exposed in the base of the landslide near the northeastern portion of the source suggesting the failure was probably structurally controlled locally.

Evidence of distress was observed in the insitu decomposed tuff through dilated joints in the moderately decomposed tuff exposed in the backscarp and deformed quartz veins in the completely decomposed tuff near the lower portion of the source area. The presence of the deformed quartz veins and increased degree of decomposition of the volcanic tuff near the lower portion of the landslide source suggest the presence of a fault, but a fault was not directly observed. There was also evidence of soil piping and voids were observed between cobbles and boulders in the colluvium in the backscarp. The vegetation located immediately adjacent to the landslide scarp comprises shrubs and grass.

The landslide probably initiated as a translational slide breaking up to a debris avalanche which developed into a debris flow immediately upon entering the drainage line below and subsequently became channelised.

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

B1.4.3 Debris Trail

On entering the drainage line the debris ran-up onto the opposite flank of the drainage line depositing boulders and large trees up to 8 m above the centre line of the drainage line. Debris levees (thin) have been deposited along the flanks of a pre-existing permanent drainage line. The gradient of the debris trail varies from 15° to 30° but is less nearer to the road of long section before runout alongside the Yu Tung Road.

Between CH65 and CH340, the drainage line was predominantly incised and moderately steep (about 25°). Based on super-elevation (Hungr et al, 1984), data the debris flow was estimated to have been travelling at about 12 m/s at CH100 and was eroding materials from the flanks and base of the drainage line with only minimal deposition along the flanks of the drainage line. The active volume increased to a maximum of about 3,345 m^3 by CH340. It is apparent that all perched materials in the drainage line were entrained with few boulders remaining in the drainage line after the debris flow. The side slopes of the drainage line were scoured but the depth of erosion from the flanks was typically less than 200 mm. The 1963 aerial photographs indicated that the drainage line was incised through this portion of the debris trail and its overall geometry was similar to that after the 7 June 2008 debris flow (see Figures Nos. A3 to A5 in Appendix A).

Between CH330 and CH510, the drainage line becomes less channelised with the gradient decreasing to less than 20°, with intermittent rock steps in the channel. Based on super-elevation measurements taken during the field mapping the debris was travelling at about 10 m/s through this section of the drainage line. Estimated debris velocities based on super-elevation data (Hunger et al, 1984) were 9.94 m/s at CH413, 9.82 m/s at CH439, 10.42 m/s at CH462 and 10.89 m/s at CH477 (Tattersall et al, 2009b).

Based on the field evidence the leading edge of the debris flow appeared to have continued to entrain the existing perched materials including boulders along the drainage line, although deposits of debris from which the fines were subsequently washed away by post landslide fluvial erosion leaving cobbles and boulders (generally less than 300 mm in dimension) were evident along the less steep sections of the drainage line. There was little change in the active volume between CH330 and CH510.

The drainage line gradient decreased to about 12° to 15° and opened out between CH510 and CH550, at which point debris disposition along the flanks of the drainage line occurred were apparent although based on the video evidence the main pulse of debris velocity did not appear to decrease towards the crest of the cut slope No. 9SE-B/C27 adjacent to Yu Tung road. The largest proportion of debris, including many large boulders continued to discharge at high velocity over the cut slope, ripping the trees from the surface of slope No. 9SE-B/C27, with an estimated volume of over 3,100 m^3 of debris being deposited on Yu Tung Road.

B1.4.4 Debris Lobe and Outwash

The debris ran onto Yu Tung Road, and spread over and came to rest on the two westbound lanes of the road and the vegetated central reservation separating the westbound and eastbound carriageways. Although the debris appeared to contain a high quantity of

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

water it was also apparent that the debris contained a significant proportion of boulders (possibly up to 40% boulder content), and some up to 2.5 m in size. A small quantity of debris reached the eastbound lanes of Yu Tung Road (Plate 38), which indicated that the debris had slowed down rapidly on impacting with Yu Tung Road. According to the Highways Department, about 3,500 m^3 of debris were removed from Yu Tung Road. Following removal of the debris from Yu Tung Road and the drainage channel the damage to the concrete could be observed, which suggested significant boulder impact had occurred during the debris flow.

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

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

APPENDIX C

SUMMARY OF PREVIOUS GROUND INVESTIGATION

Table C1 - Summary of Previous Ground Investigation in the Vicinity of the Study Area (Sheet 1 of 2)

Project	Contractor	Date carried out	Types of works carried out	Remarks
Public Work Development Hong Kong (P.W.D.) Contract No. 682/77	Gammon (Hong Kong) Ltd.	November 1978	2 Drillholes (D124 to D125)	D124 (in catchment No. 23): 12m colluvium (mainly sandy silt with porphyry boulder) over CD to SD feldsparphyric rhyolite; D125(in catchment No. 24): 14m colluvium (mainly sandy silt with porphyry boulder) over CD to MD feldsparphyric rhyolite;
Trunk Road to Replacement Airport at Chek Lap Kok Phase I	Bachy Soletanche Group	March 1982 to April 1982	6 Drillholes (TRL113 to TRL114, TRL116 to TRL118, TRL331)	(In catchment Nos. 23 to 26): Up to 10m of colluvium over CDT
North Lantau Development Phase I Development at Tung Chung (Contract No. GC/89/08)	Geotechnics & Concrete Engineering (H.K.) LTD.	November 1991	1 Drillhole (NL205)	NL205 (in catchment No. 27): 6m colluvium; 9m CD feldsparphyric rhyolite Piezometer installed with response zone from 13.7m to 15m, dry on 16^{th} and 18^{th} to 23^{rd} November 1991.
Natural Terrain Hazard Studies at North Lantau Expressway and Luk Keng Village – Feasibility Study (North Lantau Study Area) (Agreement No. CE89/2002 (GE)) (Contract No. GE/2001/14)	Geotechnics & Concrete Engineering (H.K.) LTD.	September 2003 to December 2003	2 drillholes (BH1 to BH2) 7 Trial Pits (TP11, TP16 to TP19, TP22, TP26)	BH1& BH2(in catchment No. 24): up to 3m of colluvium over CDT and MDT Trial pits: All terminated in colluvium apart from TP18 (in catchment No. 26) which terminated at 2.22m in CDT.

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

Table C1 - Summary of Previous Ground Investigation in the Vicinity of the Study Area (Sheet 2 of 2)

Project	Contractor	Date carried out	Types of works carried out	Remarks
Natural Terrain Hazard Mitigation Works at North Lantau Expressway and Yu Tung Road Near Tung Chung Eastern Interchange Design and Construction (Agreement No. CE9/2007) (Contract No. GE/2006/02)	Gammon (Hong Kong) Ltd.	March 2008 to May 2008	11 drillholes (DH13 to DH23) 5 Trial Pits (TPA to TPB, TP6 to TP8)	Most GI stations encountered up to 3m colluvium over CDT and MDT. About 16m of colluvium was encountered in DH20 (in catchment No. 30).
Notes: CDT HDT MDT SDT	 Completely decomposed tuff Highly decomposed tuff Moderately decomposed tuff Slightly decomposed tuff			

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

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

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

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

Writing to
Publications Sales Section,
Information Services Department,
Room 402, 4th Floor, Murray Building,
Garden Road, Central, Hong Kong.
Fax: (852) 2598 7482

or
- Calling the Publications Sales Section of Information Services Department (ISD) at (852) 2537 1910
- Visiting the online Government Bookstore at http:// www.bookstore.gov.hk
- Downloading the order form from the ISD website at http://www.isd.gov.hk and submitting the order online or by fax to (852) 2523 7195
- Placing order with ISD by e-mail at puborder@isd.gov.hk

讀者可採用以下方法購買土力工程處刊物(地質圖及免費刊物除外)：

書面訂購
香港中環花園道
美利大廈4樓402室
政府新聞處
刊物銷售組
傳真: (852) 2598 7482

或
- 致電政府新聞處刊物銷售小組訂購 (電話：(852) 2537 1910)
- 進入網上「政府書店」選購，網址為 http://www.bookstore.gov.hk
- 透過政府新聞處的網站 (http://www.isd.gov.hk) 於網上遞交訂購表格，或將表格傳真至刊物銷售小組 (傳真：(852) 2523 7195)
- 以電郵方式訂購 (電郵地址：puborder@isd.gov.hk)

1:100 000, 1:20 000 and 1:5 000 geological maps can be purchased from:

Map Publications Centre/HK,
Survey & Mapping Office, Lands Department,
23th Floor, North Point Government Offices,
333 Java Road, North Point, Hong Kong.
Tel: (852) 2231 3187
Fax: (852) 2116 0774

讀者可於下列地點購買1:100 000、1:20 000及1:5 000地質圖：

香港北角渣華道333號
北角政府合署23樓
地政總署測繪處
電話: (852) 2231 3187
傳真: (852) 2116 0774

Requests for copies of Geological Survey Sheet Reports and other publications which are free of charge should be directed to:

For Geological Survey Sheet Reports which are free of charge:
Chief Geotechnical Engineer/Planning,
(Attn: Hong Kong Geological Survey Section)
Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon, Hong Kong.
Tel: (852) 2762 5380
Fax: (852) 2714 0247
E-mail: jsewell@cedd.gov.hk

For other publications which are free of charge:
Chief Geotechnical Engineer/Standards and Testing,
Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon, Hong Kong.
Tel: (852) 2762 5346
Fax: (852) 2714 0275
E-mail: florenceko@cedd.gov.hk

如欲索取地質調查報告及其他免費刊物，請致函：

免費地質調查報告:
香港九龍何文田公主道101號
土木工程拓展署大樓
土木工程拓展署
土力工程處
規劃部總土力工程師
(請交:香港地質調查組)
電話: (852) 2762 5380
傳真: (852) 2714 0247
電子郵件: jsewell@cedd.gov.hk

其他免費刊物:
香港九龍何文田公主道101號
土木工程拓展署大樓
土木工程拓展署
土力工程處
標準及測試部總土力工程師
電話: (852) 2762 5346
傳真: (852) 2714 0275
電子郵件: florenceko@cedd.gov.hk

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

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