DETAILED STUDY OF THE 20 AUGUST 2005 LANDSLIDE ON SLOPES NOS. 11SE-A/C285, 11SE-C/DT1 AND 11SE-C/DT6 ABOVE TAI HANG DRIVE HAPPY VALLEY

GEO REPORT No. 217

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GEOTECHNICAL ENGINEERING OFFICE

CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT

THE GOVERNMENT OF THE HONG KONG SPECIAL ADMINISTRATIVE REGION

Table of Contents

Table of Contents

Table of Contents

Table of Contents

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

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

PREFACE

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

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

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

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

FOREWORD

This report presents the findings of a detailed study of a major landslide (Incident No. 2005/08/0364), which occurred at the central portion of slope No. 11SE-A/C285 and at the toe of disturbed terrain (DT) features Nos. 11SE-C/DT1 and 11SE-C/DT6 above, opposite Ronsdale Garden, in Tai Hang Drive on 20 August 2005. The landslide involved the displacement of ground mass of about 2,100 m^3 in volume. Localised detachment of about 40 m^3 of soil occurred at the lower portion of the displaced ground mass and the debris was deposited on the pavement of Tai Hang Drive. Consequently, both lanes of the road were closed temporarily. No casualties were reported as a result of the landslide.

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

Mr S.M. Tam of Landslip Preventive Measures Division 1 prepared the report. Fugro Scott Wilson Joint Venture, the 2006 and 2007 Landslide Investigation Consultants for Hong Kong Island and Outlying Islands, provided support in respect of aerial photographic interpretation, geological mapping and engineering analyses.

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

CONTENTS

1. INTRODUCTION

At about 9:35 p.m. on 20 August 2005, during a Landslip Warning (which had been in force for about 24 hours), a landslide (Incident No. 2005/08/0364) was reported to have occurred at the central portion of slope No. 11SE-A/C285 and the toe of registered disturbed terrain (DT) features Nos. 11SE-C/DT1 and 11SE-C/DT6 above, opposite Ronsdale Garden, in Tai Hang Drive (Figures 1 and 2, and Plates 1 and 2). The landslide involved the displacement of a generally intact ground mass of about 2,100 m^3 in volume (including an adjacent area of distressed ground). Localised detachment of about 40 m^3 of soil also occurred at the lower portion of the displaced ground mass (Figure 2 and Plate 3) and the debris was deposited on the pavement of Tai Hang Drive (Plate 4). Consequently, both lanes of the road were closed temporarily. No casualties were reported as a result of the landslide.

Following the incident, the Landslip Preventive Measures Division 1 of the Geotechnical Engineering Office (GEO) carried out a detailed study of the landslide, with support provided by Fugro Scott Wilson Joint Venture (FSW), the 2006 and 2007 Landslide Investigation Consultants for Hong Kong Island and Outlying Islands.

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

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

(a) review of all known relevant documents relating to the development history of the site and the sequence of events leading to the incident,

(b) engineering geological mapping, detailed field inspections and measurements at the landslide site,

(c) aerial photograph interpretation (API),

(d) analysis and interpretation of the results from topographical survey, ground investigation and laboratory testing,

(e) analysis of rainfall records,

(f) theoretical stability analysis of the slope, and

(g) diagnosis of the probable mechanisms and causes of the failure.

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

2. THE SITE

2.1 Site Description

Slope No. 11SE-A/C285 is a north-facing soil and rock cut slope above Tai Hang Drive, which is a two-lane, two-way cul-de-sac (Figure 2 and Plate 2). Topographical survey carried out after the landslide incident revealed that the cut face of the slope should be more extensive than that shown in the Slope Information System (SIS) of the GEO (see Figure 2). The slope is about 174 m long, up to 22 m high (as opposed to 16 m high as recorded in the SIS, see Section 4.4), and has an average inclination of about 40° (Figures 2 to 4). An unsheltered public light bus terminus stand is present on the pedestrian pavement at the slope toe (see Figure 2). Residential buildings, viz. Ronsdale Garden, and a construction site for residential development (The Legend) are located about 15 m to the north of the slope toe on the opposite side of Tai Hang Drive (Figure 2). A section of Tai Hang Drive is elevated and supported on caissons (see Figure 2, Plate 5 and Section 4.2).

Slope No. 11SE-A/C285 comprises up to three 45° steep slope batters separated by 0.5 m to 1 m wide berms (see Figures 2 to 4, and Plate 6). The slope is generally covered by dense vegetation comprising grass, shrubs and trees (Plate 2). Surface drainage of the slope consists of U-channels along the crest and the toe as well as on the berms of the slope (Figure 5). The channels along the slope crest are 300 mm wide with the exception of two 10 m to 20 m long sections on the western side, which reduce locally to 225 mm wide. The toe channel that discharges to the east is 375 mm wide whereas the toe channel, which collects the majority of the surface run-off from the slope and discharges to the west, has a width of between 250 mm and 300 mm. 225 mm wide berm channels and a system of chevron drains, each comprising four 225 mm U-channels connecting to a 225 mm stepped channel, are also present on the slope (Figure 5). Surface water is discharged into a 450 mm wide stepped channel, which runs down the hillside to the east of Ronsdale Garden, and also to a stormwater drain to the west of slope No. 11SE-A/C285 (Figures 2 and 5).

A strip of sloping ground up to 2 m high and 35° steep, immediately above the crest channel, is covered with chunam (Plate 7). A planter wall, up to 0.8 m high with trees, is present along the toe of the slope immediately behind the toe channel.

In general, slope No. 11SE-A/C285 can be divided into three portions, namely the eastern, central and western portions, according to its configurations and slope-forming material (Figure 2).

The eastern portion is about 52 m long, up to 21 m high and is inclined at an average angle of about 40° (Plate 8). The lower part of this portion is predominantly a rock cut (Grade II to III rock) with a bare surface and the upper part being generally a soil cut. The rock cut decreases in height from about 14 m at the eastern end to about 9 m at the western end. An abandoned platform, which is about 5 m long by 4 m wide, probably associated with previous squatter structures, is located immediately above the crest of this portion of the slope.

The central portion of slope No. 11SE-A/C285 is a 35 m long, up to 16 m high and 40° steep soil cut (Plate 1). The 20 August 2005 landslide occurred on this portion of the slope and extended to the registered DT features above, with the main scarp (Plate 9) located about 18 m above Tai Hang Drive.

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

The western portion of slope No. 11SE-A/C285 comprises a soil cut about 87 m long, up to 22 m high and inclined at an average angle of about 40° (Plate 10).

Registered DT features Nos. 11SE-C/DT1 and 11SE-C/DT6 are located above slope No. 11SE-A/C285 (Figure 1 and Plate 2). DT feature No. 11SE-C/DT1 has a maximum elevation difference of about 100 m and an overall slope angle of about 32° (ranging from 15° to 50°), while DT feature No. 11SE-C/DT6 has a maximum elevation difference of about 60 m and an overall slope angle of about 32° (ranging from 32° to 34°). These DT features have a dense vegetation cover comprising grass, shrubs and mature trees. Abandoned squatter platforms, cultivation terraces and footpaths are present on these registered DT features (see Section 3.2). A 1 m high concrete baffle wall is present on DT feature No. 11SE-C/DT6 to the west of the main scarp, and an ephemeral drainage line discharges into a 300 mm stepped channel via the baffle wall prior to the 20 August 2005 landslide (Figure 5 and Plate 11).

2.2 Water-carrying Services

Based on the information provided by the Drainage Services Department (DSD) and the Water Supplies Department (WSD), buried water-carrying services are present at Tai Hang Drive about 5 m to 10 m from the toe of slope No. 11SE-A/C285. These include a 225 mm diameter stormwater pipe and a 225 mm diameter sewer (maintained by DSD) and a 150 mm diameter fresh watermain (maintained by WSD).

Tai Hang No. 1 and No. 2 Fresh Water Service Reservoirs are located at about 150 m to the south of slope No. 11SE-A/C285. Results of 'drop tests' carried out by the WSD in March 2006 at the southern and northern half of Tai Hang No. 1, and at Tai Hang No. 2 Fresh Water Service Reservoirs indicated a leakage rate of 3.41 m^3/day, 0.43 m^3/day and 1.23 m^3/day respectively.

2.3 Regional Geology

According to the Hong Kong Geological Survey (HKGS) 1:20,000 geological map sheet for the area (GCO, 1986), the landslide site is underlain by fine-grained granite of the Mesozoic formation (Figure 6). A NW-SE trending fault is shown about 70 m to the northeast of the site.

2.4 Maintenance Responsibility

According to the Slope Maintenance Responsibility Information System (SMRIS) of the Lands Department (Lands D), slope No. 11SE-A/C285 falls within Government land and the maintenance responsibility (MR) rests with the Highways Department (HyD). Also, DT feature No. 11SE-C/DT1 and the majority of DT feature No. 11SE-C/DT6 (which is of mixed MR), including the portion affected by the 20 August 2005 landslide, are located within Government land under the MR of the Lands D.

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

3. SITE HISTORY AND PREVIOUS INSTABILITY

3.1 General

The history of site development has been determined from an interpretation of all the available aerial photographs and old survey maps, together with a review of the relevant documentary information and site observations. Plans showing the geomorphology, development history and past instability of the site are shown in Figures 7 to 9 respectively. Detailed observations from the API are given in Appendix A.

3.2 Site History

The earliest available aerial photographs (taken in 1945) show that the present-day location of slope No. 11SE-A/C285 was near the toe of a north-descending hillside (Figure 7). The western end of the site was overgrown with medium dense vegetation and scattered man-made features were possibly present. Tiger Balm Garden, characterised by a high-rise white pagoda (viz. Tiger Pagoda), is evident below the study site. Cultivation terraces are visible particularly to the west of Tiger Pagoda (Figure 8).

The 1949 aerial photographs show that the site was located within a catchment generally defined by two major north and northwest trending spurs to the east and west respectively (Figure 7). A major ephemeral drainage line to the west of the catchment and a minor drainage line at about mid-height of the catchment, both running in a northerly direction, merged into a west-running, possibly man-made, drainage channel (shown along the toe of the catchment on the 1974 survey map), which discharged downhill at the west. Two major ephemeral drainage lines located to the east of the catchment which merged into a NW-SE trending perennial stream to the southeast of the catchment are also noted in the 1949 aerial photographs (Figure 7). In addition, three light toned areas are visible above the site (Figure 8). This indicates possible excavation works for the erection of additional pagodas. Footpaths traversing the natural terrain above the site are also visible in the 1949 aerial photographs (Figure 8).

The 1959 aerial photographs show the presence of squatter structures on terraces beyond the eastern flank of the catchment. Tai Hang No. 1 Fresh Water Service Reservoir was being constructed in 1959 and was completed by 1963 (Figure 8). Tiger Balm Garden appears to have been fully developed by 1963.

Other developments within the catchment continued to take place up to at least 1963. These included the erection of squatter structures and cultivation terraces at the eastern and western portions as well as the formation of cultivation terraces at the middle portion (Figure 8). The presence of colluvium and tors (probably locally displaced) at the western portion of the catchment are clearly evident in the 1963 aerial photographs (Figure 7).

Some of the cultivation terraces above the site noted in the 1945 aerial photographs were abandoned by 1967 and the rest were abandoned by 1972. Since 1973, these terraces have been overgrown with medium dense vegetation. The squatter structures visible on the 1959 aerial photographs were demolished by 1963.

Construction of the initial (western part) phase of Tai Hang Drive was completed in

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

1975. The 1976 aerial photographs show that the mid-portion of the site was overgrown with dense vegetation whereas the remaining area of the site and the catchment were covered with light to medium dense vegetation.

Between 1981 and 1982, slope No. 11SE-A/C285 was formed by cutting into the hillside along with the construction of Tai Hang Drive extension, which was formed between 1981 and 1985 in conjunction with the development at Ronsdale Garden between 1982 and 1986. Construction of Tai Hang No. 2 Fresh Water Service Reservoir began some time between 1988 and 1989, and was completed by 1991. Between 2001 and 2002, Tiger Pagoda was demolished and construction for The Legend apartment tower began.

3.3 Previous Instability

In the 1949 aerial photographs, a few relict landslide scars at the site and the hillside above are observed (Figure 9). The approximate dimensions of the scars are up to 15 m long by 15 m wide.

Based on the API, a shallow landslide occurred in 1983 at the toe of the middle portion of slope No. 11SE-A/C285, corresponding approximately to the location of the 20 August 2005 landslide (Figure 9). The scar was about 12 m wide by 8 m long. The exposed slope surface was inferred to be wet by its relatively dark tone on the respective aerial photographs.

Two light tones, being signs of possible erosion, located near the crest at the eastern side of slope No. 11SE-A/C285 are visible in the 1984 aerial photographs (Figure 9). A small landslide is noted above the central portion of slope No. 11SE-A/C285 opposite Ronsdale Garden in the 1985 aerial photographs (Figure 9).

On 27 September 1993, a 100 m³ landslide (Incident No. HK93/9/10) occurred on the lower portion of slope No. 11SE-A/C285 at approximately the same location as the 1983 and 20 August 2005 landslides (Figure 9 and Plate 12). The landslide scar was about 20 m wide by 10 m long. According to the incident report of the GEO, the distal end of the "slipped soil mass" travelled only up to the outer edge of the pedestrian pavement (i.e. a horizontal distance of about 1.5 m, which implies that the landslide debris was not mobile). No local detachment of the "slipped soil mass" was recorded in the incident report. The pedestrian pavement was closed temporarily as a result of the landslide. The incident report also noted that "groundwater", "infiltration" and "lack of maintenance" (evident by "blocked/broken drains" and "excessive growth of vegetation") were the possible causes of failure. Slope repair works comprising backfilling of the eastern portion and the upper half of the central portion of the failure scar with no-fines concrete, rock dowels to the lower half of the central portion of the scar, hard surface cover with weepholes to both the eastern and central portions of the failure scar, and backfilling of the western portion of the failure scar with compacted rockfill were completed by the HyD by June 1994. Chunam and hydroseeding were also applied as surface cover to the eastern/central portions and the western portion of the failure scar respectively (Plate 13).

On 7 September 1997, a boulder fall (Incident No. HK97/9/2) occurred, which involved a 0.5 m³ rectangular boulder that originated from the disturbed terrain, about 6 m

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

above the crest of slope No. 11SE-A/C285 (Figure 9). The boulder came to rest in the middle of Tai Hang Drive resulting in temporary closure of both lanes of the road. The incident report prepared by GEO noted that "infiltration" and "probably scour around boulder and p.p. [pore pressure] in joint" were the possible contributory causes of the incident.

According to the Natural Terrain Landslide Inventory (NTLI) (King, 1997), the Enhanced Natural Terrain Landslide Inventory (ENTLI) (Maunsell Fugro Scott Wilson, 2005) and the large landslide study (Scott Wilson, 1999), there are no records of landslides that occurred at slopes Nos. 11SE-A/C285, 11SE-C/DT1 and 11SE-C/DT6 in the vicinity of the August 2005 landslide.

4. PREVIOUS ASSESSMENT AND SLOPE WORKS

4.1 Previous Ground Investigation

Between 1981 and 2001, various ground investigations were undertaken at, and in the vicinity of, slope No. 11SE-A/C285 for various public and private developments (Figure 10). In particular, between December 1980 and January 1981, a ground investigation comprising thirty drillholes was carried out by Compact Construction Company Limited for the residential development of Ronsdale Garden and the associated extension of Tai Hang Drive (see Section 4.2).

4.2 Private Development Submissions

Between 1981 and 1982, slope No. 11SE-A/C285 was constructed to its present-day layout under the Phase 1 site formation for a residential development on I.L. 5710 and Extension (now Ronsdale Garden), during which half width of Tai Hang Drive extension was formed (Plate 14). The formation of Tai Hang Drive extension to its full width, together with site formation works within the private lot, was completed under the Phase 2 site formation works in 1985. HyD was responsible for the construction of the pavement of the road. An outline of the various items of site formation works associated with the formation of Tai Hang Drive extension is presented in Figure 11. The development was undertaken by Paringa Investment Limited. Leslie Ouyang of Wong & Ouyang & Associates was the Authorized Person (AP) and Fugro (Hong Kong) Limited (FHK) was the geotechnical consultant for the project.

On 9 April 1981, site formation plans together with a supporting geotechnical submission (FHK, 1981), which were prepared by FHK, for the Phase 1 site formation works (including the then proposed cut slope No. 11SE-A/C285) were submitted by the AP to the Buildings and Lands Department (BLD, renamed Buildings Department (BD) in 1993).

According to the slope stability assessment in the geotechnical submission, the proposed cut slope was designed based on a site-specific ground investigation carried out in January 1981 by Compact Construction Company Limited (see Section 4.1 and Figure 10). The entire ground investigation comprised thirty drillholes, installation of piezometers and laboratory testing, including consolidated undrained triaxial compression tests. Six of these drillholes were put down on and above slope No. 11SE-A/C285. The stratification for the proposed cut slope based on the ground investigation comprised colluvium, completely

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

decomposed granite (CDG), and completely to highly decomposed granite (C/HDG). Shear strength parameters of c' = 8 kPa and ϕ' = 40° for both colluvium and "loose" CDG, and c' = 15 kPa and ϕ' = 45° for "dense" C/HDG, were adopted by FHK. Groundwater at the piezometers in the drillholes put down on and above slope No. 11SE-A/C285 were monitored between December 1980 and January 1981 (during the dry season). The highest groundwater levels recorded at these piezometers ranged between 6 m and 12 m below ground level. There are no records of groundwater monitoring carried out after January 1981. The required minimum factors of safety were 1.4 and 1.12 for groundwater conditions corresponding to rainstorms with return periods of 10 years and 1000 years respectively. A groundwater rise of about 5 m above the measured groundwater level was assumed as the groundwater condition under a 1000-year return period rainstorm event. The slope stability analyses indicated that the minimum calculated factor of safety of the slope after site formation under a 1000-year return period rainstorm event was 1.33. No stability analyses for a 10-year return period rainstorm event have been presented in the geotechnical report.

The surface drainage of the proposed cut slope shown on the site formation plan consists of crest channels with a width of 300 mm throughout and also toe channels having widths of 380 mm and 300 mm discharging to the east and the west respectively. The plan also shows 225 mm wide berm channels and a system of chevron drains, each consists of four 225 mm U-channels connecting to a 300 mm stepped channel, on the slope. The sizes of the surface channels shown on the plan differ locally from the actual arrangement revealed from post-landslide observations (see Section 2.1).

The site formation plans and the supporting geotechnical submission were checked and accepted by the Geotechnical Control Office (GCO, renamed GEO in 1991) on 8 May 1981, and approved by the BLD on 9 May 1981. In accepting the site formation plans, the GCO noted that "the internal friction of 45° for dense D.G. is not acceptable but since the factors of safety calculated in the geotechnical report are very high, F.O.S. on reduced strength parameters are likely to be within acceptable values".

The site formation works for Tai Hang Drive extension under Phase 2 of the Ronsdale Garden development included in particular the construction of three L-shaped retaining walls and a caisson retaining wall (anchored temporarily during construction) along the northern (downhill) side of Tai Hang Drive, as well as the erection of an elevated deck of the road, resting on caissons, located between these retaining walls (Figure 11). The site formation plans of these works were approved by the BLD between September 1981 and May 1986 following checking and acceptance by the GCO. These plans indicate that temporary excavations involving the formation of up to 5 m high 45° steep cut slopes below and within about 3 m of the toe of slope No. 11SE-A/C285 were required to facilitate the construction of the L-shaped retaining walls. The plans also depict that there was an excavation up to about 15 m below ground level in front of the caisson wall, located about 12 m from the toe of slope No. 11SE-A/C285. According to BLD's file records, the excavation works associated with retaining wall construction took place between 1982 and 1984 and the maximum movement of the caisson retaining wall during construction was recorded to be 11 mm.

4.3 SIFT and SIRST Studies

In 1992, the GEO initiated a project entitled 'Systematic Inspection of Features in the

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

Territory' (SIFT). This project aimed to search systematically for slopes not included in the 1977/78 Slope Catalogue and to update information on previously registered features by studying aerial photographs, together with limited site inspections. In May 1995, the SIFT study of slope No. 11SE-A/C285 was carried out and the slope was designated SIFT Class 'C2', i.e. a slope that was "assumed formed post 1977 [assumed to have been checked by GEO]".

In May 1995 and July 1995, the SIFT studies of DT features Nos. 11SE-C/DT1 and 11SE-C/DT6 respectively were carried out and both features were designated SIFT Class 'C1', i.e. slopes that "have been formed or substantially modified before 30.6.78".

In January 1994, the GEO commenced a project entitled 'Systematic Identification and Registration of Slopes in the Territory' (SIRST), to update the 1977/78 Slope Catalogue. The record of inspection of slope No. 11SE-A/C285 in January 1996 by Binnie Consultants Limited, the SIRST consultant, noted that the slope was 175 m long, up to 12 m high and 45° steep (Plate 15). The consequence-to-life category was rated as '2'. No signs of distress or seepage were noted during the inspection and the surface cover, being mainly vegetation, was assessed to be in fair condition.

The layout of the cut slope as identified in the SIFT and SIRST studies corresponds to the slope boundary recorded in the SIS prior to the 20 August 2005 landslide (Figure 2).

4.4 Slope Maintenance Inspections

4.4.1 Maintenance Inspections of Slope No. 11SE-A/C285

4.4.1.1 Engineer Inspections

On 19 February 1998, on behalf of the HyD, Halcrow Asia Partnership Limited (HAP, renamed Halcrow China Limited in April 1999) carried out an Engineer Inspection (EI) of the western 100 m portion of slope No. 11SE-A/C285 (see Figure 2 and Plate 16). This portion of the slope was referred to as HyD slope reference No. 12104C00010, and was merged with its adjoining slopes to form slope No. 11SE-A/C285 later in 1998 (see below). This slope was also referred to as "GEO slope No. 11SE-A/C397" on the EI report, which was an error, as according to the SIS, slope No. 11SE-A/C397 is situated at a different location to slope No. 11SE-A/C285.

On the record completed in conjunction with the above EI, the slope height and angle were recorded as "6 m" and "60°" respectively, and the consequence-to-life category of the slope was recorded as "low". The EI report noted that routine maintenance works had not been satisfactorily carried out and classified the overall state of maintenance as "Fair". The EI did not identify any signs of distress on the slope. The 1993 landslide was not recorded in the EI report. Routine maintenance works (RMW) recommended in the EI report included clearing of blocked drainage channels, catchpits, sandtraps and culverts, repair of cracked drainage channels and slope surface cover, removal of vegetation causing cracking of surface cover and instability as well as overhanging channels and access routes, clearing of loose rock debris and tipped debris from slope surface and re-grassing of bare areas on soil slope surface. The EI report did not identify any previous Stability Assessment for the slope and did not recommend any Stability Assessment to be carried out.

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

On 10 September 1998, an EI of slope No. 11SE-A/C285 (Plate 17) was carried out by Maunsell Geotechnical Services Limited (MGSL) for the HyD, in which it recommended merging several adjoining slopes, including HyD slope reference No. 12104C00010, to form a single slope feature. On the EI record, the slope length, height and angle were recorded as "145 m", "15 m" and "40°" respectively, and the consequence-to-life category of the slope was recorded as "low". The EI report noted that there was "No previous Stability Assessment" and recommended that "No immediate Stability Assessment is required. However, …… Stability Assessment is still required for feature if resources is allowed". The EI report also noted "No previous routine maintenance record found" and the overall state of maintenance was assessed as "Fair". The EI did not identify any signs of distress on the slope. The 1993 landslide was not recorded in the EI report. Routine maintenance works (RMW), including clearing of blocked drainage channels and weepholes, repairing cracks or spalling of rigid surface cover and removing loose rock debris, were recommended in the EI report.

On 27 November 2002, another EI of slope No. 11SE-A/C285 was carried out by MGSL for HyD (Plate 18). On the EI record the slope length, height and angle were recorded as "174 m", "16 m" and "45°" respectively, and the consequence-to-life category of the slope was recorded as "low". The EI report indicated the consequence-to-life category of the slope has changed and recommended a stability assessment of the slope "as no previous Stability Assessment record could be found". The overall state of maintenance was assessed as "Fair". No signs of distress on the slope were identified in the EI. The 1993 landslide was not recorded in the EI report. RMW, including clearing of blocked drainage channels, removing of debris and other obstruction from slope surface and clearing of undesirable vegetation from the rock slope surface, were recommended. Based on a slope height of 16 m and in the absence of any evidence of confirmed or inferred past instability, the NPCS score calculated for the slope by MGSL in conjunction with the EI is 16.237 and the corresponding CNPCS score is 3.085.

Whilst the slope was identified as 16 m high, there is one photograph in the 2002 EI report showing that the 'crest' of the slope was a berm, above which existed a stepped channel (Plate 19).

No Slope Maintenance Manual has been prepared for slope No. 11SE-A/C285.

4.4.1.2 Routine Maintenance Inspections

HyD's file records indicate that Routine Maintenance Inspections (RMIs) for slope No. 11SE-A/C285 were carried out more or less annually since 1998. The RMIs carried out in January 1998, January 2000 and March 2001 did not identify any necessary works. Routine maintenance works recommended during the rest of the RMIs generally involved clearing of drainage channels of accumulated debris and repairing of cracked or damaged drainage channels or pavements along crest and toe of slope. In addition, the removal of surface debris and vegetation that was causing severe cracking of surface cover and drainage channels was recommended in the RMIs carried out in January 1999 and March 2005 respectively, the repair or replacement of cracked or damaged slope surface cover were recommended in the RMI carried out in December 2001, and the removal of fallen trees were recommended in the RMIs carried out in December 2002 and November 2003 respectively.

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

Works orders and completion records for the recommended maintenance works were found in HyD's file records.

4.4.2 Maintenance Inspections of Disturbed Terrain Feature No. 11SE-C/DT1

On 18 June 2002, an EI of DT feature No. 11SE-C/DT1 was carried out by Maunsell Fugro Joint Venture on behalf of the Lands D (Plate 20). The overall state of maintenance was assessed as "Good". No routine or preventive maintenance works were recommended in the EI report.

On 27 July 2005, an RMI of the DT feature was carried out by Maunsell Geotechnical Services Limited. No routine maintenance works were recommended in the RMI report.

4.4.3 Maintenance Inspections of Disturbed Terrain Feature No. 11SE-C/DT6

On 21 November 2002, an EI of the Government portion of DT feature No. 11SE-C/DT6 (which is of mixed MR, see Section 2.4) was carried out by Maunsell Fugro Joint Venture on behalf of the Lands D (Plate 21). The overall state of maintenance was assessed as "Good". No routine or preventive maintenance works were recommended in the EI report.

On 3 September 2004, an RMI of the Government portion of the DT feature was carried out by the Lands D. No routine maintenance works were recommended in the RMI report.

5. THE 20 AUGUST 2005 LANDSLIDE

The 20 August 2005 landslide was referred to the GEO by the Police at 9:35 p.m. on 20 August 2005, at which time a Landslip Warning had been in effect for about 24 hours. The landslide occurred on the central portion of slope No. 11SE-A/C285 (at approximately the same location as the landslides in 1983 and 1993) and the upper DT features (Nos. 11SE-C/DT1 and 11SE-C/DT6) opposite Ronsdale Garden (Figures 1 and 2, and Plates 1 and 2). It involved the downward displacement of about 2 m of a generally intact ground mass involving a volume of about 1,800 m^3 (see Section 6.1). Distressed ground associated with en-echelon tension cracks and deformed drainage channels, with an area and volume of about 140 m^2 and 300 m^3 respectively, was located adjacent to the western flank of the landslide. The total volume of the August 2005 landslide, including distressed ground, is about 2,100 m^3. Localised detachment of about 40 m^3 of soil occurred at the lower portion of the displaced ground mass (Plate 3), and the debris was deposited on the pavement of Tai Hang Drive (Plate 4). As a result of the incident, both lanes of the road were closed temporarily. No casualties were reported as a result of the landslide.

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

6. FIELD OBSERVATIONS FOLLOWING THE 20 AUGUST 2005 LANDSLIDE

6.1 Post-landslide Observations

FSW inspected the site on 22 August 2005 and on several occasions during the course of this landslide study.

The displaced ground mass was up to a maximum 29 m wide by 27 m long, and the main scarp was at about 18 m above the road level (Figure 12, and Plates 1 and 2). The failure was of limited mobility, with a downward displacement of about 2 m at the main scarp (horizontal displacement at the toe being unknown as some of the debris at the toe had been cleared by the time FSW first visited the landslide site). The failed ground mass, which remained largely intact, did not completely detach from the slope. The near-surface material of the displaced mass comprised dislocated and generally broken concrete surface channels in a matrix of CDG and disturbed soil of granitic origin (Plate 1). The main scarp was up to 2 m high and was inclined at an angle of about 65° (Plate 9). No seepage from the main scarp or the surface of the displaced ground mass was observed during the inspections.

Localised detachment of about 40 m^3 of soil, occurred over an area of about 8 m wide by 5 m long, at the toe of the displaced mass (Figure 2 and Plate 3). The debris derived from this local failure comprised blocks of no-fines concrete, sections of broken concrete surface channels, wire mesh and cobble- and boulder-sized Grade III granite, some of which probably originated from the repair works to the 1983 and 1993 landslides (see Section 3.3 and Plate 3).

During the inspection on 24 August 2005 by FSW, the surface drainage channels in the western portion of the cut slope were noted to be generally dry and clear from debris while some stepped channels showed evidence of distress resulting from the landslide, as well as scouring, probably due to excessive flow of water (Plate 22). Some signs of distress in the form of minor cracking (up to 5 mm in width) were observed on the surface channels, catchpits and berm pavement (Plate 23). The chunam cover on the strip of area above the crest channel within this portion of the slope was cracked (up to 10 mm wide) with vegetation growing inside the cracks (Plate 24).

The 300 mm stepped channel, which was connected to the baffle wall above the cut slope prior to the landslide incident, was found to have broken, with the top 1 m long section also damaged and left in position (Plate 11). From the alignment of the remaining section (Plate 25), the stepped channel should have discharged surface water towards the area where the local detachment of soil was observed. The drainage channels on slope No. 11SE-A/C285 and the ephemeral drainage that discharges onto the 300 mm stepped channel via the baffle wall were found to be dry during the inspection on 22 August 2005. Also, the drainage channels located outside the landslide area were found to be generally free from blockage.

Between the western end of the main scarp and the baffle wall, an in-situ boulder of Grade II granite (2.6 m by 2.5 m) was noted to have moved forward by about 45 mm. However, the observed movement might have been due to root action of an adjacent tree instead of being related to the present landslide (Plate 26).

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

6.2 Geological Mapping of the Landslide Site

Geological mapping of the landslide site was carried out by FSW in August 2005 after the landslide (see Figures 12 to 14).

The main scarp of the landslide was about 2 m high, 65° steep and exposed with residual soil (Grade VI granite).

The western flank of the landslide scar showed some surficial deformation with stepped (en-echelon) cracks within the slope-forming material and signs of bulging between the cracks (Figure 12 and Plate 27). At the eastern flank of the landslide scar, the interface between soil and rock was exposed at the lower slope batter (Figure 12 and Plate 28).

A distressed zone was identified on the western flank of the landslide scar, which comprised a soil cut slope with a severely cracked stepped channel on the lower batter, and an area of tension cracking and minor slope displacement adjacent to the baffle wall at the southwestern part of the landslide scar (Figure 12 and Plate 29). A similar distressed zone was also identified behind the southeastern part of the landslide scar (Figure 12 and Plate 30).

The eastern portion of slope No. 11SE-A/C285 was generally exposed with medium-grained Grade II or III granite over the lower part and medium-grained Grade V granite over the upper part whereas the western portion of the slope was predominantly in fine- to medium-grained Grade V granite with the exception of a small area near the crest, over which Grade VI granite (residual soil) was found. The approximate boundary between fine-grained and medium-grained granites trends NW-SE across the western part of the cut slope (Figure 12) and is inclined at about 20° to the northwest, based on the information from the drillholes. The granite exposed within the site comprised numerous pegmatite veins and occasionally showed evidence of hydrothermal alteration including hydraulic brecciation and schlieren.

7. POST-FAILURE GROUND INVESTIGATION

A ground investigation under GEO's ground investigation Urban Term Contract No. GE/2005/03 was carried out between September 2005 and December 2005 by Fugro Geotechnical Services Limited (FGS) under the supervision of FHK (FGS, 2005). The locations of the ground investigation stations are presented in Figure 2. The scope of the works included the following:

(a) 17 vertical drillholes (DH1 to DH17) put down using rotary drilling method to depths between 11.3 m and 26.2 m below ground surface,

(b) ten trial pits (TP1 to TP10) excavated to a maximum depth of 3.9 m below ground surface, and

(c) one slope surface strip (SS1) excavated for a length of 18.3 m (measured along slope surface).

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

Continuous retrieval of undisturbed soil samples was carried out in all drillholes. For drillholes Nos. DH7 to DH10, which were put down within the displaced/distressed area, soil sampling was undertaken using 4C-MLC sampler with air-foam as the flushing medium. For the other drillholes outside the displaced/distressed area, Mazier sampling with water as the flushing medium was adopted.

In-situ testing, which comprised constant head and falling head permeability tests in drillholes within the strata of completely and highly decomposed granite, was carried out.

Thirty-one piezometers were installed in the 17 drillholes to locate the base groundwater table and any perched water table above the interface between saprolite and the bedrock. Since April 2006, nine piezometers (in drillholes Nos. DH2, DH4, DH6, DH7, DH10, DH12, DH14, DH16 and DH17) were provided with automatic groundwater monitoring devices for continuous groundwater monitoring.

Laboratory testing was carried out by Gammon Construction Limited (GCL) between December 2005 and February 2006 (GCL, 2006). These included soil classification tests, particle size distribution analyses and triaxial compression tests.

8. SUBSURFACE CONDITIONS

8.1 General

The subsurface conditions have been assessed based on the information obtained from desk study, field mapping and the post-landslide ground investigation. Geological cross-sections through the landslide site and its vicinity to the east are presented in Figures 3 and 4 respectively.

8.2 General Ground Conditions

Notable observations from the post-landslide drillholes and trial pits are as follows:

(a) Fill

i. The presence of a 0.5 m to 1.5 m thick layer of fill, comprising general soft to firm, yellowish or reddish brown, sandy SILT with occasional fine to medium gravel at the lower part (bottom 8 m) of the eastern half of the western portion of the slope; and

ii. the presence of a 0.4 m to 1.4 m thick layer of fill, comprising generally firm to stiff, yellowish brown, sandy SILT with occasional fine to medium gravel and locally many cobble- and boulder-sized fragments of concrete at the lower part (bottom 8 m) of the central portion of the slope.

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

(b) Colluvium

The presence of a 0.4 m and 3.8 m thick layer of colluvium, comprising stiff, reddish or yellowish brown, slightly sandy, clayey SILT with occasional coarse gravel, cobbles and boulders of weak to moderately strong granite, in the western portion (trial pit No. TP9) of the slope and the DT feature above the central portion of the cut slope (surface strip No. SS1) respectively.

(c) Residual Soil (RS)

The presence of a 0.4 m to 2.6 m thick layer of RS (Grade VI) at surface or underneath the layer of fill, comprising generally firm to stiff, yellowish brown, slightly sandy to sandy, clayey SILT at the upper part near crest level of the cut slope as well as the DT feature above; the layer of residual soil is locally up to 4.8 m thick (at drillhole No. DH14).

(d) Completely Decomposed Granite (CDG)

i. CDG (Grade V) with occasional corestones (composed of strong Grade II granite) is present within the upper half of the eastern portion of the cut slope and the DT feature above (up to 4.6 m revealed from the ground investigation), with its thickness increasing in the uphill direction; it can be described as extremely weak, yellowish brown or pinkish brown completely decomposed medium-grained GRANITE, comprising firm to stiff, sandy SILT, becoming slightly silty fine to medium SAND (with some fine to coarse gravel) with depth;

ii. a 2.8 m to 4.9 m thick layer of extremely weak, yellowish brown or pinkish brown completely decomposed medium- to coarse-grained GRANITE, with corestones (composed of generally moderately weak to moderately strong MDG or strong SDG), is present within the central portion of the cut slope; the CDG comprises generally firm sandy clayey SILT and in places, becoming silty fine to medium SAND (with occasional fine to medium gravel) with depth;

iii. a 2.2 m to 6.7 m thick layer of generally extremely weak yellowish brown or pinkish brown completely decomposed fine- to coarse-grained GRANITE, with corestones (composed of generally extremely weak to weak HDG or moderately strong to strong M/SDG) in

Table of Contents
Table of Contents
Table of Contents

places, is present within the western portion of the cut slope; the CDG comprises generally firm, sandy, clayey SILT or silty fine to medium SAND both with occasional fine to medium gravel; and

iv. virtually no CDG was found on the DT feature immediately above the central and western portion of the cut slope.

(e) Highly Decomposed Granite (HDG)

i. a 0.5 m to 7.5 m thick layer of generally very weak to weak light yellowish brown and reddish grey, spotted black, highly decomposed fine- to coarse-grained GRANITE (Grade IV) comprising sandy angular fine to coarse gravel (possible loss of fines in sampling), is present within the cut slope and the DT feature above; and

ii. corestones (composed of moderately weak to moderately strong MDG and strong SDG) are present within the layer of HDG in places within the cut slope as well as the DT feature above.

(f) Bedrock

i. Moderately decomposed granite (MDG) and/or slightly decomposed granite (SDG) are present below the saprolite;

ii. there are considerable variations in grain sizes, texture and composition across the site. The approximate boundary between fine-grained and medium-grained granites trends NW-SE across the western part of the cut slope (Figure 12) and is inclined at about 20° to the northwest, based on the information from the drillholes. The granite exposed within the site comprised numerous pegmatite veins and occasionally showed evidence of hydrothermal alteration including hydraulic brecciation and schlieren;

iii MDG can be described generally as moderately strong, yellow or pinkish grey or yellowish brown, moderately decomposed, generally medium-grained GRANITE (Grade III) with closely to medium spaced, rough undulating and/or planar, extremely to very narrow, limonite and manganese stained and occasionally infilled (>2 mm), and occasionally manganese and

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

chlorite coated joints, as well as some 100 mm to 500 mm thick CDG or HDG seams;

iv. SDG is generally strong to very strong, light or pinkish grey, spotted black, slightly decomposed, medium-grained GRANITE (Grade II) with closely to widely spaced, rough undulating and/or planar, occasionally stepped, extremely narrow, limonite and manganese stained, kaolin and/or chlorite coated joints, as well as some 50 mm to 950 mm thick CDG or HDG seams;

v. rockhead at the eastern portion of the cut slope is at ground surface level on the lower part and remains relatively shallow within the upper part of the cut slope (Figure 4);

vi. rockhead at the landslide location is much deeper, being 3.2 m, 7.2 m, 11.3 m and 8 m below ground level at drillholes Nos. DH7 to DH10 respectively (Figure 3); and

vii. rockhead at the western portion of the cut slope is at between 4 m and 8 m below ground level on the lower part and becomes 9 m to 10 m below ground level at the upper part of the slope.

8.3 Geological Features of the Landslide Site

Geological mapping of the landslide site, together with plots of contoured joint measurements and stereographic projection of the measured discontinuities, are shown in Figures 12, 13 and 14 respectively. Geological sections through the site are shown in Figures 3, 4 and 15.

The basal rupture surface of the 20 August 2005 landslide was encountered in drillholes Nos. DH7, DH8 and DH9 (see Figure 3), and was inferred to be at about 6.5 m below ground surface (or 5.6 m deep perpendicular to the slope surface), within the strata of CDG and HDG where corestones of M/SDG were present (Figure 3), and inclined at about 30° to the horizontal. Drillholes Nos. DH7, DH8 and DH9 also revealed the presence of closely spaced, slickensided, manganese stained subvertical relict joints within the HDG, and medium to closely spaced chlorite, manganese and kaolin coated joints within the M/SDG below the basal sliding plane.

Inspection of an excavation across the lower portion of the landslide during the LPM works in November 2006, revealed part of the basal slip surface along an undulating sheeting joint inclined at about 30° out of the slope (Figure 15, and Plates 31 and 32). However, the sheeting joint and the basal slip surface could not be traced over the full extent of the excavation and landslide scar, suggesting that some shearing had also taken place within intact CDG. A second undulating sheeting joint, which was inclined at 20° to 40° towards

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

north northwest (340°), was located at the rockhead below the basal slip surface. Both the sheeting joints and the basal slip surface contained soft, brown clay infill (Plate 32) and some roots. The majority of the slipped material above the basal slip surface comprised disturbed CDG and occasional corestones of MDG. Intact CDG with pockets of HDG were located below the slip surface. The depth of weathering clearly increases within the landslide site as compared with the adjoining areas. Rockhead was also exposed in the excavation and was controlled by a combination of the sheeting joint and steeply dipping joints striking NW-SE, which become closely spaced and more persistent at the rockhead-saprolite boundary. As such, the boundary was stepped and undulating and inclined at 20° to 85° to north northwest (340°).

As depicted by the inferred rockhead contour plan (Figure 16), which was derived from the previous and post-failure ground investigations, and as seen from the rockhead profile exposure during the LPM works, there appears to be a rockhead depression, with a NW-SE trending axis located within and above the 20 August 2005 landslide site, which may direct sub-surface seepage towards the landslide site. The axis of the inferred rockhead depression runs approximately parallel to the strike of the steeply dipping joint set (85°/210°) and the NW-SE trending fault, which is located at about 70 m to the northeast of the landslide site (see Section 2.3).

Within the scar, CDG was overlain by a layer of RS. At the slope toe, the top layer of the disturbed ground mass was noted to contain fill material (comprising no-fines concrete, soil and rock fill, etc), which were probably placed there as part of the slope repair works completed following the 1983 and/or 1993 landslides (see Section 3.3).

The CDG in close vicinity to the inferred surface of rupture is featured by the presence of 20 mm to 30 mm thick seams (relict joints) of soft, sticky clay/silt, (some possibly with organic contents) dipping at approximately 30° (Plate 33). These relict joints were also noted within CDG both in the landslide area (central portion of the slope) as well as the eastern and western portions of the slope. Most of these joints were found to be dipping steeply (>80°) towards south into the slope and some at 30° to 50° out of the slope (at trial pits Nos. TP5 within the landslide site and TP2 in the western portion of the slope).

Trial pits Nos. TP9 and TP10 excavated in the western portion of slope No. 11SE-A/C285 show the presence of some relict joints, up to 150 mm in thickness and composed of RS, within the stratum of CDG (Plates 34 and 35).

Trial pit No. TP5 sunk at the eastern flank of the landslide (Figure 2) also revealed a 0.5 m thick layer of probably displaced material comprising clayey sandy silt with lenses of CDG overlying bedrock which contains sheeting joints dipping at 30° to 50° out of the slope (Plate 36).

Trial pit No. TP6 sunk at the western flank of the landslide (Figure 2) shows some en-echelon (i.e. stepped) cracks and bulging at the slope surface within CDG. Tension cracks, with a maximum aperture of 40 mm and a maximum depth of 250 mm, were also noted along opened relict joints and through intact CDG to a depth of exceeding 3 m in the trial pit (Plate 37).

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

8.4 Hydrogeological Setting and Groundwater Conditions

The hydrogeological setting at the site has been assessed from API and the results of the post-failure ground investigation. The central portion of the slope No. 11SE-A/C285 where the 20 August 2005 occurred is traversed by an ephemeral drainage line (Figure 5). Also, there appears to be a rockhead depression close to the landslide location, which may direct subsurface seepage towards the landslide site (Figure 16). Both of these features tend to promote the transient rise of groundwater level during severe rainfall. According to the post-landslide inspections, no seepage from the main scarp or the surface of the displaced ground mass was observed at the time of inspection.

Groundwater conditions at slope No. 11SE-A/C285 and the DT features above have been established from the readings of piezometers between November 2005 and August 2006, together with the readings of automatic piezometers between April 2006 and August 2006. Some of the piezometers could not be monitored during the period of LPM works, which commenced in March 2006.

In the central portion of the cut slope where the 20 August 2005 landslide occurred, piezometric records were only available for the period between November 2005 and March 2006 (dry season) as the LPM works were on-going during the wet period. Based on the dry season monitoring (drillholes Nos. DH7, DH8 and DH9), the base groundwater table was low within the cut slope at about 11 m below ground level (b.g.l.).

In the western portion of the cut slope, the base groundwater table was also low in the dry season at between 8 m b.g.l. and 11 m b.g.l. at drillholes Nos. DH4 and DH2 respectively. However, during the rainstorms between June and August 2006, the piezometric level within the piezometer in drillhole No. DH2 (installed at about 11 m b.g.l within MDG) rose by about 4.8 m.

On the DT features above the cut slope, the highest base groundwater levels recorded in the dry season at the piezometers in drillholes Nos. DH10, DH12, DH14 and DH15 were >7.5 m, 6.5 m, 13.8 m and >8.3 m b.g.l. respectively (see Figure 16). The highest groundwater was recorded in drillhole No. DH12, where this drillhole coincides with the location of the inferred rockhead depression (see Section 8.3), which traverses the 20 August 2005 landslide site (Figure 16). This piezometer was dry by February 2006, and probably had become blocked by the LPM works by June 2006 when automatic piezometers were installed. On the other hand, groundwater levels in the piezometers in drillholes Nos. DH10 and DH15 rose to 5.3 m b.g.l. and 6.1 m b.g.l. respectively, during the rainstorms between June 2006 and August 2006, corresponding to a rise of piezometric level of at least 2.2 m at these locations (Figure 16). The piezometric level in drillhole No. DH14 also exhibited a rise in the base groundwater level of about 1.6 m to 12.2 m b.g.l. during the wet period. Another piezometer in drillhole No. DH14 which was installed at just above the rockhead level recorded a perched water of about 4 m b.g.l. (being at 2.6 m above rockhead level) during the 2006 wet season (Figure 16).

8.5 Engineering Properties and Shear Strengths of CDG and HDG

Results from two falling head and six constant head permeability tests carried out in

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

drillholes within saprolite indicate that the coefficients of permeability of CDG and HDG do not show much difference from each other, and fall within a range of 2.1×10^{-6} m/s to 1.1×10^{-5} m/s.

Particle size distribution analyses carried out on thirteen CDG samples and nine HDG samples show that the CDG and the HDG exhibit similar grading characteristics, and comprise generally slightly clayey, silty sand with occasional or some fine to medium gravel.

Triaxial compression test results on undisturbed samples taken from the strata of CDG and HDG for the appropriate effective stress range (i.e. p' within 200 kPa for CDG and 250 kPa for HDG) indicate that CDG and HDG have similar shear strengths of c' = 9 kPa and ϕ' = 42° (Figure 17).

9. ANALYSIS OF RAINFALL RECORDS

Rainfall data were obtained from GEO automatic raingauge No. H07, which is the nearest raingauge to the site and located at Leighton Hill, approximately 860 m to the west of the landslide site (Figure 1). The raingauge records and transmits rainfall data at 5-minute intervals to the Hong Kong Observatory (HKO) and the GEO.

The 20 August 2005 landslide was referred to the GEO from the Police at 9:35 p.m. on 20 August 2005. Landslip Warning was issued on 19 August 2005 at 9:00 p.m.

The daily rainfall recorded by raingauge No. H07 over the month preceding the 20 August 2005 landslide incident, together with the hourly rainfall readings for the period between 18 and 20 August 2005, are presented in Figure 18. For the purpose of rainfall analysis, the time of the landslide was assumed to be 9:00 p.m., i.e. immediately following a prolonged period (about 24 hours) of rainfall with intensity of between 10 mm/hr and 35 mm/hr.

Table 1 presents the estimated return periods for the maximum rolling rainfall for various durations recorded by raingauge No. H07 with reference to historical rainfall data at the HKO in Tsim Sha Tsui (Lam & Leung, 1994). The results show that the 31-day rolling rainfall of 1,230 mm preceding the landslide was the most severe with a corresponding return period of about 59 years based on Lam & Leung (1994). For short durations up to 12 hours, the corresponding return period was generally less than three years while for durations of 24 hours and above, the return period was at least 20 years. The return periods were also assessed based on statistical parameters derived by Evans & Yu (2001) using data recorded by the local automatic raingauge No. H07. According to this assessment, the return periods corresponding to 24-hour and 48-hour rolling rainfall were 72 years and 69 years respectively, which were the most critical rainfall duration.

The maximum rolling rainfall for the rainstorm preceding the August 2005 landslide has been compared with the past major rainstorms between 1978 and 2005 recorded by raingauge No. H07, which came into operation in October 1978 (see Figure 19). It is noted that the maximum rolling rainfall for the rainstorm prior to 9:00 p.m. on 20 August 2005 exceeds that from previous rainstorms for durations of 24 hours, 48 hours, 4 days, 7 days and 15 days.

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

10. THEORETICAL STABILITY ANALYSES

Theoretical stability analyses using the rigorous method of Morgenstern & Price (1965) were carried out to assist in the diagnosis of the mechanisms and probable causes of the 20 August 2005 landslide. The analyses may be used to assess the operational mass shear strength parameters given the range of possible groundwater conditions at the time of the landslide.

Cross-sections through the slope included in the stability analyses are shown in Figure 20. The pre-failure slope profile was inferred from topographical survey plans, the approved site formation plans, photographic records and post-failure field observations. The geometry of the likely surface of rupture and ground profile is based on topographical survey, field observations and ground investigation carried out as part of the post-landslide study.

Based on the geological mapping (Figure 12) and the post-landslide ground investigation, the surface of rupture of the 20 August 2005 landslide was interpreted to be partly along relict joints and partly within CDG (with the exception of the top 2.5 m portion, which was within residual soil). Stability analyses were carried out using a range of values of shear strength parameters, which covers the typical range of parameters given for CDG (GEO, 1993), as well as the parameters derived from laboratory testing completed as part of the post-failure ground investigation. Analyses were carried out for both rotational and translational failure models. Various elevated groundwater levels above the surfaces of rupture were assumed for the purpose of the stability analyses.

The results of the analyses are presented in Figure 20. The analyses indicated that with shear strength parameters of $c' = 9$ kPa and $\phi' = 42°$ for the CDG/HDG (corresponding to the results of laboratory tests, Figure 17), the development of a transient groundwater pressure corresponding to a piezometric level of about 6 m above the surface of rupture, would have been required to initiate failure of the slope. However, for a range of possible lower bound shear strength parameters of c' ranging from 2 kPa to 6 kPa and ϕ' ranging from 30° to 34° for the CDG, the analyses indicated that piezometric levels of about 1 m to 3 m above the surface of rupture would have been required to initiate failure. The lower shear strength parameters and thus, the lower groundwater levels required for failure to occur, are considered to be more appropriate for the 20 August 2005 landslide given the evidence of the failure occurring partly along relict joints and partly within intact CDG.

11. DIAGNOSIS OF THE PROBABLE CAUSES OF THE LANDSLIDE

11.1 Site Setting

The 20 August 2005 landslide occurred on a 18 m high, 40° steep predominantly soil portion of an engineered soil and rock cut slope No. 11SE-A/C285 and extended into the DT feature immediately above, following a prolonged period of rainfall (maximum 37 mm/hr, see Figure 18).

Slope No. 11SE-A/C285 was formed by excavation into the natural hillside between 1981 and 1982. The location of the 2005 landslide site has a history of past instability. Several relict landslide scars are visible in the 1949 aerial photographs at the hillside near the crest of the present-day slope No. 11SE-A/C285. Prior to the 20 August 2005 landslide,

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

slope No. 11SE-A/C285 had experienced landslides in 1983 and 1993, both of which occurred within the same location as the 20 August 2005 landslide. The 1983 landslide was about 12 m by 8 m in size with a volume estimated to be about 30 m^3 to 50 m^3. The 1993 landslide was more extensive at about 20 m wide by 10 m long and having a failure volume of about 100 m^3 according to the incident report, although given the dimensions of the scar, the volume was likely to have been larger. Urgent repair works were carried out following the previous instabilities.

Post-landslide ground investigation revealed that below the surface of rupture, there exists closely spaced slickensided, manganese stained subvertical relict joints within the CDG/HDG, as well as closely to medium spaced manganese, chlorite and kaolin coated joints within the M/SDG. There are also 20 mm to 30 mm thick seams of soft sticky clay/silt, with occasional organic contents, within the CDG in the vicinity of the surface of rupture. No similar slickensided joints are identified in the areas outside the distressed zone. The presence of sheeting joints dipping at 30° to 50° out of the slope and steeply dipping joints striking NW-SE at the interface between CDG and bedrock at the eastern flank also suggests that the landslide at the eastern flank was controlled by moderately steeply to steeply inclined, joint-controlled soil/rock interface.

Shear strength parameters for CDG/HDG derived from triaxial compression tests are found to be very high with $c' = 9$ kPa and $\phi' = 42°$. However, it is likely that the insitu strength of CDG/HDG at the location of the 20 August 2005 landslide site is much lower, as the material might have been disturbed and weakened by intense weathering and previous minor slope movements as inferred by the presence of pre-existing soil-infilled cracks and joints, and slickensided, chlorite and kaolin coated joints below the surface of rupture (see Section 8.3). This postulation is supported, to a certain extent, by the results of theoretical stability analyses, which indicate that groundwater would have to rise to quite a high level (about 6 m above the surface of rupture) before a failure could occur if the high shear strength of CDG were operational along the surface of rupture. However, if lower values of shear strength are used in the analyses, groundwater levels of 1 m to 3 m would be required for failure to occur assuming a combination of translational and rotational failure modes as observed.

Slope No. 11SE-A/C285 is located at the toe of a hillside that was disturbed by various cultivation activities and squatter inhabitation up to the early 1970's. The central portion of the slope where the 20 August 2005 occurred is traversed by an ephemeral drainage line. Based on the available ground investigation information, there appears to be a rockhead depression close to the landslide location, which may direct subsurface seepage towards the landslide site at the time of heavy rainfall (Figure 16). This is supported by the fact that groundwater recorded at the inferred rockhead depression about 7 m above the landslide site is relatively high (i.e. 6.5 m below ground level as recorded at drillhole No. DH12 in dry season) compared to other locations.

11.2 Probable Causes and Mechanism of the Landslide

The 20 August 2005 landslide involved a combination of both translational and rotational movements of a 29 m wide by 27 m long, approximately 1,800 m^3 volume, largely intact ground mass, with a well-defined main scarp, localised shallow detachments and

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

deformation of the near-surface slope-forming material. The major landslide was not mobile and only localised detachment of about 40 m³ of soil occurred at the lower portion of the displaced ground mass. Distressed ground associated with en-echelon tension cracks and deformed drainage channels, with an area and volume of about 140 m^2 and 300 m³ respectively, was located adjacent to the western flank of the landslide.

The surface of rupture was within CDG and HDG at a maximum vertical depth of about 6.5 m. The displaced ground mass was not mobile. The relatively gentle inclination of the ground (overall slope angle about 40°), together with possible rapid dissipation of groundwater pressure along the surface of rupture when the ground mass started to move, might have played a part in reducing the mobility of the landslide.

The close relationship between the rainfall recorded on 19 and 20 August 2005 and the time of the failure suggests that the landslide was triggered by prolonged rainfall. The fairly severe long-duration rainfall was probably conducive to a significant build-up of groundwater.

The repeated instability, including two significant previous failures on slope No. 11SE-A/C285 at the same location as the 20 August 2005 landslide, suggests that the landslide site was susceptible to failure given intense rainfall. The landslide site has probably been affected by intense weathering activities, which led to weakening of the slope-forming materials, as well as promoting rapid weathering in the locality. The presence of clay-infilled relict joints dipping out of the slope and closely spaced subvertical relict joints within the slope-forming material probably also played a contributory role in the landslide by facilitating basal sliding and forming release surfaces. The presence of these localised adverse geological features was not detected during the previous ground investigation and was not taken into account in the previous stability assessment.

The presence of an inferred local rockhead depression could have promoted subsurface seepage flow towards the landslide site, causing a more significant build-up of transient groundwater pressure during severe rainstorms.

12. CONCLUSIONS

The 20 August 2005 landslide probably involved a combination of rotational and translational movements of an approximately 1,800 m³ volume of largely intact ground mass, with localised detachment at the lower portion, on an engineered cut slope. Distressed ground associated with en-echelon tension cracks and deformed drainage channels, with an area and volume of about 140 m^2 and 300 m³ respectively, was located adjacent to the western flank of the landslide. The close relation in timing between the 20 August 2005 rainstorm and the failure suggests that the landslide was probably triggered by prolonged and intense rainfall.

The landslide site was susceptible to failure during intense rainfall given the geological conditions, as indicated by the repeated failures on the cut slope at approximately the same location. The presence of adversely orientated joints controlling part of the basal sliding and forming steep release surfaces, as well as an inferred rockhead depression potentially directing groundwater towards the landslide site are probably contributory factors to the landslide.

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

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Table of Contents
Table of Contents
Table of Contents

LIST OF TABLES

Table of Contents
Table of Contents
Table of Contents

Table 1 - Maximum Rolling Rainfall at GEO Raingauge No. H07 for Selected Durations Preceding the Landslide on 20 August 2005 and Estimated Return Periods

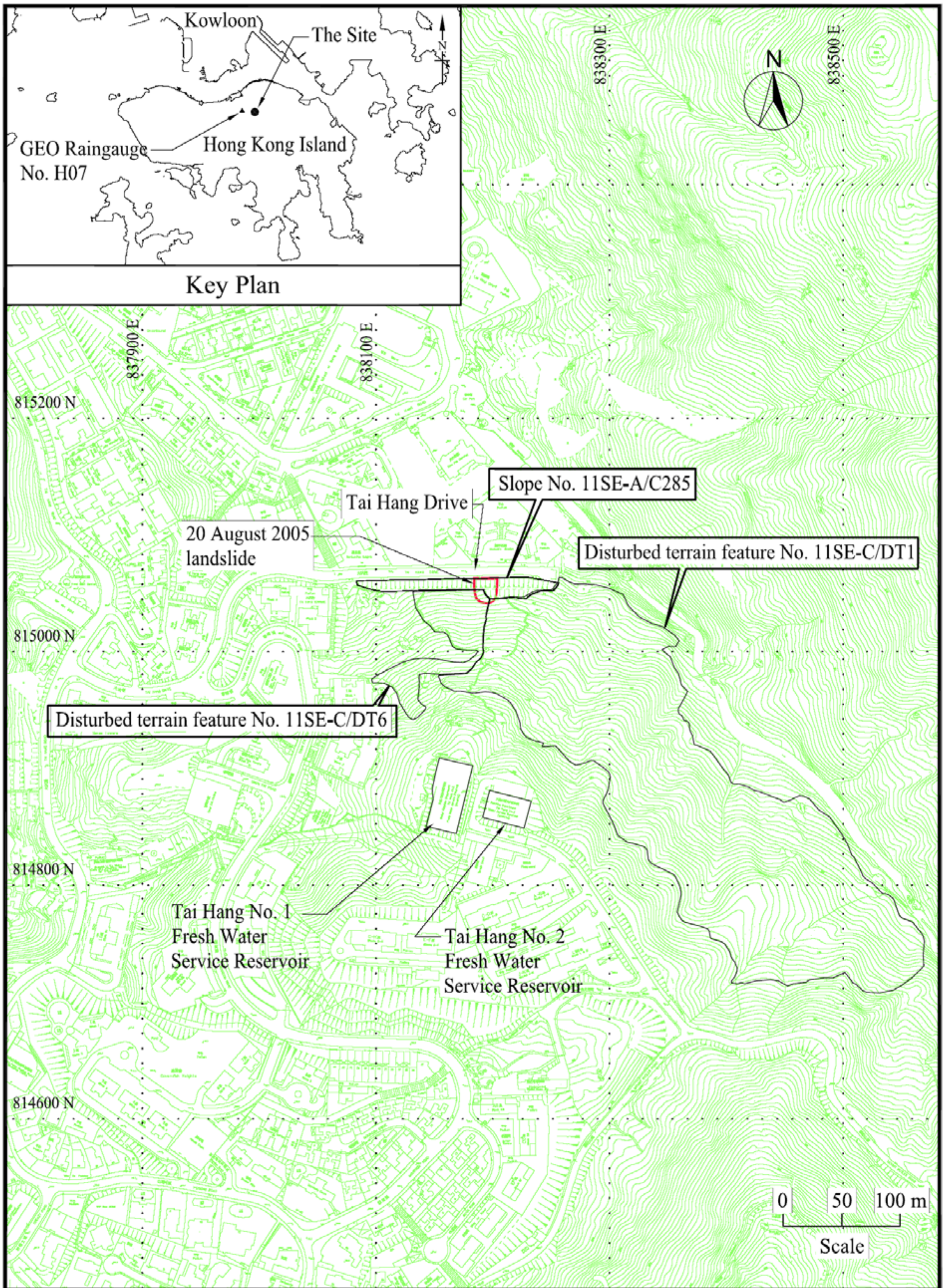
Duration	Maimum Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years) (See Notes 2)	
			By Lam & Leung (1994)	Using H07 data based on Evans & Yu (2001)
5 Minutes	2.5	8:30 p.m. on 20 August 2005	< 2	< 2
15 Minutes	5.5	8:35 p.m. on 20 August 2005	< 2	< 2
1 Hour	13	8:30 p.m. on 20 August 2005	< 2	< 2
2 Hours	27.5	7:00 p.m. on 20 August 2005	< 2	< 2
4 Hours	84.5	1:00 p.m. on 20 August 2005	< 2	< 2
12 Hours	214	4:20 p.m. on 20 August 2005	3	5
24 Hours	432	5:55 p.m. on 20 August 2005	20	72
48 Hours	581	8:55 p.m. on 20 August 2005	43	69
4 Days	651	8:40 p.m. on 20 August 2005	30	27
7 Days	767	8:55 p.m. on 20 August 2005	46	56
15 Days	928.5	8:55 p.m. on 20 August 2005	38	23
31 Days	1230	8:55 p.m. on 20 August 2005	59	23

Notes:
(1) Maximum rolling rainfall was calculated from 5-minute rainfall data.
(2) Return periods were derived from the rainfall data recorded at Hong Kong Observatory between 1884 and 1939 and between 1947 and 1990 (Lam & Leung, 1994) as well as the data recorded at local raingauge No. H07 between 1978 and 1997 (Evans & Yu, 2001). The return periods obtained from the local raingauge by Evans & Yu in one- and two-day rainstorm durations are significantly greater than those estimated by Lam & Leung.
(3) The landslide was reported to the GEO at 9:35 p.m. on 20 August 2005 and is assumed to have occurred at about 9:00 p.m. on 20 August 2005 for the purpose of rainfall analysis.
(4) The nearest GEO raingauge to the landslide site is raingauge No. H07 which is situated at about 860 m to the west of the landslide site and became operational since October 1978.

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

LIST OF FIGURES

Table of Contents
Table of Contents
Table of Contents



Notes: (1) Base plan is extracted from 1 : 1000 survey sheets Nos. 11SE-11A, B, C, & D dated May 2003.
(2) Slope boundary is taken from pre-landslide records of the GEO's SIS.

Figure 1 - Site Location Plan

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

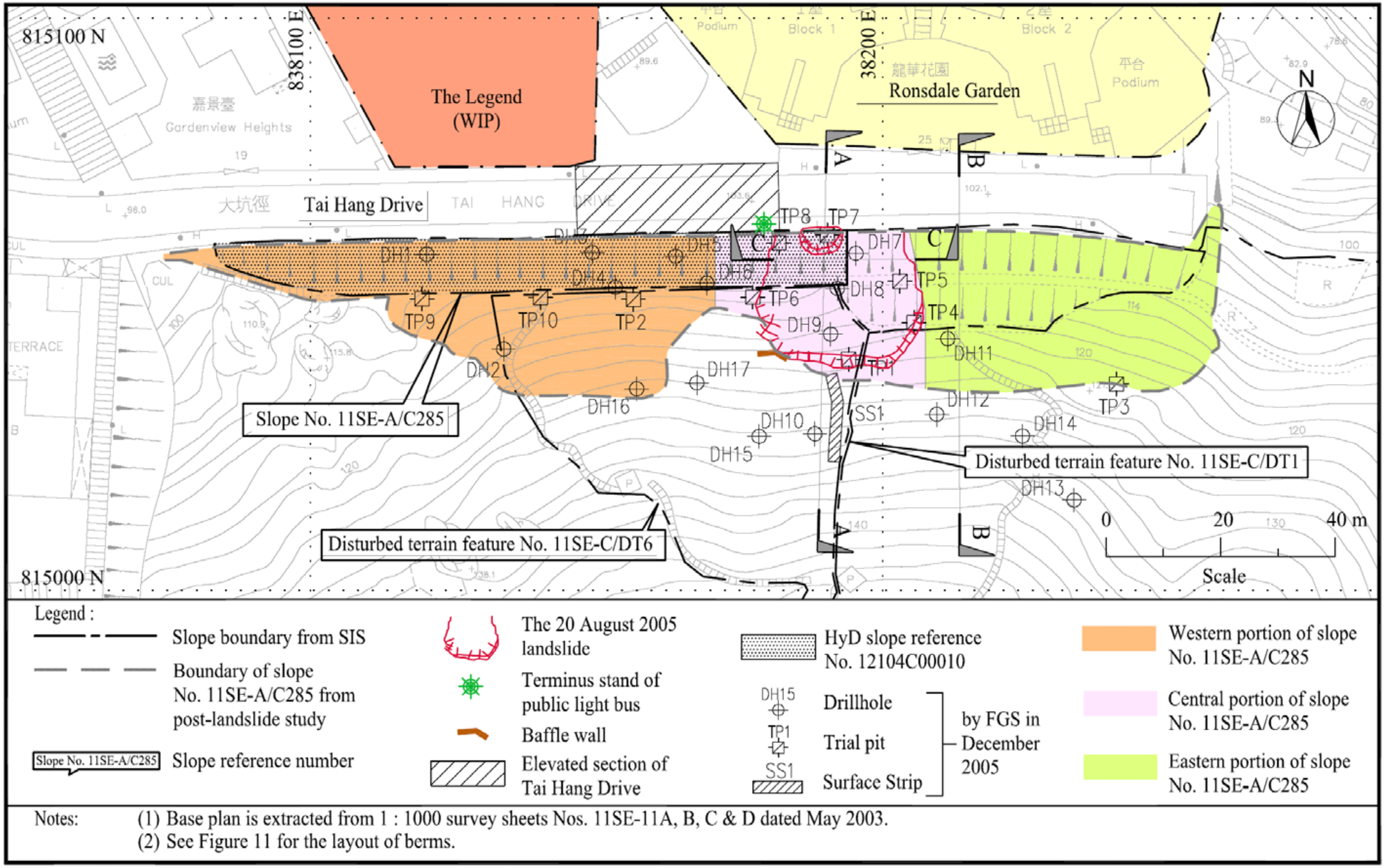
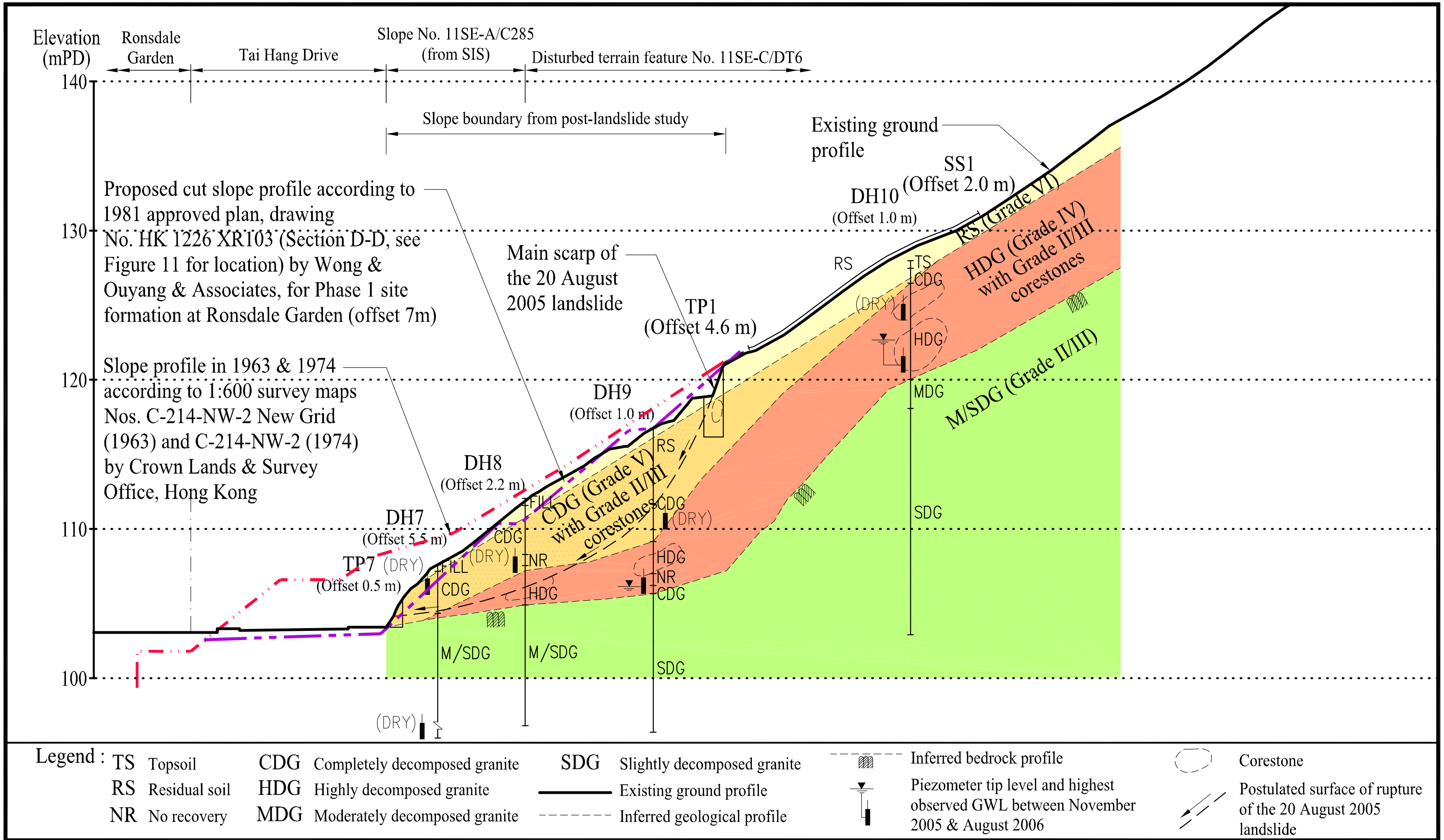


Figure 2 - Site Plan

Table of Contents



Note :

(1) See Figure 2 for location of cross-section and locations and general information of ground investigation stations.
(2) Dotted area denotes depleted zone.

Figure 3 - Section A-A through the Landslide Site

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

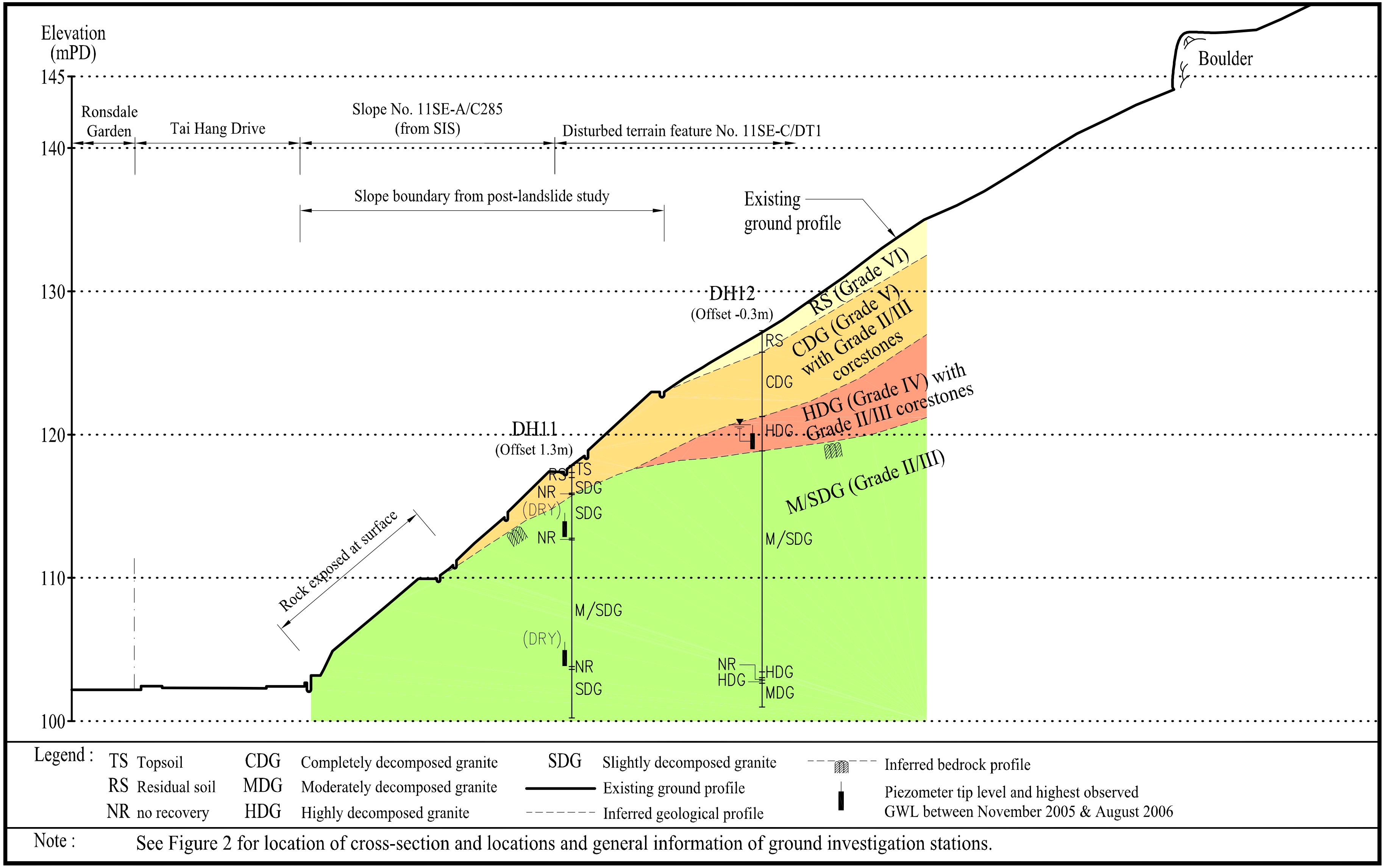
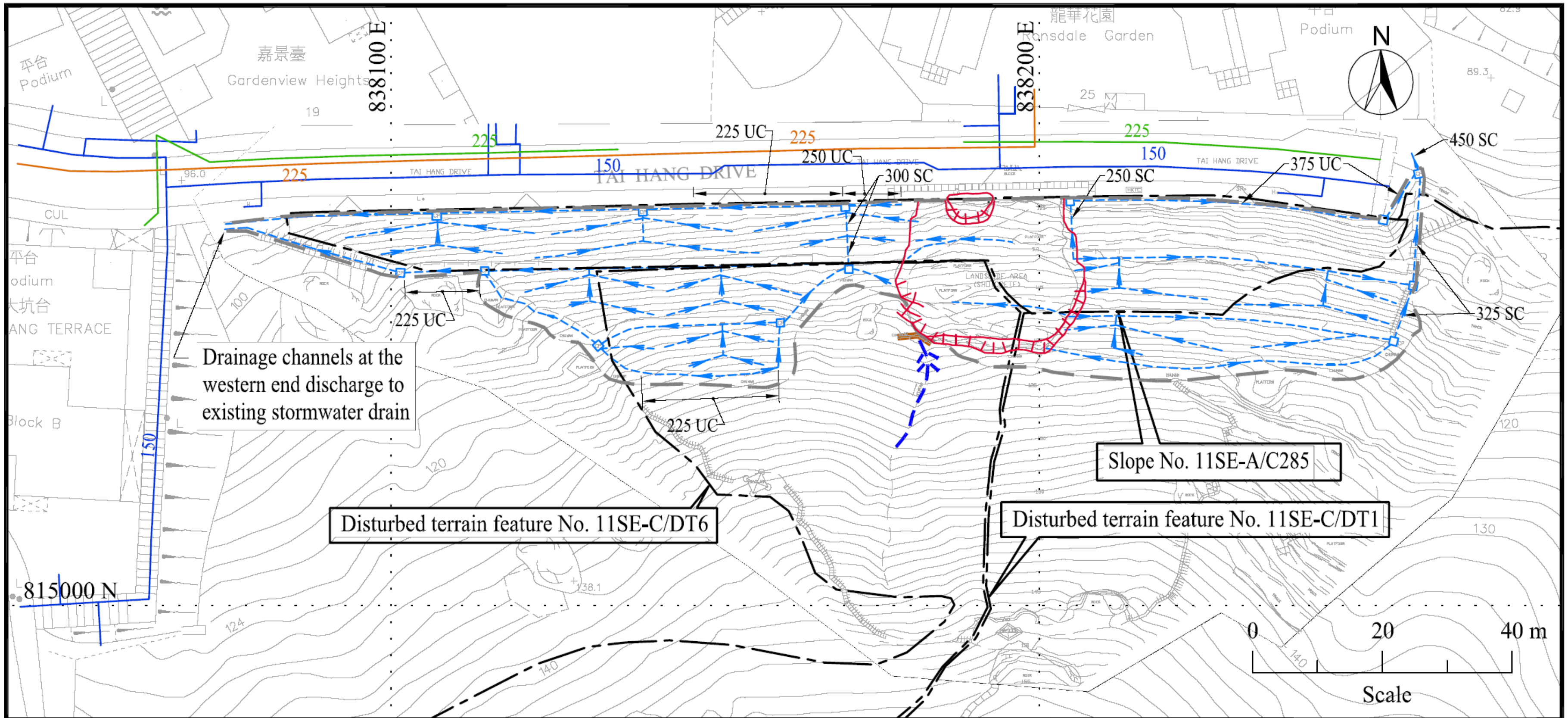


Figure 4 - Section B-B through the Eastern Portion of Slope No. 11SE-A/C285

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



Legend :

Slope boundary from SIS	Slope No. 11SE-A/C285 — Slope reference number	225 — Existing stormwater drain (size given in mm)	Baffle wall
Boundary of slope No. 11SE-A/C285 from post-landslide study	The 20 August 2005 landslide	225 — Existing foul sewer (size given in mm)	Ephemeral drainage line
		150 — Existing fresh watermain (size given in mm)	
		Surface drainage channel (see note 3)	

Notes:

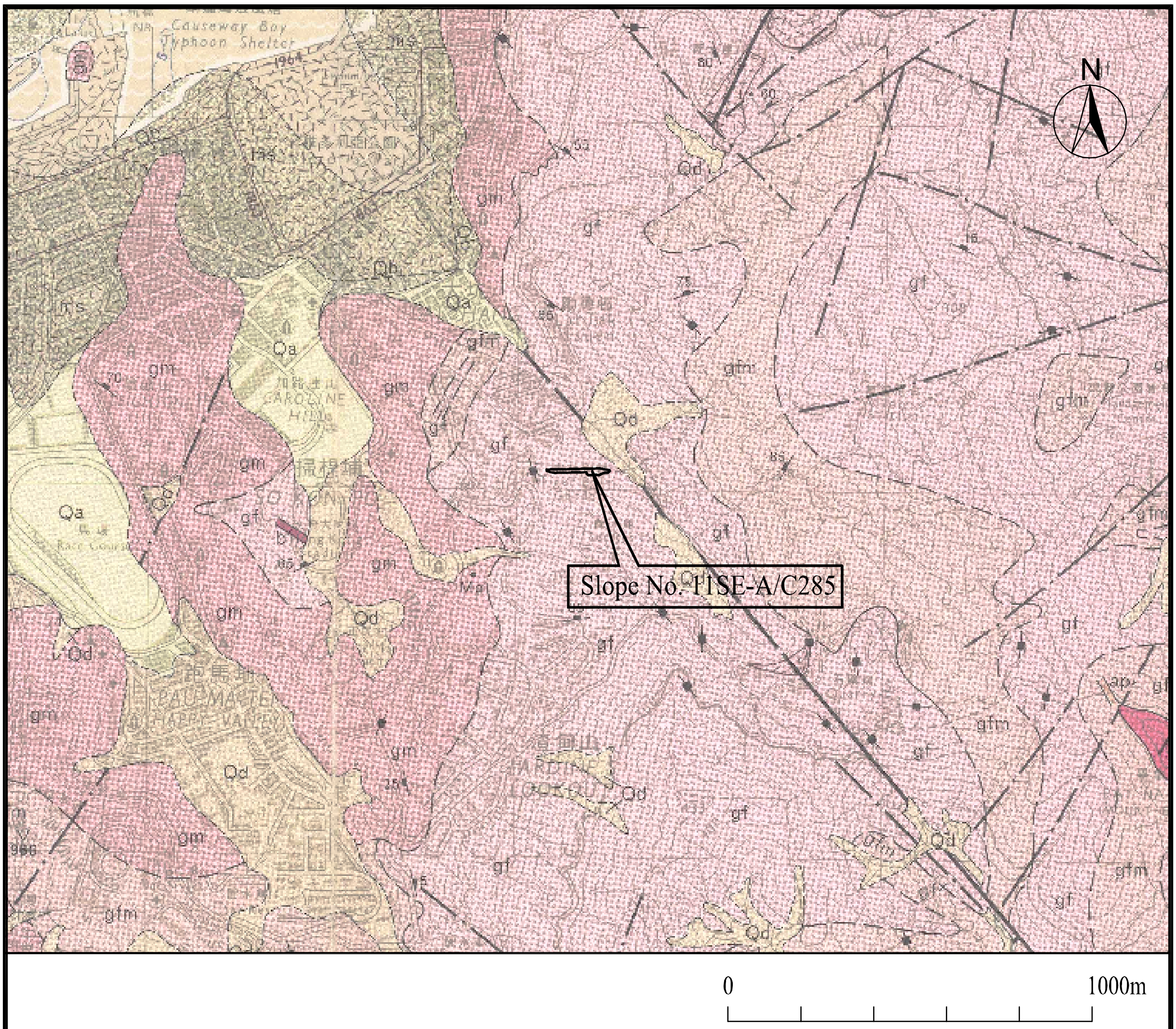
(1) Base plan is extracted from 1 : 1000 survey sheets Nos. 11SE-11A, B, C & D dated May 2003.

(2) Layout of surface drainage is from a topographical survey carried out as part of the post-landslide study.

(3) Sizes of surface channels are 225 mm on slope and 300 mm along toe and crest unless otherwise stated.

Figure 5 - Surface Drainage and Water-carrying Services

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



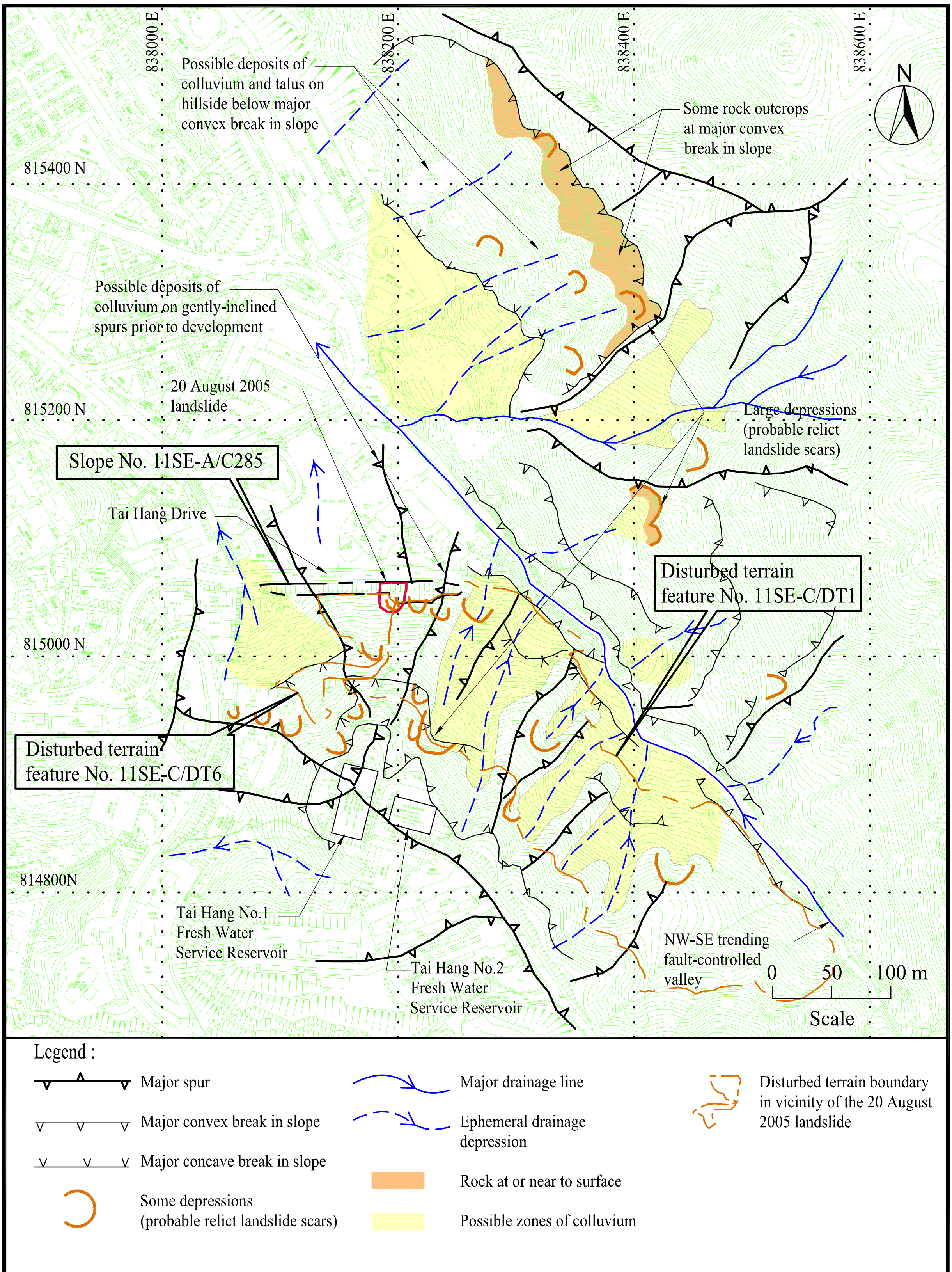
Legend :

	Natural earth and waste (Fill; sanintary fill (Qfs))
Qb	Sand (Beach deposits)
Qa	Clay/silt, sand and gravel; well-sorted to semi-sorted (Alluvium)
Qd	Unsorted sand, gravel, cobbles and boulders; clay/silt matrix (Debris flow deposits)
gf	Fine-grained granite, < 2 mm
gfm	Fine- to medium-grained granite
gm	Medium-grained granite, 2-6 mm
b	Basalt
Mo	Molybdenite
	Geological boundary
	Fault (dashed line denotes uncertainty)
	Photogeological lineament
50	Jointing (50° dip)
	Vertical jointing

Note : Figure is extracted from Hong Kong Geological Survey, Map series HGM20, Sheet No. 11, 1:20 000 scale (GCO, 1986).

Figure 6 - Regional Geology

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



Notes:
(1) Base plan is extracted from 1 : 1000 survey sheets Nos. 11SE-11A, B, C, & D dated May 2003.
(2) Slope boundary is taken from pre-landslide records of the GEO's SIS.
(3) Geomorphological boundaries are based on API.

Figure 7 - Geomorphology Plan

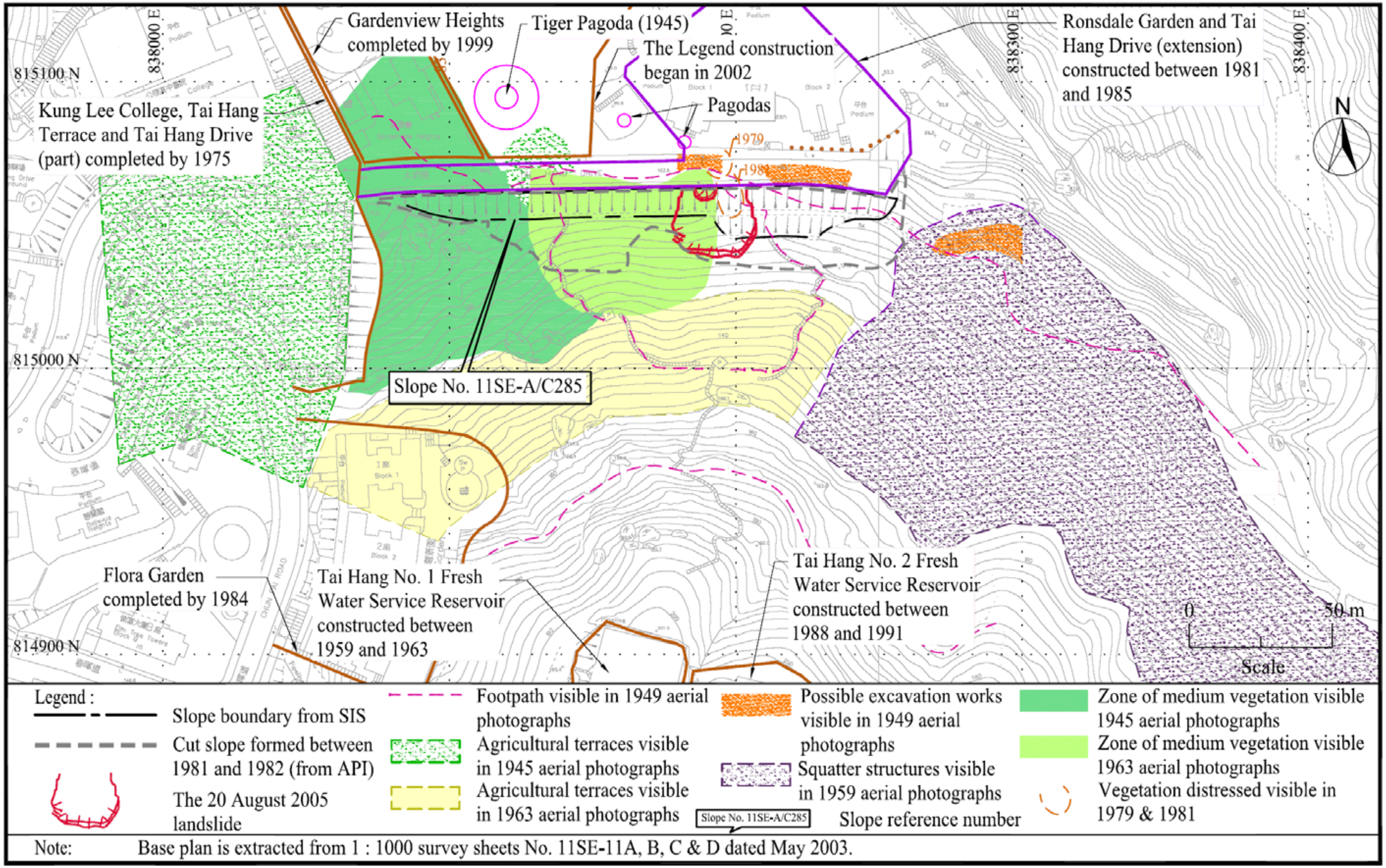


Figure 8 - Site Development History

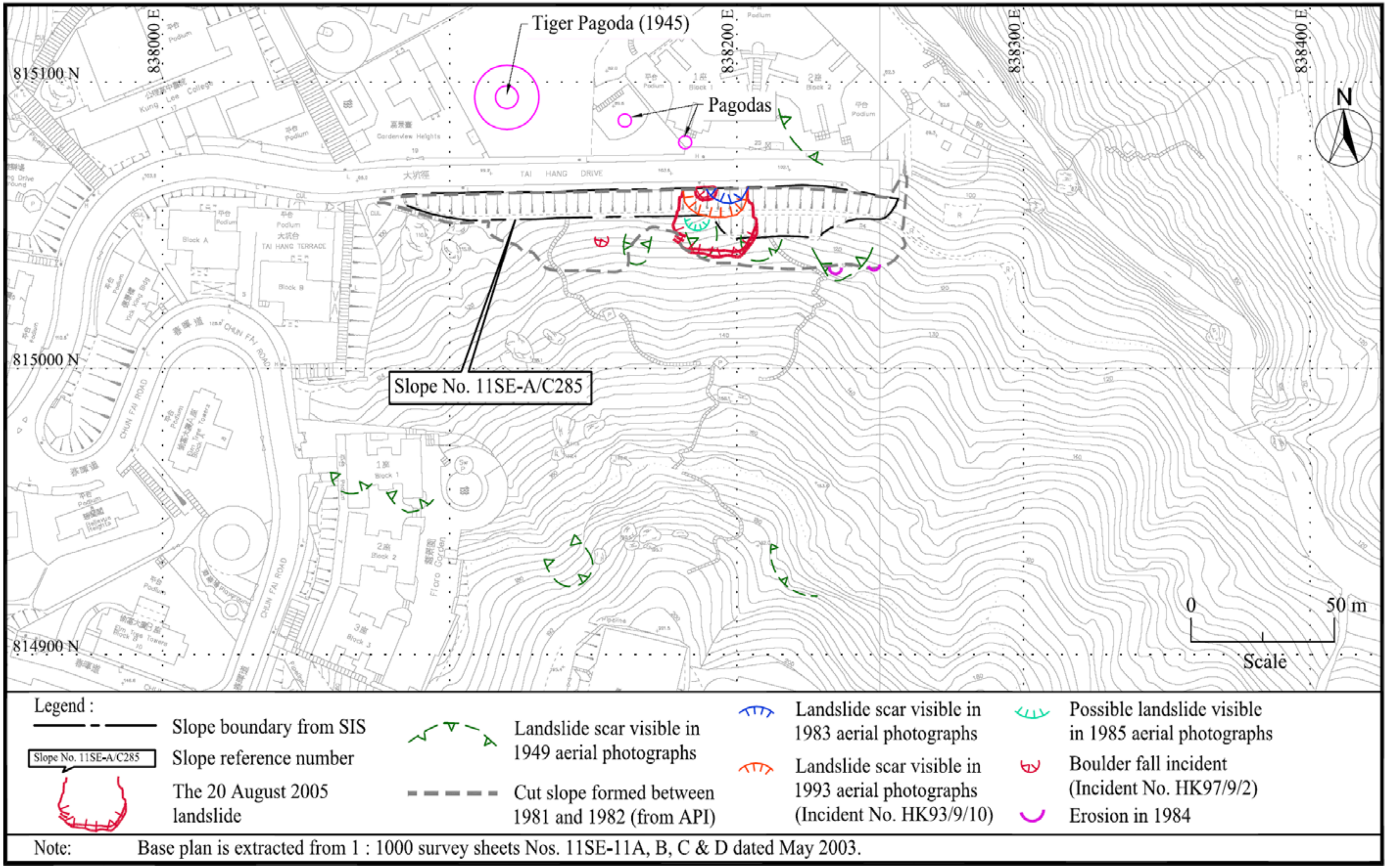


Figure 9 - Past Instability

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

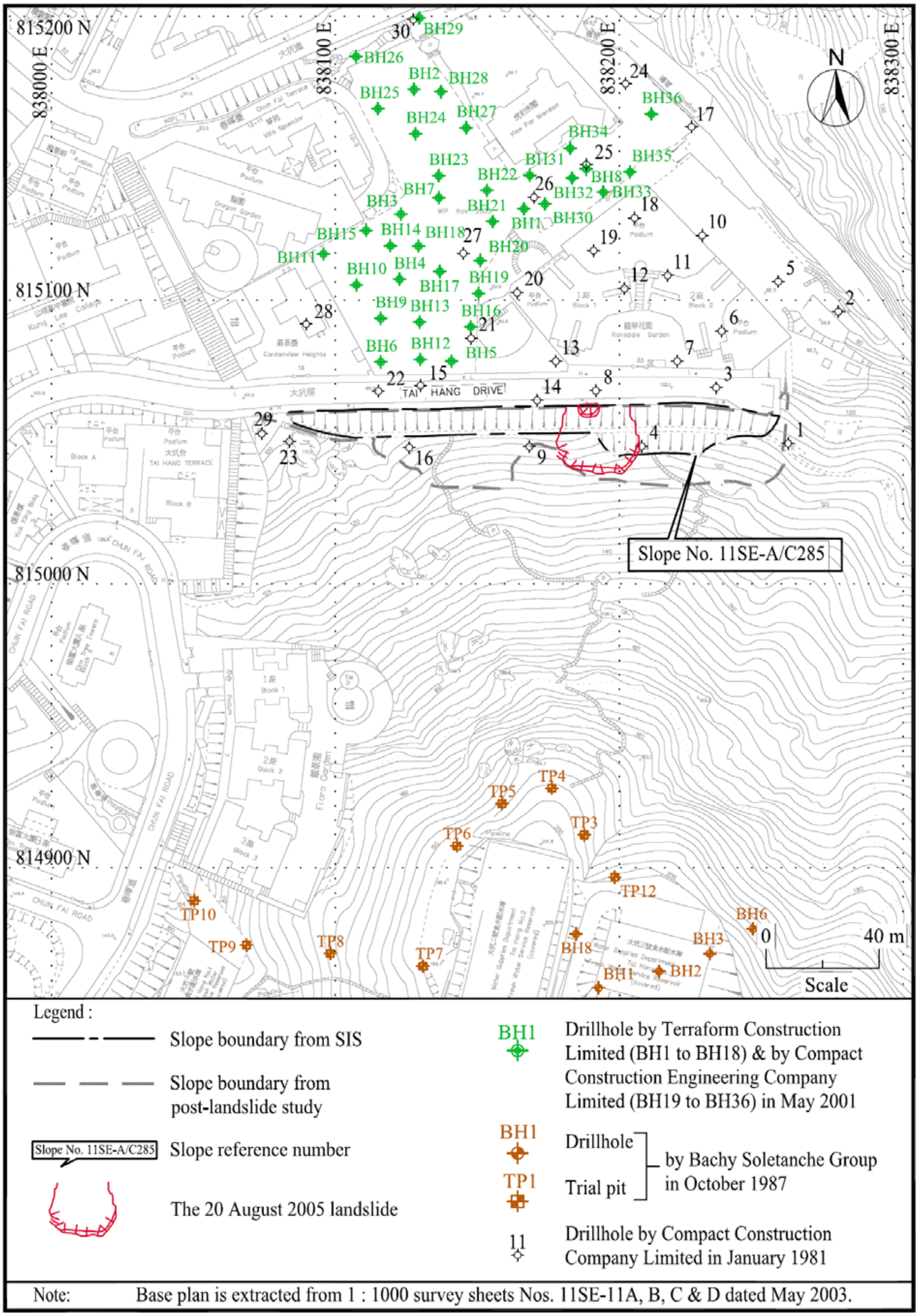
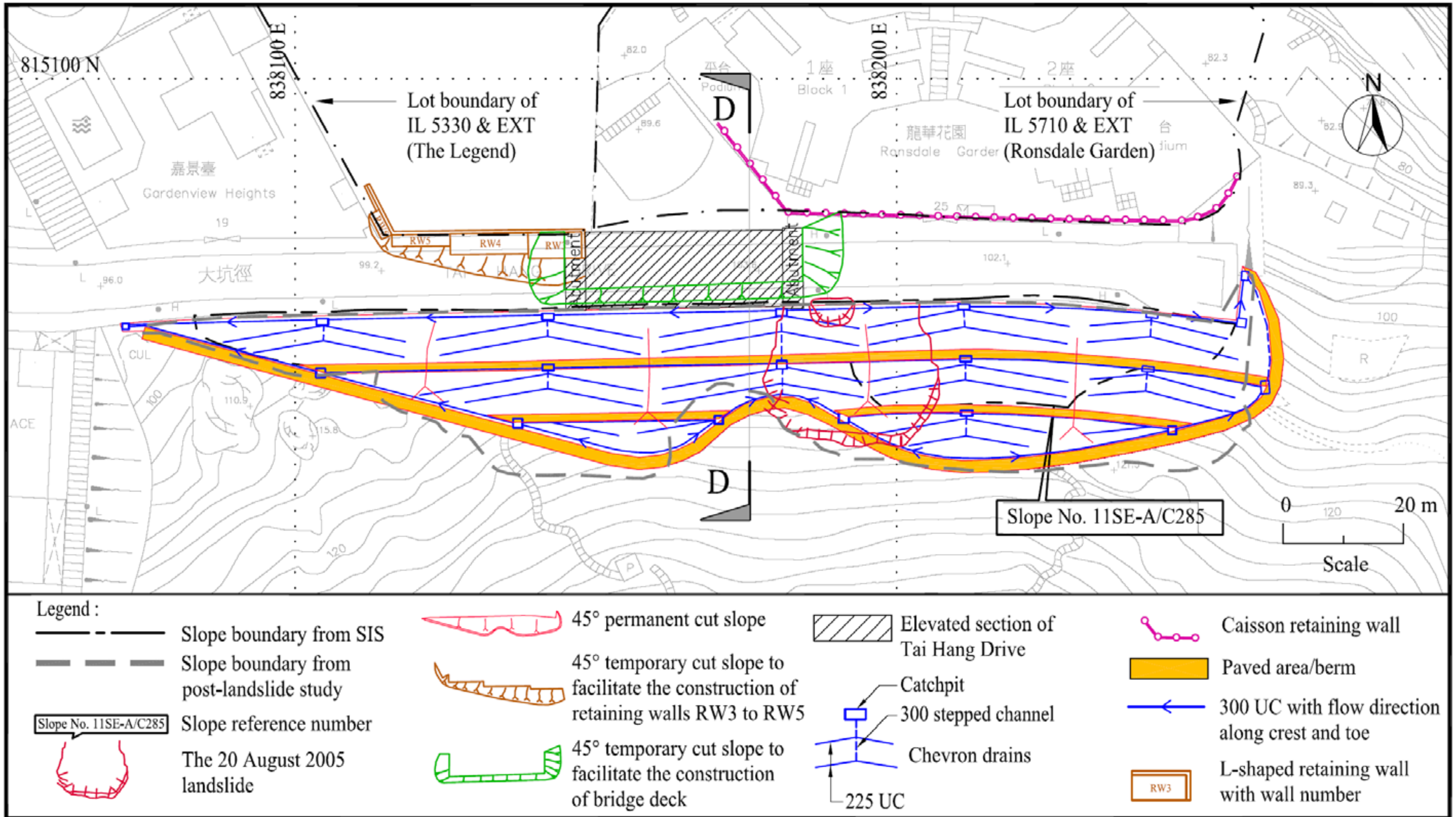


Figure 10 - Plan of Previous Ground Investigation

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



Notes: (1) The permanent and temporary site formation works shown were carred out between 1981 and 1984 in conjunction with the residential development at Ronsdale Garden.

(2) Layout and details of permanent and temporary site formation works are based on approved plans held by the BD under file ref. BLD(B) 6/1138/80.

Figure 11 - Site Formation Works at and in the Vicinity of the Site

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

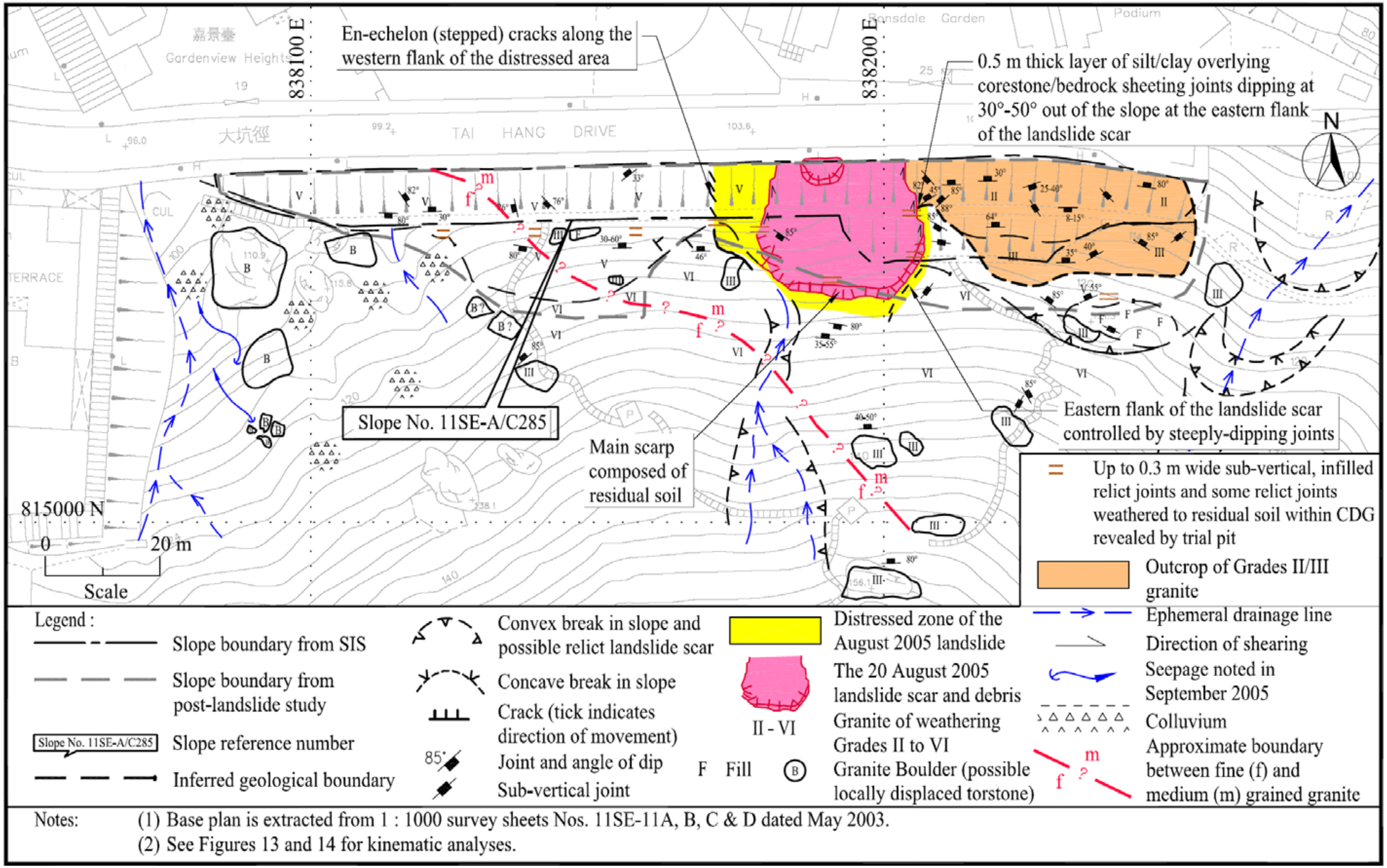
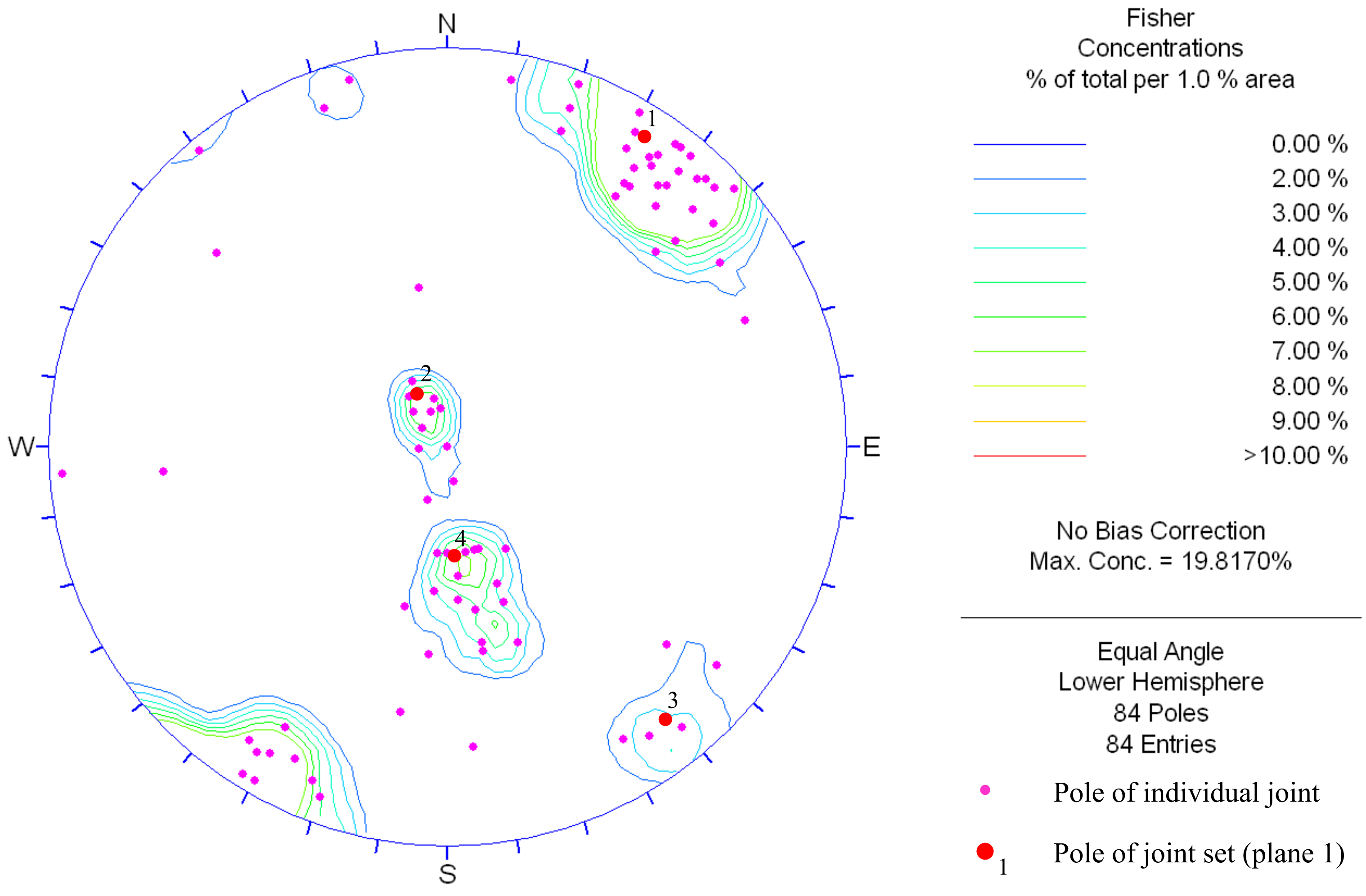


Figure 12 - Geological Mapping of the Landslide Site

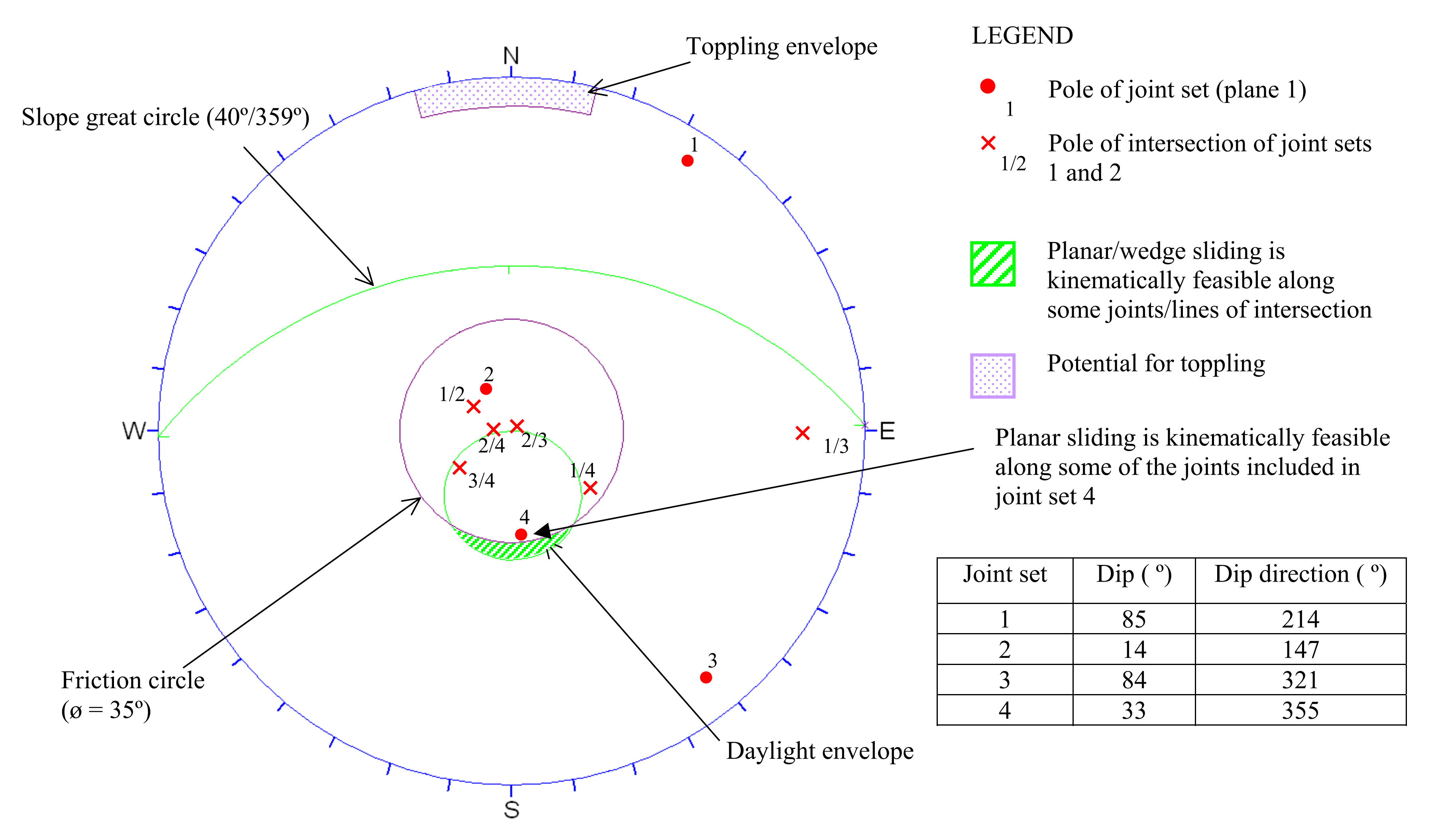
Table of Contents
Table of Contents
Table of Contents
Table of Contents



Note: See Figure 12 for rock joint mapping data.

Figure 13 - Pole Concentration Contour for Joint Measurements

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

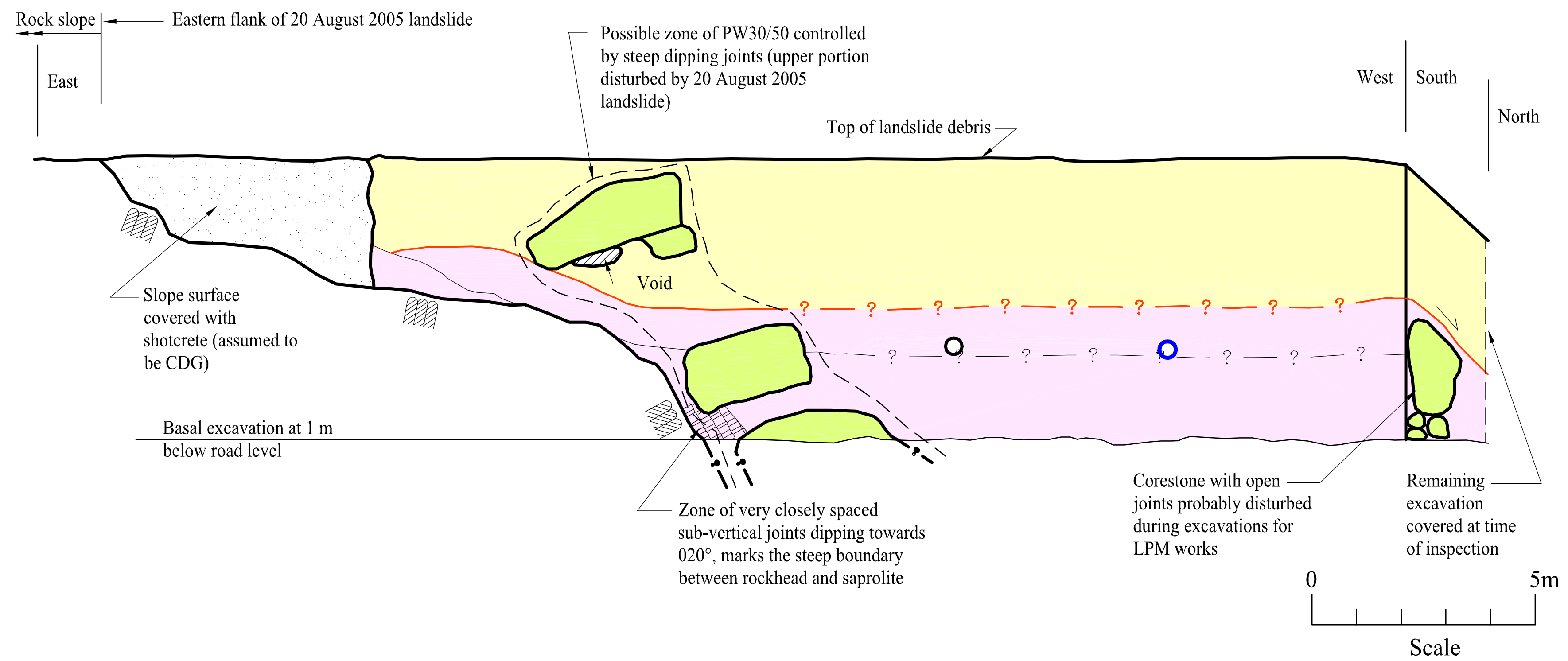


Joint set	Dip (º)	Dip direction (º)
1	85	214
2	14	147
3	84	321
4	33	355

Note: Joint sets interpreted from pole data based on contouring of pole concentrations using the Fisher Concentrations Method.

Figure 14 - Stereographic Projection of Discontinuity Survey Data

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



Legend :

(yellow)	Landslide debris comprising disturbed CDG and corestones of MDG
(pink)	Relatively intact CDG (and some HDG) below slip plane
(green)	Corestone of MDG/H-MDG
○ (black)	Horizontal drain (dry)
○ (blue)	Horizontal drain (with seepage)
— ? — ? — (red)	Basal slip plane of the August 2005 landslide (? denotes uncertainty)
— ? — ? —	Relict sheeting joint with soil in filling and roots (? denotes uncertainty)
(solid line / hatching)	Rockhead Boundary

Notes:
(1) Mapping of the excavation was carried out by FSW during LPM works on 13 November 2006.
(2) The excavation was supported by a temporary pipe pile wall at the time of mapping.
(3) Refer to Figure 2 for location of Section C - C.

Figure 15 - Section C - C Across the Landslide

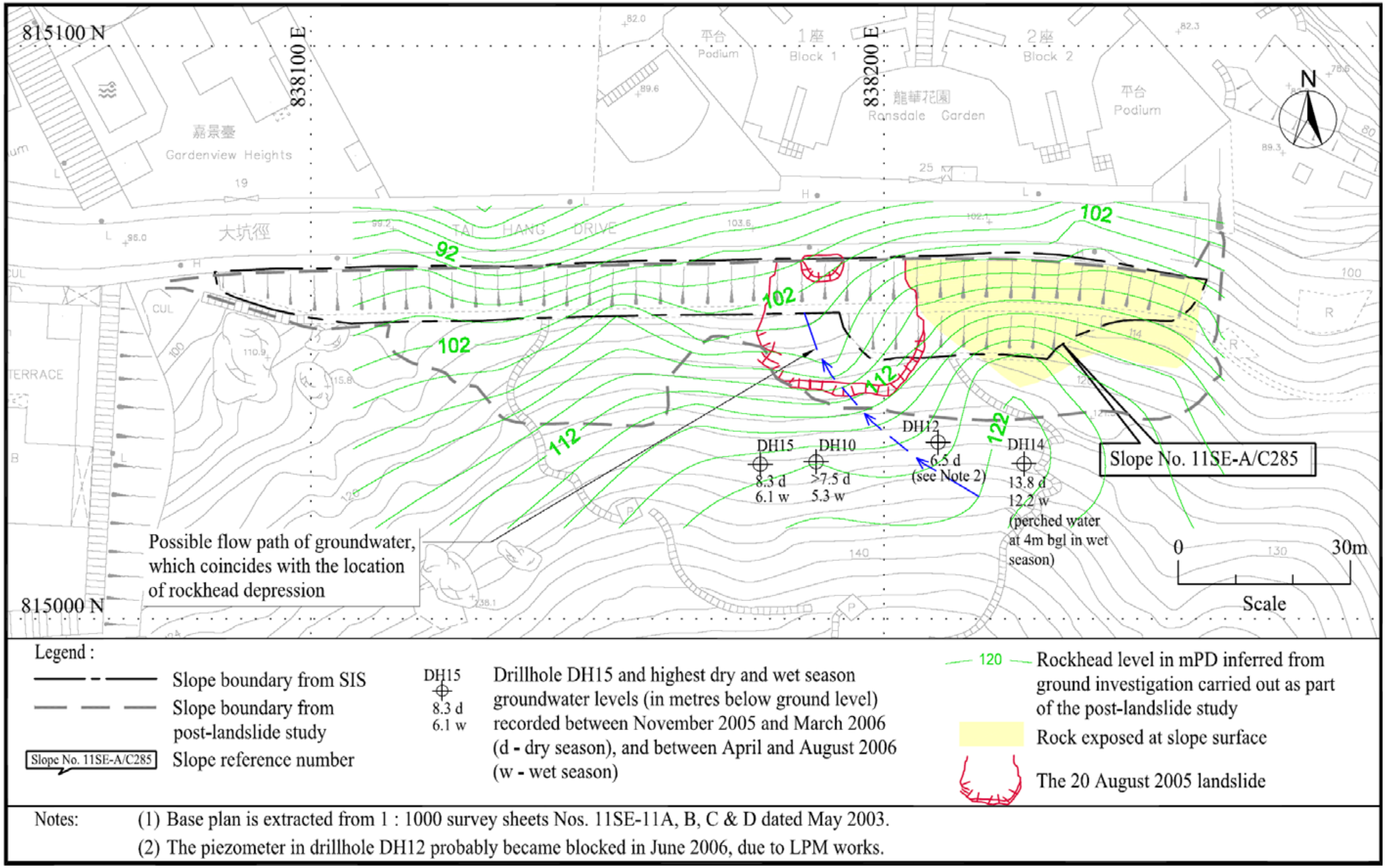
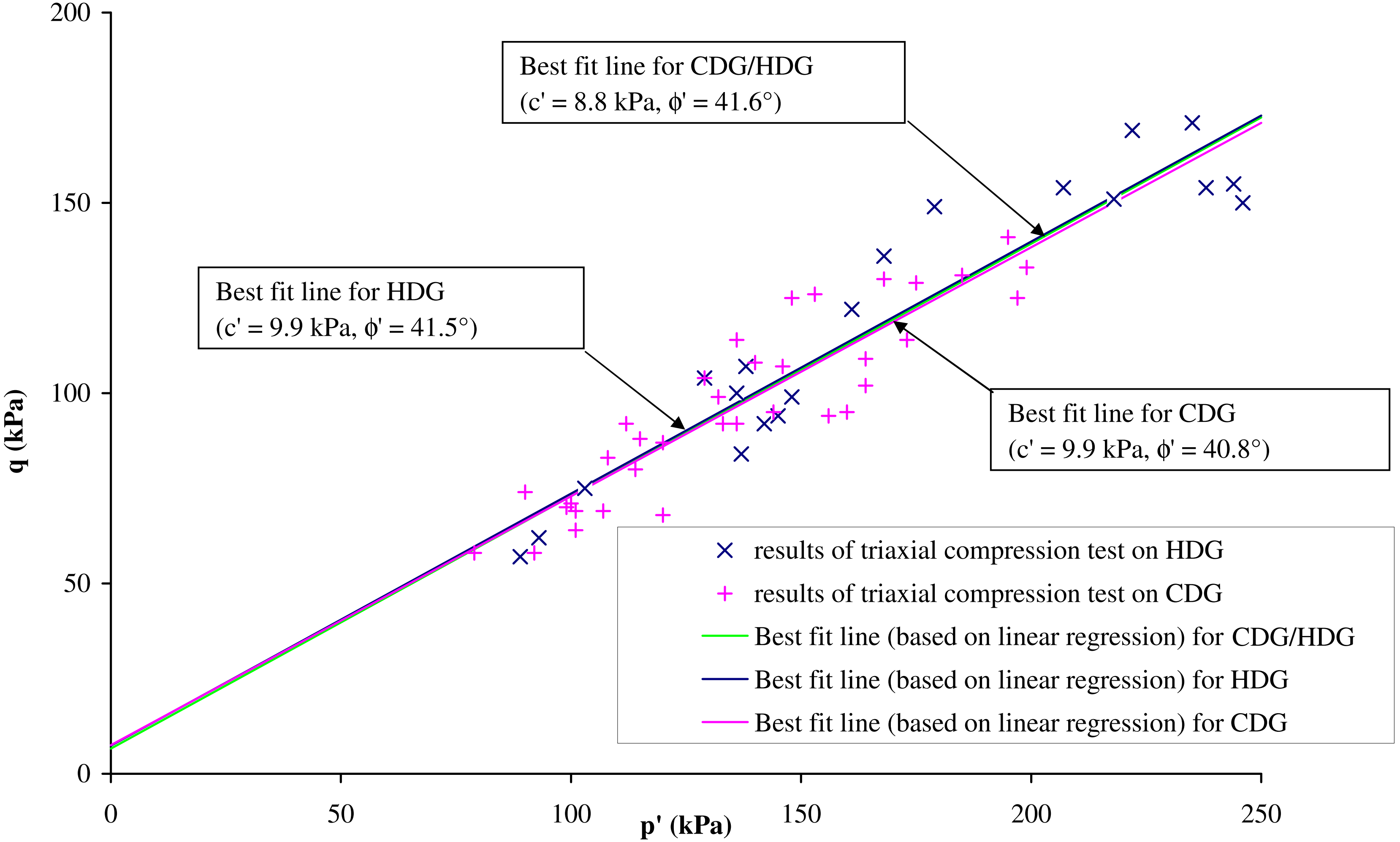


Figure 16 - Inferred Rockhead Contours

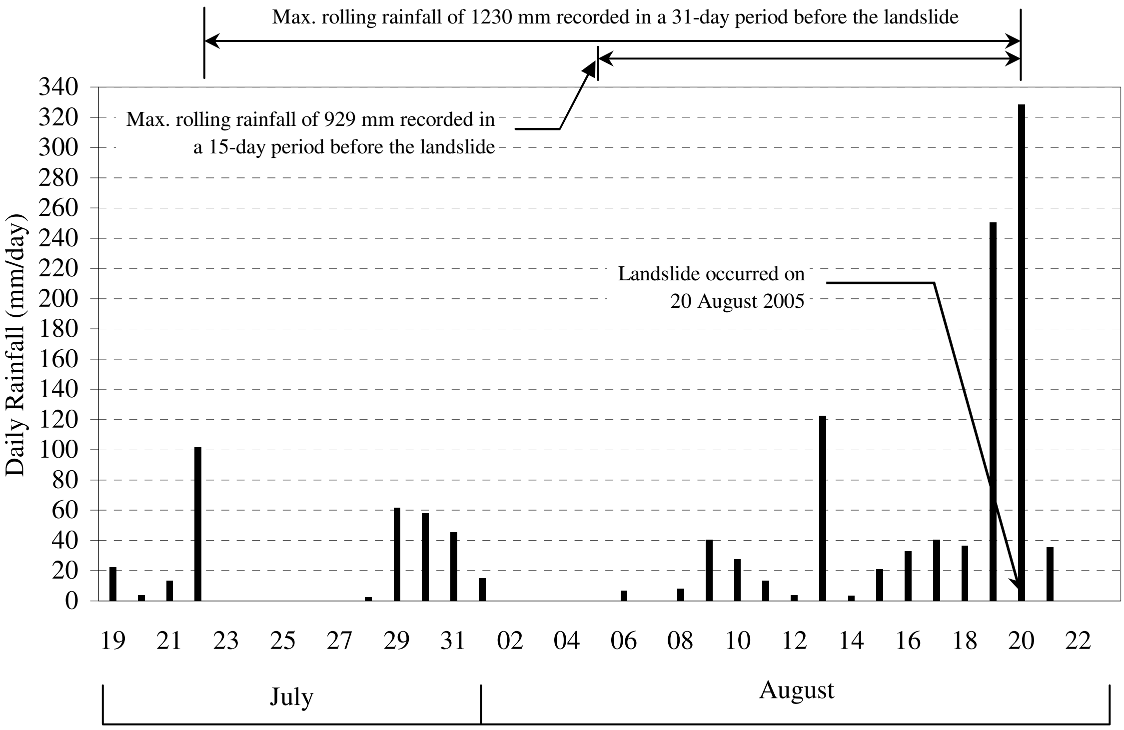
Table of Contents
Table of Contents
Table of Contents
Table of Contents



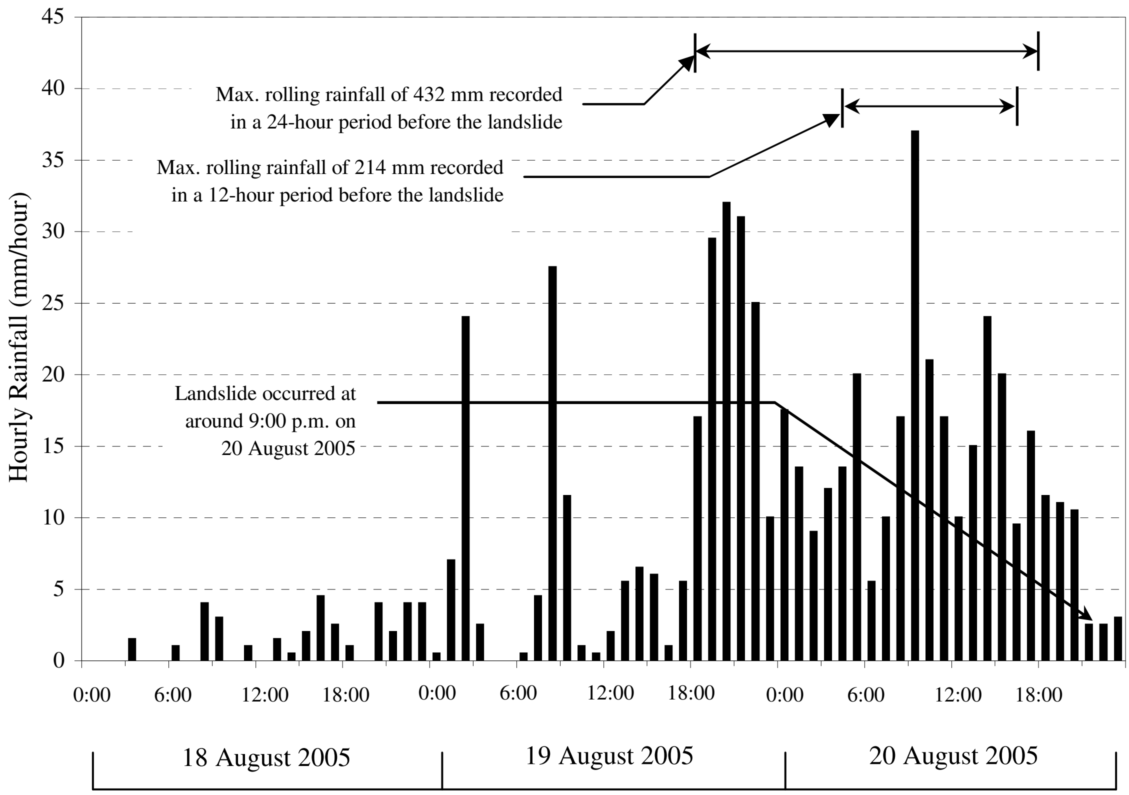
Note: Triaxial compression tests were carried out by Gammon Construction Limited between December 2005 and February 2006

Figure 17 - p'-q Plots for CDG and HDG

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



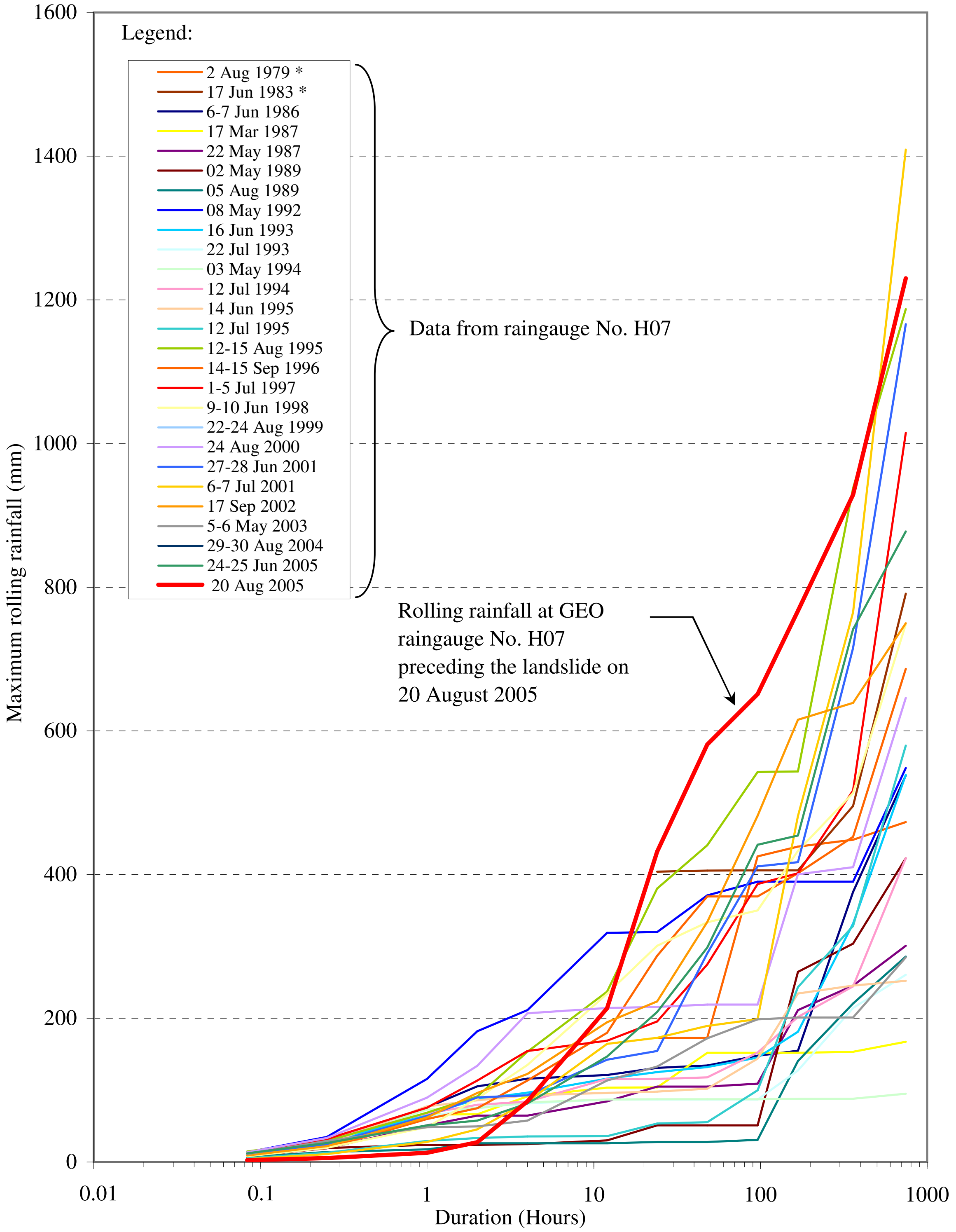
(a) Daily Rainfall Recorded at GEO Raingauge No. H07 between 19 July 2005 and 23 August 2005



(b) Hourly Rainfall Recorded at GEO Raingauge No. H07 between 18 August 2005 and 20 August 2005

Figure 18 - Daily and Hourly Rainfall Recorded at GEO Raingauge No. H07

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

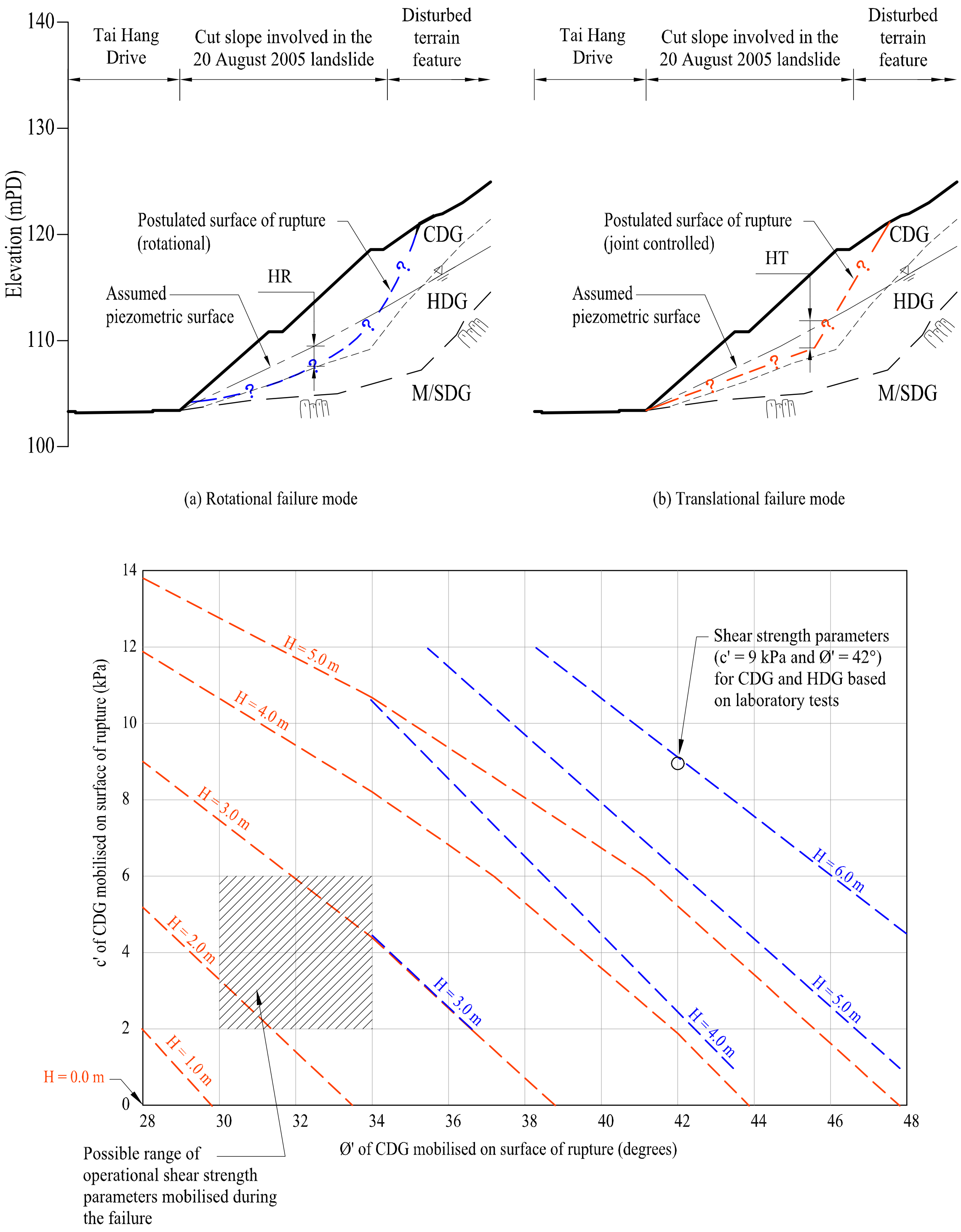


Notes: (1) Rainfall data are evaluated from 5-minute readings (with the exception of those denoted with an asterisk, in which cases daily rainfall data are used) from GEO raingauge No. H07 (located about 860 m west of the site).

(2) Rolling rainfall of previous rainstorms calculated at GEO raingauge No. H07 since October 1978 when the raingauge became operational.

Figure 19 - Maximum Rolling Rainfall for the Rainstorm Preceding the Landslide and Selected Previous Major Rainstorms Recorded at GEO Raingauge No. H07

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



Legend :
— — — Factor of safety equal to unity (i.e. limiting equilibrium) for rotational failure mode
- - - - Factor of safety equal to unity (i.e. limiting equilibrium) for translational failure mode

Note : The pre-failure slope profile and the two possible surfaces of rupture are based on topographical survey plans, photographic records, post-failure observations and ground investigation.

Figure 20 - Summary of Sensitivity Analyses

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

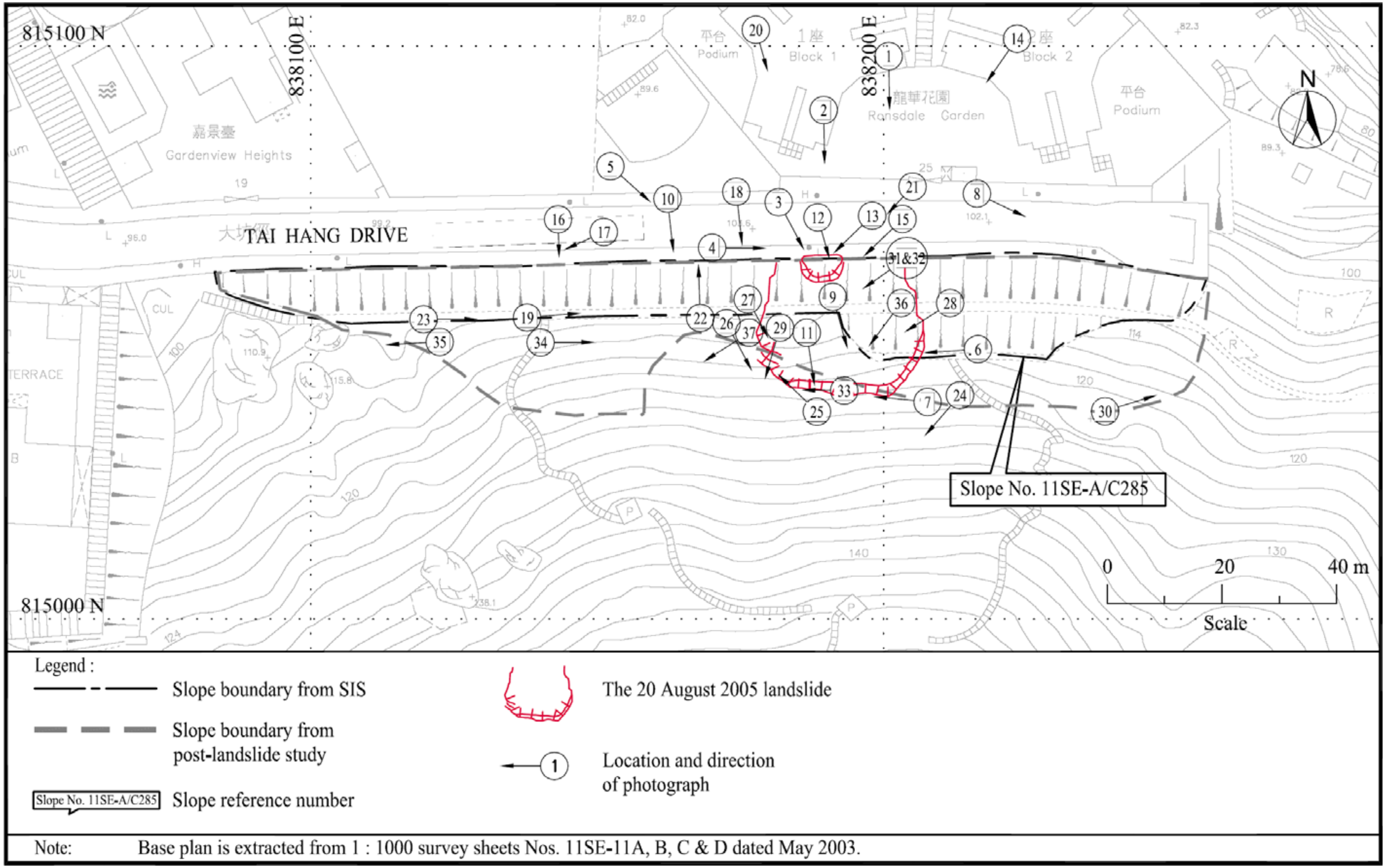


Figure 21 - Locations and Directions of Photographs

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 20 August 2005 Landslide (Photograph taken by FSW on 24 August 2005)

Note: See Figure 21 for location and direction of photograph.

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

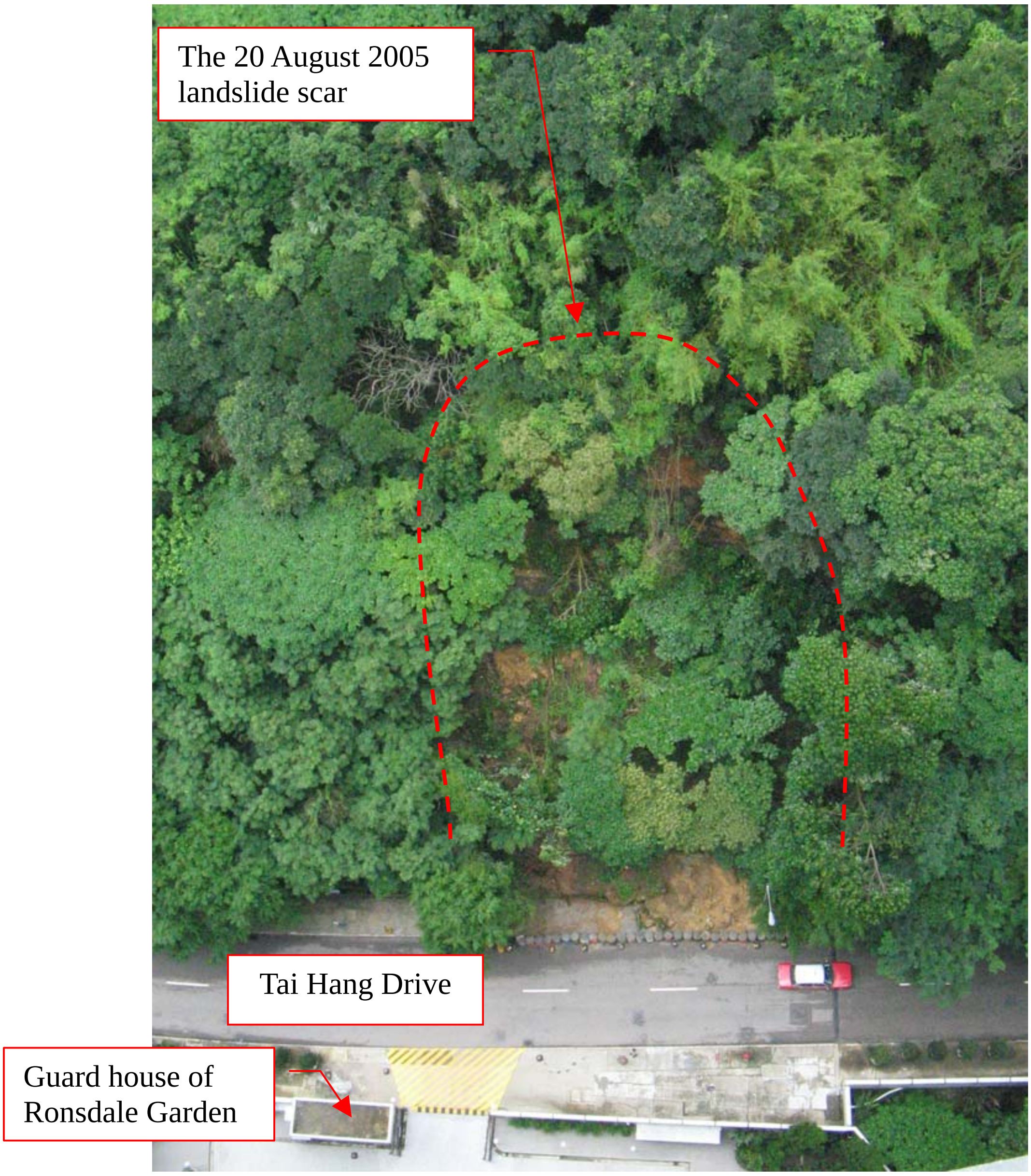


Plate 2 - Top View of the 20 August 2005 Landslide and the Disturbed Terrain Features Above (Photograph taken by FSW on 22 August 2005)

Note: See Figure 21 for location and direction of photograph.

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

Plate 3 - View of the Localised Detachment at the Lower Portion of the Displaced Ground Mass
(Photograph taken by FSW on 22 August 2005)

Note: See Figure 21 for location and direction of photograph.

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

Plate 4 - Side View of the 20 August 2005 Landslide (Photograph taken by FSW on 22 August 2005)

Note: See Figure 21 for location and direction of photograph.

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

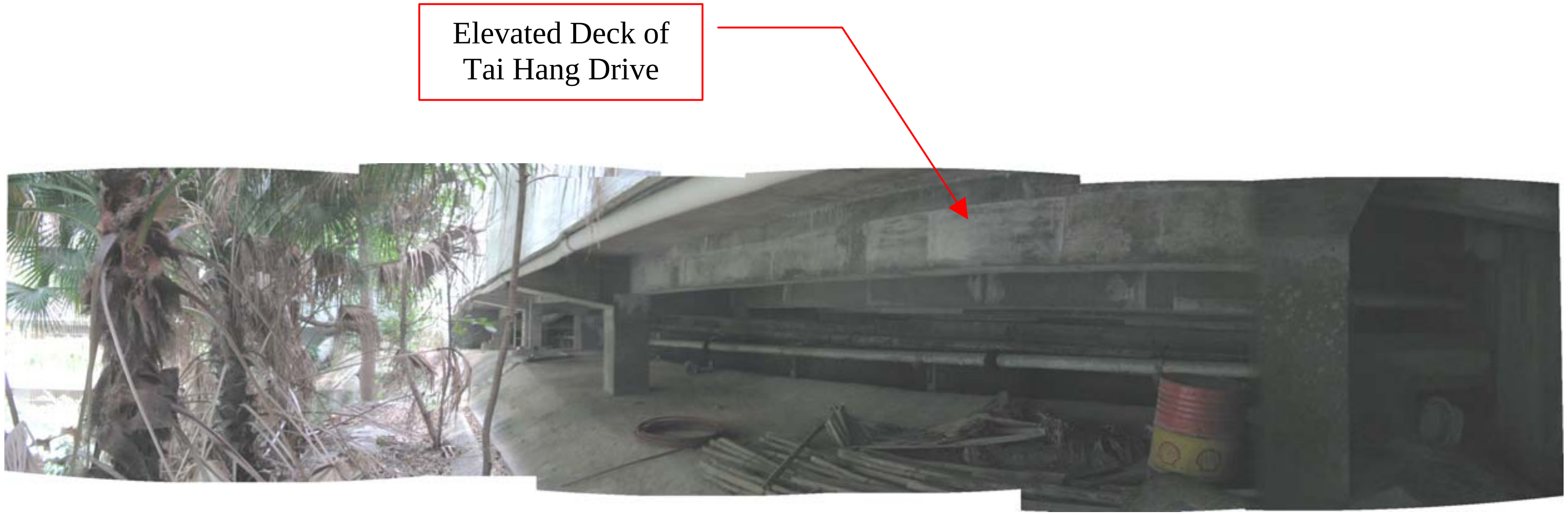


Plate 5 - Side View of the Elevated Section of Tai Hang Drive (Photograph taken by FSW on 22 August 2005)

Note: See Figure 21 for location and direction of photograph.

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

Plate 6 - Side View at the Eastern Flank of the 20 August 2005 Landslide Looking West (Photograph taken by FSW on 22 August 2005)

Note: See Figure 21 for location and direction of photograph.

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

Plate 7 - Side View of the Main Scarp of the 20 August 2005 Landslide
(Photograph taken by FSW on 22 August 2005)

Note: See Figure 21 for location and direction of photograph.

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

Plate 8 - General View of the Eastern Portion of Slope No. 11SE-A/C285
(Photograph taken by FSW on 15 December 2005)

Note: See Figure 21 for location and direction of photograph.

Table of Contents

Table of Contents

Table of Contents

Table of Contents

Plate 9 - View of the Main Scarp of the 20 August 2005 Landslide (Photograph taken by FSW on 22 August 2005)

Note: See Figure 21 for location and direction of photograph.

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

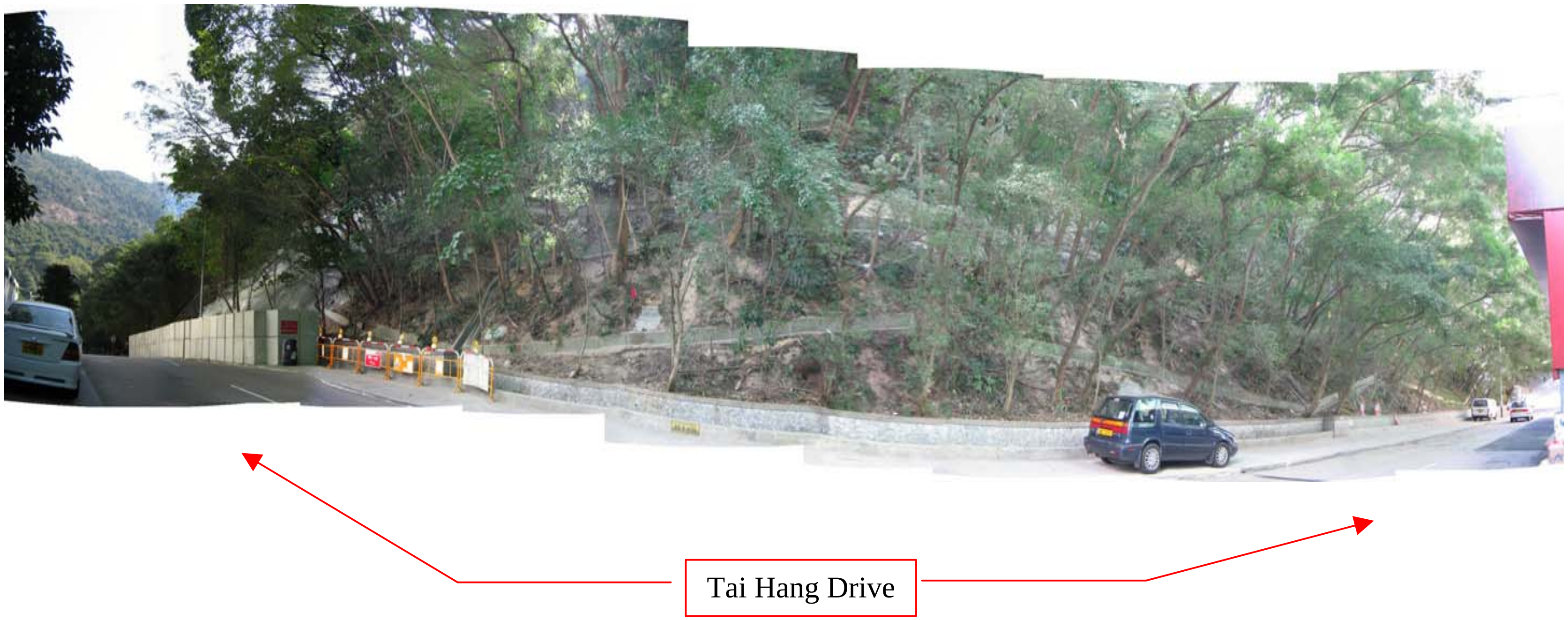


Plate 10 - General View of the Western Portion of Slope No. 11SE-A/C285 (Photograph taken by FSW on 19 December 2005)

Note: See Figure 21 for location and direction of photograph.

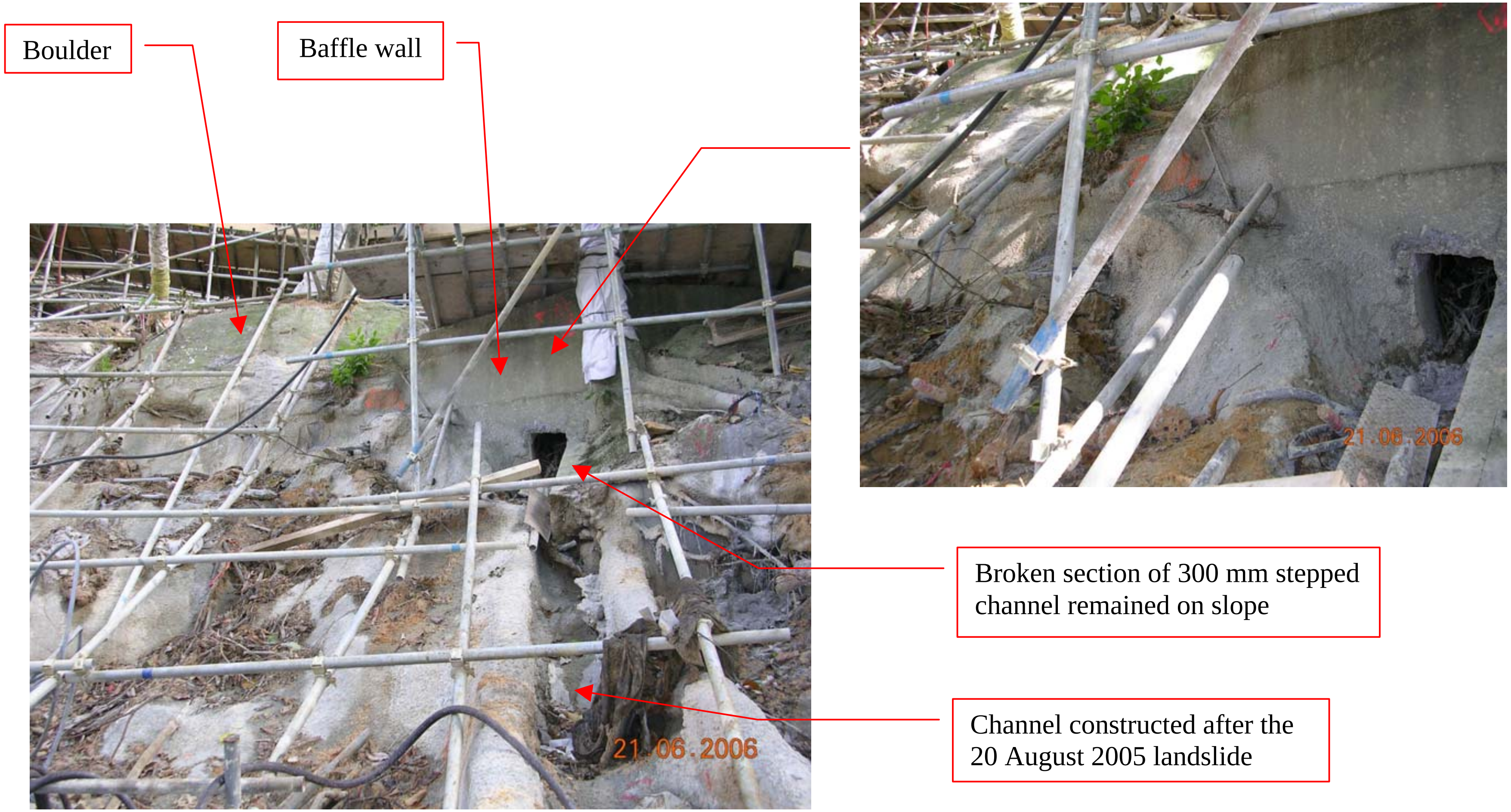


Plate 11 - View of the Baffle Wall above Slope No. 11SE-A/C285 (Photograph taken by FSW on 21 June 2006)

Note: See Figure 21 for location and direction of photograph.

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

Plate 12 - Photographic Record of the Landslide on Slope No. 11SE-A/C285 in September 1993 (Photograph taken by GEO on 27 September 1993)

Note: See Figure 21 for location and direction of photograph.

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

Plate 13 - View Showing the Completed Repair Works on Slope No. 11SE-A/C285 in June 1994 Following the Landslide in September 1993 (Photograph taken by GEO on 27 June 1994)

Note: See Figure 21 for location and direction of photograph.

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

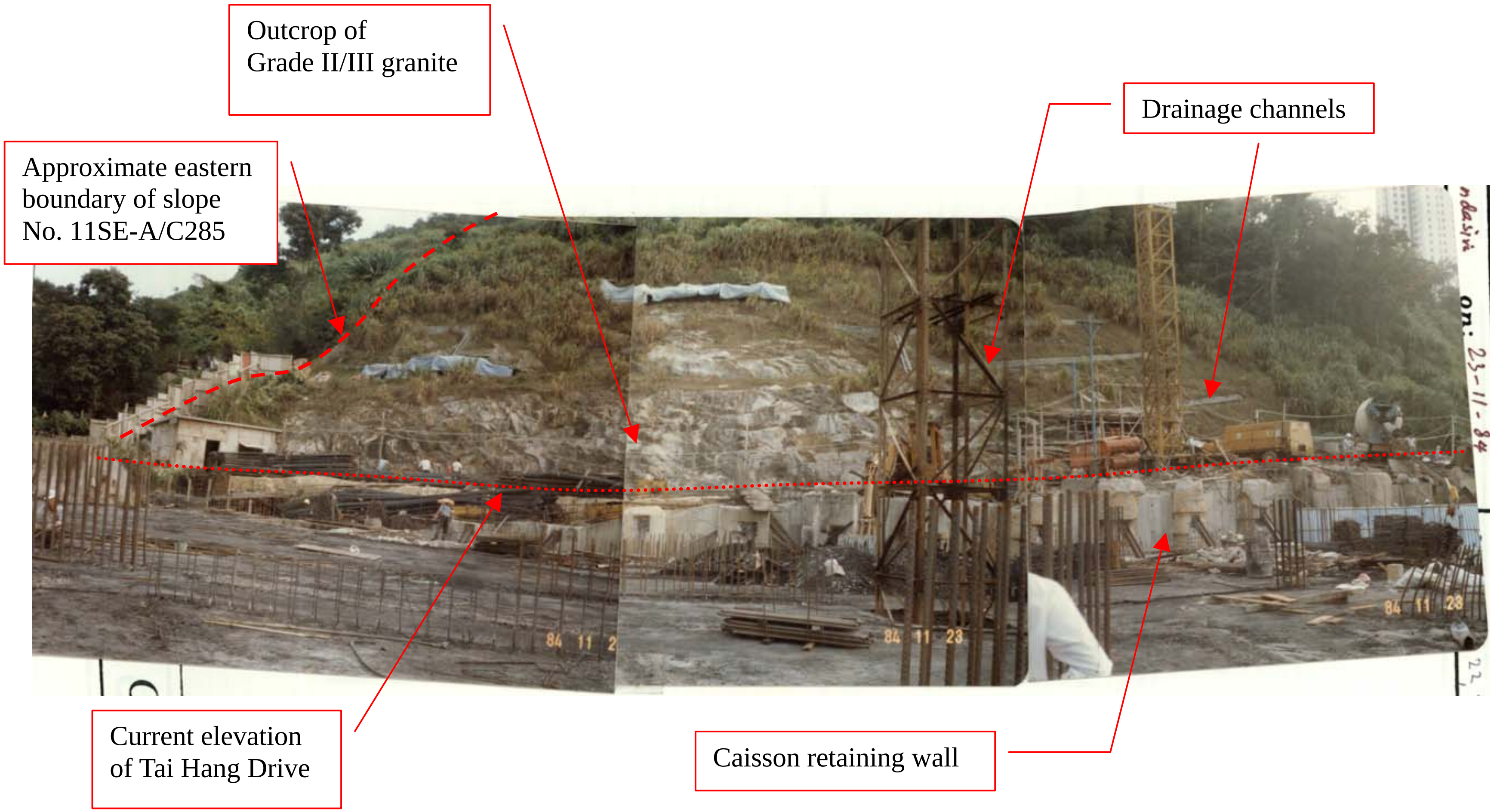


Plate 14 - View of Slope No. 11SE-A/C285 in November 1984 (Photograph taken by GCO on 23 November 1984)

Note: See Figure 21 for location and direction of photograph.

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

Plate 15 - View of the Central Portion of Slope No. 11SE-A/C285 in January 1996
(Photograph taken by the SIRST Consultant on 12 January 1996)

Note: See Figure 21 for location and direction of photograph.

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

Plate 16 - View of the Western Portion of Slope No. 11SE-A/C285 in February 1998
(Photograph taken on 19 February 1998 extracted from HyD's EI Report)

Note: See Figure 21 for location and direction of photograph.

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

Plate 17 - View of the Central and Western Portions of Slope No. 11SE-A/C285 in September 1998 (Photograph taken on 10 September 1998 extracted from HyD's EI Report)

Note: See Figure 21 for location and direction of photograph.

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

Plate 18 - View of the Central and Western Portions of Slope No. 11SE-A/C285 in November 2002 (Photograph taken on 27 November 2002 extracted from HyD's EI Report)

Note: See Figure 21 for location and direction of photograph.

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

Plate 19 - Side View of the Western Portion of Slope No. 11SE-A/C285 Looking East (Photograph taken on 27 November 2002 extracted from HyD's EI Report)

Note: See Figure 21 for location and direction of photograph.

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

Plate 20 - General View of Disturbed Terrain Feature No. 11SE-C/DT1 Looking Southeast (Photograph taken on 18 June 2002 extracted from Lands D's EI Report)

Note: See Figure 21 for location and direction of photograph.

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

Plate 21 - General View of Disturbed Terrain Feature No. 11SE-C/DT6 Looking Southwest (Photograph taken on 21 November 2002 extracted from Lands D's EI Report)

Note: See Figure 21 for location and direction of photograph.

Plate 22 - Stepped Channel Showing Signs of Distress Resulting from the Landslide and from Scouring due to Excessive Flow of Water (Photograph taken by FSW on 24 August 2005)

Note: See Figure 21 for location and direction of photograph.

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

Plate 23 - View of a Surface Channel with Minor Cracks (Photograph taken by FSW on 24 August 2005)

Note: See Figure 21 for location and direction of photograph.

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

Plate 24 - View of a Cracked Chunam Cover above the Main Scarp (Photograph taken by FSW on 24 August 2005)

Note: See Figure 21 for location and direction of photograph.

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

Plate 25 - Side View of the Slope below the Baffle Wall (Photograph taken by FSW on 21 June 2006)

Note: See Figure 21 for location and direction of photograph.

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

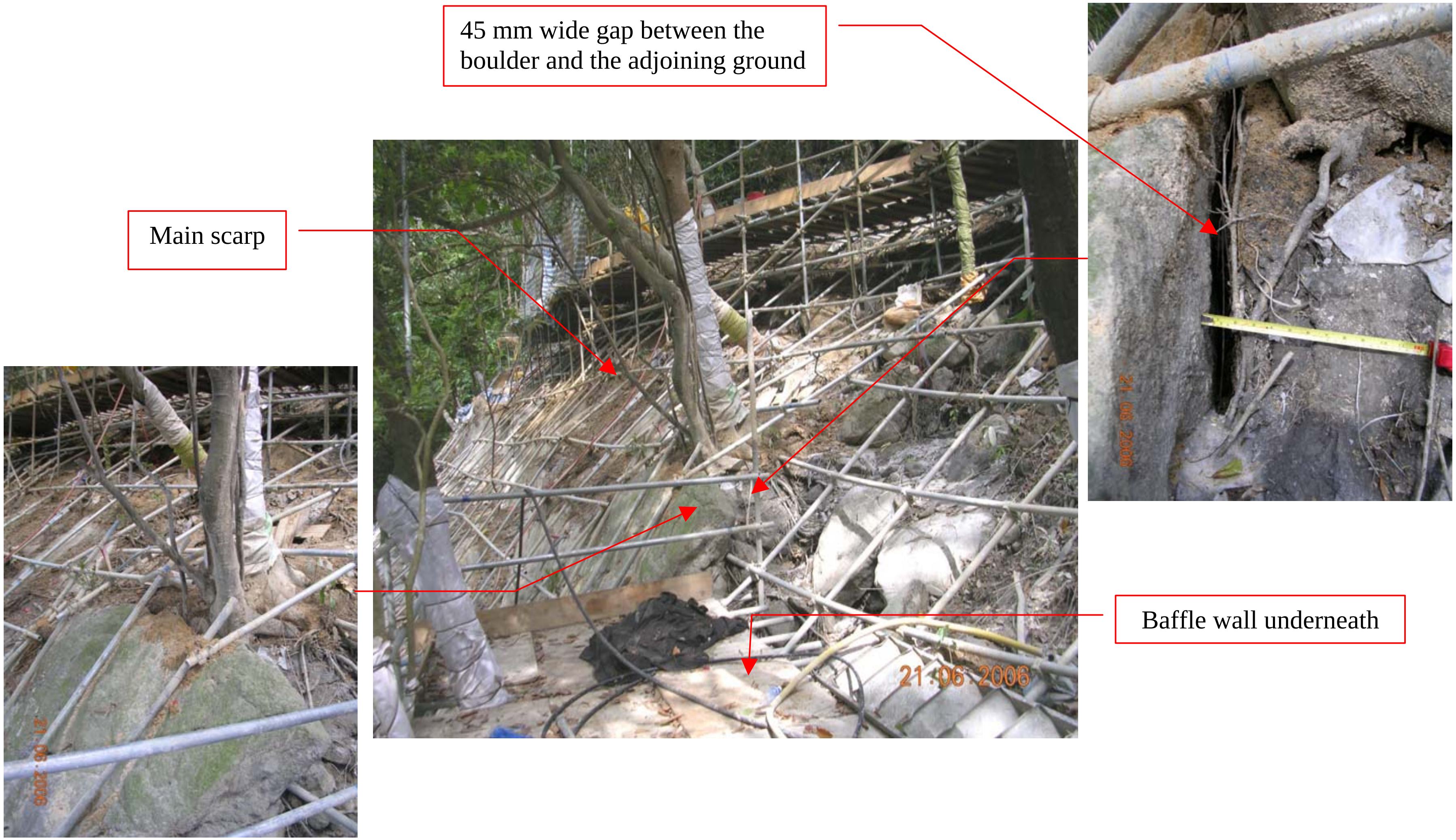


Plate 26 - View of a Boulder Adjacent to the Baffle Wall (Photograph taken by FSW on 21 June 2006)

Note: See Figure 21 for location and direction of photograph.

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

Plate 27 - View of a Cracked Chunam Cover at the Western Flank (Photograph taken by FSW on 24 August 2005)

Note: See Figure 21 for location and direction of photograph.

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

Plate 28 - View of the Soil/Rock Interface at the Lower Slope Batter
(Photograph taken by FSW on 24 August 2005)

Note: See Figure 21 for location and direction of photograph.

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

Plate 29 - View of the Minor Slope Displacement adjacent to the Baffle Wall at the Southwestern Part of the Landslide Scar
(Photograph taken by FSW on 24 August 2005)

Note: See Figure 21 for location and direction of photograph.

Plate 30 - View of the Distressed Zone behind the Southeastern Part of the Landslide Scar
(Photograph taken by FSW on 24 August 2005)

Note: See Figure 21 for location and direction of photograph.

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

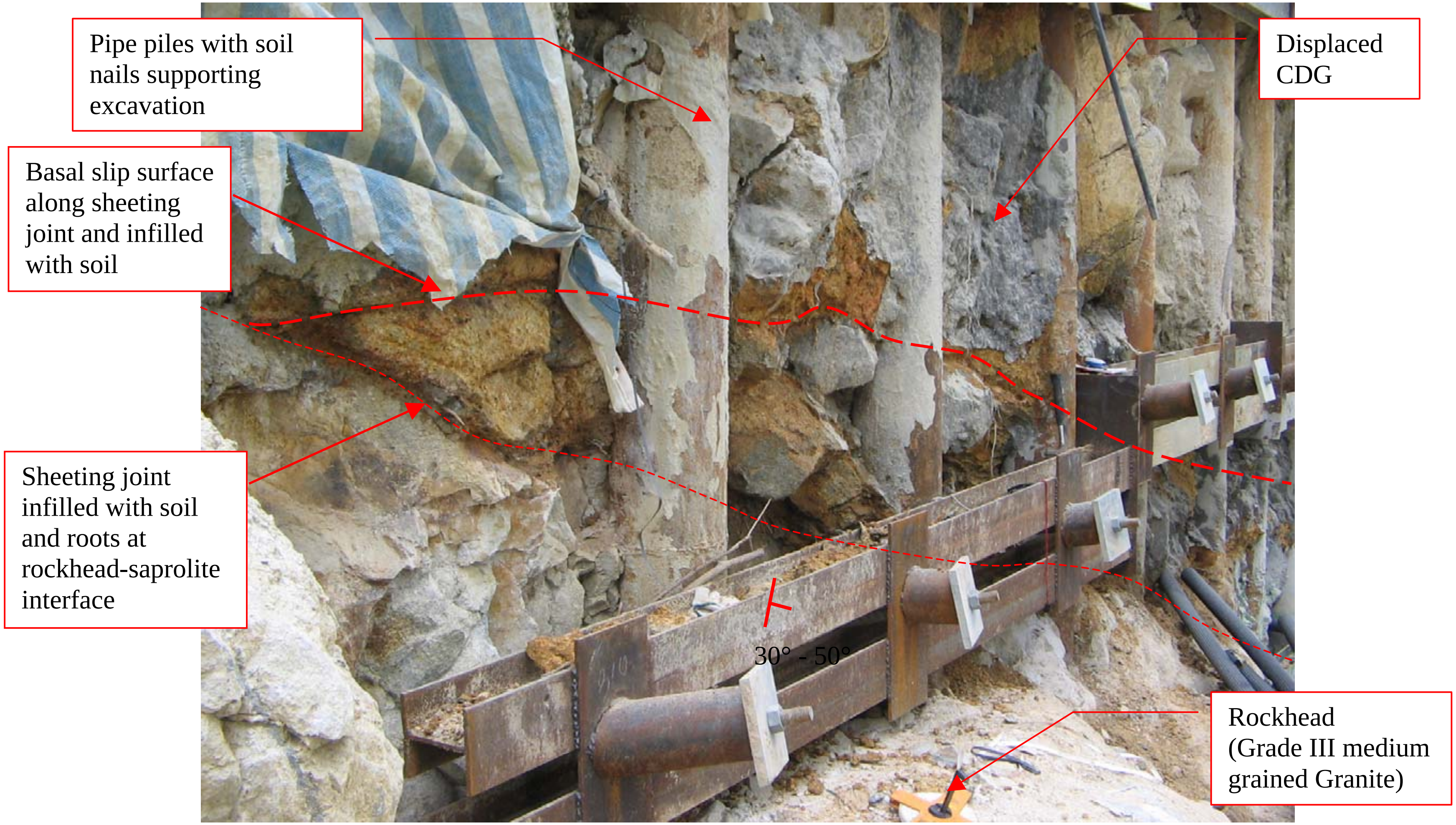


Plate 31 - View of the Basal Slip Surface and Sheeting Joint above Rockhead in the Excavation for LPM Works
(Photograph taken by FSW on 13 November 2006)

Note: See Figure 21 for location and direction of photograph.

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

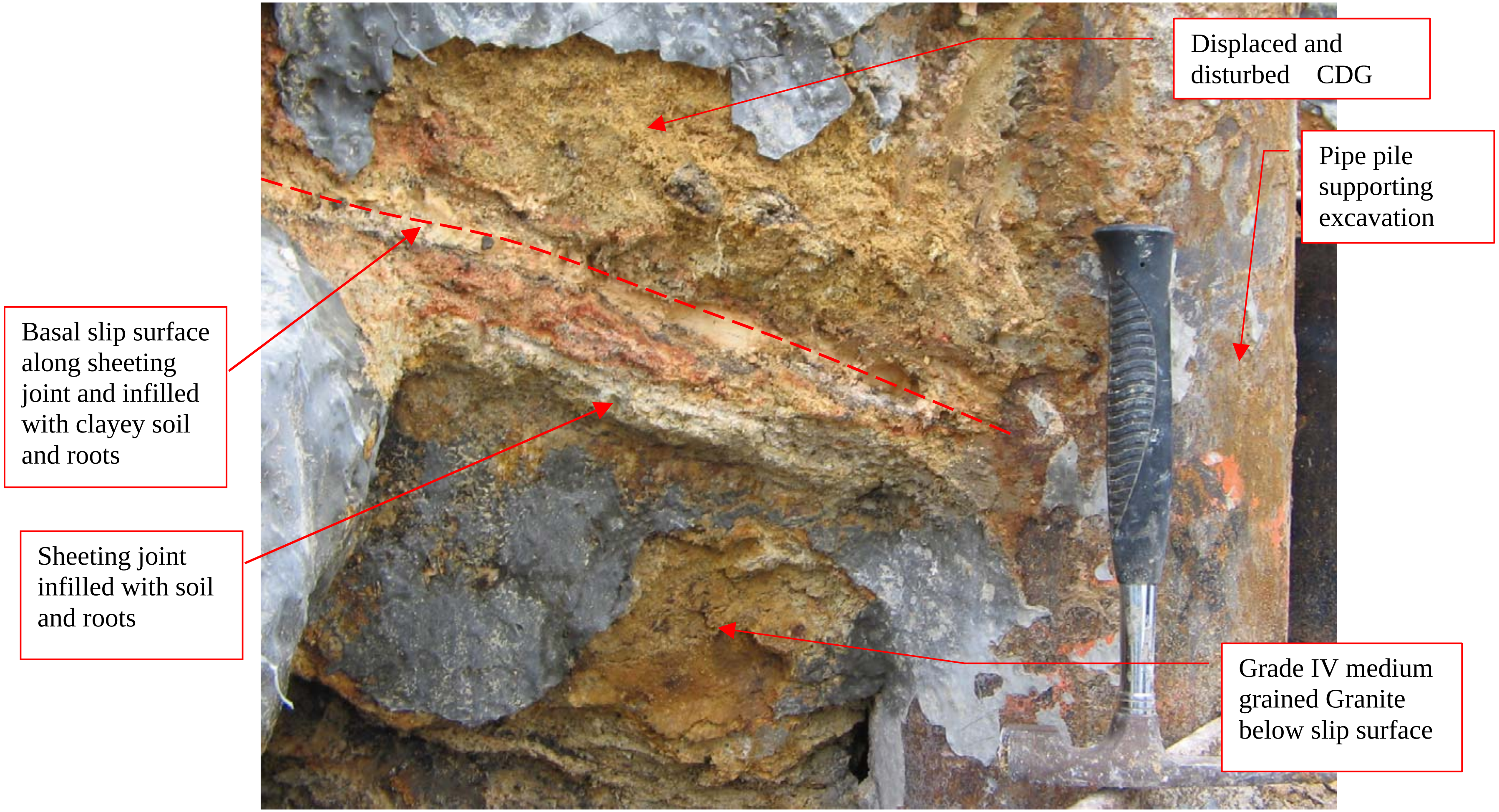


Plate 32 - Close-up View of the Basal Slip Surface and Sheeting Joint in the Excavation for LPM Works
(Photograph taken by FSW on 13 November 2006)

Note: See Figure 21 for location and direction of photograph.

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

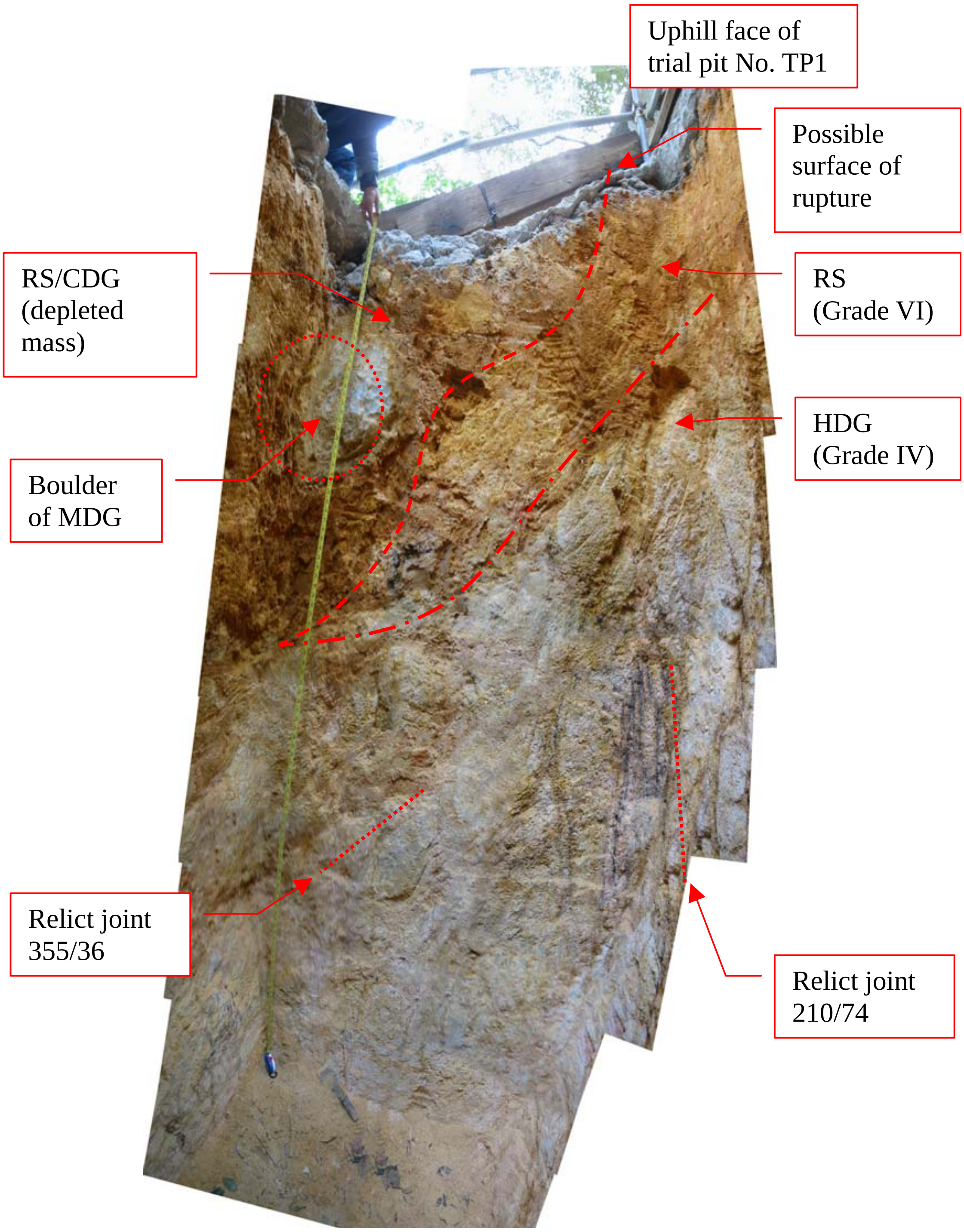


Plate 33 - View of Relict Joints in Close Vicinity to the Surface of Rupture in TP1
(Photograph taken by FSW on 12 December 2005)

Note: See Figure 21 for location and direction of photograph.

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

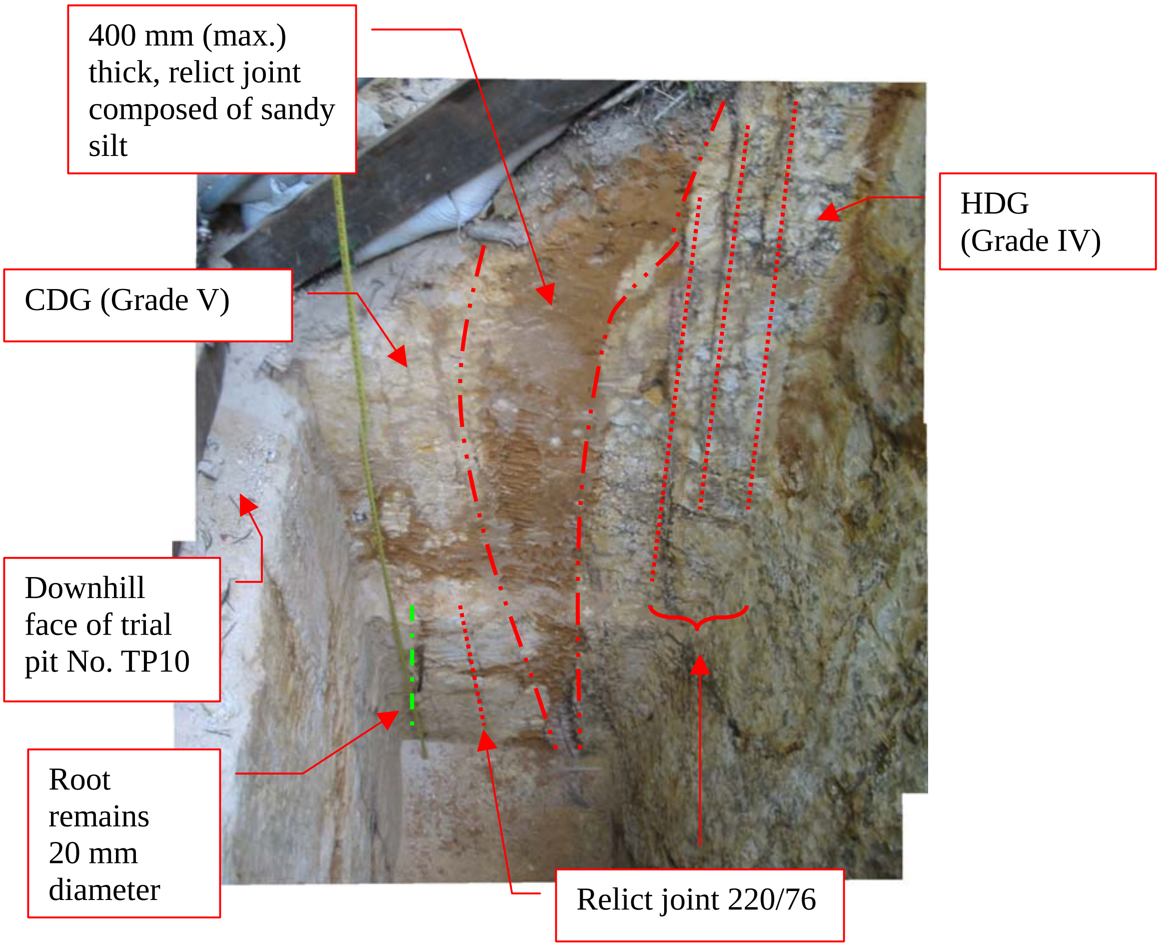


Plate 34 - View of Relict Joints Weathered to RS within CDG and HDG at TP10, in the Western Portion of Slope No. 11SE-A/C285 (Photograph taken by FSW on 12 December 2005)

Note: See Figure 21 for location and direction of photograph.

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

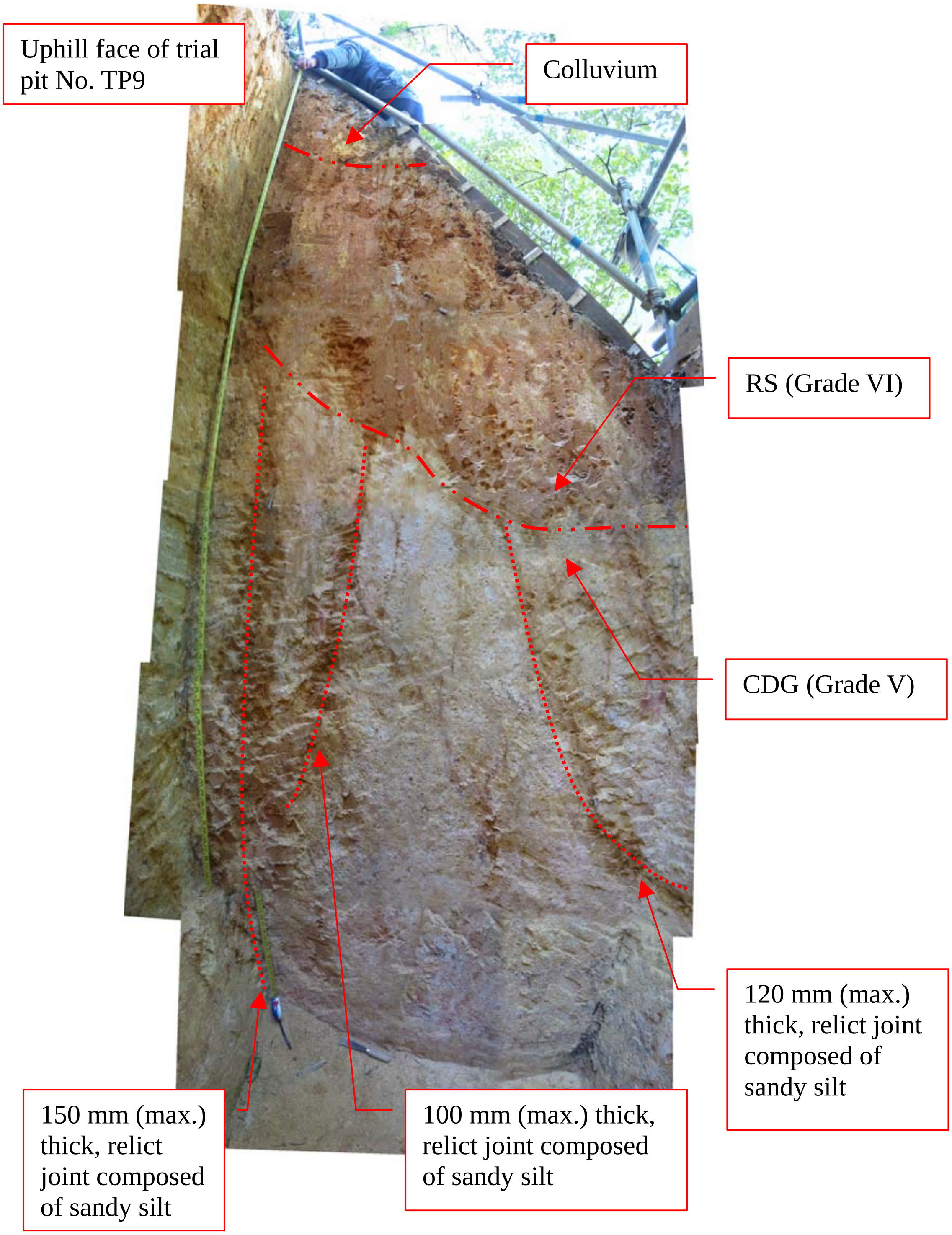


Plate 35 - View of Relict Joints Weathered to RS within CDG at TP9, in the Western Portion of Slope No. 11SE-A/C285 (Photograph taken by FSW on 15 December 2005)

Note: See Figure 21 for location and direction of photograph.

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

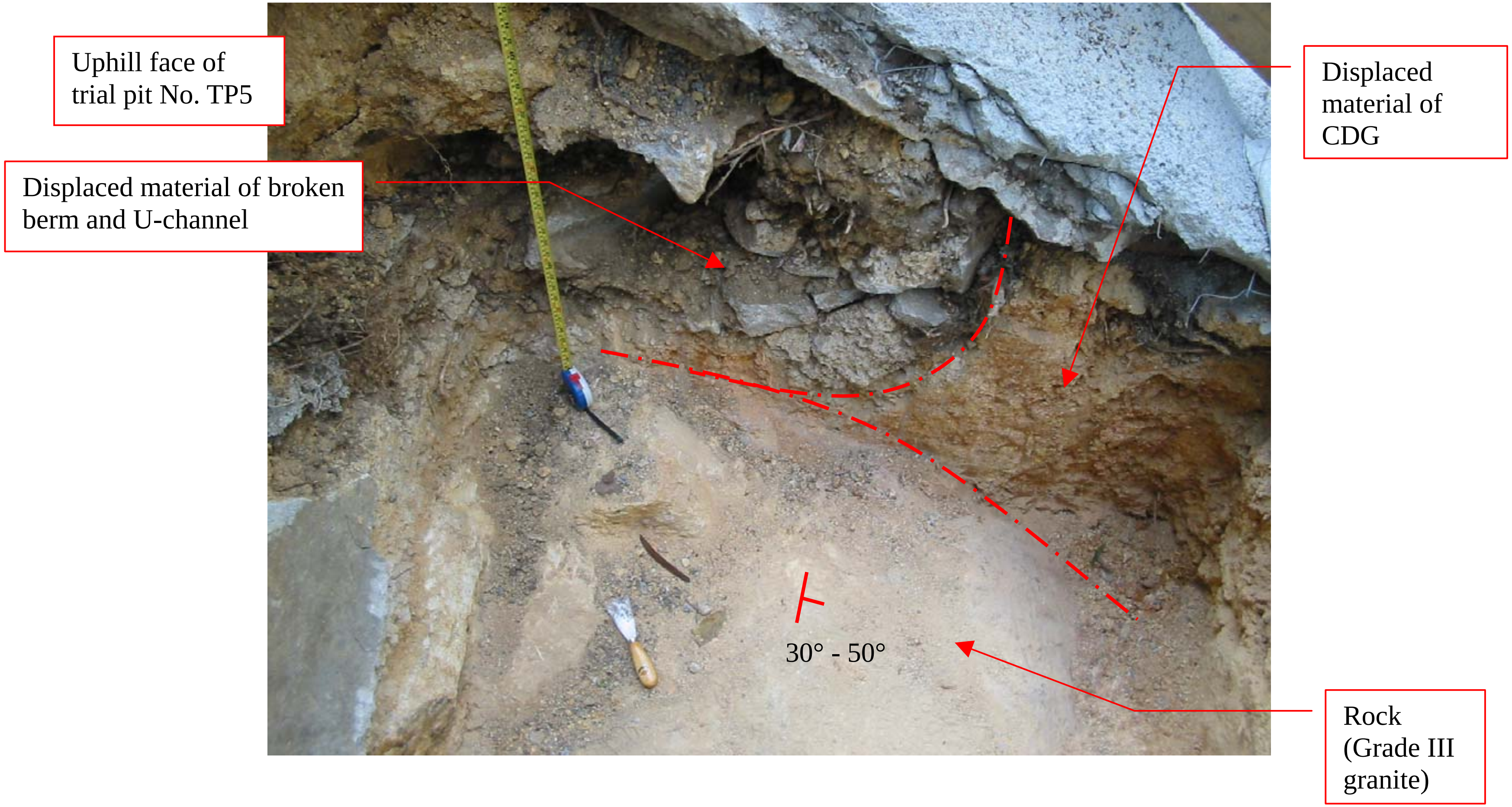


Plate 36 - View of Displaced Material of CDG Overlying Rock at TP5, at the Eastern Flank of the 20 August 2005 Landslide Site (Photograph taken by FSW on 24 November 2005)

Note: See Figure 21 for location and direction of photograph.

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

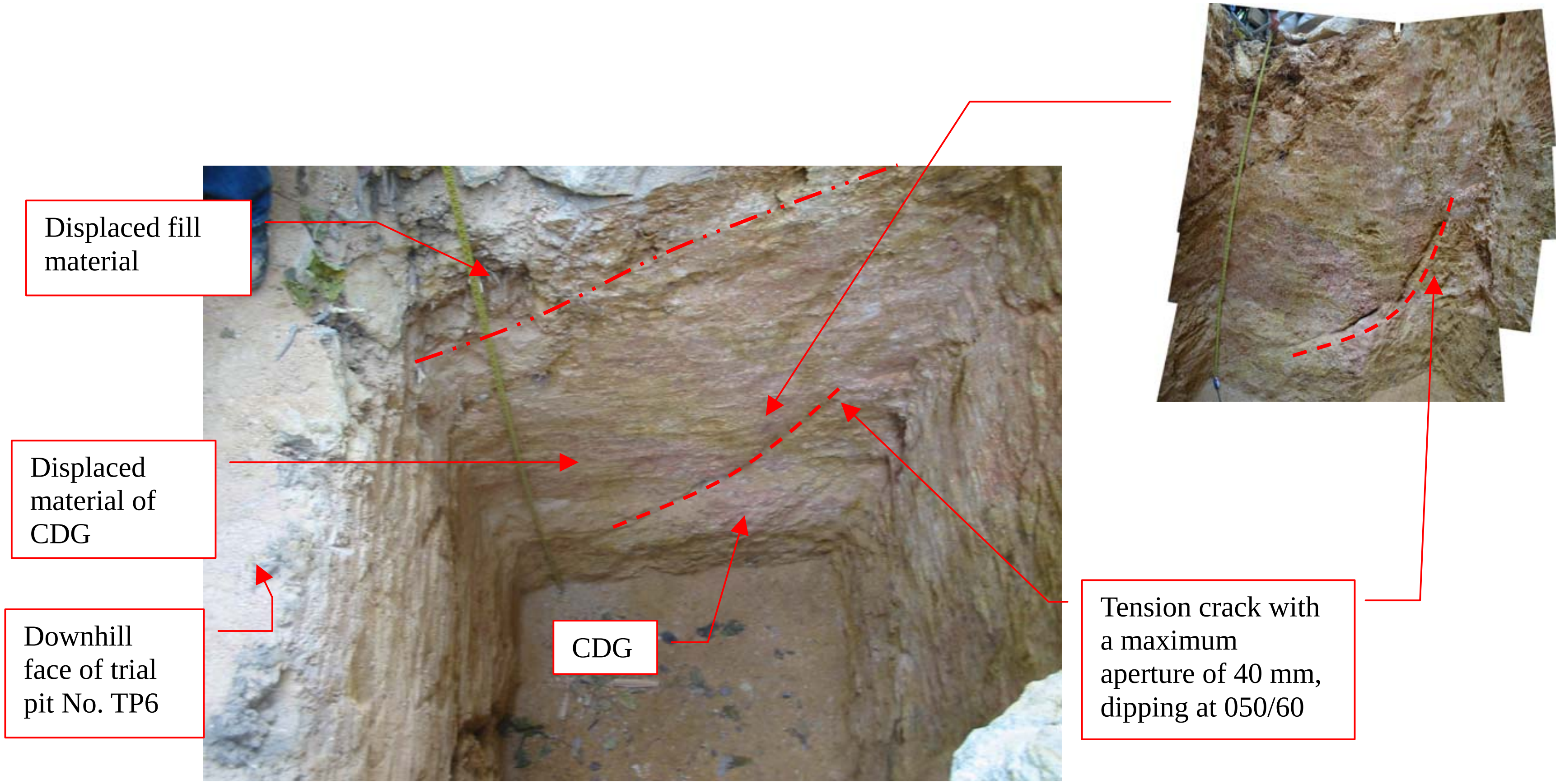


Plate 37 - View of Displaced Material of CDG and Tension Crack in TP6, at the Western Flank of the 20 August 2005 Landslide Site (Photograph taken by FSW on 7 December 2005)

Note: See Figure 21 for location and direction of photograph.

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

Table of Contents

APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

Table of Contents

Table of Contents

CONTENTS

A1. DETAILED OBSERVATIONS

This appendix sets out the detailed observations made from an interpretation of aerial photographs taken between 1945 and 2005. A list of the aerial photographs studied is presented in Table A1 and an annotated plan (Figure A1) is also attached.

YEAR	OBSERVATIONS
1945	The registered feature associated with the study landslide incident is 11SE-A/C285 (the feature) and it has not been formed yet. The site (the terrain prior the formation of the feature) is natural terrain with light vegetation overgrown on and a few minor works for small pagodas are evident above the site. The site situates near toe of a north descending natural terrain with no major streams and spur in close vicinity. The west end of the site is overgrown with medium vegetation and possibly partly occupied by man-made features. No detailed geomorphologic, geologic and hydrologic features could be interpreted from the photographs and no erosion and instability features are observed. Tiger Balm Garden is evident below the study site and characterised by a high rise, light color pagoda (solemn white Tiger Pagoda) at west toe of the site. In addition, agricultural terraces and fields are evident around the study site, particularly around the eastern spur line and the terrain between the high rise Pagoda and study site.
1949	The feature has not been formed yet and the upper and mid portion of the site have no observable changes generally. However the lower portion of the site is evident with three light toned areas and considered as possibly excavation works for the building of additional pagodas and other facilities of Tiger Balm Garden. Footpaths are noted transverses on the natural terrain above the site. In addition, a light toned area is noted above the site and possibly a minor instability feature. The site is within a catchment and is generally defined by two major spur lines, situated at the east and west above the site respectively and the spur lines are generally in the north descending direction. A major ephemeral natural stream is evident at the west of the study catchment and runs in the north descending direction. A relative minor stream in the north direction is noted at mid of the study catchment. The runoff from the two streams is possibly collected by a west-running drainage at the toe of the catchment and subsequently discharge downhill at the west. Two major natural streams with ephemeral nature are noted further east to the study catchment and both of them merge with the only northwest-running permanent stream at the southeast to the catchment. Convex slopes are noted at upper portion of the study catchment. In addition, a few relict landslide scars are evident on site and at the natural terrain above the site.
1959	The study site is under shadow. The feature has not been formed yet and terracing squatter structures are evident beyond the eastern flank of the study catchment. In addition, the service reservoir above the study catchment is being constructed. No clear observation at the development of Tiger Balm Garden could be obtained.

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

YEAR OBSERVATIONS

1963 The feature has not been formed. However, the terrain within the study catchment has been developed. The western portion is partly covered with squatters and agricultural terraces. The lower mid portion is overgrown with dense vegetation while the middle portion is covered with agricultural terraces, probably formed by minor cutting and filling. The east portion is mainly occupied by agricultural terraces with a few squatter structures. The construction works of Tai Hang No.1 Fresh Water Service Reservoir above the site has completed. Tiger Balm Garden is clearly visible at the toe of the study catchment and appears fully developed.

Boulders are now clearly evident at the upper mid portion and west portion of the study catchment. Most of the boulders at the west portion are colluvial origin and in-situ bedrock is likely present above the convex slopes at the upper mid portion of the study catchment.

1967 The feature at the site has not been formed. Agricultural terraces above the site are partly abandoned and the densely vegetated terrain at the mid portion of the study catchment is still visible. No other observable changes are noted.

1972 The feature has not been formed. Agricultural terraces above the site have now been abandoned. The construction works of Tai Hang Terrace as well as respective section of Tai Hang Drive west to the site has been commenced. No other observable changes are noted.

1973 15 October 1973
The feature has not been formed yet. No observable changes are noted. The agricultural terraces above the study site is now overgrown with medium vegetation and the squatter structures beyond the eastern flank of the study catchment are now mostly demolished.

12 December 1973
No observable changes are noted.

1974 No observable changes are noted.

1975 26 February 1975
The feature has not been formed yet. The construction works of Tai Hang Terrace and also the respective section of the Tai Hang Drive below are completed. No other observable changes are noted.

24 December 1975
The feature has not been formed yet. The study site is partly under shadow and no observable changes are noted.

1976 The feature has not been formed yet. The mid portion of the study site is overgrown with dense vegetation and the rest of the portion and also the entire study catchment are now covered with light to medium vegetation. No other

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

YEAR	OBSERVATIONS
	observable changes are noted.
1977	No observable changes are noted.
1978	No observable changes are noted.
1979	The registered feature has not been formed yet. A zone of vegetation clearance is noted at mid toe of the site, situated approximately at the upslope side of the closest pagoda to the study site. The zone is located in close vicinity to the 2005 landslide site. The zone is possibly an area of instability which causes relative less dense vegetation in the area. No other observable changes are noted.
1980	No observable changes are noted.
1981	The registered feature has not been formed yet. The previously noted distressed zone in year 1979 has now been developed further upwards and again the possibly instability zone is less dense in vegetation.
1982	4 January 1982 No observable changes are noted. 15 October 1982 The registered feature 11SE-A/C285 has been formed. The feature is clearly visible and constructed with two berms and three batters, and drainages are formed at crest and at feature. The lower east batter is relative rugged in texture and is exposed with bedrock. The rest of the feature is covered with light vegetation. The feature is formed by cutting back of the natural terrain and is formed for the construction of the extension section of Tai Hang Drive situates at feature's toe. Tai Hang Drive at the feature's toe is being formed and the eastern portion of the Road is filled with earth materials. A line of piles are evident at the downhill side of the eastern end of Tai Hang Drive and the piles could also be part of the development for Ronsdale Garden. In turn, the eastern portion of the Tiger Balm Garden and its facilities near the toe of the original natural terrain are no longer visible.
1983	3 February 1983 No observable changes are noted except construction works of Tai Hang Drive and Ronsdale Garden are in progress. 27 September 1983 An area of light tone is noted at mid toe of the feature. The area is possibly exposed with bare soil and considered as an instability feature. The landslide feature is approximately one-third height of the lowest batter and is located in close vicinity to the zone affected by the 2005 landslide. The landslide debris is cleared and the landslide is considered with limited depth of rupture. In addition, the bare soil exposed is relative dark in tone and it indicates high water content of

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

YEAR OBSERVATIONS

YEAR	OBSERVATIONS
	the respective earth materials. The construction works of Tai Hang Drive and Ronsdale Garden below the feature are still in progress.
	30 November 1983 No observable changes are noted except construction works of Tai Hang Drive and Ronsdale Garden are still in progress.
1984	Two light toned spots are evident near east crest of the feature, possibly erosion features. No other observable changes are noted except construction works of Tai Hang Drive and Ronsdale Garden are in progress.
1985	24 April 1985 No observable changes are noted.
	7 July 1985 A small landslide is noted above the central portion of the feature, opposite Block 1 Ronsdale Garden. No other observable changes are noted.
	12 June 1985 The construction works of Tai Hang Drive and Ronsdale Garden are completed. No other observable changes are noted.
1986	The surface of the feature is now covered with medium vegetation. No other observable changes are noted.
1987	No observable changes are noted.
1988	No observable changes are noted.
1989	The construction works for Service Reservoir No. 2 above the feature is in progress. No other observable changes are noted.
1990	No observable changes are noted except ongoing construction works of the Service Reservoir above the feature are evident.
1991	The construction of Service Reservoir No.2 has been completed. No observable changes are noted.
1992	No observable changes are noted.
1993	19 August 1993 No observable changes are noted.
	5 December 1993 An instability feature (Incident No. HK93/9/10) is evident at the mid toe of the feature, situates at close vicinity of the 2005 landslide. The debris has been cleared and it appears that the incident had affected the full height of the lowest

Table of Contents
Table of Contents
Table of Contents

YEAR	OBSERVATIONS
	batter of the feature.
1994	5 May 1994 An area of vegetation clearance is noted at the lowest batter of the feature, at the exact location of the 2005 landslide incident. The cleared zone is relative light tone and possibly some trimming and backfilling works have been done recently. 17 November 1994 The feature is covered with medium vegetation generally except the area once cleared is now light toned, possibly covered by hard surface. No other observable changes are noted.
1995	No observable changes are noted.
1996	No observable changes are noted.
1997	No observable changes are noted.
1998	No observable changes are noted.
1999	No observable changes are noted.
2000	No observable changes are noted.
2001	No observable changes are noted.
2002	Tiger Pagoda has been demolished and site formation works are ongoing below west toe of the feature. The site is known as present day ‘The Legend at Jardine’s Lookout’.
2003	The construction works of The Legend at Jardine’s Lookout are in progress. No other observable changes are noted.
2004	No observable changes are noted except the construction works below west toe are in progress.
2005	5 March 2005 No observable changes are noted except the construction works below west toe are in progress. 23 November 2005 The study landslide incident (Incident No. 2005/08/0364) is evident at the mid toe of the feature. No other observable changes are noted.

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

LIST OF TABLES

Table A1 - List of Aerial Photographs used in Aerial Photograph Interpretation

Date Taken	Altitude/ft	Photograph Number (Sortie Number, if any)
11 November 1945	20000	4065-66 (681/6)
8 May 1949	8600	6114-15 (81A/128)
05 October 1959	40000	0291 (F63/58A/RAF/175)
17 January 1961	30000	126-127 (F43/81A/RAF/600)
1 February 1963	2700	7063-65
16 May 1967	6250	5612-13
24 June 1972	2400	1836-38
15 October 1973	2000	5167-68
12 December 1973	3000	7085
21 November 1974	12500	9694
26 February 1975	4000 <Oblique Photo>	10913
24 December 1975	12500	12071-72
28 January 1976	4000	12612-13
4 October 1976	4000	15496-98
15 September 1977	4000	19296-98
21 December 1977	4000	20432-34
5 December 1978	4000	23892-94
14 September 1979	4000	26850-52
16 April 1980	4000	29809-11
6 November 1980	4000	32411-12
17 May 1981	4000	37155-57
4 January 1982	4000	40835-37
15 October 1982	4000	45334-36
3 February 1983	4000	47627-28
27 September 1983	4000	49576-78
30 November 1983	10000	51338-39
2 March 1984	4000	53693
22 October 1984	4000	56618-19
24 April 1985	4000	66037-39
7 July 1985	10000	A01709-10
6 December 1985	4000	A03745-47
20 September 1986	4000	A05962-63
9 September 1987	4000	A10353-54
8 January 1988	3500	A11620-21

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

Date Taken	Altitude/ft	Photograph Number (Sortie Number, if any)
27 September 1988	4000	A14419-20
7 July 1989	3500	A17322-23
15 August 1989	4000	A17643-44
20 March 1990	4000	A20845-46
4 October 1991	4000	A28063-64
15 October 1992	4000	A32539-40
19 August 1993	10000	CN4160-61
5 December 1993	4000	A36956-58
5 May 1994	4000	CN6857-58
17 November 1994	4000	CN7908-09
7 December 1995	3500	CN12641-42
23 October 1996	4000	CN15556-57
26 May 1997	4000	CN17053-54
8 November 1997	4000	CN18267-68
31 October 1998	4000	CN22133-34
3 November 1999	5000	CN24007-08
22 August 2001	4000	AW52268-69
4 November 2002	8000	CW45994-95
25 November 2003	4000	CW53282-83
5 October 2004	4000	CW60348-50
5 March 2005	6000	RW05184-86
23 November 2005	6000	RW06507-09

Notes:
(1) Aerial photographs are in black and white except for those prefixed with CN, CW and RW.
(2) Aerial Photographs are of good quality, with the exception of the 1945 and 1959 photographs, which are of moderate quality.

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

LIST OF FIGURES

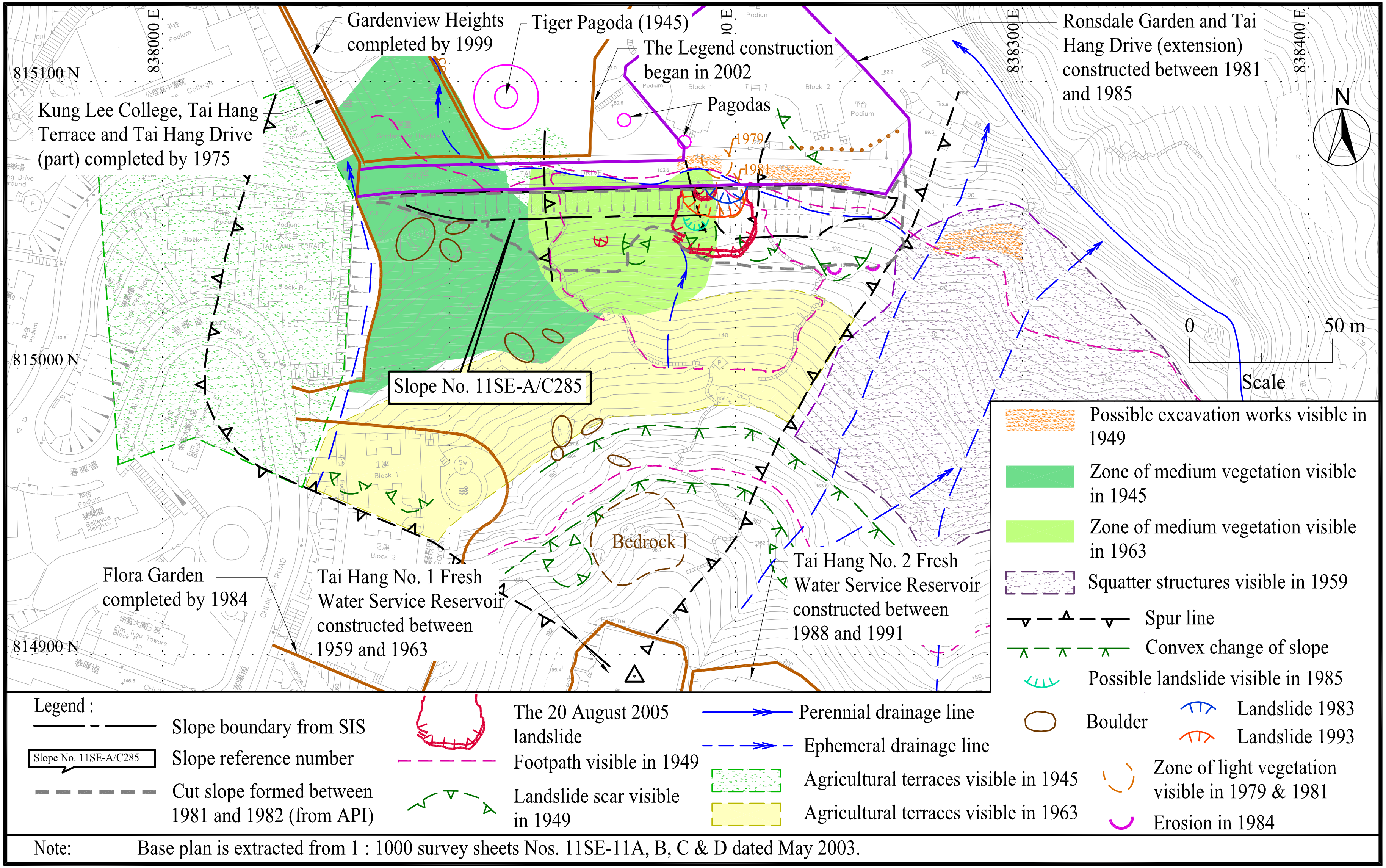


Figure A1 - API Plan

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

or

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

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美利大廈4樓402室
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或

- 致電政府新聞處刊物銷售小組訂購 (電話：(852) 2537 1910)
- 進入網上「政府書店」選購，網址爲 http://bookstore.esdlife.com
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Civil Engineering and Development Department,
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Fax: (852) 2714 0275
E-mail: wmcheung@cedd.gov.hk

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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