INVESTIGATION OF SOME SELECTED LANDSLIDES IN 1999 (VOLUME 4)

GEO REPORT No. 123

Fugro Maunsell Scott Wilson Joint Venture

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

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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. A charge is made to cover the cost of printing.

The Geotechnical Engineering Office also publishes guidance documents as GEO Publications. These publications and the 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
December 2001

EXPLANATORY NOTE

This GEO Report consists of two Landslide Study Reports on the investigation of selected slope failures that occurred in 1999. The investigations were carried out by Fugro Maunsell Scott Wilson Joint Venture (FMSW) for the Geotechnical Engineering Office as part of the 1999 Landslide Investigation Consultancy.

The LI Consultancies aim to achieve the following objective through the review and study of landslides:

(a) establishment of an improved slope assessment methodology,

(b) identification of slopes requiring follow-up action, and

(c) recommendation of improvement to the Government's slope safety system and current geotechnical engineering practice in Hong Kong.

The Landslide Study Reports prepared by FMSW are presented in two sections in this Report. Their titles are as follows:

The Landslip Investigation Division of the Geotechnical Engineering Office worked closely with the LI Consultants and provided technical input and assistance to the landslide studies.

SECTION 1: DETAILED STUDY OF THE LANDSLIDE BELOW THE BENJAMIN FRANKLIN CENTRE CHINESE UNIVERSITY OF HONG KONG ON 7 JUNE 1999

Fugro Maunsell Scott Wilson Joint Venture

This report was originally produced in August 2000
as GEO Landslide Study Report No. LSR 4/2000

FOREWORD

This report presents the findings of a detailed study of a landslide, which was reported on 7 June 1999 in a cut slope located below the Benjamin Franklin Centre at the Chinese University of Hong Kong, Shatin. Debris from the landslide was deposited on the platform at the toe of the slope. No casualties were reported as a result of the landslide.

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. The scope of the study comprised site reconnaissance, limited ground investigation and laboratory testing, desk study and engineering analysis. Recommendations for follow-up actions are reported separately.

The report was prepared as part of the 1999 Landslide Investigation Consultancy (LIC), for the Geotechnical Engineering Office (GEO), under Agreement No. CE 101/98. This is one of a series of reports produced during the consultancy by Fugro Maunsell Scott Wilson Joint Venture (FMSW).

Y.C. Koo
Project Director/Fugro Maunsell Scott Wilson
Joint Venture

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1. INTRODUCTION

On the morning of 7 June 1999, a landslide was noted in slope No. 7NE-C/C23 located below the Benjamin Franklin Centre at the Chinese University of Hong Kong (CUHK), Shatin (Figure 1 and Plate 1). Debris from the landslide was deposited on the platform at the toe of the slope. No casualties were reported as a result of the landslide.

Following the landslide, Fugro Maunsell Scott Wilson Joint Venture (FMSW), the 1999 Landslide Investigation Consultants, carried out a detailed study of the failure for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 101/98.

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 failure. The scope of the study comprised site reconnaissance, limited ground investigation and laboratory testing, desk study and engineering analysis. 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 documents relating to the history of the site,

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

(c) limited ground investigation and laboratory testing,

(d) analysis of rainfall records, and

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

2. THE SITE

2.1 Site Description

Slope No. 7NE-C/C23 is located east of the Benjamin Franklin Centre on University Road at the CUHK, Shatin (Figure 1 and Plate 1).

The campus grounds occupy a low hill (maximum elevation about 150 mPD) west of the mouth of Sha Tin Hoi. Slope No. 7NE-C/C23 is located on the south-facing slopes of the landform, into which extensive cut earthworks have been carried out to form platforms for the university buildings and associated infrastructure.

The slope is approximately 45 m long and 'L-shaped' in plan, comprising an east-facing portion, which is 15 m long, 11 m to 14.5 m high and 60° slope angle (Plate 2), and a south-facing portion, which is 30 m long, 13 m high and 30° slope angle (Plate 3). The change in height in the east-facing portion occurs at a south-facing slope No. 7NE-C/C395

(Figure 1) of 50° face angle, producing a sudden set-down in crest elevation. Berms are included in the slope geometry 6 m and 11 m above the slope toe and carry surface drainage channels. The south-facing portion is vegetated with grass and mature trees. The east-facing portion has a chunam surfacing with weepholes, largely obscured by unplanned vegetation.

The crest area of the south-facing portion of the slope is occupied by University Road (elevation 86 mPD to 89 mPD and 10 m wide) and sloping ground (vegetated) leading up to an extensive levelled platform (elevation 95 mPD) around 50 m to the north occupied by other structures and paved open areas. The crest area of the east-facing portion of the slope is occupied by an open paved carpark at 90 mPD about 5 m to the west and the Benjamin Franklin Centre about 10 m to the west. A 50-metre swimming pool is located to the south of the Benjamin Franklin Centre.

The ground beyond the slope toe (elevation 75.5 mPD) has been levelled by cutting to form a platform about 25 m wide. This area is occupied by buried sewage digestion and filtration tanks, which discharge effluent to a natural stream course south of the site.

2.2 Geology

Sheet 7 of the Hong Kong Geological Survey 1:20 000 scale map series HGM20 (GCO, 1986) indicates that the solid geology of the landslide site and its surroundings comprises medium-grained granite (Figure 2). To the east of the site, the medium-grained granite intruded by fine-grained granite and quartzphyric rhyolite dykes both striking generally north-east. Quartzphyric rhyolite dykes with similar strike occur widely in other rock types in the area.

2.3 Water-carrying Services and Utilities

The locations of existing exposed and buried water-carrying services in the vicinity of the landslide site are shown on Figure 3. The layout of the services has been based on the records of the CUHK and visual confirmation of valve pits, manholes, etc. The CUHK holds maintenance responsibility for the services.

Pressurised water-carrying services are concentrated behind the crest of the east-facing portion of the slope and comprise a 150 mm diameter galvanised iron fresh water main, 35 mm diameter galvanised iron irrigation pipe, 50 mm diameter concrete encased PVC flush water main and 75 mm diameter galvanised iron fire services main.

Gravity-fed services comprise 150 mm and 225 mm diameter vitreous clay foulwater sewers located behind the crest of the east-facing portion of the slope and traversing the slope face. Surface drainage provisions on the slope face comprise a network of U-channels and stepped channels feeding into the toe drainage. Stepped channels located on the south-facing portion of slope also carry collected runoff from beyond the slope boundary. The catchment includes the adjacent car park and University Road, as well as other areas of the campus; however, the available records are incomplete. A 1 m high concrete barrier wall separates the slope crest from the car park.

The CUHK have been unable to locate records on the date of installation of these services or historical maintenance records.

2.4 Maintenance Responsibility

According to the "Systematic Identification of Maintenance Responsibility of Slopes in the Territory" (SIMAR) project undertaken by the Lands Department, slope No. 7NE-C/C23 is under the maintenance responsibility of the CUHK.

3. SITE HISTORY AND PREVIOUS STUDIES

3.1 General

The development history of the landslide site and details of previous studies carried out on slope No. 7NE-C/C23 have been compiled from a review of available aerial photographs and relevant documentation. Details of observations from aerial photographs are given in Appendix A and the salient points are given in the following sections.

3.2 Site History

Aerial photographs from 1963 indicate natural hillside at the present landslide site. The local topography in the general vicinity comprised the upper reaches of a south-easterly trending valley between a southerly trending spur and an east-west aligned ridge. A possible natural drainage path or small pre-existing landslide scar was located at the present landslide site.

Site formation works for the CUHK were underway in the 1964 aerial photographs and were well advanced by 1969, at which time slope formation in the area surrounding the landslide site (including slope No. 7NE-C/C23) had been completed and the Benjamin Franklin Centre constructed. The slope geometry appears to be the same as at present (Section 2.1). Chunam had been applied to the east-facing portion of slope No. 7NE-C/C23 at the present landslide location. The remainder of the slope face remained exposed and unvegetated. A concave feature (possible landslide scar) is visible at the northern end of slope No. 7NE-C/C22 (Figure 1) in the upper batter. No record of any instability in slope No. 7NE-C/C22 from this time could be located. It is possible that this feature was pre-existing at the time of site formation and was subsequently incorporated into the slope geometry, or that the cutting was locally flattened to remove unsuitable material associated with the natural drainage line traversing this area prior to site formation.

The 1973 aerial photographs show the CUHK site formation to be complete and the campus to be operational. The swimming pool to the south of the Benjamin Franklin Centre was also completed by this time. Slope No. 7NE-C/C23 was uniformly vegetated and trees were established on the levelled platform at the slope toe. Services and utilities had been installed on the slope face and behind the crest.

From 1973 onwards, the vegetation on the slope face and on the platform at the slope toe gradually became heavier, obscuring the view of the slope face. The chunam surfacing remained largely exposed throughout and is observed to vary in tone and brightness over time, suggesting weathering and possible periodic maintenance or replacement. The vegetated portions of the slope showed signs of minor erosion.

The 1994 aerial photographs show a part of the east-facing portion of the slope now located within slope No. 7NE-C/C160 to the south of slope No. 7NE-C/C23 to be much lighter in appearance than the surrounding slope and the platform at the toe of the slope to have been locally cleared of vegetation. This may indicate a past instability, the location of which corresponds to a possible shallow scar feature that was observed by FMSW (Section 3.4). No file records relating to this feature could be located.

The available information, including detailed Aerial Photograph Interpretation (API) by FMSW, indicates that slope No. 7NE-C/C23 has undergone relatively little change since original formation between 1964 and 1969, and has experienced periodic minor instability, mainly in the form of erosion. The slope appears to have been subject to periodic, though irregular, maintenance. Shallow failure has possibly occurred in the east-facing portion of the slope face to the south of the present slope boundary.

3.3 Previous Studies

The slope was inspected in February 1978 by consultants engaged by Government to register sizeable slopes in Hong Kong and subsequently registered as slope No. 7NE-C/C23 in the 1977/78 Catalogue of Slopes (Binnie & Partners, 1978).

In 1988, a detailed Stage 1 Study was undertaken by the Planning Division of the Geotechnical Control Office (GCO, 1988). Investigation of the slope was limited to visual inspection, which indicated that the slope was formed in Grade V and Grade IV granite and the central portion of the feature, where the 1999 landslide subsequently developed, was covered with chunam, the remainder having a vegetation cover. No indication is given in the report as to why only the central portion of the slope was covered with chunam. However, subsequent observations by FMSW (Section 5.4.2) indicate that weathering is locally more advanced in this area.

No signs of seepage were observed (when inspected on 22 July 1988), although evidence of infiltration from a leaking water pipe at the slope crest was noted. Minor cracking and bulging of the chunam surfacing were also observed.

An assessment of the slope using the CHASE criteria as presented in Brand & Hudson (1982) indicated that the slope lay within the zone of “Moderate Risk of Instability”. A stability analysis was carried out on the critical section (present landslide site), chosen on the basis of maximum slope angle with greatest slope height, and using shear strength parameters ($c' = 8.5$ kPa, $\phi' = 40°$) obtained from laboratory tests on samples of similar material retrieved during an earlier ground investigation associated with the adjacent slope No. 7NE-C/FR19 (Figure 1). A range of $c' = 5$ kPa to 10 kPa and $\phi' = 35°$ to $40°$ was adopted for sensitivity analysis. The section was analysed assuming dry conditions on the basis of a limited catchment area behind the crest. The sensitivity analysis indicated factors of safety to be less

than 1.1 and some below unity for the range of parameters considered. The assumption of shear strength parameters obtained from laboratory testing gave a minimum factor of safety in excess of 1.1.

The slope was considered adequately stable on the basis of "…absence of major and distinct sign of distress…", "…adequate factor of safety possessed by the critical section…", "…absence of seepage and apparent dry condition…", and "…lack of catchment area behind the crest that would allow infiltration…". A recommendation was made for "No Further Study". Several items of maintenance were recommended, including repair of cracks and bulging in chunam, a check for leakage of all "water pipes" behind the crest and clearance of channels and catchpits. A Type 2 Advisory Letter was issued by the Buildings and Lands Department in May 1989 informing CUHK of the required maintenance works. Various items of correspondence indicate that maintenance works were completed in October 1989 and confirmed as satisfactory by the GCO in December 1989.

In 1992, the GEO initiated the consultancy agreement entitled "Systematic Inspection of Features in the Territory" (SIFT) which, inter alia, aimed to identify features not registered in the 1977/78 Catalogue of Slopes and to update information on registered slopes based on studies of aerial photographs and limited site inspection. Slope No. 7NE-C/C23 was categorised as Class "C1", i.e. "Assumed formed pre-1978 or illegally formed".

In 1994, the GEO initiated the consultancy agreement entitled "Systematic Identification and Registration of Slopes in The Territory" (SIRST) to update the 1977/78 Catalogue of Slopes and to prepare a New Catalogue of Slopes. A SIRST inspection carried out on 27 May 1997 indicated that the slope face was in fair condition and that no signs of seepage, distress or previous failure was observed.

3.4 Past Landslides

There are no past failures in the natural terrain in the vicinity of the landslide site recorded in the GEO's Natural Terrain Landslide Inventory (NTLI). This is consistent with the detailed API carried out by FMSW. The GEO landslide database indicates no records of past failure at slope No. 7NE-C/C23.

Visual inspection by FMSW identified a possible landslide scar in the adjacent slope No. 7NE-C/C160, approximately 10 m south of the slope boundary with slope No. 7NE-C/C23 (Plate 4). The scar was about 3 m to 4 m wide and extended from the lower berm level to about 1 m above the slope toe, exposing Grades III to V granite. The maximum depth of the scar was about 0.2 m to 0.3 m. No remedial works were apparent. No records relating to the incident resulting in this feature or any subsequent assessment could be located. Detailed API indicates that the incident may have occurred in 1994 (Section 3.2).

4. THE LANDSLIDE

4.1 Description of the Landslide

The landslide (Plates 5 and 6) occurred in the east-facing portion of the cut slope and

was confined between the lowermost berm and the slope toe. A section through the landslide is presented in Figure 4. The scar measured approximately 6 m in width and extended to berm level, approximately 6.5 m above the toe.

The sub-vertical main scarp (Figure 4) aligned with the rear edge of the berm and followed persistent relic jointing within the weathered rock profile, providing a release surface to the failed mass. The maximum exposed height of the scarp above the debris was about 1.8 m. The remainder of the scarp was obscured by debris, as was the surface of rupture.

Landslide debris, comprising Grade IV and Grade V granite, with an estimated volume of 30 m^3, was deposited in the scar area and between 3 m to 5 m beyond the slope toe. The travel angle of the debris (Wong & Ho, 1996) was about 35°.

Debris deposited against the main scarp was largely intact, as evidenced by chunam surfacing maintaining original orientation (Plates 7 and 8). Debris extending beyond the slope toe was highly disturbed. Portions of chunam surfacing were observed to have rotated at the approximate transition from semi-intact to disturbed material. A 150 mm diameter foulwater drain (Plate 9) in a trench backfilled with granular material situated along the berm was severed at both flanks of the scar and continued to discharge sewage for a number of hours after the landslide, resulting in outwash of debris at the southern flank, until temporary diversion works were completed. The section of drain contained in the debris had a fresh break at one location (Plate 10). There were no obvious signs of prior leakage from the drain. The rear face of the trench containing the drain was coincident with the main scarp (Plate 9).

4.2 Observations Made Prior to the Landslide

In the months prior to the landslide, a number of visits were made to the site by the GEO Mainland East Division in relation to refurbishment works carried out on the swimming pool facility to the south of slope No. 7NE-C/C23. These works were designed and supervised by consultants engaged by the CUHK and included upgrading of the adjacent slope No. 7NE-C/C160. During this time, the condition of slope No. 7NE-C/C23 was observed by the GEO to be poor and the CUHK was advised that the slope should be considered for upgrading. Specific observations on slope No. 7NE-C/C23 have not been recorded, however, it is understood from verbal discussions with the GEO that the slope was lacking maintenance and in a dilapidated condition. In mid-May 1999, the CUHK included slope No. 7NE-C/C23 in a package of slopes located within the campus grounds identified as requiring upgrading, with the design and supervision of slope upgrading works to be let under competitive tender.

A site visit was made by representatives of Maunsell Geotechnical Services Ltd (MGS), on 3 June 1999 (4 days prior to the landslide), as consultants engaged by CUHK for the design and supervision of upgrading works for a separate package of slopes including the adjacent slope No. 7NE-C/C22 (Figure 1). CUHK staff accompanied MGS during the visit and recorded the observation that minor seepage was issuing from the lower portion of slope No. 7NE-C/C23 where the 1999 landslide subsequently developed.

The CUHK called for expressions of interest regarding the upgrading of the package of slopes including slope No. 7NE-C/C23 on 11 June 1999.

4.3 Observations Made Following the Landslide

The landslide was reported by CUHK staff at around 9:00 am on 7 June 1999. The exact time of failure is not known. FMSW staff first visited the site on 10 June 1999 and again on 15 June 1999 to map the landslide scar. The pertinent observations from these inspections are presented below:

(a) A number of exposed water-carrying services were present at the crest of the slope behind the landslide scar. A number of these appeared to have had works completed on them recently as indicated by the condition of fittings and presence of fresh sealant (Plate 11). A local arrangement of services was also observed (Plate 12) where temporary spigots and a metering system had been fitted to a water supply main.

(b) Seepage of water into the scar from a joint aperture (282°/75°(Dip Direction/Dip Angle), 40 mm wide) in the main scarp approximately 3 m below berm level was observed near the southern flank (Plate 13). The water issuing from the joint was clear and the flow rate (estimated at 10 l/min) was steady.

(c) A steady flow of water was noted in the 600 mm stepped channel located on the slope face to the north of the landslide location, despite the generally fine weather conditions experienced in the days following the landslide. No flow of water was noted in the 300 mm stepped channel 20 m to the west of the 600 mm stepped channel.

FMSW staff inspecting the site during June and July 1999 observed that both the seepage from the open joint in the main scarp and in the 600 mm stepped U-channel remained constant over this period.

Urgent repair works were completed by the CUHK during this time and comprised shotcreting of the landslide scar and debris mass (not removed) and placement of rockfill against the slope up to berm level to act as a toe weight. These works were advised by Pypun Engineering Consultant Ltd (Pypun), who were engaged by CUHK for the design and supervision of permanent upgrading works for the package of slopes including slope No. 7NE-C/C23. Urgent repair works were agreed with the GEO. To facilitate monitoring of the flow of water from the scar after completion of these works, FMSW recommended that a PVC pipe be installed prior to shotcreting to collect seepage through the open joint and carry it to the drainage channel at the slope toe. A steady flow similar to that estimated in item (b) above was observed following completion of the urgent repair works (Plate 14).

In late July 1999, CUHK staff observed damage to the carpark pavement behind the slope crest believed to be caused by trucks delivering rockfill to the landslide site (Plate 15). Repair works to the pavement exposed a 75 mm diameter fire services main in which a leak was identified (Plate 16). The section of main was isolated and repairs effected (Plate 17) during which time it was observed that flow from the PVC pipe had ceased. The flow resumed when the fire services main was re-pressurised following repair.

A short time later, further damage to the pavement at the same location was observed, also believed to have been caused by trucks delivering rockfill. Repair works were subsequently carried out (Plate 18), during which a second leak was identified in the 75 mm diameter fire services main. The main was again isolated and the leak repaired (Plate 19). Flow from the PVC pipe in the scar did not resume when the main was subsequently re-pressurised. Flow in the 600 mm stepped U-channel continued throughout this period. The source of flow in the channel could not be positively identified.

5. SUBSURFACE CONDITIONS

5.1 General

The subsurface conditions within the landslide site have been assessed on the basis of information obtained from the desk study, field mapping and post-failure ground investigation.

5.2 Previous Ground Investigations

A number of previous ground investigations have been undertaken within or in close proximity to the concerned slope. The locations of previous investigation stations are shown in Figure 5.

5.3 Current Investigation

Limited ground investigation by FMSW (Figure 5) was carried out between June and October 1999. Ground investigation comprised GCO probing through debris remaining in the landslide scar, geological mapping of the landslide scar, trial pitting and surface stripping. The purpose of the GCO probing was to attempt to identify the surface of rupture along the base of the sliding mass. Results are presented in Materialab (1999). The results of the mapping exercise are presented on Figure 6.

Trial pitting works comprised the excavation of three trial pits to a depth of 3 m and the retrieval of disturbed and undisturbed samples. Stripping of the chunam cover was also carried out at a single location to expose the ground beneath. Logs for the trial pits and surface stripping are presented in Appendix B. Photographs detailing the various observations made during the investigation are presented in Plates 20 to 26.

Laboratory testing on retrieved samples has included classification, moisture content determination and compaction tests. A summary of the laboratory test results is presented in Table 1.

Samples of the water flowing from the landslide scar were collected in the early stages of the investigation, as well as from a number of other sources including the adjacent stormwater channel, the fresh water supply to the Benjamin Franklin Centre (same source as for fire services), the foulwater sewer diversion and groundwater from an existing piezometer installation (Figure 5). All samples were analysed for impurities (Table 2).

In addition to the FMSW investigation, Pypun completed a more extensive ground investigation during September and October 1999. Investigation stations relevant to slope No. 7NE-C/C23 comprised four drillholes and six trial pits. Locations of the ground investigation stations are indicated on Figure 5. Details of the ground investigation are given in Pypun (1999a, b, c & d).

5.4 Ground Conditions

5.4.1 General

The area covered by the available ground investigation information (Figure 5) includes slope No. 7NE-C/C23 and the continuation of the easterly facing slopes to the south, the platform extending beyond the slope toe and slope Nos. 7NE-C/C22 and 7NE-C/FR19 to the east. A section showing the typical stratigraphy through the landslide site is presented in Figure 7.

The typical sequence of materials encountered across the site comprises fill overlying an insitu profile of weathered granite. Deposits of colluvium overlying the insitu profile were also observed towards the northern and southern extent of the platform, as well as in slope No. 7NE-C/FR19 near the northern end of slope No. 7NE-C/C22.

Fill material is present in layers ranging from 1 m up to a maximum of about 14 m on slope No. 7NE-C/FR19. This material may be generally described as a silty, fine- to coarse-grained sand, with occasional clay and gravel content. The consistency varies from loose to very dense, with Standard Penetration Test (SPT) blow counts (all results from slope No. 7NE-C/FR19) ranging from 9 to 96, with an average of 41. Of significance to slope No. 7NE-C/C23 is the approximately 2 m to 3 m of fill, described as having a soft to firm consistency, that was repeatedly encountered in trial pits located along the slope crest (also observed for the adjacent slope No. 7NE-C/C160), as well as in drillholes and trial pits located on the south-facing portion of the slope face (Plate 22). This suggests that a significant portion of the slope may have been formed in fill.

Deposits of colluvium are described as a medium dense, fine- to coarse-grained sand and sandy clayey silt with occasional gravel. No colluvium was encountered in the vicinity of slope No. 7NE-C/C23.

The insitu ground profile over the depth investigated predominantly comprises Grade V granite underlain by Grade II/III granite. Grade III/IV granite was encountered as an intermediate layer in some instances. The thickness of the Grade V granite varies substantially across the site from 2 m to about 24 m at one location. This range should be viewed in the light of the extensive site formation works carried out in the general area, which will have removed significant quantities of overburden. However, the depth to continuous

Grade III or better material is very variable and reflects the uneven weathering profile observed in the exposed face of slope No. 7NE-C/C23. The Grade V granite is generally described as a medium dense to very dense silty fine to coarse sand. SPT blow counts range from 2 to in excess of 200, with an average of 76 excluding refusals (25 out of 82 tests). Available laboratory test data (C M Wong & Associates, 1995), relating to samples recovered from slope No. 7NE-C/C160, indicate best fit matrix shear strength parameters of $c' = 20$ kPa and $\phi' = 40°$.

The Grade II/III granite is described as a moderately strong to strong medium-grained granite with closely- to widely-spaced, manganese oxide-coated and limonite-stained joints. Chlorite coating, kaolin infill (1 mm to 2 mm) and quartz veins were also noted.

5.4.2 Landslide Scar

The ground investigation carried out by FMSW identified a number of features to suggest local variation of geological conditions in the vicinity of the landslide site. Surface stripping on the slope face to the south of the scar indicated uneven weathering of the insitu profile with Grade III granite (PW 50/90) exposed near the slope crest underlain by Grade V granite (PW 0/30) and localised Grade III/IV granite (PW 30/50).

Jointing exposed in trial pits was often infilled with manganese oxide up to 2 mm in thickness and a number of quartz veins were observed, also with manganese oxide present (Plates 20, 21 & 23). Kaolin was also present as joint infill material, although not to the same extent as observed in the landslide scar. Joint infill surfaces were often slickensided and a further indication of past movement encountered in trial pit TP2 where about 200 mm of vertical displacement was indicated across a sub-horizontal quartz vein (Plate 23).

Dyke material (Grade V rhyolite) was encountered directly beneath the fill horizon in trial pit TP3 (Plates 24 and 25) at the contact with the weathered granite. It is noted that dyke material was also encountered during the previous investigation of slope No. 7NE-C/C22 (Compact, 1998). The orientation of the dyke could not be determined from the exposure in the trial pit.

The landslide scar (Figures 4 and 6) exposed Grade IV and Grade V medium-grained granite (PW 0/30). Five predominant local joint orientations were observed in the landslide scar. These are: 280°/75° (Dip Direction/Dip Angle) and 088°–092°/72°–81° (main scarp), 030°/75° (southern flank), 133°/70° (northern flank) and 090°-100°/50° (dipping out of the slope face). The contribution of this latter set to the failure geometry is not certain. GCO probing through the debris was not conclusive in defining the surface of rupture, indicating a best estimate of inclination in the range of 10° to 25° below horizontal, which is substantially lower than the dip angle of this set.

Joint sets forming the main scarp and those dipping out of the slope face (possible basal sliding plane/surface of rupture) are closely- to extremely closely-spaced with persistence in excess of 5 m to 7 m. The joint sets defining the flanks are closely- to widely-spaced, with observed persistence of about 1 m. Manganese oxide and kaolin infill up to 2 mm thickness were prevalent on joint surfaces. Evidence of past movement was observed in the form of open, root-filled joints in the main scarp (Figure 6) and in the

polishing and slickensiding of exposed joint surfaces, with slickensides typically plunging parallel to the joint dip direction. Jointing of similar orientations to those observed in the scar was also exposed in the surface strip to the south (Plate 26), as well as a joint set dipping into the slope (270°/35°).

A thick (120 mm) lens of kaolin-rich material (Plate 27) in which relic joints were present was observed at the southern flank of the landslide scar. The completely decomposed granite matrix in adjacent exposures also contained significant quantities of kaolin. These two observations are suggestive of kaolinisation of the parent rock as a result of processes such as hydrothermal action, as opposed to kaolin deposition along joint surfaces resulting from groundwater flow. The limited extent of the ground investigation does not permit meaningful interpretation of the primary mechanism for the presence of kaolin at the site.

The landslide debris comprised a large raft/block of semi-intact Grades IV and V granite (Plate 28) towards the rear of the mass and more disturbed material towards the toe comprising predominantly sand-sized particles with cobble- and small boulder-sized blocks of intact material. Jointing within the semi-intact mass was broadly identifiable as comprising examples of the joint sets exposed in the scar, with similar infilling and appearance (polishing and slickensiding). Isolated blocks of kaolin-rich material were also observed in the landslide debris (Plate 29).

A geological model of the landslide site, constructed from the available ground investigation information, is presented in Figure 8.

5.4.3 Groundwater

Available groundwater monitoring data for the site is limited. Piezometer and standpipe installations and groundwater levels, where recorded, are presented on Figure 7. Installations typically extend to at least 71 mPD, i.e. approximately 3 m to 4 m below the slope toe (75.5 mPD).

Piezometer and standpipe installations from the December 1994 ground investigation associated with the upgrading of slope No. 7NE-C/C160 (Section 5.2) all recorded a “dry” result.

Standpipe installations associated with the August/September 1998 ground investigation associated with the upgrading of slope No. 7NE-C/C22 (Section 5.2) indicated groundwater at an elevation of 58 mPD near the central portion of the platform beyond the slope toe (B03A, Figure 5) and 66 mPD near the toe of slope No. 7NE-C/C23 (B04A, Figure 5).

Trial pits associated with the current investigation by FMSW extending to around 3 m below the toe of slope No. 7NE-C/C23 did not encounter a high base groundwater table. Localised seepage was observed in trial pit TP3 (Figure 5) at the base of the fill material (approximately 2.5 m below the slope toe elevation). However, the largely unsaturated condition of the insitu ground profile beneath indicated that this was probably a result of localised perching.

Piezometer and standpipe installations associated with the September/October 1999 ground investigation for the selected slopes for upgrading works, including slope No. 7NE-C/C23 (Section 5.3), generally identified groundwater levels below the toe of the slope. A standpipe in drillhole CB2 (Figure 5) located 1 m behind the crest of the south-facing portion of the slope indicated groundwater at about 84.5 mPD, which coincides with the interface of fill material and the underlying Grade II/III bedrock at that location.

The available information suggests that the general base groundwater table in the vicinity of the landslide site lies at least 1 m to 2 m below the slope toe level.

6. ANALYSIS OF RAINFALL RECORDS

The nearest GEO automatic raingauge to the landslide site is No. N09, which is located at the Meteorological Laboratory of the CUHK, approximately 360 m south-east of the site. The raingauge records and transmits rainfall data at 5-minute intervals via a telephone line to the GEO.

Daily rainfall for one month preceding and seven days following the reporting of the landslide, together with hourly rainfall for 48 hours before and 8 hours following the time of reporting, are given in Figure 9.

The daily rainfall records indicate rainfall occurring from 7 June 1999 to 10 June 1999. Hourly data for 7 June 1999 indicates rainfall from around 1:00 a.m. and a peak intensity of 36.5 mm/hr from 3:00 a.m. to 4:00 a.m.

For the purposes of rainfall analysis, it is assumed that the landslide occurred at 4:00 a.m. on 7 June 1999. The rainfall between 4:00 a.m. and 9:00 a.m. on 7 June 1999 (when the landslide was reported) was not heavy and would not have any significant effect on the rainfall analysis.

Table 3 presents the estimated return period for the maximum rolling rainfall for various durations based on historical rainfall data at the Hong Kong Observatory (Lam & Leung, 1994). A return period of less than two years is indicated for duration ranging from 5 minutes to 31 days. A comparison of the severity of the June 1999 rainstorm and past major rainstorms is presented in Figure 10. This shows that a number of substantially more severe rainstorms have been previously experienced at the site.

7. THEORETICAL STABILITY ANALYSIS

Theoretical stability analyses to assist in the diagnosis of the probable causes and mechanisms of the landslide could not be meaningfully carried out because of the uncertainty regarding the location of the surface of rupture. There is also significant uncertainty regarding the influence of the kaolin-infilled joints on the operational mass shear strength. The build-up of groundwater pressure is likely to be complex and highly variable, given the kaolin-infilled joints and the presence of open joints, which may be conducive to the development of cleft water pressure.

8. DIAGNOSIS OF PROBABLE CAUSES OF THE LANDSLIDE

The landslide in Slope No. 7NE-C/C23 involved a steep cut slope predominantly formed in Grade IV and Grade V granite with some fill. The local weathering of the decomposed granite is very variable.

The mode of instability probably involved sliding failure of the debris mass and local disintegration. This was evidenced by the semi-intact debris at the rear of the mass which appeared to have experienced an essentially vertical downward movement, compared with the highly disturbed material near the toe of the mass, which had been transported beyond the slope toe.

The geometry of the failure was partly controlled by relic joint orientations with weak infill of kaolin and manganese oxide, a number of which exhibit signs of past movement in the concerned portion of the slope (i.e. open, root-filled joints and polishing/slickensiding of joint surfaces). However, conditions at the surface of rupture remain uncertain in the absence of direct inspection. The presence of the joint set dipping 090°-100°/50° in conjunction with the low angle basal rupture surface provides a favourable setting for a failure mechanism akin to 'rock slumping' (Keiffer, 1998), which is typical of slopes in which there is a discontinuity set dipping relatively steeply in the same direction as the slope.

Observations from aerial photographs taken prior to slope formation indicate possible past instability or a pre-existing drainage line at the location where the 1999 landslide subsequently developed (Section 3.2). This may be related to the locally mass weathered nature of the variable weathering profile and history of part movement of the site.

The flow of water observed from the scar has been positively related to leakage from fire services main located beyond the slope crest (Section 4.3). It is probable that the leak preceded the failure by some time, but it is not certain whether the leak worsened over time. It is possible that some initial slope movement was initiated by the leak prior to the moderate rainstorm of 7 June 1999 and that the slope condition had deteriorated progressively.

The results of chemical testing of water samples (Section 5.3) suggest that gross leakage from the foulwater sewer installed along the lowermost berm did not take place prior to it being severed by the landslide. The principal sources of water ingress into the slope were leakage from the fire services main and direct infiltration into the slope through the vegetated surface and unplanned vegetation in the chunam surface.

The cause of the failure is postulated as being due to the build-up of water pressure within the soil mass and development of cleft water pressure in the local open joints.

It is noted that the previous stability analysis of the slope (GCO, 1988) was based on the use of saturated shear strength parameters for the matrix material as determined in the laboratory and assuming no build-up of positive water pressure. The presence of relic joints with weak infill (Section 5.4.2), which played a significant role in the failure was not considered.

The presence of extensive unplanned vegetation on the chunam portion of the slope surface indicates that lack of slope maintenance may have been a contributory factor to the

failure by rendering the slope more vulnerable to infiltration. Signs of past slope movement (Section 5.4.2) also suggest that the slope may have suffered progressive deterioration for some time. In particular, the presence of open, root-filled joints would have promoted infiltration and was favourable to the rapid build-up of cleft water pressure.

9. CONCLUSIONS

The 7 June 1999 landslide was probably primarily triggered by the leaking fire services main at the crest of the slope, together with the rainfall preceding the failure. The failure was caused by the build-up of groundwater pressure. The failure surface largely exploited relic joints with weak infill comprising kaolin and manganese oxide, which were not considered in the previous design geological model and stability analysis. The presence of open, root-filled joints and signs of local slope movement suggest that the slope may have been suffering progressive deterioration for some time prior to the failure.

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Table 1 – Summary of Laboratory Test Results for Soil Samples

Material Type	Sample Location	Depth (m)	Sample Type	Particle Size Distribution				LL (%)	PL (%)	IP (%)	Moisture Content (%)	Maximum Dry Density (Mg/m^3)	Insitu Dry Density (Mg/m^3)	Remarks
				Gravel (%)	Sand (%)	Silt (%)	Clay (%)							
Fill	TP1	0.5-0.6	SDS	-	-	-	-	-	-	-	16	-	1.53	*
HDG		0.8-1.0	LDS	44	46	7	3	63	NP	NP	23	1.57	-	
HDG		1.8-2.0	LDS	40	50	7	3	51	40	11	23	1.63	-	
Fill	TP2	0.5-0.6	SDS	-	-	-	-	-	-	-	17	-	1.54	
Fill		0.8-1.0	LDS	27	44	17	12	43	29	14	21	1.79	-	
Fill		1.0-1.45	U76	24	45	18	13	45	28	17	22	-	-	
HDG		1.8-2.0	LDS	40	51	6	3	61	NP	NP	21	1.61	-	
Fill	TP3	0.5-0.6	SDS	-	-	-	-	-	-	-	15	-	1.55	*
Fill		0.5-0.8	HCB	26	48	16	10	41	28	13	16	1.87	-	
Fill		0.8-1.0	LDS	38	51	5	6	38	27	11	16	1.80	-	
Fill		1.0-1.3	HCB	37	51	7	5	38	23	15	12	1.88	-	
Fill		1.0-1.5	U76	23	62	8	7	NP	NP	NP	13	-	-	
Fill		1.5-1.6	SDS	-	-	-	-	-	-	-	14	-	1.46	*
Fill		1.8-2.0	LDS	36	51	5	8	41	28	13	13	1.92	-	
Fill		2.0-2.3	HCB	19	44	22	15	45	29	16	34	1.66	-	
Fill		2.0-2.5	U76	17	38	29	16	59	32	27	24	-	-	
HDR		2.0-2.5	U76	5	15	63	17	52	37	15	19	-	-	
HDR		2.7-3.0	LDS	43	20	26	11	53	42	12	22	1.67	-	

Legend:

LL	Liquid Limit	C/HDG	Completely/Highly Decomposed Granite	TP2	Trial Pit 2
PL	Plastic Limit	C/HDR	Completely/Highly Decomposed Rhyolite	S/LDS	Small/Large Disturbed Samples
PI	Plasticity Index	NP	Not Plastic	HCB	Hand-Out Block Sample
*	Tests carried out by Soil and Materials Engineering Co. Ltd			U76	76 mm Dia. Undisturbed Sample

Note: See Figure 5 for locations of trial pits.

Table 2 – Summary of Laboratory Test Results for Water Samples

Sample No.	Source	pH	Chloride Ion Concentration (mg/l)	Calcium Ion Concentration (mg/l)	Fluoride Ion Concentration (mg/l)	Sulphate Ion Concentration (mg/l)
LS01	Landslide Scar	5.2	30	6	<.02	28
LS02		5.8	72	6	<.02	27
LS03		5.7	70	6	<.02	27
SC01	Stormwater Channel	8.1	19	20	0.5	22
SC02		7.9	28	23	0.4	20
SC03		8	32	23	0.4	21
SD01	Sewage Diversion	5.6	6500	130	0.7	110
FW01	Fresh Water Supply	8.5	18	17	0.6	21
FW02		8.1	17	21	0.5	20
FW03		8.1	17	28	0.4	20
PI01	Piezometer Installation No. B04A	7.2	580	72	0.3	88
PI02		7.1	320	66	0.4	56
PI03		7	500	75	0.2	76

Note: See Figure 5 for source locations.

Table 3 - Maximum Rolling Rainfall at GEO Raingauge No. N09 for Selected Durations Preceding the 7 June 1999 Landslide and the Estimated Return Periods

Duration	**Maximum Rolling Rainfall (mm)**	**End of Period**	**Estimated Return Period (Years)**
5 Minutes	7.5	03:35 on 7 June 1999	<2
15 Minutes	17.0	03:40 on 7 June 1999	<2
1 Hour	39.5	03:40 on 7 June 1999	<2
2 Hours	50.5	03:45 on 7 June 1999	<2
4 Hours	57.0	04:00 on 7 June 1999	<2
12 Hours	57.0	04:00 on 7 June 1999	<2
24 Hours	57.0	04:00 on 7 June 1999	<2
2 Days	57.0	04:00 on 7 June 1999	<2
4 Days	57.0	04:00 on 7 June 1999	<2
7 Days	57.0	04:00 on 7 June 1999	<2
15 Days	102.5	04:00 on 7 June 1999	<2
31 Days	189.0	04:00 on 7 June 1999	<2

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

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

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

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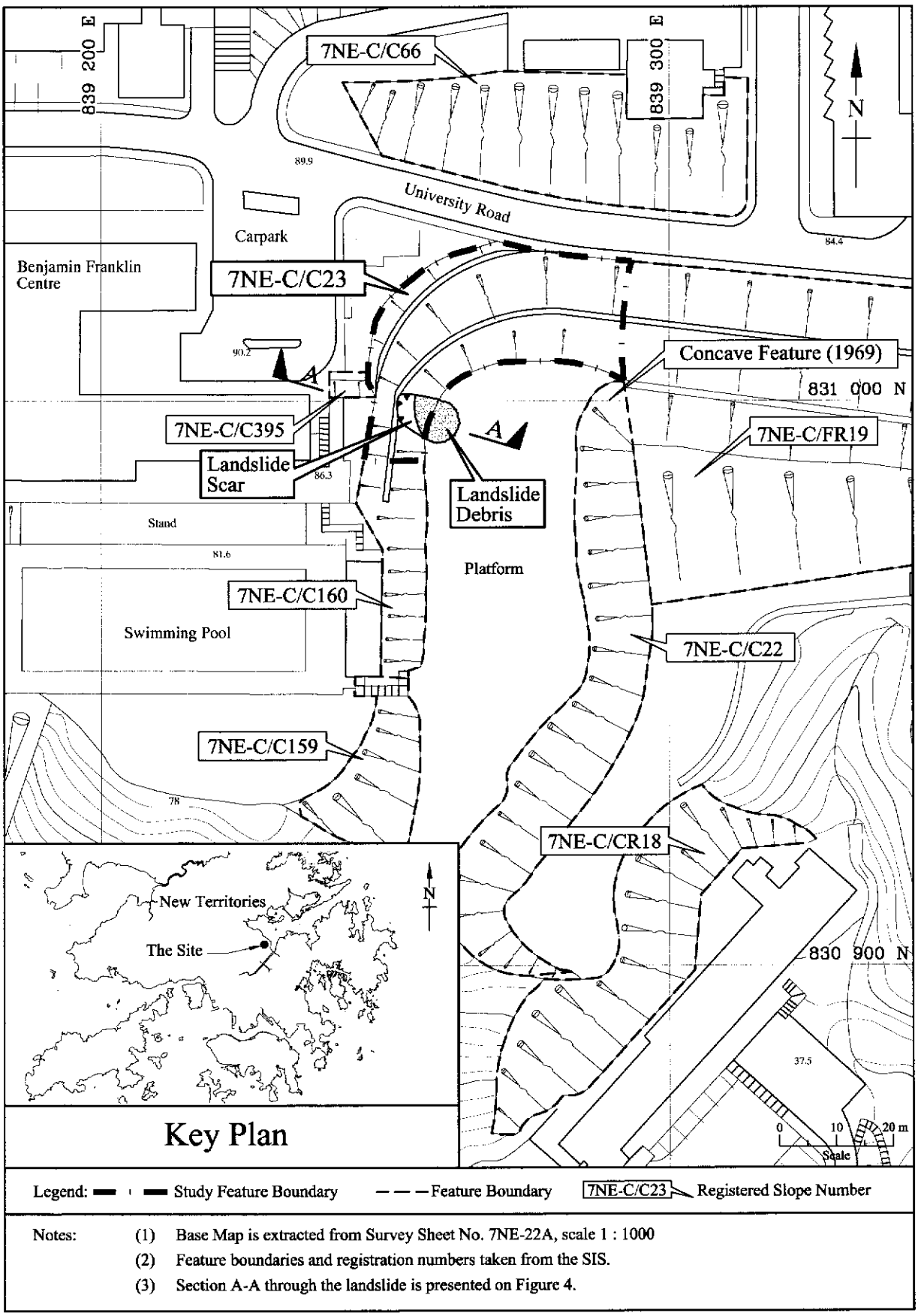
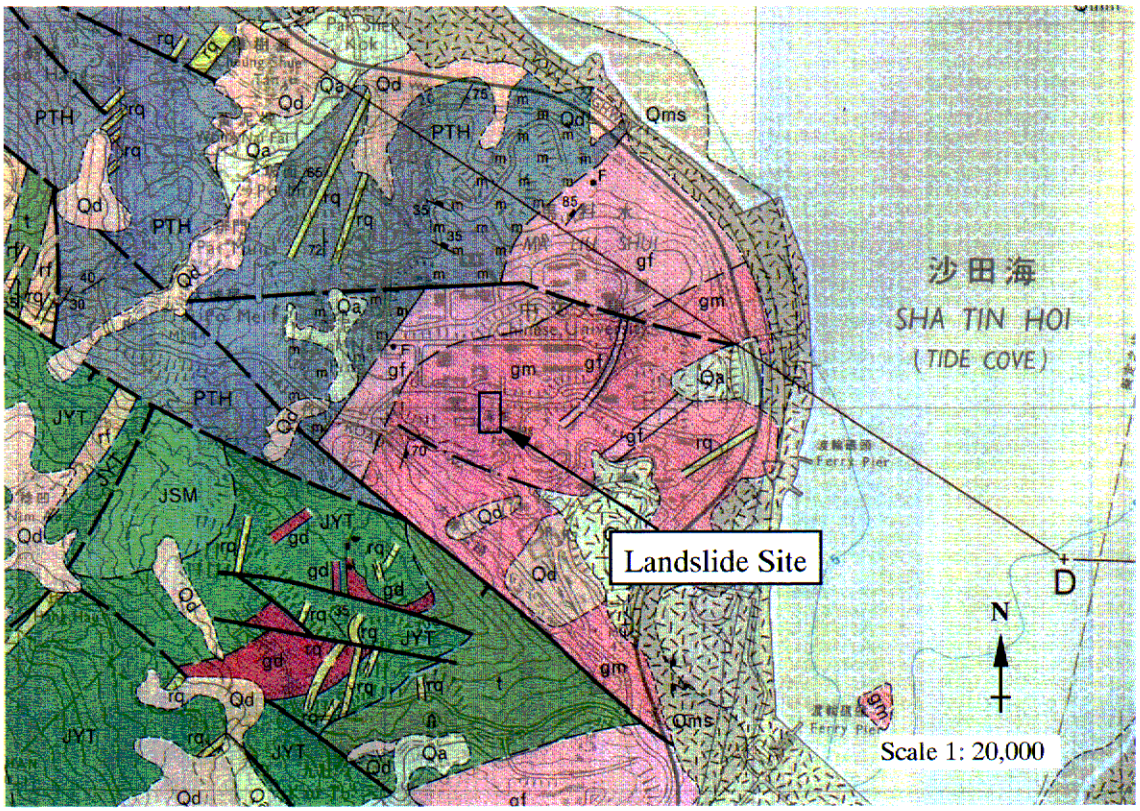


Figure 1 - Site Location Plan



LEGEND:

SUPERFICIAL DEPOSIT

- Fill, sanitary fill (Qfs)
- Qms — Marine sand
- Qa — Alluvium
- Qd — Debris flow deposits

SOLID GEOLOGY

- JSM — Crystal and lithic tuff, tuff-breccia and tuffite
- JYT — Crystal tuff, with hornblende
- t — Undifferentiated tuff and tuffite
- PTH — Mudstone, siltstone and sandstone
- gf — Fine-grained granite; < 2 mm
- gm — **Medium-grained granite; 2-6 mm**
- gd — Granodiorite
- rq — Quartzphyric rhyolite

GEOLOGICAL LINES

- Geological boundary, superficial deposit
- Geological Boundary, solid rock
- Fault (crossmark indicates downthrow side)
- Photogeological lineament

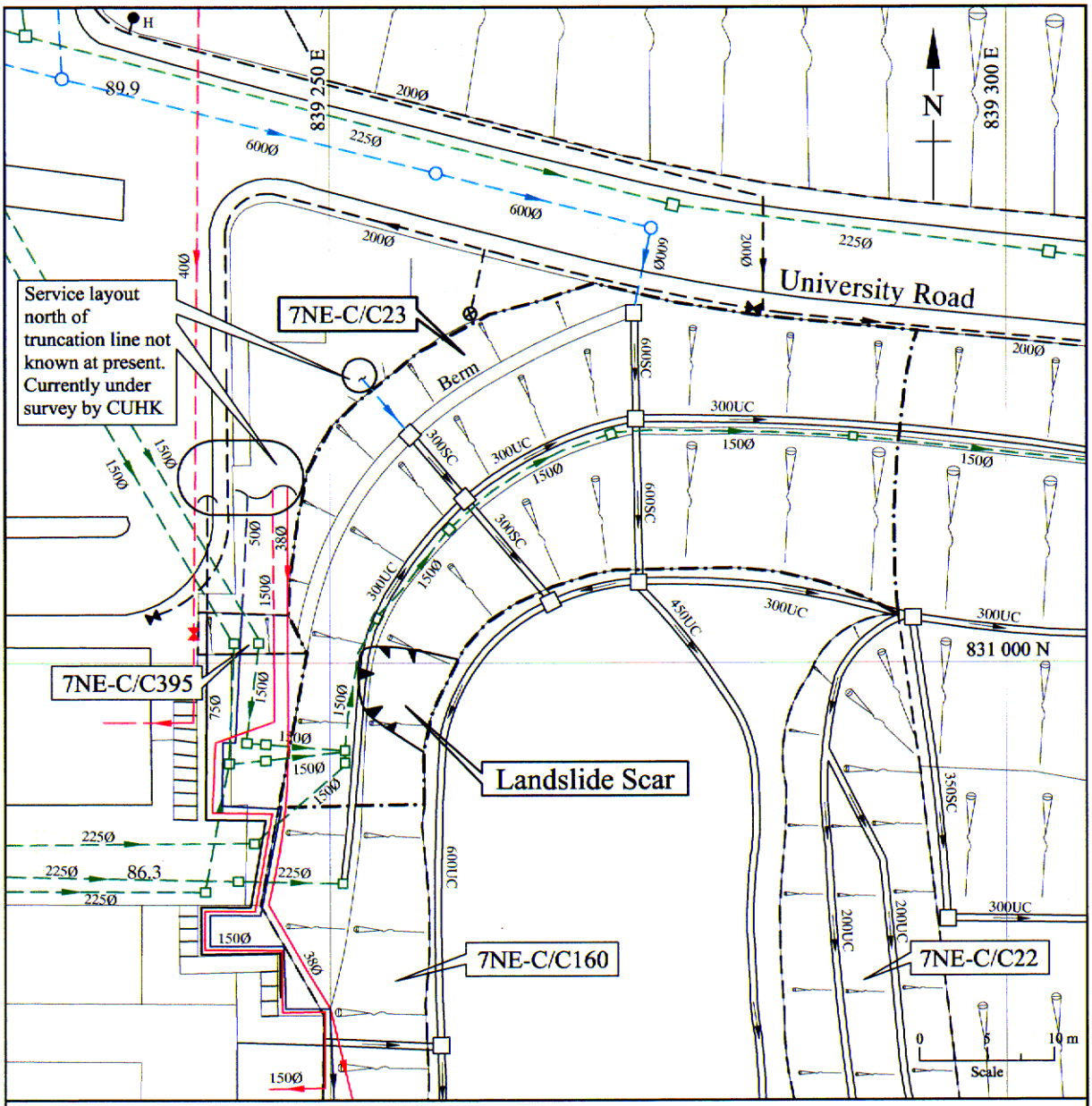
(* Broken lines on map face denote uncertainty)

STRUCTURAL SYMBOLS

- 20 — Inclined bedding
- 20 — Inclined jointing

Notes: (1) Geology relevant to study area shown bold.
(2) Extract from Sheet 7 of the Hong Kong Geological Survey 1 : 20,000 Scale Map Series GM20 (GCO, 1986).

Figure 2 – Solid and Superficial Geology of the Landslide Site



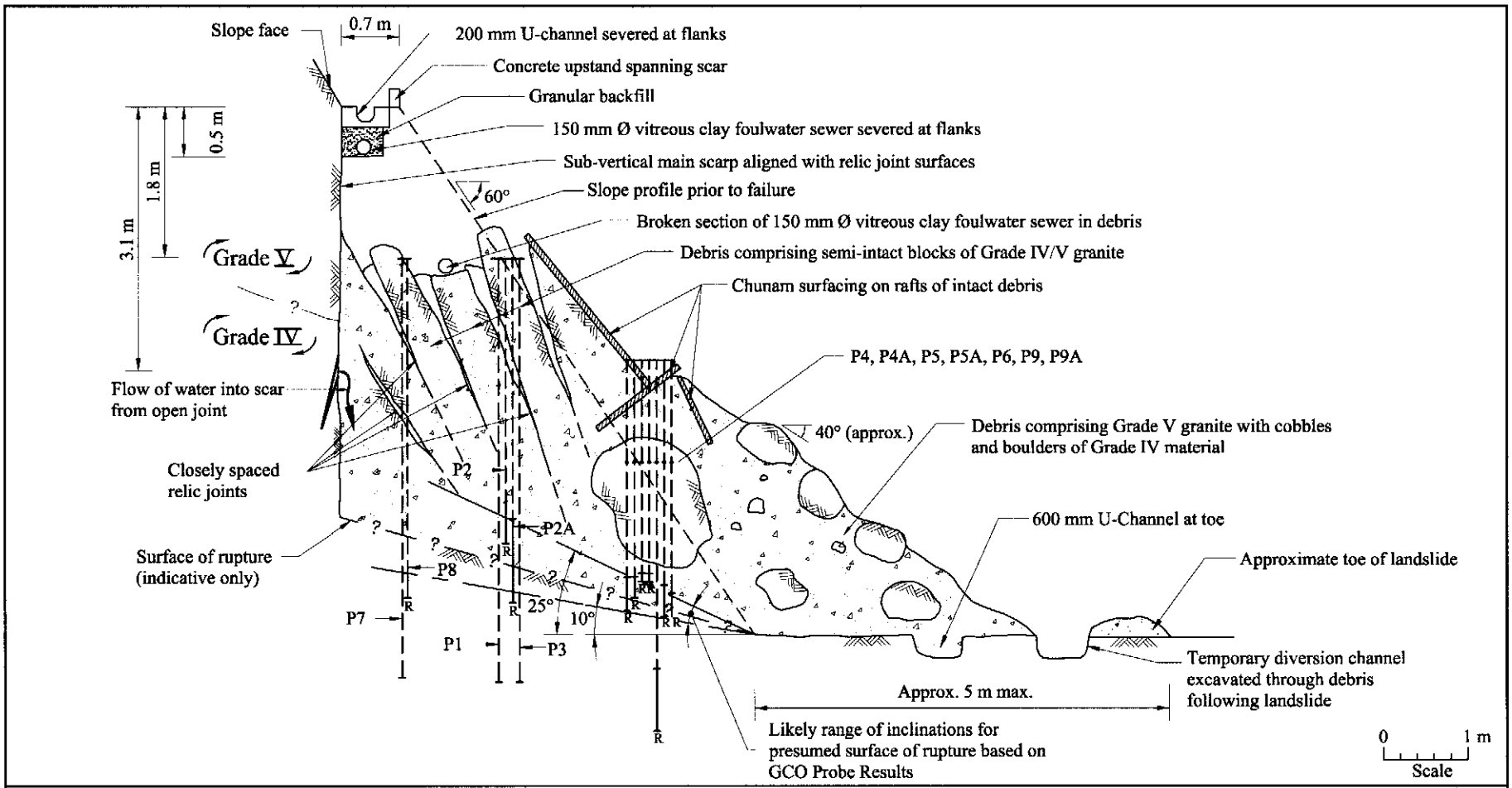
Notes:

(1) Solid line indicates above ground service, dashed line indicates buried service.

(2) Pipe diameters and channel widths are in millimetres.

(3) The locations of the various existing services are based on visual inspection and the following CUHK drawings/sketches: Drg. Nos. 114/12/P-1, 114a/12/P-1 & 114b/12/FS-1 (1992) and 60/1/DR-4 (1997). Sketch Nos. SK/C22/01 & SK/SP/01 (1999).

Figure 3 - Existing Services



Legend:

P4 — GCO probing number and location. Hard layer (blow count exceeding 20) indicated by solid line.
R – Refusal (blow count exceeding 50)

Notes:
(1) Refer to Figure 1 for location of Section A-A.
(2) Target depth for GCO probing = 5 m.

Figure 4 - Section A-A through the Landslide

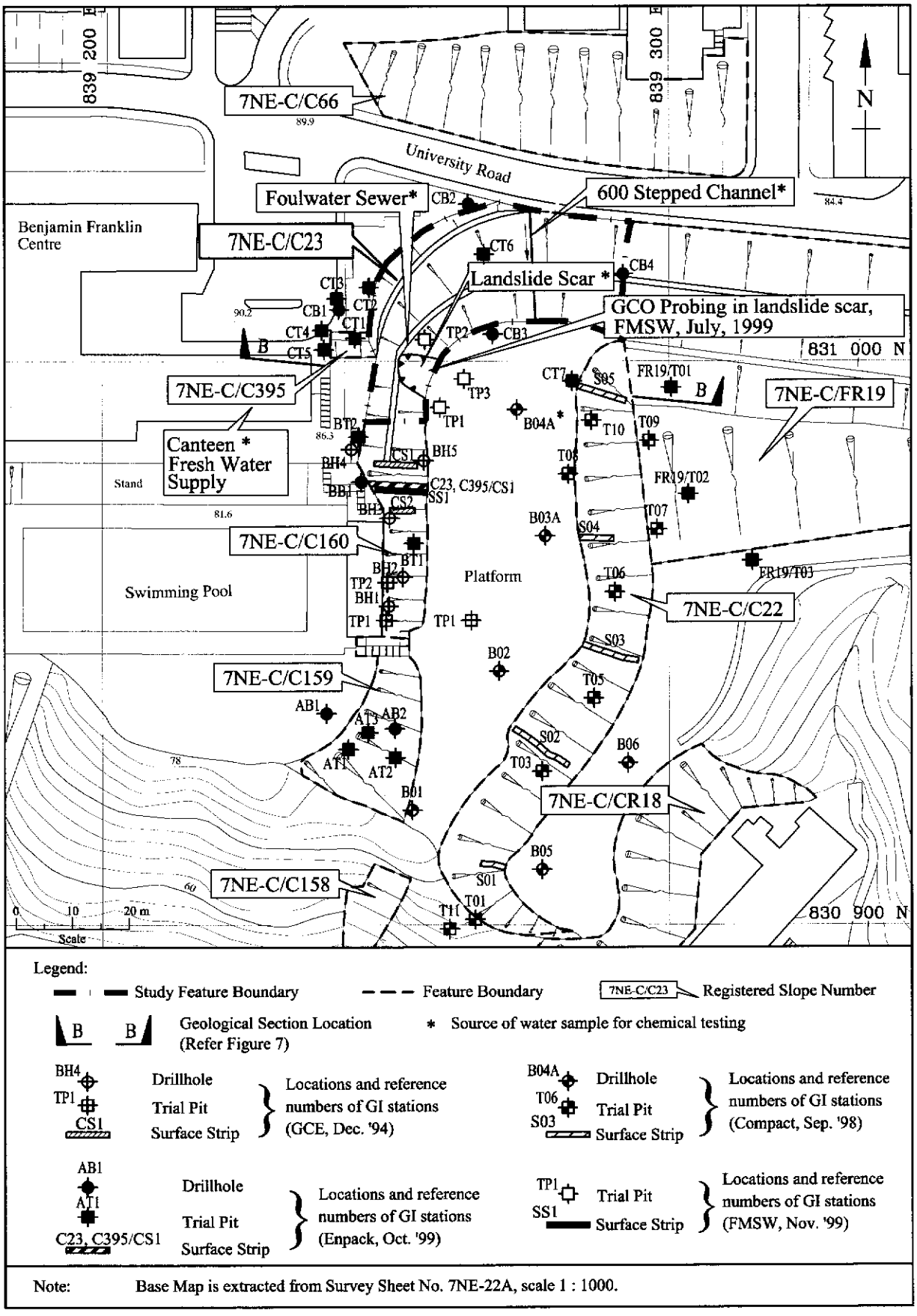


Figure 5 - Ground Investigation Stations

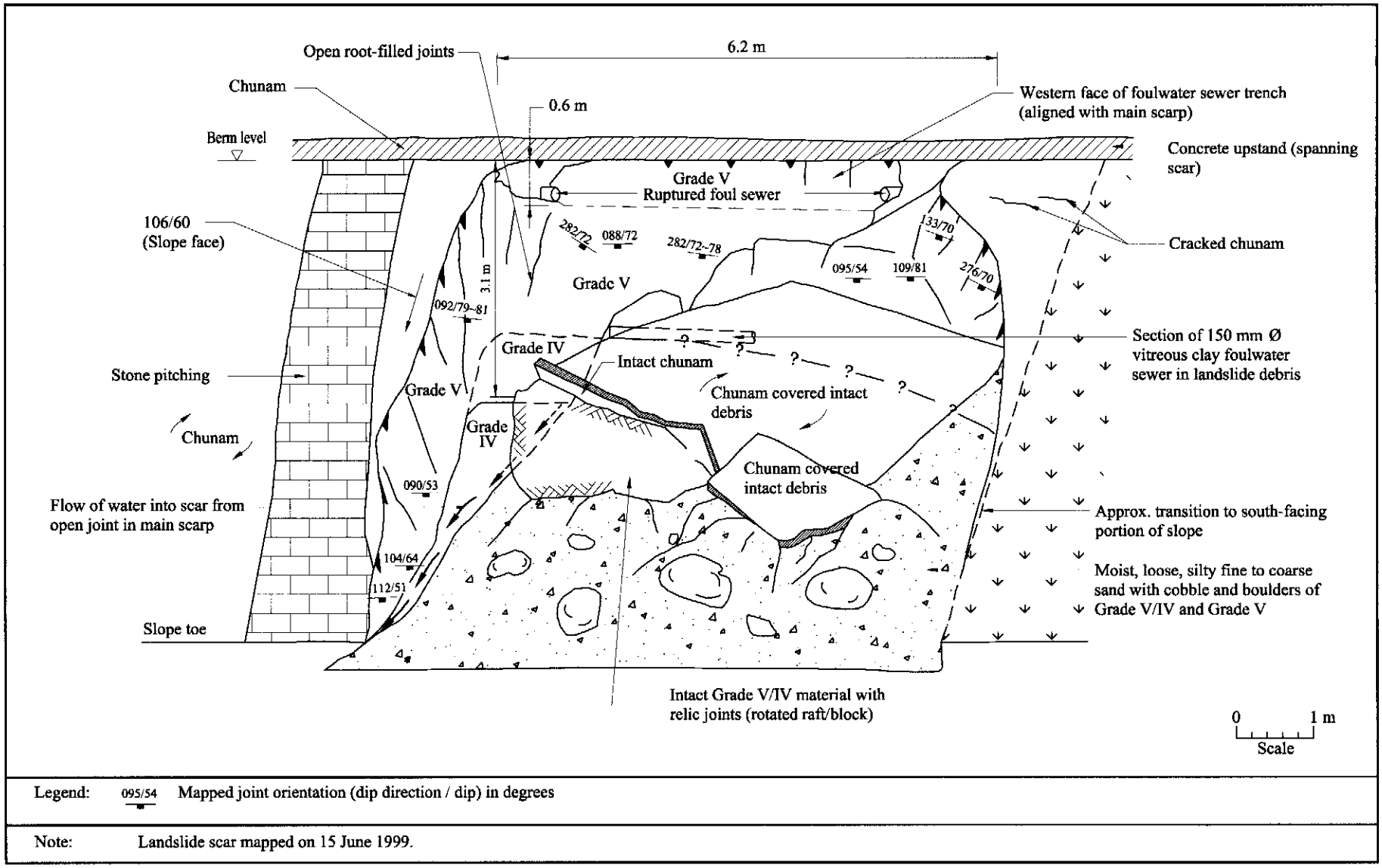


Figure 6 - Geological Mapping of the Landslide Scar

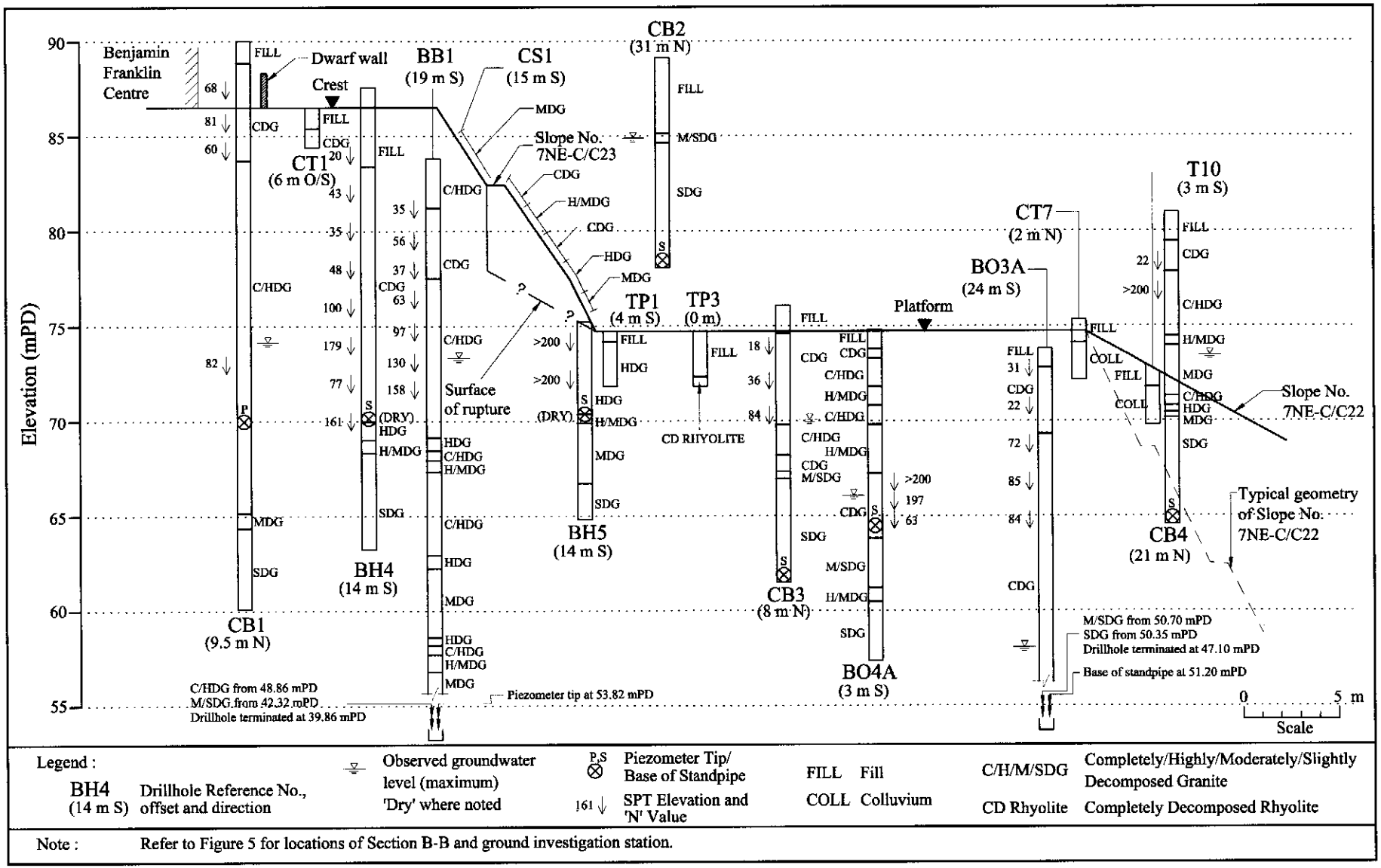
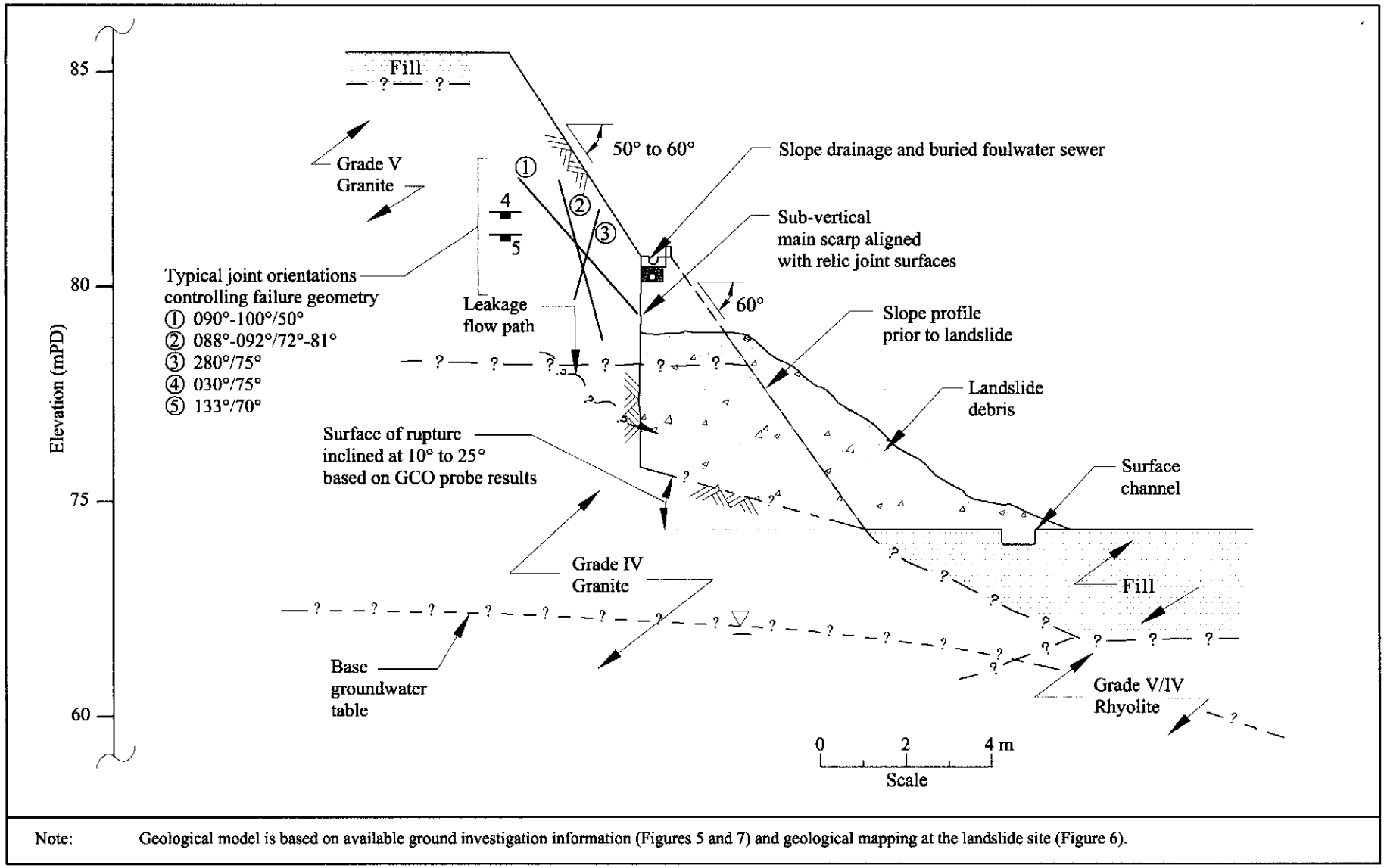
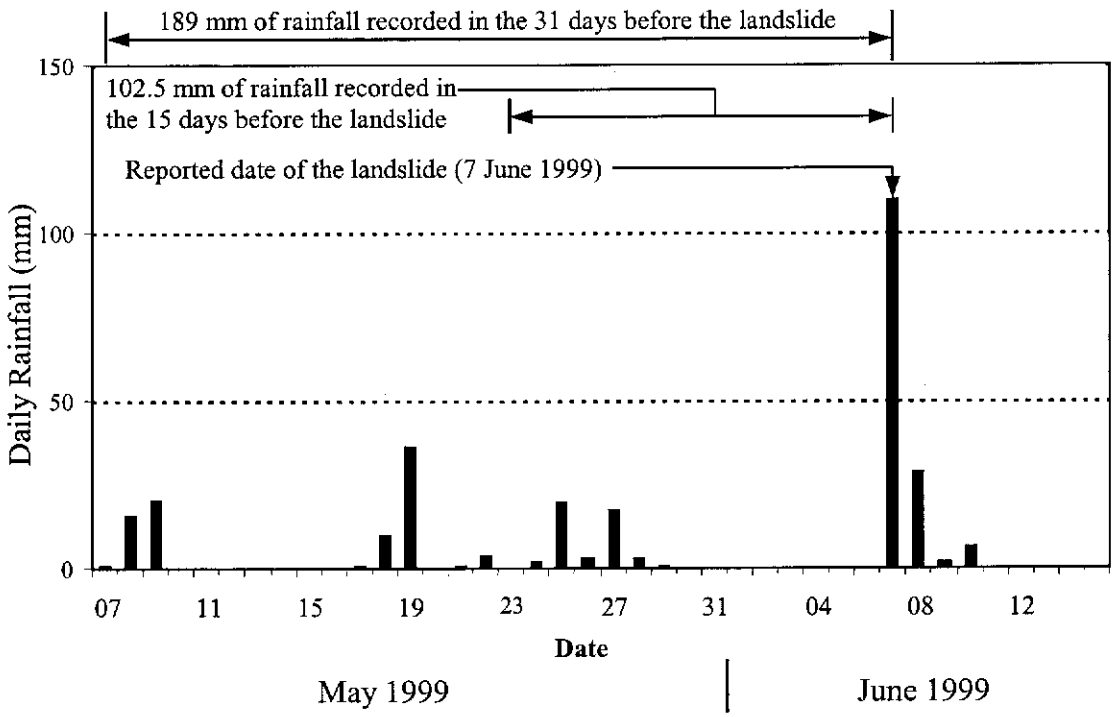


Figure 7 - Section B - B through the Site

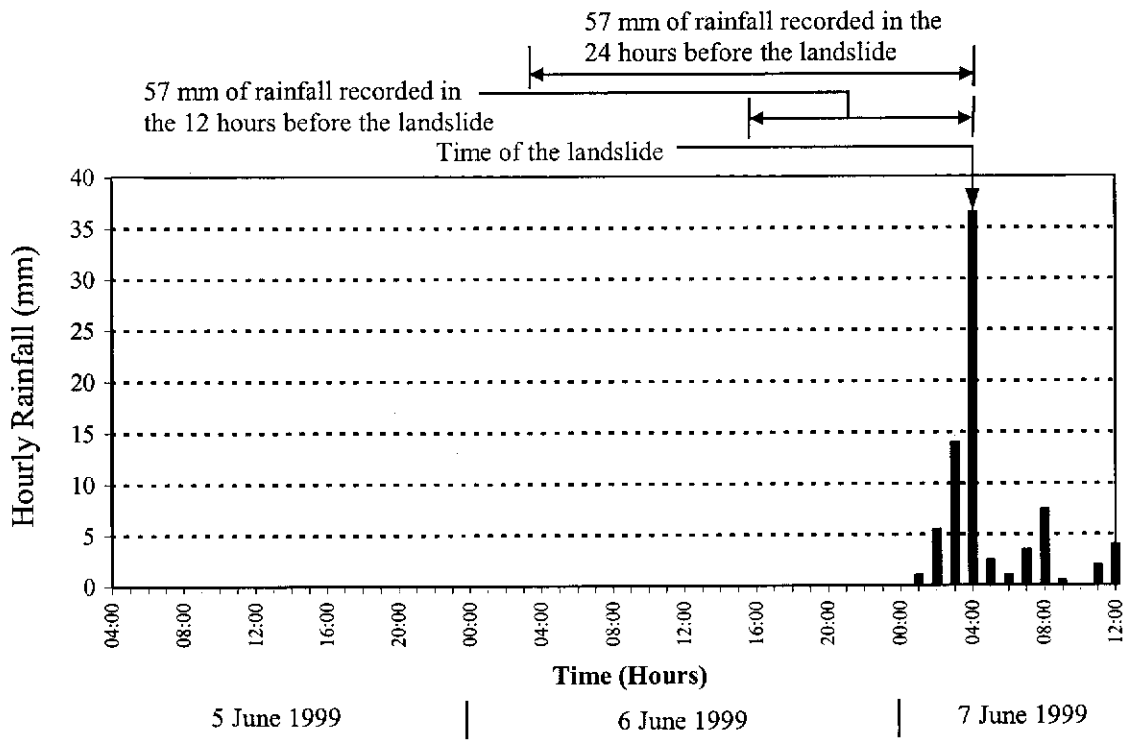


Note: Geological model is based on available ground investigation information (Figures 5 and 7) and geological mapping at the landslide site (Figure 6).

Figure 8 - Geological Model

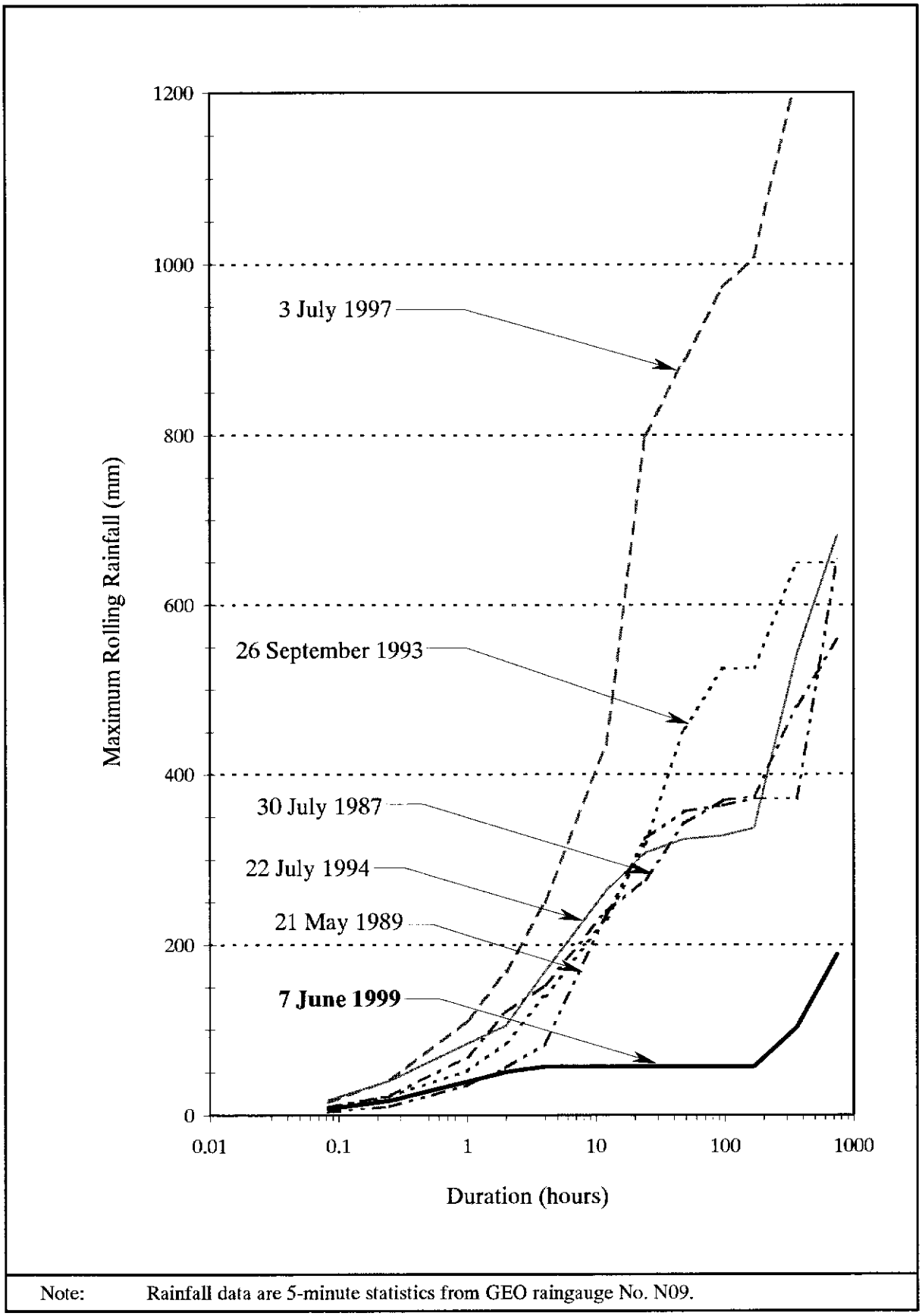


(a) Daily Rainfall Recorded between 7 May and 15 June 1999



(b) Hourly Rainfall Recorded between 04:00 hours on 5 June and 12:00 hours on 7 June 1999

Figure 9 - Rainfall Recorded at GEO Raingauge No. N09



Note: Rainfall data are 5-minute statistics from GEO raingauge No. N09.

Figure 10 - Maximum Rolling Rainfall Preceding the Landslide of 7 June 1999 and Selected Major Rainstorms Recorded at GEO Raingauge No. N09

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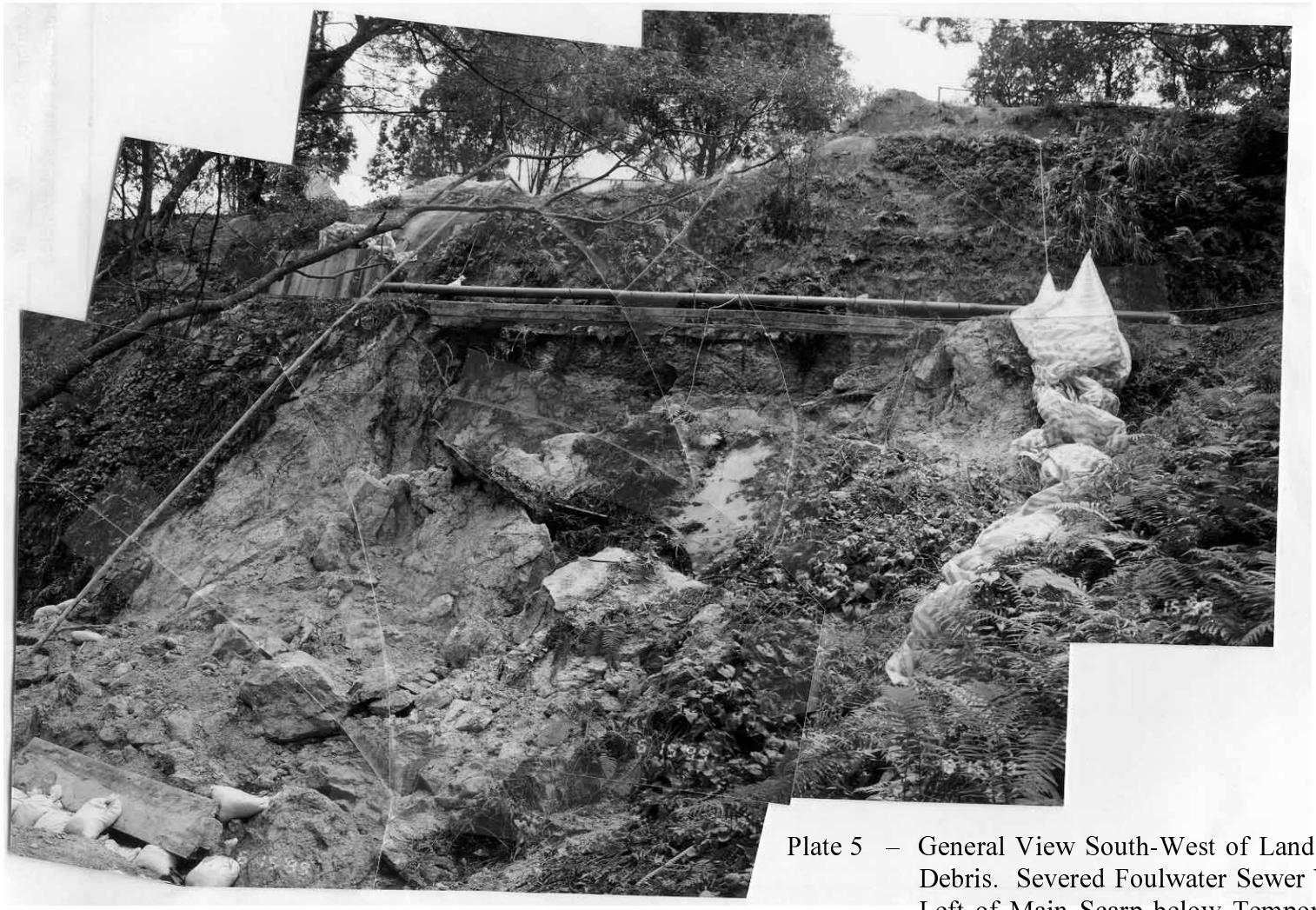

Plate 5 – General View South-West of Landslide Scar and Debris. Severed Foulwater Sewer Visible at Top Left of Main Scarp below Temporary Diversion Pipe (Photograph Taken on 15 June 1999)

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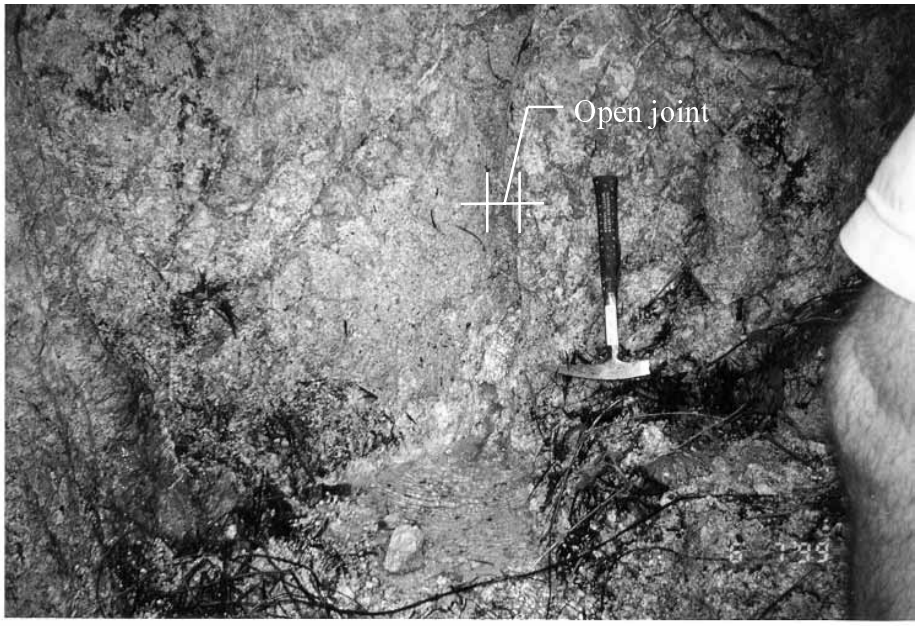

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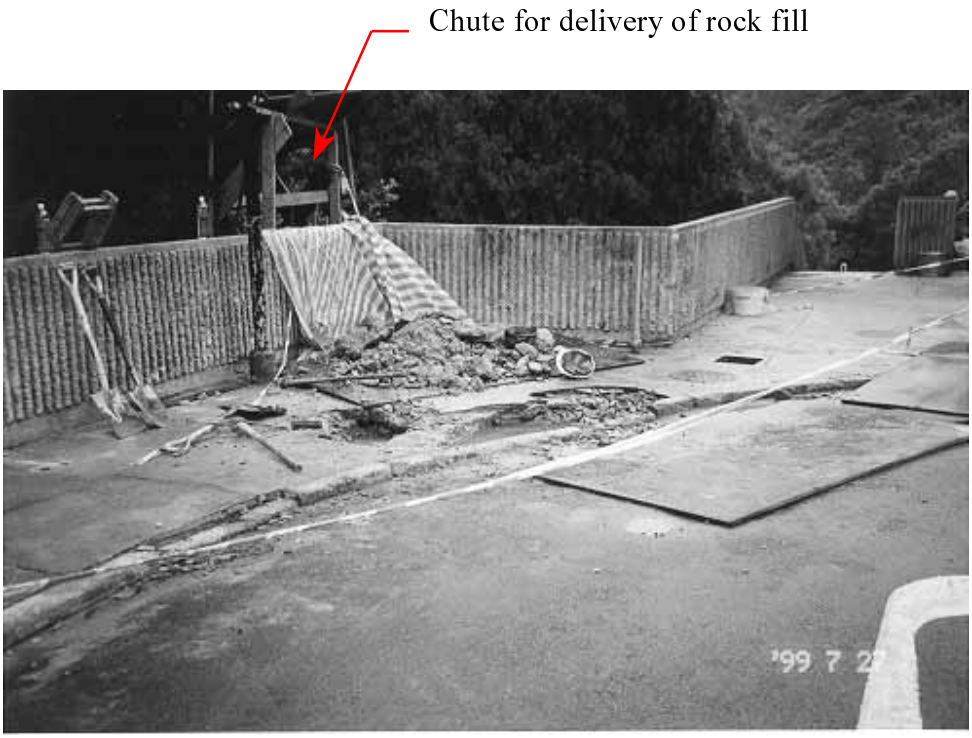

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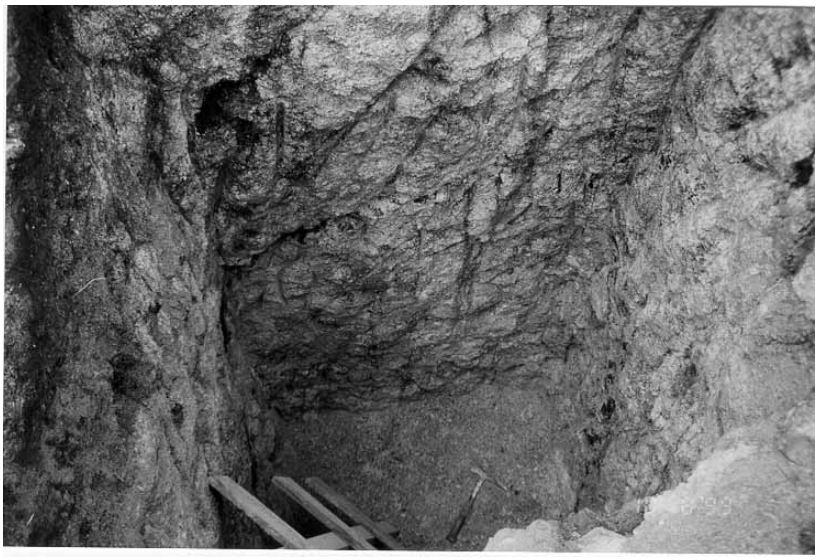

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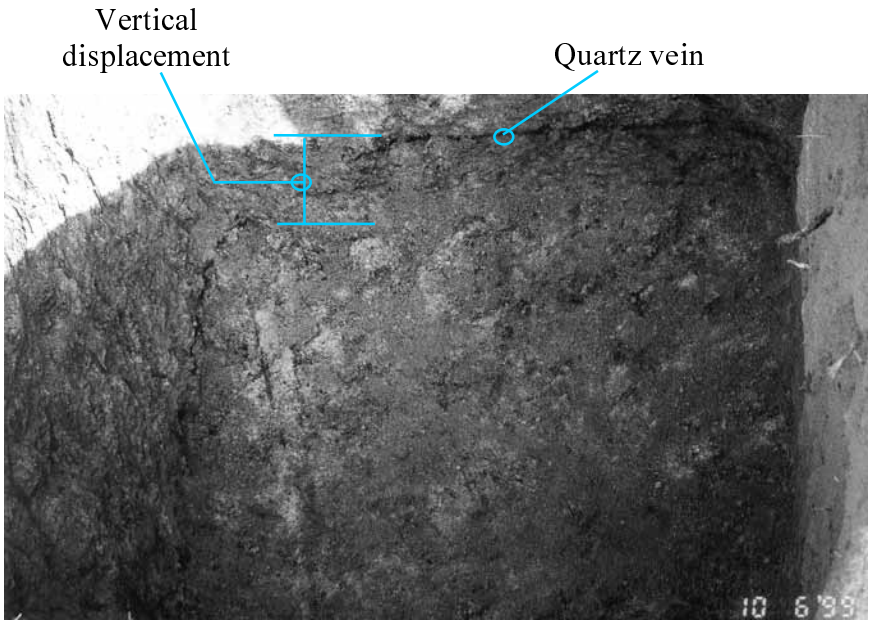


Plate 23 – Trial Pit TP2: Base of Pit Facing North. Sub-Horizontal Quartz Vein with Manganese Oxide Infill Visible near Base of Pit. Vertical Displacement across Vein Visible on Left of Frame (Photograph Taken on 6 October 1999)

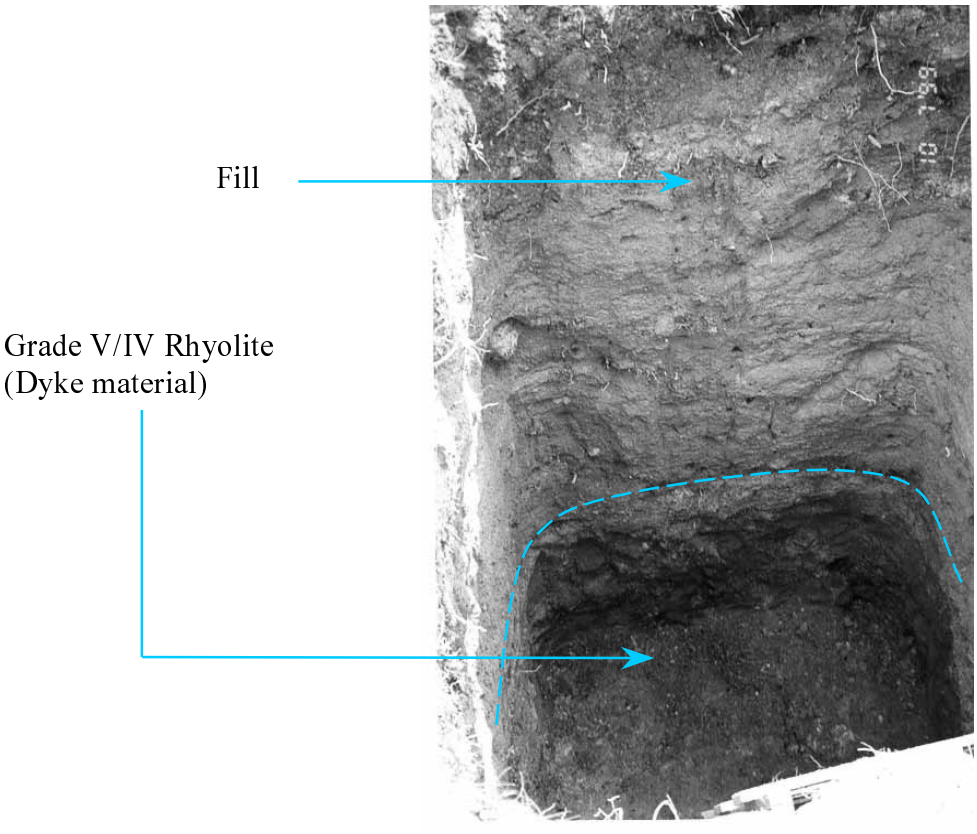


Plate 24 – Trial Pit TP3: View of South Face and Base of Pit Showing Grade IV/V Rhyolite below Fill (Photograph Taken on 7 October 1999)

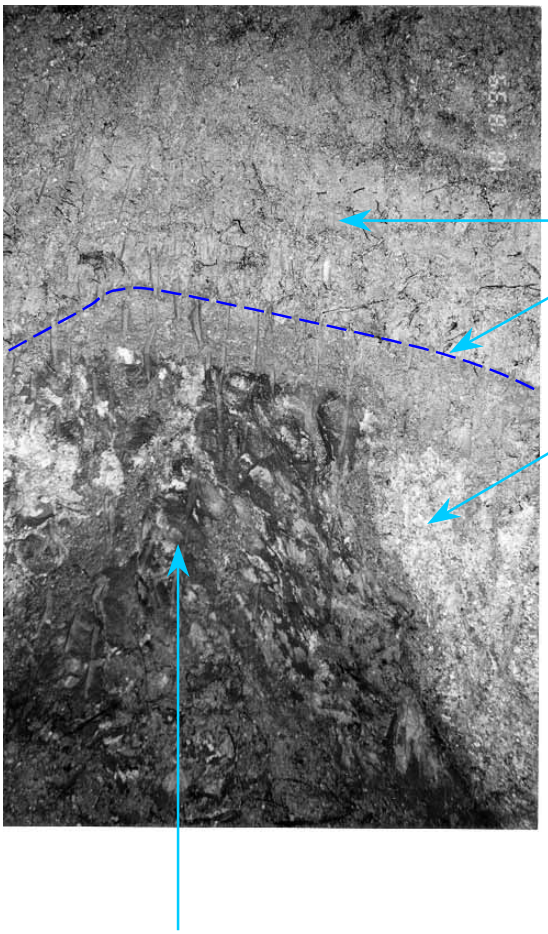


Plate 25 – Trial Pit TP3: View of Interface (Indicated) between Fill and Grade V/IV Rhyolite and Granite (Right of Frame) (Photograph Taken on 8 October 1999)

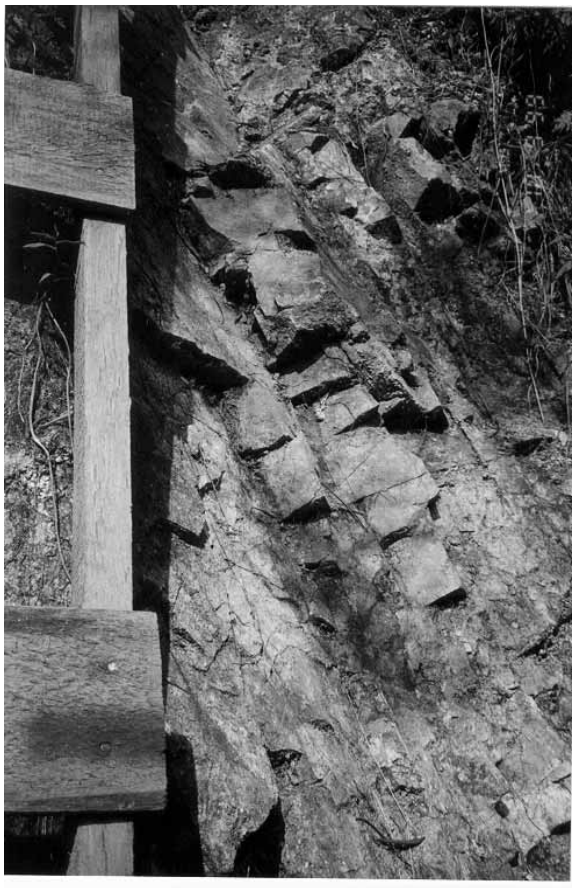


Plate 26 – Strip SS1: Joint Surfaces Exposed in Grade III Outcrop (Photograph Taken on 9 October 1999)

Plate 27 – Investigation of Kaolin-Rich Zone (Plate 9) (Photograph Taken on 7 July 1999)

Plate 28 – Manganese Oxide (Black) Infill on Relic Joint Surfaces Exposed in Landslide Debris. Infill Thickness up to 2 mm (Photograph Taken on 15 June 1999)

Plate 29 – Cobble-Sized Piece of Kaolin-Rich Material Observed in Landslide Debris (Photograph Taken on 10 June 1999)

APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

A.1 DETAILED OBSERVATIONS

The following comprise the detailed observations made from the aerial photographs studied. Relevant photographs are referenced in Section A.2.

YEAR	OBSERVATIONS
1963	Future location of slope No. 7NE-C/C23 occupies upper reaches of short SE-trending valley between S trending spur and E-W aligned ridge. Surrounding area comprises undisturbed hillside with narrow paths along ridges. Relic instabilities are visible in the general area and a possible drainage feature/ small relic scar is located at the site on an approximate NW-SE axis.
1964	Site formation works for Chinese University of Hong Kong (CUHK) commenced. Broad swathe of vegetation clearance along contours passing through and beneath site, possibly as site clearance prior to commencement of earthworks. Additional instabilities identified in the surrounding hillside, though mostly affecting S-SW trending slopes.
1969	CUHK site formation well advanced. Benjamin Franklin Centre (BFC) completed and adjacent cut slopes (including slope No. 7NE-C/C23) formed. Swimming pool to south of BFC not yet commenced. University Road under construction and fill slope No. 7NE-C/F19 completed. Slopes are unvegetated. Trees are planted along the crest. Possible chunam surfacing on slope face at present landslide location and excavated 'slot' visible to south. Stepped channel visible to define original southern boundary of feature. Leveled platform at toe of slope with surface drainage channels along slope toe and eastern perimeter. Outline of buried structure (sewage treatment tanks) visible in platform and bowl-shaped feature (possible scar) remaining in cut slope geometry (slope No. 7NE-C/C22) below platform. Site formation comprises series of leveled platforms extending to the north of the site with a high rock cutting approximately 150 m distant.
1973	CUHK site formation complete. A number of structures to the north of the landslide site are complete and the campus is operational. The swimming pool south of the BFC is completed. Slope No. 7NE-C/C23 is uniformly vegetated and trees are established on the platform at the slope toe. (Foulwater) manhole structure is visible on the slope at berm level. Excavated slot (1969) on slope face below manhole is more pronounced. Small diameter pipe present on slope face north of manhole and services are visible on stone-pitched slope (7NE-C/C395) behind crest. Some disturbance (possibly erosion) on slope face to north of present landslide site.
1974	High altitude photographs. Little detail discernible. Possible staining of chunam at present landslide location. Sparse vegetation on south-facing portion of slope.

YEAR	OBSERVATIONS
1975	High altitude photographs. Area near toe of slope at present landslide location lighter in colour than surrounding area.
1976	East-facing portion of slope becoming obscured by vegetation. Possible clearance of drainage channel at toe of slope. Patch in asphalt pavement in carpark above present landslide location.
1977	Stone pitched strip at location of slot (1969) below manhole structure (1973) visible. Chunam surfacing at present landslide location is mottled in appearance and a zone at the northern extent is lighter in colour, possibly indicating recent maintenance. South-facing portion of slope remains sparsely vegetated.
1978	East-facing portion of slope in partial shadow. Possible erosion features to south of present landslide location. Heavier vegetation cover on slope face at southern end.
1980	Present landslide location contrasts sharply (lighter) against surrounding slope. Possible erosion features in upper batter to south. Vegetation heavier on lower batter. Vegetation is also becoming more established on south-facing portion of slope.
1981	No stereo-pair available. No change obvious from single photograph.
1982	High altitude photographs. No obvious changes.
1983	No obvious changes. Vegetation on east-facing portion has matured into a number of small to medium trees on the upper batter at the southern end of the slope and three larger trees on the south-facing portion with low cover between.
1984	East-facing portion of slope in shadow. No obvious changes. Possible erosion below berm at present landslide location.
1985	No obvious changes. Vegetation becoming heavier on platform at toe and on slope. Possible erosion features around base of trees on south-facing portion. Large patch in asphalt pavement on University Road to north of slope.
1986	Narrow linear feature present from slope crest to berm above present landslide location. Possibly back-filled trench for buried service. Possible minor erosion features on other portions of slope. Berm on South-facing portion very bright, possibly indicating new apron slab. Extensive slope surfacing/re-surfacing works on slope No. 7NE-C/C22 below platform to east.

YEAR	OBSERVATIONS
1987	East-facing portion of slope in partial shadow. Southern portion of slope obscured by vegetation up to present landslide location. Vegetation on south-facing portion of slope heavier. Lady Shaw Building commenced construction to north-east of site.
1988	East-facing portion of slope in partial shadow. Possible erosion features in upper batter. Lower batter on south-facing portion of slope and berm extending to present landslide location is very light in appearance, possibly indicating new section of apron slab and reduced vegetation. Large section of asphalt pavement replaced on University Road adjacent to Carpark.
1989	Lower batter and berm on south-facing portion of slope (1988) are still very light in colour. The greater portion of the slope is obscured by vegetation. Possible erosion features in upper batter of east-facing portion of slope (1988) are still visible.
1990	Slope largely obscured by vegetation. Present landslide location and batter above remains exposed. Lower batter lighters in colour than upper and has darker streaks suggesting previous water flow over slope face. Lady Shaw Building completed.
1991	No major changes. Berm above present landslide location has lost definition as vegetation becomes heavier. A patch in the lower batter is much lighter than the surrounding slope, suggesting possible maintenance works to hard surfacing. Possible erosion features /minor instabilities on slope No. 7NE-C/C22 and slope No. 7NE-C/FR19 to east.
1992	East-facing portion of slope in shadow. Remainder of slope obscured by vegetation.
1993	Light streaky appearance to slope surfacing at present landslide location, possibly indicating a previous flow of water over the slope face.
1994	Berm above present landslide location again visible due to lighter tone. East-facing portion of slope between BFC and swimming pool to south is very light in appearance. The ground beyond the toe of the slope at this location has been cleared and is of a similar shade to the slope (possible instability?).
1995	First colour photographs. East-facing portion of slope is in shadow. Surrounding vegetation is dense and the south-facing portion of the slope is completely obscured. The present landslide location and cleared area to the south (1994) remain free of vegetation.

YEAR	OBSERVATIONS
1996	Chunam at the present landslide location is visible and there is an area cleared of vegetation beyond the toe of the slope. The chunam appears weathered, but uniform and intact. Vegetation has re-established on the previously cleared portion of slope to the south (1994). Substantial area of asphalt pavement replaced on University Road adjacent to carpark.
1997	East-facing portion of slope in shadow and obscured by heavy vegetation. Large area of asphalt pavement in carpark behind present landslide location darker than surrounding pavement.
1998 (Jul)	East-facing portion of slope in shadow and mostly obscured by vegetation. Possible erosion feature on south-facing portion of slope. Asphalt completely replaced in carpark behind slope crest.
1998 (Nov)	High altitude photographs and hazy conditions. No obvious changes.
1999 (Feb)	High altitude photographs. No obvious changes.

A.2 LIST OF AERIAL PHOTOGRAPHS

A list of aerial photographs used in this API study is presented below.

YEAR	PHOTOGRAPHS
1963	Y09457 Y09458 Y09459
1964	Y12398 Y12399
1969	Y15613 Y15614 Y15617 Y15618
1973	7140 7141
1974	10080 10081
1975	11723 11724
1976	12539 12540
1977	17484 17485
1978	23449 23450
1980	30756 30757
1981	36652
1982	44628 44629
1983	50020 50021
1984	56842 56843
1985	A2383 A2384
1986	A04855 A04856
1987	A09317 A09318
1988	A15393 A15394
1989	A16151 A16152

1990	A23418 A23419
1991	A27114 A27115
1992	A31935 A31936
1993	A34654 A34655
1994	A39080 A39081
1995	CN10693 CN10694
1996	CN14934 CN14935
1997	CN17316 CN17317
Jul/1998 Nov/1998	CN20459 CN20460 A48097 A48098 CN21564 CN21565
1999	CN22284 CN22285

APPENDIX B

TRIAL PIT AND SURFACE STRIP LOGS

Fugro Maunsall Scott Wilson Joint Venture
Agreement No. CE 101/98
1999 Landslide Investigation Consultancy
Detailed Study No. 1
Slope No. 7NE-C/C23, The Chinese University of Hong Kong

TRIAL PIT RECORD

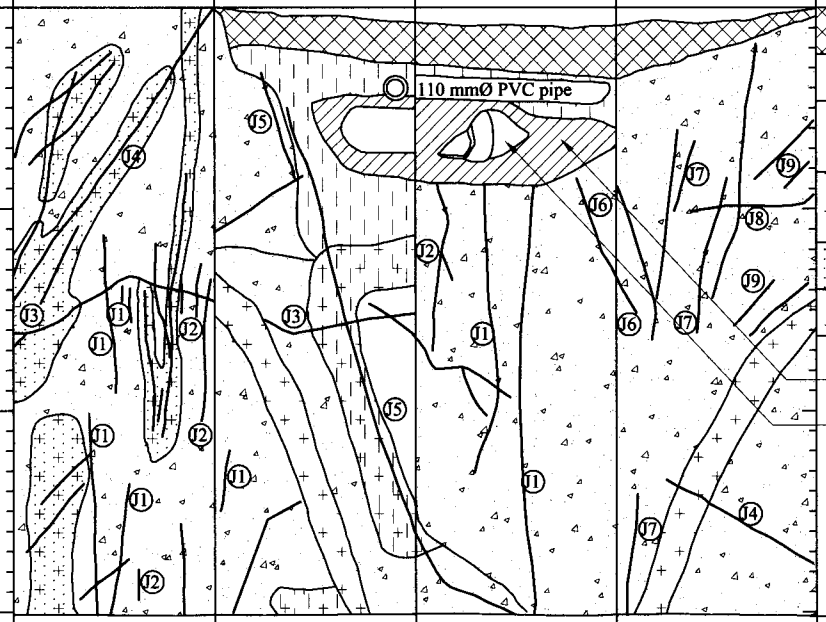
TRIAL PIT No. 1

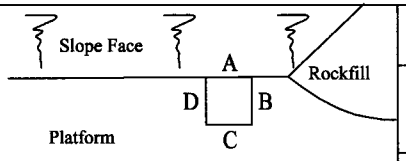
CO-ORDINATES 839255.343 E 830990.524 N
GROUND LEVEL 74.825 mPD

Sheet 1 of 2

EXCAVATION DATE: from 27-09-99
BACKFILL DATE: 09-10-99
LOGGED BY: JLKS DATE: 08-10-99
CHECKED BY: ICM DATE: 06-11-99

Samples & tests	Depth (m)	FACE A: 1.50 m	FACE B: 1.50 m	FACE C: 1.50 m	FACE D: 1.50 m	Legend	Grade	Description
								Soft, moist, dark grey/black, very sandy gravelly CLAY with tree roots. (FILL)
								Medium dense, moist, brown, slightly silty fine to coarse SAND with occasional tree roots. (FILL)
							IV	Weak, moist, yellowish-brown mottled with pink, black and white, highly decomposed GRANITE. (Dense to very dense, gravelly fine to coarse SAND)
	1						III/II	Moderately strong to strong, light grey with black surface staining, moderately to slightly decomposed GRANITE. (Quartz-Rich Band)
							IV	Weak, moist, reddish-brown, some black and white mottled, highly decomposed GRANITE (Surrounding joints on Face A)
							IV	Weak, moist, light pink spotted with some grey, highly decomposed GRANITE with kaolin-rich zones.
	2							Concrete surround to pipe
								150 mm diameter vitreous clay pipe
								(Refer sheet 2 of 2 for joint description)
	3							Trial pit complete at 2.9 m depth



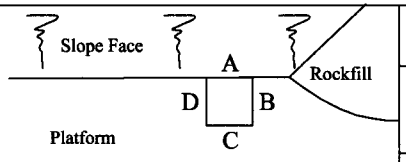
SYMBOL	SAMPLES/TESTS/WATER	PLAN (NOT TO SCALE)	REMARKS
•	SMALL DISTURBED SAMPLE		Pit sides stable. No water encountered.
↕	BULK DISTURBED SAMPLE		
▬	UNDISTURBED SAMPLE HORI. (U100/U76)		
▯	UNDISTURBED SAMPLE VERT. (U100/U76)		
⊠	BLOCK SAMPLE		
⊔	IN-SITU DENSITY TEST		
△	WATER SAMPLE		
∿	SEEPAGE		

KEY

NORTH ARROW

Fugro Maunsall Scott Wilson Joint Venture Agreement No. CE 101/98 1999 Landslide Investigation Consultancy Detailed Study No. 1 Slope No. 7NE-C/C23, The Chinese University of Hong Kong	TRIAL PIT RECORD		Sheet 2 of 2
	TRIAL PIT No. 1	EXCAVATION DATE:	from 27-09-99
		BACKFILL DATE:	09-10-99
	CO-ORDINATES 839255.343 E 830990.524 N	LOGGED BY: JLKS	DATE: 08-10-99
	GROUND LEVEL 74.825 mPD	CHECKED BY: ICM	DATE: 06-11-99

Samples & tests	Depth (m)	FACE A: 1.50 m	FACE B: 1.50 m	FACE C: 1.50 m	FACE D: 1.50 m	Legend	Grade	Description
	1 2 3							Joint Orientations J1 210°/85° (Ave) J2 175°/85° (Face A), 190°/78° (Face C) J3 093°/54°, 100°/60°, 155°/15° (Face B) J4 192°/50°, 190°/50° (Face D) J5 110°/75° (Face B) J6 200°/65° (FaceB) J7 087°/80° (Ave) J8 185°/55° (Ave) J9 170°/70° (Ave)

SYMBOL	SAMPLES/TESTS/WATER	PLAN (NOT TO SCALE)		REMARKS
•	SMALL DISTURBED SAMPLE		KEY	Pit sides stable. No, water encountered.
↕	BULK DISTURBED SAMPLE			
▬	UNDISTURBED SAMPLE HORI. (U100/U76)			
▯	UNDISTURBED SAMPLE VERT. (U100/U76)			
☒	BLOCK SAMPLE			
⊔	IN-SITU DENSITY TEST			
▵	WATER SAMPLE			
∿	SEEPAGE		NORTH ARROW	

Fugro Maunsall Scott Wilson Joint Venture
Agreement No. CE 101/98
1999 Landslide Investigation Consultancy
Detailed Study No. 1
Slope No. 7NE-C/C23, The Chinese University of Hong Kong

TRIAL PIT RECORD

TRIAL PIT No. 2

CO-ORDINATES 839257.928 E 831000.152 N
GROUND LEVEL 76.549 mPD

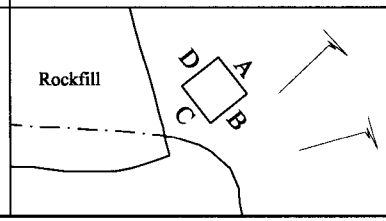
EXCAVATION DATE: from 30-09-99
BACKFILL DATE: 09-10-99
LOGGED BY: JLKS DATE: 06-10-99
CHECKED BY: ICM DATE: 06-11-99

Samples & tests	Depth (m)	FACE A: 1.50 m	FACE B: 1.70 m	FACE C: 1.70 m	FACE D: 1.50 m	Legend	Grade	Description
U76	1	J1, J3, J2, J3, J4, J5, J6	J3, J8, J9, J3, J7, J5	J10, J10, J10, J3, J3, J3, J5	J11, J11, J12, J11, J4, J10, J12, J4			Loose, moist, dark brown, slightly clayey coarse SAND. (FILL)
	2							Medium dense, moist, yellowish-brown spotted with some white and pink, silty and clayey coarse SAND. (FILL)
								Loose, moist, dark brown, clayey and gravelly coarse SAND. (FILL)
								Soft, moist, dark greyish-brown, very sandy, gravelly CLAY. (FILL) Tree roots on Face B. Steel rod found at a depth of approx. 1.1 m on Face B.
	3						IV	Weak, moist, brown mottled with white and pink and spotted with some black, highly decomposed GRANITE. (Very dense, slightly silty gravelly fine to coarse SAND)
								(Refer sheet 2 of 2 for joint description)
								Trial pit complete at 2.85 m depth

SYMBOL	SAMPLES/TESTS/WATER	PLAN (NOT TO SCALE)	REMARKS
•	SMALL DISTURBED SAMPLE	Rockfill; A, B, C, D	Pit sides stable. No water encountered.
↕	BULK DISTURBED SAMPLE	KEY	
▬	UNDISTURBED SAMPLE HORI. (U100/U76)		
▯	UNDISTURBED SAMPLE VERT. (U100/U76)	N	
☒	BLOCK SAMPLE		
⊔	IN-SITU DENSITY TEST	NORTH ARROW	
△	WATER SAMPLE		
∿	SEEPAGE		

Fugro Maunsall Scott Wilson Joint Venture Agreement No. CE 101/98 1999 Landslide Investigation Consultancy Detailed Study No. 1 Slope No. 7NE-C/C23, The Chinese University of Hong Kong	TRIAL PIT RECORD	Sheet 2 of 2
	TRIAL PIT No. 2	EXCAVATION DATE: from 30-09-99 BACKFILL DATE: 09-10-99
	CO-ORDINATES 839257.928 E 831000.152 N GROUND LEVEL 76.549 mPD	LOGGED BY: JLKS DATE: 06-10-99 CHECKED BY: ICM DATE: 06-11-99

Samples & tests	Depth (m)	FACE A: 1.50 m	FACE B: 1.70 m	FACE C: 1.70 m	FACE D: 1.50 m	Legend	Grade	Description
	1 2 3							Joint Orientations J1 Sub-vertical, approx. 10 mm aperture, quartz infill manganese stained J2 032°/58° J3 56° to 63°/128° to 133° 124°/70° 130° to 135°/64° J4 110°/85° 126°/85° J5 Sub-horizontal, approx. 10 mm aperture, manganese and iron stained, quartz infill) J6 Sub-horizontal, approx. 10 mm to 20 mm aperture, manganese stained, quartz infill) J7 120°/85° J8 210°/65° J9 296°/85° J10 217°-225°/70°-85° 296°/85° J11 052°/68°-70° J12 170° to 190°/48° to 60°

SYMBOL	SAMPLES/TESTS/WATER	PLAN (NOT TO SCALE)	REMARKS
•	SMALL DISTURBED SAMPLE		Pit sides stable. No water encountered.
↕	BULK DISTURBED SAMPLE		
▬	UNDISTURBED SAMPLE HORI. (U100/U76)		
▯	UNDISTURBED SAMPLE VERT. (U100/U76)		
⊠	BLOCK SAMPLE		
⌐⌐	IN-SITU DENSITY TEST		
▵	WATER SAMPLE		
∿	SEEPAGE		

Fugro Maunsall Scott Wilson Joint Venture
Agreement No. CE 101/98
1999 Landslide Investigation Consultancy
Detailed Study No. 1
Slope No. 7NE-C/C23, The Chinese University of Hong Kong

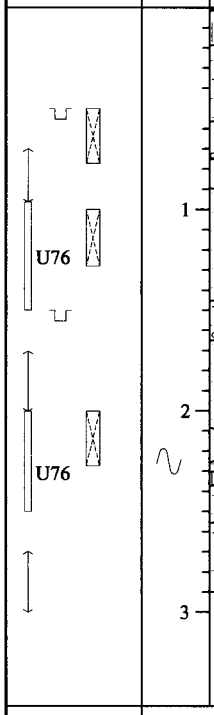
TRIAL PIT RECORD

TRIAL PIT No. 3

CO-ORDINATES 839265.113 E 830994.925 N
GROUND LEVEL 74.517 mPD

Sheet 1 of 1

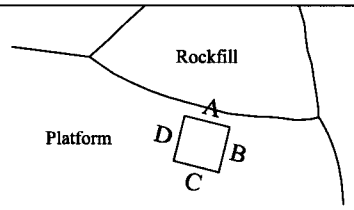
EXCAVATION DATE: from 27-09-99
BACKFILL DATE: 08-10-99
LOGGED BY: JLKS DATE: 07-10-99
CHECKED BY: ICM DATE: 06-11-99



Samples & tests	Depth (m)	FACE A: 1.50 m	FACE B: 1.50 m	FACE C: 1.50 m	FACE D: 1.50 m	Legend	Grade	Description
								Loose, moist, dark grey/black, slightly clayey, sandy SILT with many tree roots and occassional clay bricks (FILL)
								Medium dense, moist, yellowish-brown mottled with some orangish-brown, pink and white, clayey, silty and gravelly SAND. (FILL) Sub-rounded cobble in Face B
								Loose, Moist, dark greyish-brown, very clayey, gravelly fine to coarse SAND with many tree roots and occasional refuse. (FILL)
	1							Medium dense, light greyish-brown mottled with white, black and some reddish-brown, silty gravelly SAND (FILL)
								Loose, moist, brown, silty fine to coarse SAND (FILL)
								Loose, moist to wet, dark brown, clayey, gravelly coarse SAND with many tree roots and some completely decomposed granite cobbles. (FILL)
								Loose, wet, yellowish-brown, slightly clayey fine to coarse SAND with many tree roots. (FILL)
	2							Soft, wet, brownish and greenish-grey, very sandy CLAY with many tree roots. (FILL) Odour of decaying organics.
								Soft, wet orangish-brown, slightly sandy CLAY.
U76							V	Extremely weak, moist, reddish-brown mottled and streaked with white and yellowish-brown completely decomposed RHYOLITE. (Stiff, moist, reddish-brown clayey SILT)
							IV	Weak, moist, yellowish-brown mottled with pink and white, highly decomposed fine to medium GRANITE. (Very dense, moist, clayey coarse SAND)
	3							Trial pit complete at 2.9 m depth.

SYMBOL	SAMPLES/TESTS/WATER
•	SMALL DISTURBED SAMPLE
↕	BULK DISTURBED SAMPLE
▬	UNDISTURBED SAMPLE HORI. (U100/U76)
▯	UNDISTURBED SAMPLE VERT. (U100/U76)
⊠	BLOCK SAMPLE
⊔	IN-SITU DENSITY TEST
△	WATER SAMPLE
∿	SEEPAGE

PLAN (NOT TO SCALE)



KEY

NORTH ARROW

REMARKS

Water seeping from horizontal layers at 2.1~2.4 m depth

Fugro Maunsall Scott Wilson Joint Venture
Agreement No. CE 101/98
1999 Landslide Investigation Consultancy
Detailed Study No. 1
Slope No. 7NE-C/C23, The Chinese Univerity of Hong Kong

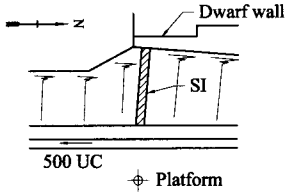
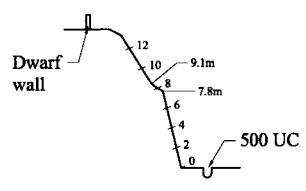
SURFACE STRIP RECORD

STRIP No. S1

Sheet 1 of 1

Date Start : 04-10-99 Date Completed : 04-10-99 Date Reinstated : 22-11-99	Datum (toe) CO-ORDINATES : E 839257.150 N 830976.230 LEVEL 74.875 mPD	Datum (crest) CO-ORDINATES : E 839248.500 N 830977.125 LEVEL 84.954 mPD
LOGGED BY: JLKS CHECKED BY: ICM		

Distance from Datum (m)	Slope Angle	Reduced Level (mPD)	Discription and Sample Data	Legend	Discontinuites: Dip Direction / Dip	Discontinuites: Nature of infilling	Grade
13			Top of stripping				
12			Weak to medium strong, light brown, highly to moderately decomposed GRANITE.				IV/III
10	≈45°		Medium strong, brown mottled with grey and white, moderately decomposed GRANITE with closely spaced joints.		040°~050° /54°~65° 161°~172° /41°~55°		III
9.1							
	≈40°		Weak to medium strong, light brown mottled with pink, highly to moderately decomposed GRANITE.				IV/III
8							
7.8							
6			Medium strong, brown mottled with grey, black and white, moderately decomposed GRANITE with closely spaced joints.		J1: 030°~055° /50°~60° J2: 245°~285° /35°~42° J3: 114°~145° /40°~69° J4: 004°~68°(ave.) J5: 013°~85°(ave.)		III
4	≈60°						
3.4							
2			Weak, light brown mottled with yellowish-brown, pink and white, highly decomposed GRANITE (Dense, gravelly SAND).				IV
			Bottom of stripping				
0							

SYMBOL	SAMPLES/TESTS/WATER	PLAN (NOT TO SCALE)	SECTION (NOT TO SCALE)
•	SMALL DISTURBED SAMPLE		
✦	LARGE DISTURBED SAMPLE		
▨	BLOCK SAMPLE		
⌐⌐	IN-SITU DENSITY TEST		
m	MOISTURE CONTENT TEST		
△	WATER SAMPLE		
⊥	SEEPAGE		
⊏⊐	PHOTOGRAPH		