DETAILED STUDY OF THE 20 AUGUST 2005 LANDSLIDE AT BOWEN ROAD ABOVE NO. 120 KENNEDY ROAD

GEO REPORT No. 214

FUGRO SCOTT WILSON JOINT VENTURE

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

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This report was originally produced in March 2007
as GEO Landslide Study Report No. LSR 12/2006

First published, October 2007

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PREFACE

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

The Geotechnical Engineering Office also produces documents specifically for publication. These include guidance documents and results of comprehensive reviews. These publications and the printed GEO Reports may be obtained from the Government's Information Services Department. Information on how to purchase these documents is given on the second last page of this report.

R.K.S. Chan
Head, Geotechnical Engineering Office
October 2007

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

FOREWORD

This report presents the findings of a detailed study of two major landslides (Incident No. 2005/08/0304), which affected Slope No. 11SW-D/C1352 above Bowen Road and the adjacent natural hillside at about 9:30 a.m. on 20 August 2005. Bowen Road and a playground were blocked as a result of the landslides and debris deposited on to an abandoned platform area and the unoccupied apartment blocks at No. 120 Kennedy Road. St. James' Primary School at No. 110 Kennedy Road and the unoccupied buildings at Nos. 98 and 120 Kennedy Road were temporarily closed after the landslides. No casualties were reported as a result of the landslides.

The key objectives of the study were to document the facts about the landslides, present relevant background information and establish the probable causes of the landslides. The scope of the study comprised desk study, field mapping and topographic survey, ground investigation and laboratory testing, rainfall analysis and engineering analysis. Recommendations for follow-up actions are reported separately.

The report was prepared as part of the 2004/2005 Landslide Investigation Consultancy (LIC) for Hong Kong Island and Outlying Islands, for the Geotechnical Engineering Office (GEO), under Agreement No. CE 29/2003 (GE). This is one of a series of reports produced during the consultancy by Fugro Scott Wilson Joint Venture (FSW).

Y C Koo
Project Director
Fugro Scott Wilson Joint Venture

Agreement No. CE 29/2003 (GE)
Study of Landslides Occurring in
Hong Kong Island and Outlying
Islands in 2004 and 2005 –
Feasibility Study

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

CONTENTS

1. INTRODUCTION

Two major landslides (Incident No. 2005/08/0304) affected Slope No. 11SW-D/C1352 and the natural hillside above Bowen Road (upper landslide), together with the hillside below a public playground on Bowen Road (lower landslide), at about 9:30 a.m. on 20 August 2005, during which time an Amber Rainstorm Warning and a Landslip Warning were in force. The upper landslide involved about 750 m^3 of debris, which blocked Bowen Road and the playground. Some of the debris on the playground subsequently travelled onto the lower landslide. The lower landslide involved about 200 m^3 of debris, which travelled down the hillside below Bowen Road and the debris was deposited at the rear of an unoccupied apartment block at No. 120 Kennedy Road, and within an adjacent abandoned platform area, at the toe of the affected hillside. No casualties were reported as a result of the landslides.

Washout debris inundated the ground floor of the unoccupied apartment block at No. 120 Kennedy Road. St. James' Primary School at No. 110 Kennedy Road was closed after the landslides and was re-opened on 14 September 2005. The unoccupied buildings at Nos. 98 and 120 Kennedy Road were also closed after the landslides. The Closure Order for both properties was lifted on 21 December 2005 after emergency slope repair works had been completed.

Following the incidents, Fugro Scott Wilson Joint Venture (FSW), the 2004 and 2005 Landslide Investigation Consultants for Hong Kong Island and Outlying Islands, carried out a detailed study of the landslides for the Geotechnical Engineering Office (GEO), Civil Engineering and Development Department (CEDD), under Agreement No. CE 29/2003 (GE).

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

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

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

(b) geological and geomorphological field mapping and topographic survey,

(c) aerial photograph interpretation (API),

(d) ground investigation and laboratory testing,

(e) analysis of rainfall records,

(f) engineering analysis, and

(g) diagnosis of the probable modes, mechanisms and causes of the landslides.

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

2. THE SITE

2.1 Site Description

The two landslides occurred on a north-facing, moderately to steeply inclined (33° to 45°), densely vegetated hillside above and below Bowen Road (Figure 1 and Plates 1 and 2). Bowen Road traverses the hillside at about 120 mPD and is a single-lane road with restricted access, which is used predominantly by pedestrians. The unoccupied apartment blocks of Nos. 98 (Caine Terrace) and 120 Kennedy Road, together with an adjacent abandoned platform, are located at about 50 mPD at the toe of the subject hillside below Bowen Road. A plan and cross section of the landslide site are shown in Figures 2 and 3 respectively.

Slope No. 11SW-D/C1352 was formed by cutting into a north trending spur in connection with the construction of Bowen Road. The registered soil cut slope is about 60 m long, 6 m high and inclined at about 60° to 75°. The slope was generally covered with dense vegetation, except on the lower 1 m to 2 m of the slope, which was covered with only minor vegetation. The east portion of the slope, unaffected by the 2005 landslides, is covered with patches of chunam and shotcrete, especially near the slope toe.

A public playground is located on a platform alongside the northern edge of Bowen Road at the landslide site. The platform, affected by both landslides, was about 6 m wide and contained fitness apparatus and a sitting-out area prior to the failure.

The two landslides occurred within the middle and lower portions of a catchment (with a plan area of approximately 14,000 m^2) that extends up to Stubbs Road at about 214 mPD (Figure 1). Above Bowen Road, the catchment is defined by rounded spurs to the west and east with ephemeral drainage lines in between. The main drainage line is located about 20 m to the west of the upper landslide scar, and is intersected by a man-made drainage channel at about 3 m above Bowen Road. This drainage line extends as a waterfall over a steep rock cliff within the catchment below Bowen Road, which is located to the west of the lower landslide scar (Figure 2). Cross-road drains are located at both ends of Slope No. 11SW-D/C1352. Adjacent to the rock cliff, the hillside below Bowen Road comprises steeply inclined terrain (45°), which becomes less steeply inclined (33°) below about 80 mPD.

2.2 Water-carrying Services

According to the Water Supplies Department (WSD) records, there is a buried 24-inch (i.e. 610 mm) diameter fresh water mains below Bowen Road at the landslide site (Figure 2). According to WSD, there are no records of any leakage from the pipeline in the vicinity of the landslide site. The pipeline was not affected by the landslides.

Records of the Drainage Services Department (DSD) indicate that there are no buried drainage works or foulwater sewers in the immediate vicinity of Slope No. 11SW-D/C1352.

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

2.3 Maintenance Responsibility

According to the Slope Maintenance Responsibility Information System of the Lands Department, the maintenance responsibility of Slope No. 11SW-D/C1352 rests with the Highways Department (HyD).

3. SITE HISTORY AND PAST INSTABILITY

3.1 General

The site history has been established from aerial photograph interpretation (API) based on available aerial photographs taken between the years 1945 and 2003, as well as a review of the relevant documentary information. A plan of site development history and past instability is shown in Figure 4. Detailed observations from API are given in Appendix A.

3.2 Site History

Bowen Road, Slope No. 11SW-D/C1352 and a platform were all formed before 1945. Slope No. 11SW-D/C1352 is first observed clearly on the 1949 aerial photographs when the vegetation cover was relatively less well-developed. At this time, a drainage channel was evident about 16 m above (and about 14 m in plan distance) from Bowen Road (Figures 3 and 4). The slope between the drainage channel and the crest of Slope No. 11SW-D/C1352 may have been modified by some minor trimming. The platform for the playground on the opposite side of Bowen Road from Slope No. 11SW-D/C1352 appears to have been formed mostly on fill. Fill covered by vegetation is also inferred from the aerial photographs covering a large portion of the hillside below the platform. The fill may have been placed on this part of the hillside during spoil disposal activities in the construction of Bowen Road. The platform was extended between 1949 and 1963 by additional filling on the hillside below the previous platform. A playground was erected on the platform in 1994. It is not known if this involved additional fill materials.

The natural drainage has been modified in the vicinity of the landslide site. The upper and lower man-made drainage channels, which connect to the main drainage line within the catchment (i.e. that which passes over the rock cliff), were both constructed before 1945 (Figure 4).

Platforms with multi-storey buildings were formed before 1945 at the toe of the hillside at the present-day locations of Caine Terrace apartments, No. 120 Kennedy Road and adjacent abandoned platform, and Grandview Tower apartments. Grandview Tower apartments replaced the original building in 1976 to 1977. In 1979, the building originally located to the east of No. 120 Kennedy Road was demolished. No other construction has been carried out at this location since. Caine Terrace and No. 120 Kennedy Road apartments were constructed in 1989 (Figure 4).

A man-made trench is observed across the spur at about 16 m above and 23 m plan distance to the south of the upper landslide, in the 1945, and more clearly in the 1949, aerial photographs (Figure 4). The reason for the trench is not certain, however, it may have been formed during the Second World War.

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

3.3 Past Instability

The hillsides and cut slopes in the vicinity of the landslide site have a history of instability. The review of aerial photographs and field mapping have identified six relict landslides (R1 to R6), together with three relatively recent natural terrain landslides (NT1 to NT3), and thirteen relatively recent landslides affecting man-made slopes or disturbed terrain (DT1 to DT13). Five erosion scars (E1 to E5) have also been identified. The past landslides and erosion scars in the vicinity of the 2005 landslides are shown in Figure 4.

There are no records of reported landslide incidents in GEO's landslide database for Slope No. 11SW-D/C1352. However, a landslide scar (DT1-1949) covered by vegetation is observed on the 1949 aerial photographs on the slope between the drainage channel and Slope No. 11SW-D/C1352 (Figure 4). In addition, a small landslide (DT5-1967) was noted on the 1967 photographs at the west end of the slope, and small cut slope failures could have occurred at the eastern portion of the slope given the presence of possible scars covered with chunam in this area.

A relict landslide (R1) is evident immediately adjacent to the west flank of the upper 2005 landslide scar. The scar is covered partially with vegetation but appears to have been affected by erosion in the 1949 aerial photographs (E3-1949).

Two of the recent natural terrain landslides (NT1-1967 and NT2-1967) were observed in the 1967 photographs above the rock cliff to the west of the lower 2005 landslide scar. Debris from these two landslides was deposited within the natural drainage line below the rock cliff.

Two erosion scars (E1-1949/67 and E2-1949), comprising relatively deep gully channels, are evident on the possible fill covered portion of the hillside affected by the lower 2005 landslide.

4. PREVIOUS STUDIES AND ASSESSMENTS

4.1 Slope Registration by Binnie & Partners in 1977

Slope No. 11SW-D/C1352 was not included in the slope registration exercise by the Government's consultant, Binnie & Partners, in 1977.

4.2 Geotechnical Area Studies Programme

Terrain classification data relating to the study area were compiled as part of the geotechnical Control Office's (GCO, renamed GEO in 1991) Geotechnical Area Studies Programme (GASP) Report I, Hong Kong and Kowloon. The data are shown on a 1:20 000 scale map, which is intended to be used for regional appraisal and strategic planning purposes. The Geotechnical Land Use Map (GLUM) designated the study catchment as generally GLUM Class IV (i.e. a site with extreme geotechnical limitations, probably unsuitable for development, very high engineering costs for development and very intense site investigation required). However, it should be noted that the above terrain classification maps are not

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

intended for assessment of local areas such as the subject hillside because of the limited resolution of the maps.

4.3 Enhanced Natural Terrain Landslide Inventory

In the mid 1990's, the GEO compiled the Natural Terrain Landslide Inventory (NTLI) of historical landslides on the natural terrain of Hong Kong based on API using high-altitude (>8,000 feet) aerial photographs. In 2005, the Enhanced Natural Terrain Landslide Inventory (ENTLI) Pilot Study was completed by the GEO for Hong Kong Island and Kowloon (Maunsell Fugro Scott Wilson, 2005) using low-altitude (i.e. <8,000 feet) aerial photographs to improve the identification of landslides and update the existing NTLI. The ENTLI includes one relict landslide (ENTLI reference No. 11SWDX471, corresponding to landslide R4 in Figure 4) and one recent landslide (ENTLI reference No. 11SWDY062, corresponding to landslide DT4-1967 in Figure 4) in the vicinity of the August 2005 landslide.

Given the presence of historical landslides (i.e. those that occurred during or before 2003) recorded in the NTLI, the study area was classified as a High Priority Area (HPA) catchment (ENTLI reference No. 11SWD_C01) under the ENTLI project prior to the 20 August 2005 landslide. HPA catchments were defined as those whereby the crown of an NTLI landslide is located within 100 m of the upslope boundary of an important facility, or when the toe of an NTLI landslide trail is within 40 m or 40% of the trail length, whichever is greater, of the upslope boundary of an important facility.

4.4 SIFT and SIRST

In September 1995, under the "Systematic Inspection of Features in the Territory" (SIFT) project initiated by the GEO, Slope No. 11SW-D/C1352 was designated as SIFT Class 'C1' (i.e. a slope that had "been formed or substantially modified before 30.6.78").

In April 1996, Slope No. 11SW-D/C1352 was inspected under the "Systematic Identification and Registration of Slopes in the Territory" (SIRST) project initiated by the GEO. The SIRST field sheet indicates an 8 m high (maximum) soil cut slope inclined at about 70° (maximum) with 15% of the surface covered by chunam, 45% by vegetation and 40% having bare soil. No seepage or signs of distress were observed and the slope was recorded as being in a 'fair' condition. The consequence-to-life category of the slope was rated as '2'. The priority ranking score (referred to as the CNPCS score) was not recorded at this time. Photographs of the slope taken in May 1996 are shown in Plate 3.

The SIRST field sheet was updated in November 1997 when Slope No. 11SW-D/C1352 was described as 4 m high and inclined at 50°, with 60% of the slope face identified as 'bare soil/rock'.

4.5 Stage 1 Study

In July 1996, Binnie Consultants Ltd (BCL) completed a Stage 1 Study report for Slope No. 11SW-D/C1352. The field inspection data are the same as those for the initial

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

SIRST field observations, which indicated an 8 m high (maximum) soil cut slope inclined at about 70° (maximum) with 15% of the surface covered by chunam, 45% by vegetation and 40% having bare soil. The Stage 1 Study was revised in September 1997. In this version, the slope height (denoted H1 in the report) is indicated as 4 m although the maximum height shown on the attached figure is 8 m.

4.6 Selection of Slopes for Inclusion in Enhanced Maintenance Programme

In June 1999, Slope No. 11SW-D/C1352 was included in a list of HyD's slopes that were deemed "potentially suitable for upgrading by prescriptive measures, i.e. likely to meet the qualifying criteria laid down in GEO Report No. 56". The subject slope had not been included in HyD's Enhanced Maintenance Programme prior to the August 2005 landslide.

4.7 Slope Maintenance Inspections

Engineer inspections (EI) for Slope No. 11SW-D/C1352 were carried out by HyD's consultants, Maunsell Geotechnical Services Limited (MGSL), in October 1998 and January 2003 respectively. Routine maintenance inspections (RMI) were carried out by HyD in February 2000, December 2000, November 2001, January 2002, September 2002, August 2003 and November 2004 respectively.

The October 1998 EI report noted "Minor soil erosion due to scouring of surface water flow", "Slope cover adjacent to trees was cracked due to jacking action of tree roots", "Migration of soil material from weepholes, this probably be caused by internal erosion" and "Part of surface cover has lost contact with underlying soil". The report also noted "Poor soil condition", "Oversteepened slope surface" and "Lack of drainage provision at the crest of the slope". Recommendations were made for routine maintenance works. In addition, the plan attached to the EI report indicated "Renew or install 'rigid' surface cover for whole slope" as part of the proposed maintenance works. However, this recommendation was not included in the written part of the report. The photographs that are included in the February 2000 RMI (Plate 4) indicate recently repaired rigid surface cover on parts of the slope, suggesting that some works were carried out following the recommendations of the October 1998 EI.

The inspection records for the February 2000 RMI noted the need to "Repair cracked/damaged drainage channels or pavements along crest and toe of slope and retaining wall" and to "Repair or replace cracked or damaged slope surface cover".

The inspection records for the December 2000 (Plate 5), November 2001 (Plate 6) and January 2002 RMI's indicated that no specific follow-up actions had been recommended.

The inspection records for the September 2002 RMI noted the need to "Remove surface debris and vegetation causing severe cracking of slope surface cover and drainage channels" at the east end of the slope, "Unblock weepholes" and "Replant bare area on slope surface" at the west end of the slope. These works, including provision of local patches of reinforced shotcrete, were reported to have been underway in April 2003.

The second EI was carried out in January 2003, i.e. before the routine maintenance

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

works were carried out following the recommendations made in the September 2002 RMI. The second EI noted that there was no confirmed past instability but "Multiple Minor" inferred past instability; that there were no signs of seepage or distress; and that bare soil was present at the west end of the slope, which was possibly the same area as that noted in the September 2002 RMI. Routine maintenance works including "Replant vegetation in bare surface areas with provision of erosion mat", were recommended. Another recommendation was that a stability assessment should be carried out.

The slope records were updated in July 2003 following the January 2003 EI and included a calculation of the CNPCS score for the slope. The updated CNPCS score was based on a revised slope height and face angle at the critical section of 6 m and 60° respectively, and facility groups 5B (undeveloped green belt) and 4R (road/footpath with low traffic density) at the slope crest and toe respectively (see Wong, 1998). The calculated CNPCS score was 1.442 instead of the previous CNPCS of 0.171, which was based on a 4 m high and 50° slope with a facility group of 5R (road/footpath with very low traffic density) at the slope toe.

The August 2003 RMI noted the need to "Repair or replace cracked or damaged slope surface cover" at the central part of the slope. According to the HyD, the repair to the cracked slope surface cover was carried out in 2003 under Works Order No. AA108283.

The November 2004 RMI noted the need to "Repair or replace cracked or damaged impermeable slope surface cover" at the east part of the slope; to "Remove surface debris and vegetation causing severe cracking of slope surface cover and drainage channels" at the west end of the slope; and to "Unblock weepholes and outlet drainpipes". According to the HyD, the repairs to the cracks were completed by HyD's maintenance term contractor on 29 November 2004.

5. THE LANDSLIDES

5.1 Description of the Landslides

Two landslides affected the hillsides above and below Bowen Road in the morning of 20 August 2005. The upper landslide affected Slope No. 11SW-D/C1352 on Bowen Road and the hillside above. Part of the debris from this landslide was deposited onto Bowen Road and an adjoining playground. Some of the debris on the outer edge of the playground travelled downslope on to the lower landslide scar. The lower landslide affected the downslope edge of the playground and the hillside below. Some of the debris from the upper landslide, together with the debris from the lower landslide, travelled downslope on the hillside below Bowen Road and were deposited at the rear of an unoccupied apartment block at No. 120 Kennedy Road, and within an adjacent abandoned platform area, at the toe of the affected hillside.

A plan and section of the landslides are shown in Figures 2 and 3 respectively. General views of the landslides and outwash debris are shown in Plates 1, 2 and 7 to 16.

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

5.2 Eye-witness Account

A resident of Grandview Tower at Nos. 126 to 130 Kennedy Road, noted the following on the morning of 20 August 2005: "Between 0930 and 0945 I awoke from hearing a grumble like a far away thunderstorm but accompanied by a sound as if many matchsticks were breaking simultaneously." When the resident looked at the hillside shortly after the noises were heard, the landslide scars were observed. He noted the following: "… I saw a large part of the vegetation below Bowen Road sliding downwards and slightly to the right, about 20 m wide. This happened in slow motion, 1 to 2 minutes maybe. The raw soil was now exposed with the exception of 2 small trees, each anchored to a rock." The resident also observed that the landslide debris below Bowen Road destroyed and entrained the majority of vegetation in its path as it travelled down slope.

The resident noted that the debris continued to move slowly in small pulses, along the hillside below Bowen Road and that erosion gullies began to form within the surface debris in the afternoon of the same day during the subsequent rainfall. He noted the following: "I left the flat at around 1100, returned around 1430 and watched most of the afternoon. The exposed area had extended far further to the left, one of the two trees was gone. There was a constant process of erosion, sometimes just a trickle of what looked like mud, sometimes a small avalanche. The soil movement was faster than in the morning, but still not very fast (I come from the mountains and I have seen snow avalanches)."

The eye-witness did not notice any significant concentrations of water on or near the upper and lower landslide scars at any time during his observations.

5.3 Timing of the Landslides

The exact timing of the landslides is uncertain. However, based on the eye-witness account, it is likely that the landslides occurred at around 9:30 a.m. on 20 August 2005.

5.4 Field Mapping and Observations After the Landslides

Field mapping of the landslides was undertaken by FSW commencing on 22 August 2005, the results of which are shown in Figures 2, 3, 7 and 8. The upper landslide scar is about 28 m wide at the toe, up to 22 m high and is estimated to be up to some 2.5 m deep. The volume is estimated to be 750 m^3. The debris was relatively intact with many trees remaining upstanding at the top of the debris. Several large corestones (up to 4 m long and 3 m wide) were noted in the debris, which comprised both residual soil and completely decomposed granite (CDG).

The upper landslide scar was relatively planar suggesting predominantly translational sliding movement. The main scarp and upper portion of each flank comprised up to 1.2 m thick of residual soil with rounded corestones over extremely weak medium-grained CDG. The basal surface of rupture was planar downslope but gently undulating across the scar suggesting that the sliding surface was influenced by the presence of rounded corestones within the weathered soil mass.

The basal surface of rupture was composed of extremely weak CDG. No obvious

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

discontinuities were observed to have had a controlling influence on the landslide. In addition, there was no evidence of any clay-rich layers along the surface of rupture. However, clay infill materials (up to 100 mm thick) were observed along highly persistent, medium spaced, relict joints dipping into the slope at 45° towards the mid to lower portion of the east flank of the scar (Plate 17). In addition, a 300 mm to 500 mm thick zone of clay-rich, disturbed CDG was noted dipping out of the scar at about 25° located about 4 m below the main scarp near the western flank (Plate 18). The lateral extent of this zone is uncertain. This zone could have influenced the failure of the upper portion, and its presence suggests previous slope deformation in the upper part of the scar, which could have been associated with landslide DT1-1949 observed from API (Section 3.3). The clay-rich layers could have influenced the hydrogeology of the slope by forming less-permeable barriers to groundwater flow, leading to the formation of local perched groundwater conditions.

Seepage from a soil pipe was observed by a Geotechnical Engineer from the GEO in the afternoon of 20 August 2005 near the toe of the upper landslide scar, during which time an Amber Rainstorm Warning was in force (see Incident Report No. 2005/08/0304). There were no obvious signs of seepage, piping or concentrated surface water flow on the upper landslide scar during the subsequent field inspections by FSW on 22 August 2005 and thereafter.

The crest of the lower landslide scar is located immediately below the playground. The postulated extent of the source area for the lower landslide is shown in Figures 2 and 3 and in Plate 7. The source area was relatively concave in shape (Plate 7) and the surface of rupture was relatively planar and steep (40° to 45°).

The main scarp of the lower landslide comprises about 2 m thick loose fill, which formed part of the playground on Bowen Road. The postulated extent of the fill prior to the failure is shown in Figures 4, 7 and 8. Below the main scarp, the scar was covered with about 1m thick, soft, clayey debris and fill, which contained deep gullies formed by surface runoff on the scar during the heavy rain following the landslide. Below this material, the original ground surface had been stripped of vegetation and topsoil, and comprised CDG and locally highly decomposed granite (HDG) with corestones.

Landslide debris was deposited over the middle and lower portions of the lower landslide scar. A small amount of landslide debris was deposited on the level ground at the toe of the affected hillside. However, a large amount of outwash debris was deposited at this location, which probably accumulated during the heavy rain following the failures on 20 August 2005. The extent of the outwash debris is shown in Figure 2. However, it is possible that a large proportion of the landslide debris indicated on the lower part of the scar behind No. 120 Kennedy Road, was also outwash debris.

The landslide debris comprised wet, soft, fine to coarse sand becoming finer and predominantly silty further from the source. Outwash debris was also present on the ground floor of No. 120 Kennedy Road (Plate 16), which was unoccupied at the time of failure. The travel angle (Wong & Ho, 1996) of both the upper and lower landslide debris (not including outwash debris beyond the rear wall of No. 120 Kennedy Road) is about 37º and the travel distance of the lower landslide debris was about 90 m.

Based on the eye-witness account of slow moving, pulse-like debris movement, the lower landslide probably occurred as an open hillside-type landslide or sliding failure within

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

fill, which was probably not liquefied. Although the debris was not channelised, some entrainment of vegetation and fill materials occurred as the debris travelled downslope.

The lower landslide scar was located adjacent to a rock cliff, which forms a waterfall during periods of heavy rain. The waterfall forms part of the natural drainage system in the area, although the channel has been lined with masonry above the cliff. A heavy flow of water was noted over the rock cliff during the time of the landslide.

According to the eye-witness account, there were no significant concentrations of water on or near the upper and lower landslide scars at any time during his observations.

A tension crack up to about 6 m long, 60 mm wide and 0.6 m deep (see Section 7.3) was observed on the east section of the playground in January 2006, after the completion of the emergency slope works (see Section 10). The tension crack is shown in Figures 2, 4 and 7 and in Plates 19 and 20. The timing of the development of the tension crack is not certain as the playground was covered with landslide debris and subsequently covered by construction materials and equipment following the August 2005 landslides.

6. GROUND INVESTIGATION

6.1 Previous Ground Investigations

A number of previous ground investigation (GI) works have been undertaken within and in close proximity to Nos. 98 and 120 Kennedy Road at the toe of the lower landslide scar (Figure 5). However, no previous GI works have been carried out in the vicinity of the landslide source areas.

6.2 Current Ground Investigation

The ground investigation plan is given in Figure 5. The ground investigation works for the detailed study were carried out between March and May 2006, and comprised the following:

(a) one drillhole (BH1) to 20 m depth below ground surface,

(b) installation and monitoring of one piezometer and one standpipe in BH1,

(c) 24 GCO probes at trial pit locations,

(d) eight trial pits (TP1 to TP8) excavated to a maximum depth of 3 m below ground surface, and

(e) five slope surface strips (SS1 and SS2a to SS2d).

In-situ testing comprised falling head permeability tests in BH1, and in-situ density tests using the sand replacement method in trial pits. Sampling in BH1 included the recovery of continuous, undisturbed Mazier samples within soil with foam used as the flushing medium.

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

Large disturbed samples, together with undisturbed U100 and block samples, were recovered from the trial pits.

Laboratory testing on samples included classification, moisture content determination and triaxial compression tests. The results of the laboratory tests are summarised in Table 3 and discussed in Sections 7.4 to 7.6.

7. GROUND CONDITIONS

7.1 General

The subsurface conditions of the study area have been assessed on the basis of information obtained from the desk study, field mapping and ground investigation.

7.2 Geology and Geomorphology

According to the Hong Kong Geological Survey (HKGS) Sheet 11 of the 1:20,000-scale, HGM20 Series geological map, the study area is underlain predominantly by fine-grained granite of Jurassic age (Figure 6). Medium-grained granite is indicated by the HKGS at the toe of the hillside in the deposition zone of the lower landslide. A major northeast-southwest trending fault is indicated about 150 m to the west of the 2005 landslide sites, and the boundary between granite and fine ash vitric tuff of the Ap Lei Chau Formation (part of the Repulse Bay Volcanic Group), is indicated at about 80 m to the west of the upper landslide.

The results of the field mapping and ground investigation indicate that the study area comprises medium to coarse-grained granite. A contact between the medium to coarse-grained granite and fine-grained granite was mapped at about 60 m to the west of the upper landslide. The granite contact occurs as a fault dipping at about 70° towards west-northwest (295°).

A plan of the geology and geomorphology of the subject site is presented in Figure 7.

The landslides occurred on a north-facing, moderately to steeply inclined (33° to 45°) hillside, within the middle and lower portions of a catchment (Figure 1), which is defined by rounded, north-trending spurs to the west and east with ephemeral drainage lines in between. The main drainage line is located about 20 m to the west of the upper landslide scar, and is intersected by a man-made drainage channel at about 3 m above Bowen Road. This drainage line extends as a waterfall over a steep rock cliff within the catchment below Bowen Road, which is located to the west of the lower landslide scar (Figure 2). Adjacent to the rock cliff, the hillside below Bowen Road comprises steeply inclined terrain (45°), which becomes less steeply inclined (33°) along a concave break in slope below about 80 mPD.

The rock cliff located on the west flank of the lower landslide is aligned northeast-southwest and could be controlled by an extension of the faulted granite contact. A similarly trending rock cliff is noted below the playground to the east of the lower landslide scar, located on a platform below Bowen Road. The two rock cliffs appear to be offset from each other, which may have been the result of faulting.

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

A number of photolineaments were observed from the API, including the two northeast-southwest trending rock cliffs either side of the lower landslide. Photolineaments were also observed along the north northwest trending drainage lines above Bowen Road, and a northwest-southeast orientated photolineament was noted traversing the hillsides either side of the landslides.

Granite corestones are exposed within CDG in Slopes Nos. 11SW-D/C1351 and 11SW-D/C1352 located either side of the upper landslide (Figure 7). The CDG is covered in some parts with chunam, which is cracked in places. The faulted granite contact is exposed at the boundary of Slopes nos. 11SW-D/C2167 and 11SW-D/C1349 (Figures 4 and 7). Bouldery colluvium is exposed within the major drainage line to the east of the upper landslide (Figure 7).

7.3 Ground Profile

A geological section through the landslide site is presented in Figure 8.

The additional data provided by the current investigation are in general agreement with the information obtained from field mapping and API. The local hillside above the landslide scar comprises 2 m to 3 m thick of residual soil described as firm to stiff, moist, yellowish brown sandy clayey silt, overlying CDG with corestones. The CDG is described as extremely weak yellowish brown medium to coarse-grained granite (stiff moist sandy clayey silt with some fine to coarse gravel). There were no obvious signs of tension cracks on the hillside above the main scarp of the upper landslide.

The surface of rupture of the upper landslide exposed CDG with corestones. No adverse joints or other features were observed in the subsurface investigation of the upper landslide.

Bedrock, in the form of slightly to moderately decomposed medium to coarse-grained granite, is located at about 6.2 m below ground surface at the platform above the lower landslide. This is overlain by about 3.5 m of C/HDG. Fill overlies the C/HDG over the majority of the platform. The fill becomes thicker towards the outer portion of the platform, where the thickness exceeded 3 m.

Four different types of fill material (Types 1 to 4) were identified during the subsurface investigation below the platform adjacent to Bowen Road. The most common basal fill (Type 1) consists of predominantly dry to moist, firm, yellowish brown, sandy, clayey silt with gravel and boulders. This layer was more than 1 m thick on the platform and more than 3 m thick on the slope below the platform and adjacent to the east flank of the lower landslide main scarp. Overlying the Type 1 fill material on the west side of the platform, the fill material (Type 3) was up to 1.2 m thick and is described as moist, firm, reddish brown, sandy, clayey silt with some fine gravel. Other less extensive fill materials (Types 2 and 4) were only observed locally below the platform. For example, in trial pit TP3 (Plate 21), Type 3 fill material was underlain by dense, yellow brown, silty fine to coarse sand fill materials with some fine gravel (Type 2). Type 4 fill material was observed locally in trial pit TP5 and comprised dry, firm, dark grey, sandy, clayey silt with some angular fine to coarse fragments of rock and concrete.

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

The fill exposed in the main scarp and the source area of the lower landslide was loose consisting of patches of remoulded CDG and residual soil with gravel and many small granite boulders. This fill material is different from the four types of fill material encountered during the subsurface investigation.

Layered fill materials were also encountered in trial pit TP6 in the depositional area of the lower landslide scar (Figure 5 and Plate 22). The fill was about 1 m thick and overlain by about 0.5 m thick landslide debris. Below the fill, subvertical patches of residual soil, a soil pipe (about 150 mm diameter) and corestones were encountered within CDG.

The tension crack observed on the platform adjacent to Bowen Road (Figures 2 and 7, and Plates 19 and 20) was further investigated by trial pit TP8 (Plate 23), together with slope surface strips SS2a and SS2b. At each location, the crack was noted to be within fill and was poorly developed as compared with the crack observed at ground surface. In trial pit TP8, the crack was observed up to about 0.6 m depth at the rear of a concrete block. The crack was about 30 mm wide and comprised some loose soil infill.

GCO probe blowcounts within the residual soil above the main scarp of the upper landslide were generally above 10 blows/100 mm penetration, indicating a medium dense soil, except between ground level and 0.8 m depth where the probe blowcounts ranged from 3 to 10 blows/100 mm penetration, indicating a loose soil. Also, it was noted that two thirds of the probe blowcounts obtained from 2.3 m to 3 m depths were less than 10 blows/100 mm penetration, which also indicate loose soil.

GCO probe blowcounts within the CDG below the surface of rupture of the upper landslide were below 10 blows/100 mm penetration, between ground level and 0.8 m depth indicating a loose soil, and for a third of the probe blowcounts between 0.8 m and 1.6 m depth, indicating some loose soil also at this horizon. The GCO probe blowcounts within the CDG below the fill on the platform above the lower landslide were mostly below 10 blows/100 mm penetration, indicating that the CDG is predominantly loose in this area.

The majority of the GCO probe blowcounts within the fill on the platform above the lower landslide recorded zero to 4 blows/100 mm penetration, except where boulders were encountered. This indicates that the fill materials are loose to very loose.

7.4 Material Characteristics

A summary of the laboratory test results is presented in Table 3. Particle size distribution and soil plasticity plots are given in Appendix B.

The particle size distribution of the Type 1 fill materials recovered on the platform above the lower landslide indicates that this material comprises a slightly gravelly, clayey, very silty sand. The finer fraction of this material falls within the high plasticity range in the plasticity chart with a Plasticity Index of 29% to 33% and a Liquid Limit of 59% to 65%. The particle size distribution of the Type 2 fill materials recovered in trial pit TP3 on the platform above the lower landslide indicates that this material comprises a slightly clayey, very silty, very gravelly sand. The particle size distribution of the Type 3 fill materials recovered on the platform above, and on the slope adjacent to the lower landslide indicates that this material comprises a clayey, silty, gravelly sand. The finer fraction of this material falls within the

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

high to very high plasticity range in the plasticity chart with a Plasticity Index of 34% to 41% and a Liquid Limit of 65% to 74%. No tests were carried out on the Type 4 fill material.

The particle size distribution of the residual soil indicates that this material comprises a slightly gravelly, sandy, very silty clay to a clayey, very silty, very gravelly sand. The finer fraction of this material falls within the high to very high plasticity range in the plasticity chart with a Plasticity Index of 28% to 50% and a Liquid Limit of 58% to 86%. The particle size distribution of the CDG indicates that this material comprises a clayey, very silty, very gravelly sand. The finer fraction of this material falls within the low plasticity range in the plasticity chart with a Plasticity Index of 16% to 22% and a Liquid Limit of 42% to 48%.

7.5 In-situ Density

The results of in-situ density tests are given in Table 1.

In-situ density tests of the Type 1 fill materials (comprising firm, dry to moist yellowish brown, sandy, clayey silt with gravel) encountered in trial pits TP4, TP7 and TP8 indicated a range of in-situ dry density values of between 1.19 Mg/m^3 and 1.42 Mg/m^3 (average 1.26 Mg/m^3) from 7 results. In-situ moisture contents were measured as 18.7% to 23.8% (average 20.0%).

In-situ density tests of the Type 2 fill materials in trial pit TP3 (comprising loose, yellow brown, silty fine to coarse sand with some fine gravel) indicated a range of in-situ dry density values of between 1.07 Mg/m^3 and 1.13 Mg/m^3 (average 1.10 Mg/m^3) from 3 results. In-situ moisture contents were measured as 17.6% to 21.3% (average 19.0%).

In-situ density tests of the Type 3 fill materials (comprising firm, moist, reddish brown, sandy, clayey silt with some fine gravel) encountered in trial pits TP3 and TP7 indicated a range of in-situ dry density values of between 1.10 Mg/m^3 and 1.54 Mg/m^3 (average 1.30 Mg/m^3) from 3 results. In-situ moisture contents were measured as 18.6% to 23.5% (average 21.3%).

The results indicate that the fill materials are relatively loose, which supports the GCO probe data and visual observations on site. This suggests that the fill materials were not properly compacted.

In comparison, in-situ density tests of the CDG in trial pit TP5 (comprising silty, fine to coarse sand with some fine to medium gravel) indicated a range of in-situ dry density values of between 1.29 Mg/m^3 and 1.40 Mg/m^3 (average 1.36 Mg/m^3) from 5 results. In-situ moisture contents were measured as 15.9% to 21.0% (average 18.2%). The results also indicate that the CDG is relatively loose in this area as compared to typical values of dry density of CDG in other areas of Hong Kong (GEO, 1993).

7.6 Shear Strength

A summary of the laboratory test results is presented in Table 3. The results of triaxial tests on soil samples are given in Appendix C.

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

Multi-stage consolidated undrained triaxial compression tests with pore water pressure measurements were undertaken on saturated specimens prepared from Mazier and block samples recovered from the fill, residual soil, CDG and C/HDG respectively. Tests performed on the fill materials at the playground area of Bowen Road indicated shear strength parameters of c' = 4 kPa and ϕ' = 30°. The results are generally consistent with the loose nature of the fill materials observed on site. Tests performed on the residual soil indicated shear strength parameters of c' = 6 kPa and ϕ' = 31°. Tests performed on the CDG indicated shear strength parameters of c' = 5 kPa and ϕ' = 36°. The results suggest that the samples of CDG taken at the landslide site have a strength within the lower range of the typical values of shear strength obtained in other areas of Hong Kong (i.e. c' = 5 kPa to 15 kPa and ϕ' = 35° to 44°) (GEO, 1993). The majority of fill, residual soil and CDG samples tested exhibited contractive rather than dilative behaviour. The lower than average values for the CDG could be associated with an advanced state of weathering at the site. Tests performed on the C/HDG samples indicated shear strength parameters of c' = 20 kPa and ϕ' = 40° based on limited number of samples.

7.7 Permeability

Falling head permeability tests were carried out in drillhole BH1 at 2.2 m depth within fill materials and CDG, and at 4.4 m depth within CDG and HDG. The results, given in Table 2, indicate a coefficient of permeability of 1×10^{-7} m/s to 5×10^{-7} m/s for the lower part of the fill and CDG layer between 2.2 m and 3.7 m depths, and 2×10^{-6} m/s for the CDG and HDG layer between 4.4 m and 5.9 m depths.

It should be noted that the permeability tests were carried out after the completion of emergency slope repair works, which included soil nail installation and sprayed concrete cover within the upper and lower landslide scars (Section 10). As such, the ground conditions in the area of drillhole BH1 may have been affected by the works.

7.8 Groundwater

Instrumentation for groundwater monitoring at the site comprises a piezometer at 5.8 m depth and a standpipe at 12 m depth in drillhole BH1, which were installed in March 2006, together with 8 standpipes installed in May 2006 at 0.5 m to 3 m depths in the backfilled trial pits. The piezometer and standpipe in drillhole BH1 were installed within the HDG and bedrock respectively. The manual readings for the piezometer in drillhole BH1 and the standpipes in the trial pits indicated 'dry' results throughout the monitoring period. The manual readings for the standpipe in drillhole BH1 indicated groundwater at 8.84 m to 8.75 m below ground level.

Both the piezometer and standpipe installations in drillhole BH1 were subsequently fitted with automatic piezometer units (i.e. LevelTroll monitoring devices) in June 2006. The piezometer remained dry throughout the monitoring period. Monitoring data obtained from the end of June to 18 September 2006 indicate that the base groundwater level measured within the standpipe remained relatively constant at about 8.6 m below ground level, i.e. similar to that measured after the initial installation. The results also indicate a lack of groundwater response to rainstorms throughout the monitoring period, such as a daily rainfall

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

of 260.5 mm on 14 September 2006. Groundwater monitoring data are presented in Appendix D.

It should be noted that the drillhole instrumentation and groundwater monitoring have been carried out after the completion of emergency slope stabilisation works, which included soil nail installation and shotcrete cover within the upper and lower landslide scars. As such, the groundwater conditions in the area of drillhole BH1 may have been affected by the works and are not necessarily representative of the conditions prior to the August 2005 landslide. Also, the rainfall condition in 2006 has not been as severe as that in 2005, and hence the actual piezometric responses under more severe rainfall could not be ascertained.

8. ANALYSIS OF RAINFALL RECORDS

Rainfall data were obtained from GEO automatic raingauge No. H06 at St. Margaret's College, Shiu Fai Terrace, which is located about 300 m to the northeast of the landslide site (Figure 1). The raingauge records and transmits rainfall data at 5-minute intervals to the Hong Kong Observatory and the GEO.

The timing of the failure was assumed to be 9:30 a.m. on 20 August 2005 based on the eye-witness account. An Amber Rainstorm Warning was issued at 8:35 a.m. on 20 August 2005.

The daily rainfall recorded by the raingauge between 20 July and 25 August 2005, and the hourly rainfall between 9:30 a.m. on 18 August 2005 and 11:30 p.m. on 20 August 2005 are shown in Figure 9. The 24-hour and 12-hour rainfall before the landslide was 326 mm and 188.5 mm respectively. The maximum 1-hour rolling rainfall was recorded as 36 mm between 8:05 p.m. and 9:05 p.m. on 19 August 2005.

Table 4 presents the estimated return periods for the maximum rolling rainfall for various durations recorded by raingauge No. H06 with reference to historical rainfall data at the Hong Kong Observatory in Tsim Sha Tsui (Lam & Leung, 1994). The results show that the 31-day rolling rainfall of 1,103 mm before the landslide was the most severe, with a corresponding return period of about 26 years. The results also show that the 7-day rolling rainfall of 661 mm had a corresponding return period of about 19 years. For rainfall durations of less than 4 hours, the corresponding return periods were less than 2 years.

The return periods were also assessed based on the statistical parameters derived by Evans & Yu (2001) for rainfall data recorded by local raingauge No. H06 between 1984 and 1997. The return periods of the 7-day and 31-day rainfall was about 9 and 6 years respectively (Table 4). It is noted that the estimated return periods of the August 2005 rainstorm based on rainfall data at local raingauge are generally less than those estimated by the historical rainfall data at the Hong Kong Observatory.

The maximum rolling rainfall for the rainstorm on August 2005 has been compared with the past significant rainstorms between 1983 and 2000 recorded by raingauge No. H06, which came into operation in 1983 (Figure 10). The results indicate that the August 2005 rainstorm was the most severe in terms of 4-day to 9-day duration rainfall since the installation of the raingauge in 1983.

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

9. THEORETICAL STABILITY ANALYSES

Theoretical stability analyses using the rigorous method of Morgenstern & Price (1965) were carried out to assist in the diagnosis of the mechanism and probable causes of the upper landslide. These analyses were undertaken to examine the likely operative range of shear strength parameters along the rupture surface, corresponding to different groundwater conditions, at the time of failure.

The information used in the analyses was obtained from the post-failure ground investigations, fieldwork and laboratory testing, together with site observations and measurements. A representative cross-section of the landslide site is shown in Figure 11. The pre-failure slope profile was established from topographic survey plans, aerial photographic records, the adjoining slope profiles and inference using engineering judgement. The geometry of the rupture surface was determined by site measurements undertaken by FSW and post-failure topographic survey.

The results of the analyses are presented in Figure 11. The results suggest that the slope possessed a factor of safety close to unity prior to the landslide under zero groundwater pressure, when the shear strength parameters for CDG obtained from laboratory tests on samples taken from the site (i.e. $c' = 5$ kPa and $\phi' = 36^o$) were adopted. As such, prior to the August 2005 failure, the slope might have been in a marginally stable condition. The results of the analyses reflect the susceptibility of the hillside to rain-induced landslides arising from the reduction of soil suction and the build-up of transient groundwater pressures in the near-surface materials through infiltration and subsurface seepage.

10. EMERGENCY SLOPE REPAIR WORKS

Following the failures, emergency slope repair works were completed by the HyD on the upper and lower landslide scars between September and December 2005 at the recommendations of the GEO. The prescribed urgent works to the upper landslide scar included the installation of 9 rows of 15 m long soil nails installed at 20° below horizontal, with 2 m horizontal spacing and 2.5 m vertical spacing. The works to the upper portion of the lower landslide scar included the installation of 3 rows of 15 m long soil nails installed at 20° below horizontal, with 3 m horizontal spacing and 3 m vertical spacing. Both landslide scars were subsequently covered with sprayed concrete.

11. DIAGNOSIS OF THE CAUSES OF THE LANDSLIDES

11.1 Mode and Sequence of Failure

In the absence of direct eye-witness accounts of the upper landslide and the initial phase of the lower landslide, reconstruction of the mode and sequence of failure is based upon information from the observations of the debris movement involved in the lower landslide after 9:30 a.m. provided by the eye-witness, together with information from the geometry of the landslide scars and landslide debris.

The mode of failure of the upper landslide comprised a predominantly translational slide of debris along a rupture surface that extended from the natural hillside, some 16 m

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

above the crest of Slope No. 11SW-D/C1352, to about 2 m above the toe of the cut slope, passing through residual soil and CDG.

The nature of the debris, which comprised some large corestones surrounded by intact CDG and residual soil within the displaced mass on Bowen Road and the playground, suggests that the failure of the upper landslide probably occurred mostly as a singular detachment that impacted on Bowen Road and the playground, involving little disintegration of the detached ground mass.

The lower landslide is considered to be an open hillside-type or sliding failure involving primarily fill materials. The initial mode of failure of the lower landslide is likely to have comprised a translational debris slide. The failure occurred along a steep rupture surface that extended from the playground to about 20 m horizontal distance downslope, passing through fill near the main scarp and possibly along the fill-CDG boundary further downslope. It is not certain whether the debris moved in a single phase or multiple phases in the initial stages of the failure. The eye-witness report of hearing sounds that were likened to "many matchsticks…breaking simultaneously" suggests that the initial phase of the lower landslide involved a fairly rapid movement of debris, which resulted in the vegetation being destroyed 'simultaneously' thereby producing the sound heard by the eye-witness. The locally steep nature of the slope (about 45°) in the source area could have contributed to a more mobile initial phase of debris movement.

After the initial failure, the eye-witness reported that the landslide debris moved fairly slowly and in small pulses down the slope from the upper to middle portions of the lower landslide scar, destroying the majority of the vegetation in its path. This type of movement suggests that the material moved in several separate and relatively small masses of debris involving possible mixing with relatively wet, near-surface fill materials, which became entrained as the vegetation was gradually stripped from the slope surface.

Following the landslides, heavy rain continued to scour the landslide scars causing significant gullying and washout erosion, together with subsequent deposition of outwash debris on the platform at the toe of the hillside.

11.2 Probable Causes of Failure

The close correlation between the upper landslide and the prolonged and heavy rainfall suggests that the failure was probably triggered by rainfall.

The upper landslide was probably caused by the build-up of transient groundwater pressures within the soil mass due to direct infiltration and subsurface seepage. Theoretical stability analyses indicate that the slope was likely to have been only marginally stable prior to failure.

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

(a) a history of slope instability, which could have contributed to local opening up of the relict discontinuities and/or possible changes in infiltration and subsurface seepage flow

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

patterns, promoting progressive deterioration of the slope condition, and

(b) the presence of clay-infilled relict joints at the slope toe and the 300 mm to 500 mm thick zone of clay-rich and disturbed CDG below the main scarp, which could have an adverse influence on the local hydrogeology and were probably conducive to the build-up of local groundwater pressures.

The lower landslide occurred on the outer edge of the platform (which was covered by the upper landslide debris) and on the hillside below the platform. Although the sequence of the landslides is not certain, the lower landslide was possibly triggered by the impact from, and surcharging by, the upper landslide debris on the fill platform and the slope below, which has a mantle of old fill. The near-surface ground mass of the slope below Bowen Road was likely to have been saturated, or near saturated, by the prolonged rainfall preceding the landslides and therefore probably susceptible to failure when subjected to impact or surcharge from the upper landslide.

In addition, a likely contributory factor to the lower landslide was the build-up of transient elevated groundwater pressures within the fill materials due to direct infiltration leading to possible development of perched water conditions at the boundary between the in-situ ground and the overlying fill. Other factors that probably contributed to the lower landslide include the uncontrolled dumping of fill materials during the construction of Bowen Road before 1945, and the loose nature of the fill materials.

11.3 Discussion

The upper landslide occurred on an old, steep (about 60º) soil cut slope and a large portion of the hillside above. Both the residual soil and CDG exhibit relatively low shear strength values based on the results of triaxial tests, and the CDG was found to be relatively loose by visual inspection and from the results of the GCO probes within the upper landslide scar.

The locations of the upper landslide and the adjacent hillside have a history of slope instability. The past instability may have contributed to local opening of relict discontinuities and/or the development of local shear planes, which could have altered the surface water infiltration and subsurface seepage flow patterns as well as general weakening of the ground mass. The past instability may also have led to some loosening of the ground mass, making it more vulnerable to water ingress. This could have promoted progressive deterioration of the slope condition, which was possibly manifested by the repeated cracking of local patches of hard surface cover to the soil cut requiring repeated maintenance actions, although it should be noted that some of the cracks were reported to have been caused by root action from the significant vegetation cover.

Rainfall analyses suggest that the short-term rainfall preceding the 2005 landslide was not as severe as the past significant rainstorms but that the severity of the long-duration rainfall was comparable to some of the past rainstorms. Given that there appears to be no obvious adverse changes in the environmental setting of the landslide sites, progressive

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

deterioration of the slope conditions with time probably played a key role in the upper landslide.

Both the clay-infilled relict joints at the slope toe and the 300 mm to 500 mm thick zone of clay-rich and disturbed CDG below the main scarp could have an adverse influence on the local hydrogeology and the build-up of local groundwater pressures. However, these might have been a local effect and it is uncertain whether they have played a significant role in the upper landslide.

The lower landslide occurred within loose fill below the platform and on the steep to moderately steep hillside located immediately downslope of the platform, which was covered by the debris from the upper landslide. Given the close proximity of the two failures and the similar time of occurrence, the upper landslide had probably contributed to triggering the lower landslide, due to impact from, and/or surcharge by, the debris of the upper landslide on the edge of the fill platform and the slope below.

The fill slope below Bowen Road is a registerable feature given that it is more than 5 m high. However, this type of fill slope is fairly difficult to detect from routine API given the dense vegetation cover, which was already well established at the time the first aerial photograph was taken of the site (i.e. in 1945).

The undercutting of a hillside with a history of failures in the course of forming the cutting for Bowen Road would have contributed to reducing the margin of stability against larger-scale instability. The presence of an open man-made trench across the spur above the upper landslide would have had some adverse influence as it probably promoted water ingress into the hillside. However, given that the trench is at some distance above the upper landslide, this is unlikely to have been a major contributory factor to the failure.

The failures illustrate the potential knock-on effects from one landslide to another. In this case, it was the lower landslide, probably triggered by the upper landslide, which led to more significant consequences. The lower landslide also highlights the potential hazards to developed areas posed by old, previously undetected loose fill on relatively steep hillsides covered by dense vegetation.

12. CONCLUSIONS

It is concluded that the upper landslide of 20 August 2005 was triggered by prolonged and heavy rainfall. The upper landslide affected a steep, old soil cut slope and the hillside above. The failure occurred in a locality that has been affected by a history of instability. The upper landslide was probably caused by the reduction of soil suction and the build-up of groundwater pressures within the soil mass following infiltration and subsurface seepage.

The lower landslide was probably triggered by the impact from, and/or surcharge by, the upper landslide. The lower landslide affected the outer edge of an old, loose fill platform and the hillside below, the majority of which was covered with old, loose fill materials.

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

13. REFERENCES

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 Geotechnical Services Ltd. (1999). Final Factual Fieldwork Report No. 04-0480-03-259/R001. Fugro Geotechnical Services Ltd, Hong Kong.

Geotechnical Control Office (1986). Hong Kong & Kowloon: Solid and Superficial Geology. Hong Kong Geological Survey, Map Series HGM 20, Sheet No. 11, 1:20,000-scale. Geotechnical Control Office, Hong Kong.

Geotechnical Engineering Office (1993). Guide to Retaining Wall Design (Geoguide 1) (Second Edition). Geotechnical Engineering Office, Hong Kong, 268 p.

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

Maunsell Fugro Scott Wilson (2005). Task I – Enhanced Natural Terrain Landslide Inventory, Pilot Study (Volume I). Geotechnical Engineering Office, Hong Kong.

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

Wong, C.K.L. (1998). New Priority Classification for Slope and Retaining Walls (GEO Report No. 68). Geotechnical Engineering Office, Hong Kong, 117p.

Wong, H.N. & Ho, K.K.S. (1996). Travel distance of landslide debris. Proceedings of the Seventh International Symposium on Landslides, Trondheim, Norway, vol. 1, pp. 417 – 422.

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 1 - Summary of In Situ Density Test Results

Trial Pit No.	Depth (m)	Bulk Density (Mg/m^3)	Moisture Content (%)	Average Moisture Content (%)	Dry Density (Mg/m^3)	Average Dry Density (Mg/m^3)	Soil Type
TP3	0.5	1.82	18.6	19.46	1.54	1.188	Fill (Type 3)
	1	1.34	21.8		1.1		Fill (Type 3)
	1.5	1.37	21.3		1.13		Fill (Type 2)
	2	1.3	18		1.1		Fill (Type 2)
	2.5	1.26	17.6		1.07		Fill (Type 2)
TP4	0.5	1.45	19.7	19.28	1.21	1.246	Fill (Type 1)
	1	1.49	18.8		1.25		Fill (Type 1)
	1.5	1.46	19.6		1.22		Fill (Type 1)
	2	1.45	19.6		1.21		Fill (Type 1)
	2.5	1.59	18.7		1.34		Fill (Type 1)
TP5	0.5	1.67	19.2	19.23	1.4	1.397	Fill (Type 2)
	1	1.69	21		1.4		Fill (Type 2)
	1.5	1.63	17.5		1.39		Fill (Type 4)
	2	1.52	15.9	16.75	1.31	1.3	CDG
	2.5	1.52	17.6		1.29		CDG
TP6	0.5	1.72	13.5	11.05	1.52	1.525	Fill
	1	1.66	8.6		1.53		Fill
TP7	0.5	1.54	23.5	23.65	1.25	1.22	Fill (Type 3)
	1	1.48	23.8		1.19		Fill (Type 1)
TP8	0.5	1.7	20	20	1.42	1.42	CDG

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

Table 2 - Summary of Permeability Test Results

Soil Stratum	Coefficient of Permeability, k (m/s)			
	BH1			Average, k (m/s)
	Test 1	Test 2	Test 3	
Fill/ CDG (2.2m – 3.7m)	5.13×10^{-7}	1.08×10^{-7}	3.08×10^{-7}	3.097×10^{-7}
CDG/ HDG (4.4m – 5.9m)	2.09×10^{-6}	1.98×10^{-6}	-	2.035×10^{-6}

Notes:

(1) Bracketed figures indicate depth at which test was performed.

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

Table 3 - Summary of Laboratory Test Results (Page 1 of 4)

GI Station No.	Sample Depth (m)	Material	Test Results: Moisture Content (%)	Atterberg Limits: Liquid Limit (%)	Atterberg Limits: Plastic Limit (%)	Atterberg Limits: Plasticity Index (%)	Atterberg Limits: Liquidity Index	Particle Size Distribution: Clay (%)	Particle Size Distribution: Silt (%)	Particle Size Distribution: Sand (%)	Particle Size Distribution: Gravel (%)	Triaxial Compression Test: Type of Test	Triaxial Compression Test: Confining Pressure (kPa)	Triaxial Compression Test: s' (kPa)	Triaxial Compression Test: t' (kPa)	Triaxial Compression Test: Behaviour
DH1	2.6	CDG	22	-	-	-	-	5		51	44	cum	30	179	136	Dilative
													60	272	201	
													120	472	338	
	3.7	CDG	24	-	-	-	-	9		56	36	cum	40	146	110	Dilative
													80	276	202	
													160	466	325	
	4.8	H-CDG	24	-	-	-	-	9		54	37	cum	50	164	123	Dilative
													100	284	205	
													200	454	315	
TP1	0.50	Residual Soil	22	86	36	50	0.00	21	31	32	16	cum	30	40	25	Contractive
													60	60	32	
													120	98	50	
	1.0	Residual Soil	9.8	58	30	28	-0.27	11	17	41	31	cum	35	56	36	Contractive
													70	66	43	
													140	110	71	
	1.5	Residual Soil	16	43	26	17	0.73	15	22	40	23	cum	40	50	30	Contractive
													80	78	43	
													160	129	64	
	2.0	Residual Soil	20	-	-	-	-	14	24	44	18	cum	40	52	33	Contractive
													80	78	45	
													160	108	68	
TP2	0.50	CDG	24	-	-	-	-	6	21	54	19	cum	30	84	54	Contractive
													60	118	73	
													120	171	103	

Table of Contents
Table of Contents
Table of Contents

Table 3 - Summary of Laboratory Test Results (Page 2 of 4)

GI Station No.	Sample Depth (m)	Material	Test Results													
			Moisture Content (%)	Atterberg Limits				Particle Size Distribution				Triaxial Compression Test				
				Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Liquidity Index	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	Type of Test	Confining Pressure (kPa)	s' (kPa)	t' (kPa)	Behaviour
TP2	1.0	CDG	25	-	-	-	-	6	21	47	26	cum	35	59	35	Contractive
													70	89	49	
													140	141	77	
	1.5	CDG	21	-	-	-	-	9	19	46	26	cum	40	64	42	Contractive
													80	107	64	
													160	149	94	
	2.0	CDG	18	-	-	-	-	9		58	33	cum	40	127	93	Dilative
													80	218	153	
													160	430	303	
TP3	0.50	Fill (Type 3)	21	65	31	34	0.25	16	23	37	24	cum	30	38	21	Contractive
													60	63	32	
													120	105	56	
	1.0	Fill (Type 3)	23	74	33	41	0.12	16	34	33	17	cum	35	43	27	Contractive
													70	75	37	
													140	125	61	
	1.5	Fill (Type 2)	21	-	-	-	-	5	19	54	22	cum	40	52	31	Contractive
													80	71	37	
													160	119	65	
TP4	0.5	Fill (Type 1)	21	-	-	-	-	5	14	55	26	cum	30	42	26	Contractive
													60	58	34	
													12	104	64	
	1.0	Fill (Type 1)	20	-	-	-	-	6	18	50	26	cum	35	54	35	Contractive
													70	78	48	
													140	132	83	

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

Table 3 - Summary of Laboratory Test Results (Page 3 of 4)

GI Station No.	Sample Depth (m)	Material	Test Results													
			Moisture Content (%)	Atterberg Limits				Particle Size Distribution				Triaxial Compression Test				
				Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Liquidity Index	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	Type of Test	Confining Pressure (kPa)	s' (kPa)	t' (kPa)	Behaviour
TP4	2.0	Fill (Type 1)	20	65	32	33	0.26	16	20	45	19	cum	40	42	23	Contractive
													80	64	36	
													160	137	71	
TP5	0.5	Fill (Type 2)	18	Non-plastic				13	23	47	17	cum	30	42	27	Contractive
													60	63	34	
													120	78	47	
TP5	1.5	Fill (Type 4)	17	42	26	16	0.5	13	20	46	21	cum	40	44	22	Contractive
													80	65	29	
													160	123	53	
TP6	1.5	CDG	8.4	-	-	-	-	9		44	47	cum	40	80	50	Dilative
													80	128	74	
													160	257	155	
TP6	2.5	CDG	8.8	-	-	-	-	9		47	44	cum	45	66	43	Contractive
													90	119	68	
													180	206	126	
TP7	0.50	Fill (Type 3)	27	43	26	17	0.73	15	22	40	23	cum	30	39	22	Contractive
													60	56	30	
													120	103	49	
TP7	1.0	Fill (Type 1)	28	-	-	-	-	14	24	44	18	cum	35	39	26	Contractive
													70	62	35	
													140	86	54	

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

Table 3 - Summary of Laboratory Test Results (Page 4 of 4)

GI Station No.	Sample Depth (m)	Material	Test Results													
			Moisture Content (%)	Atterberg Limits				Particle Size Distribution				Triaxial Compression Test				
				Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Liquidity Index	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	Type of Test	Confining Pressure (kPa)	s' (kPa)	t' (kPa)	Behaviour
TP8	0.50	CDG	23	-	-	-	-	10	18	46	26	cum	30	76	56	Dilative
													60	115	85	
													120	173	126	
TP8	1.0	CDG	23	-	-	-	-	8	24	45	23	cum	35	76	50	Contractive
													70	115	73	
													140	184	112	

Notes:

* If the particles finer than 0.063mm are less than 15% by weight, the Atterberg Limits will not be determined.

If the particles finer than 0.063mm are less than 10% by weight, the sedimentation analysis will not be carried out.

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

Table 4 - Maximum Rolling Rainfall at GEO Raingauge No. H06 for Selected Durations Preceding the 20 August 2005 Landslides and the Estimated Return Periods

Duration	Maximum Rolling Rainfall (mm)	End of Period (Hours)	Estimated Return Period (Years) (based on Lam & Leung 1994)	Estimated Return Period (Years) (based on Evans & Yu 2001)
5 Minutes	3.5	09:05 on 20 August 2005	<2	<2
15 Minutes	9.0	09:30 on 20 August 2005	<2	<2
1 Hour	29.5	09:30 on 20 August 2005	<2	<2
2 Hours	40.5	09:30 on 20 August 2005	<2	<2
4 Hours	60.5	09:30 on 20 August 2005	<2	<2
12 Hours	244	09:30 on 20 August 2005	5	6
24 Hours	327	09:30 on 20 August 2005	6	5
48 Hours	426	09:30 on 20 August 2005	9	5
4 Days	510	09:30 on 20 August 2005	9	4
7 Days	661	09:30 on 20 August 2005	19	9
15 Days	753	09:30 on 20 August 2005	11	4
31 Days	1,103	09:30 on 20 August 2005	26	6

Notes: (1) Return periods were derived from Table 3 of Lam & Leung (1994) and Evans & Yu (2001).

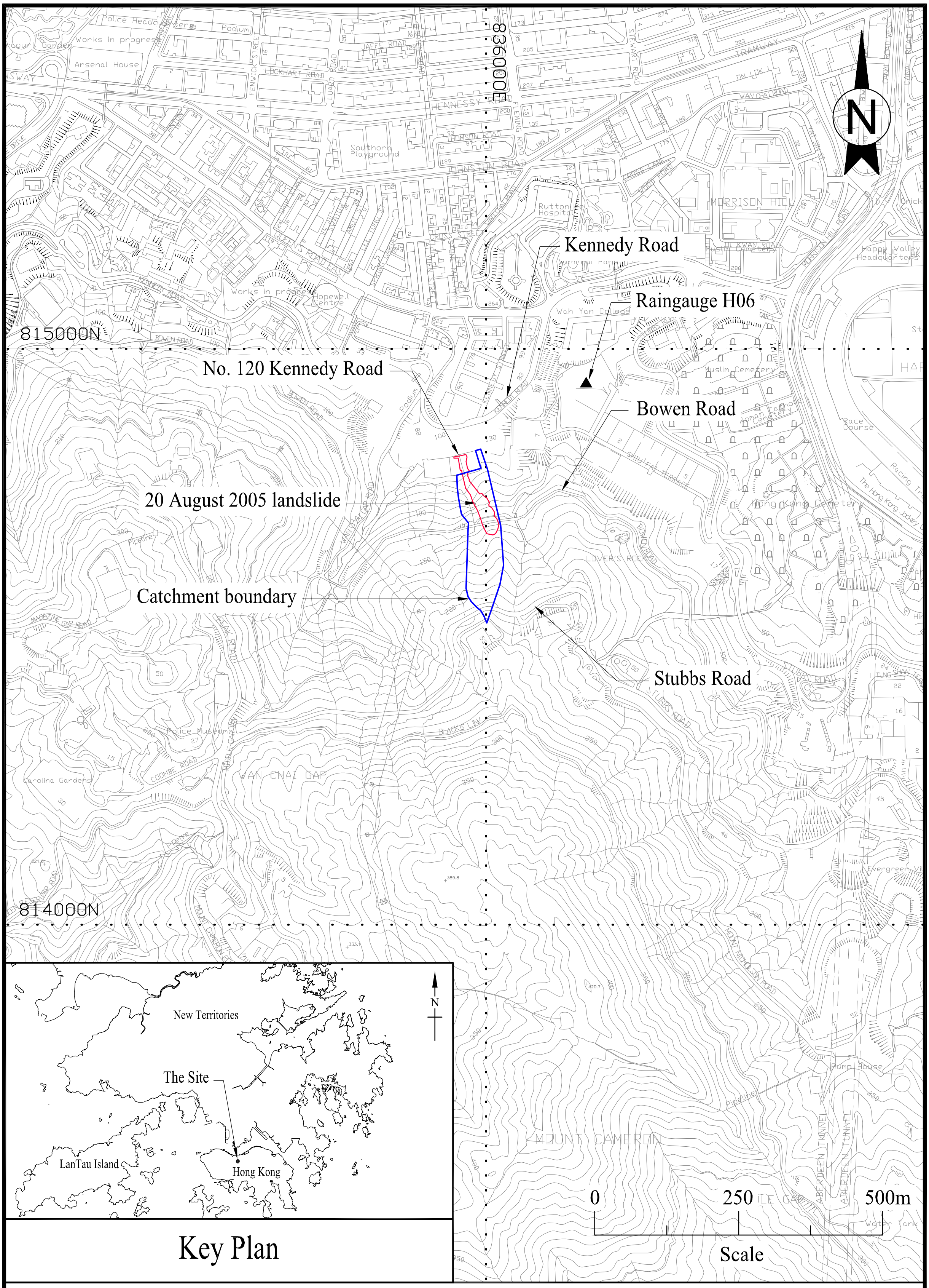
(2) Maximum rolling rainfall was calculated from 5-minute data.

(3) The use of 5-minute data for durations between 4 hours and 31 days results in better data resolution, but may slightly over-estimate the return periods using Lam & Leung (1994)'s data, which are based on hourly rainfall for these durations.

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

LIST OF FIGURES

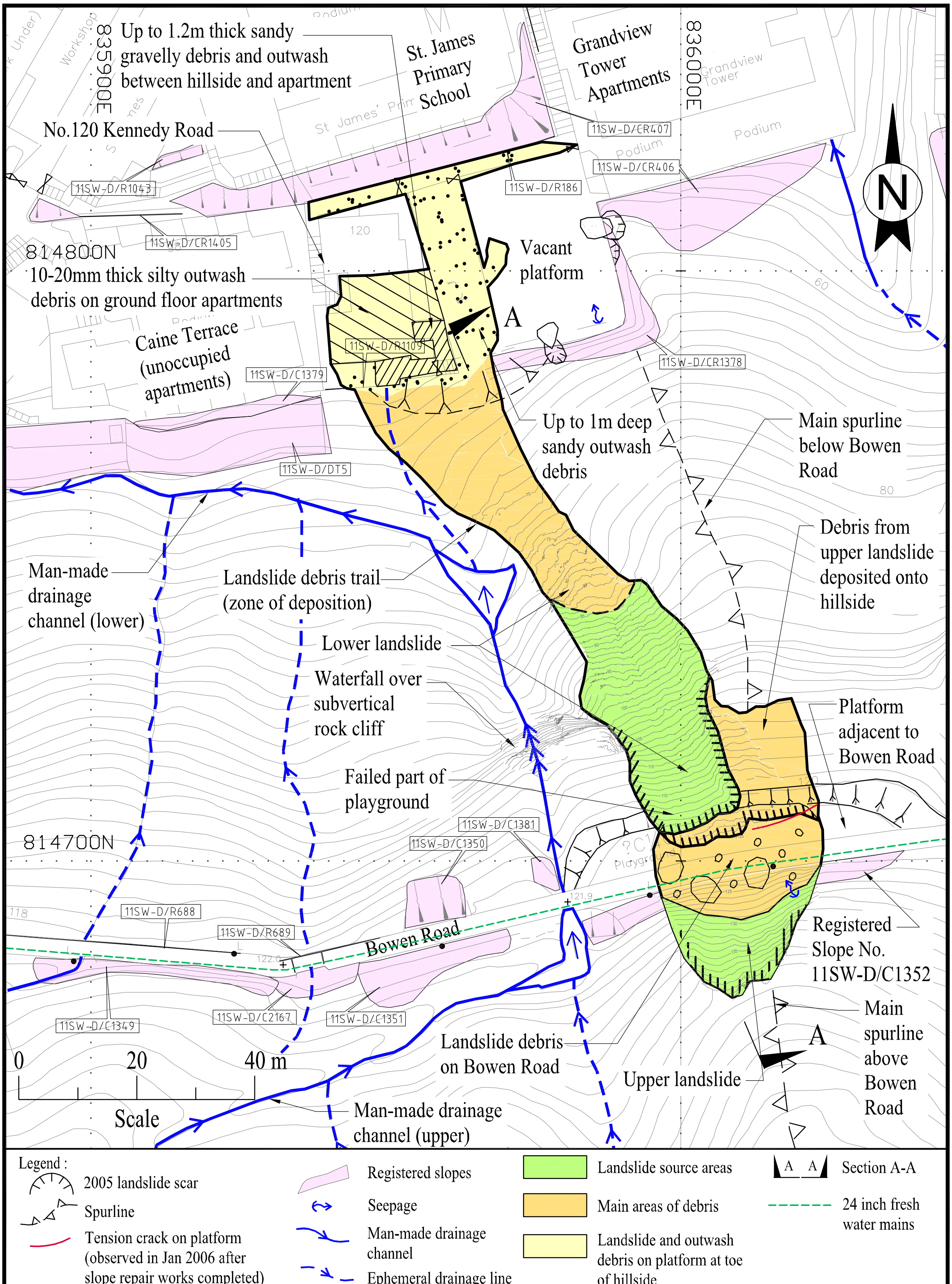
Table of Contents
Table of Contents
Table of Contents



Note : Base map is extracted from Survey Sheet No. 11SW-B & D, Scale 1 : 5000, dated 1992

Figure 1 - Site Location Plan

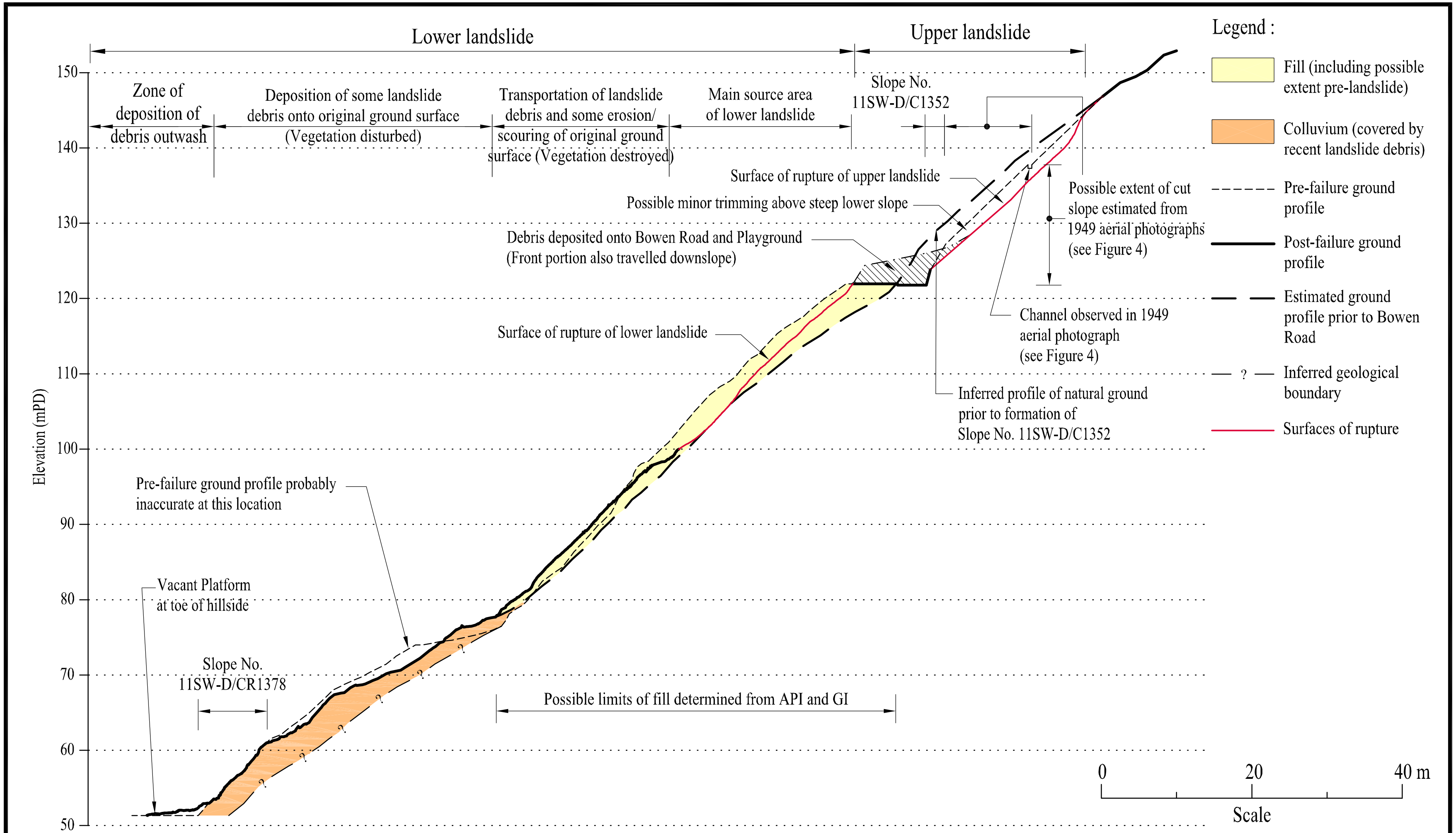
Table of Contents
Table of Contents
Table of Contents
Table of Contents



Notes : (1) Base Map is extracted from Survey Sheet No. 11SW-14D & 15C, dated 1999.
(2) Detailed survey of scar provided by Survey Division of CEDD, Goverment of HKSAR, September 2005.
(3) The location of seepage on the upper landslide scar is taken from the GEO incident Report (Incident No. 2005/08/0304).

Figure 2 - Plan of the Landslides

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



Notes : (1) Section is extracted from CEDD Survey Division, dated September 2005.
(2) Section at Bowen Road estimated from FSW site measurements and observations, and API.

Figure 3 - Section A - A Through the Landslides

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

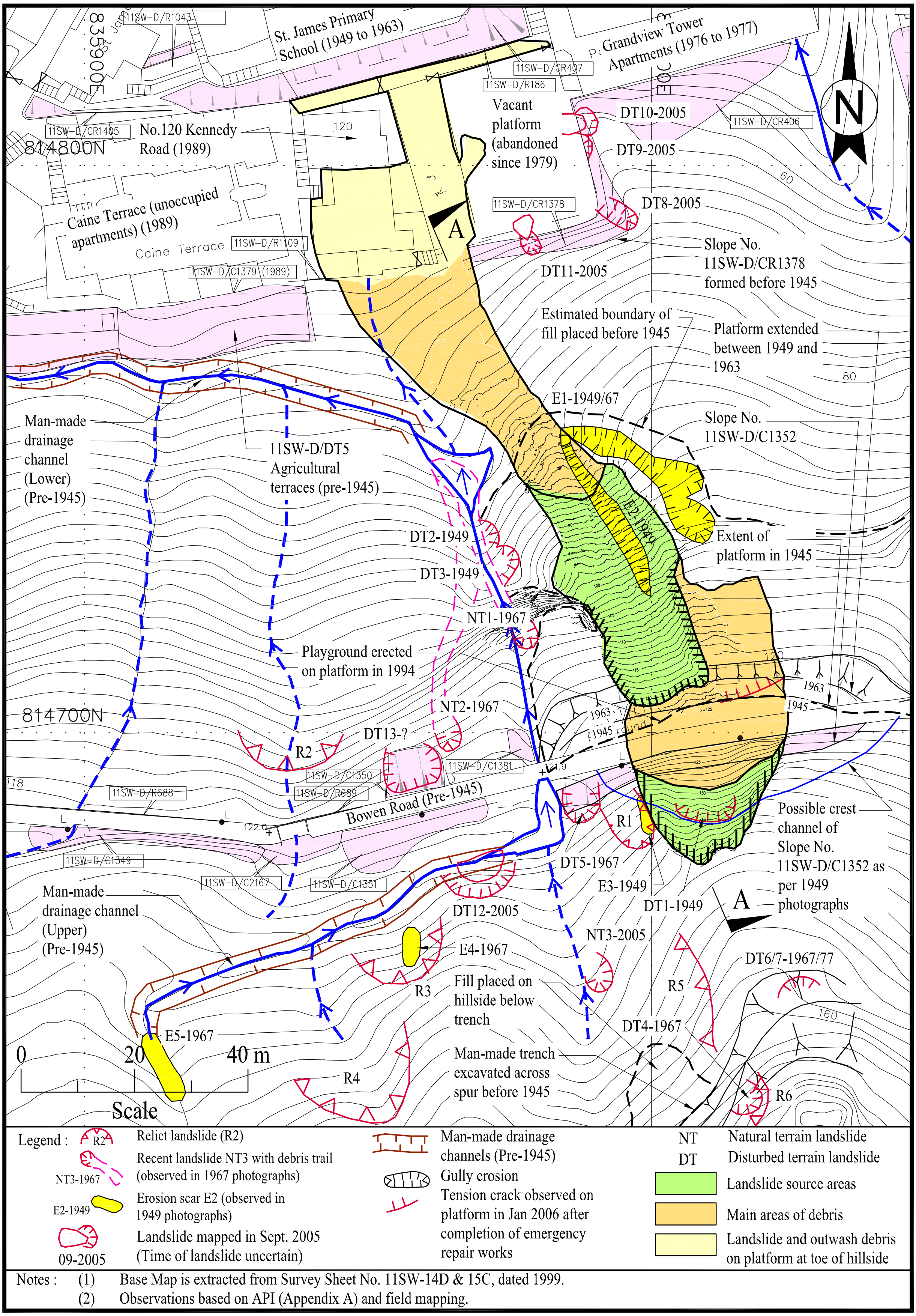


Figure 4 - Site Development History and Past Instability

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

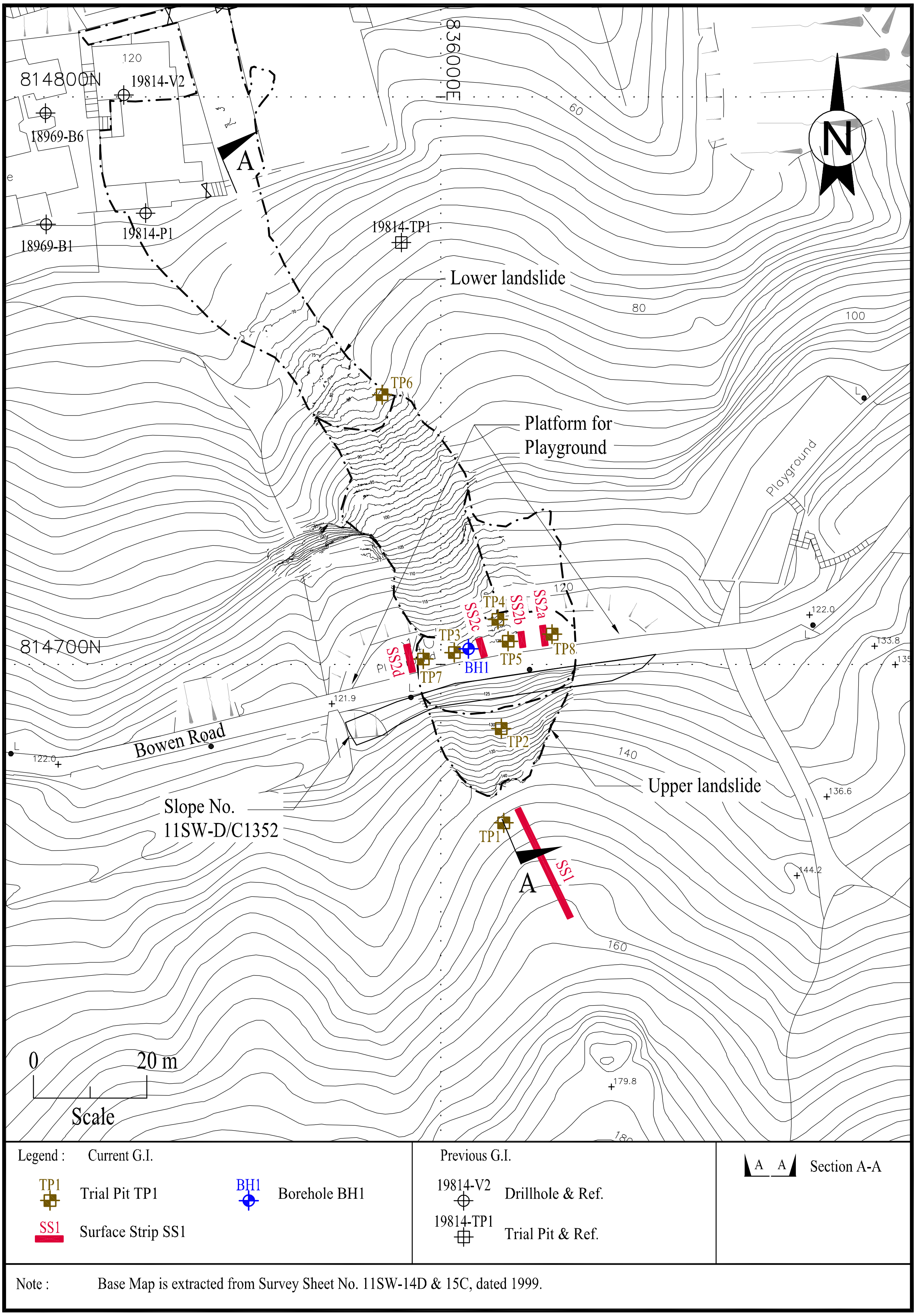
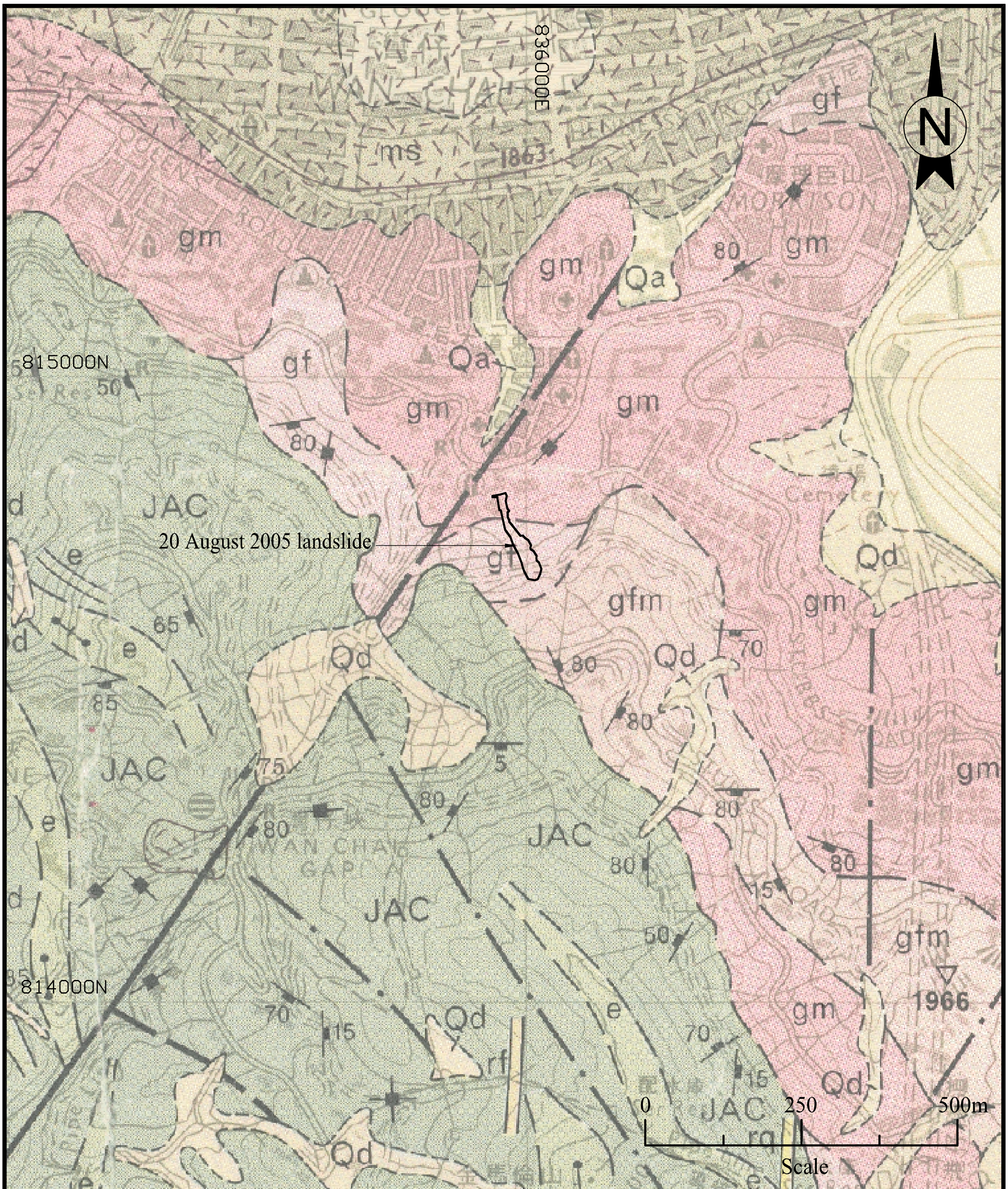


Figure 5 - Ground Investigation Plan

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



Legend :

JAC	Fine ash vitric tuff	Qd	Unsorted sand, gravel, cobbles and boulders; clay/silt matrix		Fault
gfm	Fine to medium-grained granite	Qa	Alluvium		Geological Boundary
gf	Fine-grained granite, <2mm	e	Eutaxite		Photogeological lineament
gm	Medium-grained granite, 2-6 mm			50	Jointing (50° dip)

Note : Base Map is extracted from Solid and Superfical Geology Map No. HGM20, Sheet 11, dated 1986.

Figure 6 - Regional Geology

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

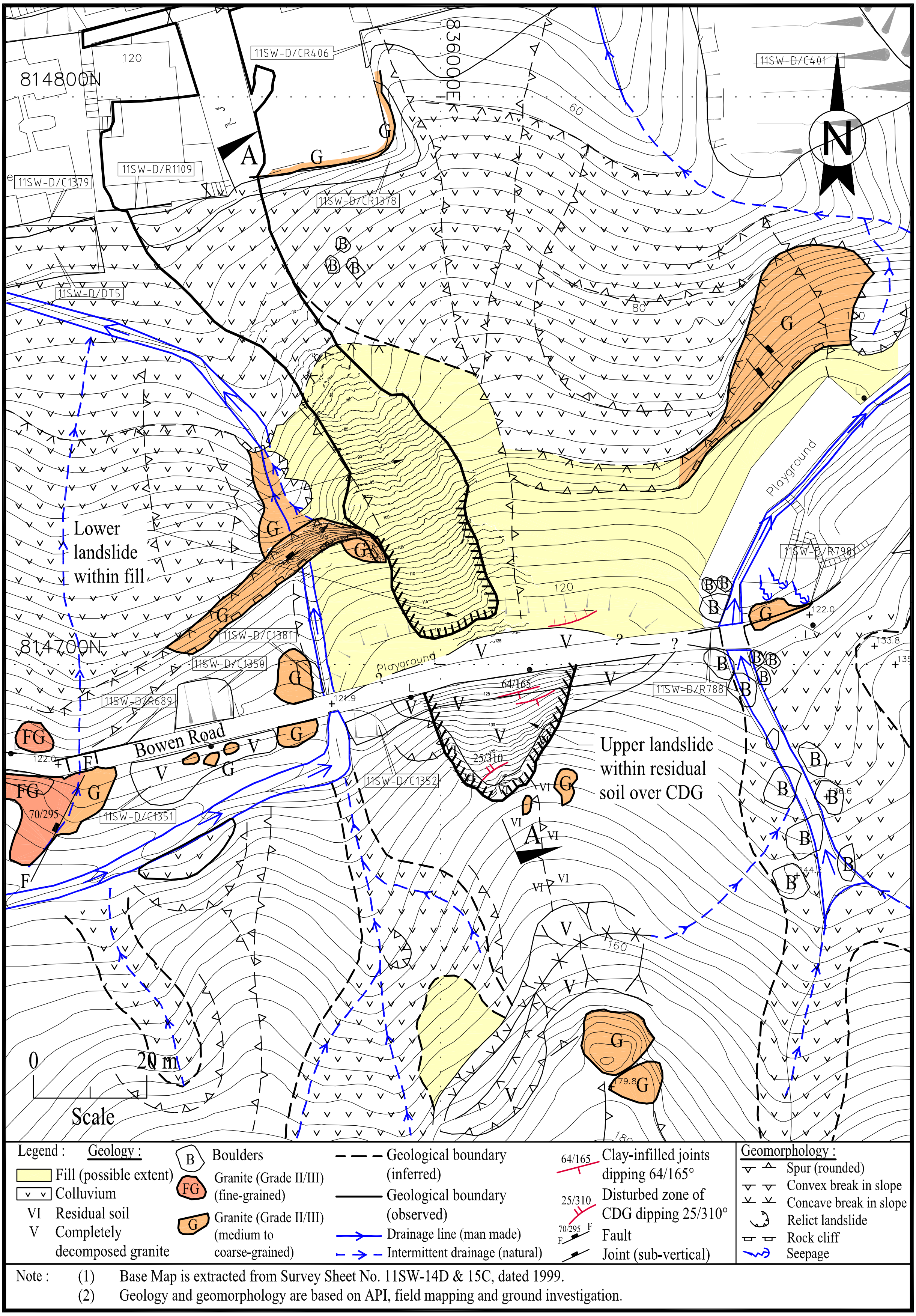
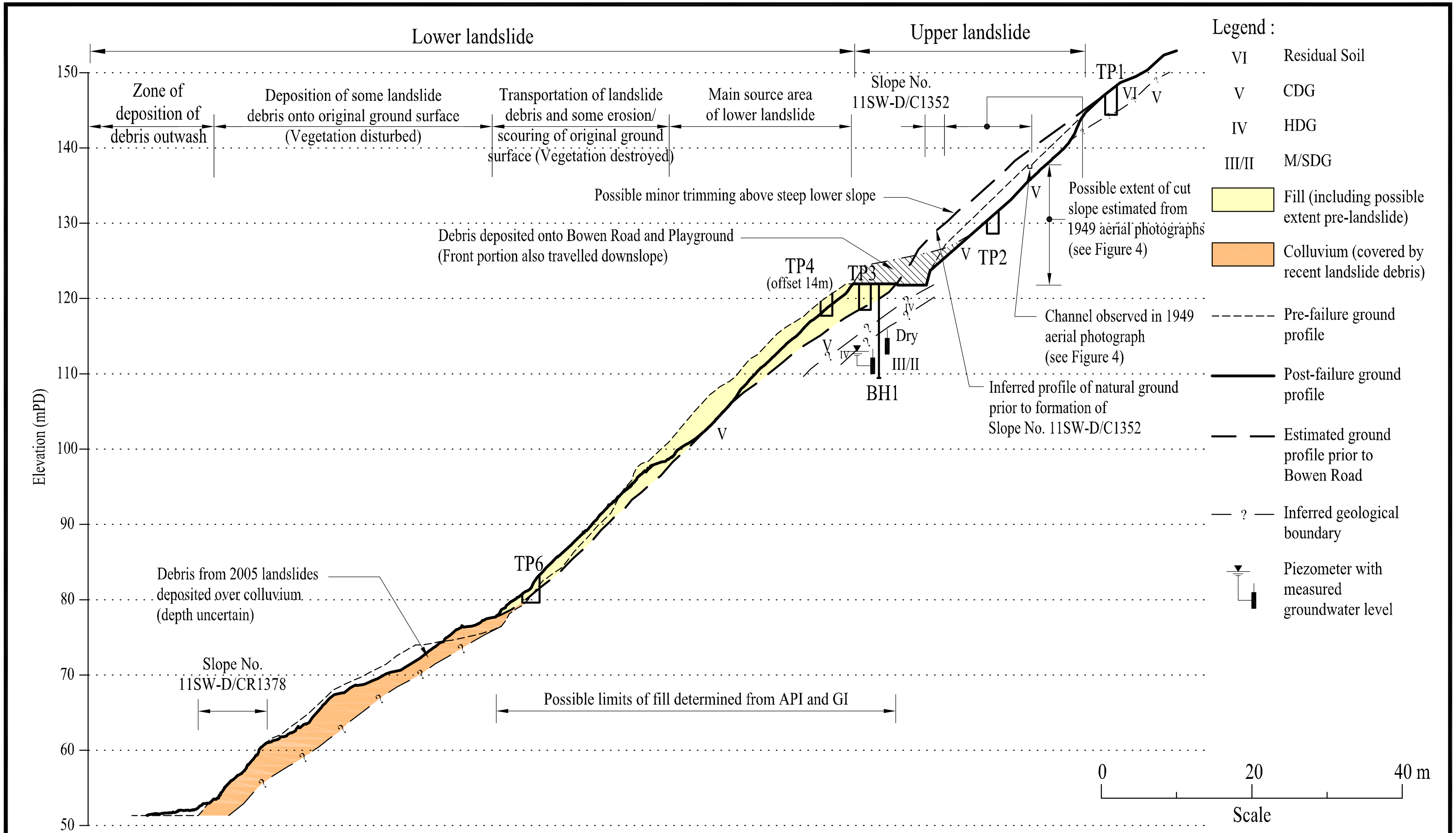


Figure 7 - Geology and Geomorphology

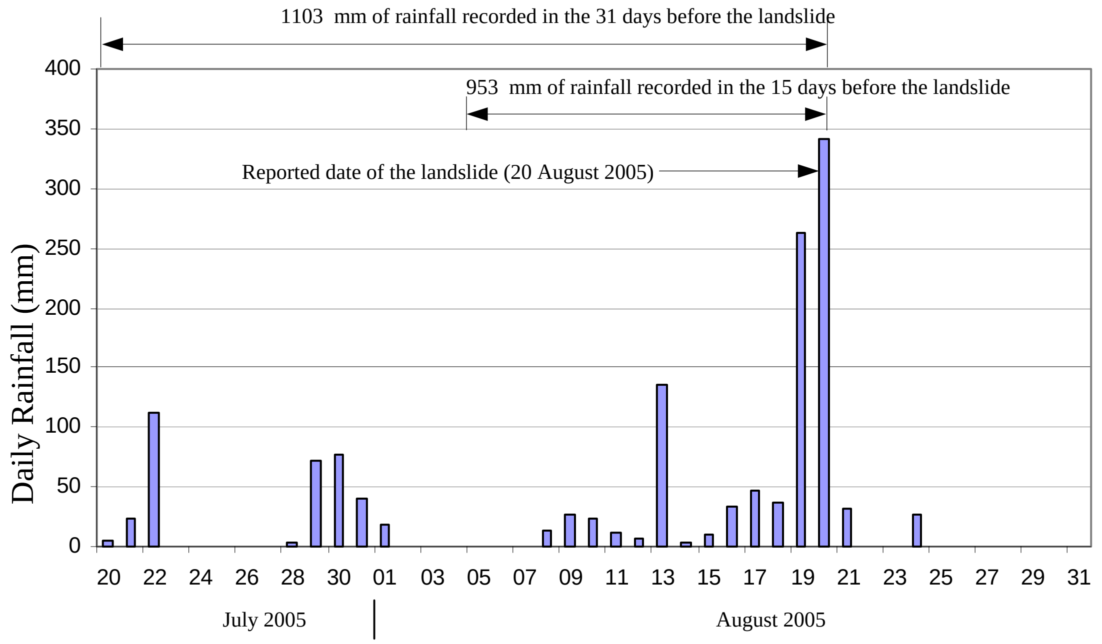
Table of Contents
Table of Contents
Table of Contents
Table of Contents



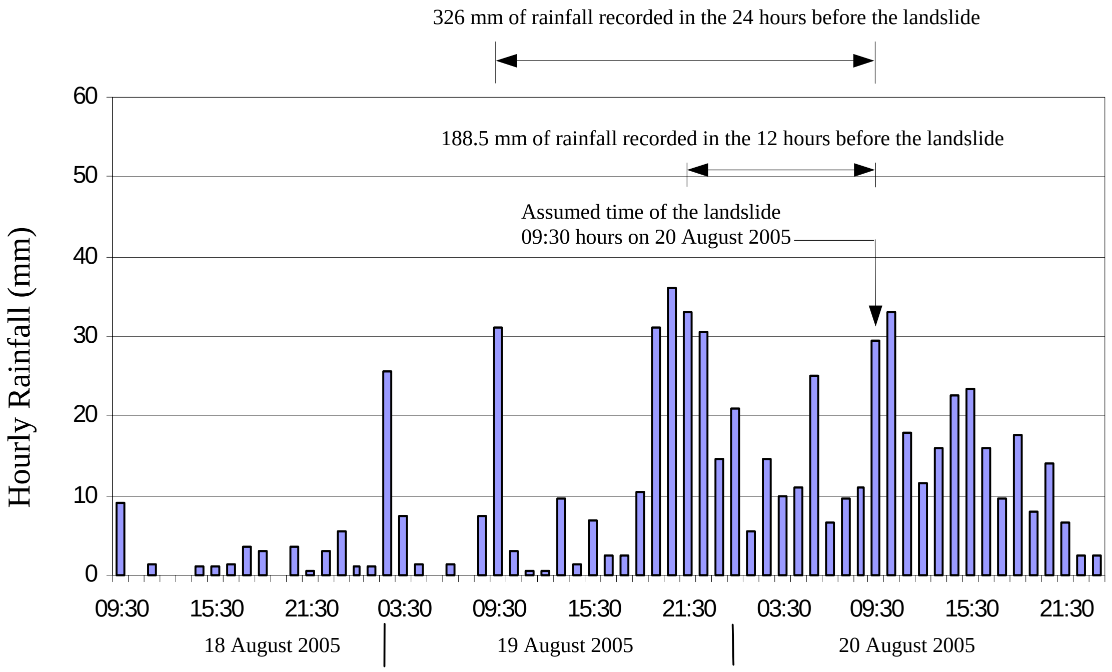
Notes :
(1) Section is extracted from CEDD Survey Division, dated September 2005.
(2) Section at Bowen Road estimated from FSW site measurements and observations, and API.
(3) Geological information from current GI, field mapping and API.

Figure 8 - Geological Section A - A

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



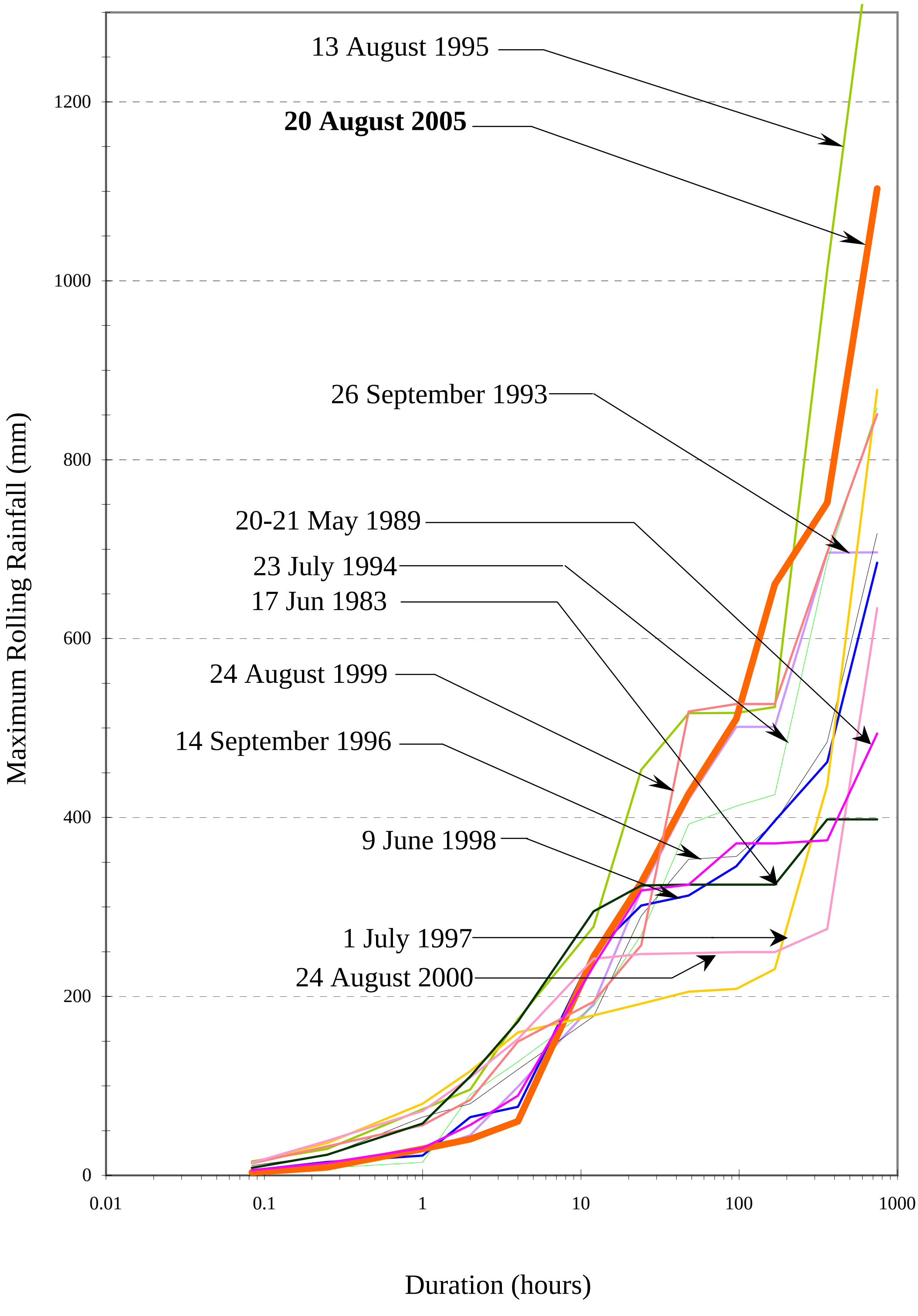
(a) Daily Rainfall Recorded between 20 July and 25 August 2005



(b) Hourly Rainfall Recorded between 09:30 hours on 18 August and 23:30 hours on 20 August 2005

Figure 9 - Rainfall Records of GEO Raingauge No. H06

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



Note : Rainfall data are 5-minute statistics from GEO raingauge No. H06

Figure 10 - Maximum Rolling Rainfall Preceding the 20 August 2005 Landslides and Selected Previous Major Rainstorms Recorded at GEO Raingauge No. H06

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

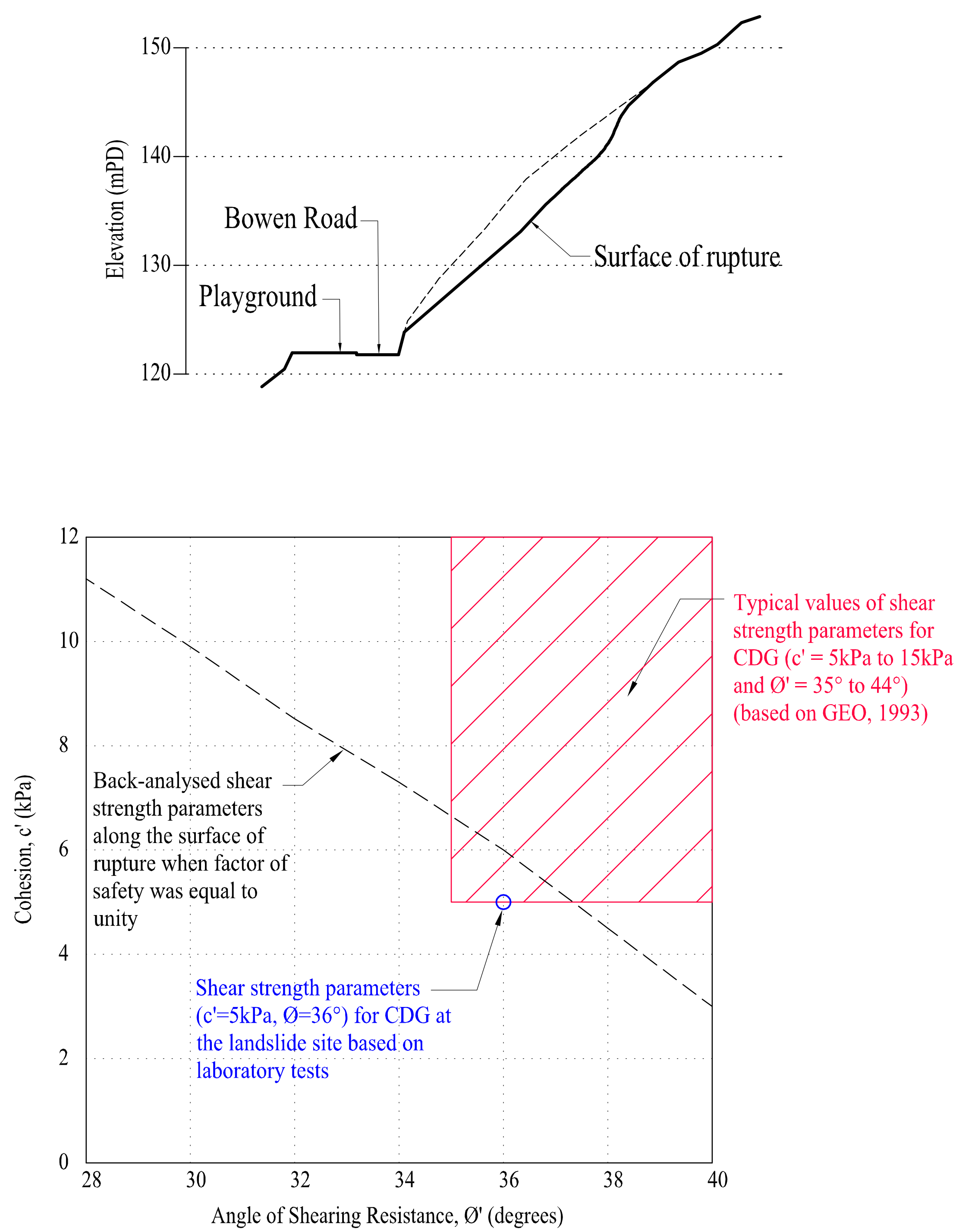
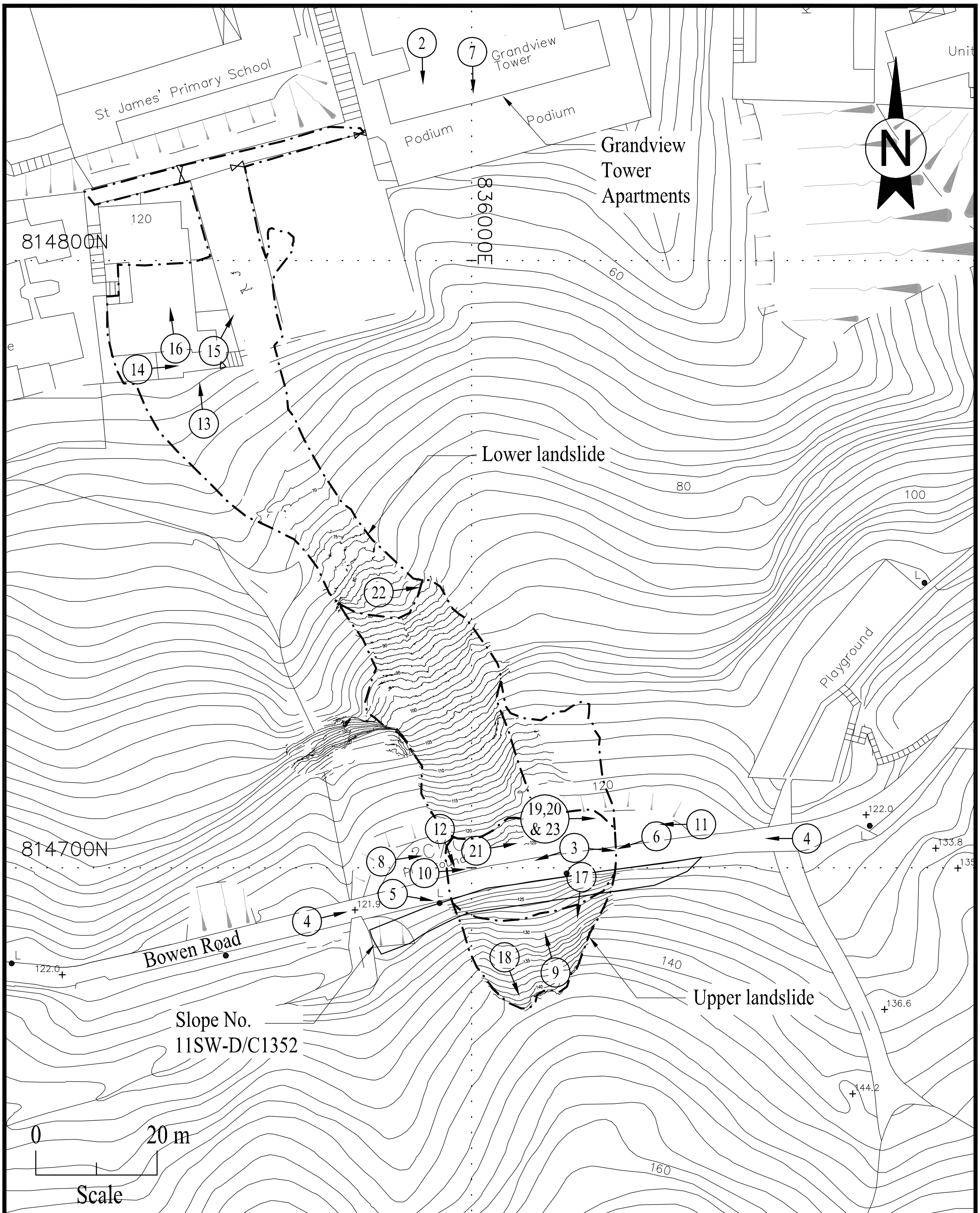


Figure 11 - Results of Theoretical Slope Stability Analyses

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



Legend :

(2) Plate 2 and direction of photograph

Notes :

(1) Base Map is extracted from Survey Sheet No. 11SW-14D & 15C, dated 1999.
(2) Plate 1 photograph taken from helicopter looking south.
(3) Plates 2 and 7 taken from Grandview Tower apartment block looking south.

Figure 12 - Locations and Directions of Photographs

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

LIST OF PLATES

Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents

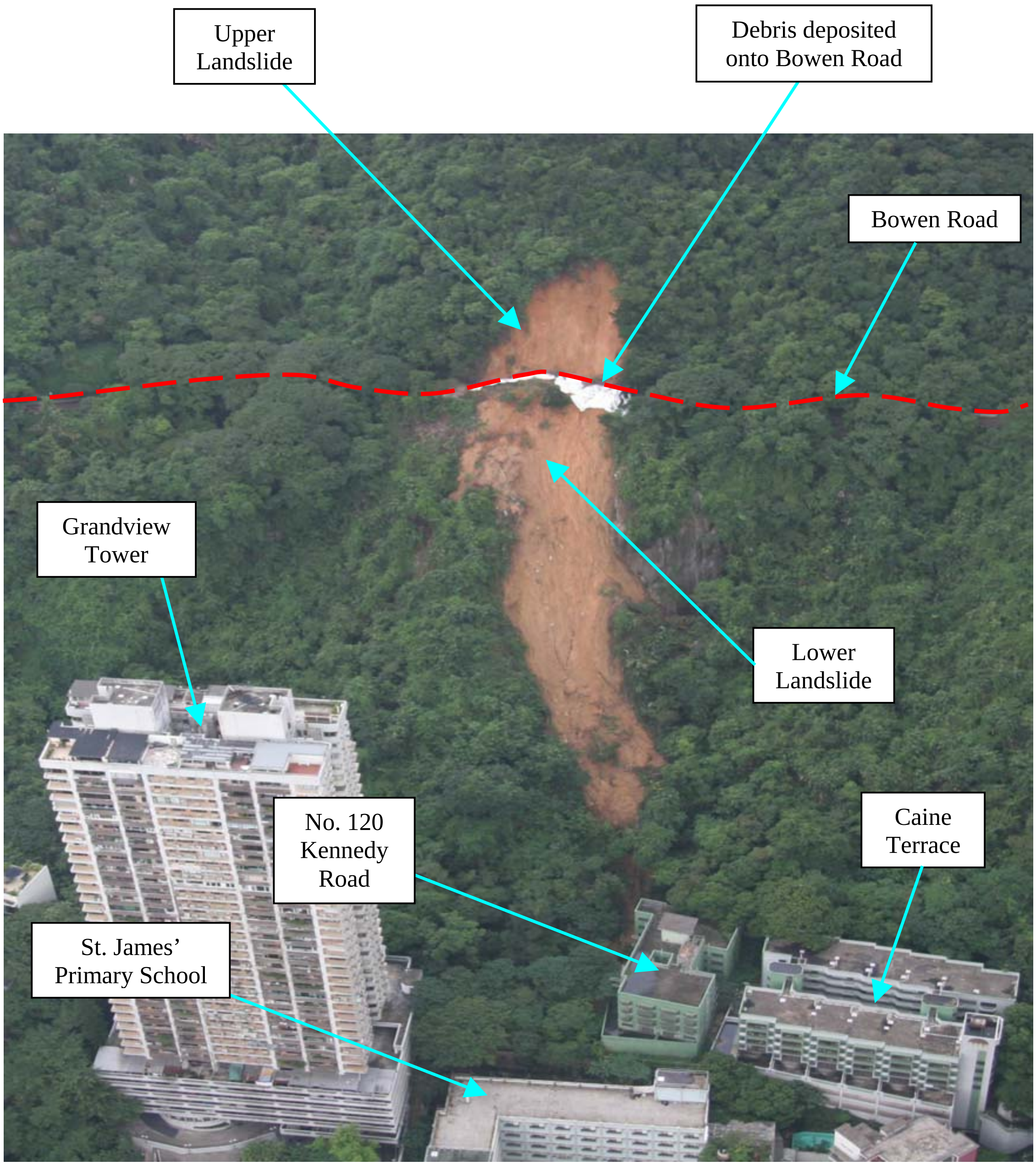


Plate 1 - General View of the Landslide Site (Photograph Taken on 22 August 2005)

Note: See Figure 12 for location of photograph

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

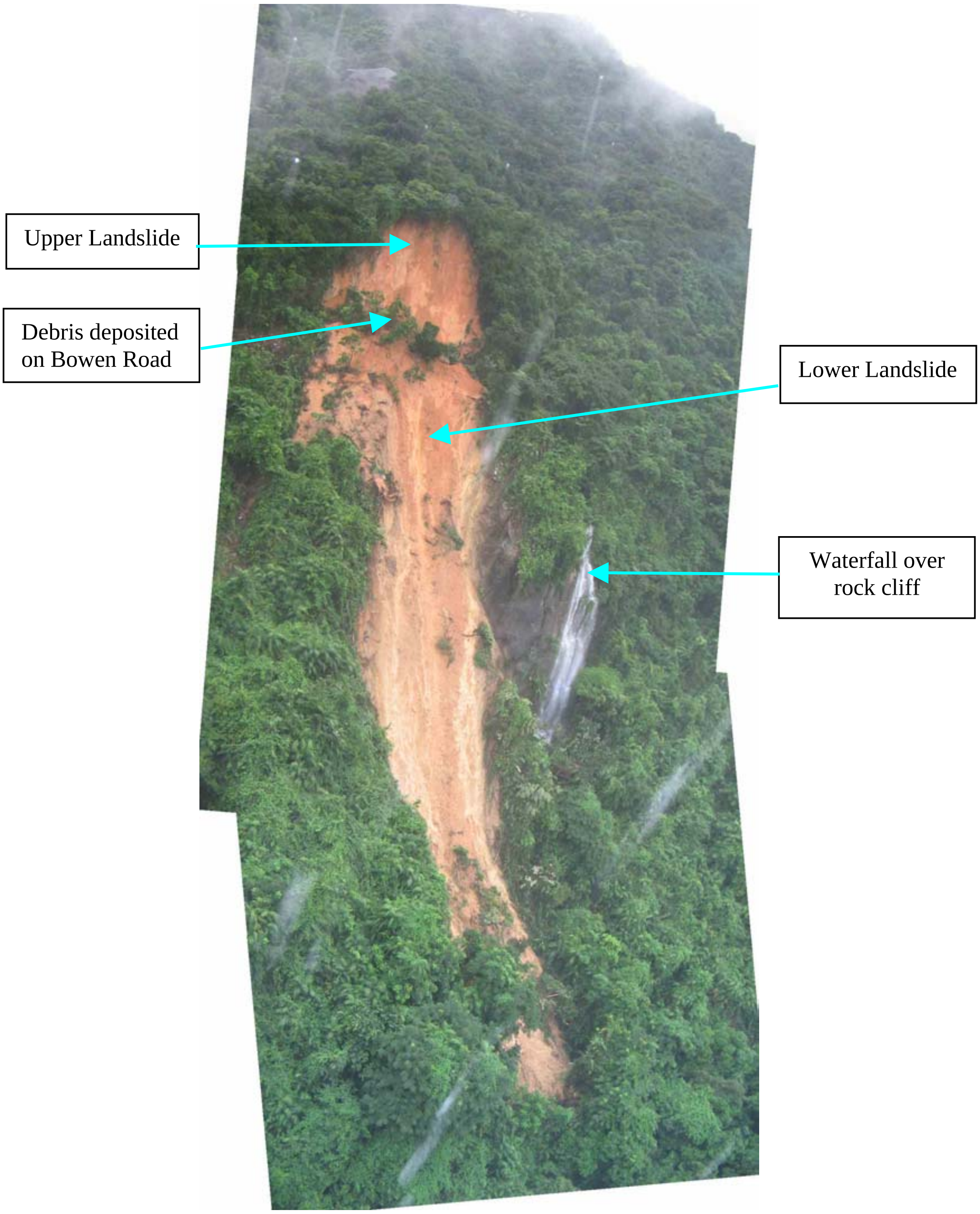


Plate 2 - View of the Landslides from Grandview Tower (Photograph Taken on 20 August 2005)

Note: See Figure 12 for location of photograph

Table of Contents
Table of Contents
Table of Contents

Plate 3 - Record Photographs of Slope No. 11SW-D/C1352 Taken in May 1996

Note: See Figure 12 for location of photograph

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

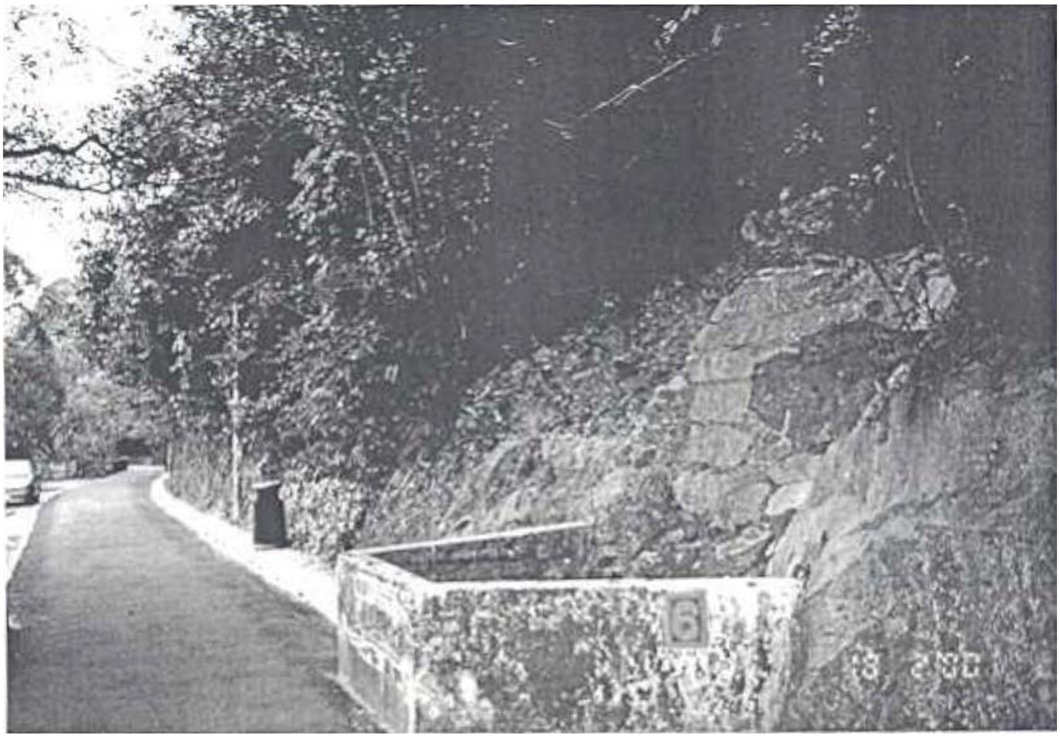


Plate 4 - Record Photographs of Slope No. 11SW-D/C1352 Taken in February 2000

Note: See Figure 12 for location of photograph

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

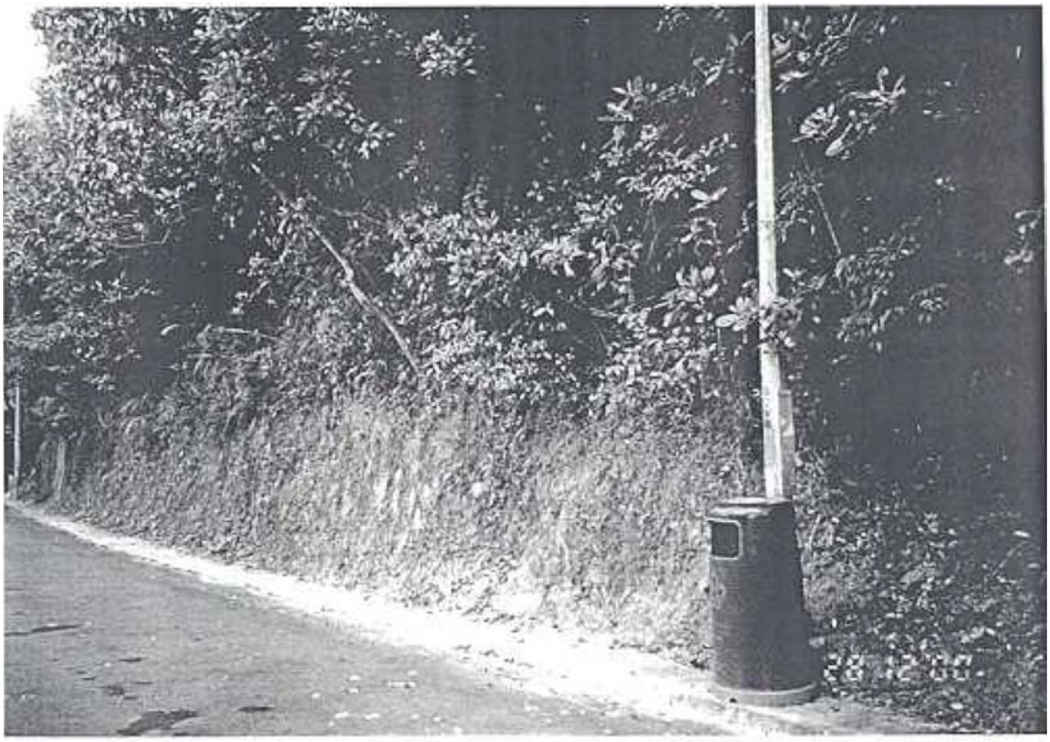


Plate 5 - Record Photograph of Slope No. 11SW-D/C1352 Taken in December 2000

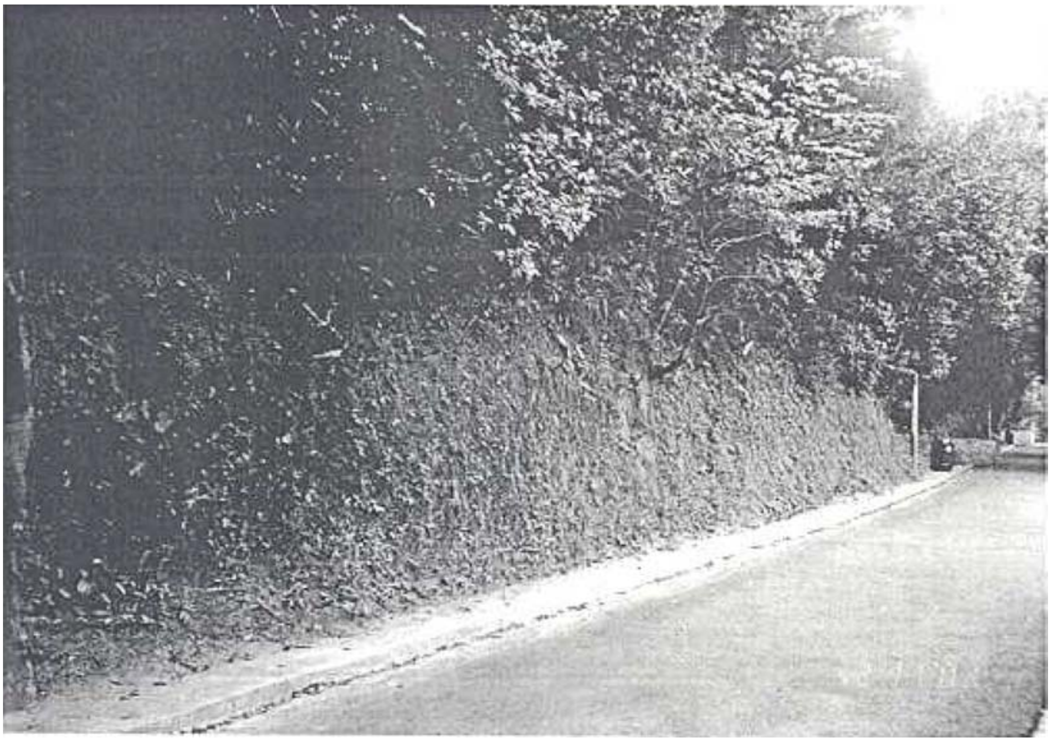


Plate 6 - Record Photograph of Slope No. 11SW-D/C1352 Taken in November 2001

Note: See Figure 12 for location of photograph

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

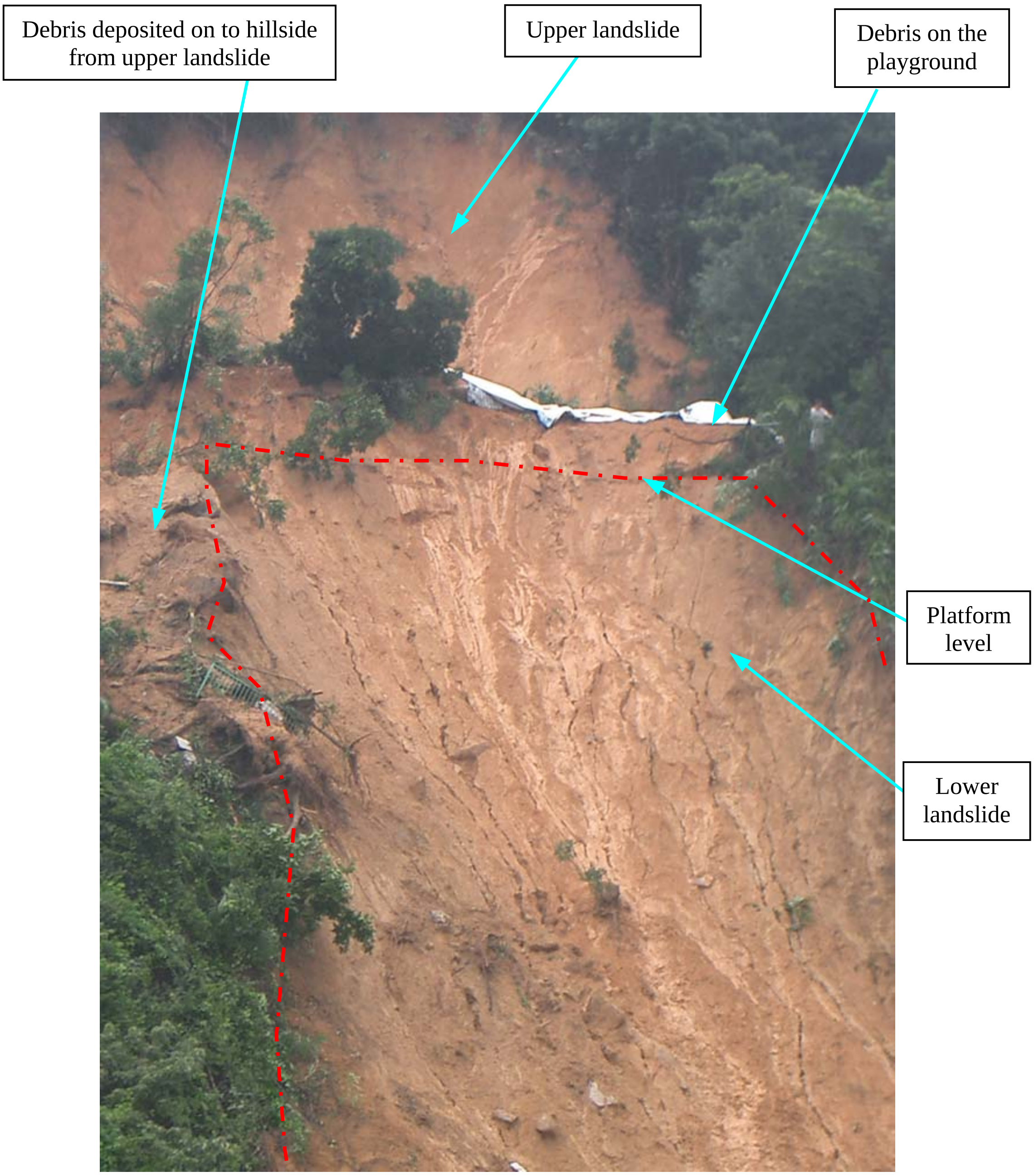


Plate 7 - Main Scarp and Source Area of the Lower Landslide below the Playground (Photograph Taken on 21 August 2005)

Note: See Figure 12 for location of photograph

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

Plate 8 – View of Upper Landslide and Main Scarp of Lower Landslide From Bowen Road (Photograph Taken on 22 August 2005)

Note: See Figure 12 for location of photograph

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

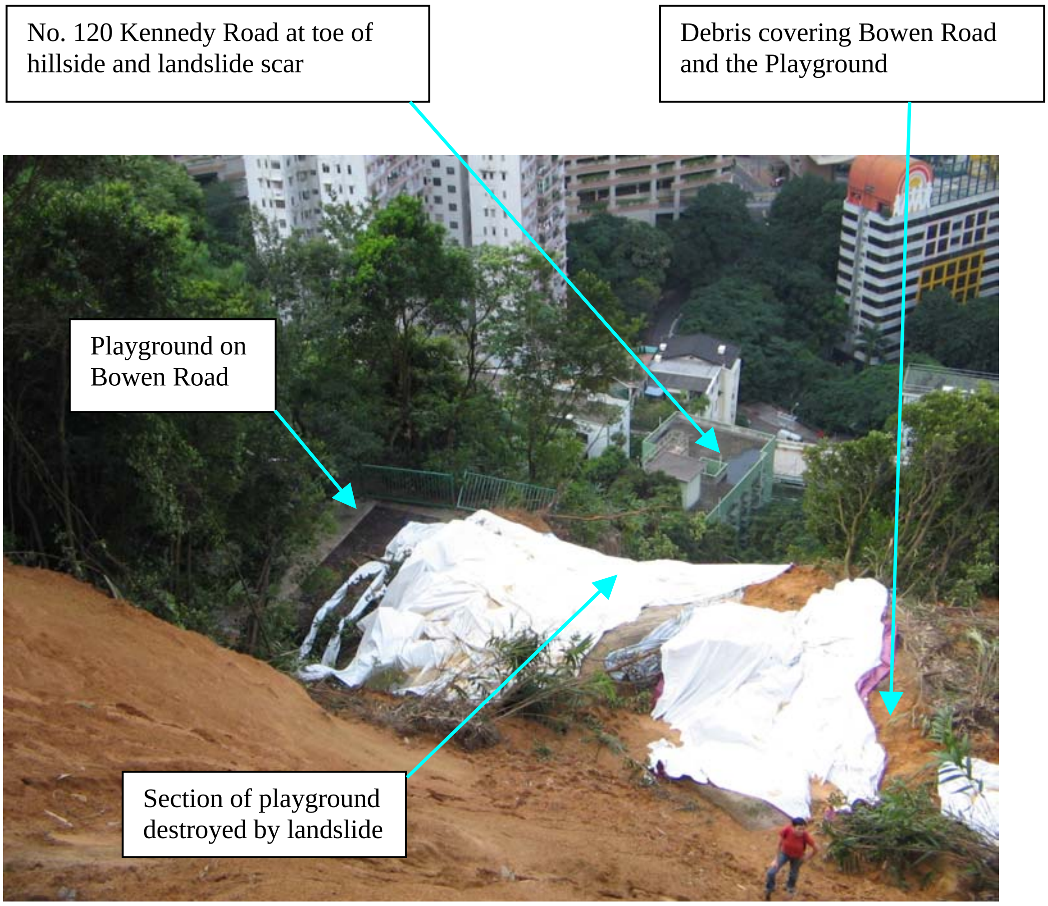


Plate 9 - View from Upper Landslide above Bowen Road (Photograph Taken on 23 August 2005)

Note: See Figure 12 for location of photograph

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

Plate 10 - Debris Blocking Bowen Road on Western Flank of Upper Landslide (Photograph Taken on 22 August 2005)

Plate 11 - Debris Blocking Bowen Road on Eastern Flank of Upper Landslide (Photograph Taken on 23 August 2005)

Note: See Figure 12 for location of photograph

Table of Contents

Table of Contents

Table of Contents

Table of Contents

Plate 12 - Upper Landslide Scar above Bowen Road after Debris Clearance and Shotcreting (Photograph Taken on 6 September 2005)

Plate 13 - Debris Deposited at Abandoned and Unoccupied Apartments at No. 120 Kennedy Road (Photograph Taken on 6 September 2005)

Note: See Figure 12 for location of photograph

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

Plate 14 - Debris and Outwash (up to 1.2 m deep) Deposited between Hillside and No. 120 Kennedy Road (Photograph Taken on 6 September 2005)

Note: See Figure 12 for location of photograph

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

Plate 15 - Debris and Outwash Deposited onto Abandoned Platform Behind St. James' Primary School (Photograph Taken on 6 September 2005)

Plate 16 – Fine-grained Silty Outwash Debris (10 mm to 20 mm deep) Deposited within Ground Floor Apartment at No. 120 Kennedy Road (Photograph Taken on 6 September 2005)

Note: See Figure 12 for location of photograph

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

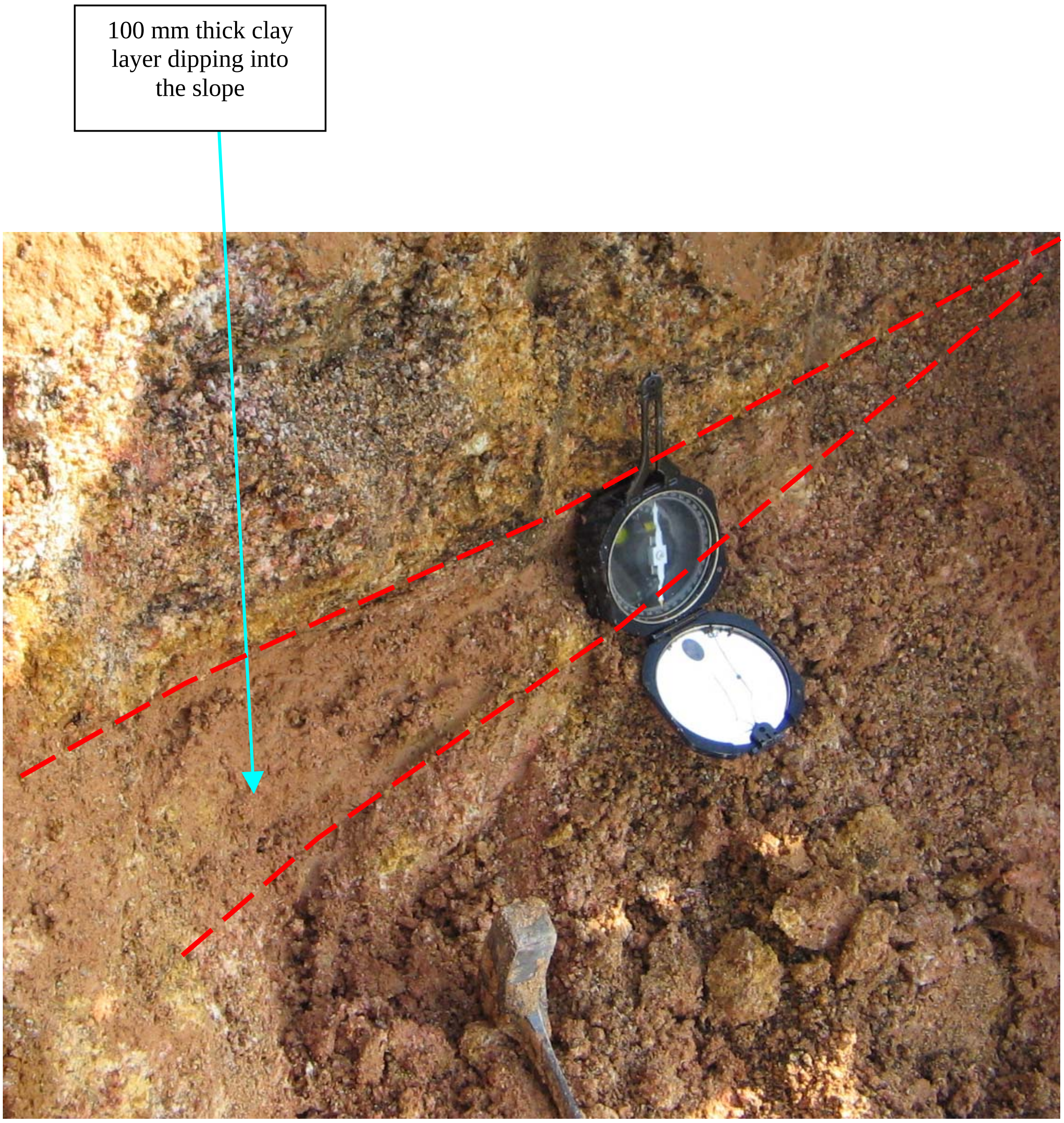


Plate 17 – Clay-infilled Relict Joints within CDG at the Toe of Upper Landslide
(Photograph Taken on 24 August 2005)

Note: See Figure 12 for location of photograph

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

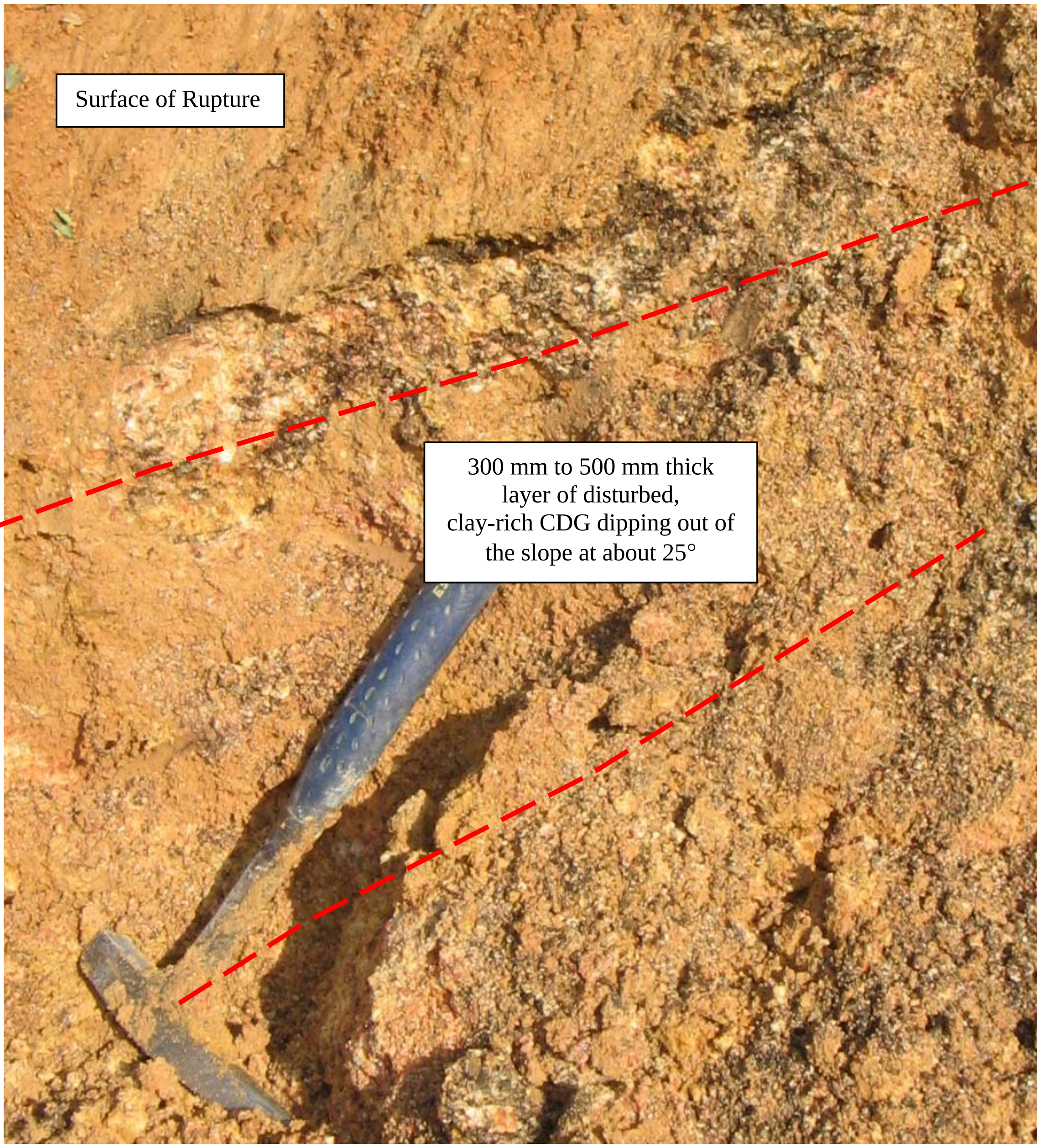


Plate 18 – Layer of Disturbed and Clay-rich CDG near the Main Scarp of the Upper Landslide (Photograph Taken on 24 August 2005)

Note: See Figure 12 for location of photograph

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

Tension crack below rubber mats on playground

Plate 19 - Tension Crack on the Playground (Photograph Taken on 8 March 2006)

Note: See Figure 12 for location of photograph

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

Plate 20 - Close-up of Tension Crack on the Playground (Photograph Taken on 13 January 2006)

Note: See Figure 12 for location of photograph

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

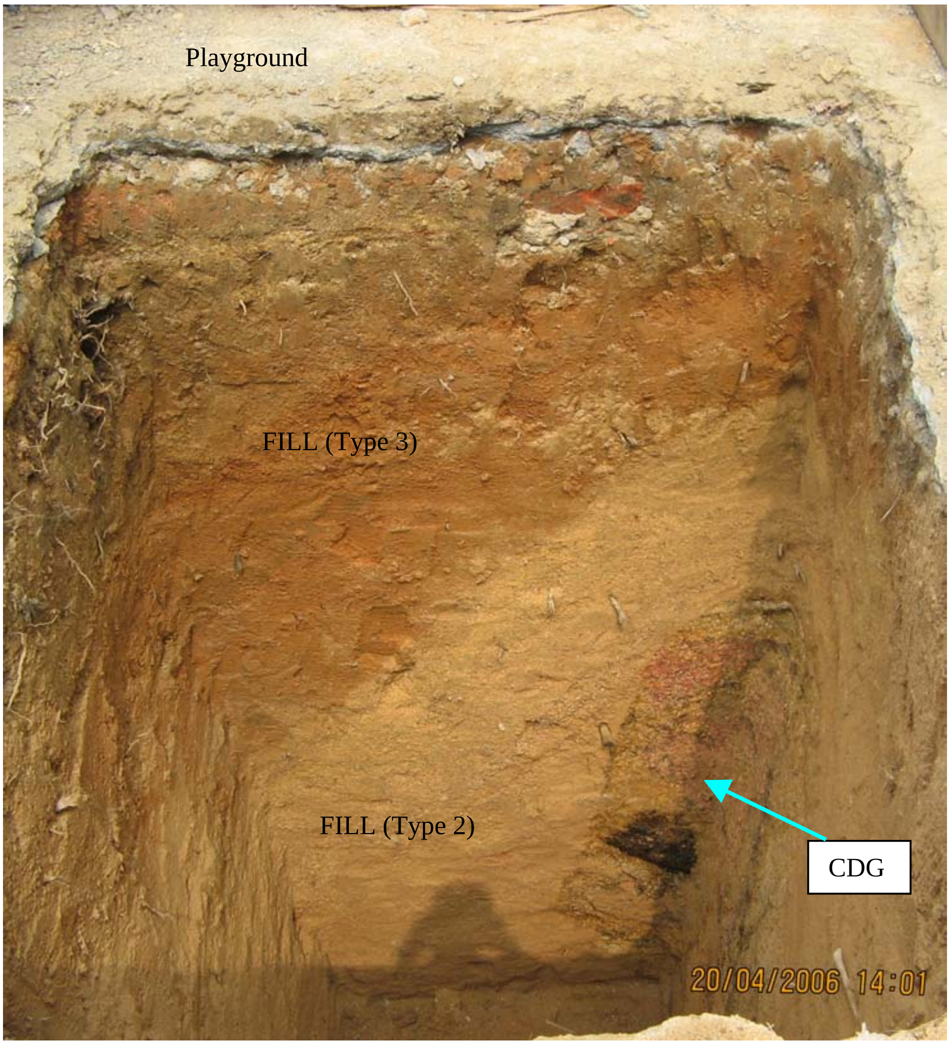


Plate 21 – Layered Fill (Types 2 and 3) Overlying Steeply-inclined CDG in Trial Pit No. TP3 (Photograph taken on 20 April 2006)

Note: See Figure 12 for location of photograph

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

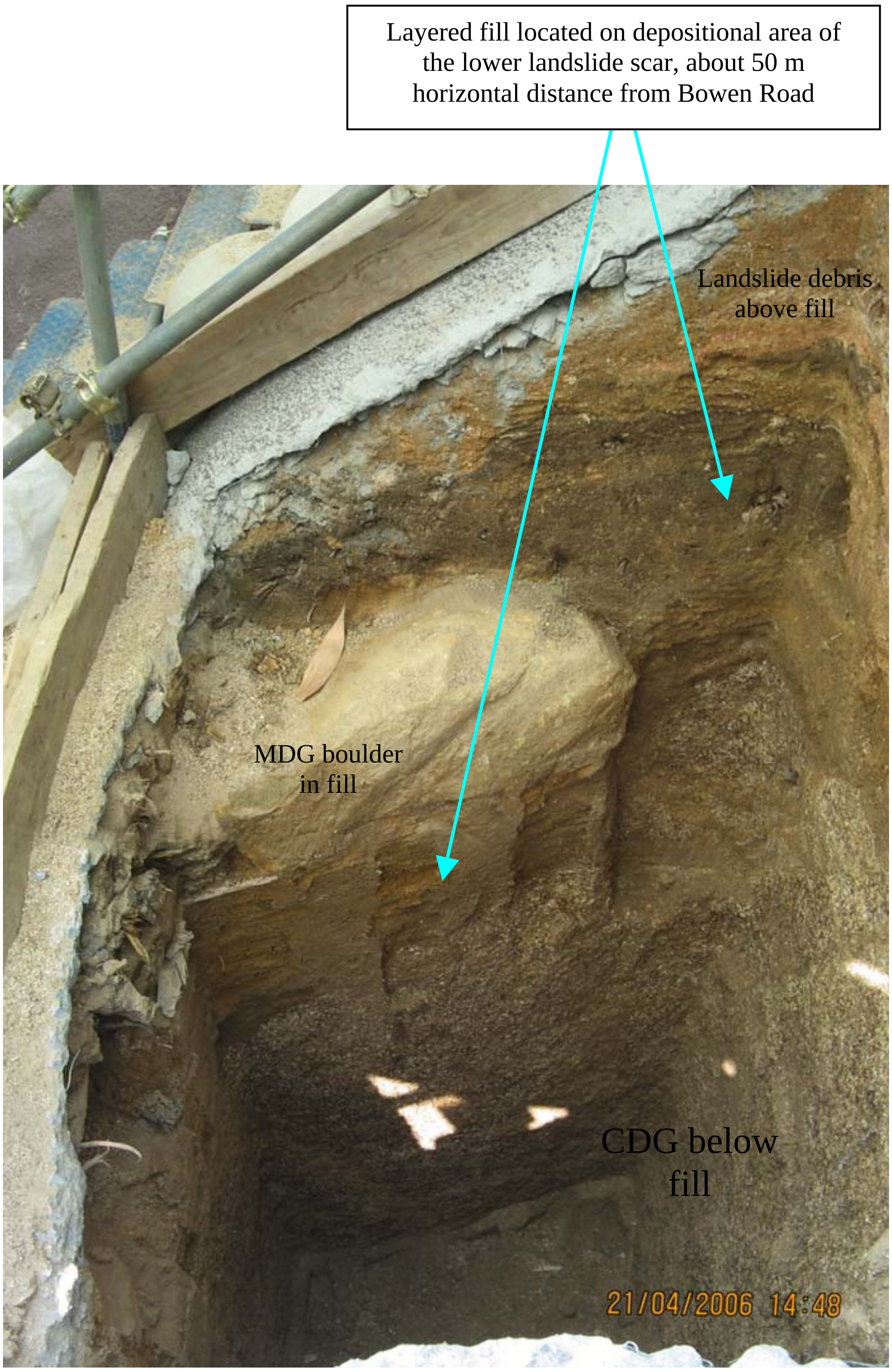


Plate 22 - Layered Fill with Granite Boulder above CDG in Trial Pit No. TP6 (Photograph Taken on 21 April 2006)

Note: See Figure 12 for location of photograph

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

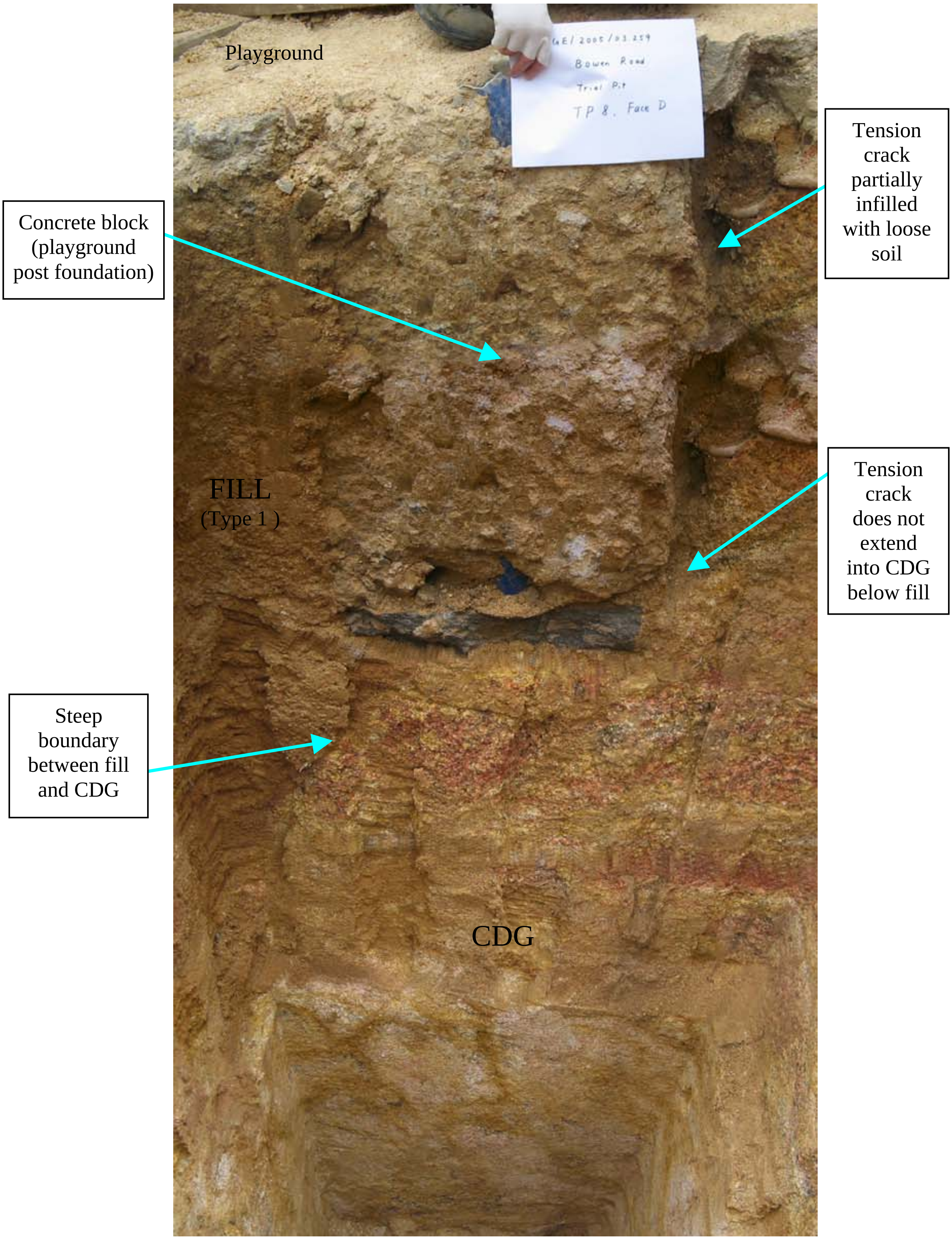


Plate 23 - Tension Crack within Fill in Trial Pit No. TP8 (Photograph Taken on 11 April 2006)

Note: See Figure 12 for location of photograph

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

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

APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

A.1 DETAILED OBSERVATIONS

The following comprise the detailed observations made from the aerial photographs studied (see Figure 4 of main report). A list of aerial photographs used in this study is given in Section A.2.

Year	Observations
1945	Bowen Rd, Slope No.11SW-D/C1352 and the platform are evident. Multi-storey buildings are evident at the present day locations of Caine Terrace, No. 120 Kennedy Road, and at the adjacent, currently vacant platform at the toe of the hillside. There is evidence of a linear feature (confirmed as the lower drainage channel in the later photographs) traversing the hillside above the building at present day Caine terrace. There is evidence of a linear feature (confirmed as the upper drainage channel in the later photographs) across the hillside above Bowen Road and to the west of the 2005 upper landslide. There is also evidence of disturbed terrain to the south of the 2005 upper landslide. Some cut and fill may occur but the area is in considerable shadow. There is evidence of erosion (E2) associated with this feature.
1949	Agriculture terraces are apparent on the hillside behind the building in the current location of Caine Terrace. A formed drainage channel is evident along the main drainage line below Bowen Road and to the west of the 2005 lower landslide. The drainage channel located to the west of the landslides is lined. There is also a relatively large area of disturbed terrain to the south of the 2005 upper landslide. This was first observed in the 1945 photographs but was mostly covered in shadow at that time. The feature comprises a trench excavation across the spur above the location of the 2005 upper landslide. The reason for the excavation is not certain, although, it may have been formed during the Second World War. Slope No.11SW-D/C1352 is clearly evident with a crest channel and is covered with vegetation. The slope appears to be about 12 m high. A landslide (DT1-1945) is also evident and covered with vegetation at the central part of the crest of the slope. A relict landslide (R1) is evident immediately adjacent to the west flank of the upper 2005 landslide scar. The scar is covered partially with vegetation but appears to have been affected by erosion in the 1949 aerial photographs (E3-1949). The platform for the playground on the opposite side of Bowen Road from Slope No. 11SW-D/C1352, appears to have been formed mostly on fill. Fill covered by vegetation is also inferred from the aerial photographs covering a large portion of the hillside below the platform. The fill may have been placed on this part of the hillside in relation to spoil disposal activities during construction of Bowen Road.

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

Year	Observations
	Two disturbed terrain landslides (DT2-1949 and DT3-1949) are evident on the hillside below the rock cliff.
	An area of erosion (E3-1949) is associated with a relict scar (R1) adjacent to the west flank of Slope No.11SW-D/C1352. Deep gully erosion scars (E1-1949 and E2-1949) are evident on the hillside affected by the lower landslide in 2005, and may be associated with erosion of disturbed terrain (i.e. fill materials).
	In general, the area is covered with grassy vegetation
1954	No significant changes are evident on this single photograph, except that the vegetation appears to have increased.
1963	The platform appears to have been extended since 1949 by additional filling on the hillside below the previous platform. However, the fill is not evident between the dense vegetation covering the hillside.
	The eastern block of the multi-storey building at Caine Terrace evident in 1949, has been demolished and a new multi-storey apartment building is evident at the central part of present-day Caine Terrace. The multi-storey buildings for St James' Primary School are evident.
	There is a marked increase in vegetation cover, which is now characterised by relatively dense tree and shrub growth. By comparison, in 1945 almost no tree growth was evident.
1964	No significant changes are evident
1967	There is evidence of a number of natural terrain landslides. NT1-1967 and NT2-1967 are located on the hillside above the rock cliff. Debris from these landslides travelled downslope over the rock cliffs and in to the drainage line.
	A small landslide (DT5-1967) was noted on the 1967 photographs at the west end of the Slope No. 11SW-D/C1352.
	There is evidence of landslides (DT4-1967 and DT6-1967) associated with disturbed terrain of the trench excavation above the 2005 upper landslide. There is evidence of works in the eastern part of the feature. Erosion (E4-1967) is evident within R3 above the upper drainage channel. There is also evidence for erosion (E5-1967) and or a possible small landslide above the upper drainage channel, to the west of E4.
1968	No significant changes are evident.

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

Year	Observations
1972	The area to the west of No. 120 Kennedy Road at the toe of the hillside and 2005 lower landslide scar, has been cleared some years previously and now appears overgrown.
1973	The vegetation in the area continues to increase in density.
1974	The original buildings at the present location of Grandview Tower have been demolished and the general platform area has been cleared. The vegetation continues to increase in density.
1975 to 1976	No significant changes are evident. Construction works are underway at present-day location of Grandview Tower.
1977	Landslide DT6-1967 has been reactivated (DT7-1977), and there is evidence of a small landslide L23-1977 in Catchment C01. A new multi-storey block is evident at M6 (Grandview Tower). The vegetation density continues to increase.
1978	There is evidence of a small structure on the platform (currently vacated) to the west of Grandview Tower.
1979	There is evidence that the remaining part of the old building at present-day Caine Terrace at the toe of the hillside and 2005 lower landslide, is undergoing demolition. By November 1979, the demolition noted in September 1979 is complete and the platform is clear.
1980	There are a number of small structures completely covering the platform (currently vacated) to the west of Grandview Tower.
1981	There is further evidence of erosion associated with the area of landslide DT6/7-1967/77.
1982 to 1985	No significant changes are evident.
1986	A new building is apparent at present-day location of No. 120 Kennedy Road at the toe of the hillside and 2005 lower landslide.
1987	The old buildings at present-day Caine Terrace have been demolished. A cleared platform is now evident.
1988	Site formation is evident associated with part of the cleared platform at the present location of Caine Terrace. The vegetation in the general area continues to increase in density.

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

Year	Observations
1989	Building construction is underway at Caine Terrace.
1990	The buildings at Caine Terrace have been completed.
1991 to 1993	No significant changes are evident.
1994	Playground fixtures are clearly evident on the platform adjacent to Bowen Rd.
1995 to 2003	No significant changes are evident except that the vegetation density continues to increase.

A.2 List of Photographs

Aerial Photograph Reference	Flight Elevation (feet)	Date
Y0470-1	20000	11/11/45
Y01418-19-20	8600	08/05/49
Y03179	16700	27/12/56
8013-15-16	2700	1963
Y12828-9	12500	13/12/64
Y13279-80	6250	16/05/67
Y13303-4	6250	16/05/67
Y14027-9	4000	1968
5463-4	12500	24/10/73
8057-8	12500	20/12/73
8273-8	12500	28/02/74
9693-4	12500	21/11/74
Y16404-5	10000	23/11/75
11703-4	12500	19/12/75
12644-5	4000	28/01/76
15920-1	12500	04.11.76
18432-3	4000	14/06/77
19693-4	9000	05/12/77
20461-2	4000	21/12/77
20799-800	12500	10/01/78
23826-7	4000	30/11/78
23870-1	4000	05/12/78
27151-2	5500	28/09/79
27772-3	10000	06/11/79
28008	10000	28/11/79
29834-5	4000	16/04/80
32436-7	4000	06/11/80

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

Aerial Photograph Reference	Flight Elevation (feet)	Date
33419-20	10000	28/11/80
37150-1	4000	17/05/81
37403-4	4000	18/05/81
39016-7	10000	26/10/81
40663-5	4000	04/01/82
43056	3500	28/07/82
44471-2	10000	10/10/82
47231-2	20000	24/01/83
49206	1500	21/06/83
49236-7	1400	21/06/83
53670-1	4000	02/03/84
A01706-7	10000	07/07/85
A03786-7	4000	06/12/85
68013	9000	08/12/85
A06008-9	4000	20/09/86
A03249-50	10000	21/12/86
A08381-2	20000	05/01/87
A09900-1	9000	13/07/87
A10356-7	4000	09/09/87
A12264-5	10000	16/01/88
CN2101-2	6000	19/01/88
A13644-5	10000	04/06/88
A14494-5	4000	27/09/88
A15273-4	10000	03/11/88
A17785-6	4000	16/08/99
A19894-5	20000	30/11/89
A20823-4	4000	20/03/90
A23802-3	4000	14/11/90
A24673-4	10000	04/12/90
A27801-2	4000	02/10/91
A28059-60	4000	04/10/91
A28534-5	10000	21/10/91
A29748-9	20000	13/12/91
A30944-5	4000	12/05/92
A32502-3	4000	15/10/92
A33140-1	10000	11/11/92
A35406-8	4000	09/07/93
CN4161-2	10000	19/08/93
CN4528-9	20000	04/10/93
A36993-4	4000	05/12/93
CN5681-2	10000	06/12/93
A37332-3	20000	31/12/93
CN6120-1	10000	20/03/94
CN6891-2	4000	05/05/94

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

Aerial Photograph Reference	Flight Elevation (feet)	Date
A39706-7	10000	24/10/94
CN8105-6	4000	17/11/94
CN12189-0	10000	23/11/95
CN12703-4	3500	07/12/95
CN14128-9	4000	07/06/96
CN15560-1	4000	23/10/96
CN16295-6	10000	21/11/96
CN17056-7	4000	26/05/97
CN17654-5	4000	23/07/97
CN18636-7	10000	31/10/97
CN22016-7	8000	10/11/98
CN22241-2	20000	03/02/99
CN24037-8	5000	03/11/99
CN25639-40	8000	09/12/99
CN25963-4	20000	16/02/00
CN27554-6	4000	26/07/00
CN28260-1	4000	16/09/00
CW31233-4	4000	31/05/01
AW52339-40	4000	22/08/01
CW34327-8	4000	27/09/01
CW38347-8	2500	03/01/02
CW39543-4	3500	17/04/02
RW01498-9	4000	25/10/02
CW47303-4	4000	11/05/03
CW53610-1	4000	26/11/03

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

Table of Contents

Table of Contents

APPENDIX B

SOIL CLASSIFICATION TEST RESULTS

Table of Contents

Table of Contents

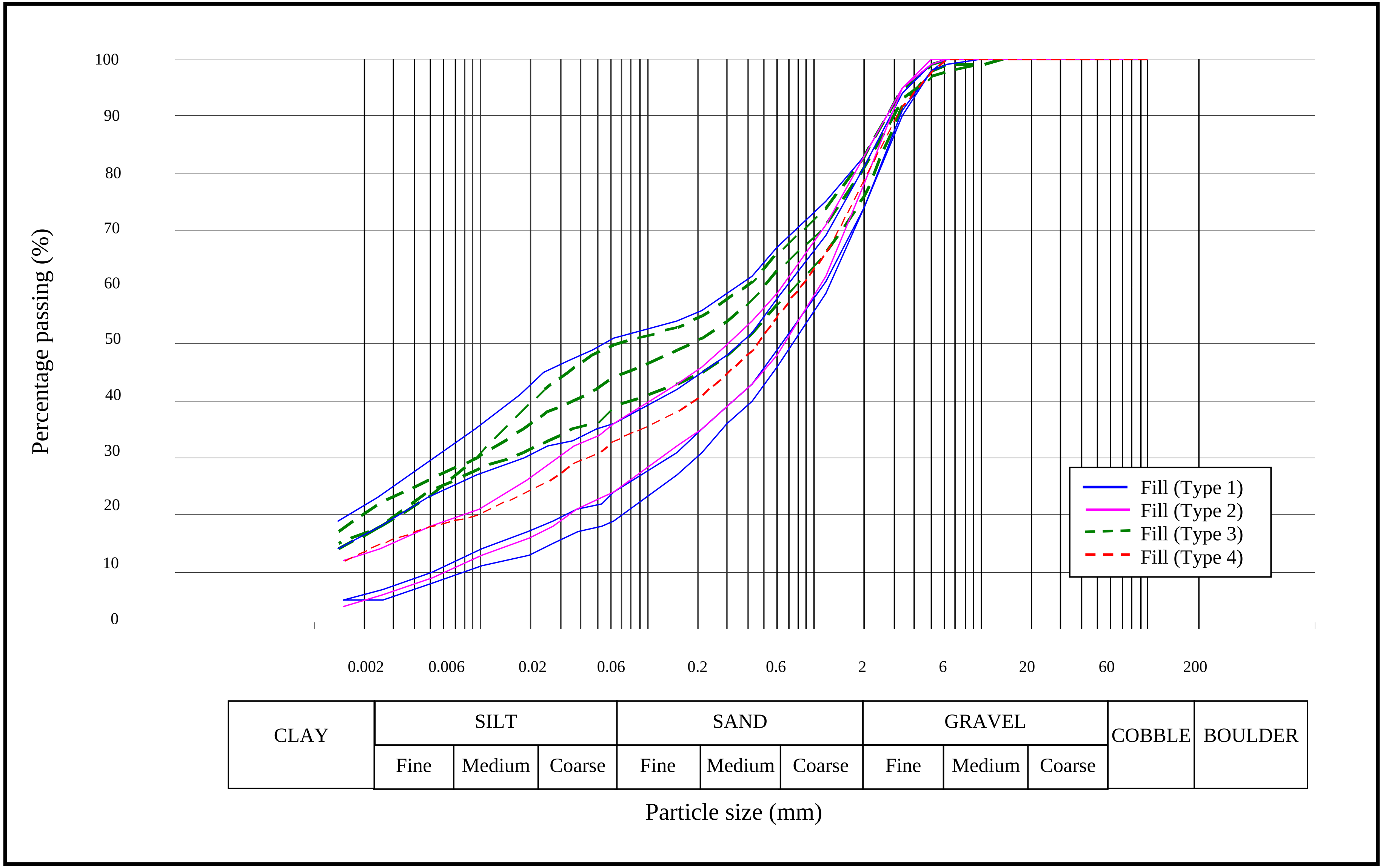


Figure B.1 - Particle Size Distribution for Fill

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

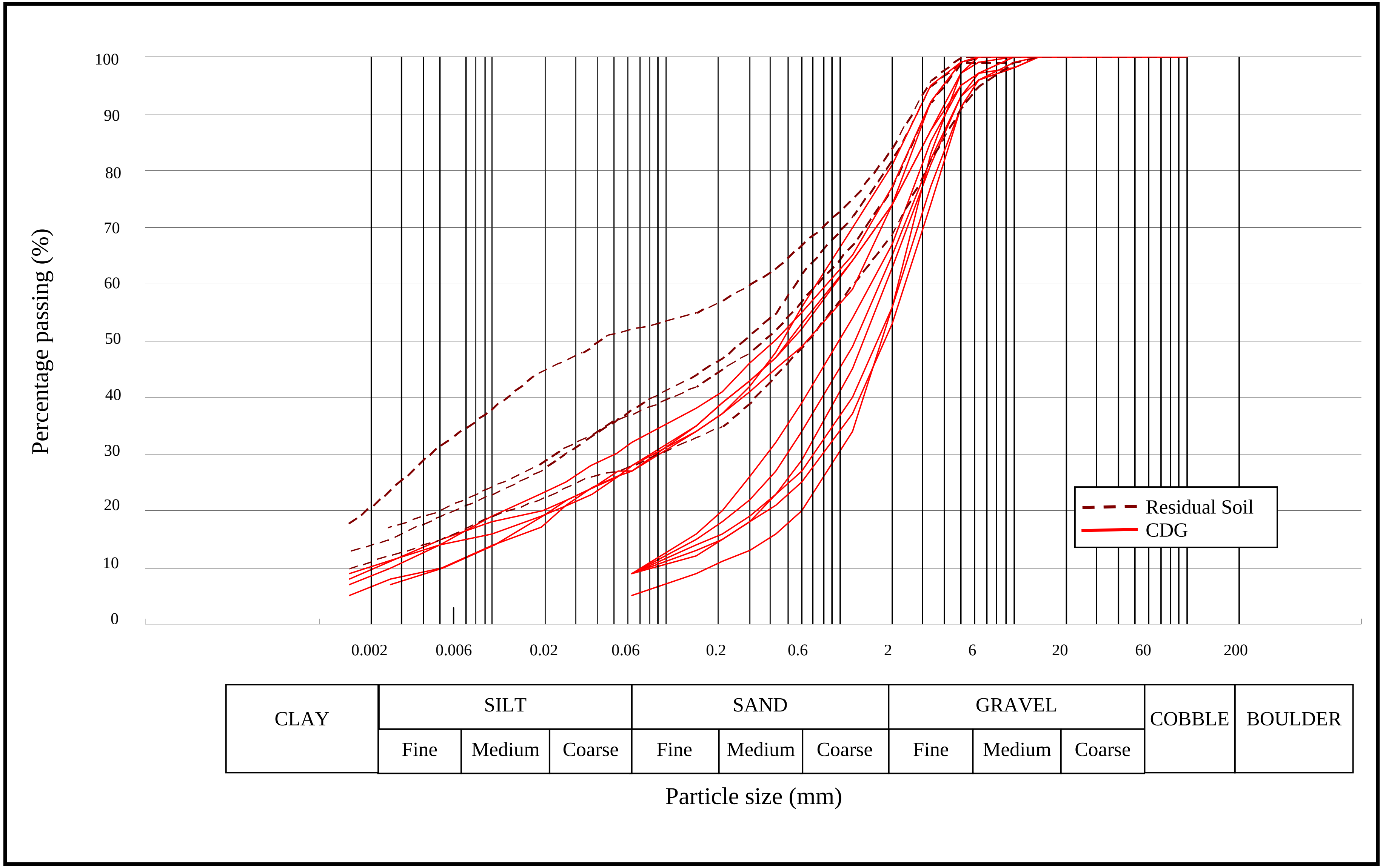


Figure B.2 - Particle Size Distribution for Residual Soil and Completely Decomposed Granite

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

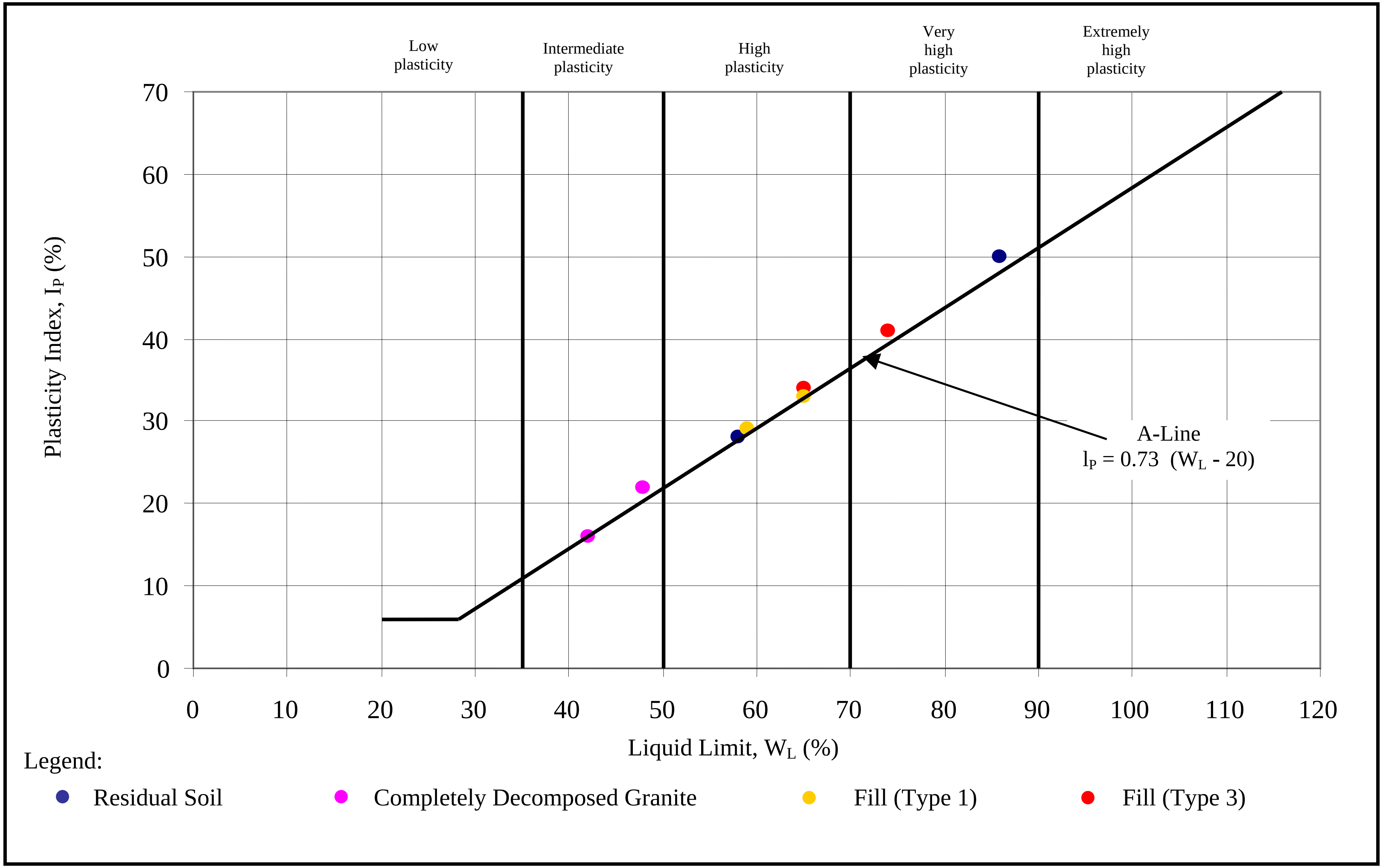


Figure B.3 - Plasticity Chart for Residual Soil, Completely Decomposed Granite, Fill (Type 1) and Fill (Type 3)

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

Table of Contents

Table of Contents

APPENDIX C

TRIAXIAL TEST RESULTS

Table of Contents

Table of Contents

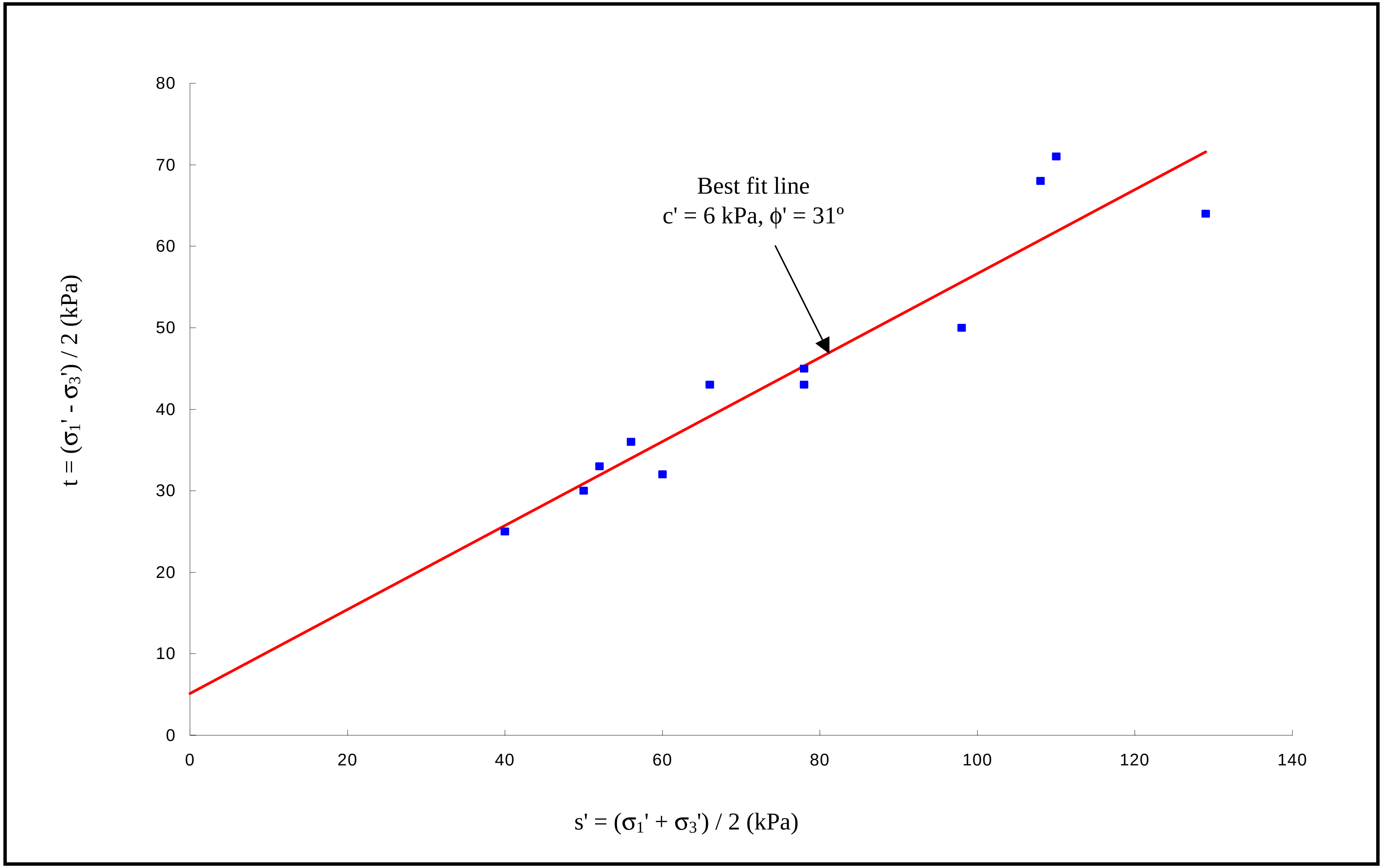


Figure C1 – Plot of s' – t for Residual Soil based on Multi-staged Undrained Triaxial Tests

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

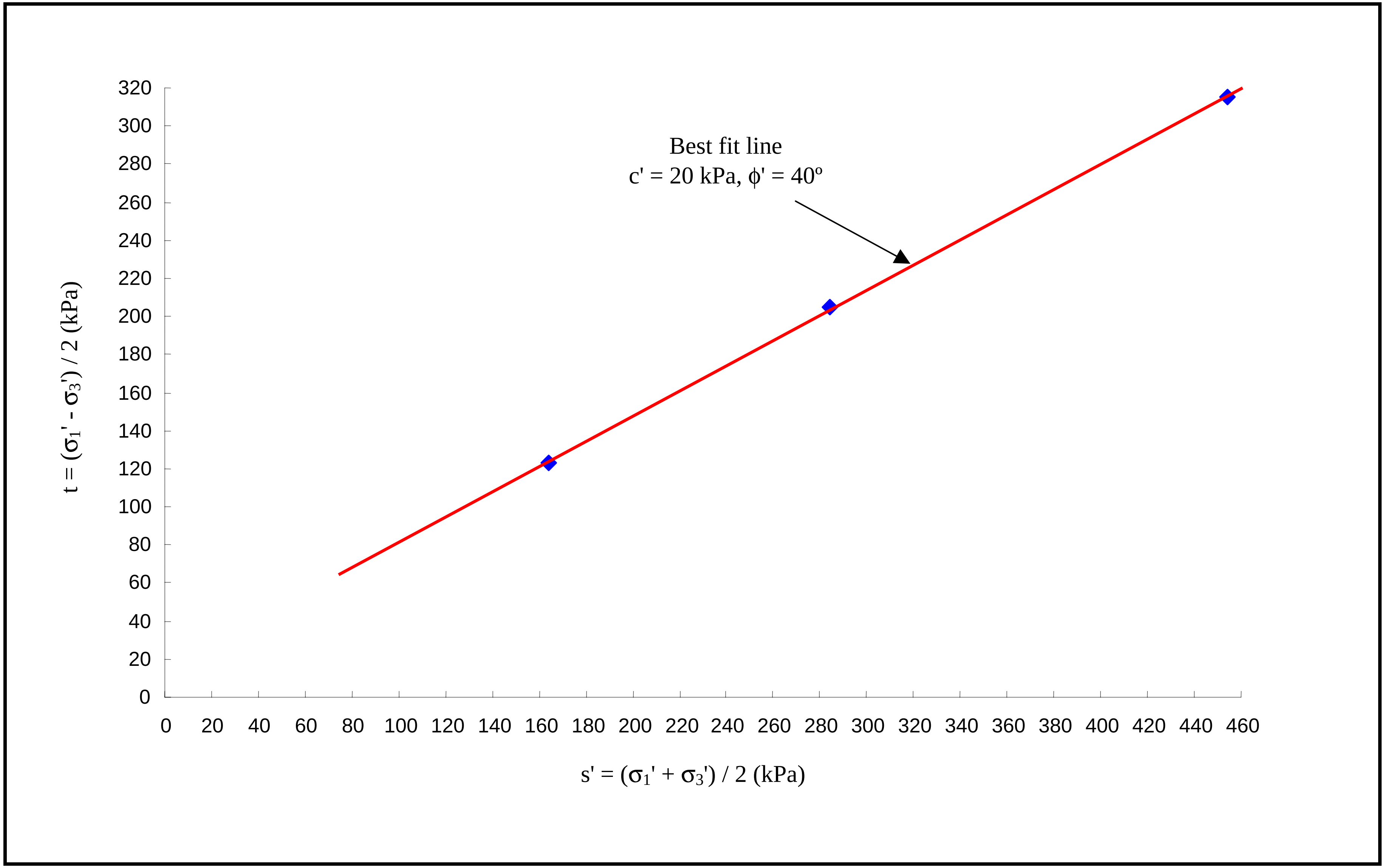


Figure C2 – Plot of s' – t for Highly/Completely Decomposed Granite based on Multi-staged Undrained Triaxial Tests

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

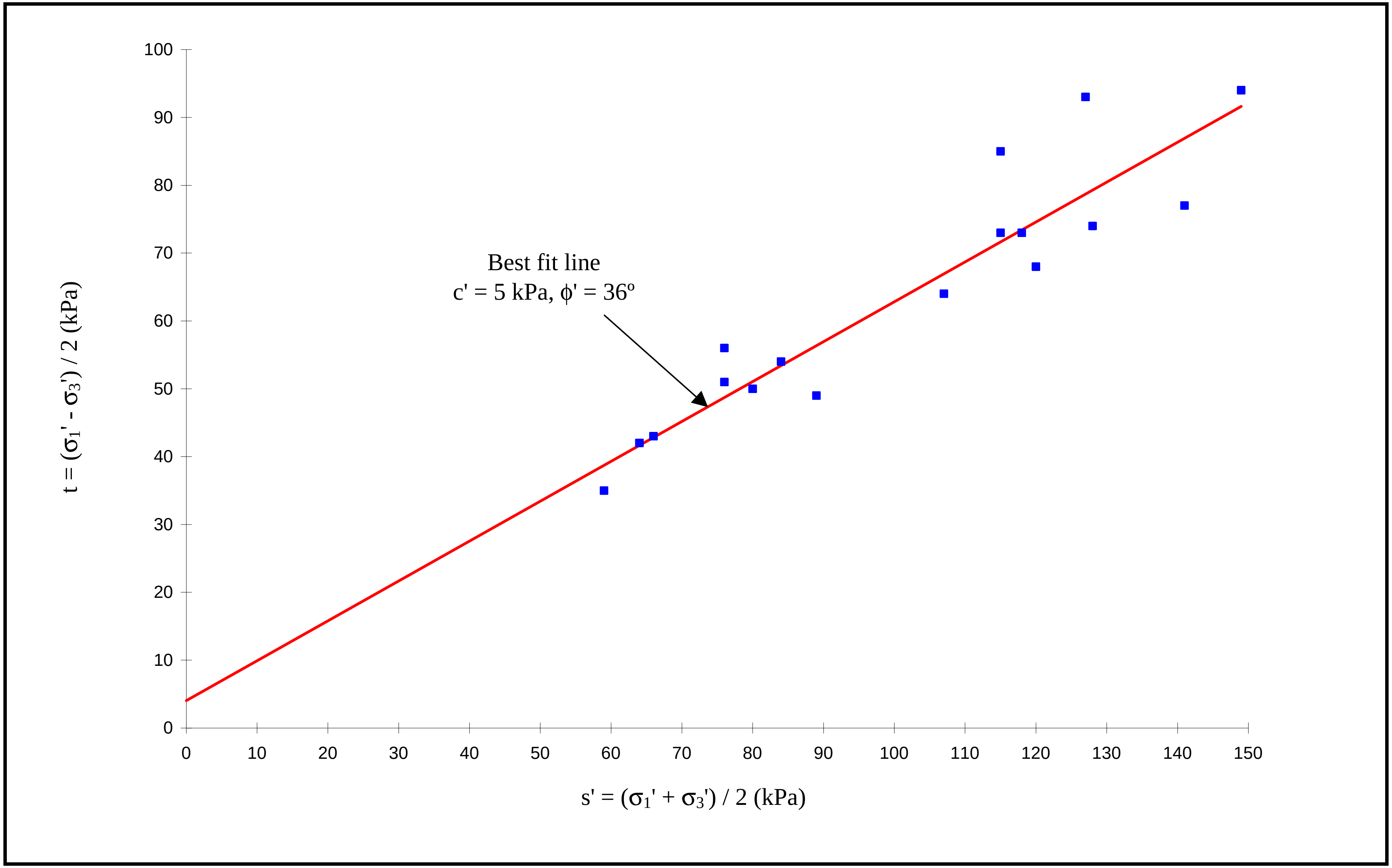


Figure C3– Plot of s' – t for Completely Decomposed Granite based on Multi-staged Undrained Triaxial Tests (s’ < 150kPa)

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

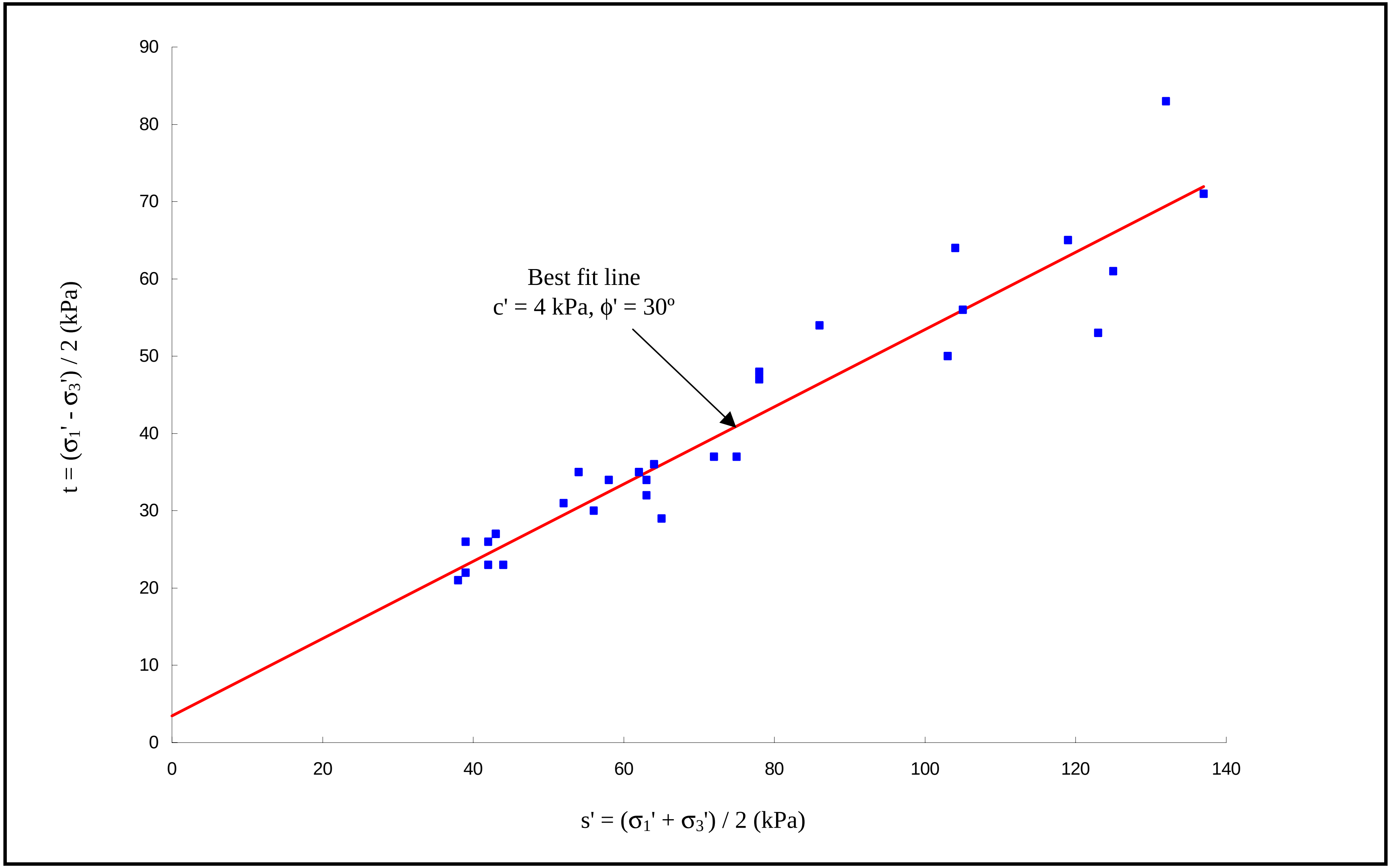


Figure C4– Corrected Plot of s' – t for Fill based on Multi-staged Undrained Triaxial Tests

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

Table of Contents

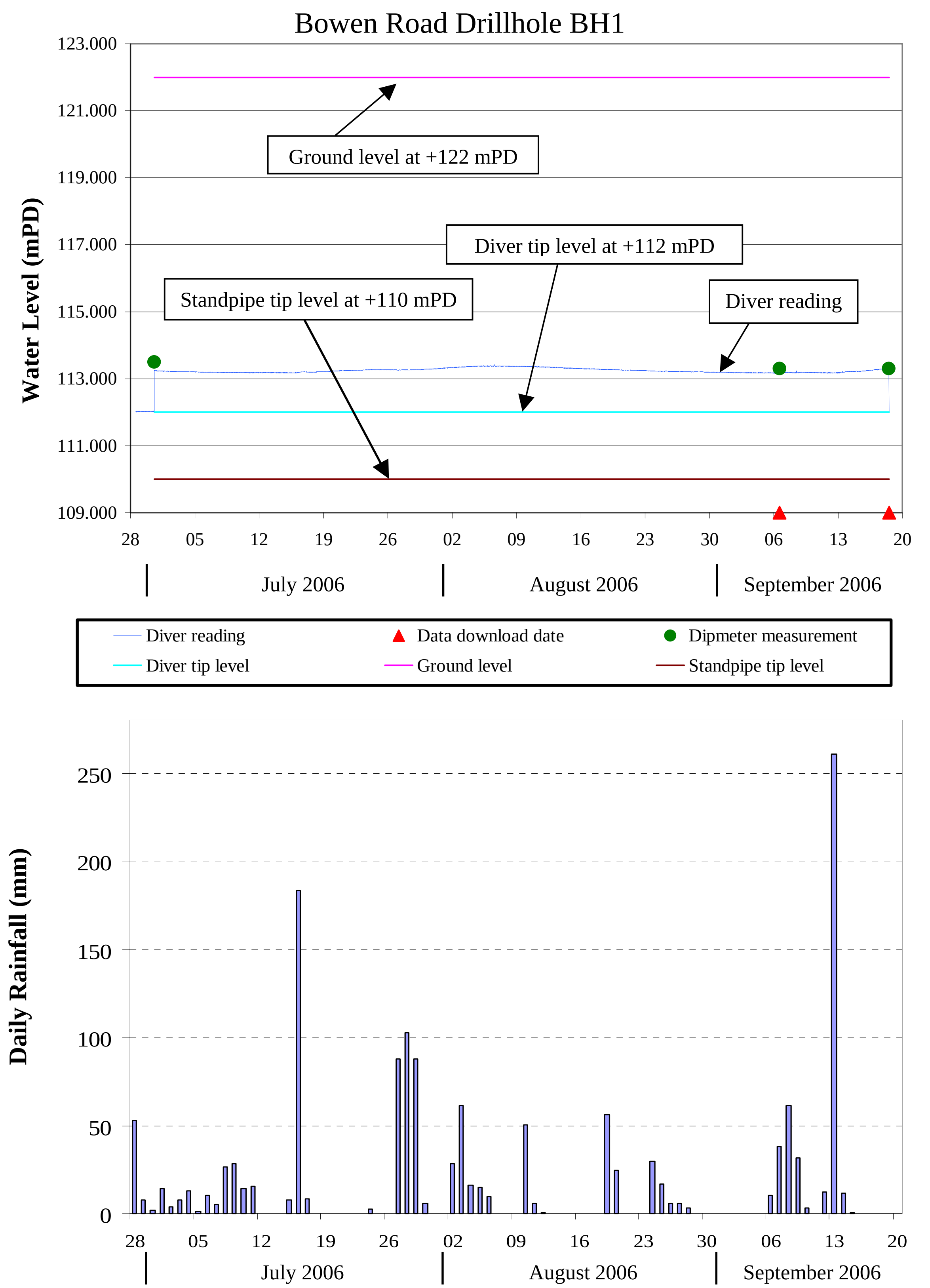
Table of Contents

APPENDIX D

GROUNDWATER MONITORING DATA

Table of Contents

Table of Contents



Daily Rainfall Recorded at GEO Raingauge H06 Between 28 June and 18 September 2006

Graphical Plot of Groundwater Monitoring Data and Rainfall

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。

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

GEOSPECS

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

GEO PUBLICATIONS

GCO Publication No. 1/90	Review of Design Methods for Excavations (1990), 187 p. (Reprinted, 2002).
GEO Publication No. 1/93	Review of Granular and Geotextile Filters (1993), 141 p.
GEO Publication No. 1/2000	Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls (2000), 146 p.
GEO Publication No. 1/2006	Foundation Design and Construction (2006), 376 p.
GEO Publication No. 1/2007	Engineering Geological Practice in Hong Kong (2007), 278 p.

GEOLOGICAL PUBLICATIONS

The Quaternary Geology of Hong Kong, by J.A. Fyfe, R. Shaw, S.D.G. Campbell, K.W. Lai & P.A. Kirk (2000), 210 p. plus 6 maps.

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

TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents

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