DETAILED STUDY OF THE 1 SEPTEMBER 2001 LANDSLIDE ON SLOPE NO. 11NE-B/FR249 BELOW NO. 56 DENON TERRACE, TSENG LAN SHUE, SAI KUNG

GEO REPORT No. 159

Maunsell Geotechnical Services Limited

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

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Prepared by:

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

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PREFACE

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

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

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

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FOREWORD

This report presents the findings of a detailed study of a landslide incident (GEO Incident No. 2001/09/0066) on fill slope No. 11NE-B/FR249 and the natural hillside, situated below No. 56 Denon Terrace, Tseng Lan Shue, Sai Kung, which occurred at about 10:30 p.m. on 1 September 2001 during heavy rainfall and while the Red Rainstorm Warning was hoisted. The landslide involved a failure volume of about 50 m^3. An inhabited squatter structure located at the toe of the natural hillside was severely damaged by the landslide debris and was subsequently permanently evacuated. No casualties were reported as a result of the failure.

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 incident. Recommendations for follow-up actions are reported separately.

The report was prepared as part of the 2001/2002 Landslide Investigation Consultancy for landslides reported within Kowloon and the New Territories between April 2001 and the end of 2002, for the Geotechnical Engineering Office, Civil Engineering Department, under Agreement No. CE 72/2000. This is one of a series of reports produced during the consultancy by Maunsell Geotechnical Services Limited.

L.J. Endicott

Dr. L.J. Endicott
Project Director
Maunsell Geotechnical Services Limited

Agreement No. CE 72/2000
Landslide Investigation Consultancy for Landslides Reported within Kowloon and the New Territories between April 2001 and the End of 2002

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1. INTRODUCTION

At about 10:30 p.m. on 1 September 2001, during heavy rainfall and when a Red Rainstorm Warning was hoisted, a landslide (GEO Incident No. 2001/09/0066) occurred on fill slope No. 11NE-B/FR249 and the natural hillside below, near No. 56 Denon Terrace, Tseng Lan Shue, Sai Kung (Figure 1 and Plate 1). The landslide involved a failure volume of about 50 m^3. An inhabited registered squatter structure located at the toe of the natural hillside was severely damaged by the landslide debris and was subsequently permanently evacuated. No casualties were reported as a result of the failure.

Following the landslide, Maunsell Geotechnical Services Limited (MGSL), the 2001/2002 Landslide Investigation Consultants for Kowloon and the New Territories, carried out a detailed study of the landslide for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 72/2000.

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 failure. Recommendations for follow-up actions are reported separately.

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

(a) a review of relevant documentary records relating to the development history of the site and the sequence of events leading to the incident,

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

(c) interviewing witnesses,

(d) limited ground investigation,

(e) aerial photograph interpretation (API),

(f) analysis of rainfall data,

(g) engineering analysis of the failure, and

(h) diagnosis of the probable causes of the incident.

2. THE SITE

2.1 Site Description

The landslide occurred on the northeast facing section of slope No. 11NE-B/FR249, which is located below a residential development of village houses at Denon Terrace, Tseng Lan Shue, Sai Kung (Figure 1). The slope has a total length of about 110 m and runs along the northeast and southeast boundaries of Denon Terrace (Figure 2). Denon Terrace consists

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of 14 three-storey high New Territories Exempted Houses (NTEH) located on a series of platforms at elevations of between about 217 mPD on the southeast side and 225 mPD on the northwest side (Figure 2). The platforms are separated by a series of cut slopes and retaining walls.

A concrete paved footpath, about 1 m to 2 m wide, is situated along the crest of slope No. 11NE-B/FR249 with an approximately 2.5 m wide grassed area between the footpath and house No. 56 Denon Terrace (Plate 2). Immediately to the southwest of the grassed area, there is a 1.8 m high concrete retaining wall, which supports a raised platform, on which house No. 56 Denon Terrace has been constructed.

In the vicinity of the landslide site, slope No. 11NE-B/FR249 is about 5 m high and inclined at about 38°. The slope surface is covered with vegetation and strewn with rubbish and building refuse including plywood, steel window frames and a steel folding gate (see Section 5.1). The ground directly below slope No. 11NE-B/FR249 is natural hillside which is about 12 m high and inclined at about 30°. A 1.5 m high, 70° steep chunamed cut slope is situated at the toe of the hillside (Figure 3). A single-storey timber and brick squatter structure, No. 27 Tseng Lan Shue Village (Figures 2 and 3), which is assigned squatter control survey Nos. UTLS/76/386 and UTLS/76/387 by the Housing Department under their 1982 Squatter Structure Survey, is located within licensed land (Licence No. S10845) about 0.5 m from the toe of the small cut slope (Figure 3).

A 15 m long slope No. 11NE-B/FR250 (Figure 2 and Plate 3) is located immediately to the northwest of slope No. 11NE-B/FR249. It comprises an 8 m high, 30° steep fill slope and a 9 m long, up to 1.7 m high toe retaining wall dressed with masonry blocks. The soil portion of slope No. 11NE-B/FR250 is covered with chunam and has a 1 m wide berm at about 2 m below the slope crest.

2.2 Surface Drainage and Water-carrying Services

Surface runoff from the platforms of houses Nos. 56 to 58, 63 and 65 Denon Terrace is collected by a system of 225 mm U-channels and downpipes, which connect to a 0.3 m by 0.3 m covered catchpit (Figure 2 and Plate 4), which is in turn connected to a 0.6 m by 0.6 m covered catchpit (Figure 2 and Plate 4). A 225 mm U-channel runs along the toe of the 1.8 m high concrete retaining wall below house No. 56 (Figure 2 and Plate 4) and also connects to the 0.6 m by 0.6 m covered catchpit. An underground 150 mm diameter PVC pipe protruding from slope No. 11NE-B/FR249 at about 0.5 m below the slope crest and 6 m to the east of the landslide scar is connected to the 0.6 m by 0.6 m catchpit and discharges onto slope No. 11NE-B/FR249 (Figure 2 and Plate 5).

A 1.2 m by 1.2 m catchpit, which connects to a 450 mm stepped channel through a 75 mm diameter opening (Figure 2 and Plates 6 and 7) near the boundary of slopes Nos. 11NE-B/FR249 and 11NE-B/F250 is located on the crest and near the west end of slope No. 11NE-B/FR249. The lower end of the 450 mm stepped channel connects to another catchpit, which discharges directly into a drainage line on the hillside below (Figure 2). The 1.2 m by 1.2 m catchpit also connects to a 100 mm diameter PVC pipe (Figure 2 and Plate 7) which is buried within slope No. 11NE-B/FR249 at a depth of between 0.3 m and 1.5 m below ground surface (Plate 8). The approximate alignment of the pipe is shown in Figure 2.

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A septic tank, which has two outlets, is present on the northwest side of house No. 56 (Figure 2 and Plate 9). One outlet from the septic tank is connected to a 250 mm by 250 mm duct, which runs to the northwest and discharges into the 1.2 m by 1.2 m catchpit (Figure 2). Another outlet from the septic tank is connected to a 75 mm diameter PVC pipe (Plate 10) that runs approximately to the northeast and is buried within the house platform and the paved footpath. A section of this pipe is exposed on slope No. 11NE-B/FR249 (Plate 8). The pipe changes direction several times along its course and passes on the north side of the squatter structure (Figure 2 and Plate 11) and eventually discharges into a natural streamcourse about 100 m to the southeast of the landslide site.

Another septic tank is present to the northwest of No. 63 Denon Terrace (Figure 2 and Plate 12). It connects to an underground 100 mm diameter pipe which runs down the natural hillside to the west of Denon Terrace and then turns its direction at the west end of the 1 m wide berm of slope No 11NE-B/FR250 to run along the berm where it becomes partly exposed (Figure 2 and Plate 13). This 100 mm diameter pipe discharges into the 250 mm by 250 mm duct which is connected to the 1.2 m by 1.2 m catchpit (Figure 2).

2.3 Geology

The 1:20,000 scale geological map sheet 11 of Hong Kong and Kowloon (GCO, 1986) indicates that the site is mainly underlain by Jurassic/Cretaceous fine-grained granite with some alluvium deposited along the toe of the hillside and in the vicinity of Tseng Lan Shue Village. The geological map indicates that no faults or lineaments are present within the immediate vicinity of the site.

2.4 Maintenance Responsibility

In 1996, the Lands Department (Lands D) commissioned a project entitled "Systematic Identification of Maintenance Responsibility of Slopes in the Territory" (SIMAR) to identify the maintenance responsibility of all man-made slopes registered in the Government's New Catalogue of Slopes. A SIMAR report prepared in May 2000 indicated that slope No. 11NE-B/FR249 has been divided into four portions (Sub-divisions 1 to 4) for assignment of maintenance responsibility (Figure 4). The September 2001 landslide occurred on the north section of Sub-division 1 and extended into unallocated Government land on the natural hillside below. According to the SIMAR report, Sub-division 1 of slope No. 11NE-B/FR249 was jointly maintained by the owners of lots Nos. 834, 835, 838 to 843 and 845 to 847, 851, 928 and 933 in D.D. 226 (where Nos. 50 to 53, 55 to 63 and 65 Denon Terrace are located).

Subsequent to the 1 September 2001 landslide, the maintenance responsibility of slope No. 11NE-B/FR249 was reviewed. Based on a memo dated 25 March 2002 from the Lands D to the Buildings Department (BD), Lands D is now responsible for the maintenance of Sub-division 1 of slope No. 11NE-B/FR249.

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2.5 Site History

A brief account of the site development history has been established from a review of relevant documentation and observations from aerial photographs taken between 1949 and 2001 (Figure 5). Details of the Aerial Photograph Interpretation (API) are presented in Appendix A.

The earliest aerial photograph taken in 1949 showed that the study site was a natural hillside. Based on API, a squatter structure (at the location of No. 27 Tseng Lan Shue Village, which was damaged during the September 2001 landslide) was first noted in the 1963 aerial photographs.

According to API, site formation works that appear to have included depositing fill immediately to the north and southeast of the site for the development of Denon Terrace, commenced some time between 1976 and 1978 (Figure 5). The site formation works were completed by 1979 (i.e. before the enactment of Buildings Ordinance (Application to the New Territories) Ordinance, Cap. 121 in 1987, which required submission of site formation plans for works associated with NTEH to the Buildings and Lands Department (BLD, renamed BD in 1993)). Formation of the platforms with associated slopes within the site including slope No. 11NE-B/FR249, appears to have taken place between 1978 and 1979. The first phase of the building works for the development comprised the construction of twelve 3-storey high residential buildings, including houses Nos. 50 to 53, 57 to 63 and 65 on the platforms and associated man-made slopes formed between 1978 and 1979. Between 1979 and 1988, the land now occupied by houses Nos. 55 and 56 Denon Terrace was a garden, with a footpath running along its northwest edge. House No. 55 Denon Terrace was constructed in 1991 and house No. 56 Denon Terrace was constructed between 1992 and 1995.

2.6 Past Instability

Prior to the September 2001 landslide incident, there are no records of previous landslides at slope No. 11NE-B/FR249 or the hillside below in the GEO's landslide database. No signs of instability on slope No. 11NE-B/FR249 or the hillside below were observed from the API carried out by MGSL.

According to the Natural Terrain Landslide Inventory (NTLI), prior to 1964 two landslides (Tags Nos. 11NEB0024 and 11NEB0025) occurred on the natural hillside immediately to the northwest of slope No. 11NE-B/FR249 (Figure 6). Based on API carried out by MGSL, the two landslides corresponding to the locations identified by the NTLI were first visible on the aerial photographs taken in 1967. The approximate dimensions of the landslides were 18 m long by 6 m wide (corresponding to Tag No. 11NEB0024) and 22 m long by 5 m wide (corresponding to Tag No. 11NEB0025) and these landslides occurred some time between 1964 and 1967. However, these natural terrain landslides to the northwest do not appear to be of relevance to the September 2001 landslide below No. 56 Denon Terrace.

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3. PAST ASSESSMENTS

3.1 1977/78 Catalogue of Slopes

Site formation works for Denon Terrace, including the formation of slope No. 11NE-B/FR249 were completed in 1979. Slope No. 11NE-B/FR249 was not included in the 1977/78 Catalogue of Slopes.

3.2 Site Formation at Denon Terrace in 1978

According to file records held by District Lands Office, Sai Kung (DLO/SK) made available to MGSL for this study, extensive site formation works were carried out in 1978 and 1979 in conjunction with the NTEH development at Denon Terrace, covering slope No. 11NE-B/FR249 on which the landslide occurred. No geotechnical submission for the site formation works, including a stability assessment of slope No. 11NE-B/FR249, was found in DO/SK's file record. DO/SK noted that the works extended outside the areas covered under the grant and that they were being carried out without approval from the appropriate authority (i.e. unauthorised).

In July 1980, the Geotechnical Control Branch (GCB) of the Buildings Ordinance Office requested DO/SK to require the owners to "employ an engineering consultant…prepare a report of the condition and stability of all site formation works … [and] recommend … any remedial works" to the GCB for checking. In response to GCB via memo dated 17 July 1980, DO/SK noted that "it is impracticable…at that stage to require the grantees …to employ an authorised person or engineering consultant to prepare a report on the condition and stability of all site formation works" and suggested that GCB should "re examine the safety of the site formation and its related works".

In a memo to DO/SK on 6 September 1980, GCB noted that "While it was apparent that most of the site formation works were below the current acceptable standard, …[they] did not notice that the situation has deteriorated …since [their] site inspection in last April [1980]" and GCB was of the opinion that "…it is difficult to commence applying the powers of the Buildings Ordinance at this late stage…". In the memo, GCB suggested that DO/SK should urge the owners, inter alia, to "remove loose fill and recompact the slope surface and regrass" and "pave the access".

3.3 Residential Development of No. 56 Denon Terrace

The development of No. 56 Denon Terrace constitutes the last phase of residential development of Denon Terrace. The September 2001 landslide site, comprising a portion of slope (now registered as No. 11NE-B/FR249 in the Catalogue of Slopes, see Section 3.5) and the natural hillside below, was covered by a slope stability assessment carried out under a geotechnical submission for the site formation works associated with the development of "Lot No. 933 in D.D. 226 Tseng Lan Shue, Sai Kung, N.T." (i.e. house No. 56 Denon Terrace).

On 27 October 1993, the Authorised Person (AP) for the above-mentioned development project, Mr W K Poon, made a site formation re-submission to the Buildings

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Department (BD), following disapproval by the BLD in March 1993 of an earlier site formation submission because of, inter alia, the absence of any justification of the stability of the adjoining slope/retaining walls. The re-submission included a slope stability assessment, substantiated by a site-specific ground investigation prepared by the geotechnical consultant for the development project, Geo Con Engineers (GCE, 1993a). To supplement the re-submission, a geotechnical report covering additional ground investigation and a slope stability assessment were submitted by GCE to the GEO on 19 November 1993 (GCE, 1993b).

For this site formation re-submission, site-specific ground investigations including laboratory tests were carried out by Geotechnics & Concrete Engineering (H.K.) Limited (GCEHK) in September 1993 and November 1993. The ground investigation comprised three trial pits (Nos. TP1 to TP3), two of which had standpipe piezometers installed, 13 GCO probe tests (Nos. G1 to G13), three in-situ density tests, one standard compaction test, two triaxial compression tests and one particle size distribution analysis. The locations of the ground investigation stations are shown in Figure 7.

The three trial pits, which were located along the footpath at the crest of the north end of slope No. 11NE-B/FR249, were excavated to depths of between 1.8 m and 3 m below ground surface and indicated the presence of a 0.7 m to 1.0 m thick layer of yellowish brown silty sand (fill) overlying a 200 mm to 300 mm thick layer of topsoil. As opposed to the geology presented in the Hong Kong Geological Survey (HKGS) 1:20,000 Solid and Superficial Geology Map Sheet 11 - Hong Kong and Kowloon (GCO, 1986) and also the ground conditions revealed from the ground investigation works carried out under this landslide study (see Section 6.2), "completely decomposed volcanics (CDV)", instead of completely decomposed granite, comprising medium dense to dense pinkish and yellowish brown silty sand, were recorded in the trial pit log by GCE between depths of about 0.9 m and 1.3 m below ground surface. The two standpipe piezometers installed in trial pits Nos. TP2 and TP3, to a maximum depth of 2.6 m below ground surface, were both reported to be dry. The 13 GCO probe tests were all carried out within the area of slope No. 11NE-B/FR249 to a depth of 2 m below ground surface. The probe values, recorded as the number of blows for every 100 mm depth of penetration, ranged between 4 and 18, with values of 4 to 10 between ground surface and a depth of 0.5 m and values of 10 to 18 below 0.5 m.

The three insitu density tests were carried out by GCEHK in trial pits Nos. TP2 and TP3 at depths of 0.5 m and 1 m below ground surface (i.e. within the fill). The dry densities recorded in the three insitu density tests ranged from 1.671 Mg/m^3 to 1.683 Mg/m^3. The depth and location of the sample recovered for laboratory standard compaction testing was not indicated in the submission. The sample was described as yellowish brown silty sand and the maximum dry density was recorded as 1.755 Mg/m^3. The relative compaction of the fill recorded in the test report ranged from 95.2% to 95.9%.

Multistage consolidated undrained triaxial compression tests with pore water pressure measurements were carried out on two samples of "CDV" obtained from trial pit No. TP1 and mean shear strength parameters of $c' = 9.4$ kPa and $\phi' = 30°$ were obtained.

In the stability analysis carried out by GCE, the critical section of the slope (Section D-D) was taken to be 23 m high, inclined at an angle of approximately 30° and to consist entirely of "CDV" whereas the record of trial pit No. 2 indicates the presence of a

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layer of fill with a maximum thickness of about 1 m at the top. With an assumed groundwater table between 1 m and 2.5 m below ground surface (no discussion was presented in the report on the groundwater table assumption), the minimum factor of safety of the slope was found to be 1.22 and the corresponding critical slip surface extended from the slope crest to the slope toe with a maximum depth of 5 m measured normal to the slope surface. The figure showing the results of the stability assessment (GCE, 1993b) is reproduced in Appendix B.

The surface drainage layout shown on the site formation plan submitted by the AP to the BD (Drawing No. SF-1 reproduced in Appendix B) indicates that surface water collected within the site would be carried by a 225 mm U-channel running along the northeast side of house No. 55 Denon Terrace and would be connected to an existing 800 mm by 1000 mm "box channel" located to the southeast of the site. On 3 December 1993, the site formation plans (including Drawing No. SF-1) were approved by the BD following checking and acceptance of the geotechnical submission by the GEO on 22 November 1993.

During a site inspection in March 1994, District Lands Office/Sai Kung (DLO/SK) discovered some illegal dumping of soil debris on the footpath to the northeast of house No. 56 Denon Terrace above slope No. 11NR-B/FR249 (Figure 5). Following the service of a notice by DLO/SK under Crown Land Ordinance on 29 March 1994, which required the removal of the illegal dumped soil debris, the AP for the development of house No. 56 Denon Terrace advised DLO/SK on 30 March 1994 that the registered contractor responsible for the site work would remove all the dumped soil adjacent to the footpath within ten days. No further details regarding this illegal dumping were found in DLO's files.

In response to a complaint made by the Mutual Aid Committee of Denon Terrace to the DLO/SK on 23 March 1995, regarding its concern about dumping of building refuse and storage of building materials on slopes and Government land, a site inspection was carried out by DLO/SK on 21 April 1995. During the inspection, 'suspected illegal dumping of building refuse' was noted by DLO/SK at various locations above and within the boundary of slope No. 11NE-B/FR249 (Figure 5). A further site visit by DLO/SK in May 1995 confirmed that the concerned building refuse had been removed.

According to the file records of the BD, an inspection of the site carried out by the BD on 8 June 1995 revealed that "the outstanding items were the surface channels only" and that "as the electrical cable was laid along the proposed 225 c.c. surface channel, the contractor could not commence the work until the dispute has been settled".

On 14 December 1999, a letter from the DLO/SK was sent to the AP, quoting a comment from the Drainage Services Department (DSD), stating that "the drainage systems within or outside the lot boundaries were not constructed according to the plans of site formation approved by the Buildings Department on 3.12.93". In the letter, DLO/SK also indicated to the AP the requirement "to rectify the above situation… to the Drainage Services Department's satisfaction …Otherwise the issuance of the Certificate of Compliance will be affected in respect of the above Lot".

On 27 March 2000 the AP advised the BD that the site formation works on the subject lots were complete. According to DLO/SK, a Certificate of Compliance for house No. 56

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has not been issued (although Certificates of Compliance have been issued for all other houses within the development).

3.4 Systematic Inspection of Features in the Territory

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

The SIFT Study of the slopes in the vicinity of the September 2001 landslide was carried out in June 1996. Slope No. 11NE-B/FR249 was designated SIFT Class "B2", i.e. a slope that had "been formed or substantially modified after 30.6.78". The SIFT report noted that "Fill emplaced post 1978 (20750/20751) pre 1979 (28078/28079)".

3.5 Systematic Identification and Registration of Slopes in the Territory

In July 1994, the GEO initiated a project entitled "Systematic Identification and Registration of Slopes in the Territory" (SIRST), to update the 1977/78 Catalogue of Slopes. An inspection of slope No. 11NE-B/FR249 carried out by the SIRST consultant in January 1998 noted that the slope was covered entirely with vegetation and the condition of the slope was recorded as "Poor". The inspection did not observe any signs of seepage or distress on the slope. Also, no potentially leaky services were identified during the SIRST inspection.

3.6 Non-Development Clearance

The registered squatter structure at No. 27 Tseng Lan Shue Village, which was located at the toe of the natural hillside below the landslide site, was inspected by the GEO under the 1993-94 Non-Development Clearance Programme. The squatter structure was not recommended for clearance on slope safety grounds at that time.

4. THE SEPTEMBER 2001 LANDSLIDE INCIDENT

According to GEO Incident Report (No. 2001/09/0066), the landslide occurred at 10.30 p.m. on 1 September 2001 during a heavy rainstorm when a Red Rainstorm Warning was hoisted. The timing of the landslide incident was confirmed by a resident of the damaged squatter structure during an interview conducted by MGSL. The landslide site was inspected by the GEO at 3.30 p.m. on 2 September 2001. The landslide involved a failure volume of 50 m^3. An inhabited squatter structure, which comprised cement-plastered brick walls, located at the toe of the natural hillside was severely damaged by the landslide debris and was subsequently permanently evacuated. No casualties were reported as a result of the failure.

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5. FIELD OBSERVATIONS FOLLOWING THE LANDSLIDE

Following the landslide, MGSL inspected the site on 3 September 2001 and subsequently on several occasions during the course of this study.

5.1 Landslide Scar and Debris

The landslide occurred on a portion of slope No. 11NE-B/FR249 and the natural hillside below (Figure 2 and Plate 1). The landslide scar was found to be stepped, about 5 m wide by 12 m long (measured on the slope) with a maximum depth of about 1.5 m and comprising two individual (an upper and a lower) spoon-shaped scars of comparable size. The surface of rupture extended from the crest of slope No. 11NE-B/FR249 and went beyond its toe by about 2 m into the densely vegetated natural hillside below, which is inclined at about 30°. The main scarp of the landslide was inclined at about 60° to the horizontal and the materials exposed on the surface of rupture was fill and comprised generally orangish brown mottled grey sandy clayey silt with some fine to coarse gravel-sized rock fragments and rootlets (Plate 14).

The landslide debris, with a source volume of about 40 m^3 of fill material and an entrained volume of about 10 m^3 of colluvium and residual soil, left a trail of about 15 m long and 3 m wide (Plate 1). The entrainment scar along the debris trail on the natural hillside had a maximum depth of about 0.5 m and the debris came to rest against a squatter structure (No. 27 Tseng Lan Shue Village), which was located at the toe of the natural hillside some 25 m from the source of the landslide (Figures 2 and 3 and Plate 1). The landslide debris comprised mainly a mixture of fill and residual soil/colluvium (yellowish brown, orangish brown and grey sandy clayey silt to silty sand) with a lot of construction debris (e.g. brick fragments and cobble-sized concrete blocks) and some household refuse. Other debris from the landslide was deposited along the debris trail, including a fallen tree, some vegetation and sections of a plastic drainage pipe resting on the top of the debris. The landslide debris, which piled up against the back of the squatter structure to about 2 m high, displaced the cement-plastered brick wall of the squatter structure by about 300 mm, causing severe damage (Plate 15). No splash marks of debris were observed on the wall of the squatter structure. The landslide debris at the lobe to the west of the squatter structure (Figure 2) stood at an angle of about 40° to the horizontal (Plate 15). Since the movement of the landslide debris was obstructed by the squatter structure, the travel angle of the landslide debris could not be determined. The angle measured from the crest of the main scarp to the landslide debris piled up against the back of the damaged squatter structure was about 30°.

5.2 Water-carrying Services

A water flow test carried out by MGSL on 10 December 2001 revealed that water discharged from the outlet of the 150 mm diameter PVC pipe which was connected to the 0.6 m by 0.6 m covered catchpit located to the east of house No. 56 Denon Terrace flowed over the surface of slope No. 11NE-B/FR249 and entered the debris trail about 3 m below the landslide scar. This drainage arrangement is different from the layout shown on the approved site formation plan (see Section 3.3 and Appendix B).

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During MGSL's site inspections in September 2001 and December 2001, the 100 mm diameter PVC pipe connected to the 1.2 m by 1.2 m catchpit near the west end of slope No. 11NE-B/FR249 was found to be broken and discharging water with an unpleasant odour from the end of one of its broken sections, onto the natural hillside on the west side of the landslide scar (Figure 2 and Plate 16). Immediately to the northeast of the landslide scar, there were several 1.5 m to 2 m long sections of the broken 100 mm diameter pipe on the natural hillside partly covered by a steel folding gate. These broken sections of pipe were found to be randomly orientated. Detailed inspection of these sections of PVC pipe revealed that more than 50% of the cross-section was blocked by leaves and silt indicating that the pipe was possibly broken before the 1 September 2001 landslide incident. Following the subsequent site inspection and field works, the PVC pipe was found to have been separated at the joint (Point B in Figure 2) on a 120° bend (Plate 17) about 6 m from the breakage point and it was partly blocked with soil.

6. POST-LANDSLIDE GROUND INVESTIGATIONS

6.1 General

As part of this detailed study, a ground investigation (Figure 7) comprising two trial pits (Nos. NP1 and NP2), one slope surface strip (No. S1) and 20 GCO probes tests (Nos. G1 to G20) was carried out by Gammon Skanska Limited in August 2002 under the supervision of MGSL. The objectives of the ground investigation were to determine the near-surface ground conditions at the landslide site.

6.2 Trial Pits

Trial pit No. NP1 was located within the landslide scar and was terminated at a depth of 3.0 m while trial pit No. NP2, which was located adjacent to the landslide scar, was terminated at a depth of 2.5 m. In the trial pits, a layer of fill, between 0.8 m (trial pit No. NP2) and 1.6 m thick (trial pit No. NP1) was found to overlie a layer of topsoil with a maximum thickness of about 200 mm. The fill material comprised generally orangish brown sandy clayey silt with some sub-angular fine to coarse gravel-sized rock fragments. The underlying insitu material was completely decomposed granite (CDG). The CDG comprised extremely weak light yellow mottled red and white, silty fine to coarse sand. A 0.6 m thick layer of colluvium comprising stiff to very stiff light brown clayey sandy silt was encountered above the CDG layer in trial pit No. NP1.

6.3 Slope Surface Strip

Slope surface strip (No. S1), some 12 m in length, was excavated to a maximum depth of 100 mm along the landslide scar, which comprised an upper portion and a lower portion both being spoon-shaped. Throughout the entire length of strip No. S1, fill comprising reddish brown to dark brown, sandy clayey silt with angular fine to coarse gravel-sized fragments of rock, tiles and brick, was encountered. This indicates that fill extended at least 2 m below the toe of slope No. 11NE-B/FR249 onto the natural hillside below.

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6.4 GCO Probe Tests

The 20 GCO probes tests were carried out to depths of between 1.5 m and 6.8 m on slope No. 11NE-B/FR249 near the September 2001 landslide site (Nos. G1 to G12) and an area of the natural hillside immediately below (Nos. G13 to G20). The probe values were recorded as the number of blow counts for every 100 mm depth of penetration of the probe. The locations of the GCO probe tests are shown in Figure 7 and summaries of the results of GCO probe tests carried out inside and outside the landslide scar are given in Figures 8 and 9 respectively.

Most of the GCO probe values recorded within the top 2 m were between 0 and 5 blows (indicating the presence of probably loose material) and probe values exceeding 20 were generally recorded between 2 m and 4 m below ground surface (Figures 8 and 9). The results of GCO probe tests carried out on slope No. 11NE-B/FR249 do not show much difference from those obtained from tests conducted on the natural hillside below. In summary, the GCO probe test results indicate that the fill of the slope adjacent to the landslide scar was generally loose.

7. SUBSURFACE CONDITIONS

Based on the results of ground investigation and field mapping, the layer of fill overlying slope No. 11NE-B/FR249 extends at least 2 m below the toe of the 5 m high slope No. 11NE-B/FR249, into the natural hillside below (Figure 3). Taking into account also findings from API on the extent of the fill, the total height of the fill slope was about 9 m. The layer of fill was about 2 m in thickness and in general comprised (probably loose) orangish brown sandy clayey silt with some sub-angular fine to coarse gravel-sized rock fragments. A layer of old topsoil up to 200 mm thick, comprising medium dense greyish brown clayey silty fine to coarse sand, was present below the fill layer. A 0.6 m thick layer of residual soil and colluvium, comprising stiff to very stiff light brown clayey sandy silt, was present below the layer of topsoil. The underlying insitu material was found to be completely decomposed granite (CDG), which comprised extremely weak light yellow mottled red and white silty fine to coarse sand. A geological cross-section through the landslide site is shown in Figure 3.

8. ANALYSIS OF RAINFALL RECORDS

The nearest GEO automatic raingauge (No. N08) to the landslide site is located at the Staff Quarters of Pik Uk Prison, Clear Water Bay Road, approximately 1.1 km to the northeast of the site and the second nearest GEO automatic raingauge (No. K04) is located at the Lee Cheung House, Shun Lee Estate, Lee On Road approximately 1.15 km to the southwest of the site (Figure 1). The rainfall data used in the analysis are based on GEO raingauge No. N08 except for 1989, 1993 and 1994 for which data from GEO raingauge No. K04 was used as no data were available from GEO rainguage No. N08 for these years. The incident occurred at about 10:30 p.m. on 1 September 2001 when a Red Rainstorm Warning was hoisted.

The daily rainfall recorded by raingauge No. N08 over the preceding month and two

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days following the incident, together with the hourly rainfall data for the period between mid-night on 30 August and mid-day on 2 September 2001 is presented in Figure 10. The peak hourly rainfall of approximately 63 mm was recorded between 10:00 p.m. and 11:00 p.m. on 1 September 2001. Rainfall recorded by raingauge No. K04 over the above period exhibited a similar pattern to the data received from raingauge No. N08 although the rainfall was less intense.

Analysis of the return periods of the rainfall intensities preceding the incident using the rainfall data recorded by raingauge No. N08 with reference to the historical rainfall data at the Hong Kong Observatory (Lam & Leung, 1994) is given in Table 1. The results show that the 4-day and 7-day rolling rainfalls of 405 mm and 451 mm respectively were the most severe, with a corresponding return period of 4 years. The return periods were also assessed based on statistical parameters derived by Evans & Yu (2001) from data recorded by raingauge No. N08 between 1984 and 1997. It is noted that in this case, there is no significant difference between the estimated return periods based on the historical rainfall data at the Hong Kong Observatory and the data from the local automatic raingauge No. N08.

A comparison of the patterns of selected past major rainstorms recorded at raingauge No. N08 between 1992 and 2001 is presented in Figure 11. However since no data were available from GEO raingauge No. N08 for the years 1989, 1993 and 1994, data from GEO raingauge No. K04 were used in the comparison. The rolling rainfall indicates that the rainstorm on 1 September 2001 was not exceptionally heavy as compared with the previous rainstorms.

9. THEORETICAL STABILITY ANALYSES

Theoretical stability analyses using the rigorous solution of Morgenstern & Price (1965) were carried out to assist in the diagnosis of the probable causes of the landslide. The analyses examined the likely operative range of shear strength parameters along the surface of rupture for different groundwater conditions at the time of failure. The cross-section through the landslide included in the stability analyses, assuming that the fill failed in a drained manner (i.e. it did not liquefy) was based on Section A-A presented in Figure 3. Based on the morphology of the landslide scar (i.e. two spoon-shaped scars with a step between them), it is assumed that the failure of the ground mass corresponding to the lower landslide scar occurred first (see Section 10.2 below).

As revealed from site inspections carried out shortly after the landslide incident as well as the post-landslide ground investigation (Sections 6.2 and 6.3), the surface of rupture passed through the fill material and the stability analyses for the lower landslide scar were carried out using a range of shear strength parameters which cover the typical range of values of shear strength parameters given for fill. Various piezometric levels above the surface of rupture were assumed for the purpose of the stability analyses.

The results of the analyses are presented in Figure 12. These indicate that the development of a transient groundwater pressure corresponding to a piezometric level of about 0.5 m above the surface of rupture would have been sufficient to initiate failure in the slope.

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10. DIAGNOSIS OF THE PROBABLE CAUSES OF THE LANDSLIDE

10.1 Site Setting

The September 2001 landslide occurred on fill slope No. 11NE-BFR249 and the natural hillside immediately below a residential development at Denon Terrace. The landslide site was overlain by a layer of fill up to about 2 m in thickness which in general comprised orangish brown sandy clayey silt with some sub-angular fine to coarse gravel-sized rock fragments overlying residual soil and colluvium. According to post-landslide field observations and ground investigation, the fill slope was about 9 m high. The surface of the section of the fill slope and the natural hillside in the vicinity of the landslide site was covered with vegetation and strewn with construction debris including steel doors, concrete fragments, etc.

Insitu density tests on fill material at the platform immediately beyond the crest of the failed portion of the fill slope carried out as part of a geotechnical submission for the residential development of house No. 56 Denon Terrace in 1993 indicate that the relative compaction of the fill ranged from 95.2% to 95.9% with GCO probe values ranging from 4 to 18. GCO probe tests carried out at the landslide site and its adjacent area as part of this study indicate that probe values recorded within the top 2 m were generally between 0 and 5 blows (indicating that the fill of the slope was probably loose) and probe values recorded between 2 m and 4 m below ground surface generally exceeded 20. Based on the GCO probe test, the fill of the slope adjacent to the landslide scar was generally loose.

Sewage pipes connecting to the nearby septic tanks at Denon Terrace, including one 75 mm and one 100 mm diameter PVC pipes, were partly laid on, and partly embedded within, the north end of slope No. 11NE-B/FR249. Evidence of prolonged intermittent leakage onto the slope at a location about 1 m above the toe of the landslide scar due to damage of the 100 mm diameter sewage pipe were seen in post-landslide inspections by MGSL in September and December 2001. Based on the field observations and given that the slope was strewn with construction debris it is possible that the pipe was damaged some time before the September 2001 landslide.

Surface runoff from the platforms of Denon Terrace collected by a system of 225 mm U-channels and catchpits (which were finally connected to a subsurface 150 mm diameter PVC pipe with an exposed outlet at slope No. 11NE-B/FR249) was discharged directly onto slope No. 11NE-B/FR249. Since the discharge point was about 6 m to the southeast of the September 2001 landslide scar, it is unlikely that it would have provided a direct source of water ingress into the landslide area.

A 2.5 m wide strip of grass was present just behind the crest of the failure portion of slope No. 11NE-B/FR249. This grassed area could have allowed ingress of surface water into the failure site at the time of the landslide incident.

10.2 Probable Causes and Mechanism of the Landslide

The September 2001 landslide involved sliding failure of about 40 m^3 of fill material of slope No. 11NE-B/FR249 which comprised sandy clayey silt with some fine to coarse gravel-sized rock fragments overlying the natural hillside below. The landslide scar, about

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11 m long by up to 6 m wide, comprised an upper portion and a lower portion both being spoon-shaped and up to about 1.5 m in depth. The surface of rupture was located within the fill material.

The possibility of a liquefaction failure was remote since the debris angle at the toe of the debris lobe is rather steep (40°) and no splash marks were observed at the wall of the squatter structure against which the landslide debris piled up.

The presence of two individual portions of the landslide scar suggests that the landslide probably occurred in two stages. The geometry of the landslide source and the location of the surface of rupture being close to the interface between the fill and colluvium/residual soil suggest that the failure was a retrogressive rotational slide.

The September 2001 landslide could be attributed to prolonged intermittent leakage from the broken sewer onto the slope and was probably triggered at the lower portion by the development of transient elevated water pressures within the fill slope as a result of the ingress of surface water through direct infiltration during modest rainfall. The rainfall intensity immediately prior to the landslide was not particularly severe with estimated return periods of about 4 years for maximum rolling rainfall over periods of 4 days and 7 days preceding the landslide (Section 8). The fill slope had been subjected to more severe rainfall in the past without failure.

The partial saturation of the slope caused by the intermittent discharge of foul water from the 100 mm diameter damaged PVC pipe, which is located at about 1 m above the toe of the lower portion of the landslide scar and connected to the overflows from the septic tanks at Denon Terrace, was probably a key contributory factor to the landslide at the lower portion of the failure area. Coupled with this, the ingress of additional surface water through the grassed area above the landslide site could also have contributed to the failure. In addition, the presence of refuse and construction debris on the slope surface would have promoted water ingress into the slope by interrupting direct surface runoff.

Given the presence of a layer of loose fill on the slope (as inferred from the results of GCO probe tests) and hence a permeability contrast within of the slope forming materials, a perched groundwater table could possibly have developed within the fill layer and above the interface between the more permeable fill and the comparatively less permeable underlying colluvium/residual soil. A small rise in the perched groundwater could have resulted in a significant reduction in effective shear strength and triggered the instability. The theoretical stability analyses carried out for this study (see Section 9) demonstrate that the development of a transient groundwater pressure corresponding to a piezometric level of about 0.5 m above the surface of rupture would be sufficient to initiate the failure of the lower portion of the fill slope.

A higher degree of saturation resulting from the ingress of foul water due to direct discharge of foul water onto the slope would have made the lower portion of the failure area more susceptible to instability than other parts of the slope. Following the sliding failure of the lower portion of the failure area, instability of the upper portion also in the form of rotational failure would then have followed as a result of the loss of support from below.

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10.3 Mobility of the Landslide Debris

The landslide debris, comprised mainly a mixture of fill and residual soil/colluvium (sandy clayey silt to silty sand) with a lot of construction debris and some household refuse, travelled about 25 m along the approximately 30° steep natural hillside and piled up about 2 m high against the back of the squatter structure located at the toe of the natural hillside. The landslide debris displaced the cement-plastered brick wall of the squatter structure by about 300 mm, causing severe damage to the squatter structure. Since the movement of the landslide debris was obstructed by the squatter structure, the travel angle of the landslide debris could not be determined.

No field evidence of very fast movement of the landslide debris could be identified in post-failure observations by MGSL. The absence of any splash marks of debris on the wall of the squatter structure may suggest that the debris was not particularly wet and mobile at the time of impact; nevertheless, the squatter structure was severely damaged by the landslide debris.

11. DISCUSSION

The stability of the section of slope corresponding to the failure site was assessed as part of the submission of site formation plans to the BD in 1993 for the development of No. 56 Denon Terrace. In the slope stability analysis submitted to the BD, the presence of the fill material revealed during the ground investigation was modelled as a 1 m thick horizontal layer of fill at the slope crest and the groundwater table was assumed to be between 1 m and 2.5 m below ground surface. The site formation plans were checked and accepted by the GEO in November 1993. It is noted that the geological model assumed in the above stability analysis was not representative of the actual ground conditions in that the fill stratum was not properly delineated and considered.

Surface runoff from the platforms of Denon Terrace was directly discharged onto slope No. 11NE-B/FR249 through a 150 mm diameter pipe, which was inconsistent with the site formation plan approved by the BD in December 1993.

No major changes in the site setting since the completion of site formation works associated with the development of house No. 56 Denon Terrace were identified in the post-failure investigation. As evidenced from the SIRST inspection in 1998, as well as the presence of refuse and construction debris on the surface of slope No. 11NE-B/FR249 and the direct discharge of foul water from the broken 100 mm diameter PVC pipe onto the slope observed in the post-landslide inspections, the slope was in a state of poor maintenance.

12. CONCLUSIONS

The September 2001 landslide below house No. 56 Denon Terrace involved a retrogressive rotational sliding failure (with a source volume and an entrained volume of about 40 m^3 and 10 m^3 respectively) of slope No. 11NE-B/FR249 and the natural hillside below during moderate rainfall. The failure was probably caused by direct infiltration and build-up of transient groundwater pressure within the relatively thin layer of fill. The slope

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stability was previously assessed in 1993 and the geotechnical submission was accepted by the GEO. The geological model assumed in the stability analysis was not representative of the actual ground conditions in that the fill stratum was not considered.

Results of the post-landslide GCO probe tests indicate that the fill of the slope was generally loose. Development of a perched groundwater table at the lower part of the loose fill slope probably occurred as a result of direct infiltration of water during moderate rainfall and subsequent saturation. This was probably exacerbated by the discharge of foul water onto the fill slope from a 100 mm diameter PVC pipe, which had been probably broken for some time prior to the September 2001 landslide. The debris from the source area of the landslide moved downslope and entrained approximately 10 m^3 of insitu material on the natural hillside below. About 15 m below the landslide source, the landslide debris severely damaged an inhabited squatter structure, which was subsequently permanently evacuated. No casualties were reported as a result of the failure.

13. REFERENCES

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Geo Con Engineers (1993a). Geotechnical Study on the Site Formation Planning for the Proposed Village House Development, at Lot No. 933 in D.D 226 Tseng Lan Shue, Sai Kung, New Territories. Geo Con Engineers, 16 p. plus 8 appendices and 11 drawings.

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Table 1 - Maximum Rolling Rainfall at GEO Raingauge No. N08 for Selected Durations Preceding the Landslide on 1 September 2001 and the Estimated Return Periods

Duration	Maximum Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years) (See Note 2)
5 Minutes	11.5	22:20 hours on 1 September 2001	< 2
15 Minutes	30.0	22:25 hours on 1 September 2001	3
1 Hour	67.5	22:30 hours on 1 September 2001	< 2
2 Hours	110.5	22:35 hours on 1 September 2001	3
4 Hours	118.5	22:35 hours on 1 September 2001	2
12 Hours	132.5	22:35 hours on 1 September 2001	< 2
24 Hours	176.5	22:35 hours on 1 September 2001	< 2
48 Hours	191.0	22:35 hours on 1 September 2001	< 2
4 Days	405.0	22:35 hours on 1 September 2001	4
7 Days	451.0	22:35 hours on 1 September 2001	4
15 Days	451.5	22:35 hours on 1 September 2001	< 2
31 Days	570.0	22:35 hours on 1 September 2001	< 2

Notes:
(1) Maximum rolling rainfall was calculated using 5-minute rainfall data.
(2) Return periods were derived from Table 3 of Lam & Leung (1994) and statistical parameters from Evans & Yu (2000). The return periods obtained by the two methods do not show a significant difference.
(3) The use of 5-minute data for return periods of rainfall durations between 2 hours and 31 days results in better data resolution, but may slightly over-estimate the return periods using data by Lam & Leung (1994), which are based on hourly rainfall for these durations.
(4) The landslide occurred at approximately 10:30 p.m. on 1 September 2001.
(5) The nearest GEO raingauge to the landslide site is raingauge No. N08 situated at about 1.1 km to the northeast of the site.

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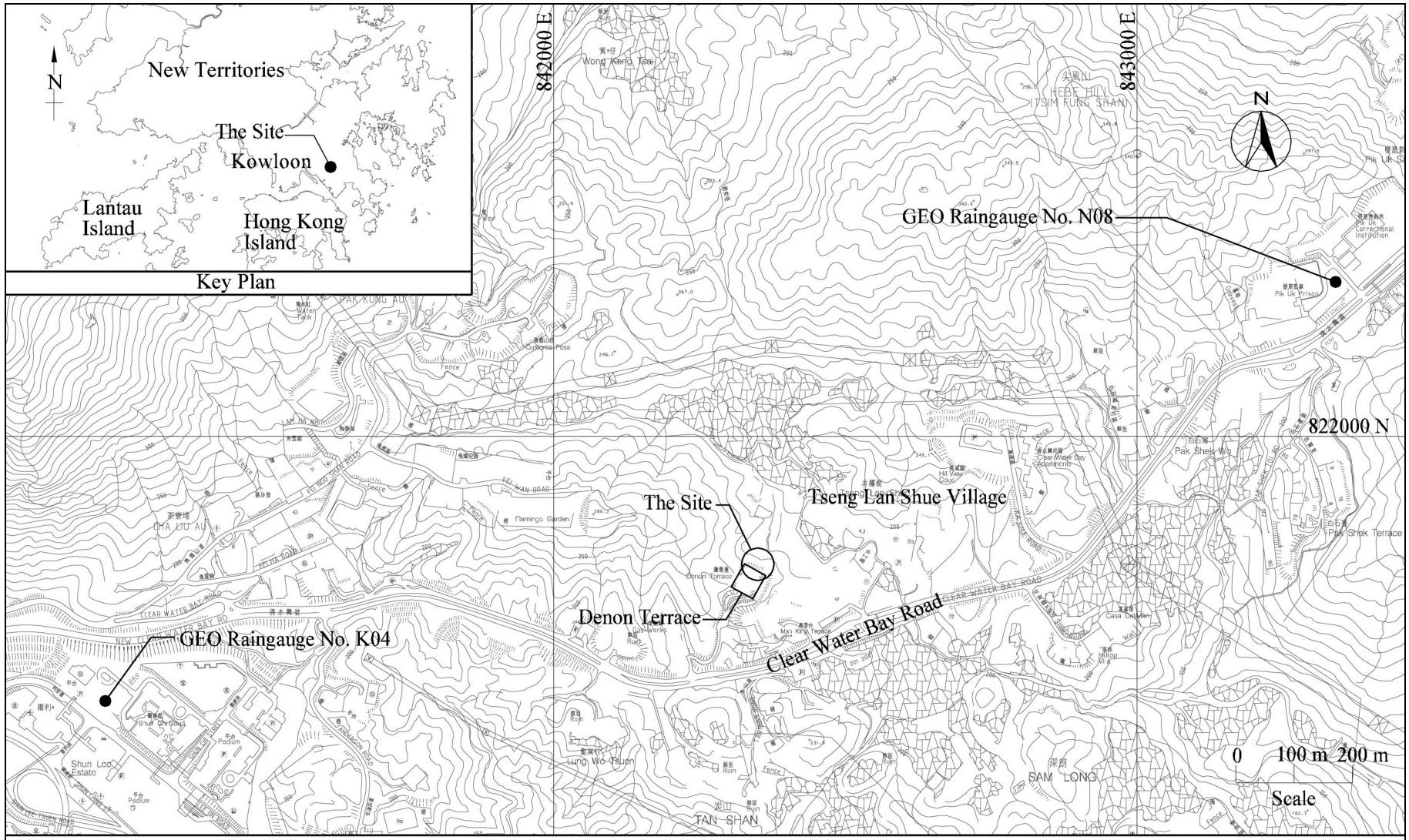
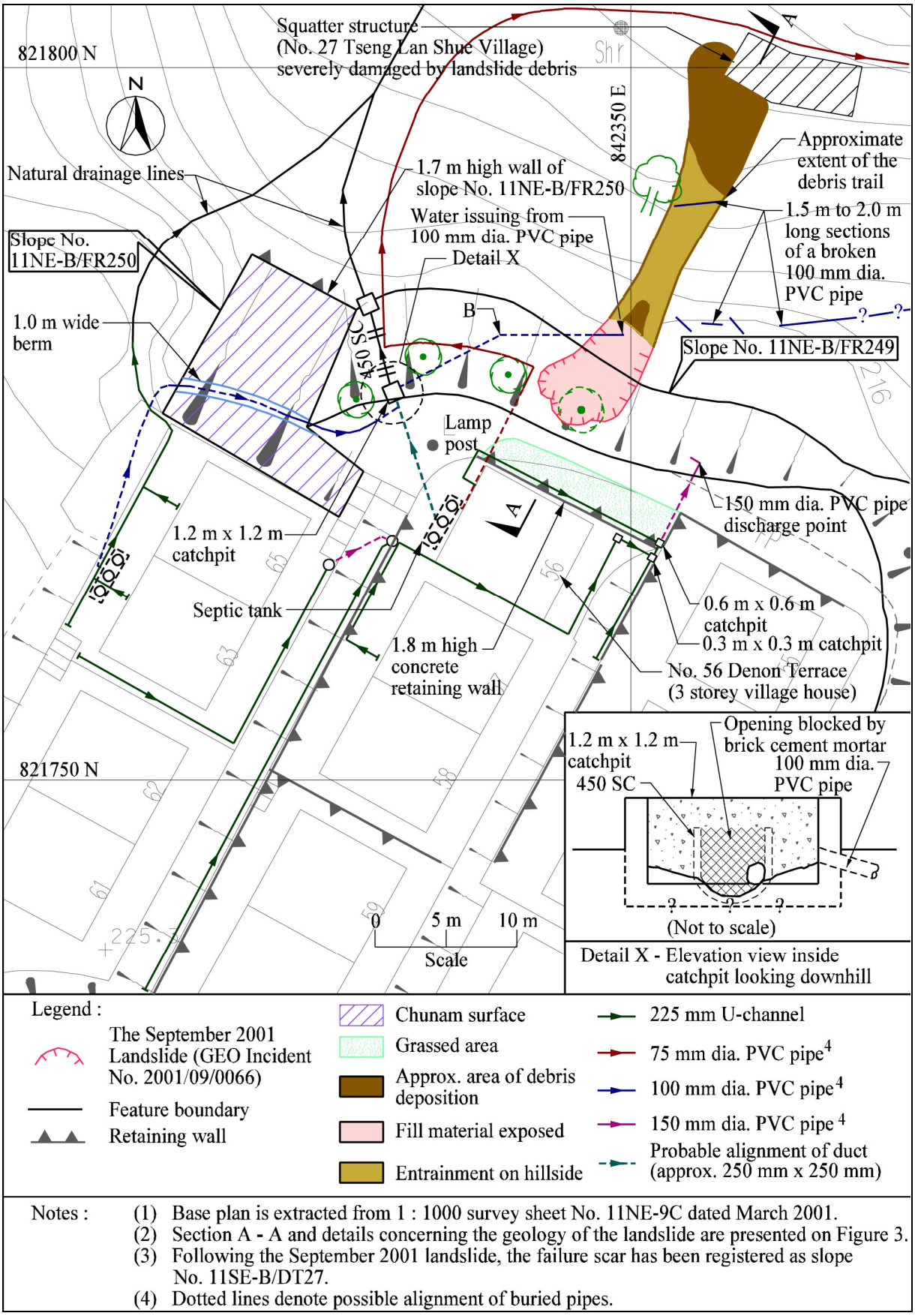


Figure 1 - Site Location Plan



Notes :
(1) Base plan is extracted from 1 : 1000 survey sheet No. 11NE-9C dated March 2001.
(2) Section A - A and details concerning the geology of the landslide are presented on Figure 3.
(3) Following the September 2001 landslide, the failure scar has been registered as slope No. 11SE-B/DT27.
(4) Dotted lines denote possible alignment of buried pipes.

Figure 2 - Site Observations

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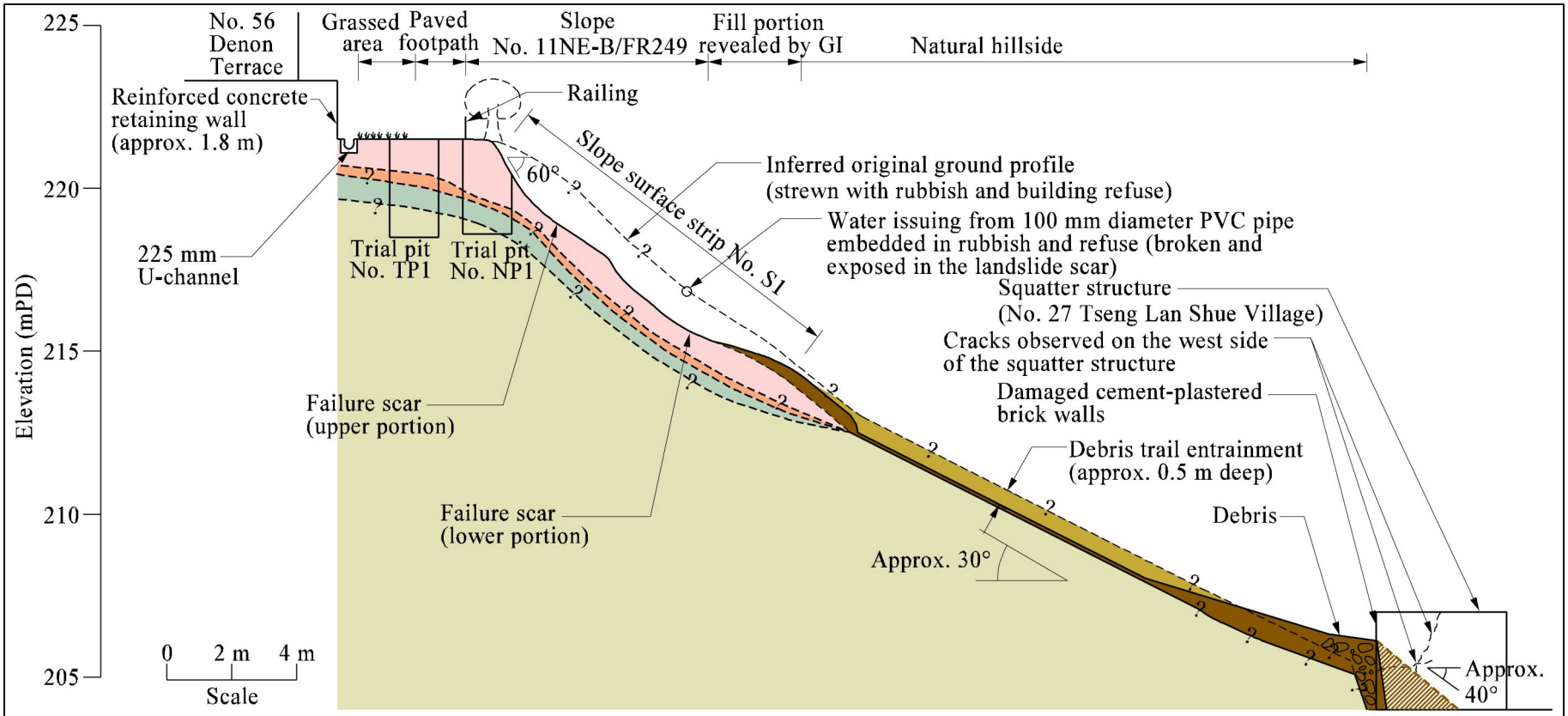

Legend :

- Fill - orangish brown mottled grey sandy clayey SILT with some fine to coarse gravel-sized rock fragments
- Landslide debris - yellowish brown, orangish brown and grey sandy clayey SILT to silty SAND with a lot of construction debris (e.g. brick fragment and cobble-sized concrete blocks)
- Zone of entrainment (probably involved topsoil and a thin layer of colluvium/residual soil) to a maximum depth of 0.5 m
- Colluvium/residual soil
- CDG
- Top soil

Notes :

(1) See Figure 2 for location of cross-section and Figure 7 for locations and general infromation of ground investigation stations.
(2) The inferred boundary between fill and colluvium/residual soil is based on information from trial pit and slope surface strip co-related with the GCO probe results.
(3) Based on trial pit No. TP1 (excavated in 1993), fill comprises silty sand, top soil comprises sandy silt; the completely weathered rock was mis-logged as CDV being silty sand.

Figure 3 - Geological Section A - A through the Landslide

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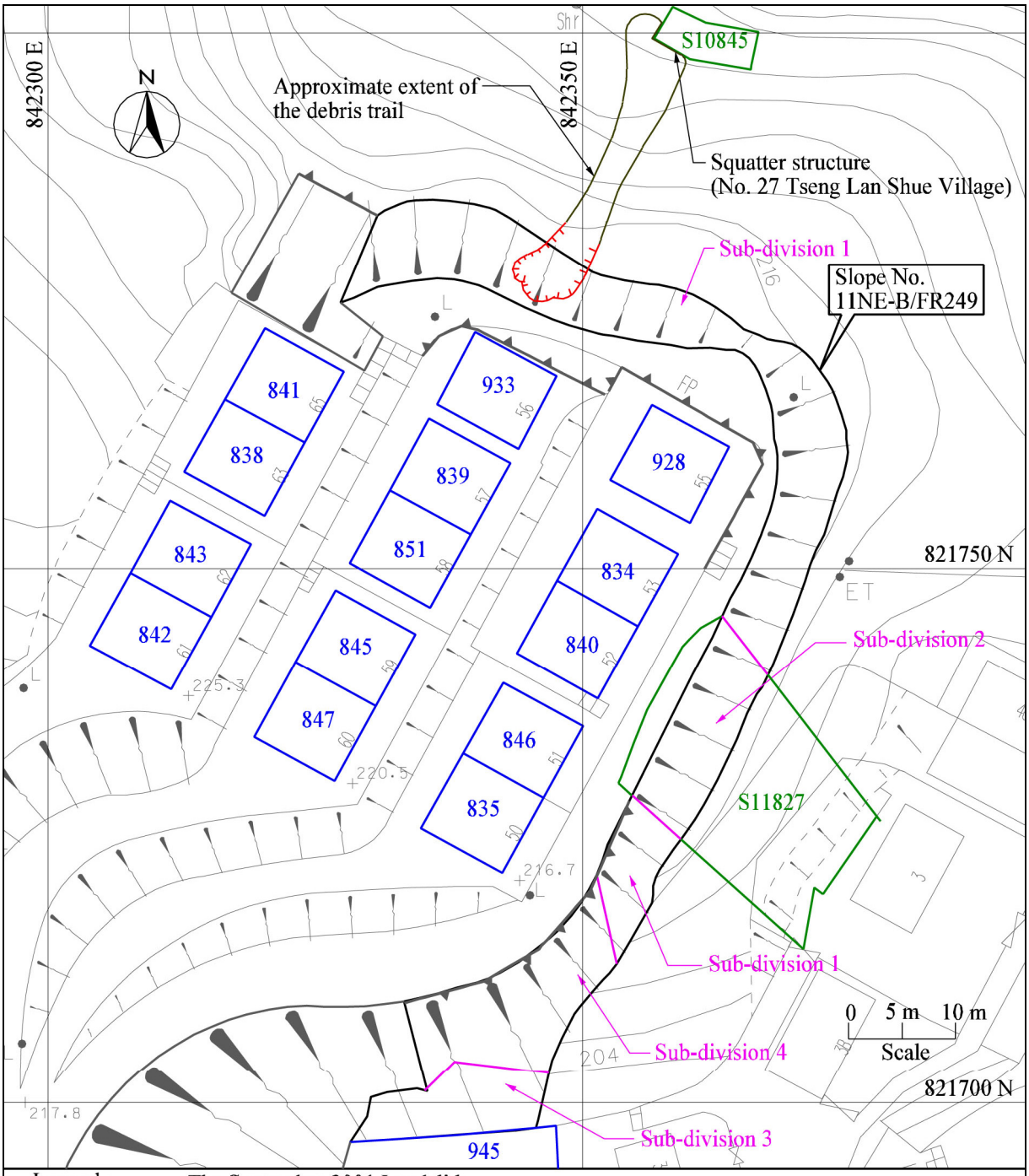

Legend :

	The September 2001 Landslide (GEO Incident No. 2001/09/0066)
933	Lot No. 933 in D.D. 226
S11827	Government Licensed Land (No. S11827)
	Feature boundary
	Retaining wall
	Boundary of Sub-division

Notes :

(1) Base plan is extracted from 1 : 1000 survey sheet No. 11NE-9C dated March 2001.

(2) According to the SIMAR report, Sub-division 1 of slope No. 11NE-B/FR249 was jointly maintained by the owners of lots Nos. 834, 835, 838 to 843 and 845 to 847, 851, 928 and 933 in D.D. 226 at the time of the September 2001 landslide incident.

(3) The maintenance responsibility of sub-division 1 of slope No. 11NE-B/FR249 was subsequentlyassigned to the Lands D according to a memo from the Lands D dated 25 March 2002.

Figure 4 - Maintenance Responsibility

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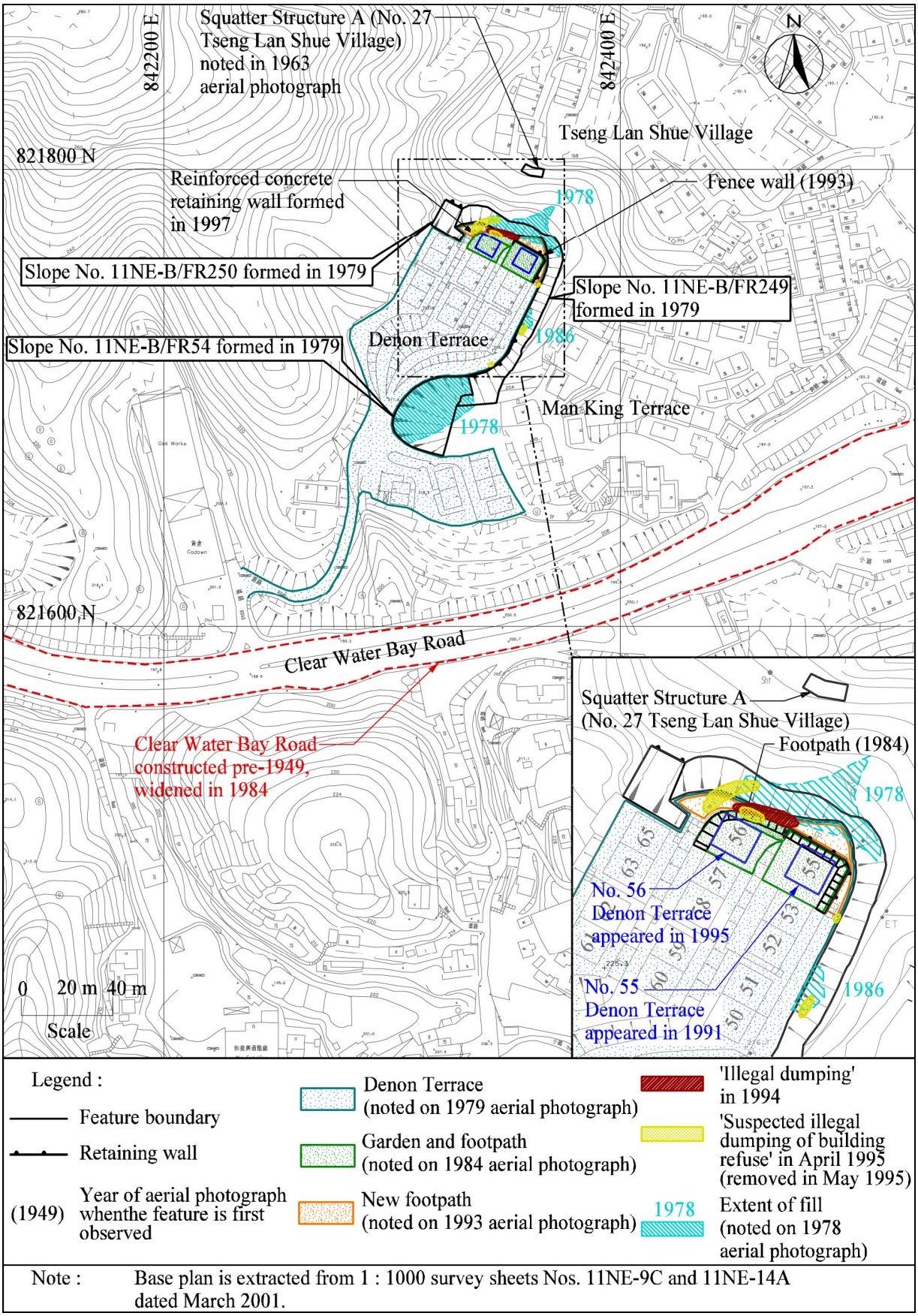

Figure 5 - Site History

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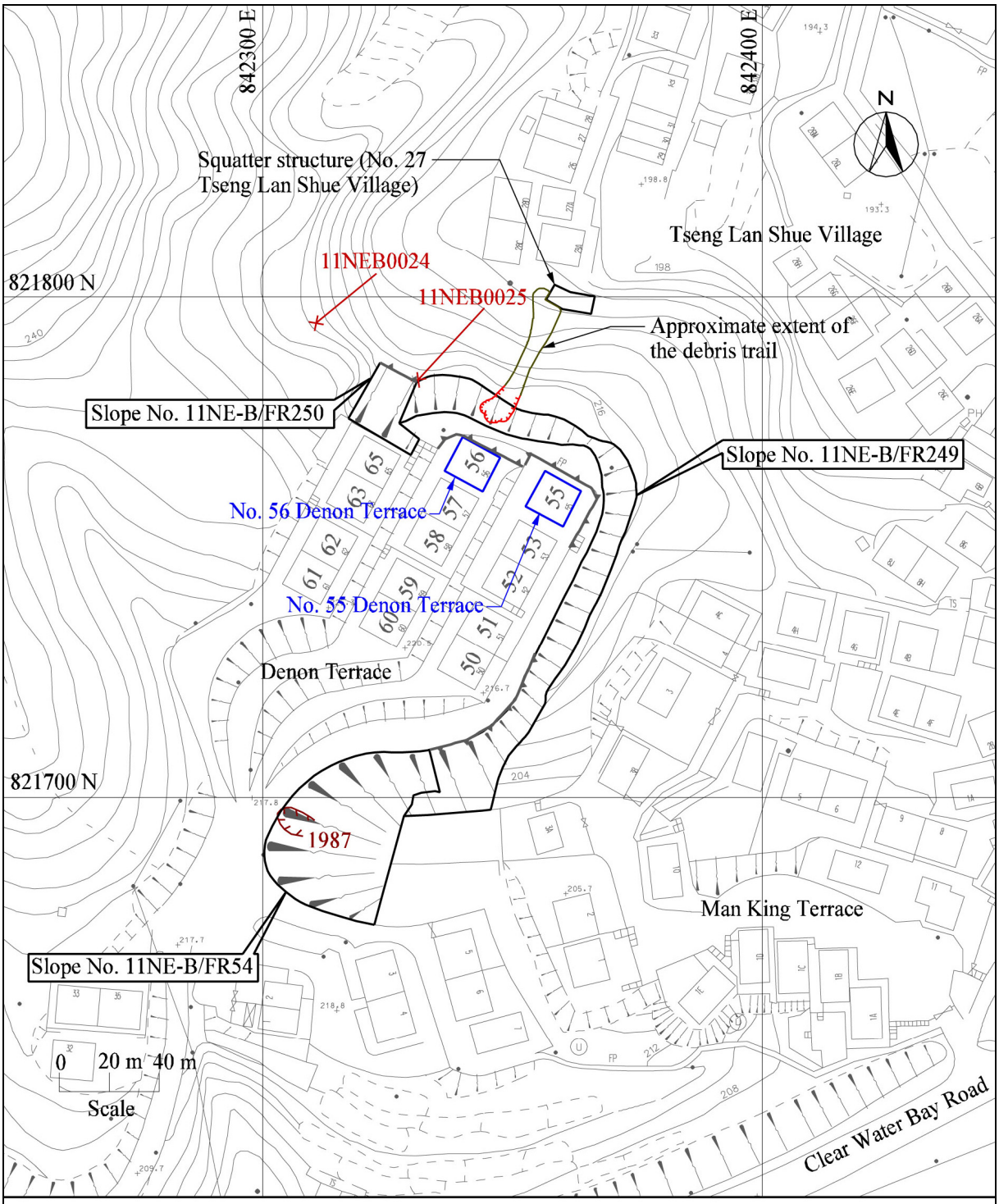

Legend :

- The September 2001 Landslide (GEO Incident No. 2001/09/0066)
- 1987 Erosion/Landslide scar (with year of aerial photograph)
- Feature boundary line
- Retaining wall
- 11NEB0024 NTLI No. 11NEB0024

Notes :

(1) Base plan is extracted from 1 : 1000 survey sheets Nos. 11NE-9C and 11NE-14A dated March 2001.

(2) Boundaries of features, which are not relevant to the September 2001 landslide incident are not indicated for clarity.

Figure 6 - Past Instability

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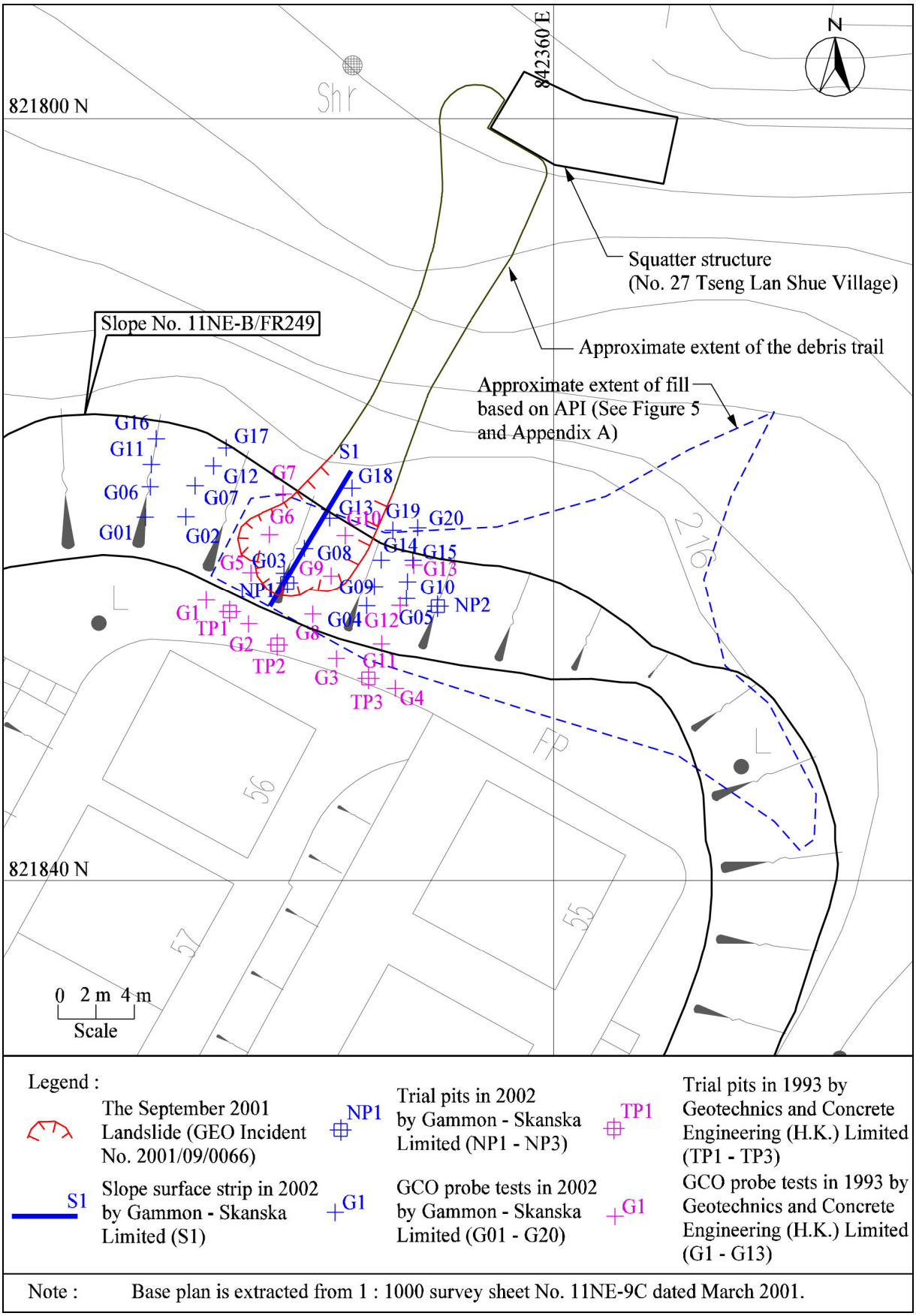

Figure 7 - Ground Investigation Plan

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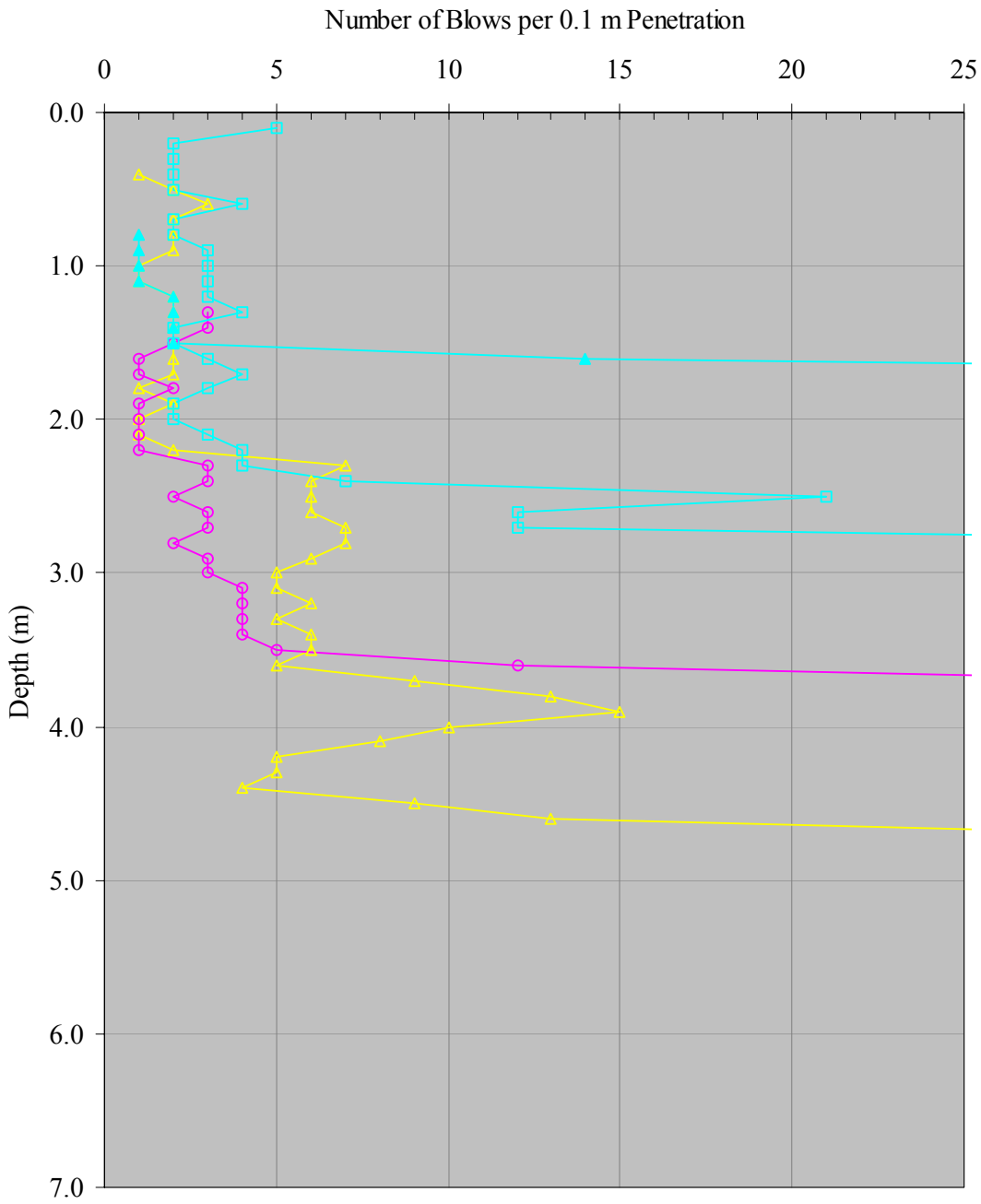

Legend:

G3 G8 G13 G18

Notes: (1) GCO probe Nos. G1 to G12 were carried out within the boundary of slope No. 11NE-B/FR249 and Nos. G13 to G20 were carried out on the hillside below.
(2) Probe values exceeding 25 are not shown for simplicity.

Figure 8 - Results of GCO Probe Tests Carried Out Inside the Landslide Scar

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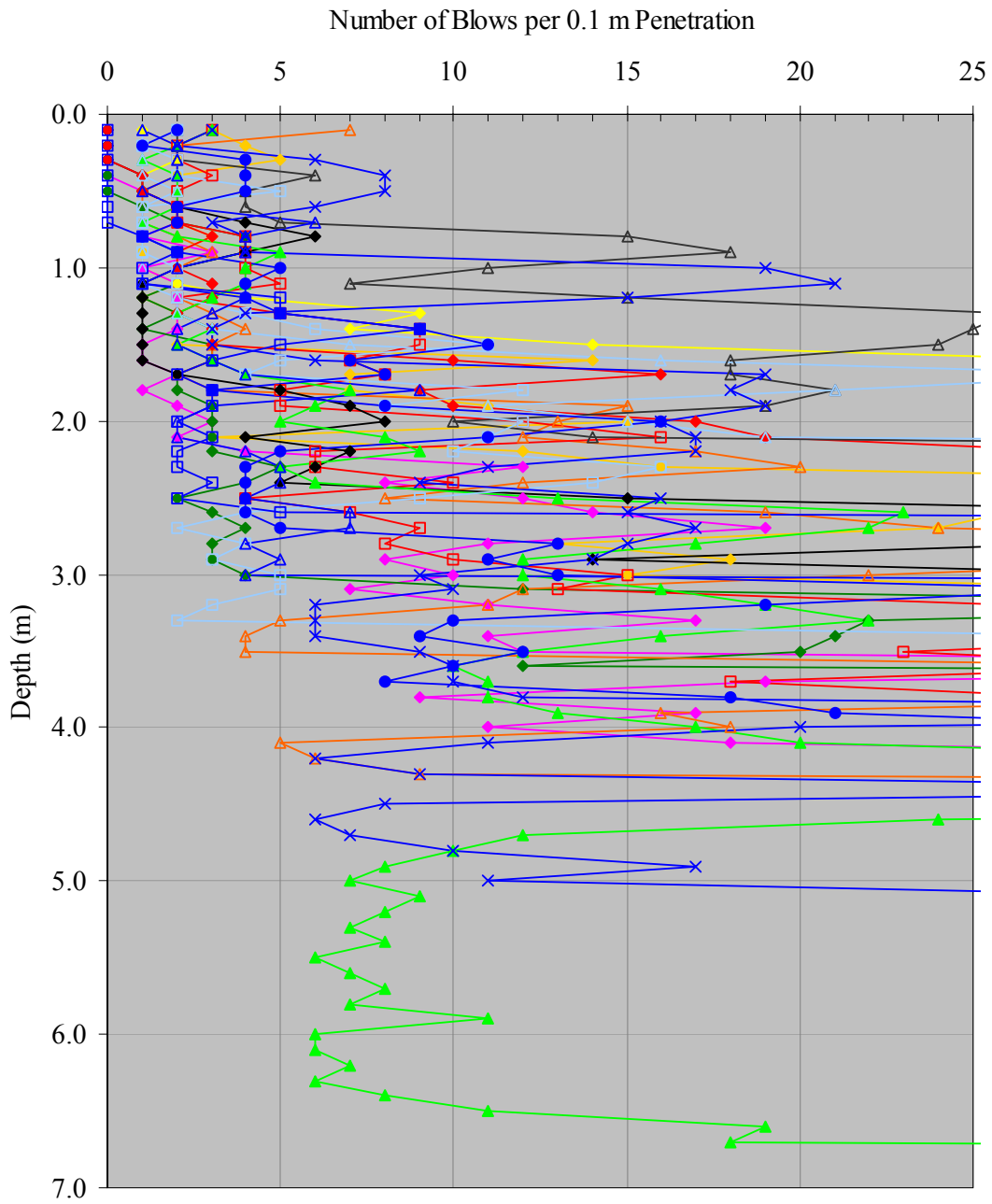

Legend:

G1 G2 G4 G5 G6 G7 G9 G10
G11 G12 G14 G15 G16 G17 G19 G20

Notes: (1) GCO probe Nos. G1 to G12 were carried out within the boundary of slope No. 11NE-B/FR249 and Nos. G13 to G20 were carried out on the hillside below.
(2) Probe values exceeding 25 are not shown for simplicity.

Figure 9 - Results of GCO Probe Tests Carried Out Outside the Landslide Scar

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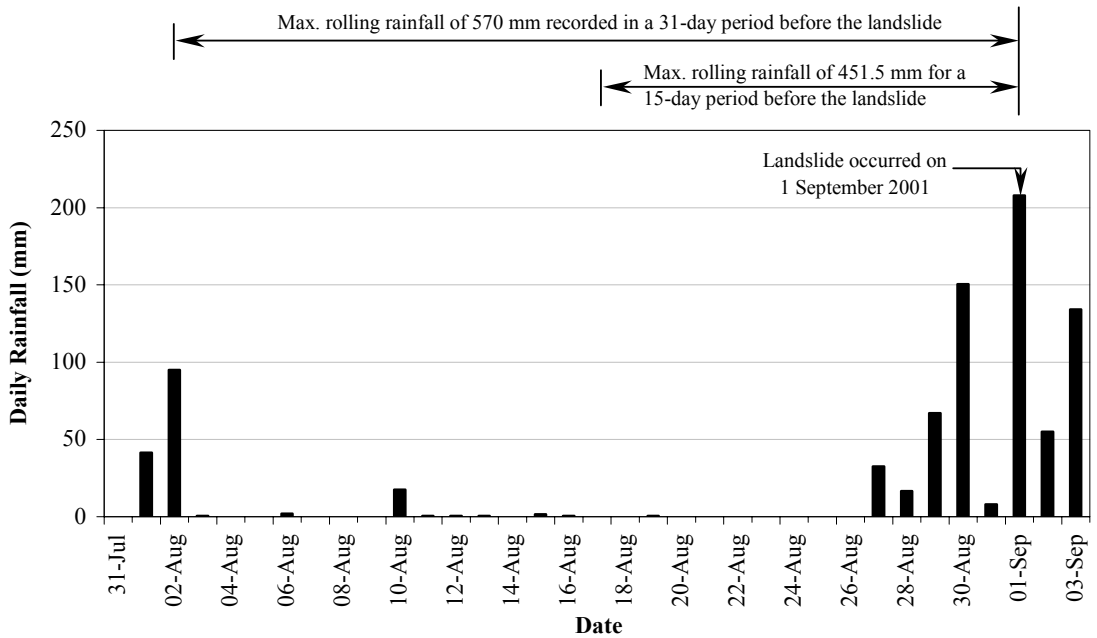
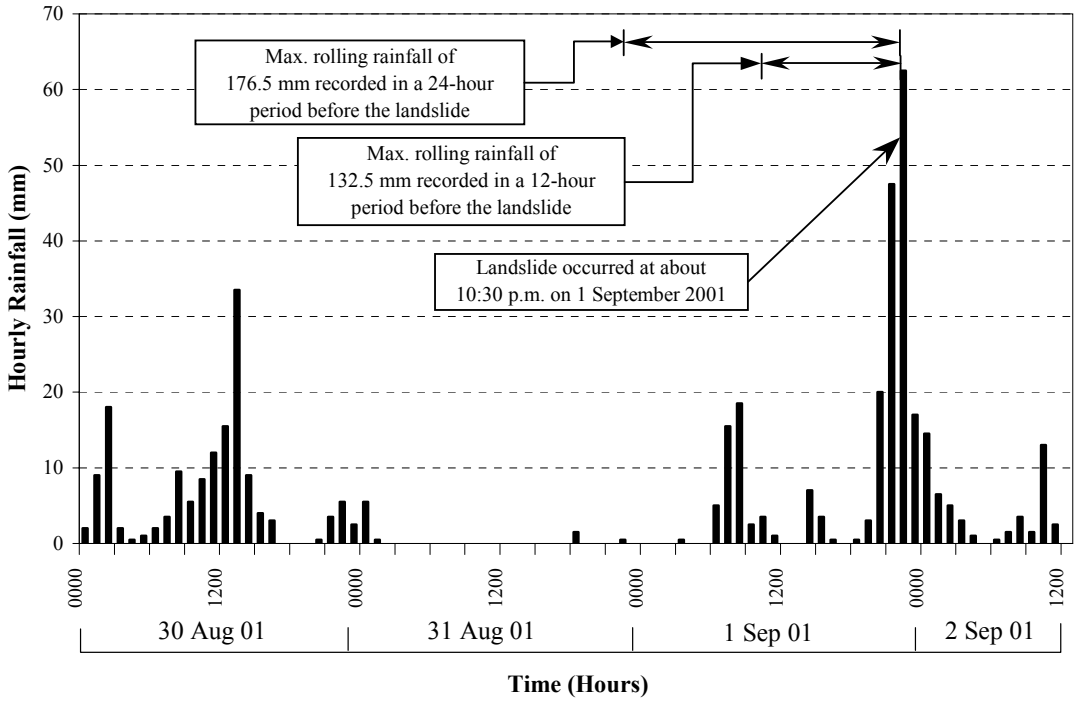


(a) Daily Rainfall Recorded at GEO Raingauge No. N08 between 31 July 2001 and 3 September 2001



(b) Hourly Rainfall Recorded at GEO Raingauge No. N08 between 30 August 2001 and 2 September 2001

Figure 10 - Daily and Hourly Rainfall Recorded at GEO Raingauge No. N08

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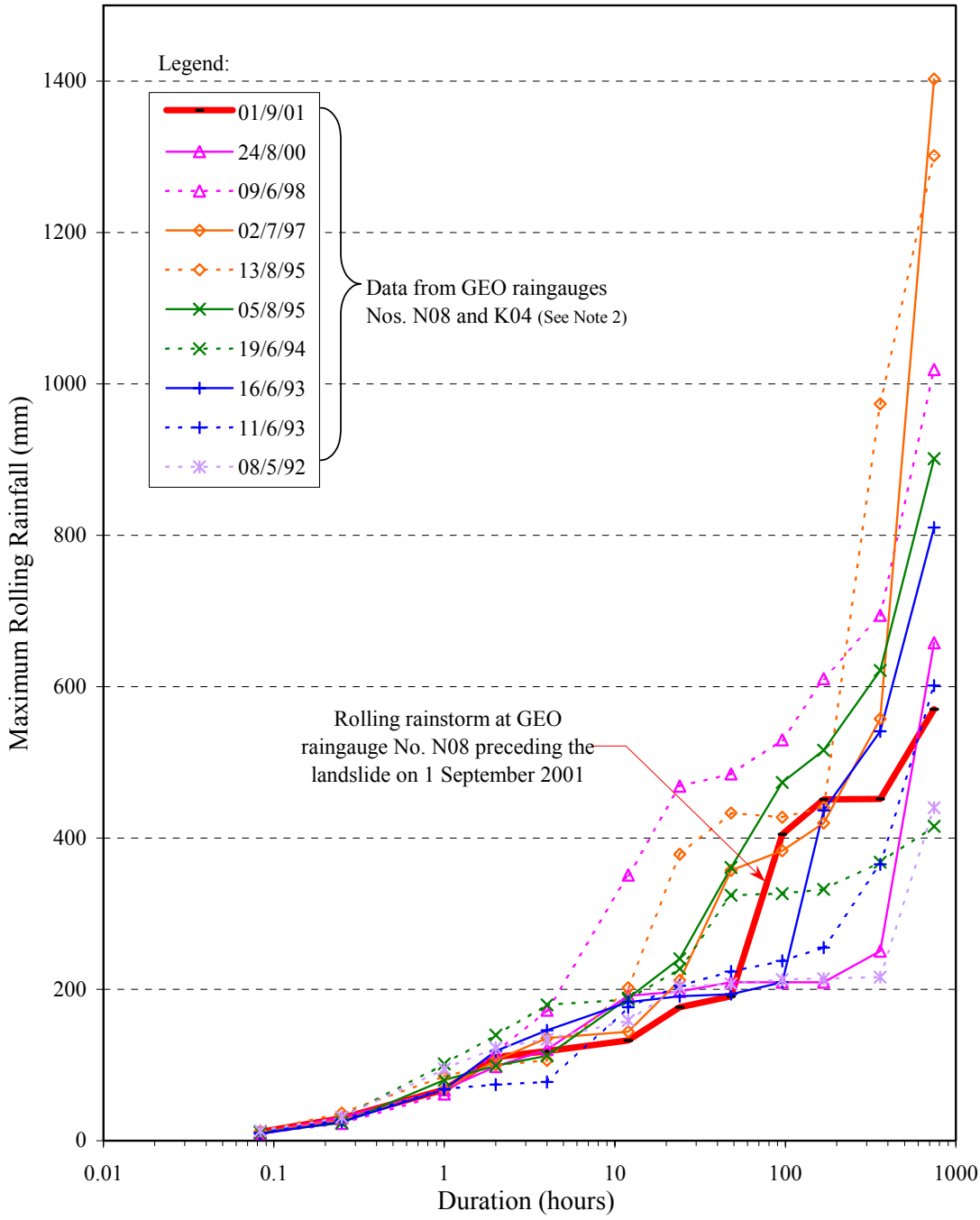

Notes:

(1) Rainfall data evaluated from 5-minute readings from GEO raingauges Nos. N08 (about 1.1 km northeast of the site) and K04 (about 1.15 km west of the site).

(2) Rolling rainfall of previous rainstorms calculated at GEO raingauge No. N08 since July 1983 when the raingauge became operational. Rainstorms in 1989, 1993 and 1994 were calculated from GEO raingauge No. K04, when no data were available from GEO raingauge No. N08.

Figure 11 - Maximum Rolling Rainfall for Previous Major Rainstorms at GEO Raingauges Nos. K04 and N08

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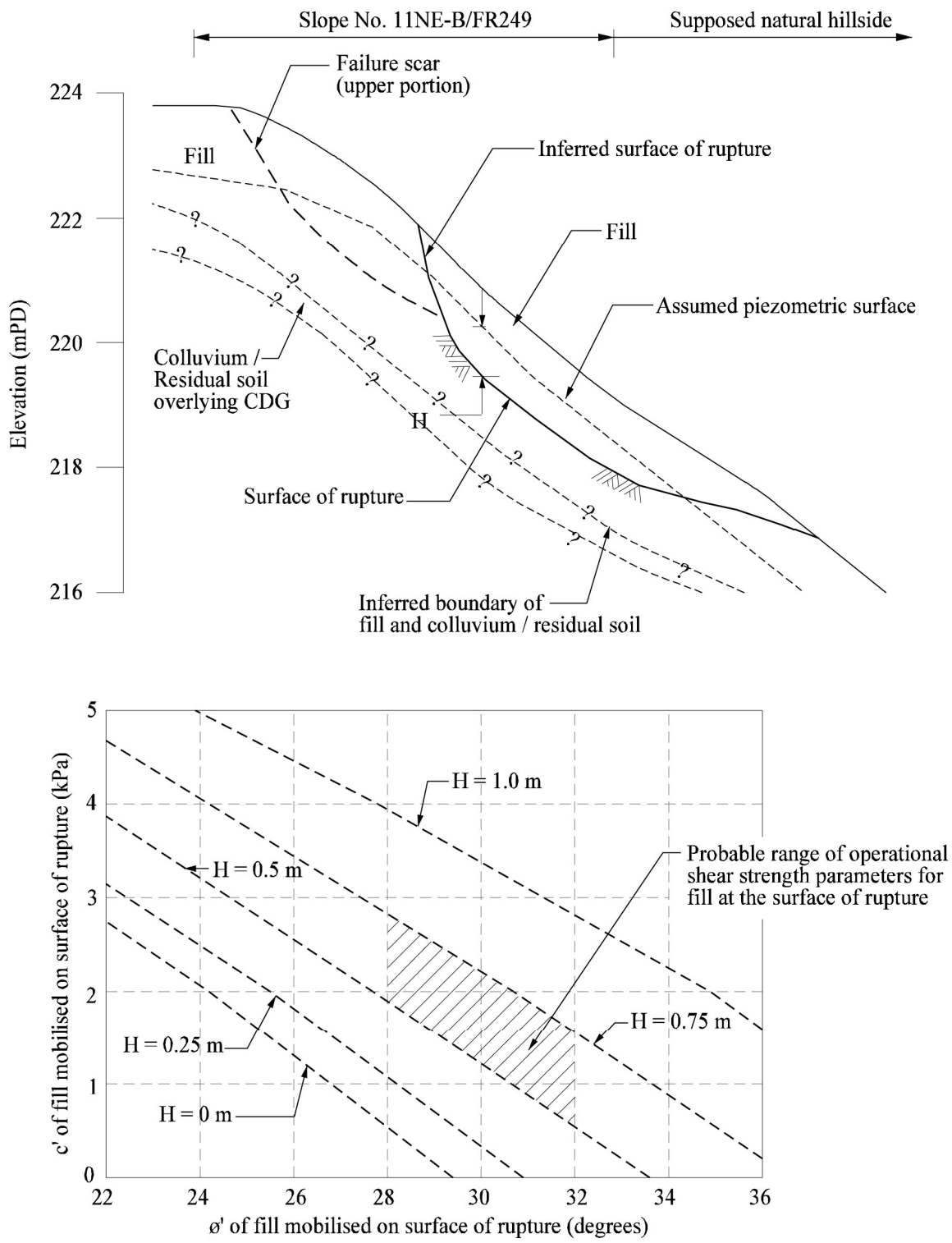

Legend :	----- Factor of safety equal to unity (i.e. limiting equilibrium)
Note :	The pre-failure slope profile and the surface of the rupture area are based on topographic survey plans, photographic records and post-failure observations.

Figure 12 - Summary of Sensitivity Analyses

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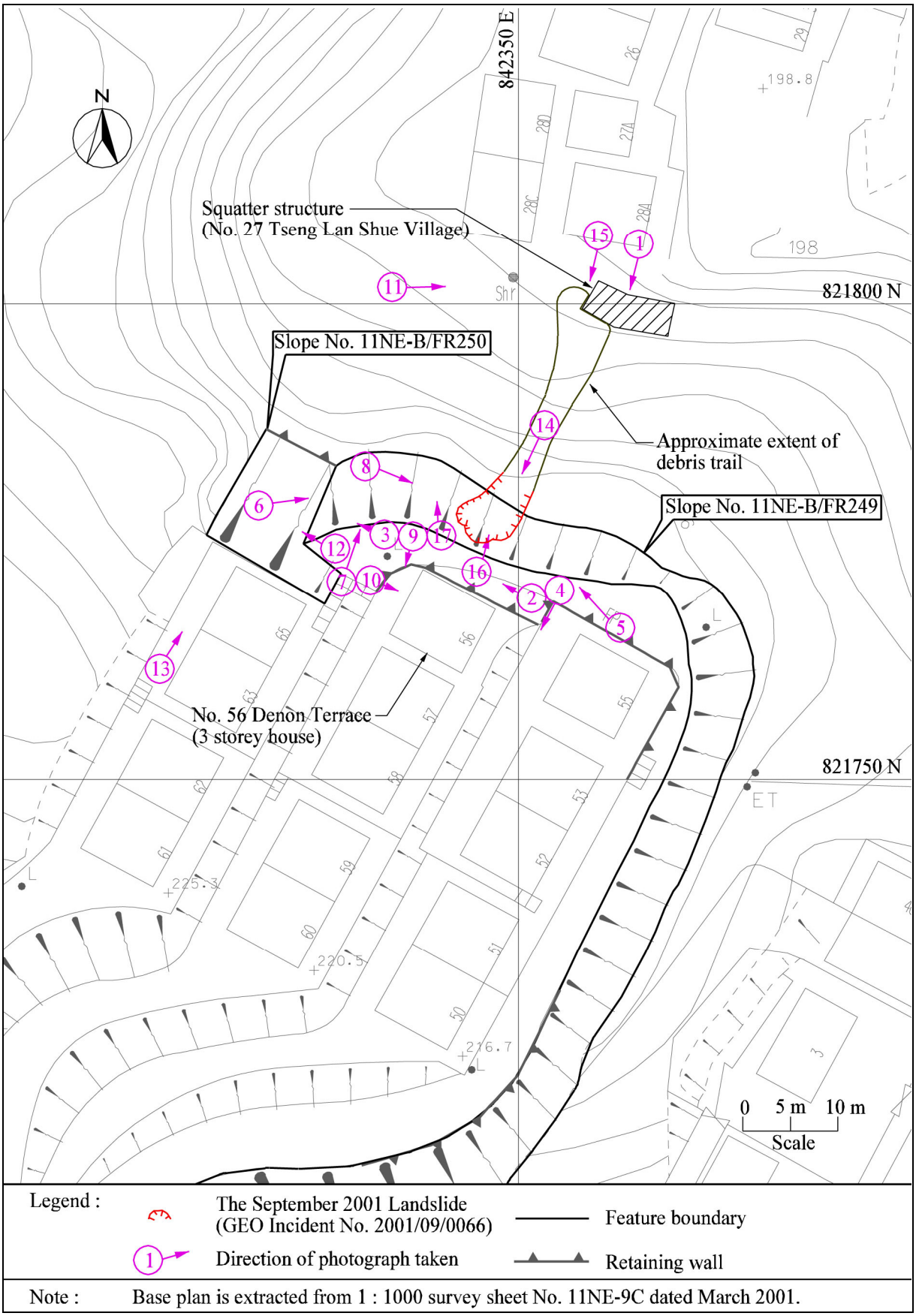

Figure 13 - Locations and Directions of Photographs

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Plate 1 - General View of the Landslide Site (Photograph taken on 3 September 2001)

Note: See Figure 13 for location and direction of photograph.

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Plate 2 - View of the Concrete Paved Footpath at the Crest of Slope No. 11NE-B/FR249 above the Landslide Site (Photograph taken on 4 June 2002)

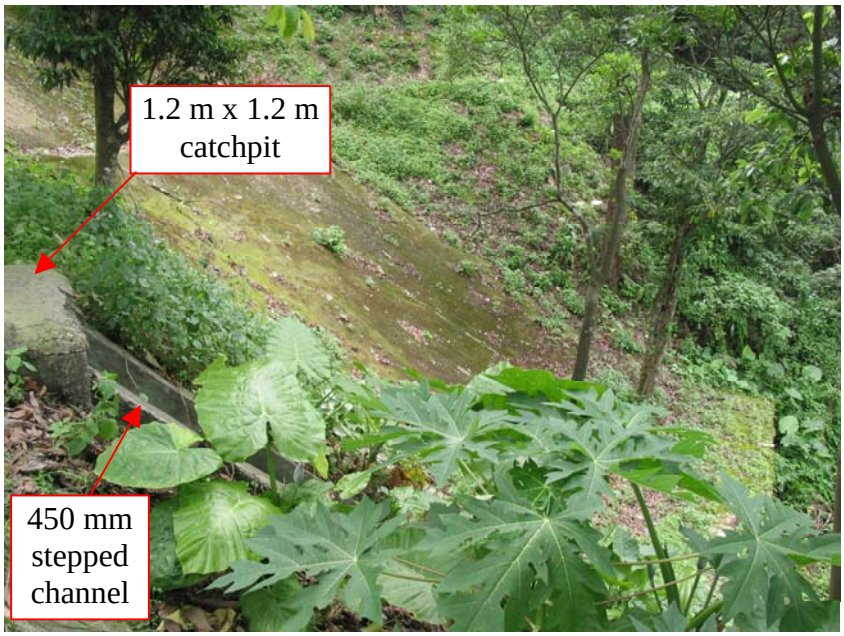

Plate 3 - General View of Slope No. 11NE-B/FR250 (Photograph taken on 4 June 2002)

Note: See Figure 13 for locations and directions of photographs.

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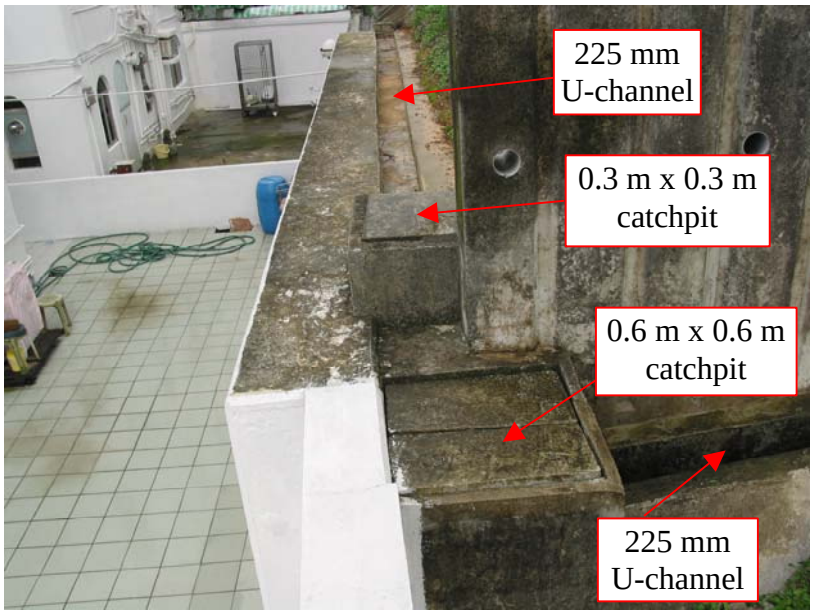

Plate 4 - View of the Catchpits at the East Corner of No. 56 Denon Terrace
(Photograph taken on 22 May 2002)

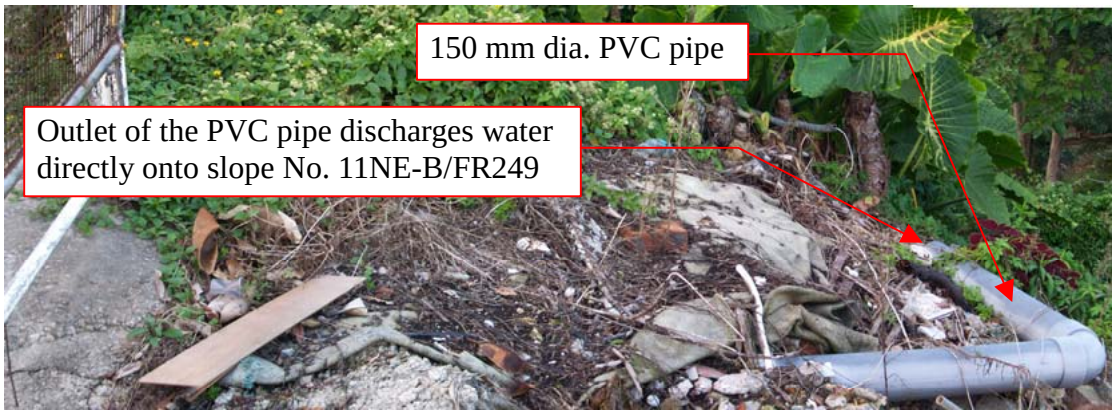

Plate 5 - View of the 150 mm Diameter PVC Pipe on Slope No. 11NE-B/FR249
(Photograph taken on 21 December 2001)

Note: See Figure 13 for locations and directions of photographs.

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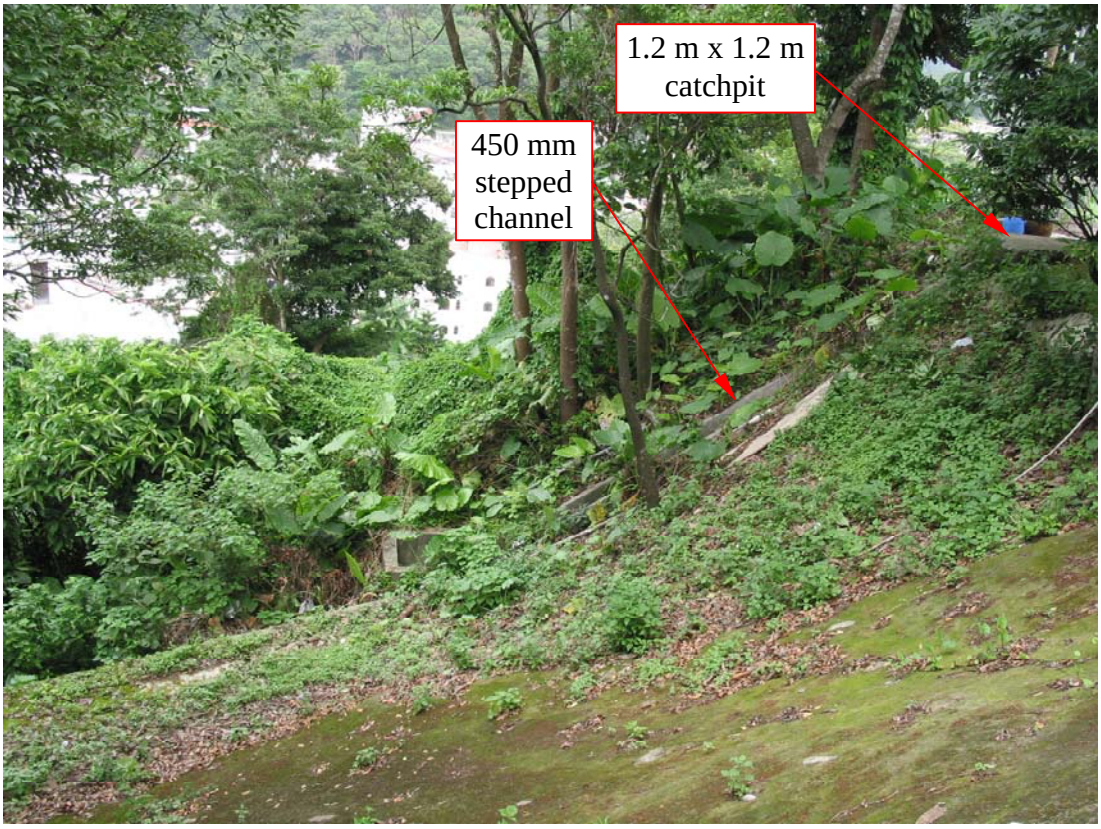

Plate 6 - View of the 450 mm Stepped Channel on Slope No. 11NE-B/FR250
(Photograph taken on 4 June 2002)

Note: See Figure 13 for location and direction of photograph.

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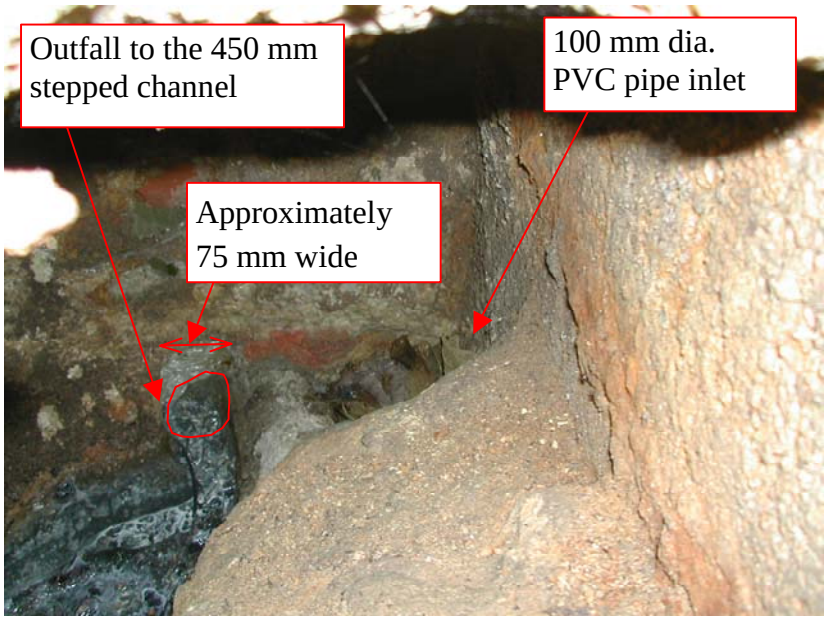

Plate 7 - View inside the 1.2 m x 1.2 m Catchpit at the Crest of Slope No. 11NE-B/FR249 (Photograph taken on 24 September 2002)

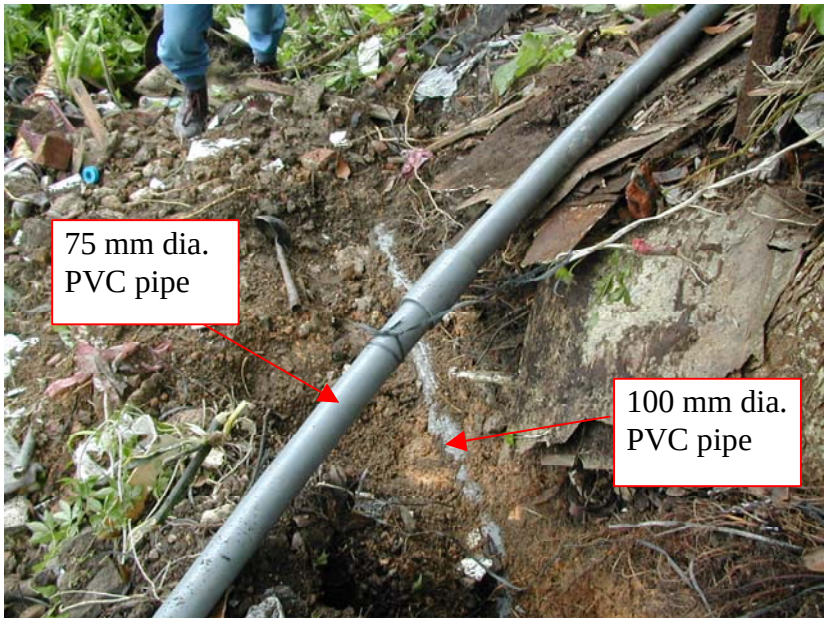

Plate 8 - View of the Buried 100 mm Diameter PVC Pipe and the 75 mm Diameter PVC Pipe on the Hillside (Photograph taken on 24 September 2002)

Note: See Figure 13 for locations and directions of photographs.

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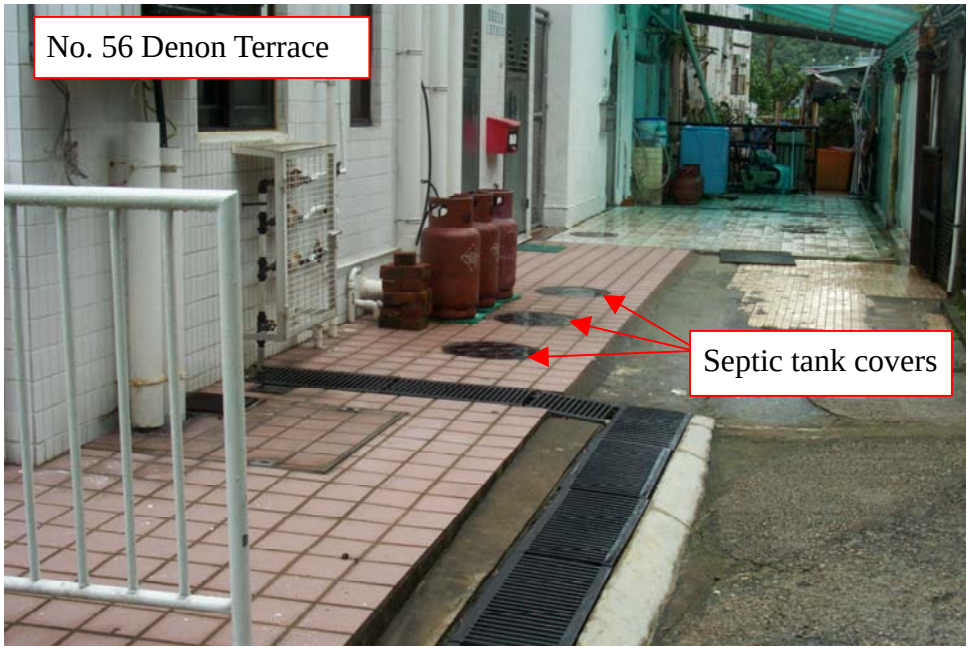

Plate 9 - View of Septic Tank Location Adjacent to No. 56 Denon Terrace (Photograph taken on 20 June 2002)

Plate 10 - View of the Septic Tank Outlet to the 75 mm Diameter PVC Pipe (Photograph taken on 24 September 2002)

Note: See Figure 13 for locations and directions of photographs.

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Plate 11 - View of the 75 mm Diameter PVC Pipe near Squatter Structure (No. 27 Tseng Lan Shue Village)
(Photograph taken on 9 October 2002)

Note: See Figure 13 for location and direction of photograph.

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Plate 12 - View of the Septic Tank Location Adjacent to Nos. 63 and 65 Denon Terrace
(Photograph taken on 9 October 2002)

Note: See Figure 13 for location and direction of photograph.

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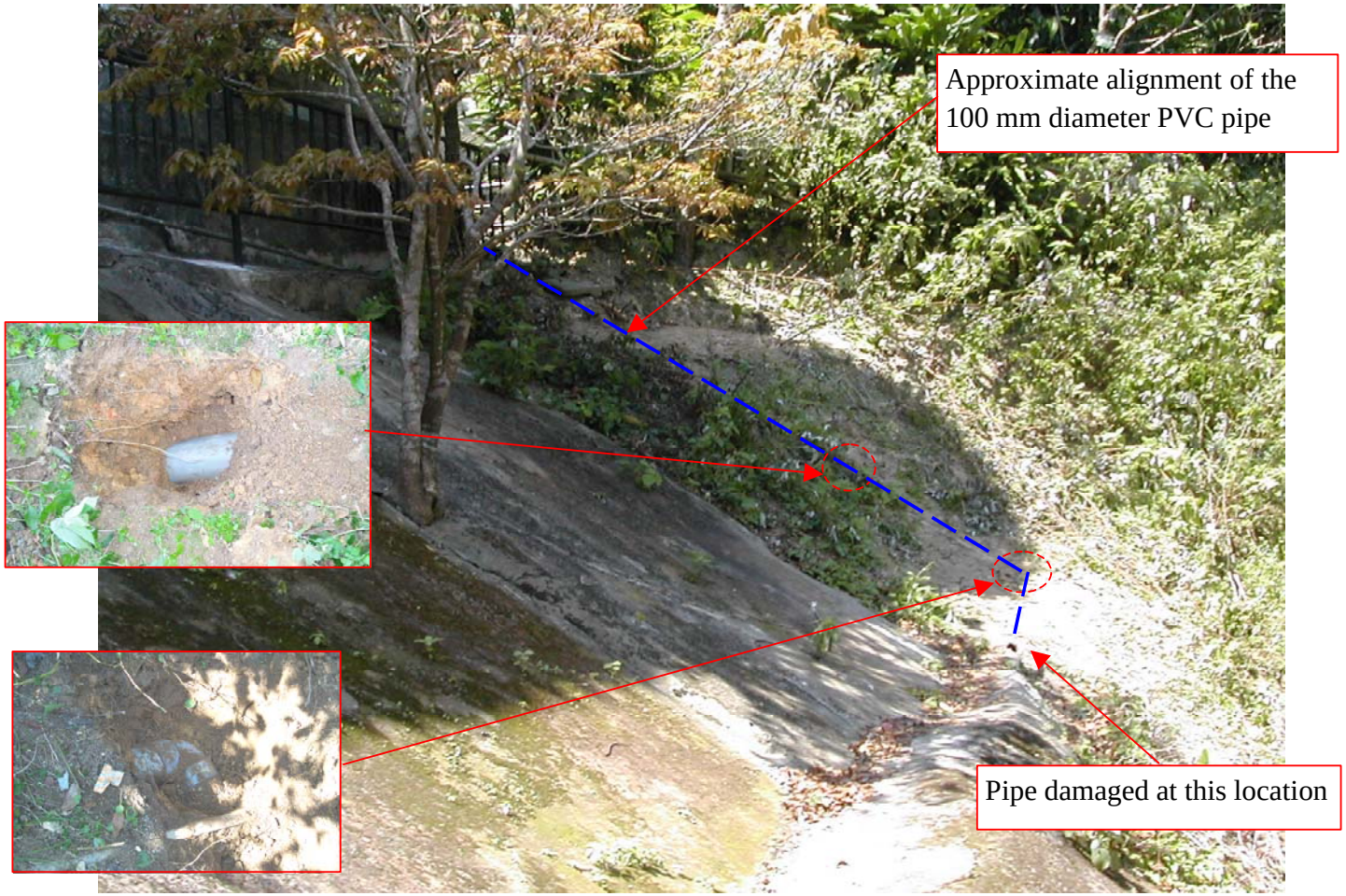

Plate 13 - View Showing the Approximate Alignment of the 100 mm Diameter PVC Pipe on Slope No. 11NE-B/FR250
(Photograph taken on 9 October 2002)

Note: See Figure 13 for location and direction of photograph.

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Plate 14 - General View of the Landslide Scar
(Photograph taken by GEO on 3 September 2001)

Note: See Figure 13 for location and direction of photograph.

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Plate 15 - View of Severely Damaged Wall of Squatter Structure (No. 27 Tseng Lan Shue Village) (Photograph taken on 3 September 2002)

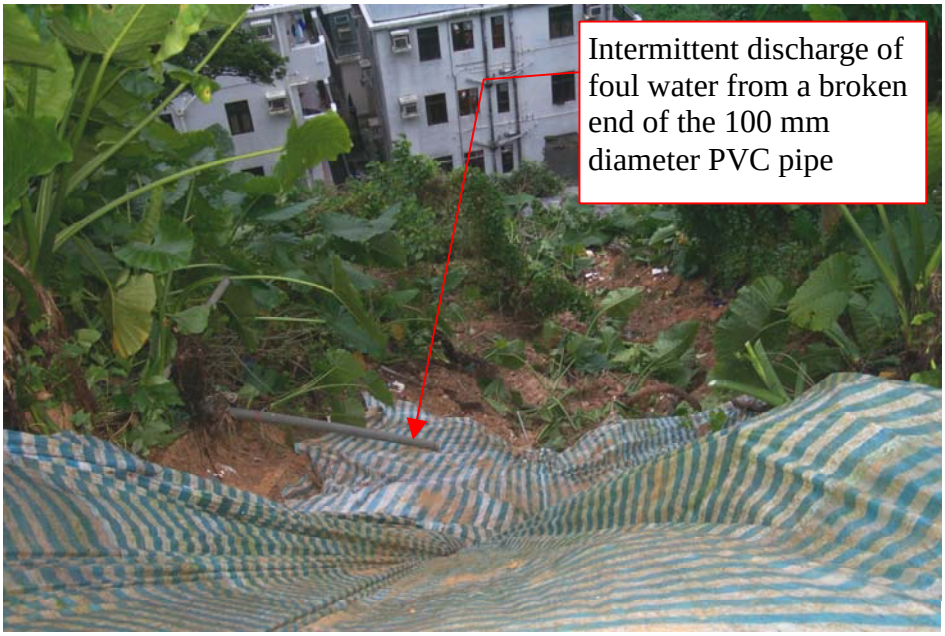

Plate 16 - View of the 100 mm Diameter PVC Pipe at the Landslide Site (Photograph taken on 3 September 2001)

Note: See Figure 13 for locations and directions of photographs.

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Plate 17 - View of the 100 mm Diameter PVC Pipe Separated at the Joint
(Photograph taken on 24 September 2002)

Note: See Figure 13 for location and direction of photograph.

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APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

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A.1 DETAILED OBSERVATIONS

This appendix sets out the detailed observations made from an interpretation of aerial photographs taken between 1949 and 2001. A list of the aerial photographs studied (Table A1) and a location plan (Figure A1) are also attached.

YEAR	OBSERVATIONS
1949	The study area was a natural terrain covered with light vegetation. A footpath was observed along the ridge of the natural terrain. Clear Water Bay Road had been constructed and was in its present-day alignment. Isolated structures probably squatter structures at the present-day location of Tseng Lan Shue Village were visible to the east of the study area. Cultivated land and terraces were observed to the east and south of the study area respectively.
1963	No observable changes to the study area. The natural terrain was generally covered with light vegetation and in places covered with dense vegetation. A structure (probably a squatter structure, designated as 'Squatter Structure A') was observed at the present-day location of No. 27 Tseng Lan Shue Village.
1964	No observable changes to the study area.
1967	No observable changes to the study area. Two landslide scars, which were covered with light vegetation, can be seen on the hillside to the northwest of the study area. The west landslide scar trends southwest-northeast and was approximately 18 m long by 6 m wide and is in "spoon-shaped". The east landslide scar, which also trends southwest-northeast, was approximately 22 m long by 5 m wide with a long debris trail. Another squatter structure (designated as 'Squatter Structure B') was observed immediately to the northwest of Squatter Structure A. HK LP Gas building has been built to the southwest of the study area.
1972	No coverage of the study area. Slope No. 11NE-B/CR722 located to the southeast and downhill of the study feature has been formed with a bare surface. The cultivation terraces to the south of the present-day Denon Terrace have become abandoned and covered with more vegetation.

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1976 No observable changes to the study area.

Another building (Godown) has been constructed next to the HK LP Gas building.

1978 Site formation work for Denon Terrace was in progress.

The natural terrain has been cut to form a platform for Denon Terrace. Fill materials were observed on several areas on the downhill side of Denon Terrace including the September 2001 landslide site to the northeast of the present-day location of No. 56 Denon Terrace.

An access road was formed connecting Clear Water Bay Road to the site next to the HK LP Gas Building.

1979 Platforms within Denon Terrace have recently been formed, including the construction of associated slopes. Residential low-rise houses Nos. 50-53, 57-60 and 61-63 and 65 Denon Terrace have been constructed on the lower, middle and upper platforms respectively. Bare surfaces were observed at the present-day locations of Nos. 55 and 56 Denon Terrace.

Slope No. 11NE-B/FR249 and adjoining features (slopes Nos. 11NE-B/FR54 and 11NE-B/FR250) with bare surfaces were formed.

The retaining wall (approximately 50 m long) associated with slope No. 11NE-B/FR249 was observed at the south end of the slope crest.

The northern end of the main access road connecting Clear Water Bay Road was diverted to form four individual roads with three connecting to platforms and the remaining one along the southeast perimeter of the crest of slope No. 11NE-B/FR249.

1984 Details of image are very clear. Two gardens at the present-day locations of Nos. 55 and 56 Denon Terrace were bounded by a paved footpath located at the north end of the crest of slope No. 11NE-B/FR249, which is generally covered with dense vegetation except for areas adjacent to the gardens where no surface cover was observed.

The widening work to Clear Water Bay Road has been completed as a dual carriageway with two lanes in each direction.

Most of the cultivated land in Tseng Lan Shue has been abandoned and more houses have been built in the area.

1985 The vegetation on the study feature appears to have become denser. The surrounding natural terrain was covered with dense vegetation.

1986 Fill material was observed on slope No. 11NE-B/FR249 adjacent to Nos. 51 and 52 Denon Terrace.

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1987 No major changes to the study area, apart from an increase in density of vegetation cover to slope No. 11NE-B/FR249.

A landslide scar is visible adjacent to slope No. 11NE-B/FR54.

1988 The study feature is mostly covered with dense vegetation except the south end, which has no surface cover.

1991 The garden at the present-day location of No. 55 Denon Terrace has been built with a new low-rise residential building.

Squatter Structure B has been demolished.

Slope No. 11NE-B/FR249 was covered with dense vegetation.

1992 No observable changes to the study slope.

1993 A fence wall has been built around the perimeter of No. 55 Denon Terrace and a new paved footpath is visible between the fence wall and the crest of slope No. 11NE-B/FR249.

1994 No observable changes to the study slope.

The garden at the present-day location of No. 56 Denon Terrace was removed and the area has been left as bare flat ground.

1995 A low-rise residential house No. 56 Denon Terrace has been constructed at the same location as the former garden.

Slope No. 11NE-B/FR249 was covered with dense vegetation.

1997 The density of vegetation cover on the northern slope surface has decreased.

1998 No observable changes to the study area.

1999 The surfaces of the natural hillside and the northern slope surface adjacent to No. 55 Denon Terrace were bare.

2000 No observable changes to the study area.

2001 No observable changes to the study area.

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Table A1 - List of Aerial Photographs Used in the Aerial Photograph Interpretation

Date Taken	Altitude (ft)	Photograph Number
24 April 1949	8000	Y01758
27 January 1963	2700	Y08048-9
13 December 1964	12500	2602-4
16 May 1967	6250	Y13397
28 December 1972	2000	2763-4
4 October 1976	4000	15359
7 December 1978	4000	24114-5
28 November 1979	10000	28077-8
3 March 1984	4000	53997
18 May 1985	Unknown	A00964
7 November 1986	4000	A06845-6
10 December 1987	4000	A10960
6 October 1988	4000	A14673-4
20 September 1991	4000	A27470-1
20 October 1992	4000	A32807-8
2 November 1993	4000	A36102-3
6 May 1994	5000	A38067
18 July 1995	4000	CN9933
14 November 1997	4000	CN18919
10 November 1998	8000	CN21918-20
11 December 1999	4000	CN25267-8
16 September 2000	4000	CN28198-9
15 March 2001	4000	CN30157-8

Note: All aerial photographs are in black and white except for those prefixed with CN.

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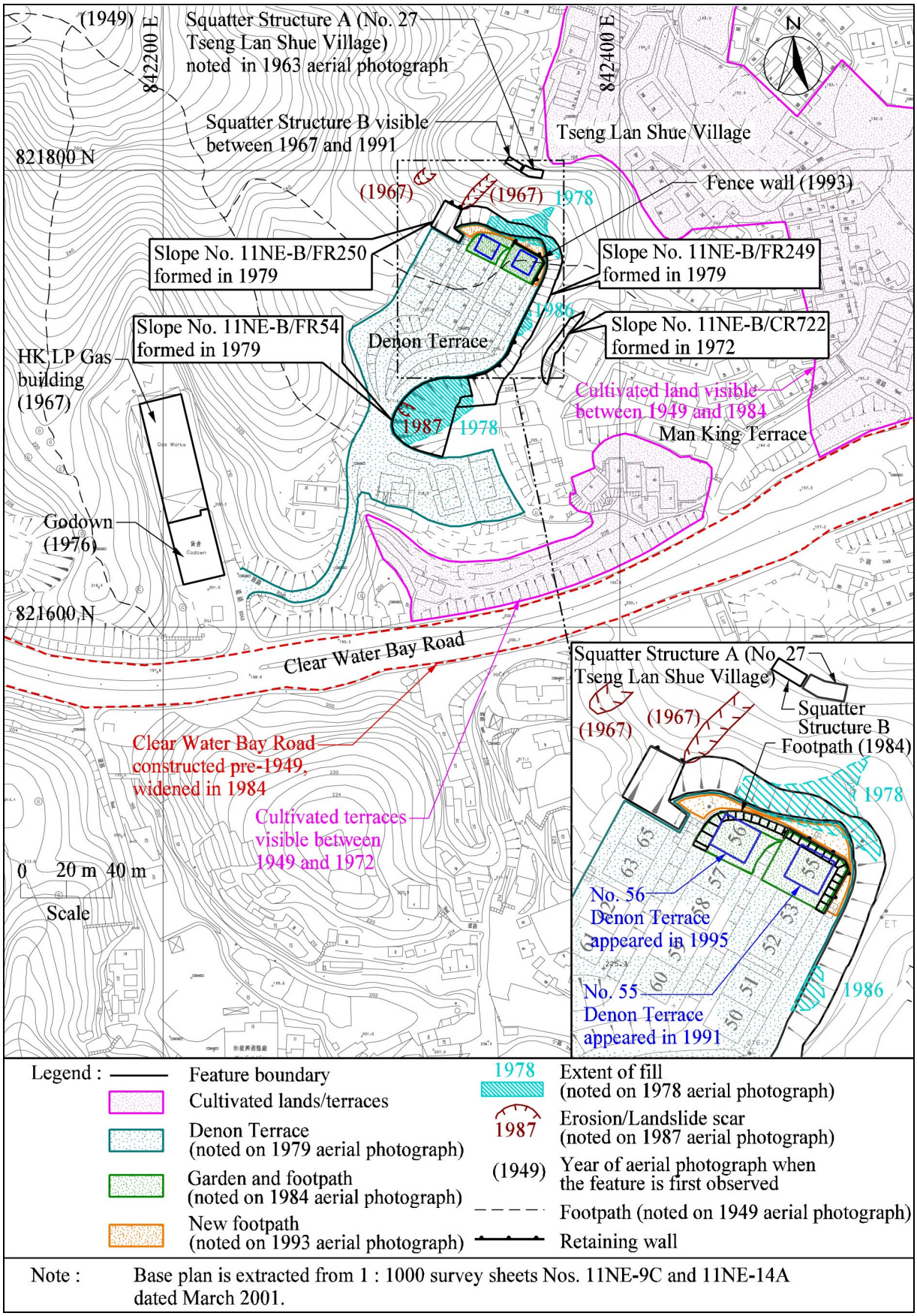

Figure A1 - Development History from Aerial Photograph Interpretation

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APPENDIX B

STABILITY ASSESSMENT OF SLOPE NO. 11NE-B/FR249
AND GENERAL DRAINAGE LAYOUT EXTRACTED FROM
SITE FORMATION RE-SUBMISSION FOR
NO. 56 DENON TERRACE

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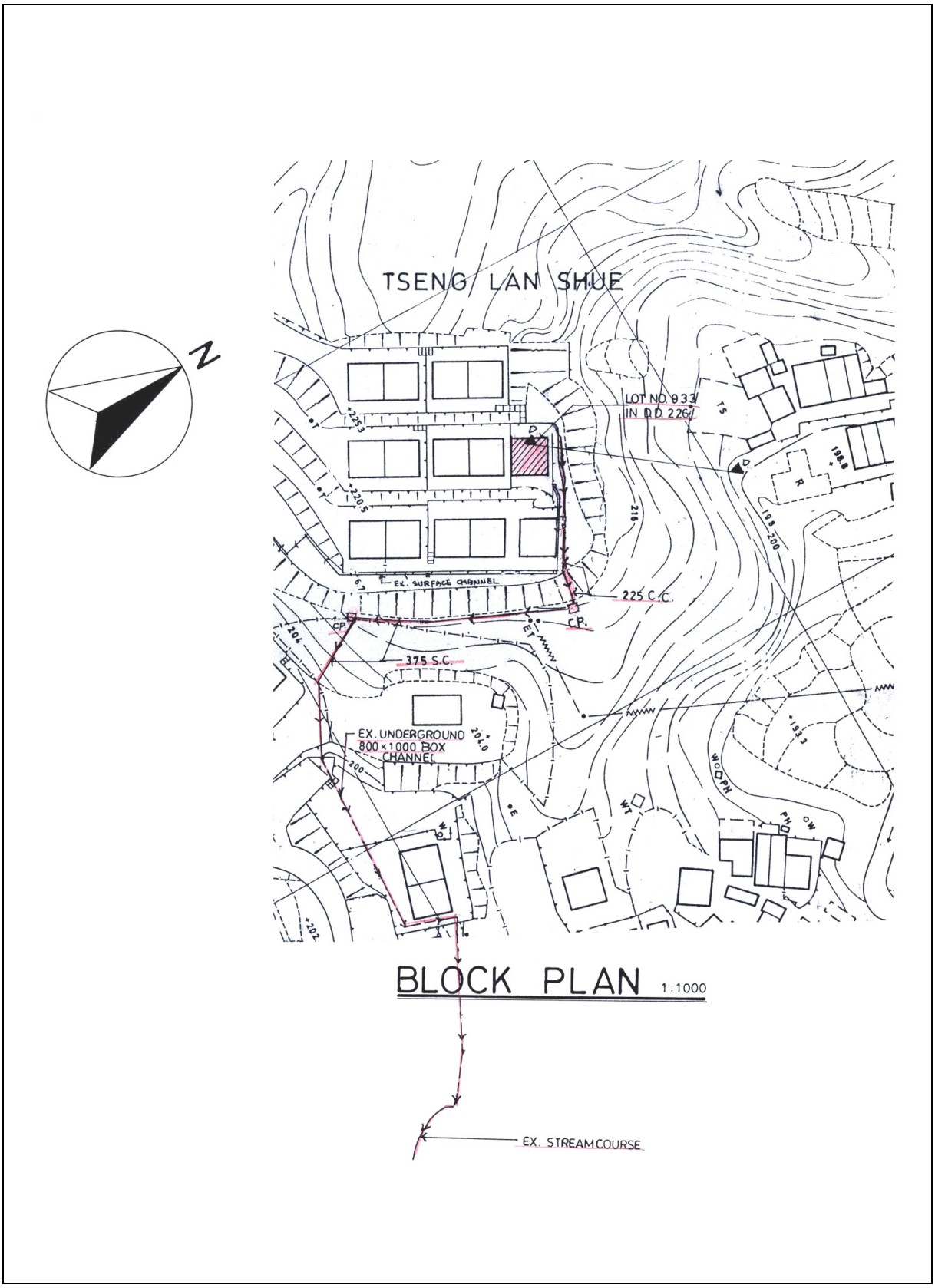

Figure B1 - Plan Showing the Location of the Designed Cross-section (D-D) and the General Surface Drainage Layout (Extracted from Approved Plan, Drawing No. SF-1, for No. 56 Denon Terrace)

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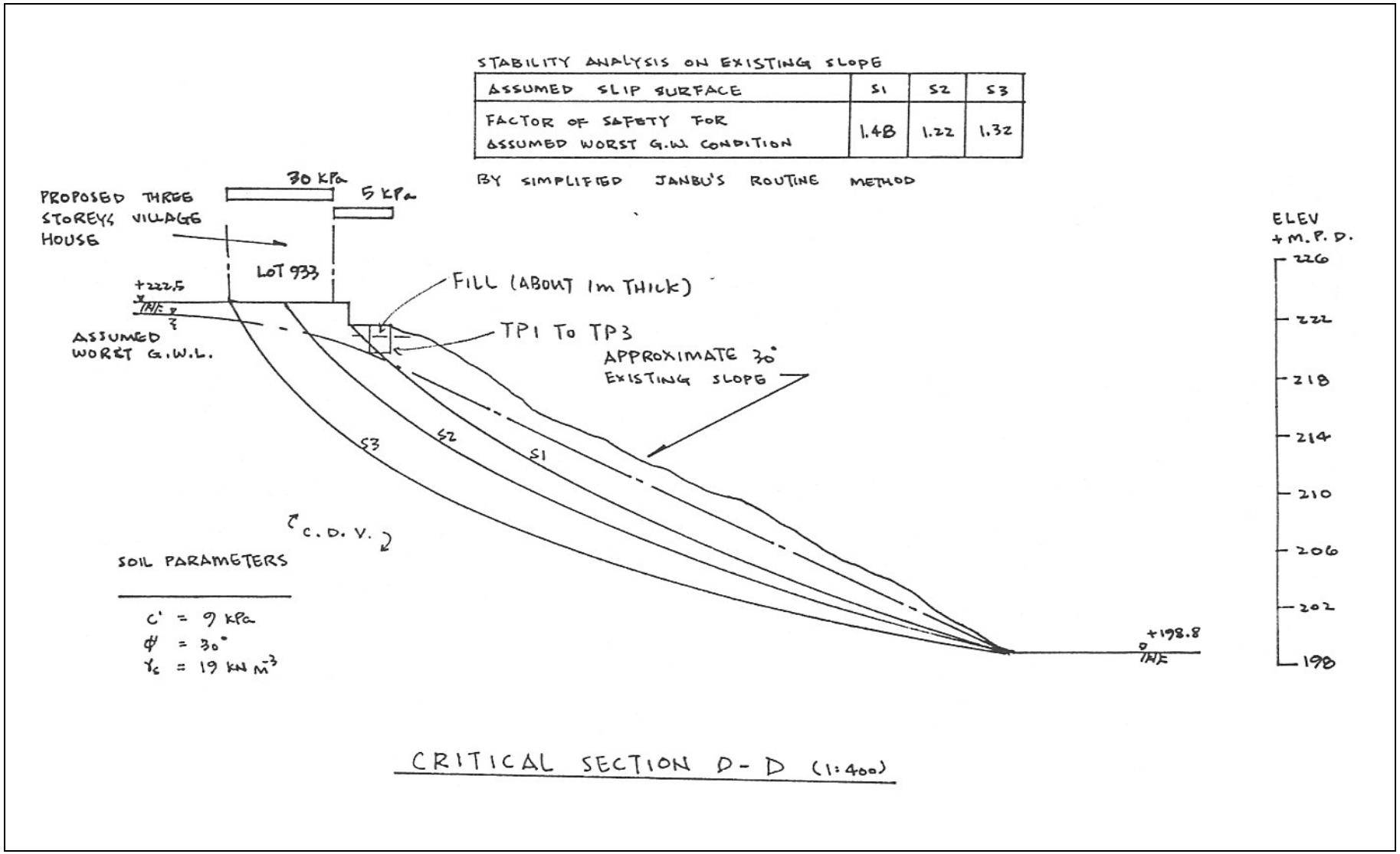

Figure B2 - Stability Assessment of Slope No. 11NE-B/FR249 (Extracted from Site Formation Re-submission Report for No. 56 Denon Terrace)

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

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

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

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

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

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

讀者可採用以下方法購買土力工程處刊物(地質圖及免費刊物除外):

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

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

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

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

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

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

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

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

For other publications which are free of charge:
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Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon, Hong Kong.
Tel: (852) 2762 5345
Fax: (852) 2714 0275
E-mail: ykhui@cedd.gov.hk

如欲索取地質調查報告、其他免費刊物及地質圖，請致函：

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

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香港九龍何文田公主道101號
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電話: (852) 2762 5345
傳真: (852) 2714 0275
電子郵件: ykhui@cedd.gov.hk

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

GEOTECHNICAL MANUALS

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

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

GEOGUIDES

Geoguide 1	Guide to Retaining Wall Design, 2nd Edition (1993), 258 p. (Reprinted, 2000).
Geoguide 2	Guide to Site Investigation (1987), 359 p. (Reprinted, 2000).
Geoguide 3	Guide to Rock and Soil Descriptions (1988), 186 p. (Reprinted, 2000).
Geoguide 4	Guide to Cavern Engineering (1992), 148 p. (Reprinted, 1998).
Geoguide 5	Guide to Slope Maintenance, 3rd Edition (2003), 132 p. (English Version).
岩土指南第五冊	斜坡維修指南，第三版(2003)，120頁(中文版)。
Geoguide 6	Guide to Reinforced Fill Structure and Slope Design (2002), 236 p.

GEOSPECS

Geospec 1	Model Specification for Prestressed Ground Anchors, 2nd Edition (1989), 164 p. (Reprinted, 1997).
Geospec 2	Model Specification for Reinforced Fill Structures (1989), 135 p. (Reprinted, 1997).
Geospec 3	Model Specification for Soil Testing (2001), 340 p.

GEO PUBLICATIONS

GCO Publication No. 1/90	Review of Design Methods for Excavations (1990), 187 p. (Reprinted, 2002).
GEO Publication No. 1/93	Review of Granular and Geotextile Filters (1993), 141 p.
GEO Publication No. 1/96	Pile Design and Construction (1996), 348 p. (Reprinted, 2003).
GEO Publication No. 1/2000	Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls (2000), 146 p.

GEOLOGICAL PUBLICATIONS

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

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

TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents