DETAILED STUDY OF THE 10 AUGUST 2002 LANDSLIDE INCIDENT ON A CUT SLOPE AT VICTORIA ROAD, HONG KONG

GEO REPORT No. 158

Halcrow China Limited

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

DETAILED STUDY OF THE 10 AUGUST 2002 LANDSLIDE INCIDENT ON A CUT SLOPE AT VICTORIA ROAD, HONG KONG

GEO REPORT No. 158

Halcrow China Limited

This report was originally produced in February 2004 as GEO Landslide Study Report No. LSR 2/2004

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

© The Government of the Hong Kong Special Administrative Region

First published, January 2005

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
Table of Contents

Table of Contents

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

R.K.S. Chan
Head, Geotechnical Engineering Office
January 2005

FOREWORD

This report presents the findings of a detailed study of a major landslide (GEO Incident No. 2002/08/0076) which occurred on 10 August 2002 on a soil/rock cut slope within an active construction site of the road improvement project along Victoria Road, Pokfulam. The volume of the failure mass was about 80 m^3. The landslide debris did not affect the traffic lanes of Victoria Road and no casualties were involved as a result of the incident.

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

The report was prepared as part of the 2002 Landslide Investigation Consultancy for landslides occurring in Hong Kong Island and Outlying Islands in 2002, for the Geotechnical Engineering Office, Civil Engineering Department, under Agreement No. CE 86/2001 (GE). This is one of a series of reports produced during the consultancy by Halcrow China Limited.

Dr X D Pan
Project Director
Halcrow China Limited

Agreement No. CE 86/2001 (GE)
Study of Landslides Occurring in Hong Kong Island and Outlying Islands in 2002 – Feasibility Study

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

CONTENTS

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

1. INTRODUCTION

At around 7:00 a.m. on 10 August 2002, shortly after the cancellation of an Amber Rainstorm Warning, a major landslide (GEO Incident No. 2002/08/0076), with a failure volume of about 80 m^3, occurred on a newly formed soil/rock cut slope within an active construction site of a road improvement project at Victoria Road, Pokfulam (Figure 1). The landslide debris was deposited within an area in front of the slope toe and did not affect the traffic lanes of Victoria Road. No casualty or road closure was involved as a result of the incident.

Following the incident, Halcrow China Limited (HCL), the 2002 Landslide Investigation Consultants, carried out a detailed study of the landslide for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 86/2001 (GE).

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

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

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

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

(c) limited ground investigation and laboratory testing,

(d) aerial photograph interpretation (API),

(e) analysis of rainfall data,

(f) engineering analysis of the failure, and

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

2. THE SITE

2.1 Site Description

The landslide occurred at the southern end of a newly formed soil/rock cut slope above Victoria Road, which is within the boundary of the 'Victoria Road Improvements Stage II Phase 2' project. A site location plan showing the boundary of the cut slope (designated as slope C7 in the road improvement project) involved in the incident, together with the approximate location of the 2002 landslide, is shown in Figure 1. A general view of the slope is presented in Plate 1.

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

The subject slope, located on the east (i.e. uphill) side of Victoria Road, is a newly formed soil/rock cut of about 180 m long with heights varying between 5 m and 22 m. The central portion of the slope is predominantly rock and comprises three batters (each about 7.5 m high) with intervening berms of 1.5 m in width. At the two ends of the slope, including the portion in which the 2002 landslide occurred (Plate 2), there is only a single batter which is predominantly soil. A pedestrian pavement, up to 3 m wide, was under construction at the slope toe, and in front of it is Victoria Road with a two-lane, two-way carriageway. Following the substantial completion of the road widening project in October 2002, the slope was registered as slope No. 11SW-C/C924 in the Government's Slope Catalogue.

The lower rock cut portions of the subject slope (up to 10 m high) generally have slope angles of between 61^{o} and 64^{o} and have been covered with steel wire mesh netting. The soil cut portions are at angles of between 42^{o} and 51^{o} and are vegetated with shrubs and grass. The area above the crest of the cut slope is natural hillside which is inclined at about 30^{o}.

Soil nails had been installed at some of the soil cut portions of the subject slope (Figure 2), at a spacing of about 1.5 m horizontally and 2.0 m vertically. Reinforced concrete grillage beams were constructed to connect the soil nail heads.

The surface drainage system for the subject slope was partially completed at the time of the landslide. The drainage channels on the slope are 300 mm wide and run along the toe, berms and crest. The drainage channels intercept surface runoff from upslope and direct the water towards stormwater inlets located at the slope toe near both ends of the slope (Figure 2). Runoff collected in each inlet is then carried by a 600 mm diameter cross-road drain and discharged onto the natural hillside at the western (downhill) side of the road.

2.2 Geological Setting

Sheet 11 of the Hong Kong Geological Survey 1:20 000 scale map series HGM20 (GCO, 1986) indicates that the solid geology at the subject slope comprises fine ash vitric tuff at the southern portion of the subject slope and fine grained granite at the northern portion of the subject slope (Figure 3). Much of the solid geology is indicated as being overlain by quaternary debris flow deposits.

2.3 Maintenance Responsibility

The contractor, Shanghai Construction (Group) General Corporation had possession of the site (including the subject slope) at the time of the landslide and was responsible for slope maintenance during the construction period.

2.4 Water-carrying Services

According to information provided by the utility undertakers together with field observations made by HCL after the landslide, two mild steel watermains of 670 mm and

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

900 mm in diameter (which are under the maintenance responsibility of the Water Supplies Department), are located underneath the carriageway of the widened Victoria Road (Figure 2). There are no other water-carrying services on or above the subject cut slope.

2.5 Site History

The history of the site has been established from a review of aerial photographs and inspection of the available documentary records. A detailed account of the aerial photograph interpretation (API) is presented in Appendix A. Salient aspects of the key observations are summarised below.

In the earliest aerial photographs (taken in 1924) examined, Victoria Road is seen to follow an alignment similar to that of the present day. A possible natural drainage line running approximately from north-east to south-west is observed to lie within about 10 m of the 2002 landslide (Plate A1). Some vegetation clearance appears to have been carried out along the drainage line. A farm with fenced or walled paddocks/fields is present at the top of the ridge line above the location of the 2002 landslide incident.

By 1949, two drainage channels directly above a roadside cut slope on the east side of the road are observed, with the channels appearing to drain towards and into an inlet pit at the approximate location of the 2002 landslide (Plate A1). The inlet pit on the eastern side of the road connects to a cross-road drain that outlets at the western side of the road and a possible debris fan is observed on the western side of the road at about the location of the probable cross-road drain outlet (Plate A1).

In the 1949 aerial photographs, a possible colluvial debris fan is observed at a location immediately above (east of) the 2002 landslide, which probably fans out from a natural drainage line about 10 m to 15 m to the south of the 2002 landslide (Plate A1).

Aerial photographs taken in 1963 show three areas that have been cleared of vegetation to the east and directly above the location of the 2002 landslide (Figure A1 and Plate A2). The nature and purpose of the cleared areas are not known. Much of the surrounding hillside comprises disturbed/cultivated terrain. In the 1968 aerial photographs, the previously prominent man-made drainage channels on the cut slope are difficult to delineate, indicating that they had possibly become blocked and overgrown, or disused, by that time (Plate A3).

By 1973, the hillside between Victoria Road and the farm on the ridgeline gives way to terrace type cultivation and several small buildings (possibly squatter huts) are observed amongst the terraces. Between 1973 and 1987, little change is observed other than a general increase in vegetation density and a slightly greater extent of terracing. However, in 1983 a structure (possibly a single-storey squatter hut) is identifiable between about 5 m and 6 m to the east of the 2002 landslide (possibly corresponding to observations at Trial Pit TP2, see Section 6). In the 1991 aerial photographs, the terraces appear to have been abandoned. Also, site inspection by HCL revealed that the structure had been cleared.

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

In 1987, HyD commenced the Victoria Road Improvements Project to improve and widen sections of Victoria Road covering a total length of about 4.2 km (Figure 4). The improvement works involved cutting into the hillside upslope of the existing road and construction of retaining walls and viaducts.

The works were divided into two stages. Stage I commenced in early 1980s and involved road sections of about 1.2 km in length. Stage II was further split into Phases 1 and 2. Stage II Phase 1 (under Contract No. HY/95/03) commenced in late 1995 involving road sections of about 1.2 km. Stage II Phase 2 (under Contract No. HY/97/03) commenced in December 1998 and involved road sections of about 1.8 km along Victoria Road. Under Agreement No. CE 19/86, the consultant for the Stage II was Rendel Palmer & Tritton (Asia) (RPT), subsequently renamed High-Point Rendel Hong Kong Limited (HPR). The contractor for the Stage II Phase 2 was Shanghai Construction (Group) General Corporation. The works were substantially completed in October 2002.

2.6 Past Slope Instabilities

There are no records of any previous reported landslides at the location of the 2002 landslide but other landslide incidents within the Victoria Road Improvements Project were reported.

In the wet season of 1996, four landslide incidents occurred within the works area of the Stage II Phase 1 of the project, which are about 1 km to 2 km to the north of the August 2002 landslide (see Figure 4). The slope works were under the supervision of RPT.

The first of the four landslide incidents (GEO Incident No. HK96/7/4) occurred on 25 July 1996 on a sub-vertical temporary cut slope for the construction of a retaining wall near No. 212 Victoria Road on the downhill side of the road, which resulted in complete closure of Victoria Road for two days. According to the GEO landslide incident report, the volume of failure was about 75 m^3. The temporary cut was about 10 m in height with an average slope angle of 80^o. Inadequate temporary support to the sub-vertical cut was probably a key factor in the failure.

The other three landslides in 1996 occurred during a rainstorm on 14 September 1996. GEO Incident No. HK96/9/1 was a rockfall (failure volume of about 24 m^3) from a 6 m high sub-vertical temporary soil/rock cut slope adjacent to No. 61 Mount Davis Road. This incident resulted in temporary evacuation of residents from three floors of Flat 1, Felix Villa. GEO Incident No. HK96/9/2 occurred near West Island School and involved a 30 m^3 washout failure which resulted in the accumulation of mud and debris in the car park, toilets and other areas of the school. GEO Incident No. HK96/9/3 occurred near the Chinese Christian Cemetery and involved a failure volume of about 45 m^3 from an 8 m high sub-vertical temporary soil cut slope which was reinforced with soil nails (but without conventional reinforced concrete soil nail heads). The landslide resulted in partial closure of the cemetery behind the slope crest.

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

3. PREVIOUS ASSESSMENTS

3.1 Geotechnical Design Submission by Binnie & Partners in 1988

In October 1988, Binnie & Partners (Hong Kong) (BPHK), the geotechnical sub-consultant to RPT, submitted a geotechnical design report entitled "SLOPE AND RETAINING WALL DESIGN" for the 'Victoria Road Improvements Stage II' project to the GCO for comments. This submission covered all the man-made slopes affecting and affected by the project, including slope C7.

According to the design report, the slope (designated as slope C7 in BPHK's report) involved in the 2002 landslide was proposed to be formed by cutting about 4 m into an existing 10 m high, 35^{o} to 40^{o} cut slope and the natural hillside above (Section A-A, Figure 5). No specific ground investigation was carried out for the subject slope and the nearest drillhole was more than 100 m to the south of the slope. As indicated in the design report, the subsurface geology of the slope comprised a thin layer (less than 3 m thick) of colluvium overlying rock (Figure 5), and the inferred rockhead was assumed to be inclined at an angle of about 30^{o}. The proposed slope profile had a maximum of three batters, with the rock cut portion inclined at 63^{o} whereas the soil portion cut back to 45^{o} with no need for lateral support such as soil nails. The report noted that "potential plane failure are likely to occur with the final [rock] cut profile" and "Buttressing and dowels may be required". The shear strength parameters of various types of soils were derived from laboratory testing on samples obtained elsewhere within the road widening project (Table 1). The consequence category of the proposed slope was assessed to be "Low" both in terms of "Risk-to-Life" (i.e. consequence-to-life) and "Economic Risk" (i.e. economic consequence) categories. The results of stability analysis indicated that with the assumption of dry condition, the proposed profile of the newly formed cut would have a minimum factor of safety (FoS) of 1.2.

GCO did not have specific comments on the proposed slope works for slope C7 (i.e. the proposed slope works for slope C7 were in effect accepted by the GCO). In the memo to HyD in December 1988, GCO recommended that "the road improvement works be supervised by an experienced geotechnical engineer or geologist who will verify the design assumptions on site" and "where actual ground and groundwater conditions differed significantly from those assumed at the design stage, re-design should be carried out for the subject slope". GCO also stated that "all rock cuts should be mapped after formation for the design of stabilisation works and records of these details should be submitted to the GCO for checking". In a memo dated 19 July 1991 from GCO to HyD confirmed that "there is no further adverse geotechnical comment" on the submission (i.e. the geotechnical submission was in effect accepted by the GCO).

3.2 Review of Existing and Proposed Slopes by Fugro (Hong Kong) Limited in 1996

In October 1995, HyD requested RPT to undertake a review of the "designs, drawings and contract documents" for the 'Victoria Road Improvements Stage II Phase 2' project. In April 1996, Fugro (Hong Kong) Limited (FHKL), the geotechnical sub-consultant to RPT, submitted a geotechnical report entitled "Review of Existing and Proposed Slopes" to GEO for comments.

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

The scope of the geotechnical report produced by FHKL included "a review of the previous GEO submission together with an assessment of the proposed and existing slopes", including slope C7. FHKL concluded that "the proposed slope works previously designed by Binnie are still valid". GEO did not have any comments on the above conclusion.

3.3 Supplementary Ground Investigation - Interpretative Report by Rendel Palmer & Tritton (Asia) in 1997

In mid-1997, a supplementary ground investigation was carried out under the supervision of RPT to "obtain information in areas where design changes have been proposed or data was sparse" and to "clarify the interpretations from the 1987 [BPHK's] investigation". As part of this supplementary ground investigation, one drillhole (DH102) was sunk near the centre of the subject slope at about 75 m to the north of the August 2002 landslide (Figure 2). In November 1997, an interpretative report was submitted by RPT to GEO. RPT considered that the shear strength parameters of the soil proposed by BPHK in 1988 (see Table 1) were still applicable. The interpretative report noted that slope C7 is likely to be underlain by a "nominal layer of Colluvium" overlying "in situ Granite". It was also indicated that BPHK's design in 1988 should remain "unchanged". The report further stated that upon completion of site clearance, the slope should be "reinspected in order to ascertain whether steeper slopes would be viable". The report noted that "a thorough evaluation of all proposed cuts by an experienced geotechnical engineer is essential during the construction period once vegetation and other coverings have been removed in order to confirm design assumptions", and that "where anomalies are noted additional soil reinforcement, such as soil/rock dowels or buttressing may be required. In extreme case local re-grading, requiring a redesign may be required".

In a memo dated 24 February 1998 to HyD, GEO requested HyD to submit the "permanent slope works design" for comment "once they are available". With reference to the queries raised in a previous memo from GEO to HyD dated 12 January 1998 concerning slope C7, it could be inferred that the above request of GEO related to the rock cut portion of slope C7 only. In the memo dated 24 February 1998, the GEO also stated the following: "most of the permanent slope works design are pending and the need of stabilization works to the existing fill alongside Victoria Road have not been finalized. It is strongly recommended that your consultant should resolve all these issues of permanent geotechnical design prior to tendering since the final scope of construction works and thus the cost may be substantially different. In addition, for those permanent slope works designs to be submitted during the construction stage, provision should be allowed in the Contract document such that the designs can be submitted for our checking prior to works commencement".

3.4 Report on Cut Slope C7 Submitted by High-Point Rendel in 2002

On 31 July 2002 (i.e. about 17 months after the bulk excavation work and soil nail installation and grillage beam construction had been carried out by the contractor and three months before the substantial completion of works of the entire project, see Section 4.3), a geotechnical report entitled "Soil Nail Design for Cut Slope C7 (Ch2180 to Ch2350)" was submitted by HPR to the GEO for comments. The report covers the design of soil nails for

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

the soil cut portion only in slope C7. According to the Island Division of the GEO, the soil nail design for slope C7 was submitted by HPR in response to a GEO's verbal query made in early July 2002 regarding the soil nailing works on various cut slopes within the project area following a site inspection. According to the GEO, given that the original design for slope C7 (as accepted by GCO in 1988) only involved cut back, the installation of soil nails was taken to be a design amendment to cater for the actual site conditions.

The general arrangement of the works for slope C7 and the surface drainage layout as presented in the geotechnical report is reproduced in Figure 2. The profile of the slope was presented using three cross-sections. The nearest design slope profile was about 30 m to the north of the 2002 landslide and consisted of two slope batters (Figure 6). The lower batter was shown as a cutting inclined at 47^{o} mostly in highly decomposed volcanics (HDV) overlying moderately to slightly decomposed volcanics (M/SDV), with the soil/rock interface at about 2 m above slope toe level. The upper batter was shown as a 43^{o} cutting in HDV.

In the geotechnical design, the proposed minimum FoS was 1.4 (the reason for adopting a higher FoS as compared with the value of 1.2 as proposed in BPHK's geotechnical report in 1988, which was accepted by the GCO, was not given in HPR's report). In the stability analyses of three cross-sections, the assumed ground model consisted of HDV overlying M/SDV. Shear strength parameters of $c' = 13$ kPa and $\phi' = 38^{o}$ were adopted for HDV, which are consistent with that presented in BPHK's design report (Table 1). A groundwater level at 1.5 m above the inferred rockhead was assumed in the stability analyses.

The results of the stability analyses indicated that in order to achieve the proposed minimum FoS of 1.4, soil nails were required. RPT proposed that the slope be cut to 45^{o} in soil and 63^{o} in rock. The design comprised installation of soil nails (at a horizontal spacing of 1.5 m and a vertical spacing of 2 m) in "all material except rock materials". The design of the soil nails was based on bonding into rock. Reinforced concrete grillage beams were proposed to connect the soil nail heads together.

According to the report, no soil nails were provided to the failed section of the August 2002 landslide (Figure 2) and no stability analysis was carried out to check the FoS of the section (which has a maximum height of 5.5 m). It was not stated in the report whether the failed section comprised soil or rock. Based on the correspondence between the consultant and the contractor in May 2000 (see Section 4.3), the consultant appeared to be aware that the section that subsequently failed on 10 August 2002 comprised entirely soil material.

The design submission was yet to be commented by the GEO at the time of the 10 August 2002 landslide.

4. SLOPE WORKS UNDER VICTORIA ROAD IMPROVEMENTS STAGE II PHASE 2

4.1 General

The 'Victoria Road Improvements Stage II Phase 2' project commenced in December 1998 to widen two sections of Victoria Road with a total length of about 1.8 km (Figure 4). Under the Stage II Phase 2 road improvement works, about 22 slope features, comprising soil/rock cuts, fill slopes and retaining walls, are to be formed/upgraded.

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

4.2 Qualified Geotechnical Supervision

Following the landslide incidents within the Victoria Road Improvements Stage II project boundary in 1996, the GEO expressed concerns to the HyD relating to the level of geotechnical control on site, in particular on the "adequacy of control on the temporary works design, geotechnical input, and site supervision". In response, RPT confirmed that for the Stage II Phase 2 project, a "qualified resident geotechnical engineer", with design support by an experienced geotechnical professional from the design office, would be provided (see Section 2.6).

According to the qualified supervision requirements as stipulated by the GEO for the geotechnical works for the 'Victoria Road Improvements Stage II Phase 2' project, the Category I supervision personnel "shall make inspections at **weekly** intervals, or more frequently, to check that the design assumptions are valid and that the works are being carried out as specified" and that the "inspection records and reports shall be kept on site and made available for inspection". Reports to be prepared by Category I supervision personnel should include, among others, "any significant deviations of geology and groundwater conditions from the design assumptions". The Category III supervision personnel is required to be "resident full time on site" to check that the works are being carried out as specified.

4.3 Formation of Cut Slope C7

The bulk excavation of slope C7 commenced in November 1999 and was completed in August 2000. HPR submitted to GEO summaries of progress of the geotechnical works to GEO at about monthly intervals from September 1999 to March 2000, and at about bi-monthly intervals from April 2000 to November 2001.

In the progress summary of November 1999, HPR submitted a list of design changes that were needed for the individual slopes. For slope C7, HPR noted that "Major" design changes would be required, involving "Redesign of cut to match actual ground condition" and that "Design principles / critical sections remain applicable".

The summary of works progress submitted in July 2000 noted that for slope C7, soil nailing works were instructed and installation was ongoing. It also noted that the rock mapping work was "pending" at that time.

The summary of works progress in February 2001 noted that for slope C7, the bulk excavation, scaling, together with the installation of soil nails, dowels, raking drains, rockfall mesh netting and erosion control mat, had been completed.

In May 2000, Resident Site Staff (RSS) of HPR identified that the 5.5 m high un-nailed slope portion involved in the August 2002 landslide was formed at an angle of about 51^{o}, and not 45^{o} as stipulated in the contract drawing. HPR requested the contractor to submit a proposal to "rectify the situation as soon as possible". Up to the time of the August 2002 landslide, no works had been carried out to rectify this oversteep portion of the slope.

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

No progress summaries were submitted by HPR between December 2001 and June 2002. Following queries by the Island Division of the GEO in early July 2002, HPR submitted on 23 July 2002 a summary of progress of works covering the period December 2001 to May 2002 and another summary of works progress covering the period June 2002 to July 2002, and subsequently on 31 July 2002 a report on the design amendment involving soil nails for slope C7 to GEO for comments. No mention was made of the oversteep cut portion formed at 51^{o} instead of 45^{o} (i.e. the un-nailed slope portion that subsequently failed in August 2002), which was observed by the RSS in May 2000, in all the submitted summaries of works progress covering slope C7 (see Section 3.4). In addition, this was also not mentioned in the July 2002 design amendment.

Surface drainage system for the subject slope comprises U-channels and stepped channels with catchpits at the intersection points. The proposed drainage layout plan is shown in Figure 2. The construction of surface drainage system commenced in August 2001. HPR noted in the progress summary for the period November 2001 to May 2002 that the "outstanding works included the installation of hand railing along the berm channel, construction of toe channel and catchpits" and that "No work was carried out due to priority being given to the adjacent carriageway works", whereas the summary for the period June 2002 to July 2002 noted that the above outstanding works "to be commenced by 26 July 2002".

5. THE INCIDENT

5.1 Description of the Incident

According to the HPR's RSS, the landslide occurred at around 7:00 a.m. on 10 August 2002 during moderate rainfall. The landslide involved the failure of a 5.5 m high unsupported soil cut portion at the southern end of the subject soil/rock cut slope (Plate 2). The volume of the failed mass was estimated to be 80 m^3. Some of the landslide debris was deposited within an area in front of the slope toe where a pedestrian pavement was under construction. No casualty or road closure was involved as a result of the incident. Details of the incident were reported by HyD to the GEO through a memo dated 14 August 2002.

5.2 Post-Failure Observations of the Landslide Site

HCL first inspected the landslide site on 16 August 2002 at about 6 p.m. The location and a general view of the landslide are shown in Figure 1 and Plate 2 respectively. Some of the key observations in the vicinity of the landslide site are presented in Figures 7 and 8.

The landslide involved about 80 m^3 of debris from a landslide scar with a width of about 11.5 m and a length of 10.5 m (Figure 7). The typical depth of the failure was about 1.5 m (maximum 2 m thick) as revealed in trial pits (see Section 6.2 below). The debris travelled a maximum distance of about 2.7 m from the slope toe position over the incomplete pedestrian pavement, with a corresponding travel angle of about 40^{o} (inclination of the line joining the distal end of the debris and the crest of the landslide scarp). The debris comprised firm to stiff, occasionally soft, light reddish brown slightly sandy silty clay with

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

occasional gravel of quartz and occasional cobbles of tuff. At the time of the inspection by HCL, a series of concrete-filled oil drums had been placed in front of the toe of the landslide (Plate 2).

About 3 m to the north of the scar of the 2002 landslide is a sharp interface between soil and rock that runs sub-parallel to the northern edge of the landslide scar (dipping at about $80^{o}/015^{o}$, see Figure 7) in the lowermost slope batter (Plate 3). The rock exposed is a strong moderately decomposed tuff (MDT) (Plate 4) within which there is a prominent set of medium spaced joints dipping steeply approximately towards the north (i.e. into the slope) and are not adverse. The rock portion was covered with steel wire mesh netting (Plate 18). The upper soil portion was observed to have been soil nailed, with the nail heads connected by means of concrete beams of about 300 mm wide by 200 mm deep (Plate 19). No soil nails were installed in the soil cut portion involved in the 2002 landslide as per the HPR's design drawing.

At the time of HCL's inspection on 16 August 2002, the main scarp of the landslide had been covered with cement mortar. As a result of the displacement of the failed ground mass, a section of the concrete apron along the first berm above the backscarp had been undermined (Plate 7), and construction waste comprising broken ceramic pipes and pieces of plastic was observed at the underside of the apron (Plate 8). Slight seepage was observed over the soil surface (Plate 9) beneath a catchpit located above the landslide backscarp (Figure 7). The mortar adjacent to the exposed soil surface was also damp.

The catchpit located above the backscarp is at the intersection point of the U-channel along the first berm and a stepped channel running from east to west (from uphill) towards the landslide scar (Figure 7). Cracks up to 30 mm wide were observed on the side wall of the stepped channel (Plate 10). A small amount of concrete debris was also observed at the base of the catchpit (Plate 5) and stepped channel (Plate 11). Just to the north of the 2002 landslide, debris comprising construction waste and fallen leaves had been placed on the concrete apron alongside the U-channel on the first berm (Plate 12). It is considered that the observed debris had probably been cleaned out from the adjacent U-channel after the landslide. Other sections of the U-channels on the slope (Figure 8) were observed to have been fully blocked with debris, which was primarily construction waste comprising broken concrete, no-fines concrete and brick fragments (Plates 13 and 14).

Observations of the drainage flow paths along the U-channels for the southern half of the slope indicate that the majority of the water collected in the U-channels would drain towards the location of the 2002 landslide (Figure 8). In particular, the U-channel along the first berm was noted to be draining a section of about 100 m in length towards the catchpit located above the backscarp of the 2002 landslide. An indication of the observed drainage flow path as compared with the drainage layout plan attached to HPR's July 2002 detailed geotechnical design report is presented in Figure 8.

According to the drainage layout plan attached to HPR's July 2002 design report, the 300 mm stepped channel at the location of the 2002 landslide, which was designed to convey water from the catchpit above the backscarp to the toe channel, was yet to be constructed (Figure 8). A catchpit at about 50 m to the north of the 2002 landslide was also yet to be constructed (Figure 8 and Plate 15).

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

During the field inspection by HCL in August and September 2002, seepage was observed at several locations at the lowest batter of the subject slope (Figure 8 and Plates 16 and 17).

During rainstorms on 16 and 17 September 2002, field inspections were carried out by HCL. A heavy constant seepage of water was observed, at about 1 m below the crest of the main scarp, emerging from between the cement mortar applied to the scarp and the newly exposed soil (Plate 20). Surface water carried by the U-channel was also observed to be overtopping the first berm at about 20 m to the north of the 2002 landslide location during a rainstorm on 17 September 2002 (Plate 21).

As part of the repair works to the failed slope, the landslide debris, together with the underlying CDV, was completely removed by the contractor and the rockhead was exposed. HCL carried out an inspection of the exposed rockhead surface (Plate 23) on 30 December 2002. The bedrock surface can be seen to be undulating and generally dipping towards the road at about 50^{o} as depicted in Figure 9. A plot of rockhead contour based on various measurements taken from the rock exposed and from observations in trial pits (see Section 6) is presented in Figure 10.

During the field inspections carried out by HCL between August and December 2002, no signs of significant slope deterioration or distress such as possible stress relief induced tension cracks were observed. Also, there are no signs of potential incipient large-scale instability in the vicinity of the August 2002 landslide.

6. GROUND INVESTIGATION

6.1 General

Following the August 2002 landslide, a ground investigation (GI) comprising four trial pits (Nos. TP1 to TP4), two slope strips (Nos. SS1 and SS2) and eight GCO probe tests (Nos. G1 to G8), was carried out by DrilTech Ground Engineering Limited under the supervision of HCL in September 2002. Locations of the GI stations are shown in Figure 11. The logs of the trial pits and slope surface strips are presented in Appendix B. The results of the GCO probe tests and in-situ density tests are included in Appendix C.

6.2 Ground Investigation Findings

The landslide debris comprised firm to stiff occasionally soft, light reddish brown slightly sandy silty clay with occasional gravel of quartz and occasional cobbles of tuff and was measured in trial pits Nos. TP1, TP3 and TP4 to be between 0.6 m and 2.0 m thick. At the main scarp, colluvium with a thickness of 1.5 m was observed, to be directly overlying moderately decomposed tuff (MDT), as in trial pit No. TP1. At the crown of the landslide (trial pit No. TP3), colluvium was found to be overlying completely decomposed tuff (CDT) (Figure 9).

The surface of rupture was marked by the presence of a thin layer of very soft, light reddish brown, slightly sandy silty clay that ran predominantly along the interface between

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

the colluvium and in-situ weathered tuff, as observed in trial pit Nos. TP1 (Plate 24) and TP3 (Plate 25), and partly within the colluvium as observed in trial pit No. TP4.

To the east (uphill) of the scarp outside the landslide site (trial pit No. TP2), colluvium was found to be overlain by localised fill of about 0.5 m thick (Plate 26), which may be the remains of the single-storey squatter hut identified in the 1983 aerial photographs (see Section 2.5 and Appendix A). The colluvium exposed in trial pit No. TP2 comprised stiff, light reddish brown slightly sandy silty clay with occasional cobbles and boulders of HDT and some roots, with a maximum thickness of about 2.5 m. As indicated in slope strip No. SS2 to the north of trial pit No. TP2, MDT was observed (Plate 27) to be directly below the fill (Appendix B).

GCO probe No. G4 carried out at the location of trial pit No. TP2 recorded blow counts typically in the range of 3 to 6 for 100 mm penetration to a depth of 2.5 m. The values are probably representative of the colluvium prior to failure and indicate that the colluvium may be loose. The dry density of colluvium, based on insitu density tests carried out in trial pit No. TP2, is in the range of 1.32 Mg/m^3 to 1.54 Mg/m^3.

It is apparent that colluvium, up to 2 m thick, was present at the location of the 2002 landslide. The underlying solid geology at the landslide location was confirmed by ground investigation to be a fine ash tuff. The tuff is weathered more deeply at the location of the landslide than at the surrounding area, which is consistent with the geological setting that the failure location is in the vicinity of a natural drainage line. Geological Section A-A through the 2002 landslide is shown in Figure 9.

As observed in trial pits Nos. TP1 and TP3, the surface of rupture of the landslide ran partly along the interface between colluvium and in-situ tuff, and partly within the colluvium as observed in TP4. The surface of rupture appeared to be concave with an average depth of about 1.5 m based on a line joining trial pit Nos. TP1 and TP3.

6.3 Laboratory Tests

Laboratory tests were carried out by the Public Works Central Laboratory. The fine content of colluvium is about 75%. The results of the grading and plasticity tests are summarised in Appendix D

Consolidated undrained triaxial (CU) tests were carried out on test specimens trimmed from block samples of colluvium taken from TP2 (above the 2002 landslide). The effective stress paths of the soil specimens for the CU tests are presented in Figure D1. It is noted that the colluvium exhibited contractive behaviour upon shearing.

7. ANALYSIS OF RAINFALL RECORDS

Rainfall data were obtained from GEO automatic raingauge No. H03, the nearest raingauge to the site, located Block 44 Baguio Villa, about 440 m to the southeast of the subject slope (Figure 1). The raingauge records and transmits rainfall data at 5-minute

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

intervals via a telephone line to the Hong Kong Observatory and the GEO.

An Amber Rainstorm Warning was hoisted on 10 August 2002 between 4:35 a.m. and 6:50 a.m. Based on the interview with HPR's RSS and for the purpose of rainfall analysis, the time of the landslide has been taken to be 7:00 a.m. on 10 August 2002.

The daily rainfall recorded by raingauge No. H03 over the preceding month and 7 days after the landslide incident are given in Figure 12. The daily rainfall records show that about 124 mm of rainfall was recorded on 10 August 2002. On the day of the landslide, the hourly rainfall records show that a peak of 48 mm was recorded at 4:00 a.m., some three hours before the reported time of the landslide at around 7:00 a.m.

Table 2 presents the estimated return periods for the maximum rolling rainfalls of various durations based on reference to historical rainfall data at the Hong Kong Observatory, Tsim Sha Tsui (Lam & Leung, 1994). The results show that the return period of the 10 August 2002 rainstorm was less than 2 years. The return period was also assessed based on statistical parameters derived by Evans & Yu (2001) for rainfall data recorded by the raingauge No. H03. It is noted that the estimated return periods of the 10 August 2002 rainstorm based on historical rainfall data at the Hong Kong Observatory and the local raingauge No. H03 are very similar in this case (see Table 2).

A comparison of the maximum rolling rainfall of the 10 August 2002 rainstorm with that of the past major rainstorms recorded by the raingauge No. H03 after the completion of the subject slope formations works in May 2000 (Figure 13). It is noted that the 10 August 2002 rainstorm was not the most critical rainstorm experienced by the subject slope after the completion of slope formation works in May 2000. The rainstorm on 9 July 2001 was more severe than that of the 10 August 2002 rainstorm for all durations considered (viz. 5 minutes to 31 days).

8. THEORETICAL STABILITY ANALYSES

Theoretical slope stability analyses were carried out to assist in the diagnosis of the mechanism and probable causes of the 10 August 2002 landslide. The analyses may be used to assess the probable operational mass shear strength parameters given the range of possible groundwater conditions at the time of the landslide.

The cross-section through the landslide for the stability analyses using the Morgenstern & Price (1965) method is shown in Figure 12. The pre-failure slope profile was interpreted from topographical survey plans provided by HPR. The geometries of the inferred surface of rupture and ground profile are based on site measurements, post-failure topographical survey and ground investigation.

The results of the analyses are presented in Figure 14 in the form of c' versus ϕ' for different water levels above the surface of rupture. The shear strength parameters for colluvium adopted in HPR's interpretative report in 1997 are also indicated in Figure 14. The results of the stability analyses revealed that with HPR's design parameters, the development of a transient water pressure corresponding to a water level of 1.0 m above the

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

surface of rupture would have been sufficient to initiate slope failure.

9. DIAGNOSIS OF THE PROBABLE CAUSES OF THE FAILURE

The 10 August 2002 landslide involved the detachment of shallow colluvium (maximum 2 m thick) from a steep, vegetated, unsupported cut during moderate rainfall (return period of about two years). The landslide debris was not particularly mobile (with a travel angle of about 40^{o}) and did not affect the traffic lanes of Victoria Road.

The close correlation between the rainstorm and the landslide suggests that the August 2002 landslide was probably rain-induced. The failed slope portion was close to an existing natural drainage line where there may be concentrated surface and subsurface water flow. Field mapping by HCL identified that the surface of rupture was close to the interface of the surface mantle of colluvium and the underlying weathered volcanic rock. It is probable that water ingress during rainfall resulted in the transient build-up of water pressure within the surface mantle of colluvium. Theoretical stability analyses carried out under this study (see Section 8) suggested that a perched water level of about 1 m above the surface of rupture would have been sufficient to initiate the slope failure.

It is noteworthy that the newly formed slope survived a more severe rainstorm a year before the August 2002 landslide. There were no records and no site evidence of significant slope deterioration after formation or presence of stress relief induced tension cracks. The site setting in relation to the drainage provisions was different in that construction of the surface drainage system had not commenced in August 2001 whereas it was almost completed at the time of the August 2002 storm. Post-failure inspections revealed blocked U-channels on slope berms and soil debris in the catchpit directly above the landslide, indicating inadequate maintenance of the drainage provisions. This environmental setting is liable to lead to overspilling and uncontrolled surface water flow during rainfall, which may result in enhanced water ingress into the soil mass. In this regard, lack of maintenance during the construction stage was probably a contributory factor to the failure.

10. DISCUSSION

Although two phases of ground investigations for the road widening project were carried out in 1988 and 1997 respectively, relatively little investigation was undertaken of slope C7 (about 180 m in length). Only one drillhole was sunk near the centre of slope C7 and there were no investigation stations in the vicinity of the failed slope section which is located close to a natural drainage line.

The soil nail design for slope C7 was submitted to the GEO on 31 July 2002 (which was made following a verbal query by the GEO in early July 2002 regarding the soil nailing works on various cut slopes within the project area) for comments, some 17 months after completion of bulk excavation and soil nail installation and 10 days before the major landslide on this slope in August 2002. This report by HPR on soil nails on slope C7 effectively amounted to a design amendment to the approved design (in 1988) to cater for changes in actual site conditions.

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

The geological model presented in the 1988 design submission by BPHK for slope C7 based on the overall ground investigation for the project (closest drillhole more than 100 m to the south of the failed section) comprised colluvium overlying MDV. The geological model presented in the 1997 submission by RPT (closest drillhole about 75 m to the north of the failed section) for slope C7 comprised a "nominal layer of Colluvium" overlying "in situ Granite". Also, the submission noted that the design by BPHK in 1988 "remains unchanged" (i.e. forming an unsupported cut by cutting back the soil portion to 45^{o}, see Figure 5).

In the submission made by HPR after slope formation (which in principle should have incorporated the findings of detailed engineering geological mapping of the cut face as the slope had already been cut back), the geological model comprised HDV overlying M/SDV. There was no detail given in the 2002 geotechnical report accompanying the submission regarding the ground condition near the section that subsequently failed, which was observed by HCL to comprise colluvium overlying MDT and in places C/HDT after the landslide.

Although there was engineering geological input by the designer (as Category I supervision personnel) and the full-time resident geotechnical engineer (as Category III supervision personnel), and that there was ample opportunity for detailed full-face mapping during the time after bulk excavation works, the more adverse ground condition and hydrogeological setting were not identified and reported in the submission of design amendment in July 2002.

At the failed section, the slope as formed (51^{o} steep) was found by the RSS to be oversteep (Section 4.3). According to the July 2002 submission (Figure 2), the design did not involve installation of soil nails at this section. In view of the oversteep cutting at this section, the RSS requested the contractor in May 2000 to rectify the situation as soon as possible. Prior to the August 2002 landslide, the oversteep soil cut portion with no soil nails was not made known by the HPR to the GEO in the submitted works progress summaries and the July 2002 report on design amendment covering the soil nailing works. Follow-up action was yet to be taken by the contractor to trim back this oversteep portion at the time of the August 2002 landslide. During the same period of May 2000 to August 2002, no specific measures were installed at the toe of the oversteep cut portion to protect the traffic lanes of Victoria Road.

The proximity of the failed section to a natural drainage line, together with its adverse hydrogeological setting (i.e. a surface mantle of colluvium overlying less permeable weathered volcanic rock), renders the slope vulnerable to the build-up of perched water pressure at the interface of colluvium/weathered rock. In addition, lack of maintenance of the partially completed surface drainage system probably led to enhanced water ingress at the failed section. The failed section was oversteep and comprised weaker material as well as with more adverse groundwater condition than that assumed in the slope design as presented in the July 2002 submission. The situation was exacerbated by the fact that no soil nails were actually installed as per the intent of the design (i.e. soil nails were to be installed in "all material except rock materials"). In view of the above, the major landslide that occurred at the newly formed slope C7 (with geotechnical engineering input) during the wet season was not a surprise. In the event, it was fortunate that the landslide debris was not mobile and did not affect the road users.

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

11. CONCLUSIONS

The 10 August 2002 landslide affected a steep, unsupported cut that was steeper and comprised weaker material as well as more adverse groundwater condition than that assumed in the slope design. It is concluded that the failure was rain-induced and was triggered by the adverse build-up of transient groundwater conditions.

The contributory factors to the failure include the following:

(a) inadequate engineering geological input, particularly during construction,

(b) adverse hydrogeological conditions involving a surface mantle of colluvium overlying less permeable weathered rock,

(c) proximity to natural drainage line that provides a source of groundwater, and

(d) inadequate maintenance of the surface drainage provisions during the construction stage.

Based on the field inspections, there are no signs of potential incipient large-scale instability in the vicinity of the August 2002 landslide.

12. REFERENCES

Binnie & Partners (Hong Kong) (1988). Victoria Road Improvements Stage II - Submission to Geotechnical Control Office on Slope and Retaining Wall Design. Report to Highways Department, Government of Hong Kong.

Bachy Soletanche Group (1988). Victoria Road Improvements Stage II - Site Investigation Report, Volumes I to V. Report to Geotechnical Control Office, Government of Hong Kong.

Enpack (Hong Kong) Ltd. (1997). Victoria Road Improvements Stage II Phase 2 - Ground Investigation: Final Field Work Report Volume 1 to 2. Report to Geotechnical Engineering Office, Government of Hong Kong.

Evans, N.C. & Yu, Y.F. (2001). Regional Variation in Extreme Rainfall Values. Geotechnical Engineering Office, Hong Kong, 81 p. (GEO Report No. 115).

Fugro (Hong Kong) Limited (1996). Victoria Road Improvements Stage II Phase 2 - Review of Existing and Proposed Slopes. Report to Highways Department, Government of Hong Kong.

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

Geotechnical Control Office (1984). Geotechnical Manual for Slopes (Second Edition). Geotechnical Control Office, Hong Kong, 295 p.

Geotechnical Control Office (1986). Hong Kong and Kowloon: Solid and Superficial Geology. Hong Kong Geological Survey, Map Series HGM 20, Sheet 11, 1:20 000 Scale. Geotechnical Control Office, Hong Kong.

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

Morgenstern, N.R. & Price, V.E. (1965). The analysis of the stability of general slip surfaces. Geotechnique, vol. 15, pp 79-93.

Rendel Palmer & Tritton (Asia) (1997). Victoria Road Improvements Stage II Phase 2 - Supplementary Ground Investigation Interpretative Report. Report to Highways Department, Government of Hong Kong.

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 1 - Soil Parameters for Geotechnical Design (RPT, 1997)

Materials	c' (kPa)	ϕ' (degrees)	Unit Weight (kN/m^3)
In-situ fill	0	37	18
Colluvium	3	37	19
Residual Soil	0	39	19
CDV	7	37	18.5
HDV	13	38	18.5

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

Table 2 - Maximum Rolling Rainfall at GEO Raingauge No. H03 for Selected Durations Preceding the 10 August 2002 Landslide and Estimated Return Periods

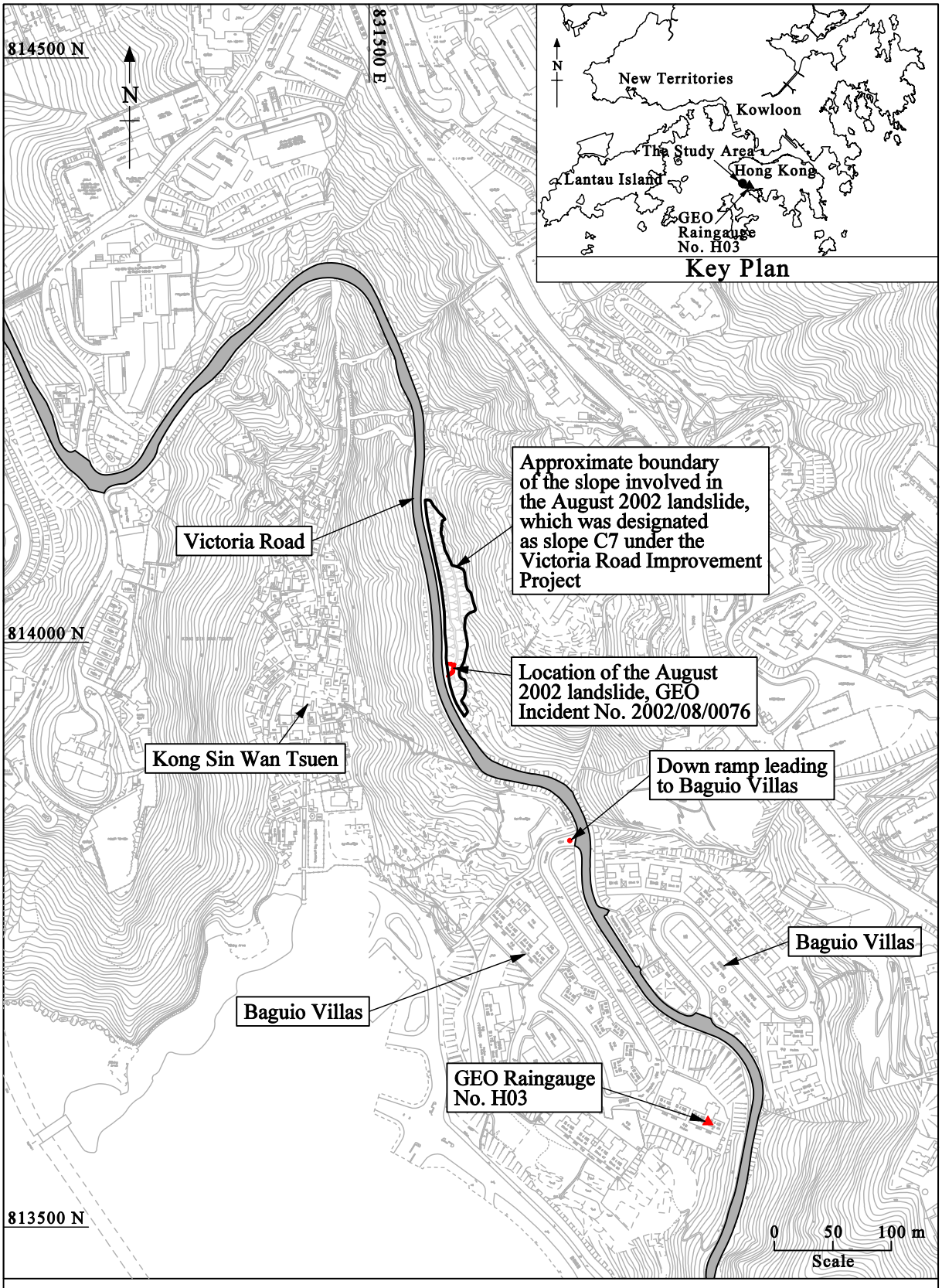
Duration	Maximum Rolling Rainfall (mm)	End of Period (Hours)	Estimated Return Period (Years)	
			$A^{(2)}$	$B^{(2)}$
5 minutes	7.0	04:45 hours on 10 August 2002	1	< 2
15 minutes	18.5	04:50 hours on 10 August 2002	1	< 2
1 hour	57.0	05:10 hours on 10 August 2002	< 2	< 2
2 hours	66.5	05:10 hours on 10 August 2002	< 2	< 2
4 hours	71.5	07:00 hours on 10 August 2002	< 2	< 2
12 hours	81.0	05:15 hours on 10 August 2002	< 2	< 2
24 hours	145.5	07:00 hours on 10 August 2002	< 2	< 2
2 days	145.5	07:00 hours on 10 August 2002	< 2	< 2
4 days	177.5	07:00 hours on 10 August 2002	< 2	< 2
7 days	223.0	07:00 hours on 10 August 2002	< 2	< 2
15 days	342.5	05:15 hours on 10 August 2002	< 2	< 2
31 days	440.0	07:00 hours on 10 August 2002	< 2	< 2

Notes:
(1) Maximum rolling rainfall was calculated from 5-minute rainfall data.
(2) Return periods were derived from Table 3 of Lam & Leung (1994) (Column A refers) and using data from Evans & Yu (2001) (Column B refers). The return periods obtained by the two methods do not show a significant difference.
(3) For the purpose of rainfall analysis, the landslide was assumed to occur at 7:00 a.m. on 10 August 2002.
(4) The nearest GEO raingauge to the landslide site is Raingauge No. H03 located at Block 44 Baguio Villa, Hong Kong about 440 m to the southeast of the site.

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

LIST OF FIGURES

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



Note : Base map is extracted from Survey Sheet Nos. 11SW-11D, 11SW-12C, 11SW-16B, 11SW-16D, 11SW-17A and 11SW-17C (Scale 1:1000).

Figure 1 - Site Location Plan

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

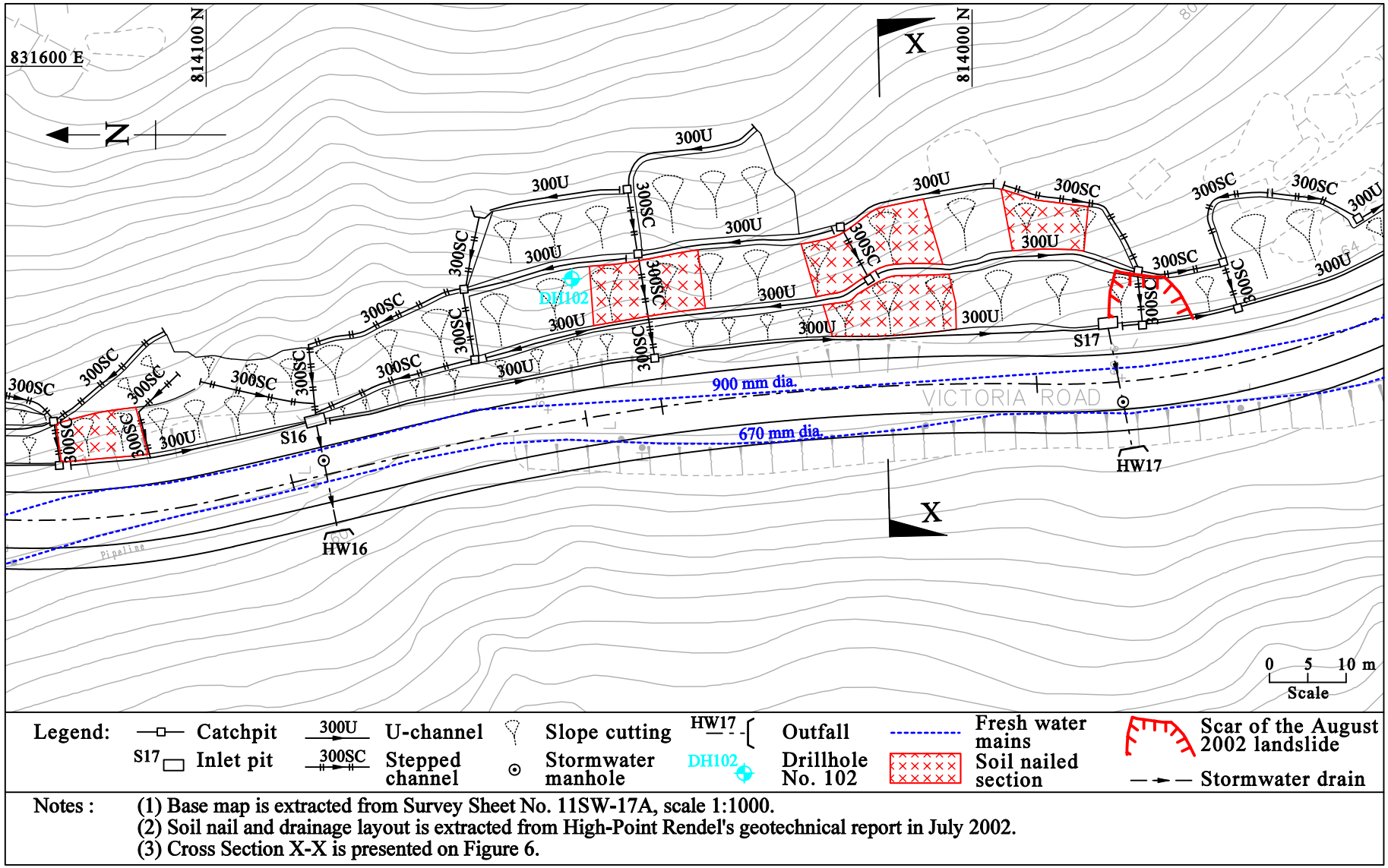
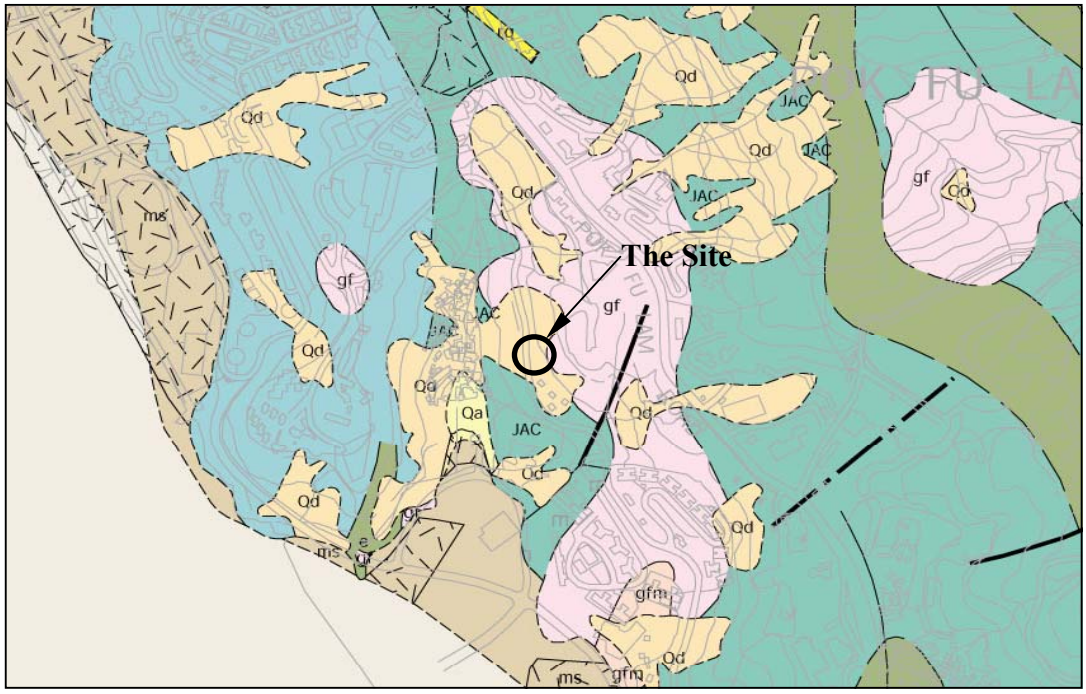


Figure 2 - General Layout Plan of Drainage Provisions and Soil Nailing Works in the July 2002 Geotechnical Report



LEGEND:

SUPERFICIAL DEPOSITS

- Fill; sanitary fill - natural earth and waste
- 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
- Marine sand, part silty

SOLID GEOLOGY

- JAC — Fine ash vitric tuff
- e — Eutaxite
- gf — Fine-grained granite
- gfm — Fine- to medium-grained granite
- b — Basalt
- ap — Aplite

GEOLOGICAL LINES

- Geological boundary, superficial deposit
- 1982 — Fill boundary
- Geological boundary, solid rock
- Fault
- Mineral vein
- Photogeological lineament

STRUCTURAL SYMBOLS

- 20 — Bedding
- 20 — Intrusive contact
- 20 — Jointing

Note: Extracted from Hong Kong Geological Survey Sheet 11 (1:20,000), Map Series HGM 20 (GCO, 1986).

Figure 3 - Geology of the Landslide Site

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

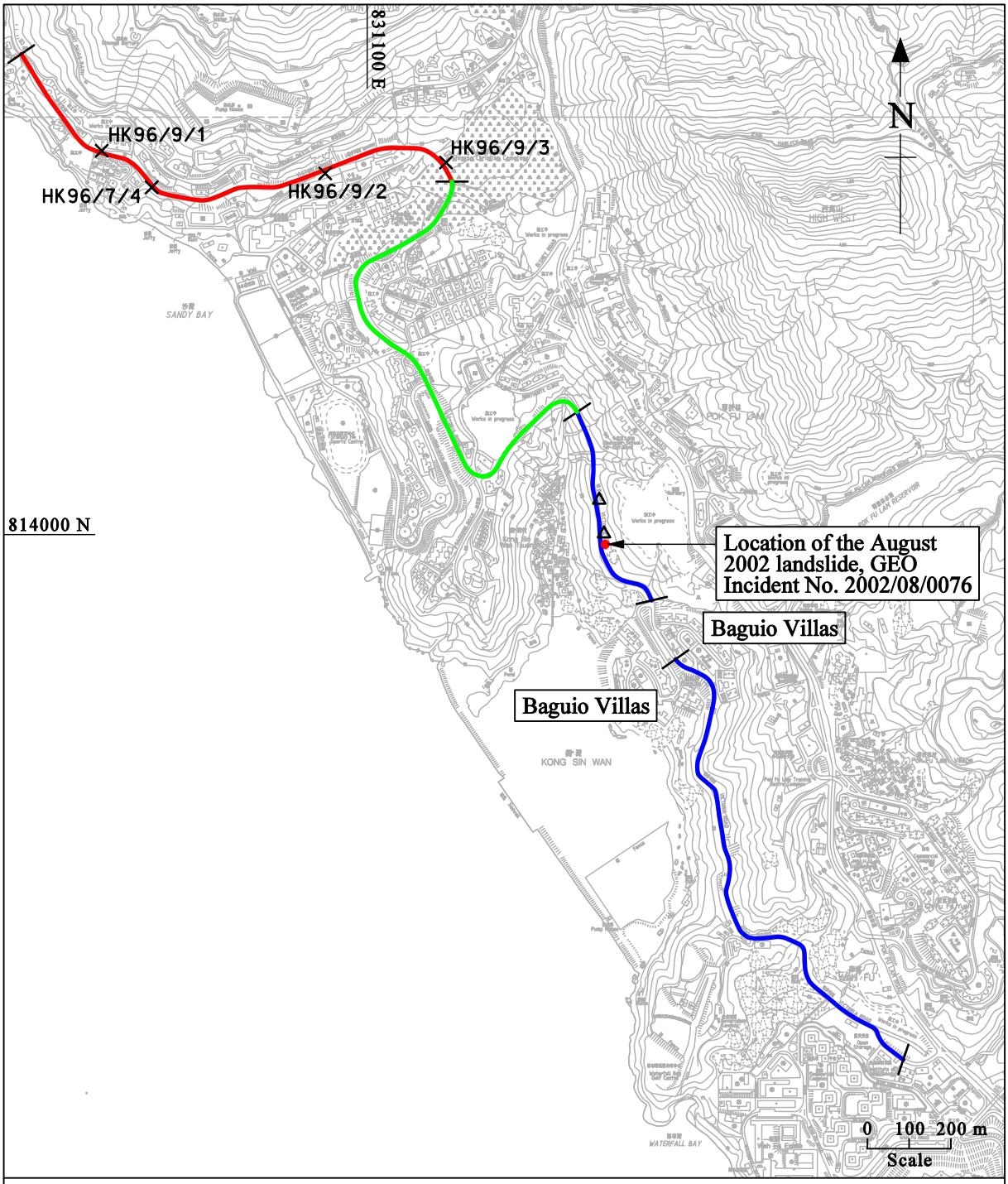
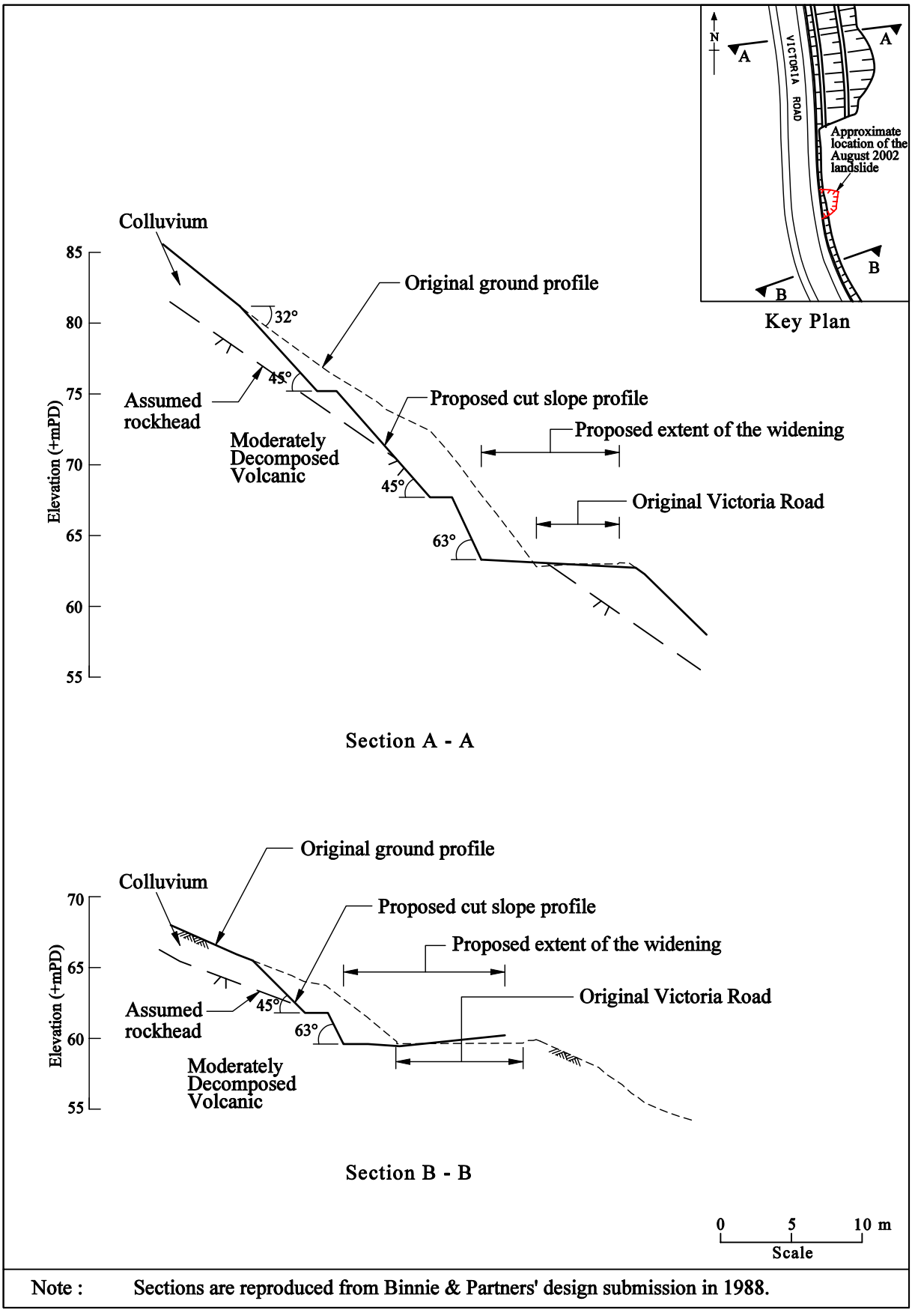


Figure 4 - Past Slope Instabilities within the Victoria Road Improvement Project

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



Note : Sections are reproduced from Binnie & Partners' design submission in 1988.

Figure 5 - Proposed Profile of the Subject Slope in the October 1988 Submission

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

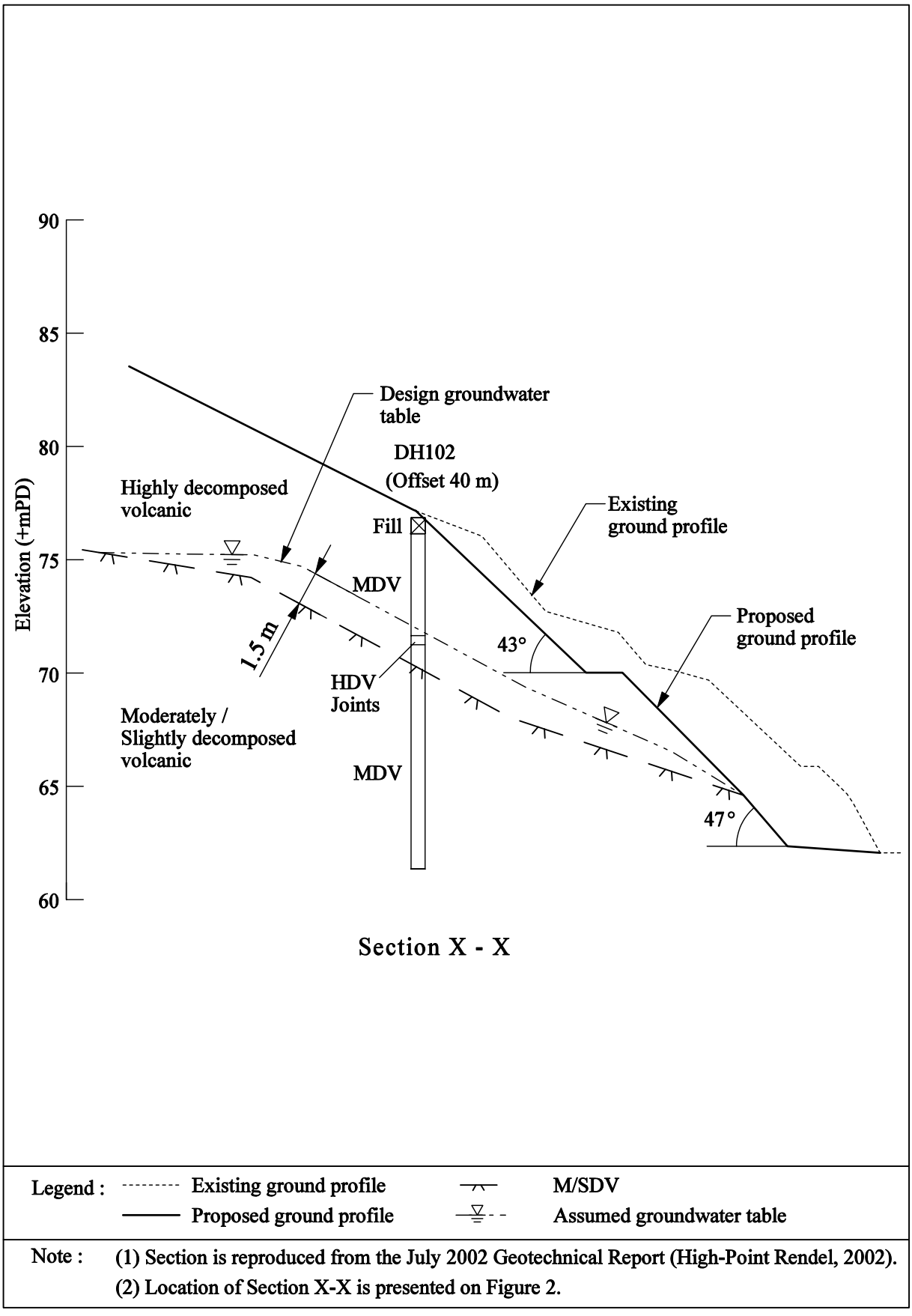


Figure 6 - Cross Section Nearest to the Subject Slope in the July 2002 Geotechnical Report

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

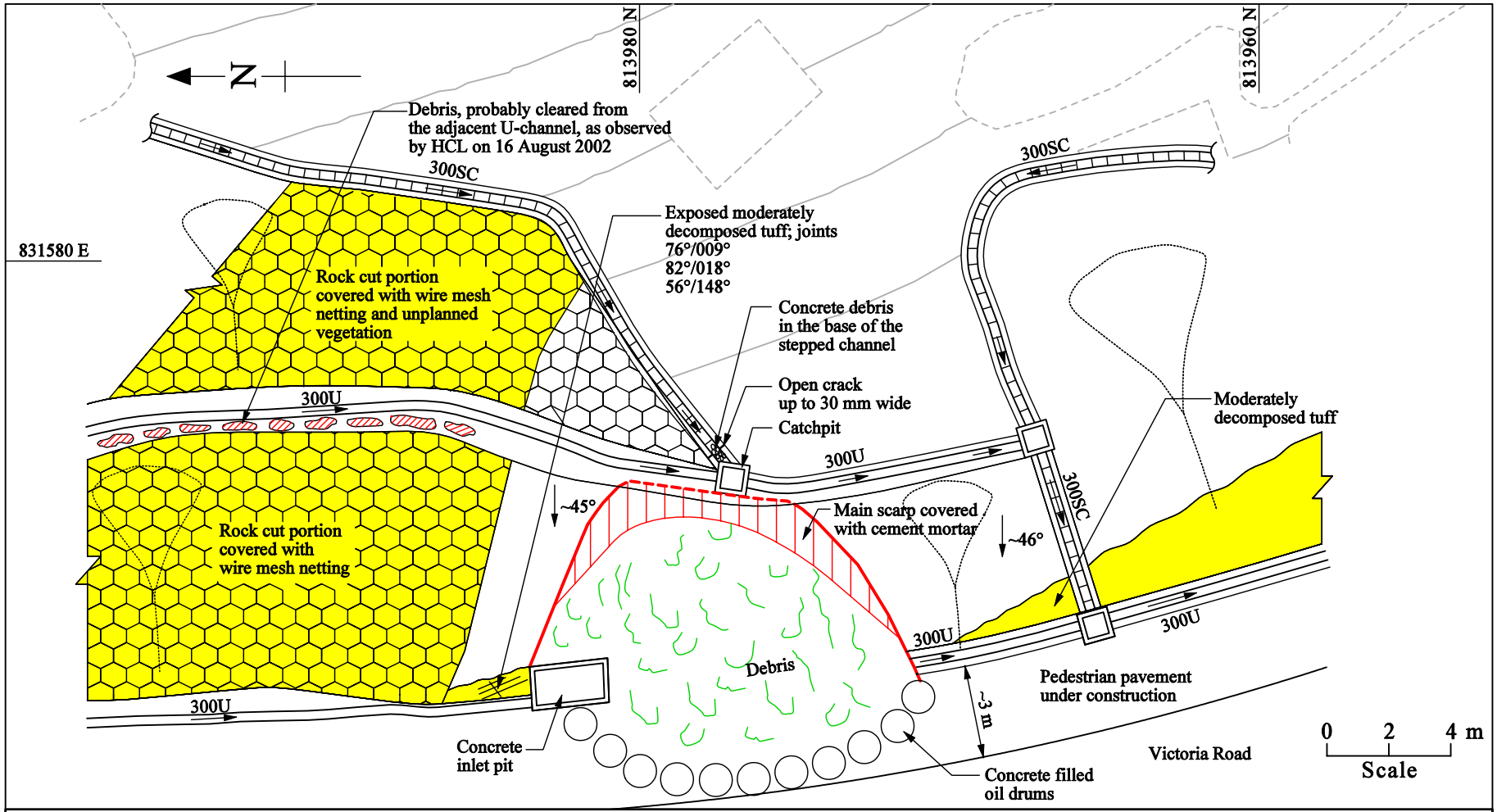


Figure 7 - Plan of the Landslide Scar

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

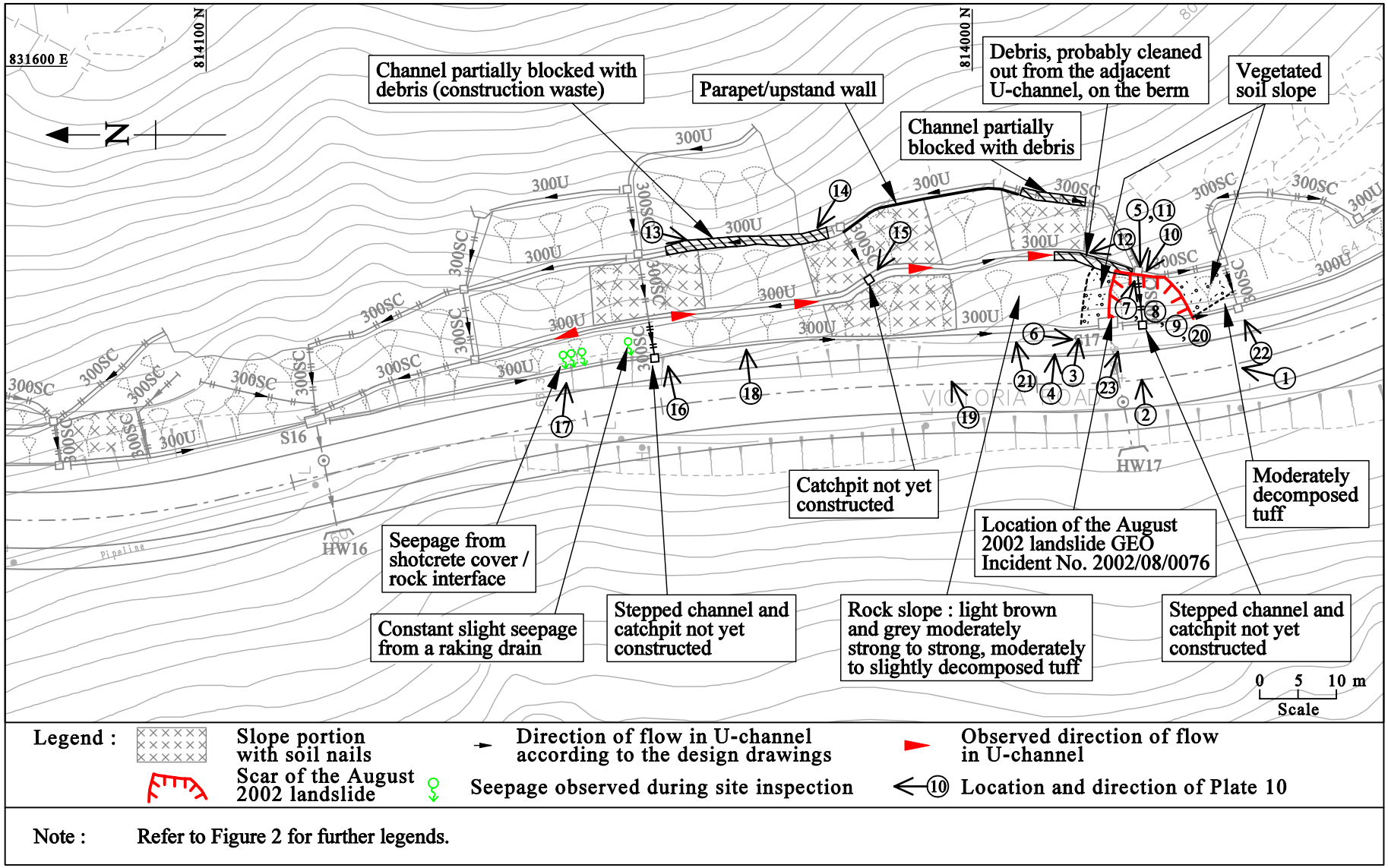
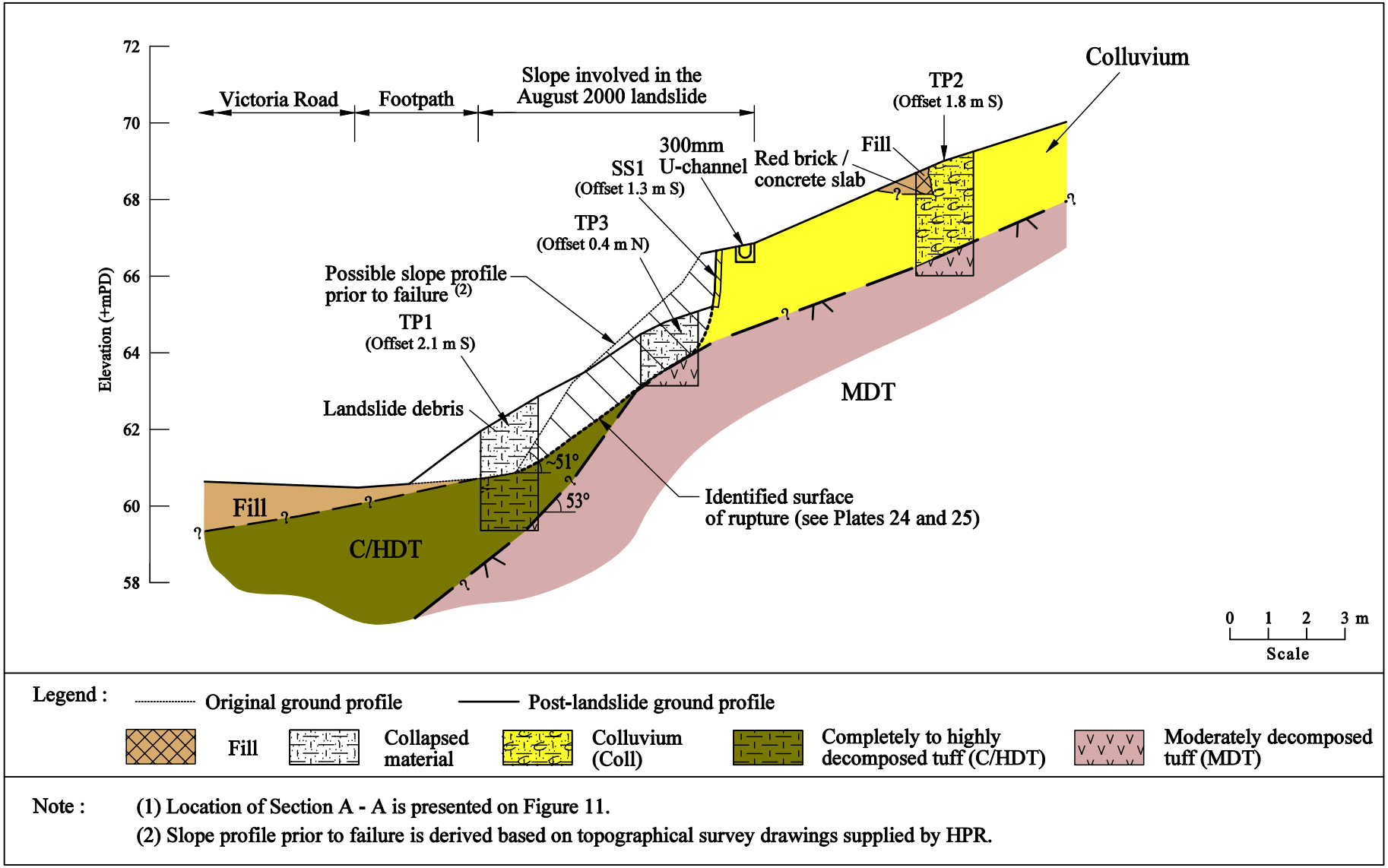


Figure 8 - Site Observations in the Vicinity of the Landslide

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



Note : (1) Location of Section A - A is presented on Figure 11.
(2) Slope profile prior to failure is derived based on topographical survey drawings supplied by HPR.

Figure 9 - Geological Section A - A through the Landslide

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

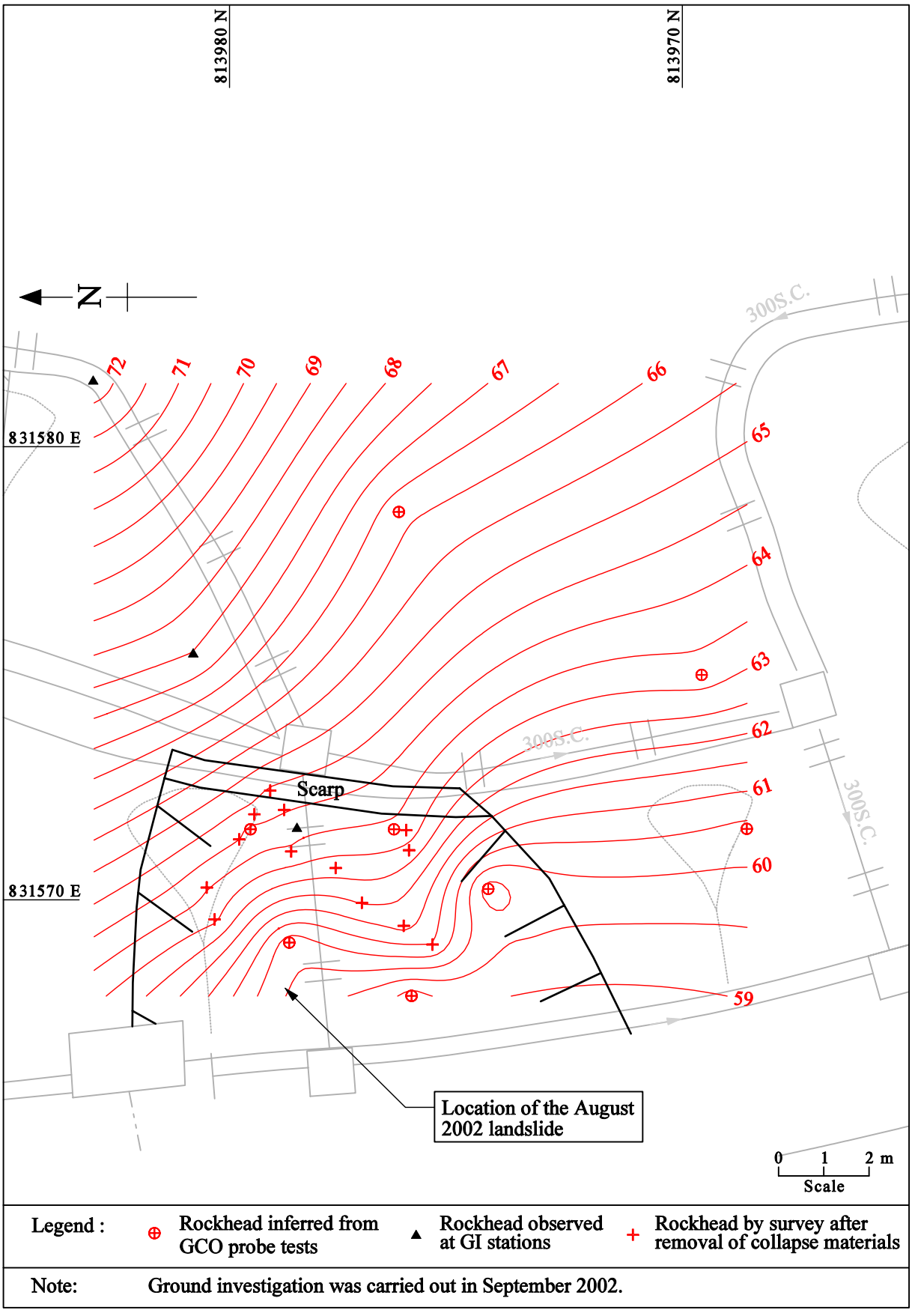


Figure 10 - Inferred Rockhead Contours at the Landslide Site

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

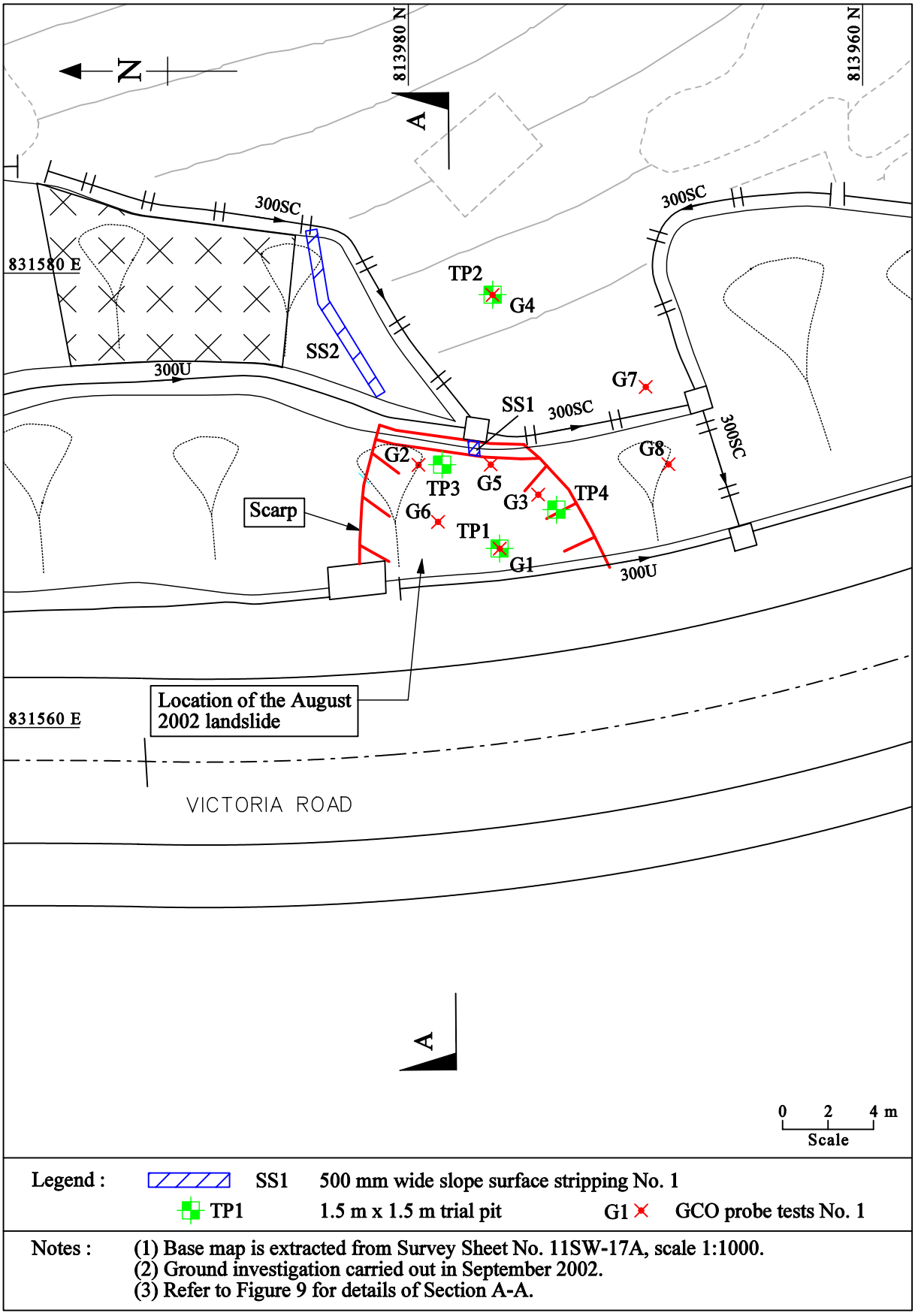
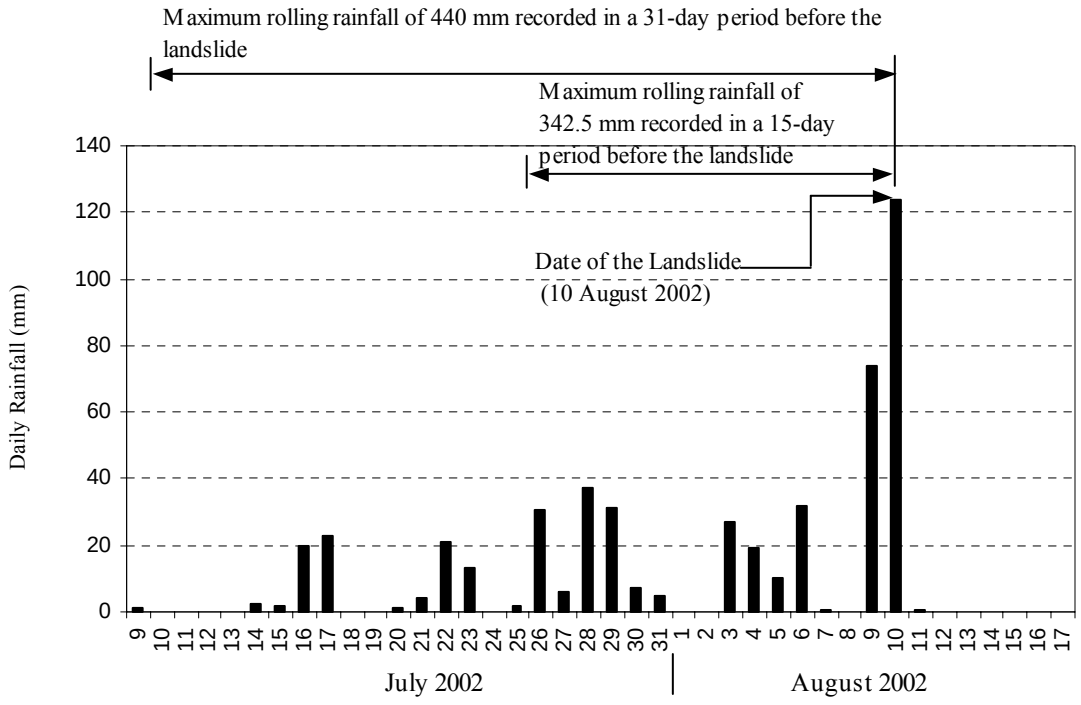
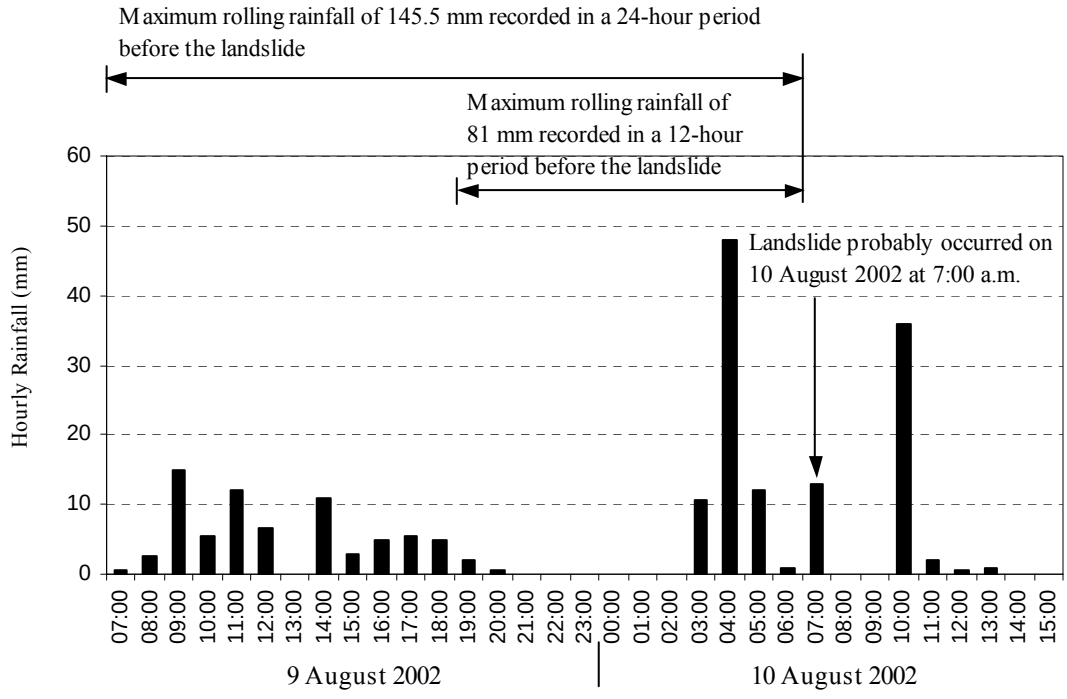


Figure 11 - Ground Investigation Layout Plan

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



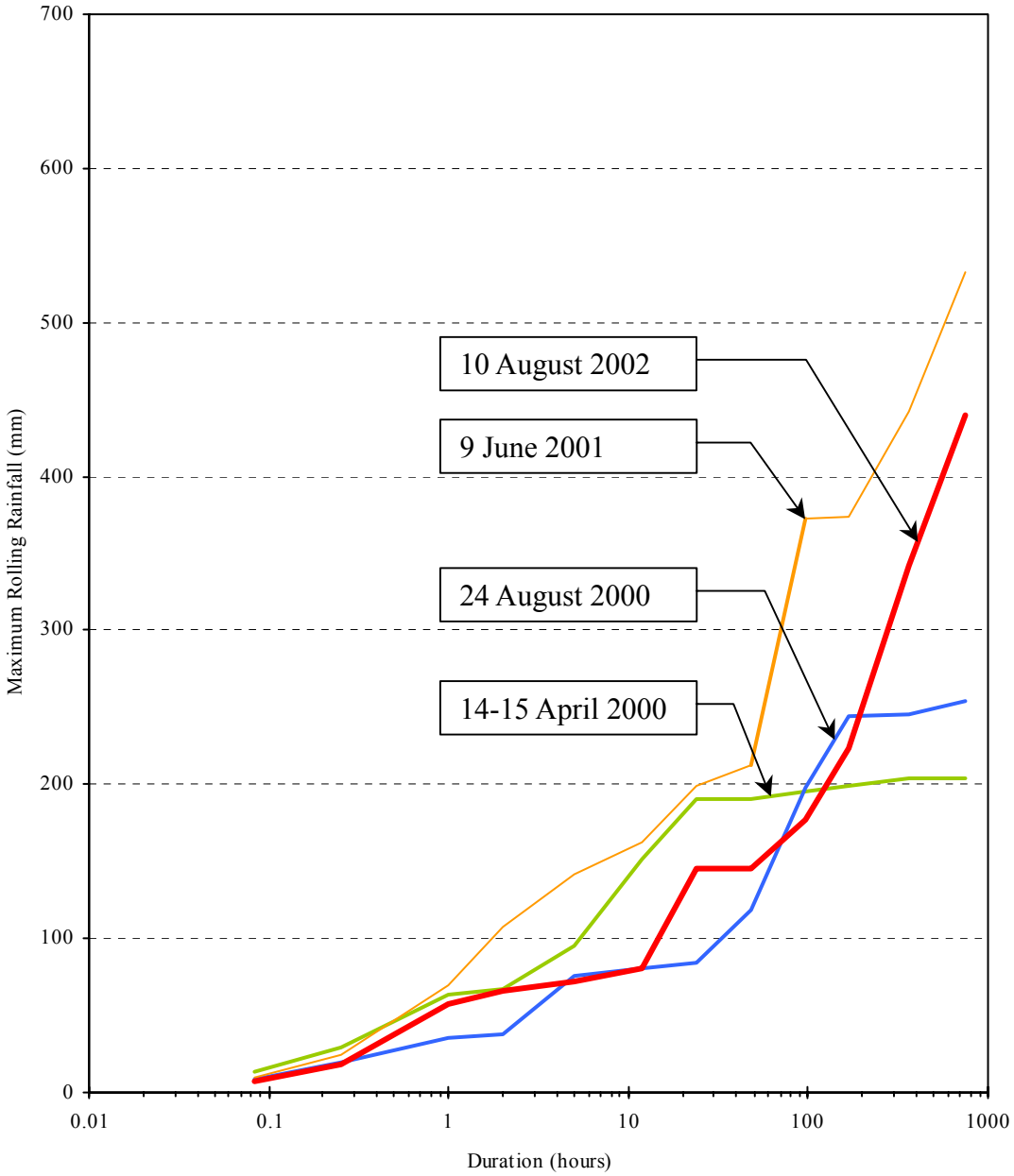
(a) Daily Rainfall Recorded between 9 July and 17 August 2002



(b) Hourly Rainfall Recorded between 07:00 hour on 9 August and 15:00 hours on 10 August 2002

Figure 12 - Daily and Hourly Rainfall Recorded at GEO Raingauge No. H03

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



Note: Rainfall data are 5-minute statistics from GEO raingauge No. H03.

Figure 13 - Maximum Rolling Rainfall at GEO Raingauge No. H03 for Major Rainstorms between April 2000 and August 2002

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

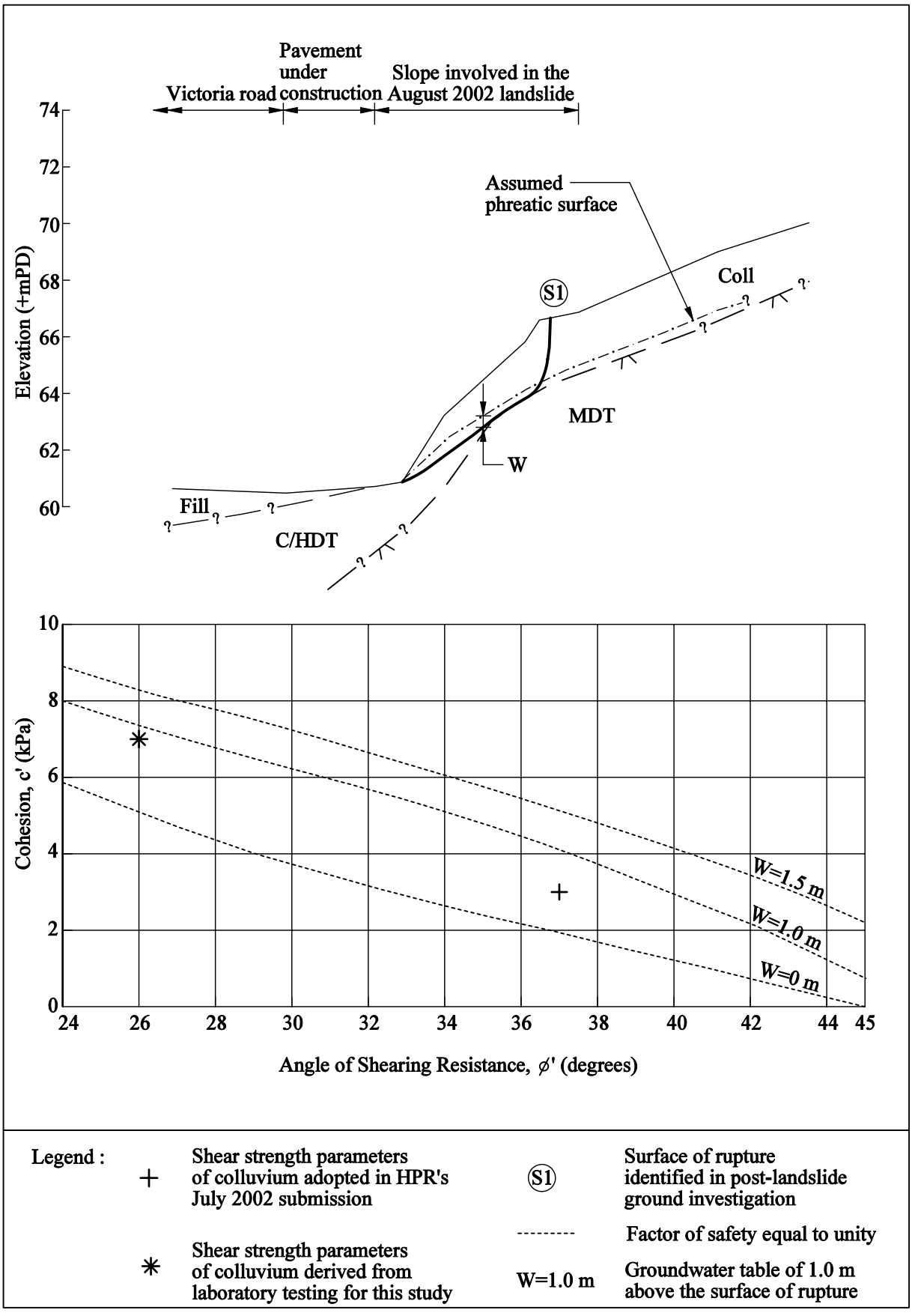


Figure 14 - Summary of Sensitivity Analyses

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

Plate 1 - View of the Subject Slope (Photograph taken on 16 August 2002)

Plate 2 - View of the Failed Portion of the Subject Slope
(Photograph taken on 16 August 2002)

Note: See Figure 8 for locations and directions of photographs.

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

Plate 3 - Moderately Decomposed Tuff to the North of the Toe of the Landslide
(Photograph taken on 16 August 2002)

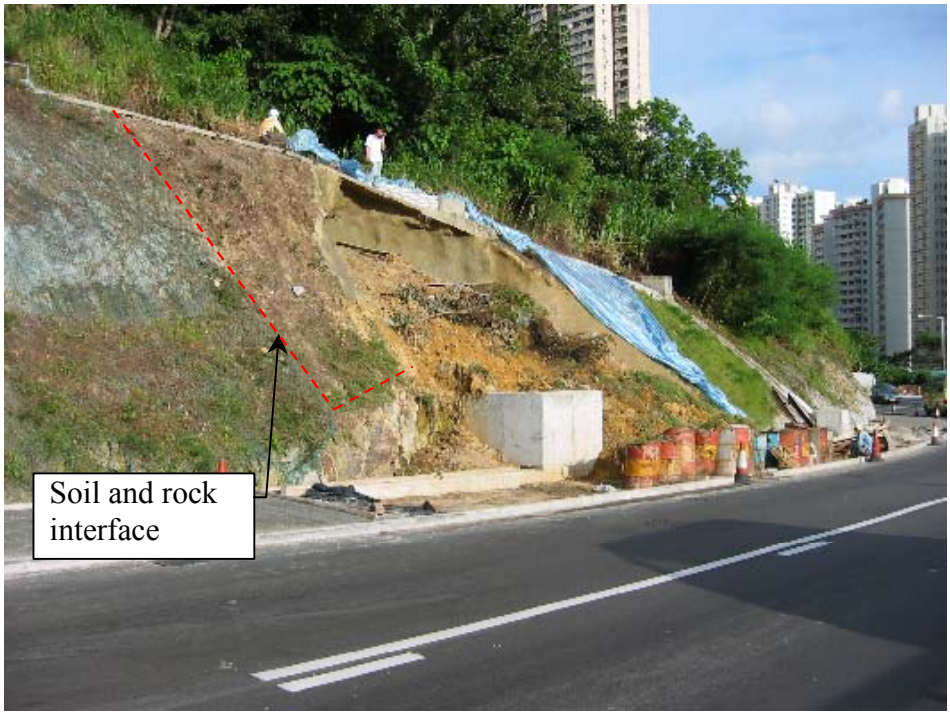


Plate 4 - Interface between Soil and Rock about 3 m to the North of the Landslide
(Photograph taken on 16 August 2002)

Note: See Figure 8 for locations and directions of photographs.

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

Plate 5 - View of the Catchpit above the 2002 Landslide
(Photograph taken on 16 August 2002)

Plate 6 - Concrete Inlet Pit at the Northern End of the Landslide
(Photograph taken on 16 August 2002)

Note: See Figure 8 for locations and directions of photographs.

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

Plate 7 - Back Scarp (Covered with Cement Mortar) and Undercut Concrete Berm (Photograph taken on 16 August 2002)

Plate 8 - Broken Ceramic Pipes and Pieces of Plastic beneath the Concrete Berm (Photograph taken on 19 August 2002)

Note: See Figure 8 for locations and directions of photographs.

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

Plate 9 - Slight Seepage from Soil Surface in the Scarp
(Photograph taken on 19 August 2002)

Plate 10 - Cracks up to 30 mm Wide along Construction Joints
(Photograph taken on 16 August 2002)

Note: See Figure 8 for locations and directions of photographs.

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

Plate 11 - "No-fines" Concrete in Stepped Channel (Photograph taken on 16 August 2002)

Plate 12 - Debris on the Concrete Berm (Photograph taken on 16 August 2002)

Note: See Figure 8 for locations and directions of photographs.

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

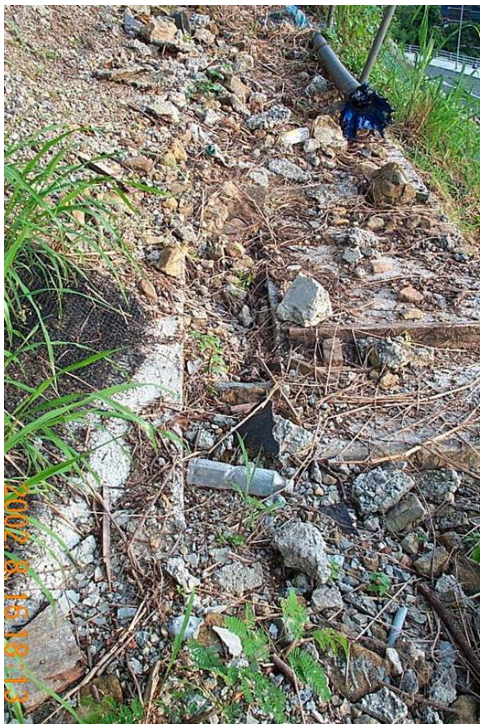


Plate 13 - Construction Waste Blocking a U-channel along the Second Berm
(Photograph taken on 16 August 2002)

Plate 14 - View of the Blocked U-channel along the Second Berm
(Photograph taken on 16 August 2002)

Note: See Figure 8 for locations and directions of photographs.

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

Plate 15 - Catchpit Yet to be Constructed on the First Berm
(Photograph taken on 16 August 2002)

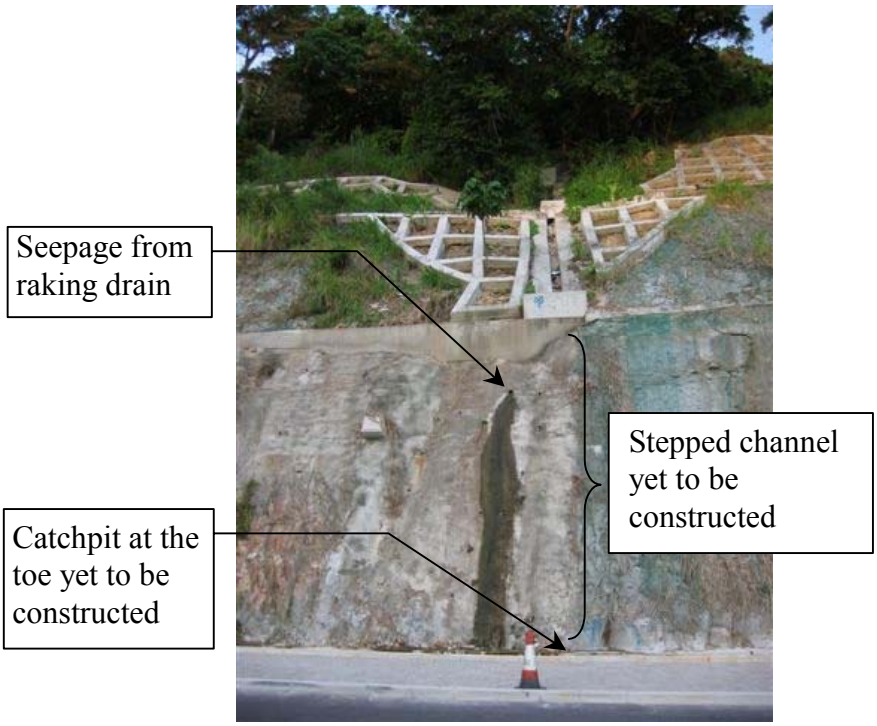


Plate 16 - Seepage from a 80 mm Diameter Raking Drain in the First Batter
(Photograph taken on 16 August 2002)

Note: See Figure 8 for locations and directions of photographs.

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

Plate 17 - Extensive Seepage below Shotcrete and above Exposed Rock
(Photograph taken on 16 August 2002)

Plate 18 - Wire Mesh Netting Cover to Rock Section
(Photograph taken on 16 August 2002)

Note: See Figure 8 for locations and directions of photographs.

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

Plate 19 - Reinforced Concrete Beam Grillage Connecting Soil Nail Heads
(Photograph taken on 16 August 2002)

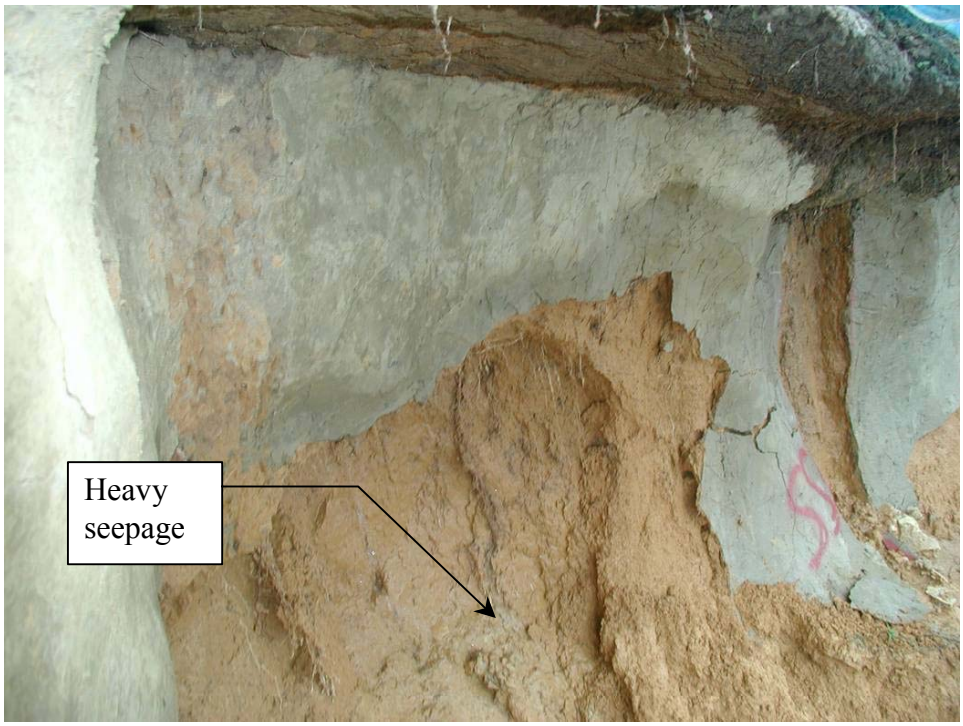


Plate 20 - Heavy Seepage from Soil below Cement Mortar Cover during a Rainstorm
(Photograph taken on 16 September 2002)

Note: See Figure 8 for locations and directions of photographs.

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

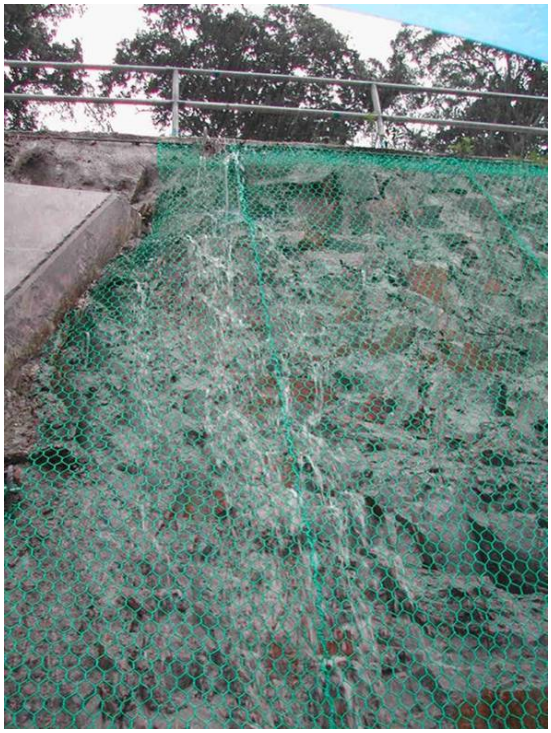


Plate 21 - Water Over-topping the First Berm during a Rainstorm (Photograph taken on 17 September 2002)

Plate 22 - Heavy Flow of Water in the Stepped Channel to the South of the 2002 Landslide during a Rainstorm (Photograph taken on 17 September 2002)

Note: See Figure 8 for locations and directions of photographs.

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

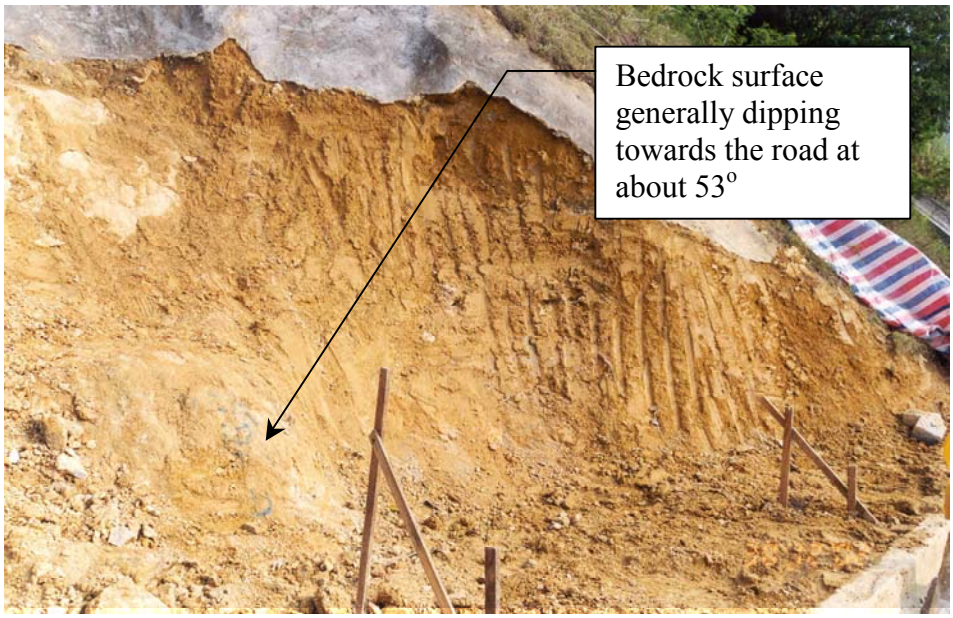


Plate 23 - View of the Landslide Area after Removal of Debris
(Photograph taken on 30 December 2002)

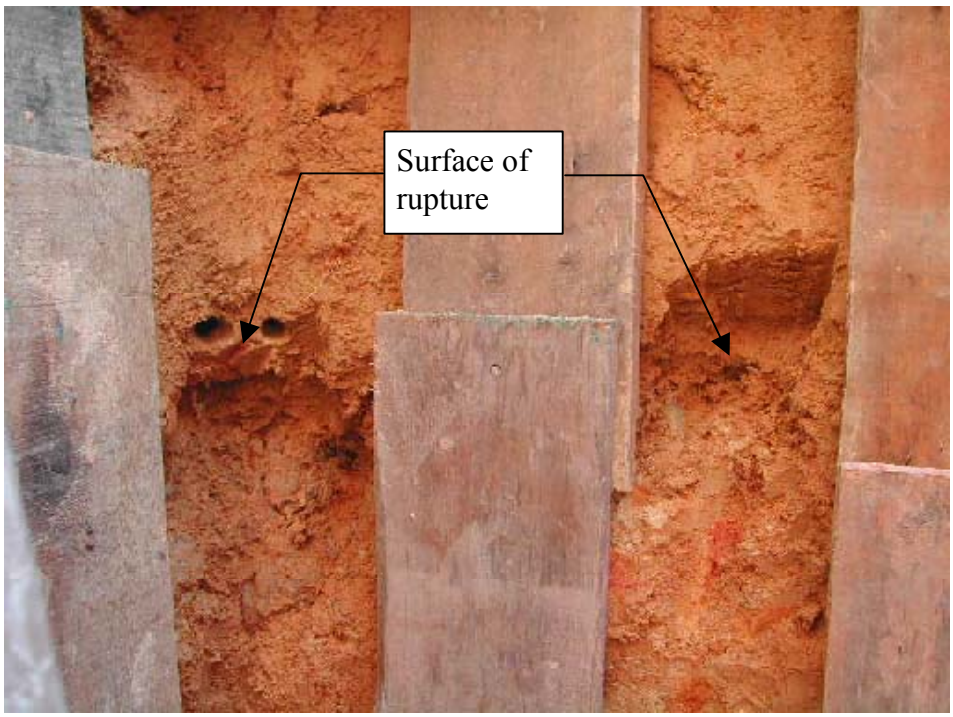


Plate 24 - Surface of Rupture at Interface between Colluvium and CDT in Trial Pit No. TP1
(Photograph taken on 5 September 2002)

Note: See Figure 8 and 11 for locations and directions of photographs.

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

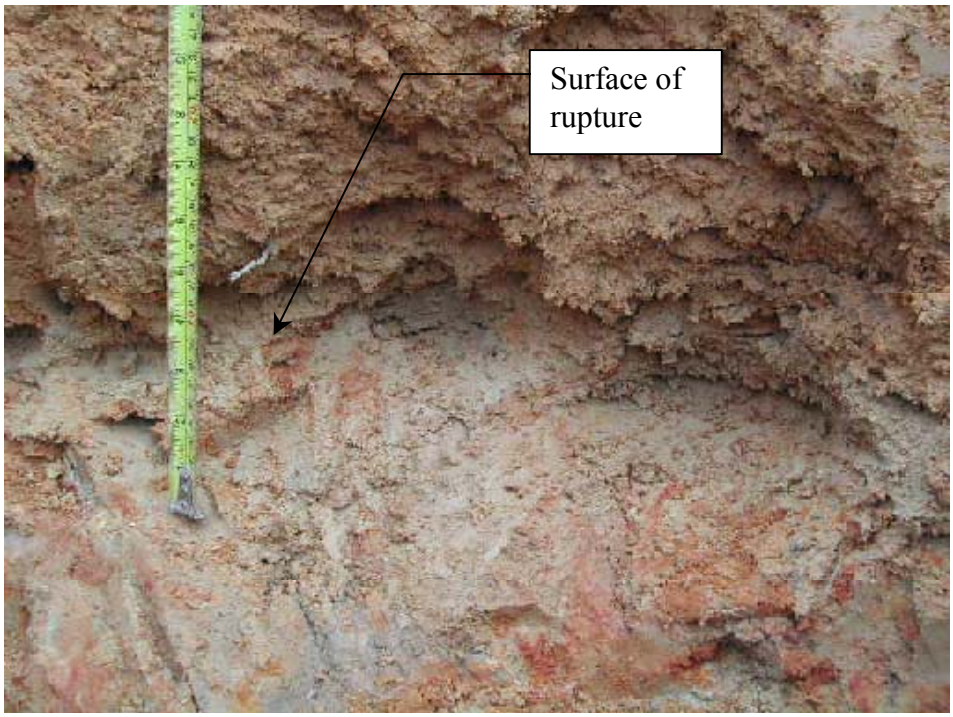


Plate 25 - Surface of Rupture at Interface between Colluvium and H/MDT in Trial Pit No. TP3 (Photograph taken on 5 September 2002)

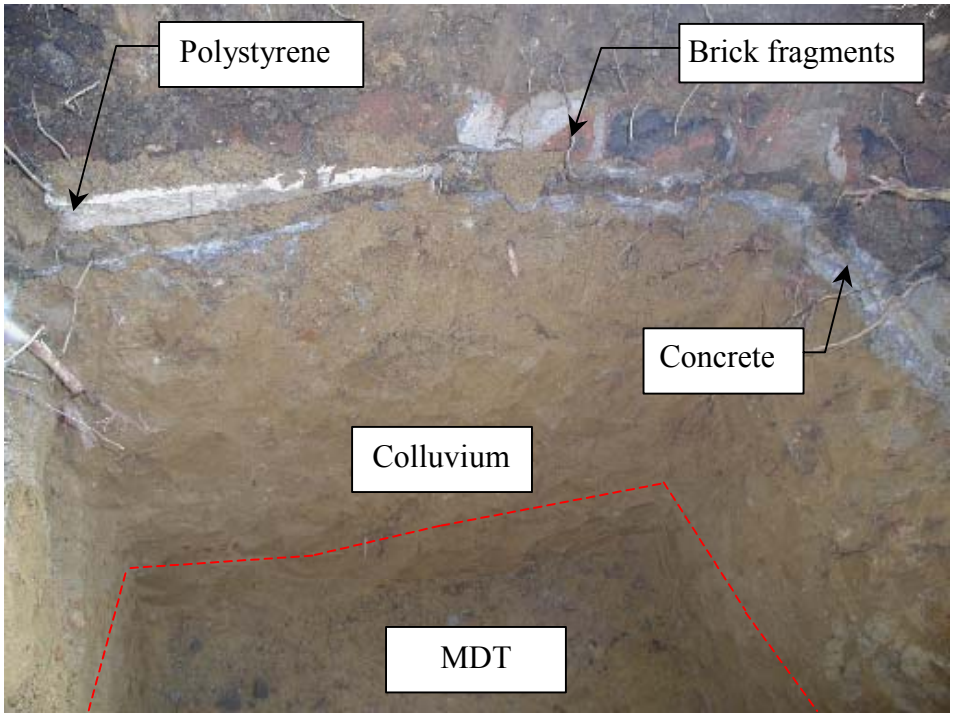


Plate 26 - Fill Containing Brick Fragments, Concrete and Polystyrene Exposed in Trial Pit No. TP2 (Photograph taken on 5 September 2002)

Note: See Figure 11 for locations of photographs.

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

Plate 27 - Moderately Decomposed Tuff Exposed in Slope Strip No. SS2 between 1.4 m and 6.6 m (Photograph taken on 5 September 2002)

Note: See Figure 11 for locations of photographs.

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

AERIAL PHOTOGRAPH INTERPRETATION (API) REPORT
ON THE 10 AUGUST 2002 INCIDENT AT VICTORIA ROAD, HONG KONG

A.1 INTRODUCTION

As a result of a landslide (GEO Incident No. 2002/08/0076) that occurred around 7:00 a.m. on 10 August 2002 on an unregistered soil/rock cut slope within an active construction site of a Highways Department project entitled "Victoria Road Improvements, Stage II, Phase 2" (Works Contract No. HY/97/03), Halcrow China Limited (HCL) was requested to carry out an API of the subject slope and the surrounding hillside.

The primary aim of the API was to identify the former topographical setting and possible origins of the soil material involved in the failure and signs of instability in recent and historic aerial photographs.

A.2 SUMMARY OF OBSERVATIONS

The subject slope at the location of the 10 August 2002 landslide appears to have been cut at a location near the head of a natural drainage channel. It is possible that an ancient fan of colluvial material was deposited in a minor depression located immediately above the location of the recent landslide (as observed in 1949). Significantly, the location of the 10 August 2002 landslide was previously traversed by drainage channels connecting to a catchpit that directed water to a cross-road drain beneath Victoria Road. Some terracing of the area above the location of the recent landslide has taken place and some filling of the area at the landslide may have occurred as a result. However this is inferential and no evidence for substantial filling at the location of the recent landslide was observed in the aerial photographs examined.

A.3 OBSERVATIONS

Date of Photograph Aerial Photo No(s) Altitude	Observations
13 November 1924 16(H12) 21 090' 27(HQ6) 22 198'	High altitude, not clear, Victoria Road present as an unpaved track. Possible area of vegetation clearance above approximate location of the 10 August 2002 landslide. The small area may mark the location of a natural drainage line, which appears to continue, and is more easily identified, below (west of) the road. Apart from this small area much of the hillside is relatively densely vegetated with some trees which are observed to be overhanging Victoria Road. A farm with fenced or walled paddocks/fields is present at the top of the ridge line above the recent incident.

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

Date of Photograph Aerial Photo No(s) Altitude	Observations
8 May 1949 6010/11 (81A/127) 8600’	At the location of the 10 August 2002 landslide, drainage channels are observed to converge into a catchpit (Plate A1), which appears to connect to a cross-road drain that crosses beneath the road and to discharge over the hillside at the opposite side of the road. The discharge does not appear to be directed to a channel which is indicated by a small fan of debris visible on the western side of the road. The fill embankment on which the western side of Victoria Road is situated is clearly identifiable (currently registered as slope No. 11SW-C/C763). About 20 m to 30 m above and southeast of the present landslide a natural drainage line can be identified. A “horse-shoe” shaped depression near the head of this drainage line is interpreted as a relict landslide scar. A dark area (or slightly darker area of vegetation) that appears to widen, almost fan shaped (Figure A1), from the natural drainage can be observed. This is a possible fan of colluvial debris, although this fan is apparently not present below the road. Two natural drainage lines are identifiable below (to the west of) the road, but neither drainage line appears to run continuous with the natural drainage line observed above the road.
16 February 1963 Y08080 - Y08081 2700’ Y07373 - Y07374 2700’	Three prominent areas of vegetation clearance are observed above and west of the location of the 10 August 2002 landslide (Figure A1 and Plate A2), it would appear that these areas have been cleared for agricultural use similar to the larger area south of these areas which are more clearly observed to be in agricultural use. In general much vegetation has been cleared from the natural terrain (disturbed terrain?) between the Farm on the ridge above the recent landslide and Victoria Road. The cross-road drain that passes beneath Victoria Road (at the location of the 10 August 2002 landslide) is now observed to discharge into the natural drainage line previously identified in the 1949 aerial photographs, on the west side of the road (opposite the 10 August 2002 landslide). It is apparent that the section of the drainage line immediately below (i.e. west of) the outlet of the cross-road drain has become incised and extends closer to the west side of Victoria road. The appearance of the incised channel that apparently extends further than previously observed, probably indicates that water that has discharged from the cross-road drain has washed through fill placed in the drainage line as a result of the construction of the fill embankment for Victoria Road. There is little evidence of filling in the area above (i.e. east of) the catchpit, i.e. at the location of the 10 August 2002 landslide.

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

Date of Photograph Aerial Photo No(s) Altitude	Observations
1968 Y14090 2000' (on photo appear to be 8000' or higher)	(Photographs appear to be higher altitude than stated) subject site visible at edges of photographs. Significantly two landslides are visible along the section of Victoria Road near the 10 August 2002 landslide (Plate A3). The two landslides, about 5 m wide by 10 m long and about 10 m wide by 10 m long, have occurred about 20 m and 100 m to the north of the l0 August 2002 landslide respectively. Based on the bright reflection from the landslide scars it is apparent that both landslide scars have been covered with hard surface. The areas of cleared vegetation above the 10 August 2002 landslide location, identified in the 1963 aerial photographs, appear to have been abandoned and have begun to re-vegetate.
12 December 1973 7045 & 7046 3000' 7087 & 7088 4000'	Good quality low altitude photos. Vegetation is beginning to overgrow the landslide scars observed in 1968. Terrace farming has established on slope directly above and adjacent to the 10 August 2002 landslide location. The natural drainage line below road is more easily identified than in previous aerial photographs. Bounding the area of terracing to the east, there is a prominent concave break in slope. This is a possible explanation for the accumulation of colluvium in this area. Much of the central portion of what later became the subject slope, is densely vegetated but a natural drainage line is identifiable through the central portion of this area.
6 May 1977 18256 & 18257 4000'	Little additional information although vegetation (mainly trees) has become very dense adjacent to road less so away from the road upslope.
14 September 1979 26866 4000'	Little observable change at location of the 10 August 2002 landslide. Terracing appears to be taking place around the outer perimeter of the farm on the ridgeline above the 10 August 2002 landslide.
6 November 1980 32429 & 32430 32439 & 32440 4000'	Area to the south of 10 August 2002 landslide has been terraced and a structure (possible drainage channel) is visible (approximately at the location of Trial Pit TP2). A possible natural drainage line is observed above the terraced area, above the location of the 10 August 2002 landslide.

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

Date of Photograph Aerial Photo No(s) Altitude	Observations
28 November 1983 50836 & 50837 2000’	(Photos taken at around mid-day) The area around the location of the 10 August 2002 landslide is densely vegetated with what appears to be mature trees. Some vegetation clearance has been carried out immediately above the present failure location (i.e. at the area previously cleared but abandoned/allowed to re-vegetate). The terracing south of the location of failure appears to be greater in extent and a building (1 storey squatter hut type) is identifiable about 5 m to 6 m to the east of the location of failure (could correspond to observations in Trial Pit TP2). The natural drainage line below the road, opposite the landslide, is delineated by vegetation.
9 September 1987 A10363 & A10364 4000’	No significant changes to the subject slope and surrounding area observed.
2 October 1991 A27811 4000’	No significant change to the subject slope near the 10 August 2002 landslide. The area of terracing south of the landslide location appears to be abandoned and vegetation is beginning to re-grow.
7 December 1995 CN12687 & CN12688 3500’	Most of the slope area above the location of the 10 August 2002 landslide is densely vegetated. The area of terracing is abandoned although squatter huts are still visible. A possible fire has occurred below road.
23 July 1997 CN17613 - 15 4000’	No significant changes.
3 November 1999 CN24042 and 47 4000’	Slope cutting works as part of the “Victoria Road Improvements, Stage II, Phase 2” project are in progress. Cutting of the subject slope at the location of the 10 August 2002 landslide has not apparently commenced.
26 July 2000 CN27520 4000’	Cutting works at the subject slope are visible and appear to be mostly complete. The slope, at location of 10 August 2002 landslide, appears to have been cut into areas previously terraced.
3 September 2000 CN28255 4000’	Slope cutting works appear to be complete.

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

LIST OF FIGURES

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

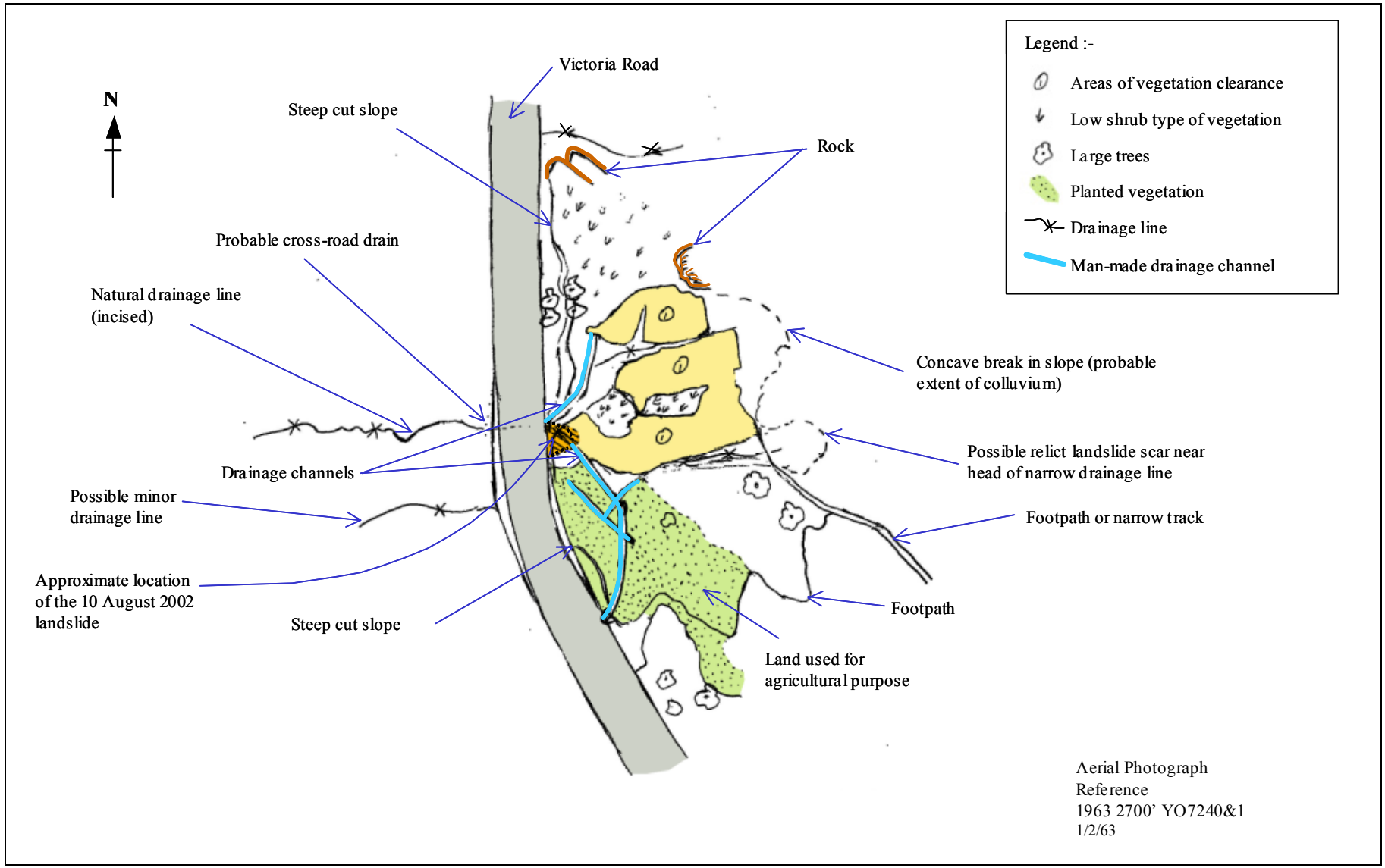


Figure A1 - Sketch Showing Aspects Identified from 1963 Aerial Photographs

LIST OF PLATES

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

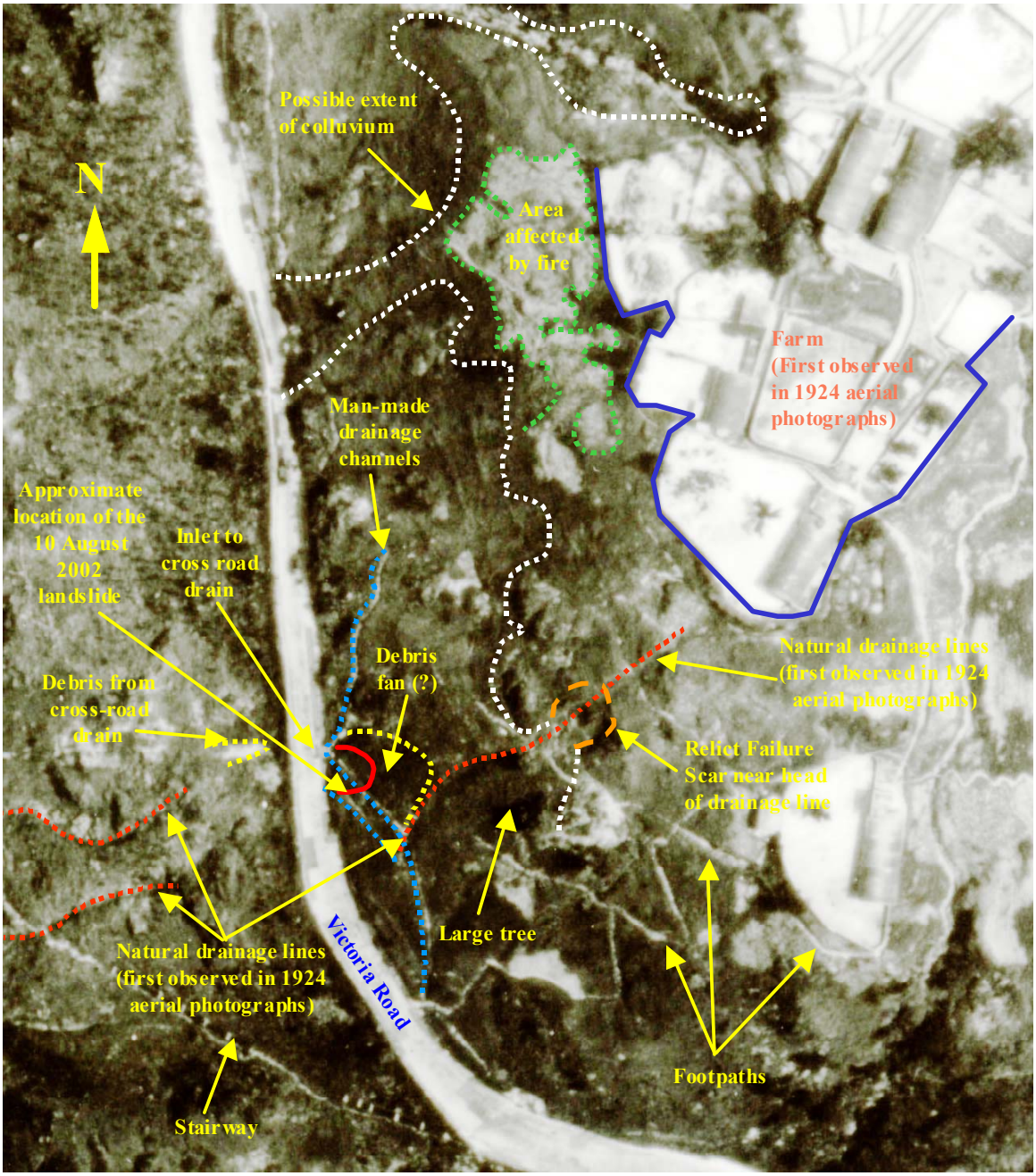


Plate A1 - Extract from 1949 Aerial Photograph (6010, 81A/127) 8600'

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

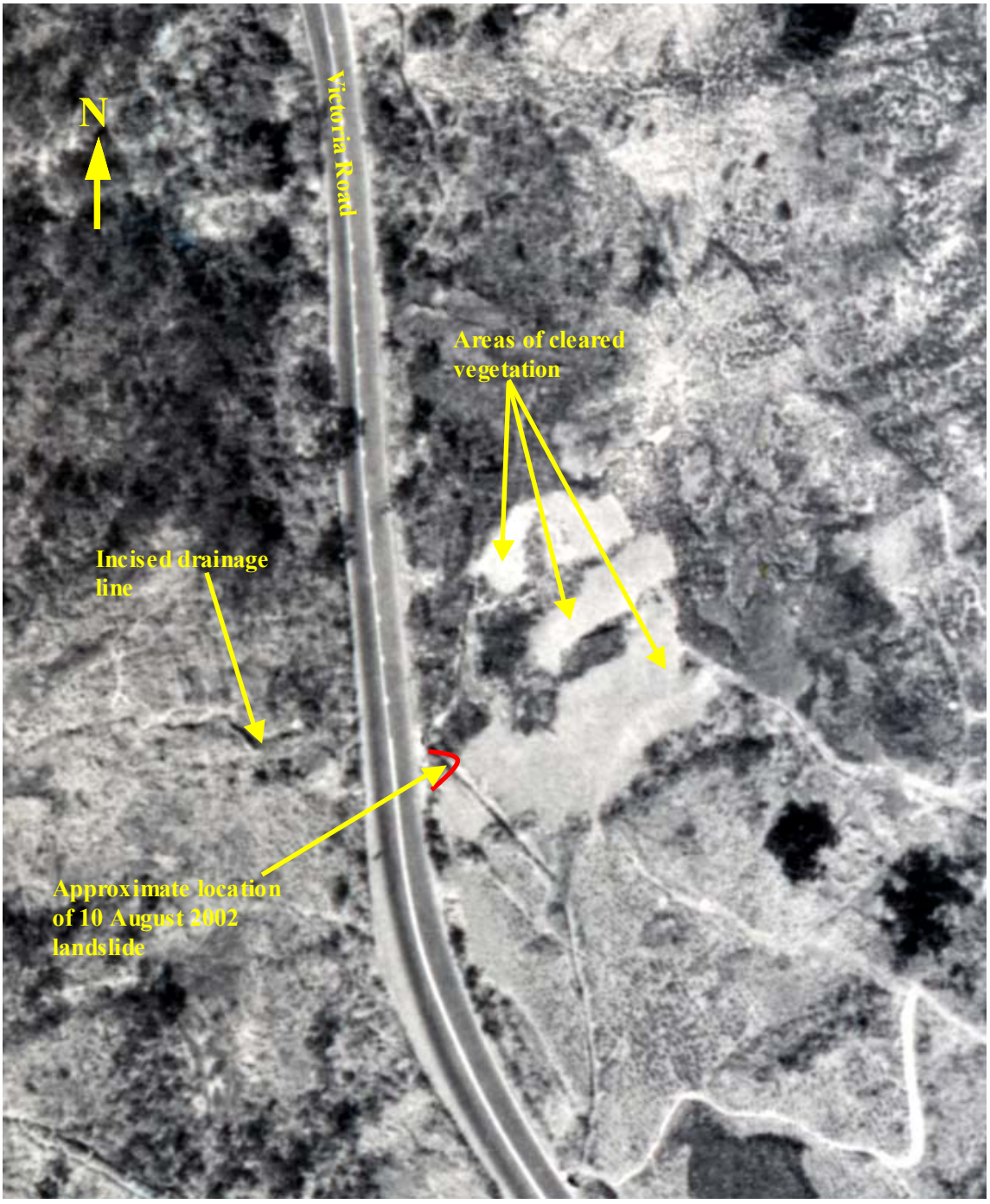


Plate A2 - Extract from 1963 Aerial Photograph (Y07240)

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

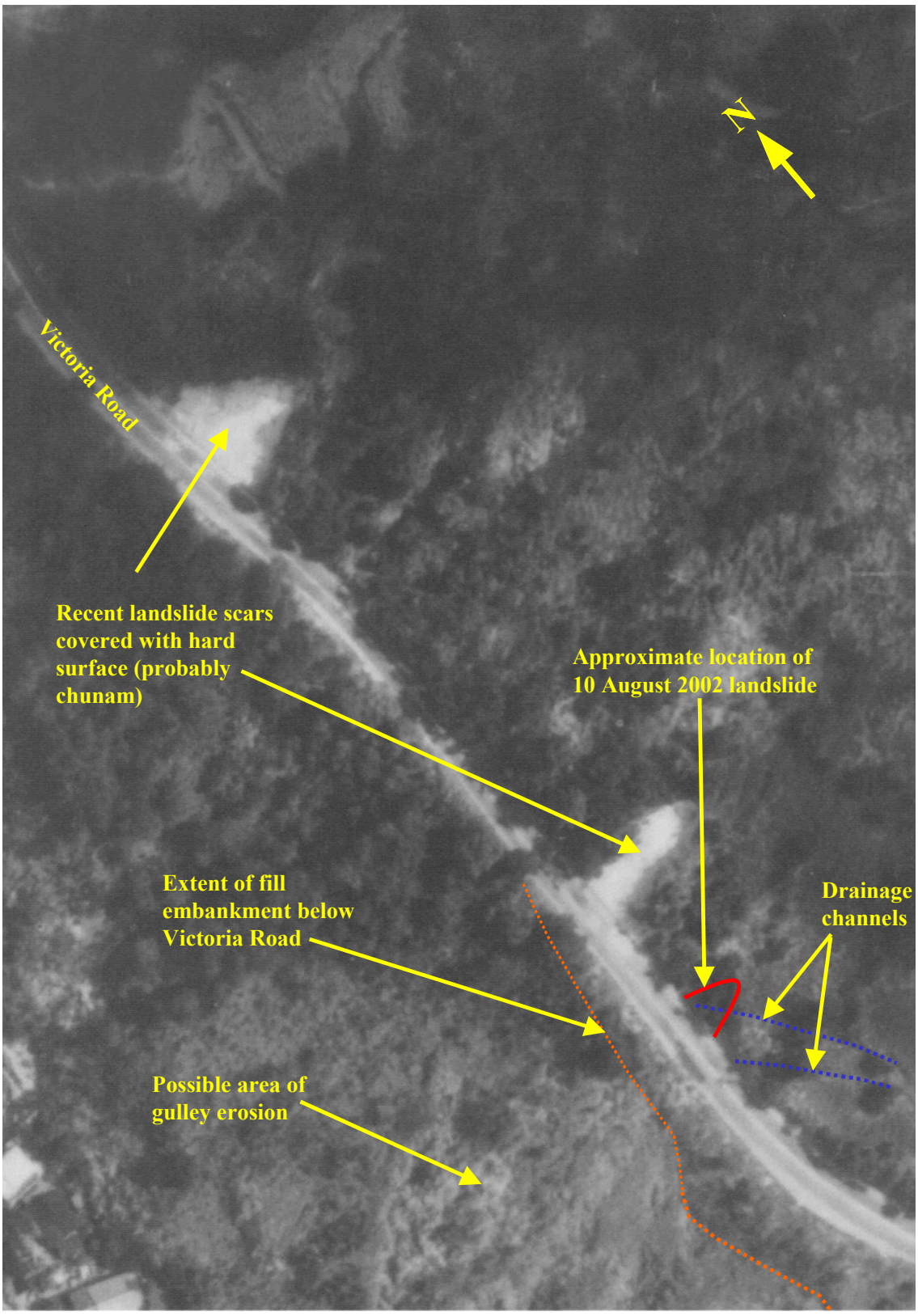


Plate A3 - Extract from 1968 Aerial Photograph (Y14090)

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

LOGS OF TRIAL PITS AND SLOPE STRIPS

Halcrow China Limited
Agreement No. CE86/2001 (GE)
Study of Landslides Occurring in Hong Kong Island and Outlying Islands in 2002 Feasibility Study
10th August 2002 Landslide
at Victoria Road, Hong Kong

TRIAL PIT RECORD

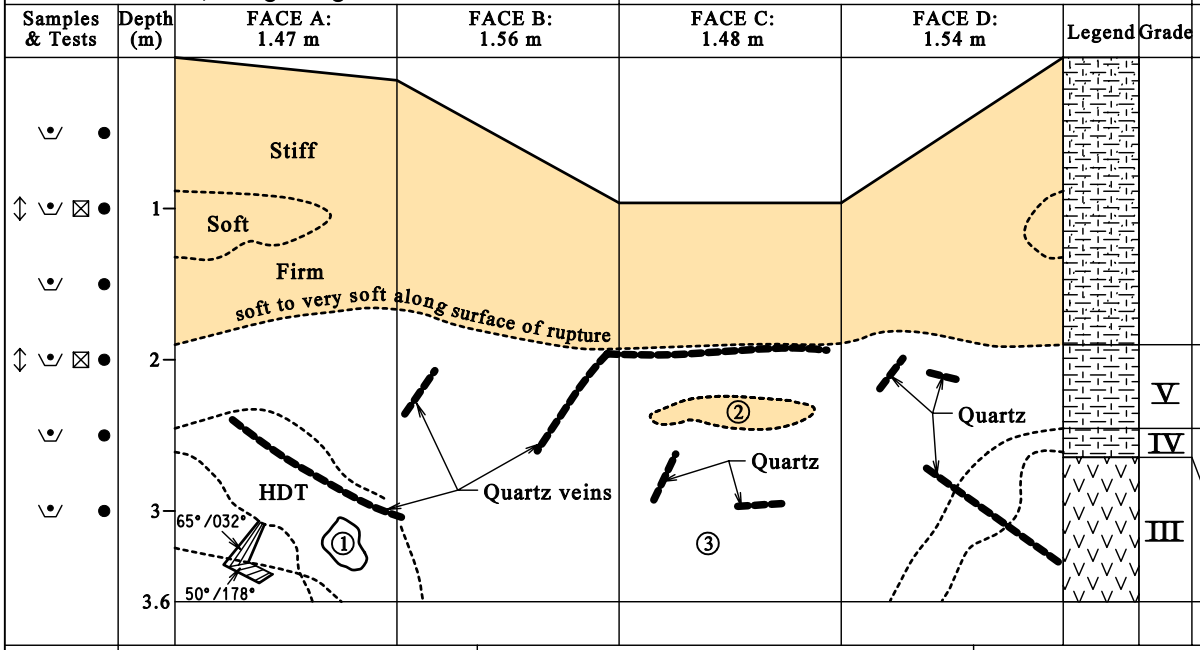
TRIAL PIT No. TP1

Sheet 1 of 1

EXCAVATION DATE : 03-09-02 to 04-09-02
BACKFILL DATE : 30-09-02 16-09-02

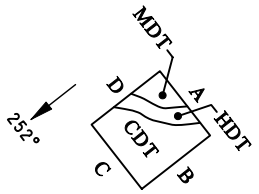
CO-ORDINATES 831567.88E 813975.98N
GROUND LEVEL +62.39 mPD

LOGGED BY : M. Devonald DATE : 05-09-02
CHECKED BY : L. Tang DATE : 16-09-02



Symbol	Samples / Tests / Water
●	Small Disturbed Sample
↕	Large Disturbed Sample
▬	U76 / U100 Horizontal
▌	U76 / U100 Vertical
⊠	Block Sample
⊔	Insitu Density Test
◡●	Jar Sample
≈	Seepage

PLAN (NOT TO SCALE)



KEY

N

NORTH ARROW

Remarks

① Soft, white to light grey CLAY (possibly decomposed feldspar)

② Very soft, light reddish brown CLAY (possible rupture through CDT)

③ Face C appears to have a higher clay content but retains quartz veins and mineral structure.

Figure B1 - Trial Pit TP1

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

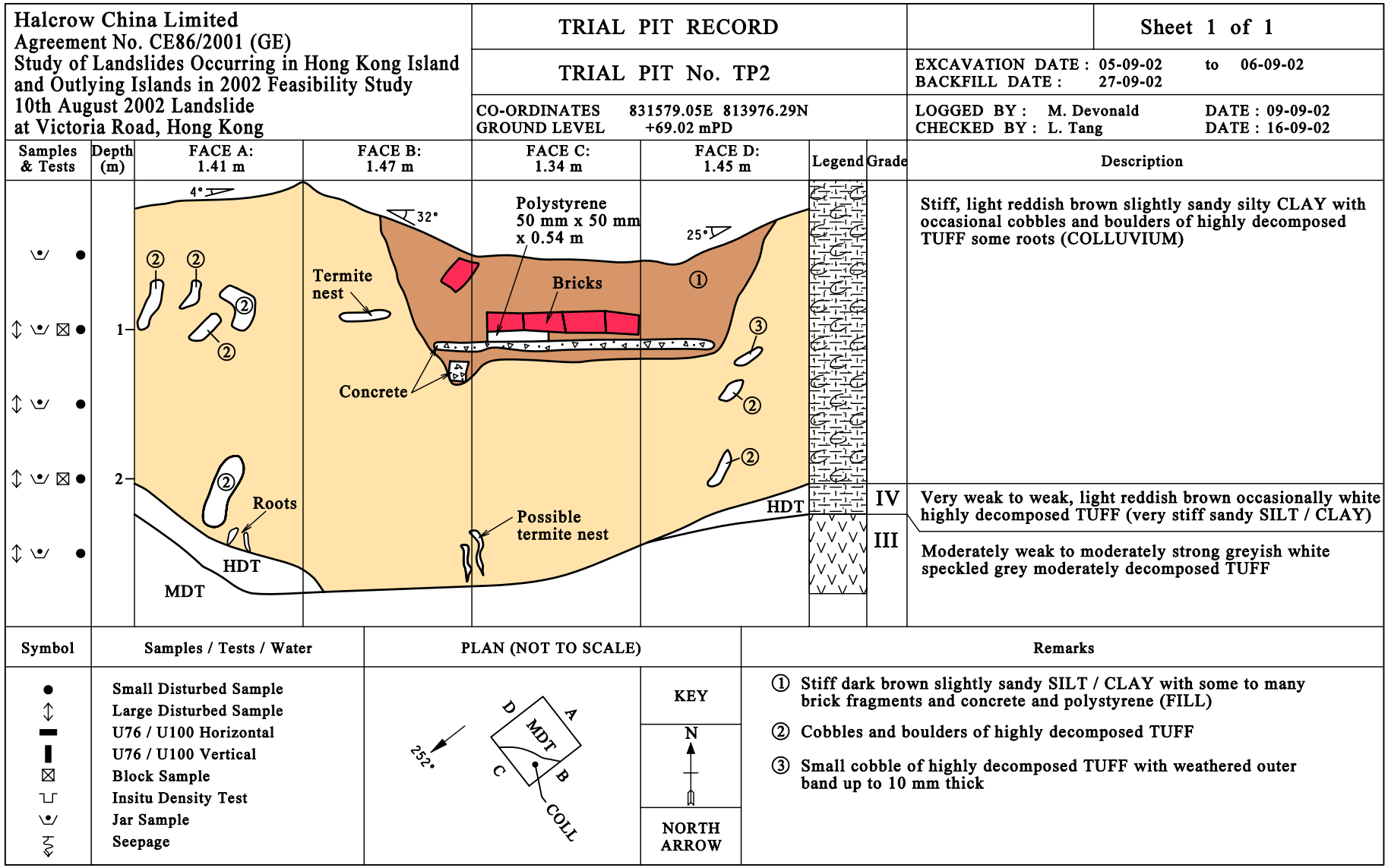


Figure B2 - Trial Pit TP2

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

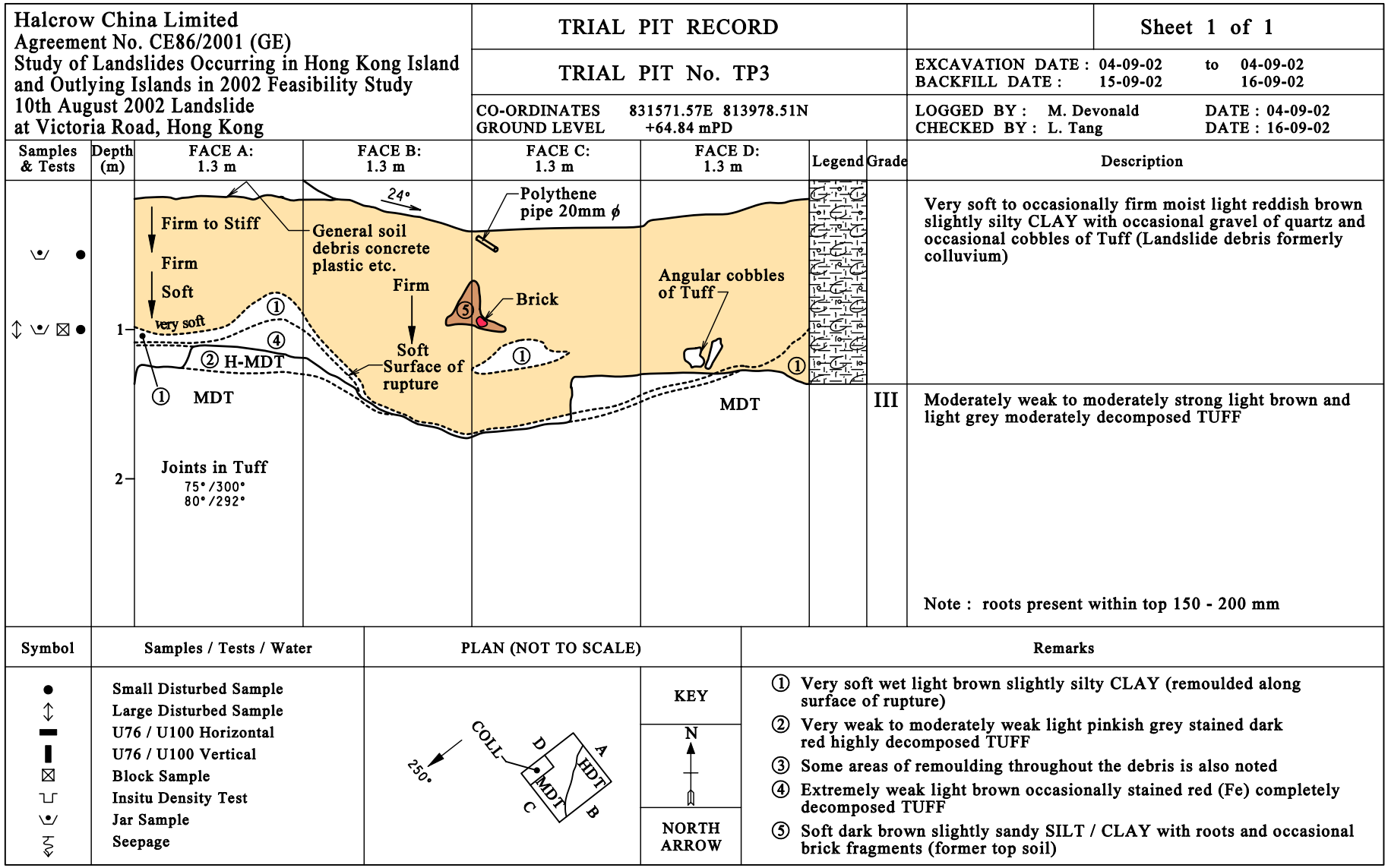


Figure B3 - Trial Pit TP3

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

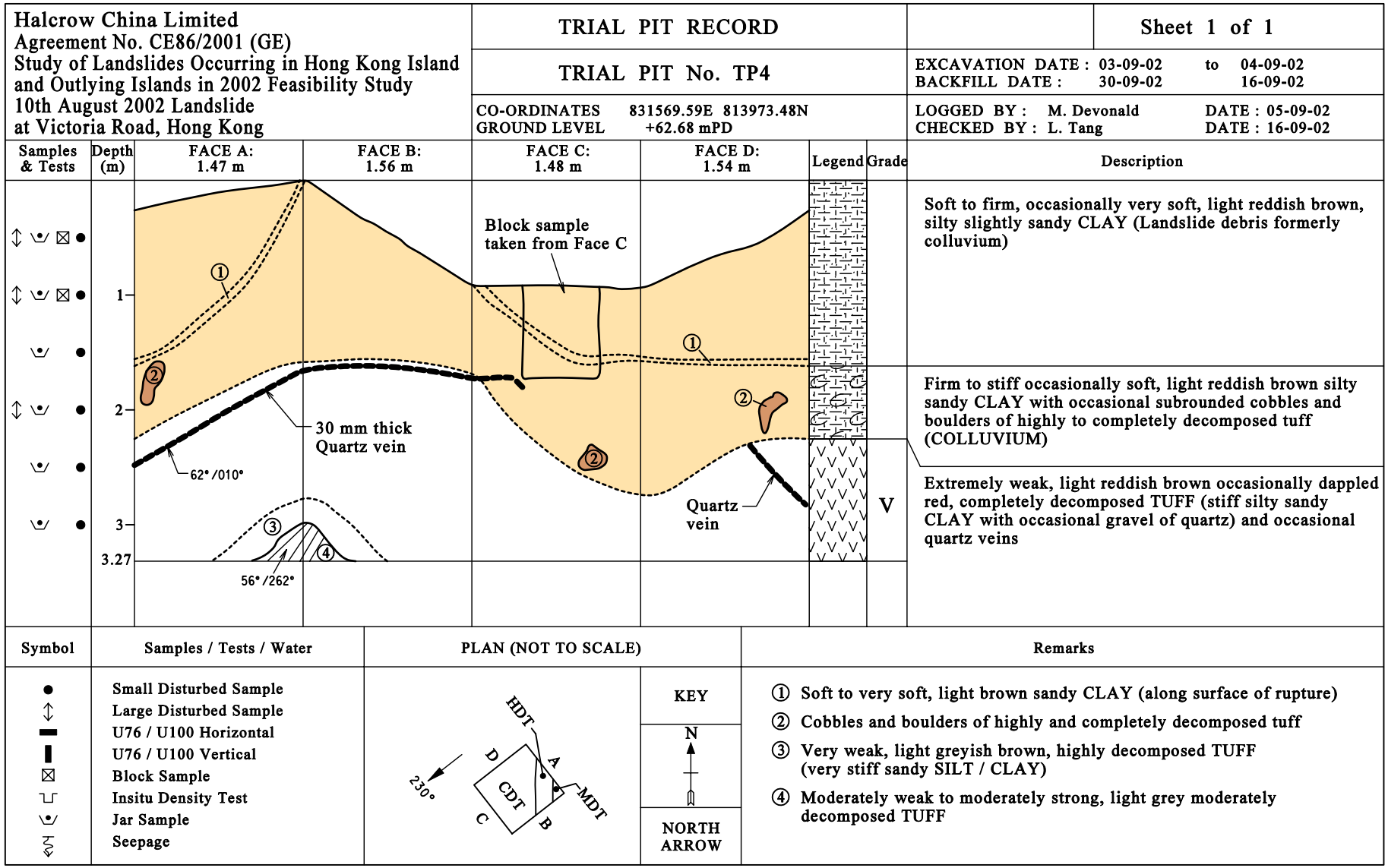


Figure B4 - Trial Pit TP4

Halcrow China Limited	SLOPE STRIP RECORD	Sheet 1 of 1

Agreement No. CE86/2001 (GE)
Study of Landslides Occuring in Hong Kong Island and Outlying Islands in 2002 - Feasibility Study
10th August 2002 Landslide at Victoria Road, Hong Kong

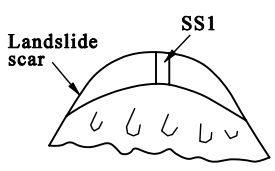
Slope Strip No.: SS1	Co-ordinates: 831573 E 813977 N Crest Level: +66.18mPD	Logged By: MD Date: 05-09-02 Checked By: LT Date: 15-09-02
	Co-ordinates: 831573 E 813977 N Toe Level: +64.73mPD	Date Constructed: 03-09-02 Date Reinstated: 30-09-02

Distance from Datum (m)	Slope Angle	Reduced Level (mPD)	Samples and Tests	Description	Legend	Grade	Discontinuities: Dip/Dip Direction	Discontinuities: Nature & Infilling
0.00		+66.20		Concrete apron associated with U-channel some plastic and broken red clay pipes with concrete				
				Firm to stiff, light reddish brown, slightly sandy silty CLAY with occasional gravel of quartz and occasional roots (Colluvium) roots				
1				becoming soft				
1.50								
2								

REMARKS:

- Small Disturbed Sample
- Large Disturbed Sample
- Undisturbed Sample
- Block Sample
- Insitu Density Test
- Water Sample
- Seepage
- N-Schmidt Hammer Test

PLAN (not to scale)



SECTION (not to scale)

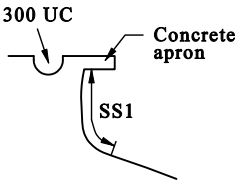


Figure B5 - Slope Strip SS1

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

Halcrow China Limited	SLOPE STRIP RECORD	Sheet 1 of 1

Agreement No. CE86/2001 (GE)
Study of Landslides Occuring in Hong Kong Island and Outlying Islands in 2002 - Feasibility Study
10th August 2002 Landslide at Victoria Road, Hong Kong

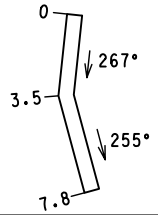
Slope Strip No.: SS2	Co-ordinates: 831581 E 813983 N Crest Level: +72.29mPD	Logged By: MD Date: 05-09-02 Checked By: LT Date: 16-09-02
	Co-ordinates: 831575 E 813981 N Toe Level: +67.95mPD	Date Constructed: 03-09-02 Date Reinstated: 30-09-02

Distance from Datum (m)	Slope Angle	Reduced Level (mPD)	Samples and Tests	Description	Legend	Grade	Discontinuities: Dip/Dip Direction	Discontinuities: Nature & Infilling
0.00	18° to 20°	+72.29		Stiff to very stiff, highly reddish brown slightly sandy SILT/CLAY with occasional cobble size fragments of moderately decomposed Tuff and brick (Fill)				
1.40								
2	35°			Moderately strong grey and light greyish brown moderately decomposed Tuff			76/012 75/015 83/013	
3.50							67/028	
4	32°			3.7 - 3.9 surface of Tuff shows 10-15 mm thick band of light brown weathering			70/020	
6.60								
7	15°			Stiff, light reddish brown, slightly sandy SILT/CLAY with occasional angular cobbles of Tuff (Fill)				
7.80								
8								

REMARKS:

- Small Disturbed Sample
- Large Disturbed Sample
- Undisturbed Sample
- Block Sample
- Insitu Density Test
- Water Sample
- Seepage
- N-Schmidt Hammer Test

PLAN (not to scale)



SECTION (not to scale)

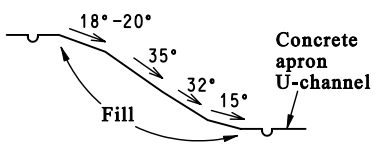


Figure B6 - Slope Strip SS2

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

RESULTS OF GCO PROBE TESTS AND IN-SITU DENSITY TESTS

Table C1 - Co-ordinates and Ground Levels of GCO Probe Tests (G1 to G8)

GCO Probe Tests	E	N	(mPD)
G1	831567.88	813975.98	62.39
G2	831571.57	813979.55	65.03
G3	831570.25	813974.28	63.18
G4	831579.05	813976.29	69.02
G5	831571.57	813976.37	64.33
G6	831569.06	813978.69	63.37
G7	831574.99	813969.55	66.17
G8	831571.58	813968.55	63.86

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

Table C2 - Summary of GCO Probe Test Results from 2 to 7 September 2002

Depth (mbGL)	GCO Probe Test Number							
	G1	G2	G3	G4	G5	G6	G7	G8
	Blows /100mm	Blows /100mm	Blows /100mm	Blows /100mm	Blows /100mm	Blows /100mm	Blows /100mm	Blows /100mm
0.1	3	1	3	1	1	1	14	30
0.2	2	1	1	3	1	1	15	40
0.3	3	1	0	4	1	0	16	36
0.4	1	1	0	2	1	0	17	17
0.5	1	1	0	4	1	0	11	8
0.6	1	1	1	2	2	1	10	15
0.7	1	1	1	3	1	2	10	9
0.8	1	1	1	4	0	1	10	11
0.9	1	1	1	4	5	3	11	8
1.0	1	1	1	3	100	2	11	8
1.1	1	4	1	5		1	9	9
1.2	1	100	1	5		1	8	6
1.3	1		1	5		1	9	5
1.4	1		4	3		2	9	5
1.5	1		3	4		1	7	5
1.6	1		5	2		1	8	7
1.7	4		4	4		3	8	8
1.8	6		4	12		5	11	11
1.9	2		3	4		4	8	14
2.0	2		4	4		5	10	12
2.1	3		4	6		24	13	9
2.2	3		5	4		12	15	11
2.3	3		5	5		12	15	15
2.4	3		7	6		29	12	12
2.5	48		11	6		16	10	12
2.6	34		22	16		15	12	12
2.7	20		67	29		10	12	15
2.8	99		73	33		10	12	19
2.9	83		34	100		6	100	14
3.0	30		43			8		14
3.1	28		33			25		10
3.2	40		37			100		18
3.3	25		34					20
3.4	15		13					23
3.5	34		11					100
3.6	16		12					
3.7	100		11					
3.8			9					
3.9			73					
4.0			100					

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

Table C3 - In-situ Bulk Density and Moisture Content of Colluvium at TP2

Trial Pit.	Depth (m)	In-situ Bulk Density (Mg/m^3)	Moisture Content (%)	In-situ Dry Density (Mg/m^3)	Void Ratio
TP2	0.5	1.60	21	1.32	0.97
TP2	1.0	1.75	20	1.46	0.78
TP2	1.5	1.81	19	1.52	0.71
TP2	2.0	1.74	20	1.45	0.79
TP2	2.5	1.85	20	1.54	0.69

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 D

RESULTS OF LABORATORY TESTING

D.1 INTRODUCTION

Laboratory tests comprising particle size distribution test, Atterberg Limit tests, moisture content and triaxial tests were carried out by the Public Works Central Laboratory. The test results are summarised in Table D1 and Figure D1.

D.2 TRIAXIAL TESTS

Consolidated undrained triaxial (CU) tests were carried out on test samples cut from block samples of colluvium taken from TP2 (above the 2002 landslide). The effective stress paths of the soil specimens for the CU tests are drawn and presented in Figure D1.

It is noted that positive excess pore pressures developed during the CU tests for colluvium and the effective stress paths in general bend to the left (after a slight increase in p' from the start of the tests). This indicates that colluvium at the subject slope was loose and with contractive behaviour similar to that of loose fill. The steady state shear strength parameters of colluvium are $c' = 7$ kPa to 12 kPa and $\phi' = 26^{o}$.

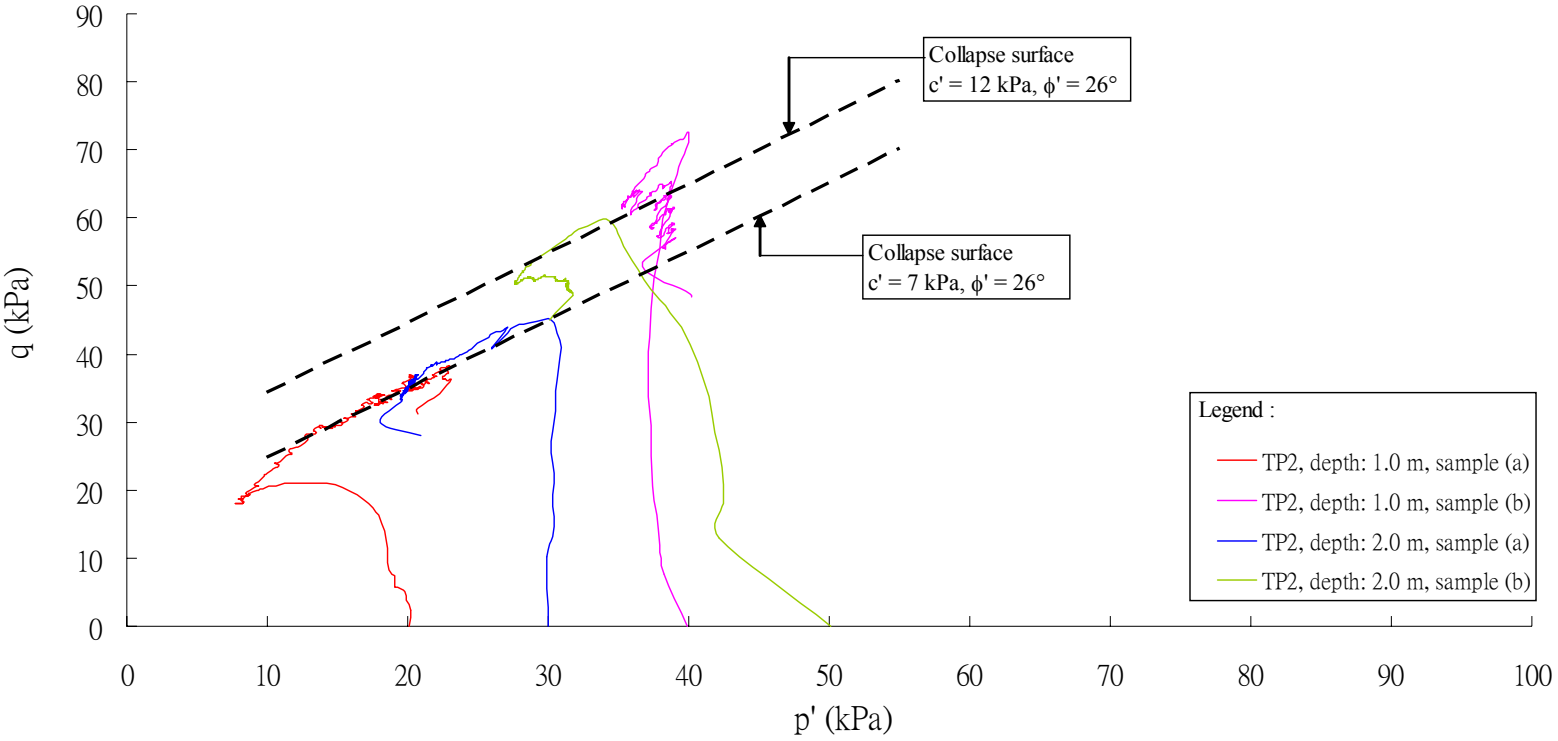
Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table D1 - Summary of Laboratory Test Results

Sample Location	Sample Depth (m)	Sample Type	Material Type	Moisture Content at 45°C±5°C (%)	Particle Size Distribution				Atterberg Limits				Triaxial Tests*		Particle Density (Mg/m³)
					Gravel (%)	Sand (%)	Silt (%)	Clay (%)	LL (%)	PL (%)	PI (%)	LI	p_o' (kPa)	Dry Density (Mg/m³)	
TP1	1.0	Block	COLL	20	2	21	54	23	43	22	21	0.14	-	-	-
	2.0	Block	CDT	22	3	21	51	25	39	23	16	0.27	-	-	2.63
TP2	1.0	Block	COLL	21.0 20.7	-	-	-	-	-	-	-	-	20 40	1.53 1.54	2.60
				19.3	4	15	42	39	-	-	-	-	-	-	-
	2.0	Block		18.8 17.9	-	-	-	-	-	-	-	-	30 50	1.49 1.55	2.60
				-	2	21	53	24	41	21	20	0.01	-	-	-
TP3	0.9 m (face A)	Disturbed	COLL	25	-	-	-	-	42	20	22	0.35	-	-	-
				-	2	20	53	25	-	-	-	-	-	-	-
	1.0	Disturbed		24	2	23	56	19	-	-	-	-	-	-	-

Legend:

* Consolidated Undrained Single-stage Triaxial Test



Note: See Table D1 for details of test data.

Figure D1 - Shear Strength Data for Colluvium

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

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 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://bookstore.esdlife.com
- Downloading the order form from the ISD website at http://www.isd.gov.hk and submit 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，網址爲 http://bookstore.esdlife.com
- 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 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: 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: 2231 3187
傳真: (852) 2116 0774

Requests for copies of Geological Survey Sheet Reports, publications and maps which are free of charge should be sent to:

For Geological Survey Sheet Reports and maps 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: sdcampbell@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 5345
Fax: (852) 2714 0275
E-mail: ykhui@cedd.gov.hk

如欲索取地質調查報告、其他免費刊物及地質圖，請致函：

地質調查報告及地質圖:
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: sdcampbell@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 5345
傳真: (852) 2714 0275
電子郵件: ykhui@cedd.gov.hk

Table of Contents
Table of Contents
Table of Contents

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

GEOTECHNICAL MANUALS

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

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

GEOGUIDES

Geoguide 1	Guide to Retaining Wall Design, 2nd Edition (1993), 258 p. (Reprinted, 2000).
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.

GEOSPECS

Geospec 1	Model Specification for Prestressed Ground Anchors, 2nd Edition (1989), 164 p. (Reprinted, 1997).
Geospec 2	Model Specification for Reinforced Fill Structures (1989), 135 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. 1/96	Pile Design and Construction (1996), 348 p. (Reprinted, 2003).
GEO Publication No. 1/2000	Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls (2000), 146 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