STUDY OF DISTRESS ON SLOPE NO. 11SW-D/FR1 BELOW STUBBS ROAD HAPPY VALLEY

GEO REPORT No. 204

Fugro Scott Wilson Joint Venture

GEOTECHNICAL ENGINEERING OFFICE

CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT

THE GOVERNMENT OF THE HONG KONG SPECIAL ADMINISTRATIVE REGION

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

PREFACE

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

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

R.K.S. Chan
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February 2007

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

FOREWORD

This report presents the findings of a study of the distress observed on slope No. 11SW-D/FR1, which is located above the Hong Kong Sanatorium and Hospital (HKSH) at Happy Valley. The distress comprised cracked drainage channels and cracked and displaced shotcrete cover.

The key objectives of the study were to document the site development history and field observations, and to establish the probable causes of the distress. The scope of the review comprised detailed mapping of the distress, CCTV survey of buried services, ground investigation and laboratory testing, desk study and engineering analyses. Recommendations for follow-up actions are reported separately.

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

Y C Koo
Project Director
Fugro Scott Wilson Joint Venture

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

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

CONTENTS

Table of Contents
Table of Contents
Table of Contents

Page No.

1. INTRODUCTION

In March 2004, the Highways Department (HyD) reported the observation of distress on slope No. 11SW-D/FR1, which is located above the Hong Kong Sanatorium and Hospital (HKSH) at Happy Valley, to the Geotechnical Engineering Office (GEO) of the Civil Engineering Department (re-named Civil Engineering and Development Department (CEDD) in July 2004). Signs of distress included cracked drainage channels, together with extensive cracked and displaced shotcrete surface cover on selected batters.

Following the report of the distress, Fugro Scott Wilson Joint Venture (FSW), the 2004 and 2005 Landslide Investigation Consultants, carried out a detailed study of slope No. 11SW-D/FR1 for the GEO under Agreement No. CE 29/2003 (GE).

The key objectives of the study were to document the site development history and field observations, and to establish the probable causes of the distress.

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

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

(b) detailed interpretation of aerial photographs relating to the site,

(c) detailed field observations and measurements,

(d) ground investigation and laboratory testing,

(e) CCTV survey of buried water-carrying services,

(f) geophysical survey, including ground penetrating radar and saline tracing tests,

(g) chemical analysis of surface water and groundwater samples,

(h) engineering analyses, and

(i) diagnosis of the probable mechanisms and causes of the distress.

Recommendations for follow-up actions are reported separately.

2. THE SITE

2.1 Site Description

Slope No. 11SW-D/FR1 is a fill slope with a toe retaining wall situated above the Hong Kong Sanatorium and Hospital (HKSH) at Happy Valley (Figure 1 and Plate 1). The

Table of Contents

Table of Contents

Table of Contents

Table of Contents

slope has a total height of about 65 m and comprises a combined masonry and mass concrete gravity retaining wall about 18 m long and 7 m high situated along the western edge of the sanatorium complex (Plate 2) at about 21 mPD, and a 60 m high fill slope extending above the wall to Stubbs Road at about 85 mPD (Plate 3).

The fill slope portion comprises eight batters inclined at around 32º separated by 1 m to 2 m wide berms incorporating surface drainage channels. The slope occupies the ground between two spur features trending NE-SW and has a maximum width of about 85 m at the crest which tapers to about 30 m at the toe. The upper four batters have a vegetated cover comprising generally small to medium-sized trees, with the exception of the upper portion of the uppermost batter, which is shotcreted. The lower four batters have a shotcrete cover, the lowest incorporating weepholes at about 1 m centres. Much unplanned vegetation is present on the shotcrete cover of the third and fourth batters above the slope toe (Plate 1).

The area above Stubbs Road opposite the subject fill slope has been extensively developed and is occupied by residential complexes within Tung Shan Terrace (Plate 4).

2.2 Water-carrying Services

The locations of buried water-carrying services in the vicinity of the crest of slope No. 11SW-D/FR1 are shown in Figure 2.

According to the Water Supplies Department (WSD), there are no pressurised water mains within the Stubbs Road corridor in the vicinity of the subject fill slope. The nearest pressurised water-carrying services, comprising freshwater and saltwater supply mains serving the residential developments at Tung Shan Terrace are located about 70 m to the west of slope No. 11SW-D/FR1.

Records of the Drainage Services Department (DSD) indicate that the drainage system in the vicinity of the subject fill slope comprises a 150 mm to 225 mm diameter vitreous clay sewer, which follows the Stubbs Road alignment above the slope crest, together with stormwater drains from Nos. 28 - 30 Stubbs Road and No. 23 Tung Shan Terrace. Stormwater drains from Nos. 28 - 30 Stubbs Road discharge into a manhole located on the western side of Stubbs Road, which connects to the surface drainage system of the subject fill slope via a cross-road drain discharging into a catchpit at the slope crest.

Records kept by HyD indicate that a gully drain located on the eastern side of Stubbs Road towards the northern end of the subject fill slope also connects to the surface drainage system via the above catchpit.

Records of the Buildings Department (BD) indicate that the privately maintained stormwater and foulwater drains for Nos. 28 - 30 Stubbs Road and No. 23 Tung Shan Terrace connect into the public system described above at manholes located at the junction of Tung Shan Terrace and Stubbs Road (Figure 2).

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

2.3 Maintenance Responsibility

According to the Slope Maintenance Responsibility Information System of the Lands Department, the maintenance responsibility of slope No. 11SW-D/FR1 is divided between the owners of lot No. IL 1702 (i.e. HKSH), who are responsible for the toe retaining wall and a narrow strip of the slope above the wall crest within the lot boundary (Figure 3), whereas HyD is responsible for the rest of the fill slope.

3. SITE HISTORY AND PREVIOUS INSTABILITIES

3.1 Site History

3.1.1 General

The site development history, summarised in Figures 4 to 6 and Appendix A, has been traced from the aerial photographs and from a review of other available documentary information.

3.1.2 Pre-1977 Events

A review of the single aerial photograph which was taken in 1924 and of low resolution (Plate 5) revealed that the area presently occupied by the subject slope comprised a bowl-shaped valley with a NE-SW trending axis between Stubbs Road and the HKSH complex. At that time, the ground within the valley appears to have been disturbed, particularly on the northern side, with drainage lines that extend above Stubbs Road into the Tung Shan Terrace area, which was then under development (Figure 4). The HKSH (Figure 5) was established in 1921 on developed ground that was previously occupied by an amusement park (Binnie & Partners (B&P), 1978a).

B&P also reported that a masonry wall situated at about mid-height of the valley above the HKSH was formed in the late 1920's and that end-tipping of fill above the wall was underway in the 1930's B&P (1978b). The above is confirmed by the 1945 aerial photographs (Plate 6) and the 1959 topographic maps (Figure 5). The 1945 aerial photographs show a large fill body in the valley, with signs of major erosion, above the masonry wall. The 1959 topographic map indicates that the lower reaches of the original drainage lines in the valley were still in use as drainage channels.

The 1963 aerial photographs and the contemporary topographic maps show the fill body above the masonry wall to have been modified to five batters and an additional small retaining wall was constructed between the third and fourth batters below Stubbs Road. B&P (1978b) indicates that this work was carried out in the late 1950's. No major changes are apparent within the valley from this time until commencement of slope upgrading works in 1977 (Plate 7). A cross-section through the valley showing the inferred ground profile prior to the upgrading works is presented in Figure 7.

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

3.1.3 Slope Works in 1977-1979

Slope No. 11SW-D/FR1 was upgraded under Public Works Department (PWD) contract No. 688/77 between 1977 and 1979. The design and construction supervision of the landslip preventive works were carried out by B&P. A contemporary account of the slope works is presented in Bowler & Phillipson (1982).

The works comprised removal of the top 3 m of ground over the upper portion and compaction of fill (involving the use of imported fill and re-use of existing fill) and placement of compacted fill over the lower portion of the valley to form a total of eight batters (about 32° steep) separated by berms. To achieve the required profile, the existing masonry wall situated near the toe of the valley just behind the HKSH complex was increased in height by about 2 m with the addition of a concrete section dowelled into the back of the masonry wall.

A cross-section through slope No. 11SW-D/FR1 is presented in Figure 8. Over the lower slope portion, the overall thickness of compacted fill was around 6 m to 7 m maximum. Over the upper slope portion, the compacted fill was 3 m thick, leaving the existing fill (about 10 m thickness) in place beneath. The slope surfacing comprised 40 mm thick shotcrete (with mesh reinforcement only along the toe of each batter) over the lower four batters and a vegetation cover over the upper four batters. Drainage blankets were provided along the base of the compacted fill for each batter.

A photograph taken in 1978 (Plate 8) indicates that a temporary drainage diversion was in place during the slope works to direct the surface water flow/discharge from the uphill area around the perimeter of the works to the south.

3.1.4 Post-1979 Events

The profile of the subject slope has not been further modified since the completion of the works in 1979. Various extensions to the HKSH complex have taken place during this time, including excavation of about 7 m depth supported by an anchored caisson wall at a distance of around 25 m from the slope toe associated with the provision of carparks beneath a new wing constructed between 1989 and 1992 (Figures 6 and 8). The various works did not involve any changes to the toe retaining wall of the slope. Similarly, Stubbs Road has undergone some widening works in 1991 to accommodate the bus stop above the southern end of the feature, but otherwise has remained substantially unchanged.

Cracking of the shotcrete on the fourth batter above the slope toe can be seen in close view from record photographs in a report by McFarlane (1980), which were taken in connection with the monitoring of tensiometers by the Geotechnical Control Office (GCO, renamed GEO in 1991), see Plate 9. A laterally extensive crack present in the shotcrete surfacing of the fourth batter above the slope toe is also seen in the 1981 aerial photographs. The 1982 and 1983 aerial photographs show that the crack on the fourth batter had become more prominent, with the development of additional cracking and discernible bulging of the shotcrete cover (Plate 10). Cracking was also observed on the third batter above the slope toe during the same period.

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

Since 1983, unplanned vegetation including grass and trees established in the cracks and became progressively heavier with time to eventually cover most of the third and fourth batters. Unplanned vegetation, mostly comprising grass, also established on the lower two batters of the slope and became heavier with time, until clearance was carried out in 1995/1996.

Possible signs of seepage issuing from near the crest of the fourth batter above the slope toe at the northern end of the feature were observed in the 1983, 1986, 1987 and 1988 aerial photographs. Evidence of repair works to the shotcrete cover at the crest of the third batter is shown in the 1997 aerial photographs and at the uppermost batter in the 2000 aerial photographs, where the shotcrete appears to be fresh by comparison with the surrounding areas.

3.1.5 Tung Shan Terrace

The development of the Tung Shan Terrace area across a ridge at the head of the valley presently occupied by the subject fill slope was underway in the 1924 aerial photograph and it could be seen in a photograph taken in 1934 (Plate 11). Various re-developments of the individual lots have been carried out since, with the majority implemented from the early 1980's onward. Aerial photographs indicate the presence of lots under redevelopment at the time cracks were observed on the third and fourth batters of the subject slope, as highlighted on Figure 4.

Topographic maps dating from 1959 suggest that stormwater drainage from the properties on the eastern side of the Tung Shan Terrace area may have been directed beneath Stubbs Road via a cross-road drain and connected to a surface drainage channel along the southern margin of the fill body that extended from a catchpit just below Stubbs Road to the masonry wall about mid-way up the valley, below which further surface drainage provisions are present.

3.2 Previous Slope Instability

Extracts from the HKSH annual reports indicate that the valley presently occupied by the subject slope was affected by significant landslides in June 1925, the spring of 1927, April 1959 and June 1960.

The operation of the hospital was reportedly suspended for sixteen months following the "unprecedented" June 1925 landslide, but it was not affected by the 1927 landslide.

The April 1959 landslide was reported to have occurred when "the uncompleted slope and retaining wall at Stubbs Road, overlooking the Hospital, caved in and caused a major landslide of earth, stones and debris". The debris reportedly blocked the hillside culverts and the hospital's drains, resulting in the flooding of the "Li Shu-Fan Block" up to the second level, and took "40 workmen sent by the Public Works Department" working a 24-hour shift, six days to clear the debris.

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

The June 1960 landslide occurred during the passage of Typhoon Mary and was reported to have involved a further failure of uncompleted slope works below Stubbs Road, and to have produced similar havoc, causing flooding of the Central and "Li Shu-Fan" Blocks up to the second level.

According to the GEO's landslide database, no landslide incidents affecting the subject slope were reported to the GEO since the completion of upgrading works in 1979.

4. PAST SLOPE ASSESSMENT AND UPGRADING WORKS

4.1 Study by Binnie & Partners in 1977

B&P, engaged by the Hong Kong Government under the "Preliminary Studies for the Special Investigation into Fill Slopes", issued a letter report in May 1977 expressing concern about the stability of the subject slope (registered as 11SW-D/FR1 in the 1977/78 Catalogue of Slopes) behind the Central Block of HKSH (Plate 12).

At that time, the slope was described as comprising a combination of sloping ground and retaining walls rising above HKSH to Stubbs Road, commencing with a 4 m high masonry retaining wall located behind the Central Block building. Above this lowermost wall, the "first slope" was described as rising at 33º over 6 m height to a second masonry wall located at 32 mPD. A "second slope" was described as rising above the "second wall" at 20º over 22 m height to a "third masonry wall" about 3 m high at 56 mPD. A "third slope" was described as rising above the wall at 27º over 7 m height to a "fourth wall" of concrete construction and 2.5 m high at 66 mPD. The "fourth slope" was described as rising above the wall at 29º over a height of 17 m to Stubbs Road.

Decomposed granite fill was exposed in trial pits excavated under the supervision of B&P in the first and second slopes, which had an insitu dry density in the range of 1.51 Mg/m^3 to 1.54 Mg/m^3. Trial pits excavated in the third and fourth slopes also exposed decomposed granite fill, which had an insitu dry density in the range of 1.28 Mg/m^3 to 1.44 Mg/m^3 and 1.53 Mg/m^3 to 1.83 Mg/m^3 respectively.

Based on the available records, the first and second slopes were estimated by B&P to be at least 36 years old, but probably older, and were being used at the time as "gardens". Terraces had been cut into the slope faces, and these were well kept and had a good grass cover. Lined channels removing "some of the surface run-off" were noted and water tanks "sunk in the slope" and lined with mortar or concrete were reported by B&P. The third slope had one berm and supported a dense cover of shrubs and small trees. Chunam surfacing had been observed on the slope face, but was old and badly cracked. The fourth slope had two paved berms and supported a dense cover of shrubs and trees. Old and cracked chunam surfacing was also observed on this slope face.

The report noted evidence of "mass movement" with the presence of leaning trees and postulated that the movement was "comparatively recent (say up to 4 years)", based on the observation "that the trunks of the younger trees were not curved". The surface drainage channels also indicated signs of movement, particularly near a rock outcrop on the northwestern side of the slope. Cracking and settlement of the concrete pavement adjacent to Stubbs Road at the slope crest were also noted. The masonry wall at the slope toe and the

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

second masonry wall were reported to be in good repair with no signs of movement, whereas the third and fourth walls were cracked in places.

In view of the concerns about the stability condition of the slope, B&P recommended a detailed investigation of the slope.

4.2 Phase IIC Landslide Study

In March 1978, B&P completed a study report on the stability of slopes in the Happy Valley and Tung Shan Terrace areas under the "Landslide Study Phase IIC" (B&P, 1978a). The report noted that the slopes above the HKSH were the subject of a detailed study, as a result of which preventive works were initiated under the Public Works Department (PWD) Contract No. 688 of 1977.

The above report presented details of the development history of the HKSH and incidents of previous slope instability recorded in the valley occupied by slope No. 11SW- D/FR1 based on the hospital's annual reports (see Section 3.2). The report also noted that the slopes above HKSH at that time were served by a system of surface channels into which a 300 mm diameter storm drain from 28 Tung Shan Terrace discharged, and that two 450 mm channels carried the flow from that system down the north side of the valley, before converging behind the HKSH and discharging into a culvert.

4.3 Special Investigation into Fill Slopes (Phase II Landslide Study)

In September 1978, B&P completed a study report on the subject slope as part of the "Landslide Study Phase II Special Investigation into Fill Slopes" (B&P, 1978b).

The study included a site-specific ground investigation comprising drillholes and trial pits (Figure 9). Piezometers were installed in seven of the drillholes. However, groundwater monitoring was mostly limited to readings taken during October 1977, as the piezometers were reportedly destroyed during the slope reconstruction works.

Two sections were cut through the study area for the purpose of analysing the slope stability, one along the main valley axis, and the second over the upper portion of the valley to the south of the main axis. The locations of these sections are shown on Figure 4. The geological model adopted comprised decomposed granite fill overlying an insitu weathering profile of generally highly decomposed granite and fresh to slightly decomposed granite at depth. The geological profiles indicate up to about 12 m of fill overlying the original ground surface above the masonry wall mid-way up the valley, and between 3 m to 6 m of fill below. The insitu weathering profile of decomposed granite was generally deep, with bedrock encountered at between 35 m and 45 m below the original ground surface along the valley axis. However, the bedrock on the southern flank of the valley near the slope crest is shallower, at about 10 m below the original ground surface.

Based on the results of triaxial tests, the design shear strength parameters were $c' = 0$ kPa and $\phi' = 36^\circ$ for fill and $c' = 0$ kPa and $\phi' = 39.8^\circ$ for the highly decomposed granite.

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

Results of 26 insitu density tests indicated a range of insitu dry density of 1.28 Mg/m^3 to 1.83 Mg/m^3 with an average of 1.52 Mg/m^3.

Piezometer monitoring data indicated a base groundwater table generally about 50 m below ground surface at the slope crest and about 10 m below ground surface at the slope toe.

Based on stability assessments, the report concluded that the slope was sub-standard and upgrading works were required. The recommended works comprised regrading the slope to a gradient of 1V:1.6H followed by recompaction of the upper 3 m of fill above 48 mPD, and excavation to the original ground surface below 48 mPD followed by backfilling with compacted fill. Filter layers were to be incorporated between the recompacted fill and the insitu soil, and the slope face was to be protected with sprayed concrete with the provision of surface drainage. Stabilisation of the toe retaining wall with mass concrete was also recommended.

The report noted the significance of the assumed shear strength parameters of the "fill/instu interface" in the results of the stability analysis and indicated that additional investigation was necessary to confirm the assumptions about the "interface material". In December 1978, B&P informed the Civil Engineering Office that samples taken from trial pits at the interface between the fill and the residual soil did not indicate the existence of weaker materials than assumed in the design report and that, consequently, modification of the design was not required. Details of this investigation and the trial pit logs could not be located by FSW.

4.4 Slope Upgrading Works under the LPM Programme

The slope upgrading works were carried out between 1977 and 1979 under PWD Contract No. 688/77, which was one of several contracts let by the Government to upgrade substandard fill slopes. The file records on the works could not be located in CEDD, except for the as-built drawing. However, Bowler & Phillipson (1982) provided an outline description of the upgrading works actually carried out on this site.

The typical specification for the reconstruction of fill slopes is described by Bowler & Phillipson (op cit) as involving the provision of at least 3 m thick soil fill compacted to a minimum 95% relative compaction according to Test 12 of British Standard 1377 and the provision of granular filters where groundwater control was required. Suitable material for use in the compacted fill comprised decomposed granite and decomposed volcanics with 20% to 40% passing the No. 200 (75μm) sieve and a coefficient of uniformity of more than 50.

The supervision arrangements involved daily visits by professional staff to augment the full time supervision at Inspector of Works/Works Supervisor level.

Bowler & Phillipson (op cit) noted the following: "Originally it was planned to use rockfill at the toe. However, a quicker solution was found by replacing the rockfill with compacted soil fill but at the expense of raising the height of the toe wall". It was also noted that the contractor had initially planned to re-use the existing fill but more unsuitable material than expected had to be removed from site.

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

The fill was placed in layers of about 450 mm uncompacted thickness. The area of each layer was about 300 m^2 and two sand replacement insitu density tests were carried out for each layer at varying depths. Approximate insitu moisture content was determined on site to allow works to proceed with some confidence, while compliance was determined by laboratory testing. The fill was compacted using a 4.5 tonne towed vibratory roller, with small drum units and vibrating plate compactors used in confined areas.

Drainage blankets were provided at the base of the compacted fill layer. It is noteworthy that for the upper six batters, these comprised 'Filter A' material only. In the lower two batters, a sandwich-type 'Filter A/B/A' was provided. The toe retaining wall backfill comprised entirely 'Filter B' material. The grading ranges specified for Filter A and Filter B materials are shown in Figure 10. The filter material was reportedly compacted to method specification according to the government specification current at the time. Bowler & Phillipson (op cit) noted that the inclined drainage blankets were awkward to construct and that "Great care was required to ensure that the hydraulic continuity of the filter was not broken by fill mixing with the filter". Drainage pipes of 75 mm diameter at 1.5 m spacing within a reinforced shotcrete strip were provided along the toe of each batter where the drainage blankets daylight (Figure 11).

As noted by Bowler & Phillipson (op cit), changes were made to the original surface drainage system to divert the majority of collected runoff at the crest area down the northern side of the slope to the northeast corner of the feature and into the existing drainage system through a newly constructed sand trap (Figure 6).

Surface protection was originally to comprise 40 mm thick shotcrete (without weepholes) on all the batters. During the course of the works, this was amended to vegetated cover for the upper four batters, based on a general government decision to allow grass to be used as surface protection on slopes where compaction had been carried out (Bowler & Phillipson, op cit).

4.5 Suction Measurements

In April 1980, three clusters of tensiometers (one on the shotcreted third batter above the toe, one on the vegetated fifth batter and one on the ground to the south of the feature) were installed by the GCO for suction monitoring (McFarlane, 1980).

Monitoring was carried out by the GCO between April 1980 and October 1980. The matric suction data for the tensiometers installed within the vegetated fifth batter above the toe and the adjacent ground were initially of the order of 60 kPa to 80 kPa during April 1980. These fell to between 10 kPa and 20 kPa following rainstorms during the 1980 wet season, returning to higher values in the intervening periods.

It is noteworthy that the suction data for the cluster of tensiometers installed within the shotcreted third batter were consistently low during the monitoring period (i.e. 0 to 5 kPa) and positive water pressures were recorded occasionally during rainstorms.

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

4.6 Inspection of Upgraded Fill Slopes by B&P

In June 1984, B&P (1984) produced a report for the GCO detailing the results of slope inspections carried out on 122 fill slopes reconstructed prior to 1981 under the LPM Programme, which included slope No. 11SW-D/FR1. The inspections were carried out between May 1983 and January 1984.

The subject slope was reported to be in “Moderate” condition, with “very few defects which are of a minor nature, such as minor cracks or minor defects in joint sealants”.

4.7 SIFT and SIRST Studies

In March 1995, under the “Systematic Inspection of Features in the Territory” (SIFT) project initiated by the GEO, slope No. 11SW-D/FR1 was designated SIFT Class ‘B2’ (i.e. a slope “Assumed to have been checked by GEO (assumed formed post 1977)”).

In June 1997, under the “Systematic Identification and Registration of Slopes in the Territory” (SIRST) project initiated by GEO, slope No. 11SW-D/FR1 was inspected. The SIRST inspection record noted that the slope was in reasonable condition and that no seepage was observed. The consequence-to-life category of the subject slope was rated as ‘1’ and the corresponding CNPCS score was 59.86.

4.8 Slope Maintenance Inspections

In May 1995, Fugro Mouchel Rendell Joint Venture (FMR), the consultant to HyD under Agreement No. CE 29/94, carried out an inspection of slope No. 11SW-D/FR1. The inspection record noted cracked and damaged drainage channels and surface cover, observed that the cover had “lost contact with soil underneath in small area”. Minor cracking and seepage stains were also observed in the retaining wall at the slope toe, as well as the presence of broken tell-tales. FMR recommended routine maintenance works comprising clearance of drainage channels and weepholes, repair of damaged slope surface cover and removal of vegetation causing damage to the slope.

Routine Maintenance Inspections (RMI) were carried out by HyD in April and June 1995, November 1998, March 2000, March 2001, October 2001 and December 2002. Engineer Inspections (EI) were carried out by HyD’s consultant, Maunsell Geotechnical Services (MGS) in July 1999 and October 2003.

The inspection records for the 1995 inspections do not indicate observation of cracked or blocked drainage channels or cracked hard surface cover. Record photographs indicate heavy vegetation on the slope face. A CCTV survey of the 300 mm diameter stormwater drain discharging into the surface drainage system of the subject slope (Figure 2) was arranged subsequent to the inspection. However, no records relating to the findings of the CCTV survey could be located by FSW.

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

The records of the 1998 inspection (Plate 13) indicate similar observations to the 1995 inspections and noted that no follow-up action was necessary, except that cracking of the toe retaining wall was reported (Plate 14).

The March 2000 RMI by HyD identified blocked and cracked drainage channels and damaged hard surface cover. Routine maintenance works comprising repair and replacement of the damaged items, unblocking of weepholes and removal of surface debris and vegetation were recommended, as well as the re-alignment of surface drainage channels being affected by unplanned trees. The recommended works were completed in October 2000.

The March 2001 RMI by HyD indicated that no routine maintenance works were necessary. Record photographs show the repairs to existing cracks on the second batter above the toe. The October 2001 inspection records indicate similar findings.

The December 2002 RMI recommended the removal of surface debris and vegetation causing severe cracking of the slope surface cover and drainage channels. The recommended works were completed in July 2003.

In the EI report issued subsequent to the MGS inspection in July 1999, it was noted that the hard surface cover was in fair condition and that the outlets of the drainage pipes near the toe of the batters were clear, while U-channels and stepped channels were blocked and severely cracked in places. Moderate cracking and partial blockage were reported in some of the catchpits and sand traps. “Signs of recent movement in the form of cracks up to 50 mm width” were observed along berms and stepped channels (Plates 15 and 16). MGS recommended that the damaged channels be reinstated and cracks sealed. Also, stability assessment of the subject slope was recommended on the basis of signs of recent movement and major consequence in the event of failure.

The October 2003 EI report by MGS noted similar observations as the 1999 EI report and recent signs of erosion as well as “unknown pollutants” entering the surface drainage system at the discharge point for the stormwater drain at the slope crest. Recommended routine maintenance works comprised clearance of debris and undesirable vegetation, clearance of weepholes, clearance of drainage channels, repair of cracked/damaged surface channels and surface cover, and re-vegetation of bare slope surface. Similar recommendations were made by MGS following their RMI in November 2003. The recommended works were completed in January 2004.

MGS also recommended preventive maintenance works in October 2003 which comprised the installation of a single row of 12 m long prescriptive raking drains at 4 m centres along the lower batter and the installation of inclinometers to monitor slope movement. MGS recommended that a stability assessment of the subject slope be carried out and that the private owner of the lower portion of the feature be advised to engage a geotechnical consultant to undertake an EI in view of the observation of cracks in the toe retaining wall.

Following discussions with HyD held in December 2003, MGS revised the recommendation for installation of inclinometers to one for the installation of survey monitoring points. A revised EI report reflecting this change was issued in early February 2004.

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

Movement monitoring has subsequently been carried out by HyD using conventional topographic survey techniques since late December 2003. The data obtained between December 2003 and June 2004 indicate no measurable movement trend.

4.9 Investigation of Buried Water-carrying Services

4.9.1 Nos. 28 - 30 Stubbs Road

In September 1997, the BD served a Drainage Order (No. BSI 16/HK/97) to the owners of lot No. IL 2946 & Ext. at Nos. 28 - 30 Stubbs Road to investigate the buried water-carrying services within the private lot in the vicinity of the subject slope.

The private owners appointed K W Kwan of The Architectural Practice Ltd. as the Authorised Person (the AP) to conduct the investigation. Two "video surveys" were carried out, based on which remedial works to the entire drainage system were recommended. These comprised replacement of all drain pipes and manholes within the backyard area, as well as repairs to the drains along the vehicular access road, including a 300 mm stormwater drain and a 150 mm foul sewer. The works were completed in April 1999 and the Drainage Order was discharged in July 1999.

4.9.2 No. 23 Tung Shan Terrace

In September 1997, the BD served a Drainage Order (No. BSI 10/HK/97) to the owners of lot No. IL 2955 at No. 23 Tung Shan Terrace to investigate the buried water-carrying services within the private lot in the vicinity of the subject slope. The private owners appointed K T Ma of Associated Architects Ltd. as the AP to conduct the investigation.

CCTV surveys revealed displacement of joints in the majority of the inspected drains. The AP concluded that all pressurised pipeworks were satisfactory but that the stormwater drains and foul sewers required repair. The remedial works were completed in August 2003 and the Drainage Order was discharged in November 2003.

4.9.3 Stubbs Road

In July 2003, CCTV survey of the buried drains in the vicinity of the subject slope was carried out by HyD. This identified multiple fractures and cracks in the 225 mm vitreous clay stormwater drain connecting the road gullies to the catchpit at the slope crest. The drain was subsequently lined and re-surveyed in June 2004, which confirmed that the works had been completed satisfactorily.

In April 2004, the Drainage Services Department (DSD) advised FSW that the buried drains beneath Stubbs Road in the vicinity of the subject slope were found to be in "good working order" based on visual inspection. It was noted by DSD that no CCTV survey records were available for these buried drains.

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

4.9.4 Water Mains at Tung Shan Terrace

WSD records indicate that leakage detection was performed on the water mains within the Tung Shan Terrace area in early September 2003, which identified two "concealed pipe leaks" in the 80 mm diameter galvanized iron water main located at No.15 Tung Shan Terrace. The leaks were repaired by WSD on 16 September 2003. WSD advised FSW that leakage detection on individual water mains is normally carried out at five-year intervals and that no out-of-turn inspection has been carried out at Tung Shan Terrace since 2003.

5. DESCRIPTION OF THE DISTRESS

5.1 General

Following the report of the distress to the GEO in March 2004, the distress observed on the subject slope has been mapped in detail by FSW and the findings are summarised in Figure 12.

5.2 Distress Mapping

5.2.1 General

Mapping of the slope distress was carried out by FSW between April and June 2004. The upper four batters are mostly heavily vegetated and therefore the distress mapping in these areas was limited to berm slabs, aprons, drainage channels, catchpits, etc. Similarly, the third and fourth batters above the toe were heavily overgrown with unplanned vegetation and it was not possible to do a detailed mapping and observations are mostly confined to the vicinity of berms and stepped channels. The extensive network of repaired cracks on the first and second batters above the toe was mapped in detail.

The results of the detailed mapping are presented in Appendix B and the key observations are discussed below.

5.2.2 Major Cracks on Berms and Two Lowermost Batters

The locations of major cracks identified on the berms and the two lowermost batters are shown in Figure B1. The crack widths are generally of 10 mm or less but locally could be up to about 70 mm. A typical example of transverse cracking across a berm slab is presented in Plate 17. The major concentration of cracks appears to be located in the central portion of the slope, between the toe of the third batter above the toe and the bottom of the sixth batter. The directions of movement related to the crack formation appear to be random (although showing a general downslope trend), and not indicative of movement in a particular prominent direction.

Cracking of the shotcrete cover on the two lowermost batters is extensive and appears to be randomly oriented, giving rise to a 'crazed' pattern as shown on Figure B1 and Plate 1.

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

5.2.3 Displaced Shotcrete

The horizontal ‘overhang’ of the displaced shotcrete cover beyond the edge of the berm drainage channel (Plate 18) was measured at regular intervals along the toe of each of the batters (Figure B2). The results show that the maximum ‘overhang’ was of about 75 mm. The locations of the greatest ‘overhang’ appear to be generally concentrated on the northern portion of the slope, except for the fourth batter above the toe. The largest ‘overhang’ was observed at the third batter above the toe.

Minor seepage was observed from behind the displaced shotcrete at a number of locations following light rainfall on 8 May 2004 (Plate 19).

It was observed that the berm slab above the lowermost batter had apparently moved downwards relative to the shotcrete cover of the lowermost batter (Plate 20). As a result, a ‘lip’ with a maximum height of about 70 mm was created over a distance of some 5 m (Figure B3). A similar effect was also observed at the crest of the third batter in the southern portion of the slope.

5.2.4 Crushed Surface Drainage Channels

The condition of the berm channels was generally found to be fair and the observed distress is shown in Figure B1. The major distress was observed in certain sections of the stepped channels which displayed signs of cracking, crushing (e.g. displacement of walls of drainage channels, see Plate 21) and local deformation of the apron slab. The most severely affected locations of each of the above forms of distress were generally coincident and occurred at the stepped channel in the central portion of the slope between the third and fifth batters above the toe as well as the stepped channel along the northern boundary of the feature between the second and fourth batter above the toe. The observations are shown in Figures B4 to B15.

5.2.5 Blocked Drainage Provisions

A probing survey of the 75 mm diameter drainage pipes along the toe of each of the batters within the subsurface drainage blankets was carried out by FSW in April 2004 (Figure B16). The results show that about 43% (109 out of 256) of the drainage pipes are blocked. The locations of the blocked drainage pipes appear to comprise the fourth batter as well as the southern portion of the upper four batters (Plate 22).

5.2.6 Unplanned Vegetation

Unplanned vegetation was most prominent on the third and fourth batters above the toe where small to medium shrubs/trees were exploiting cracks in the shotcrete cover (Plate 23). In addition, two large trees (with trunk diameters of 800 mm to 1500 mm) had established within the surface drainage system and completely blocked the channels, necessitating diversion works which were carried out to allow the continued function of the drainage

Table of Contents

Table of Contents

Table of Contents

Table of Contents

system (Plate 24). The particular tree species (ficus) proliferating on these two batters involved extensive root growth which exacerbated the surface distress.

5.2.7 Toe Retaining Wall

The toe retaining wall of slope No. 11SW-D/FR1 was generally found to be in fair condition. The 100 mm diameter weepholes of the retaining wall, spaced at 1.5 m centres, were probed for blockage. Five out of 28 (18%) could not be probed as far as the rear face of the wall. Very little seepage was observed from the weepholes. However, sustained seepage was observed issuing from cracks close to the northern end of the wall (Plate 25), which suggests the presence of groundwater behind the wall.

The plastic filler in an expansion joint located about 23 m from the northern end of the wall at a change in the direction in the wall was observed to have been compressed and a tell-tale previously mounted across the joint has failed in shear (Plate 26).

Mapping of cracks in the exposed portion of the concrete section extension constructed as part of the slope upgrading works in 1977 - 1979 indicated generally horizontally oriented cracks with widths of about 1 mm, and locally up to 2 mm to 3 mm. A concentration of horizontally and vertically oriented cracking was observed at the southeastern end of the wall. It was not possible to assess the width of the repaired cracks (Plate 27). However, photographic records (Plate 14), which indicate that these cracks have been present since at least 1998, suggest that they are of similar widths as indicated above. Relatively fewer cracks were observed in the masonry portion of the wall where maximum crack widths were about 3 mm to 4 mm.

Based on the geometry of the mass concrete portion of the toe wall and the crack orientation, the observed cracking is possibly associated with factors related to the interaction of the wall-forming materials (e.g. alkali-aggregate reaction or corrosion of reinforcement), rather than the development of bending or shear stresses.

The inclination of the upper concrete portion of the wall face was measured and compared to that (i.e. 5° recline) shown in the as-built drawing. The measured inclination indicated a recline of between zero and 8° with an average of 5°.

5.3 Topographic Survey and Movement Monitoring

The Survey Division of CED carried out a detailed topographic survey of the subject slope in May 2004. Survey plans are presented in Appendix C.

This topographic survey has been compared with the as-constructed berm elevations shown on record drawings. The comparison indicates that little, if any, measurable vertical movement has taken place along the berms.

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

5.4 Photogrammetric Analysis

The Survey Division of CED carried out an assessment of the slope using digital photogrammetric techniques on aerial photographs to identify possible surface movements that might have occurred since completion of slope upgrading works. The results indicate that any movement of the slope face between 1980 and 2000 were within the resolution of the photogrammetric technique (viz. about 300 mm).

6. GROUND INVESTIGATION

6.1 Previous Ground Investigations

A number of previous ground investigations have been undertaken within or in close proximity to the subject slope (Figure 9). The available data of those ground investigations located within the feature boundary were obtained between 1976 and 1979 (i.e. prior to and/or during the slope upgrading works).

6.2 Current Ground Investigation

The ground investigation that formed part of the present study was carried out in two phases between May 2004 and September 2004. The investigation comprised the following:-

(a) nine drillholes advanced using rotary drilling methods to about 25 m depth and two drillholes advanced using portable sampler equipment to about 12 m depth,

(b) ten trial pits excavated to maximum depths of 3 m,

(c) 246 GCO probes across the slope face,

(d) three vegetation strips and four slope surface strips,

(e) Ground Penetrating Radar (GPR) survey along berms and on individual batters, and

(f) saline tracing tests.

The locations of the ground investigation stations are shown presented in Figures 9 and 13.

Insitu testing comprised Standard Penetration Testing (SPT) and constant head insitu permeability tests in drillholes, and insitu density and field infiltrometer tests in trial pits.

Instrumentation including 34 piezometers were installed, 22 within drillholes and 12 within trial pits. In addition, three clusters of four tensiometers were installed to monitor soil suction.

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

A CCTV survey of buried drains located at the slope crest and beneath Stubbs Road was carried out by Kofrey Engineering Co. Ltd during August 2004. The survey identified cracks and displacement in a 150 mm diameter vitreous clay foulwater sewer beneath Stubbs Road. The drains included in the survey and the locations of the observations made in respect of the sewer are shown on Figure 14. The results of the survey were passed to the DSD for follow-up action in August 2004 and repairs to the sewer were completed in September 2004.

7. SUBSURFACE CONDITIONS

7.1 General

The subsurface conditions at the site were assessed using information from desk studies, field mapping and ground investigation.

7.2 Geological and Hydrogeological Setting

According to the Hong Kong Geological Survey (HKGS) 1:20,000 scale geological map (GCO, 1986), the solid geology of the subject slope and its surrounding area comprises medium-grained granite (Figure 15). Photogeological lineaments (possibly faults) are shown in the area, about 200 m to 300 m to the east and west of the catchment and trending NE-SW and N-S respectively.

Information regarding the upper reaches of the original catchment to the subject slope extending above Stubbs Road is limited to the interpretation of the single 1924 aerial photograph (see Section 3.1.2). This area has been extensively modified by the development of Tung Shan Terrace shortly after the above date.

Below Stubbs Road, the valley where the subject slope is located is bowl-shaped with a thick regolith of up to 50 m in thickness. The sharp definition of the northwestern flank to the valley as compared to the southeastern flank may reflect a certain degree of structural control in the formation of the valley. From the old aerial photographs, two well-established drainage lines are present in the upper reaches, which converge at about the mid-height of the subject slope and continue as a single feature below this level. The presence of prominent drainage lines will tend to give rise to concentrated subsurface groundwater flow.

7.3 Ground Profile

The additional data provided by the current investigation are in general agreement with the as-constructed drawing for the subject slope. In the upper slope portion, the ground profile comprises generally 3 m to 3.5 m of compacted fill and basal drainage blanket overlying about 10 m of old fill and about 50 m of weathered granite. In the lower slope portion, the ground profile comprises 5 m to 8 m of compacted fill and basal drainage blanket overlying locally disturbed ground (1 m to 2 m) and about 40 m of weathered granite. A geological profile is shown in Figure 16.

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

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

(a) the presence of locally very loose fill (possibly small voids) within the old fill beneath the compacted fill based on observations during the formation of drillholes (BH1 and BH3),

(b) the compacted fill is locally about 1.8 m thick (compacted fill was found to be underlain by sizeable rock blocks in BH6 which is located behind the old masonry wall near the mid-height of the slope) as opposed to 3 m shown on the as-built drawing,

(c) the presence of more than 2 m of disturbed ground underlying compacted fill near the bottom of the slope (BH7),

(d) the presence of oversized rock blocks (Plate 28) and foreign material, such as a plastic shoe (Plate 29), within the compacted fill in some of the trial pits,

(e) the presence of layers of plastic sandy silty clay within the compacted fill layer (Plate 30),

(f) sub-horizontal layering of the compacted fill, some of which appear to comprise a more sandy material (potentially giving rise to a locally high horizontal permeability),

(g) sustained seepage from the drainage blanket and the compacted fill below the drainage blanket following excavation of trial pits in the lower slope portion (TP4, TP5 and TP6, see Plates 31 to 33), following rainfall during the current ground investigation, and

(h) the 'Filter A/B/A' arrangement as exposed in trial pit TP5 has no discernible layering of the different materials (Plate 34).

Standard Penetration Tests (SPT) conducted within drillhole BH3 indicated that the SPT 'N' values range from 10 to 50 for the compacted fill, 4 to 10 for the old fill and 10 to 40 for the completely decomposed granite.

GCO probes within the lower batters generally met refusal at about 3 m to 3.5 m depth within the compacted fill (which is about 5 m to 8 m thick in total). About 45% of the blow counts in this area were less than 10 blows/100 mm and 14% were less than 5 blows/100 mm.

GCO probes within the upper vegetated batters generally met refusal at about 1 m to 1.5 m depth within the compacted fill. Around 38% of the blow counts in this area were less than 10 blows/100 mm and 18% were less than 5 blows/100 mm. Overall, the results

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

indicate that the lower 3 batters have lower GCO probe blow counts than the upper batters (Figure 13).

The surface strips excavated on the third and fourth batters above the toe indicated that the cracking present in the shotcrete cover did not penetrate into the underlying ground (Plate 35). At the crest of the two batters, a gap of up to 80 mm was found between the base of the berm slab and the ground beneath (Plate 36). The original shotcrete cover has moved vertically downwards with the ground, as the edge of the shotcrete now lies vertically below the edge of the berm slab, and an additional layer of shotcrete was placed some time after the movement had occurred in order to fill up the gap created.

At the toe of the above two batters, the shotcrete cover has moved outwards from the slope face, leaving a gap of up to 100 mm between the underside of the shotcrete cover and the drainage blanket below (Plate 37).

7.4 Material Characteristics

The particle size distribution of the compacted fill indicates that this material generally comprises a gravelly sand with much silt and clay (i.e. a fines content of between 10% and 65% and a clay content of up to about 30%). The majority of the results (Figure 10) indicate that the fill is in compliance with the specification presented in Bowler & Phillipson (1982), with between 20% and 40% passing a No. 200 BS sieve (75 μm) and a coefficient of uniformity of greater than 50. Nine out of 48 results were outside specification with up to 69% by weight passing the 75 μm sieve.

The finer fraction of the compacted fill generally falls within the 'low' plasticity and 'intermediate' plasticity range in the plasticity chart, with a Plasticity Index of 11% to 25% and a Liquid Limit of 31% to 50% (Figure 17). However, two of the results fall within the 'very high' plasticity range, both with a Plasticity Index of 40% and Liquid Limits of 70% and 74% respectively.

Analysis of the mineralogy of four samples of compacted fill, two from the higher range of indicated plasticity and two from the lower range, was performed by the Australian National University using X-ray diffraction (XRD) and scanning electron microscopy (SEM) techniques. The interpreted mineralogy is presented in Table 1. The results suggest that the predominant group of clay minerals present in all of the samples is kaolin, with the possibility of an amorphous clay mineral, allophone, being present in the two samples that indicated low plasticity. The 'activity' of the fraction of compacted fill samples finer than 425 μm was found to lie within a range of 0.45 to 2.25 (average 0.77). These results suggest that certain proportions of the compacted fill may be locally susceptible to movements due to changes in water content because of its high 'activity' value.

The particle size distribution of the 'Filter A' material indicates that this material generally comprises a very sandy gravel with a little silt (fines contents between about 10% and 20%). The results (Figure 10) indicate that the material is in general compliance with the specification presented in Bowler & Phillipson (1982), except for one result which has an excessive fines content. The results for the sample recovered from the 'Filter A/B/A' arrangement in trial pit TP5 indicated that the material is generally in compliance with the

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

specification for 'Filter A' material, but lies on the finer boundary of the 'Filter B' envelope, which suggests a relatively low proportion of 'Filter B' material within the sample.

The particle size distribution of the old fill (Figure 18) indicates that this material comprises a gravelly sand with some silt and clay. The finer fraction of this material generally exhibits a plasticity in the 'high' range (Plasticity Index of 13% to 36% and Liquid Limit of 49% to 68% respectively, see Figure 17).

The particle size distribution of the CDG (Figure 18) indicates a gravelly sand with much silt.

7.5 Relative Compaction

Insitu density tests of the compacted fill in trial pits using the sand replacement method indicated a range of insitu dry density (IDD) between 1.46 Mg/m^3 and 1.99 Mg/m^3 (average 1.74 Mg/m^3) from 51 results. Insitu moisture content was found to lie between 9.6% and 22% (average 15.6%).

Laboratory determination of the maximum dry density (MDD) of bulk samples recovered at each IDD location indicated a range of 1.52 Mg/m^3 to 1.92 Mg/m^3 (average 1.81 Mg/m^3) from 47 results. Optimum moisture content was found to lie between 11% and 26% (average 15%). In general, the MDD results tended to lie within the range of 1.72 Mg/m^3 to 1.92 Mg/m^3, with only four results showing a lower value.

The relative compaction values calculated for each IDD location range from 84% to 105% (average 96%). Relative compaction is generally in excess of 90% (43 out of 51 results greater than 90%). The vertical sequence of calculated relative compaction at each of the trial pit locations are presented in Figure 19.

7.6 Shear Strength

Single stage consolidated undrained triaxial compression tests with pore pressure measurement were undertaken on 41 samples recovered from the compacted fill, 20 samples from the underlying old fill material and 12 samples of the completely decomposed granite. The samples of fill materials were remoulded at a relative compaction that matches the insitu conditions as well as a range of relative compaction above and below the insitu value to investigate the behaviour of the material under shearing. In addition, tests were conducted on intact material obtained from Mazier samples. The samples of CDG were tested as intact material obtained from Mazier samples. The test results are presented in Appendix D.

The triaxial test results indicate that all the samples remoulded from the compacted fill layer contracted under shearing below a relative compaction of 90%, and generally became dilatant at relative compaction of 92%. Two of the samples remained contractive at relative compaction of 92% and 94%. The tests performed on undisturbed samples indicated shear strength parameters of $c' = 0$ kPa and $\phi' = 41°$ with a lower bound of $c' = 0$ kPa and $\phi' = 37°$. Test results for the remoulded samples corresponded to 'best fit' shear strength parameters of $c' = 0$ kPa and $\phi' = 36°$ with a lower bound of $c' = 0$ kPa and $\phi' = 34°$.

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

The triaxial tests on the undisturbed samples of the old fill generally indicated dilative behaviour above a relative compaction of 87% at confining stresses in the range of 50 kPa to 110 kPa, a number of samples at relative compaction between 87% and 94% initially contracted, before becoming dilatant at higher strains. Only one sample, which was at 82% relative compaction, displayed purely contractive behaviour. The test results indicated shear strength parameters of c' = 0 kPa and ϕ' = 38° with a lower bound of c' = 0 kPa and ϕ' = 35º.

The results of the triaxial testing on the undisturbed samples of CDG indicated shear strength parameters of c' = 5 kPa and ϕ' = 38º with a lower bound of c' = 1 kPa and ϕ' = 35º.

7.7 Permeability

Field permeability testing comprising constant head borehole permeability tests was performed within each of the four major soil strata encountered in the drillholes. Additionally, double-ring infiltrometer tests were performed on the compacted fill and drainage/filter layers within trial pits. The calculated range of permeabilities for the different materials as derived from the different methods are presented in Table 2 and Figure 20. These show that the compacted fill has a variable permeability value ranging from 4x10^{-6} m/s to 3x10^{-8} m/s and that the old fill is more permeable with a permeability value ranging from 4x10^{-5} m/s to 4x10^{-7} m/s. Notably, the permeability of the 'Filter A' material, which can have a high fines content as discussed earlier is generally high, but can be locally as low as 1x10^{-6} m/s, which lies within the range of results for the compacted fill and the old fill.

Laboratory permeability testing was carried out on undisturbed specimens cut vertically and horizontally from two block samples taken in the compacted fill to assess the vertical and horizontal permeability under different confining pressures. The results (Table 2 and Figure 20) generally indicate lower permeability values than the field tests, with results in the range of 4x10^{-7} m/s to 6x10^{-10} m/s. The effect of increasing confining stress was variable, the permeability of one sample increasing with increased confining stress, the other decreasing. Additionally, one of the horizontally cut samples indicated a higher permeability as compared with the vertically cut sample under a confining stress of 20 kPa; however, tests at increased confining stresses of 30 kPa and 50 kPa produced similar results between the horizontally cut sample and the vertically cut sample.

A saline tracing test was conducted in October 2004. The test involved the injection of a saline solution into the piezometer at TP3 located on the fourth batter from the toe. The test was conducted over a period of eight hours, with monitoring of the downstream piezometers carried out at ten-minute intervals to identify any increase in salinity. Baseline readings were taken prior to commencement of injection.

The test results are shown in Figure 21. These indicate a rapid, though moderate, response at the upper piezometer in PT2 within the drainage blanket on the second lowermost batter (Figure 16), whereas the remaining monitoring stations showed little response. Further monitoring of the downstream piezometers was performed five days following the commencement of the saline tracing test. This indicated a further increase in the salinity of the groundwater at the upper piezometer in PT2. Results from the remaining piezometers indicated no change in salinity. Hydraulic connection is therefore indicated between the

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

injection point at TP3, located within the compacted fill, and the drainage blanket of the second lowermost batter. This probably reflects the presence of sandy lenses in the compacted fill.

7.8 Groundwater

Instrumentation for groundwater monitoring at the site comprises eight piezometers installed during previous ground investigations and generally located at depth within the insitu ground and at the base of the old fill layer. These have been supplemented during the current investigation in 2004 by an additional 34 piezometers, eleven of which are located at depth within the CDG, seven located at the CDG/fill interface, and sixteen within the compacted fill and drainage/filter blanket. Seventeen of the piezometers have been fitted with automatic groundwater monitoring instruments and 42 with Halcrow buckets.

Groundwater monitoring data are presented in Appendix E. Key observations are as follows:-

(a) The base groundwater table is located within the granitic saprolite at a depth of around 10 m below the slope toe, which is consistent with historical monitoring records (see Section 4.3). The base groundwater table shows little storm response.

(b) Piezometers installed at the base of the old fill layer since September 2004 did not record any groundwater, with the exception of the upper piezometer at PT2 which has recorded water levels of almost 2.5 m below the ground surface since installation.

(c) Piezometers installed within the compacted fill in the lower batters indicate a piezometric head at between 1 m and 2 m below the ground surface. The two piezometers at TP2 and TP3, installed since May 2004, exhibited storm responses (e.g. a 0.5 m rise during an Amber Rainstorm Warning in early August 2004, with a time lag of 3 to 6 hours with respect to the peak hourly rainfall intensity (Figure 22). The response was characterised by a rapid rise, followed by a small drop and a very slow rate of dissipation.

Following the observation by FSW since April 2004 of intermittent flows of water from the stormwater discharge to the surface drainage system of slope No. 11SW-D/FR1 at the crest (which were not consistent with the weather conditions at the time) and the observation of foam in the discharged water (Plate 38), water samples were recovered and chemical tests were carried out to assist with identification of the source. Additional samples were obtained from an adjacent foulwater sewer for comparative purposes. Samples of groundwater identified from trial pits were similarly tested.

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

The results of the chemical tests are presented in Table 3. These indicate that the samples recovered from the stormwater discharge from Tung Shan Terrace have probably been contaminated to varying degrees by sewage. The water samples recovered from trial pits show results that are typical of groundwater.

It is noted that the groundwater monitoring period is of limited duration and that severe rainstorms did not take place during the monitoring. Further monitoring would be of use to assist in developing a better understanding of the groundwater response during severe rainstorms.

7.9 Tensiometer Monitoring

Three clusters of 'jet-fill' tensiometers were installed by FSW on the subject slope between June and September 2004 to monitor the matric suction in the near-surface material (Figure 9). Each cluster comprised four tensiometers installed in a square grid about 1 m from each other and to depths of between 0.4 m and 1.8 m. One cluster was installed on the vegetated fifth batter from the slope toe, while the other two were installed on the shotcreted second and third batters from the slope toe respectively.

Monitoring results from the tensiometers are presented in Appendix F. These indicate a range of matric suction up to 80 kPa during the monitoring period, with positive water pressures up to 10 kPa recorded during the 2004 wet season. Cluster 1, located on the shotcreted third batter above the slope toe, recorded matric suction up to about 10 kPa and positive water pressures of a similar magnitude during periods of rainfall in the later part of the 2004 wet season, followed by a rise to between 60 kPa and 80 kPa at the onset of the dry season, with the deeper installations recording a slower response. Cluster 2, located on the vegetated fifth batter above the slope toe, recorded a fall in matric suction from between 50 kPa and 80 kPa at the time of installation in mid-June 2004 to around zero towards the end of the 2004 wet season, with positive water pressures of 3 kPa to 5 kPa also recorded. This was followed by a rise to between 35 kPa to 70 kPa at the onset of the dry season, with no clear relationship between depth and response. Cluster 3, located on the shotcreted second batter above the slope toe, recorded positive water pressures up to 10 kPa from the time of installation late in the 2004 wet season, and a small rise to between zero and 20 kPa following the onset of the dry season.

These results are comparable to the results of an earlier round of tensiometer monitoring (McFarlane, 1980) between April and October 1980 (see Section 4.5).

7.10 Ground Penetrating Radar Survey

A survey of the near-surface ground profile was carried out by EGS Asia Ltd using ground penetrating radar equipment in June 2004 with a view to identifying features present within the fill on a broader scale than possible using invasive ground investigation techniques. The types of features that should be detectable by this technology include voids, boulders and utilities. It was also hoped that the technique may be able to detect interfaces of different materials.

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

The survey comprised a series of single line traverses located along the slope crest, each of the berms and at certain locations on the slope face, notably the second and third batters above the slope toe and the stepped U-channels in the central slope portion on the third to sixth batters above the toe.

Two traverses were generally made along each survey line using a 400 MHz and 100 MHz antenna respectively, which provided radar responses from depths of up to 2 m to 4 m below ground surface using the former, and 5 m to 8 m below ground surface using the latter.

The interpreted results of the survey are presented on Figure 23 and indicate possible voids and possible large-sized rock blocks within the upper 1 m to 1.5 m of the ground profile at various locations across the slope. No significant anomalies were indicated at greater depths. Utilities are indicated from the single line traverse along the Stubbs Road footpath at the slope crest, generally within 0.6 m to 0.7 m of the ground surface and consistent with the lighting cable indicated on the same alignment, with one sounding from a depth of 1.5 m, which is likely to be the 225 mm diameter road drain that connects with the catchpit at the slope crest (see Figure 2).

8. ANALYSIS OF RAINFALL RECORDS

The nearest GEO raingauge (No. H06) to the subject slope is located at Shiu Fai Terrace about 800 m to the northwest of the site. The automatic raingauge records and transmits rainfall data at 5-minute intervals via a telephone line to the Hong Kong Observatory and the GEO. A second automatic raingauge (No. H07) was previously located at Leighton Hill Flats on Broadwood Road, about 700 m to the north of the site, but was relocated in 1998.

The available rainfall data from these raingauges indicates that the subject slope has experienced a number of significant rainstorms since 1983, when the automatic raingauges began operation, with a 24-hour rainfall in excess of 200 mm recorded on 12 occasions (Table 4). Based on historical rainfall data at the Hong Kong Observatory (Lam & Leung, 1994), the calculated return periods for selected severe rainstorms are presented in Table 5.

Daily rainfall records are also available for raingauge No. H07 during the 1982 wet season, which indicate daily rainfalls exceeding 200 mm on two occasions, one event recording over 300 mm on 16 August 1982.

9. ENGINEERING ANALYSES

Theoretical slope stability analyses were carried out using the method of Morgenstern & Price (1965) to assess the implications of various credible conditions, as summarised in Figure 24, based on a range of shear strength parameters and the limited amount of groundwater monitoring data obtained during the investigation period. A representative cross-section through the slope and the input parameters adopted in the stability analyses are presented in Figure 24. In the stability analyses, the groundwater is taken to be

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

perched above the old fill/insitu ground interface based on the piezometer monitoring results.

The results of the analyses are shown in Figure 24. These show that where the perching of groundwater occurs within the compacted fill to different levels corresponding to the spot measurements at limited monitoring points, the calculated factor of safety for potential critical slip surfaces within the compacted fill within the lower half of the slope can approach unity where the shear strength parameters fall within the range of laboratory test results.

10. DIAGNOSIS OF THE DISTRESS

10.1 Factors for Consideration

A number of key factors are considered to be of relevance in the diagnosis of the observed distress on the subject slope. These include:-

(a) site setting prior to slope reconstruction,

(b) detailing of slope reconstruction works in the late 1970's,

(c) as-constructed condition of the fill slope,

(d) hydrogeological setting and groundwater regimes after slope reconstruction, and

(e) progressive slope deterioration.

10.1.1 Site Setting Prior to Slope Reconstruction

The subject site is located within a well defined valley that contains natural drainage lines which concentrate surface runoff from a catchment extending to the original spur ridge of the hillside prior to development. Following the modification of the hillside in connection with construction of Stubbs Road and Tung Shan Terrace development in the early 1900's, the upper regions have been partly paved. However, the portions of the upper reaches of the drainage lines remained as buried features that were likely to lead to concentrated transient groundwater flow given direct surface infiltration.

Following the development of the lower part of the hillside in the 1920's and 1930's, the lower reaches of the drainage lines probably remained intact beneath the fill associated with the construction of Stubbs Road. The portion of the drainage line below the mid-slope masonry wall continued to function as a drainage channel until the time of slope reconstruction in the late 1970's.

As the old fill was probably end-tipped with no compaction carried out pursuant to the prevailing practice at the time, it is likely to be loose and permeable. This has been confirmed by the current ground investigation. Between 1925 and 1960, four significant landslides occurred and affected the HKSH, which may reflect the presence of adverse ground and/or groundwater conditions. There is no record of how the failure scars were reinstated,

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

if at all. The affected ground may have been disturbed to some extent during the landslides and may become more permeable locally.

Overall, the initial site setting prior to slope reconstruction in the late 1970's involved a buried bowl-shaped valley, which promoted concentrated transient groundwater flow along buried natural drainage lines and preferential flow paths within the old, loose fill body.

10.1.2 Detailing of Slope Reconstruction in the Late 1970's

In the report prepared by the Independent Review Panel on Fill Slopes following the August 1976 Sau Mau Ping landslide (Government of Hong Kong, 1976), it was recommended that the minimum treatment of substandard existing loose fill slopes should consist of removing the loose surface soil to a vertical depth of not less than 3 m and recompacting to an adequate standard and that "Drainage of the fill behind the re-compacted surface layer must also be provided at the toe of the slope". The report also noted the following: "In some cases where fill of limited thickness overlies a water-bearing foundation, re-compaction of the upper few metres of fill may, although improving surface stability, in fact make matters worse by inhibiting free drainage. In these instances, it may be preferable to achieve stability by a variety of methods such as slope flattening, deep drainage, or replacement of fill with free-draining material. The design should be selected on the basis of the actual site conditions".

The slope works in the late 1970's involved placing a relatively thick layer of compacted soil fill (up to 8 m thick) within the lower half of the slope, whereas a 3 m thick compacted fill cap was constructed over a thick layer of old loose fill within the upper half of the slope. Subsurface groundwater flow along the more permeable loose fill may be subject to damming effects at the transition zone of the two different fill slope constructions near mid-slope if the capacity of the subsurface drainage provisions is not adequate to deal with the amount of inflow into the compacted fill at the lower slope portion.

The original detailing of the subject fill slope had planned to use rockfill at the slope toe. During construction, the slope detailing was amended to replace rockfill with compacted soil fill. The subsurface drainage provisions comprised a coarse drainage layer ('Filter B' material) sandwiched by a less coarse filter layer ('Filter A' material) behind the toe retaining wall and within the two lowermost batters, and only 'Filter A' material below the compacted soil fill for the upper six batters.

10.1.3 As-constructed Condition of the Fill Slope

The current ground investigation has established that the as-constructed condition of the subject fill slope is generally in compliance with the specifications. The compacted fill contains a combination of sandy and clayey materials, possibly as a result of multiple fill sources. The clayey material has a comparatively low permeability and its presence may explain why many of the GCO probes show low blow counts. On the other hand, the sandy material in the compacted fill is liable to give rise to a locally high horizontal permeability. Furthermore, some over-sized rock blocks as well as foreign material are present in the compacted fill, reflecting the heterogeneity of the fill. Overall, the compacted fill is subject

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

to spatial variability, with the presence of local sandy material (or sand lenses) interspersed with lower permeability clayey material whereby the degree of hydraulic connection of the sandy material with the drainage/filter blankets may be variable.

The proper construction of the drainage/filter blankets in a compacted fill slope is generally fraught with difficulty in practice, as noted by Bowler & Phillipson (1982). The current investigation has shown that some of the drainage blanket ('Filter A/B/A') materials have been inter-mixed, which would have impaired the intended drainage capacity.

10.1.4 Hydrogeological Setting and Groundwater Regime after Slope Reconstruction

The hydrogeological setting after slope reconstruction in the late 1970's can be vulnerable to the build-up of groundwater pressure, especially at the bottom of the old fill body at around mid-slope in the event of water ingress into the more permeable loose fill layer beneath the compacted fill cap. This would be exacerbated by the relatively low discharge capacity of the subsurface drainage provisions in the compacted fill, particularly in the lower slope portion, which may be associated with the following factors:-

(a) the incorporation of relatively short and small slotted pipes that may have a limited discharge capacity and control the efficiency of the drainage/filter blanket system (i.e. the slotted drainage pipes are liable to constitute a 'weak link' in the system),

(b) the detailing of a shotcrete cover over the slope surface in the lower four batters, together with a length of mesh-reinforced shotcrete (with no weepholes except for the outlets of the slotted drainage pipes) over the face of the drainage blankets (Figure 25) in all eight batters, which may have contributed to reducing the overall discharge capacity of the drainage blankets,

(c) the absence of more permeable 'Filter B' material in the upper six batters, including the locality where it is most vulnerable to potential damming effects (i.e. at the transition area at the fourth batter), and

(d) practical difficulty in the proper construction of the drainage blankets, especially along the inclined interface between compacted fill and the in-situ ground (which could result in 'contamination' of the more permeable material due to possible intermixing with less permeable material).

The postulated low discharge capacity of the subsurface drainage provisions are corroborated by the observation of shallow perched water within the compacted fill in all the lower four batters of the slope. The storm response of the perched water within the compacted fill during a moderate rainfall in August 2004 (with a delayed response of up to

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

six hours) points to the fact that rainfall is the primary source of water ingress that feeds the water trapped within the compacted fill, probably through preferential flow paths.

The hydrogeological setting of the site is conducive to the build-up of groundwater within the bottom of the relatively permeable old fill, which provides a hydraulic head that drives the accumulated groundwater into the compacted fill in the lower slope portion. The groundwater would tend to flow along the subsurface drainage provisions as well as any locally more sandy zones within the compacted fill that connect with the drainage blankets. The locally more permeable zones in the compacted fill may be in the form of sand lenses interspersed with clayey material of low permeability. This would be consistent with the observation that the fairly rapid build-up of perched water level took a much longer time to completely dissipate. Given the heterogeneity and anisotropy of the compacted fill and the variable as-constructed condition of the drainage blankets, the local hydrogeological conditions and groundwater regimes, particularly over the lower slope portion, can be subject to spatial variability.

The current investigation with a limited number of piezometers and a short monitoring period has not been able to detect a build-up of perched water in the old fill beneath the compacted cap in the upper portion of the slope, although perched water is observed in the compacted fill within the lower four batters. The possibility of springs associated with the natural drainage lines and geological structures daylighting at the lower slope portion has been considered, but there is no evidence of this from API and no reports of such observations during slope reconstruction. It would seem more credible that the hillside hydrology involves concentrated subsurface water flow along natural drainage lines with possible build-up of water levels at local low points within the buried old fill body that may not have been picked up by the limited number of piezometers.

The current investigation has also established that the compacted fill in the lower slope portion is locally underlain by some disturbed ground or old fill, which may have a relatively high insitu permeability. The spatial distribution of this material, together with its degree of hydraulic connectivity with the permeable old fill in the upper half of the slope is not known. However, there is the possibility that this material can provide, at least on a local scale, a potential preferential flow path for subsurface groundwater flow below the compacted fill in the lower slope portion. This could have contributed to the build-up of perched water levels within the compacted fill in the lower batters. Gravity flow will also take place from the perched water in the fourth batter given a fairly low gradient (viz. 1 in 10) of the sub-horizontal drainage blankets, as demonstrated by the saline tracing test.

The main groundwater table was found to be well below the subject slope with little storm response. There is no indication of any significant effect on the groundwater regime due to the basement construction of the HKSH complex in the late 1980's.

10.1.5 <u>Progressive Slope Deterioration</u>

The slope has suffered progressive deterioration due to strong tree root growth, which affected the surface drainage provisions at selected locations. Of greater significance, however, is the observed blockage of many of the outlets of the slotted drainage pipes in the drainage blankets. The presence of local seepage from the cracks in the drainage channels

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

with no apparent flow from the nearby slotted pipes reflects the ineffectiveness of the latter, which may have been exacerbated by progressive deterioration and inadequate maintenance as reflected by the blockage of a notable proportion of the slotted drainage pipes.

10.2 Mode and Probable Causes of Slope Distress

The occurrence of distress on the slope is distributed fairly widely across the slope face, with the majority being in the form of cracks or displacement of the hard surface cover, berm slabs and drainage channels. The distress is comparatively more severe on the third and fourth batters above the slope toe.

The road pavement above the subject slope exhibits some differential settlement across the junction of the rigid pavement and flexible pavement. There is no obvious evidence of any other distress on the road pavement or the pedestrian pavement that would suggest possible problems with impending slope instability or recent excessive slope movements.

The more localised and relatively minor distress within the upper four batters is partly related to tree root action and partly due to inadequate slope maintenance in the past. Given the large depth of loose fill beneath the compacted fill cap and the likely past leakage from the sewer below Stubbs Road, and possibly also from buried drains within the private developments in Tung Shan Terrace, it is conceivable that the minor distress of the stiff concrete elements of the slope furniture (e.g. berm slabs and channels), as well as the pavement forming materials on Stubbs Road, may be related to small settlement of the underlying loose fill that may have become locally wetted up due to the leakage. The movement monitoring carried out by HyD since December 2003 and the field observations by FSW confirm that the subject slope has not experienced any notable movement in recent times.

The distress on the third and fourth batters from the toe involving downslope displacement of the locally cracked shotcrete cover, essentially in an en-masse mode, is of a different nature to that in the upper four batters. Slope distress on the fourth batter (i.e. at the transition zone of the different fill slope constructions) was detected from API based on the 1981 to 1983 aerial photographs. It is postulated that this was possibly associated with the build-up of water pressure within the compacted fill as a result of inadequate discharge capacity of the subsurface drainage provisions for the given amount of inflow associated with the concentrated subsurface seepage. The water pressure in the compacted fill would have exerted a hydraulic thrust on the shotcrete cover which does not have any weepholes. It is possible that the shotcrete cover became dislodged near the toe of the batter as a consequence, leading to some downslope movement of the hard cover. The shallow perched water pressure in the compacted fill would have been largely released where gaps were created between the hard cover and the compacted fill surface (Figure 25).

Given the fairly compressible nature of the locally more clayey material in the compacted fill, it is also conceivable that the compacted fill may have suffered some small settlement in a non-uniform manner following wetting up as a result of water ingress, which would have reduced the effective friction of the interface between the shotcrete and the ground surface, hence making it prone to development of en-masse downslope displacement of the hard cover. Additionally, certain portions of the compacted fill may locally be

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

susceptible to movements due to change in water content as indicated by index testing and clay mineralogy analysis. Furthermore, the possibility exists that some settlement has occurred as a result of internal erosion of the old fill owing to the concentrated groundwater flow in this portion of the slope. The occurrence of settlement of the fill may have led to shortening of the slope surface, which would exacerbate the relative displacement of the shotcrete surfacing from the slope face. Evidence of settlement of the fill slope is given by the presence of a ‘lip’ at the crest of the lower batter from the toe wall, where the shotcrete is supported by the toe wall and could not move with the settled fill. A similar lip is present at the south end of the crest of the third lowest batter from the toe wall, where the shotcrete is supported by the channel. The situation may also have been exacerbated by the wedging action of tree roots, which exploited the gap below the shotcrete, possibly causing further displacement and/or localised cracking of the hard cover.

Based on the pattern of the crazing cracks in the shotcrete cover over the two lowermost batters, it would appear that the distress is probably related to shrinkage cracks in the unreinforced shotcrete portion.

Based on the current ground investigation, there is no evidence of major distress in the ground below the shotcrete cover in the form of cracks or bulging. Given the possible locally high groundwater pressure in the compacted fill, the near-surface groundmass may, or may not, have suffered local blowout or sloughing following the separation of the shotcrete cover from the ground surface on the concerned batters.

In general, the toe wall does not exhibit major distress in the form of significant cracks. It is considered unlikely that the excavation carried out within the HKSH complex in the late 1980’s and early 1990’s adjacent to Wong Nai Chung Road (Section 3.1.4 refers) has affected the ground at the slope toe.

10.3 Source of Water Ingress

Water is encountered in the majority of trial pits and piezometers within the compacted fill within the lower four batters. During the 2004 wet season, the piezometers showed a storm response of up to about 0.5 m following moderate rainfalls.

The four possible sources of water ingress that have been identified as having potentially resulted in the build-up of groundwater pressure in the compacted fill within the lower slope portion, either separately or in combination, are as follows:-

(a) a rising groundwater table,

(b) direct surface infiltration,

(c) leakage from buried water-carrying services along Stubbs Road, and

(d) leakage from buried water-carrying services within the Tung Shan Terrace development.

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

The main groundwater table was found to be well below the subject slope with little storm response, and there is no evidence to support a hypothesis that the slope distress was caused by a significant rise of the main groundwater table.

Direct surface infiltration through the Tung Shan Terrace area is possible through the localised vegetated areas although these are not particularly extensive. Some direct infiltration through the vegetated compacted fill over the upper four batters of the subject slope is possible although the amount of infiltration is probably not significant, bearing in mind the fairly low vertical permeability of the compacted fill based on field double-ring infiltrometer tests. Notwithstanding the presence of cracks in the shotcrete cover, the hard cover to the lower four batters should have prevented significant direct surface infiltration. Although there may be some small amount of water ingress through cracks in the shotcrete (which is consistent with the observation of occasional flow from below the shotcrete surface to the channels at the toe of batters), the infiltration into the compacted fill, which is of relatively low permeability, is probably not significant. Direct infiltration is possible through the limited vegetated ground on either side of the subject fill slope within the same valley. If the direct infiltration reaches the more permeable loose fill below the compacted fill, then water ingress into the lower slope portion of the subject fill slope is possible through subsurface seepage flow.

The existence of abandoned buried water-carrying services beneath Stubbs Road as a potential source of water ingress cannot be ruled out, but this is considered improbable based on the investigation results. Past leakage from the old sewer running beneath the section of Stubbs Road above the crest of the subject slope is possible based on the observations from CCTV. After relining of the sewer by DSD in late 2004, the defects should have been rectified. It is noteworthy that the leakage that took place from the defective sewer prior to this date was probably not related to rainfall events and therefore would not explain the observed storm responses in the 2004 wet season. Hence, this potential source probably did not play a key role in the build-up of perched water in the compacted fill within the lower slope portion. However, past leakage from the sewer could have wetted up the loose fill and might have played a contributory role in the development of the relatively minor distress on the stiff elements of the slope furniture.

Leakage from water-carrying services within the private lots of Tung Shan Terrace is a credible source. Drainage Orders have previously been served by BD on selected owners. Tung Shan Terrace comprises several phases of developments dating back to the early 1900's and the possibility of the presence of abandoned stormwater drains that continue to discharge into the ground cannot be ruled out. Should leakage from defective drains and/or abandoned drains in Tung Shan Terrace enter the loose fill pocket that connects with the underlying loose fill stratum on the subject slope, water ingress into the compacted fill within the lower slope portion would be possible following subsurface seepage flow, especially along the buried drainage lines and any preferential flow paths.

Leakage from defective and/or abandoned stormwater drains from the uphill area and subsequent subsurface seepage flow may explain the delayed storm response in the piezometers within the compacted fill in the lower slope portion. Direct surface infiltration through the vegetated areas in the catchment may also have played a contributory role as a source of water ingress to the subject slope.

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

10.4 Discussion

The investigation has established that the compacted fill within the lower slope portion is subject to the build-up of perched groundwater pressure with a mild storm response during moderate rainfall in the 2004 wet season, especially in the area below the inferred natural drainage lines. This finding is consistent with the 1982 tensiometer readings which apparently showed low suction values below the shotcrete cover whereas high suction values were measured below the upper and adjacent vegetated areas.

It is noteworthy that the groundwater regime within the compacted fill in the lower slope portion is subject to spatial variability, with localised perched water pressure as well as suction measured by the piezometers and the tensiometers. The composition of the compacted fill comprising a combination of sandy and clayey materials, together with a hydrogeological setting involving buried drainage lines and the presence of permeable old loose fill beneath the compacted fill cap within the upper slope portion, would have given rise to complex and variable groundwater regimes in the slope. This is further complicated by the detailing of the subsurface drainage provisions as mostly discrete units behind each batter, but conjoined behind the third and fourth batters, and the potential variability in the state of construction of this detail. The effects of deterioration of the slotted drainage pipes through possible progressive clogging with time would have exacerbated the situation. Given the above uncertainties, it is difficult to fully define the spatial distribution of groundwater pressures that may develop within the compacted fill in the slope and the loose fill underlying the compacted fill cap.

11. CONCLUSIONS

It is concluded that the distress on slope No. 11SW-D/FR1 is mainly related to water ingress into the old loose fill underlying the compacted fill cap within the upper half of the slope and build-up of water pressure in the compacted fill within the lower half of the slope. It is also partly associated with general progressive slope deterioration following reconstruction works in the late 1970's and the situation is exacerbated locally by tree root action arising from unplanned vegetation.

The key source of water ingress is probably related to leakage from stormwater drains in the upslope area, although direct surface infiltration through the vegetated areas and leakage from the sewer beneath Stubbs Road may also have played a contributory role in providing water ingress into the slope.

The investigation has established that the potential build-up of significant transient groundwater pressure in the compacted fill in the lower slope portion and/or in the old loose fill underlying the compacted fill cap during severe rainfall is liable to constitute a potential hazard.

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

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

LIST OF TABLES

Table of Contents
Table of Contents
Table of Contents

Table 1 - Summary of Clay Mineralogy Analysis on Selected Samples of Compacted Fill

Fraction	Sample No.	Location	Depth	Mineralogy (Percentage by Mass)						
				Quartz	Kaolinite	Gibbsite	Halloysite	Mica	K-Feldspar	Plagioclase
Whole Sample (see Note 1)	1A	TP4	1.50 m	44.0	37.9	3.1	2.3	2.0	7.7	3.0
	2A	TP6	3.15 m	48.5	35.5	3.3	2.4	1.4	6.5	2.4
	3A	TP9	1.70 m	55.2	19.4	1.4	1.6	2.2	14.1	6.3
	4A	TP10	0.60 m	57.4	17.4	1.5	1.8	1.8	14.5	5.6
Silt Fraction (63 μm - 2 μm)	1A	TP4	1.50 m	6.3	67.2	3.9	2.9	8.6	8.6	2.5
	2A	TP6	3.15 m	8.2	69.9	3.9	3.3	6.2	7.4	1.2
	3A	TP9	1.70 m	48.5	28.4	1.1	2.3	2.3	11.9	5.5
	4A	TP10	0.60 m	20.0	34.5	3.0	3.6	3.2	21.7	14.0
Clay Fraction (< 2 μm)	1A	TP4	1.50 m	0.0	66.0	4.0	26.0	4.3	0.0	0.0
	2A	TP6	3.15 m	0.0	52.0	3.5	41.0	3.2	0.0	0.0
	3A	TP9	1.70 m	0.0	26.0	2.6	66.0	5.2	0.0	0.0
	4A	TP10	0.60 m	0.0	52.0	6.1	36.0	5.4	0.0	0.0

Note: Whole sample analysis conducted on fraction of bulk sample < 2 mm.

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

Table 2 - Summary of Borehole Permeability Test Results

Soil Stratum	Coefficient of Permeability, k (m/s)									
	BH1	BH2	BH3	BH4	BH5	BH6	BH7	BH8	BH9	Average Permeability (m/s)
Compacted Fill	2.93×10^{-8} (2.35 m)	5.71×10^{-8} (2.65 m)	1.75×10^{-7} (2.10 m)	2.58×10^{-7} (2.30 m)	7.29×10^{-8} (2.05 m)	(3)	3.00×10^{-7} (2.35 m)	(3)	(3)	1.49×10^{-7}
Filter A	1.18×10^{-6} (3.65 m)	5.72×10^{-6} (3.65 m)	6.55×10^{-5} (3.55 m)	4.92×10^{-5} (3.85 m)	8.36×10^{-6} (4.00 m)	1.68×10^{-5} (1.85 m)	(3)	(3)	(3)	2.45×10^{-5}
Filter A and Filter B	(3)	(3)	(3)	(3)	(3)	(3)	4.17×10^{-5} (6.08 m)	$> 1.14 \times 10^{-4}$ (2.35 m)	$> 1.18 \times 10^{-4}$ (2.75 m)	-
Old Fill	1.83×10^{-5} (9.20m)	1.30×10^{-5} (6.70 m)	4.07×10^{-7} (10.85 m)	7.60×10^{-6} (2) (9.45 m)	(3)	2.59×10^{-6} (8.75 m)	4.03×10^{-5} (9.20 m)	(3)	(3)	1.49×10^{-5}
CDG	4.73×10^{-6} (11.95 m)	2.03×10^{-6} (14.95 m)	3.06×10^{-6} (15.20 m)	4.95×10^{-6} (15.95 m)	4.84×10^{-6} (16.96 m)	5.52×10^{-6} (11.33 m)	3.73×10^{-6} (12.25 m)	1.33×10^{-6} (5.65 m)	2.07×10^{-6} (12.85 m)	3.58×10^{-6}

Notes:
(1) Bracketed figures indicate depth at which test was performed.
(2) Constant-head permeability test was replaced by falling head permeability test at the old fill layer of BH4.
(3) Constant head permeability test has not been carried out as the soil strata was not of sufficient thickness.

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

Table 3 - Summary of Double Ring Infiltrometer Permeability Test Results

Soil Stratum	Coefficient of Permeability, k (m/s)									
	TP4A	TP5A	TP6A	TP7A	TP8A	TP9A	TP10A	-	-	Average Permeability (m/s)
Compacted Fill	7.85×10^{-7} (0.80 m)	(2)	(3)	3.89×10^{-7} (0.60 m)	4.61×10^{-7} (1.35 m)	3.95×10^{-6} (0.65 m)	6.05×10^{-6} (1.05 m)	-	-	2.33×10^{-6}
Filter A	(2)	(2)	4.52×10^{-4} to 4.88×10^{-4} (3) (0.23 m)	(2)	(2)	(2)	(2)	-	-	4.70×10^{-4}
Filter A and Filter B	(2)	1.08×10^{-4} to 3.37×10^{-4} (3) (1.18 m)	(2)	(2)	(2)	(2)	(2)	-	-	2.23×10^{-4}

Notes:
(1) Bracketed figures indicate depth at which test was performed.
(2) Constant head permeability test has not been carried out as the soil strata was not of sufficient thickness.
(3) Multiple tests were carried out due to high permeability of the material.

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

Table 4 - Summary of Laboratory Permeability Test Results

Soil Stratum	Confining Stress, σ_3' (kPa)	Coefficient of Saturated Permeability (m/sec)			
		TP5 (1.30-1.60 m)		TP8 (0.70-1.00 m)	
		Vertical	Horizontal	Vertical	Horizontal
Compacted Fill	20	1.72×10^{-9}	1.69×10^{-8}	2.81×10^{-7}	4.14×10^{-7}
	30	1.41×10^{-9}	1.92×10^{-9}	1.83×10^{-7}	3.65×10^{-7}
	50	6.97×10^{-10}	6.59×10^{-10}	1.10×10^{-7}	1.85×10^{-7}

Note: Bracketed figures indicate depth at which test was performed.

Table 5 - Summary of Chemical Test Results for Water Samples

Analysis Description	Date of Testing / Location / Unit	25 Mar 2004	27 Apr 2004	27 Apr 2004	14 May 2004	08 Jun 2004	30 Jul 2004	30 Jul 2004	30 Jul 2004	30 Jul 2004	13 Aug 2004	13 Aug 2004
	Level of Reporting											
		Catchpit at slope crest(1)	Catchpit at slope crest(1)	Sewer manhole, Tung Shan Terrace (2)	Stormwater manhole, Tung Shan Terrace (3)	Piezometer TP2	Catchpit at slope crest(1)	Piezometer TP2	Piezometer TP3	Piezometer RP2	Seepage from Trial pit TP5	Seepage from Trial pit TP6
pH Value @ 25ºC	-	9.7	7.8	7.2	8.5	8.2	8.6	7.8	7.2	6.4	7.6	8.5
Chloride	mg/L	43	18	22	15	25	3	22	25	19	64	20
Fluoride	mg/L	0.4	0.5	0.6	0.4	0.6	0.1	0.9	1.0	0.2	0.6	0.8
Ammonia as N	mg/L	0.46	< 0.01	3.4	0.11	0.3	0.06	0.6	0.14	0.86	2.6	2.6
Chemical Oxygen Demand	mg/L	47	22	212	118	160	8	94	19	24	178	20
E. coli	cfu/100 mL	21×10^2	32×10^2	14×10^4	62×10^3	41	1700	<1	380	<1	<1	<1

Notes:
(1) Location of catchpit shown in Figure 2 at 'Location A'.
(2) Location of manhole shown in Figure 2 at 'Location B'.
(3) Location of manhole shown in Figure 2 at 'Location C'.

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

Table 6 - Selected 24-hour Rainfalls Recorded at GEO Raingauges Nos. H06 and H07 between 1983 and 2003

Date (1)	24-Hour Rainfall Recorded at GEO Raingauge No. H06 (mm)	24-Hour Rainfall Recorded at GEO Raingauge No. H07 (mm)
16 June 1983	324.0	308.0
30 May 1984	112.5	245.5
25 June 1985	221.5	- (2)
12 July 1986	161.0	162.5
30 July 1987	130.0	113.0
20 July 1988	169.5	174.0
20 May 1989	258.0	278.0
10 September 1990	112.0	94.5
10 April 1991	129.0	107.5
8 May 1992	304.5	319.5
25 September 1992	194.0	162.5
26 September 1993	284.0	264.0
22 July 1994	221.5	219.0
3 August 1994	281.0	203.0
13 August 1995	326.5	267.0
31 August 1995	176.0	152.5
22 June 1996	165.0	161.0
1 July 1997	179.0	169.5
22 August 1997	220.5	229.5
9 June 1998	276.0	269.5
24 August 1999	194.5	- (4)
24 August 2000	244.5	- (4)
8 June 2001	151.5	- (4)
15 September 2002	164.5	- (4)
14 September 2003	- (3)	- (4)

Notes:
(1) The computed 24-hour rainfall is based on the data recorded between 00:00 and 24:00 of the selected date.
(2) Possibly missing data recorded on 25 June 1985 at GEO raingauge No. H07.
(3) No rainfall data recorded on 14 September 2003 at GEO raingauge No. H06.
(4) GEO raingauge No. H07 was relocated to South China Athletic Assn Stadium, Caroline Hill Road, Causeway Bay on 12 June 1998.

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

Table 7 - Maximum Rolling Rainfall at GEO Raingauges Nos. H06 and H07 for Selected Durations during a Number of Significant Historical Rainstorm Events and the Estimated Return Periods (Sheet 1 of 5)

Duration	June 1983, Raingauge No. H06		May 1984, Raingauge No. H07		May 1989, Raingauge No. H07	
	Maximum Rolling Rainfall (mm)	Estimated Return Period (Year)	Maximum Rolling Rainfall (mm)	Estimated Return Period (Year)	Maximum Rolling Rainfall (mm)	Estimated Return Period (Year)
5 Minutes	8.5	< 2.0	11.5	< 2.0	7.0	< 2.0
15 Minutes	23.0	< 2.0	28.0	< 2.0	15.5	< 2.0
1 Hour	58.0	< 2.0	67.5	< 2.0	34.0	< 2.0
2 Hours	110.5	4.5	89.0	2.2	62.0	< 2.0
4 Hours	172.0	6.2	133.5	2.7	95.0	< 2.0
12 Hours	295.0	11.0	244.0	5.2	252.0	5.8
24 Hours	324.0	5.9	251.5	2.7	332.5	6.4
48 Hours	327.0	3.6	298.5	2.8	367.0	5.2
4 Days	331.0	2.3	329.0	2.3	380.0	3.2
7 Days	333.5	< 2.0	406.0	2.7	389.0	2.4
15 Days	398.5	< 2.0	502.5	2.3	399.0	< 2.0
31 Days	425.0	< 2.0	578.0	< 2.0	408.0	< 2.0

Notes:
(1) Return periods were derived from Table 3 of Lam & Leung (1994).
(2) Maximum rolling rainfall was calculated from 5-minute data for durations up to 48 hours, and from hourly rainfall data for longer rainfall durations.
(3) The use of 5-minute data for durations between 2 hours and 48 hours results in better data resolutiion, but may slightly over-estimate the return periods using Lam & Leung (1994)'s data, which are based on hourly rainfall for these durations.

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

Table 7 - Maximum Rolling Rainfall at GEO Raingauges Nos. H06 and H07 for Selected Durations during a Number of Significant Historical Rainstorm Events and the Estimated Return Periods (Sheet 2of 5)

Duration	May 1992, Raingauge No. H07		September 1993, Raingauge No. H06		August 1995, Raingauge No. H06	
	Maximum Rolling Rainfall (mm)	Estimated Return Period (Year)	Maximum Rolling Rainfall (mm)	Estimated Return Period (Year)	Maximum Rolling Rainfall (mm)	Estimated Return Period (Year)
5 Minutes	13.5	2.3	8.0	< 2.0	15.5	4.6
15 Minutes	35.0	5.8	18.0	< 2.0	29.5	2.4
1 Hour	115.5	19.7	29.0	< 2.0	74.0	2.3
2 Hours	182.0	73.3	54.5	< 2.0	96.5	2.8
4 Hours	211.5	15.7	99.0	< 2.0	175.5	6.7
12 Hours	319.0	15.9	193.0	2.6	278.0	8.5
24 Hours	320.0	5.6	318.5	5.5	453.5	26.2
48 Hours	371.0	5.4	478.5	15.4	518.5	23.0
4 Days	390.0	3.5	638.5	26.9	646.0	28.7
7 Days	390.5	2.5	656.0	18.4	646.5	17.0
15 Days	464.5	< 2.0	850.0	21.6	1128.5	157.7
31 Days	466.5	< 2.0	857.0	< 2.0	1418.5	200.6

Notes:
(1) Return periods were derived from Table 3 of Lam & Leung (1994).
(2) Maximum rolling rainfall was calculated from 5-minute data for durations up to 48 hours, and from hourly rainfall data for longer rainfall durations.
(3) The use of 5-minute data for durations between 2 hours and 48 hours results in better data resolutiion, but may slightly over-estimate the return periods using Lam & Leung (1994)'s data, which are based on hourly rainfall for these durations.

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

Table 7 - Maximum Rolling Rainfall at GEO Raingauges Nos. H06 and H07 for Selected Durations during a Number of Significant Historical Rainstorm Events and the Estimated Return Periods (Sheet 3 of 5)

Duration	June 1996, Raingauge No. H06		July 1997, Raingauge No. H06		August 1997, Raingauge No. H06	
	Maximum Rolling Rainfall (mm)	Estimated Return Period (Year)	Maximum Rolling Rainfall (mm)	Estimated Return Period (Year)	Maximum Rolling Rainfall (mm)	Estimated Return Period (Year)
5 Minutes	9.5	< 2.0	14.0	2.7	16.0	5.6
15 Minutes	21.5	< 2.0	36.0	7.0	35.0	5.8
1 Hour	53.5	< 2.0	80.0	3.0	86.0	4.0
2 Hours	58.5	< 2.0	116.5	5.6	110.5	4.5
4 Hours	76.5	< 2.0	160.0	4.8	166.0	5.4
12 Hours	137.5	< 2.0	179.0	2.2	203.5	3.0
24 Hours	216.0	2.0	202.5	< 2.0	246.5	2.6
48 Hours	352.5	4.6	285.0	2.5	286.5	2.6
4 Days	413.5	4.1	407.0	3.9	298.0	< 2.0
7 Days	417.5	2.9	420.0	3.0	411.5	2.8
15 Days	515.5	2.4	515.0	2.4	590.0	3.8
31 Days	682.5	2.2	1081.0	22.4	890.5	6.8

Notes:
(1) Return periods were derived from Table 3 of Lam & Leung (1994).
(2) Maximum rolling rainfall was calculated from 5-minute data for durations up to 48 hours, and from hourly rainfall data for longer rainfall durations.
(3) The use of 5-minute data for durations between 2 hours and 48 hours results in better data resolutiion, but may slightly over-estimate the return periods using Lam & Leung (1994)'s data, which are based on hourly rainfall for these durations.

Table 7 - Maximum Rolling Rainfall at GEO Raingauges Nos. H06 and H07 for Selected Durations during a Number of Significant Historical Rainstorm Events and the Estimated Return Periods (Sheet 4 of 5)

Duration	June 1998, Raingauge No. H06		August 1999, Raingauge No. H06		August 2000, Raingauge No. H06	
	Maximum Rolling Rainfall (mm)	Estimated Return Period (Year)	Maximum Rolling Rainfall (mm)	Estimated Return Period (Year)	Maximum Rolling Rainfall (mm)	Estimated Return Period (Year)
5 Minutes	10.0	< 2.0	13.5	2.3	14.0	2.7
15 Minutes	22.5	< 2.0	32.5	3.8	38.5	11.0
1 Hour	51.0	< 2.0	56.0	< 2.0	109.5	14.1
2 Hours	94.5	2.6	84.5	2.0	152.5	22.5
4 Hours	141.0	3.2	149.5	3.8	242.0	32.9
12 Hours	249.0	5.6	194.0	2.7	247.5	5.3
24 Hours	301.5	4.6	270.5	3.3	248.5	2.7
48 Hours	336.0	3.9	518.5	12.0	253..5	2.0
4 Days	423.0	4.4	562.0	13.9	344.0	2.5
7 Days	467.5	4.2	562.5	8.7	344.5	< 2.0
15 Days	572.0	3.4	710.5	8.2	370.5	< 2.0
31 Days	793.0	3.9	886.5	6.7	729.0	2.7

Notes: (1) Return periods were derived from Table 3 of Lam & Leung (1994).
(2) Maximum rolling rainfall was calculated from 5-minute data for durations up to 48 hours, and from hourly rainfall data for longer rainfall durations.
(3) The use of 5-minute data for durations between 2 hours and 48 hours results in better data resolutiion, but may slightly over-estimate the return periods using Lam & Leung (1994)'s data, which are based on hourly rainfall for these durations.

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

Table 7 - Maximum Rolling Rainfall at GEO Raingauges Nos. H06 and H07 for Selected Durations during a Number of Significant Historical Rainstorm Events and the Estimated Return Periods (Sheet 5 of 5)

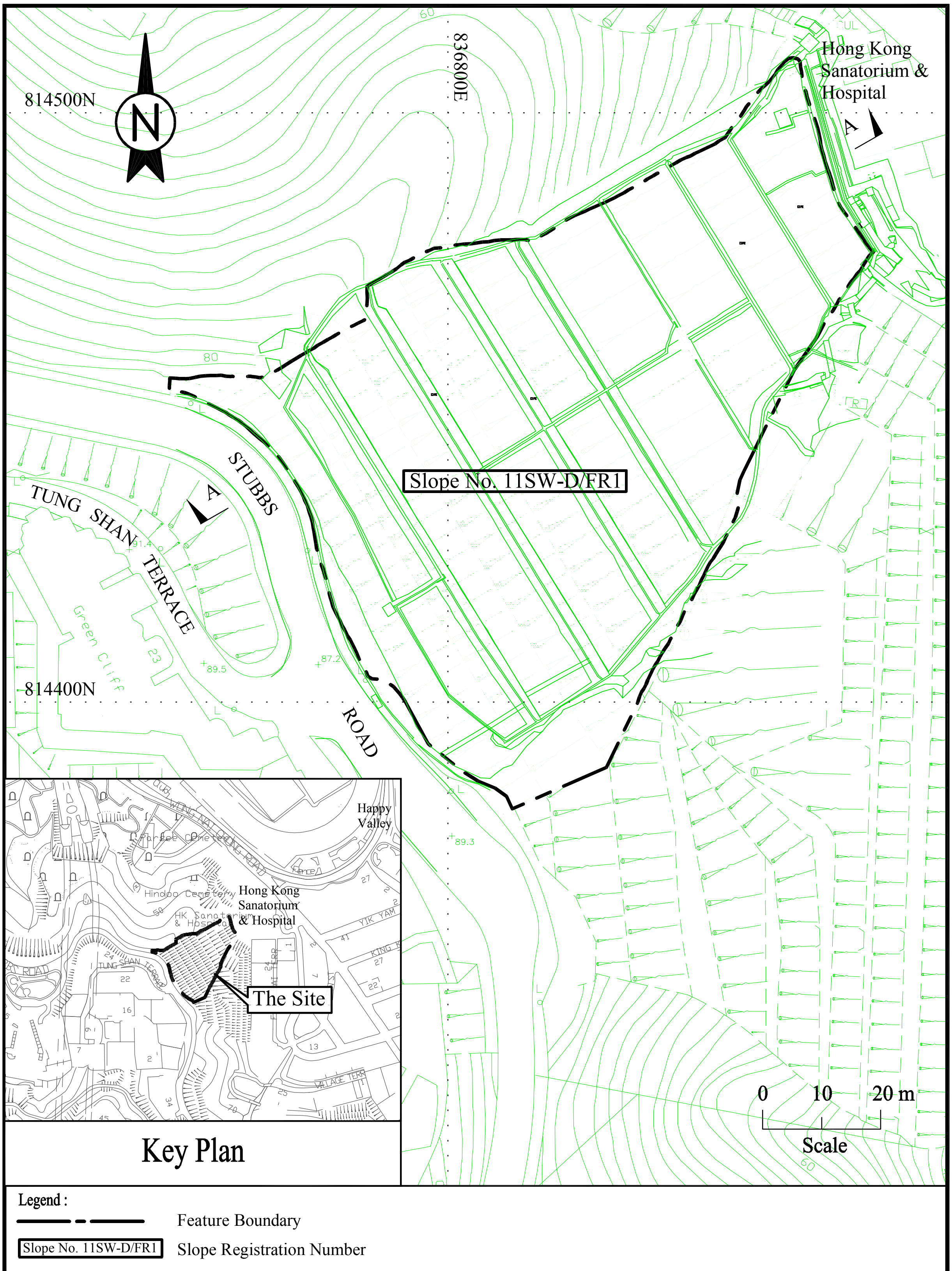
Duration	June 2001, Raingauge No. H06		September 2002, Raingauge No. H06		-	
	Maximum Rolling Rainfall (mm)	Estimated Return Period (Year)	Maximum Rolling Rainfall (mm)	Estimated Return Period (Year)	Maximum Rolling Rainfall (mm)	Estimated Return Period (Year)
5 Minutes	11.5	< 2.0	8.5	< 2.0	-	-
15 Minutes	27.5	< 2.0	18.0	< 2.0	-	-
1 Hour	72.0	2.1	42.5	< 2.0	-	-
2 Hours	90.5	2.3	73.0	< 2.0	-	-
4 Hours	118.5	2.1	97.5	< 2.0	-	-
12 Hours	160.5	< 2.0	195.0	2.7	-	-
24 Hours	192.5	< 2.0	243.5	2.5	-	-
48 Hours	243.0	< 2.0	315.5	3.3	-	-
4 Days	460.0	6.0	561.0	13.8	-	-
7 Days	656.5	18.5	670.5	20.7	-	-
15 Days	165.5	12.0	717.0	8.6	-	-
31 Days	878.5	6.3	728.5	2.7	-	-

Notes: (1) Return periods were derived from Table 3 of Lam & Leung (1994).
(2) Maximum rolling rainfall was calculated from 5-minute data for durations up to 48 hours, and from hourly rainfall data for longer rainfall durations.
(3) The use of 5-minute data for durations between 2 hours and 48 hours results in better data resolutiion, but may slightly over-estimate the return periods using Lam & Leung (1994)'s data, which are based on hourly rainfall for these durations.

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

LIST OF FIGURES

Table of Contents
Table of Contents
Table of Contents



Notes :

(1) Base Map is extracted from Survey Sheet No. 11SW-15C, scale 1 : 1000.

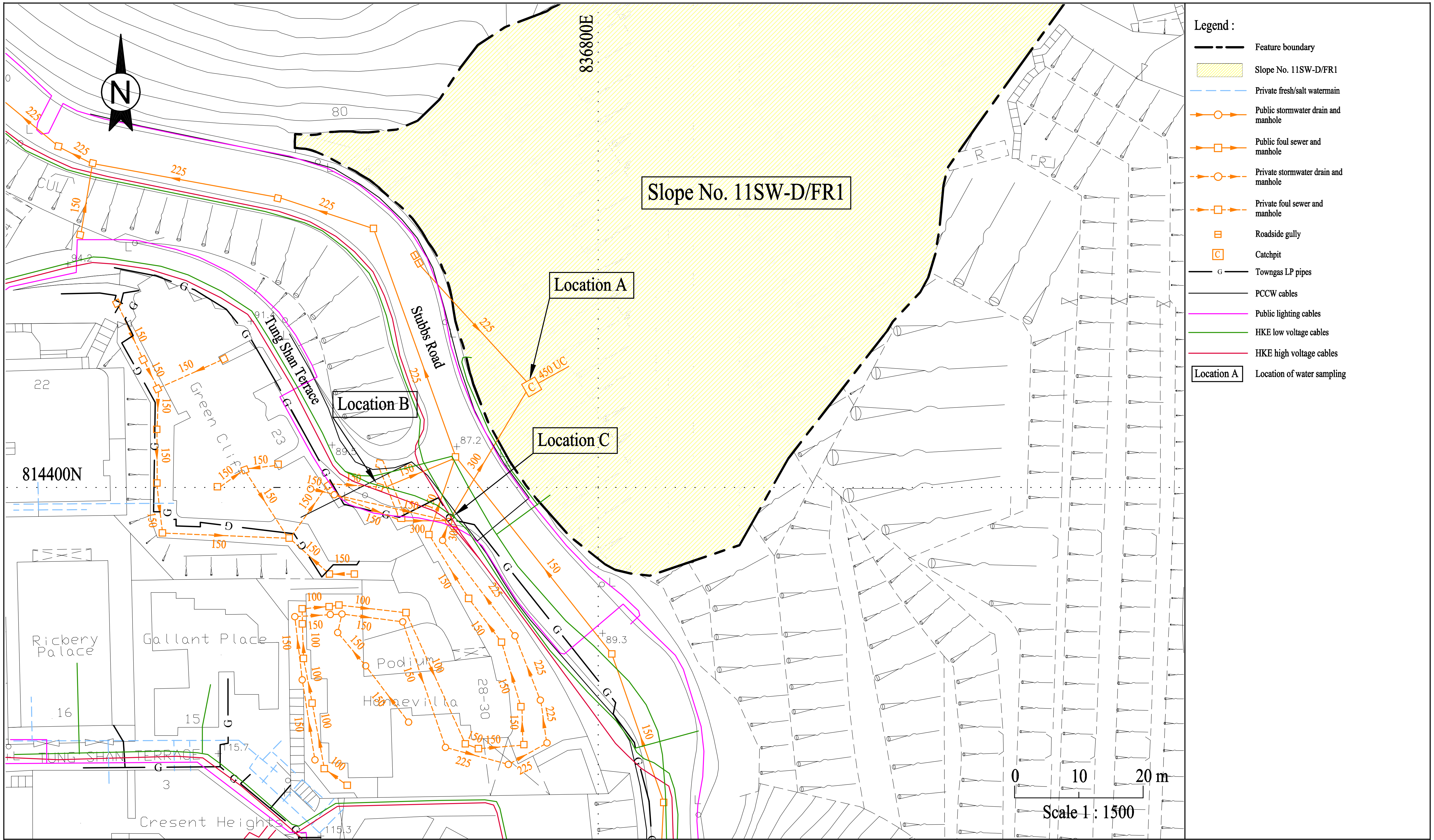
(2) General arrangement of the subject slope based on detailed topographic survey by CED Survey Division in May 2004.

(3) Feature boundary and registration numbers taken from Sheet 11NE-15C of the GEO SIRST Study (GEO, 1996)

(4) Cross-section A - A shown on Figure 7.

Figure 1 - Site Location Plan

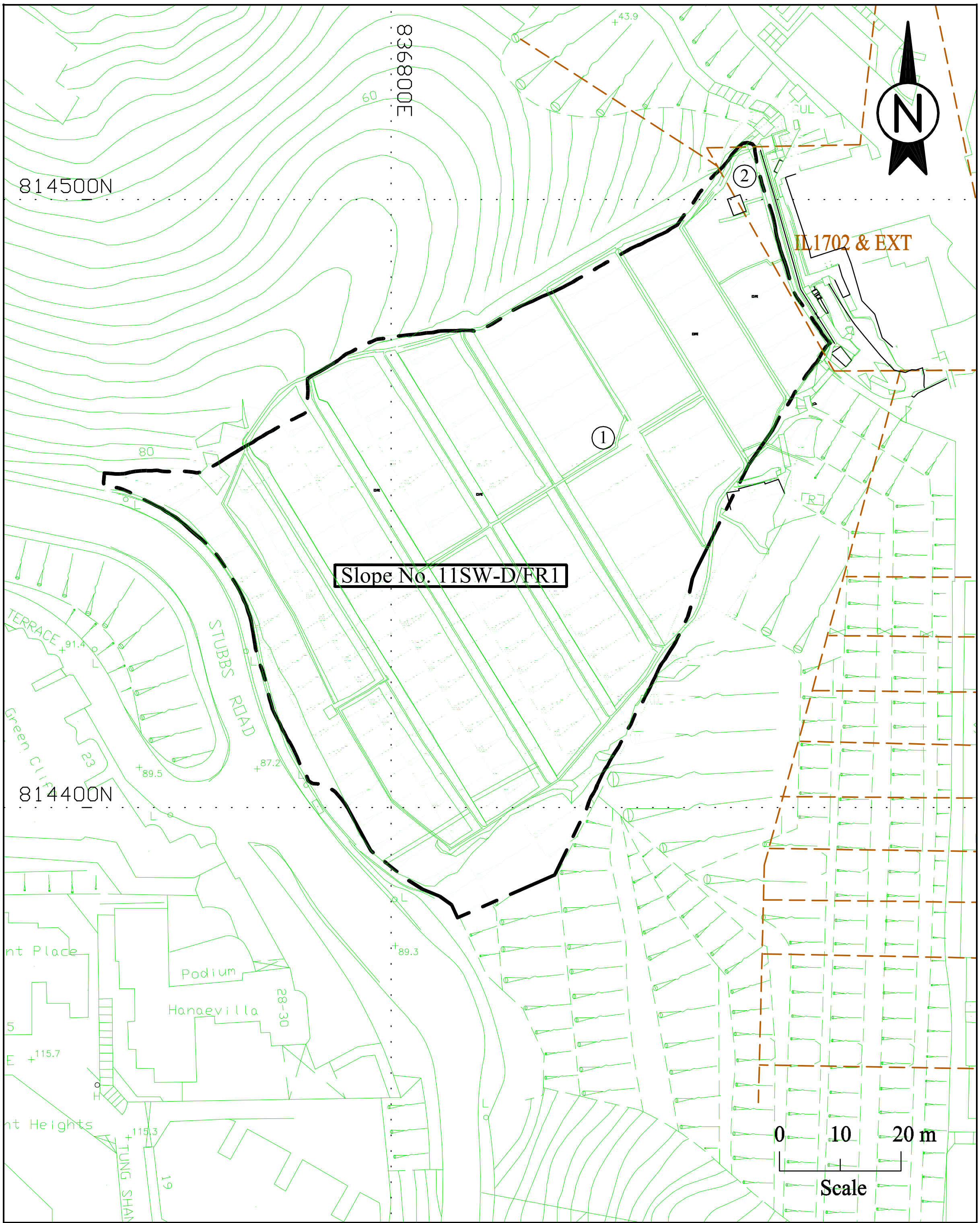
Table of Contents
Table of Contents
Table of Contents
Table of Contents



Notes : (1) Base Map is extracted from survey sheet No. 11SW-15C, scale 1 : 1000.
(2) General arrangement of the subject slope based on detailed topographic survey by CED Survey Division in May 2004.

Figure 2 - Existing Services

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



Legend :

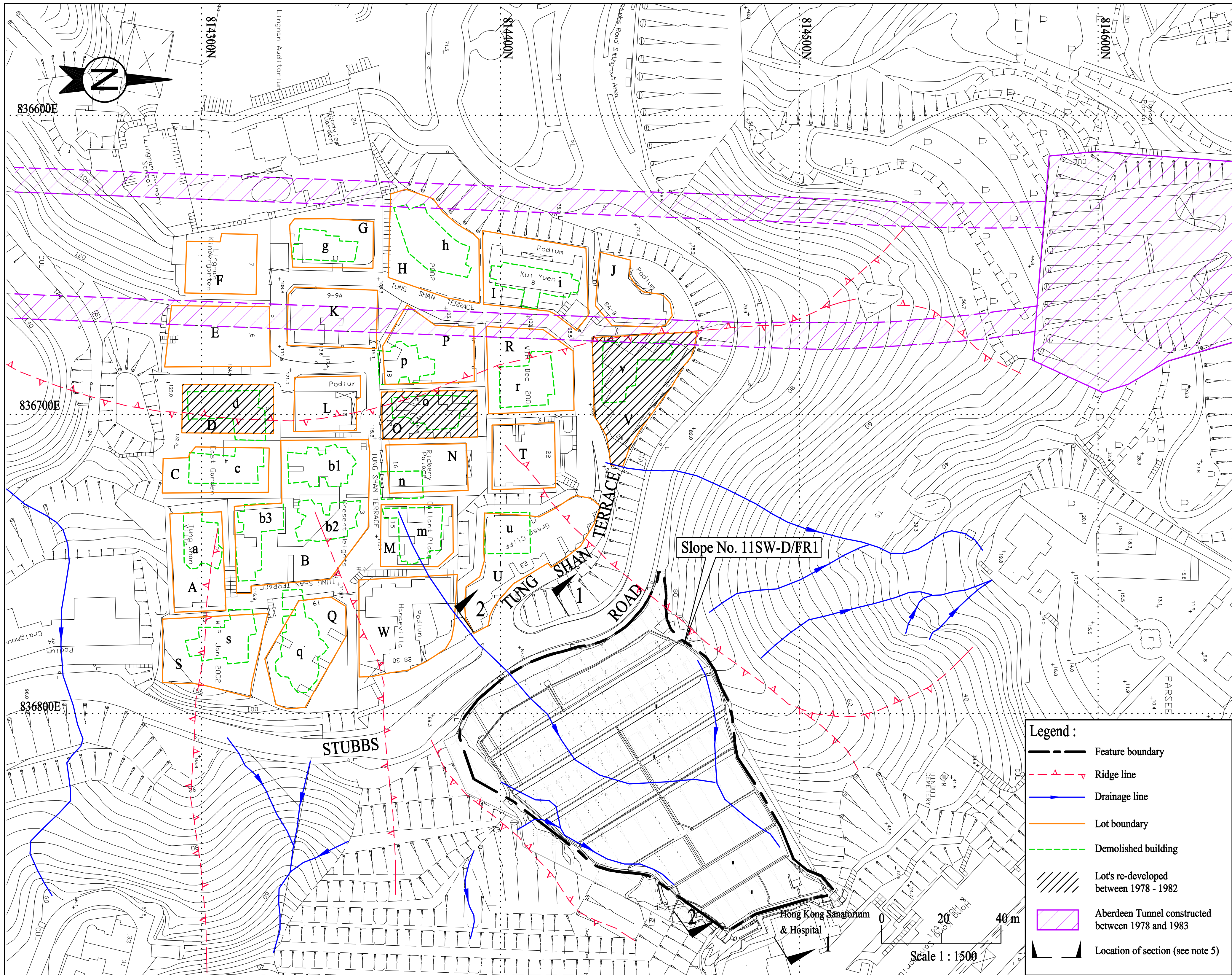
▬ ▬ ▬	Feature Boundary	IL1702	Lot Boundary & Lot Number
Slope No. 11SW-D/FR1	Slope Registration Number	①	Maintained by HyD
		②	Maintained by owners of IL1702 & EXT. (HKSH)

Notes :

(1) Base Map is extracted from Survey Sheet No. 11SW-15C, scale 1 : 1000.
(2) General arrangement of the subject slope based on detailed topographic survey by CED Survey Division in May 2004.
(3) Feature boundary and registration number taken from Sheet 11NE-15C of the GEO SIRST Study (GEO, 1996)

Figure 3 - Maintenance Responsibility

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



Developement History :

Demolished buildings

- a No.2 Constructed between 1924 -1945 Demolished in 1964
- b1 No. 11 Constructed between 1949 -1963 Demolished in 1993
- b2 No.12 Constructed between 1949 -1963 Demolished in 1994
- b3 No.13 Constructed between 1949 -1963 Demolished in 1994
- c No.4 Constructed between 1949 -1963 Demolished in 1993
- d No.5 Constructed between 1949 -1963 Demolished in 1979
- g No.7A Constructed between 1949 -1963 Demolished in 1994
- h No. 7B-C Constructed between 1949 -1963 Demolished in 1997
- i No.8 Constructed between 1949 -1963 Demolished in 1974
- m No.15 Constructed between 1949 -1963 Demolished in 1991
- n No.16 Constructed between 1924 -1945 Demolished in 1972
- o No.17 Constructed between 1924 -1945 Demolished in 1981
- p No.18 Constructed between 1924 -1945 Demolished in 1994
- q No.19 Constructed (pre-1945) Demolished in 1982
- r No.20 Constructed between 1949 -1963 Demolished in 2001
- s No.21 Constructed between 1945 -1949 Demolished in 1999
- u No.23 Constructed between 1924 -1945 Modified between 1949 - 1963 Demolished in 1988
- v No.24 Constructed between 1924 -1945 Demolished in 1974

Existing buildings

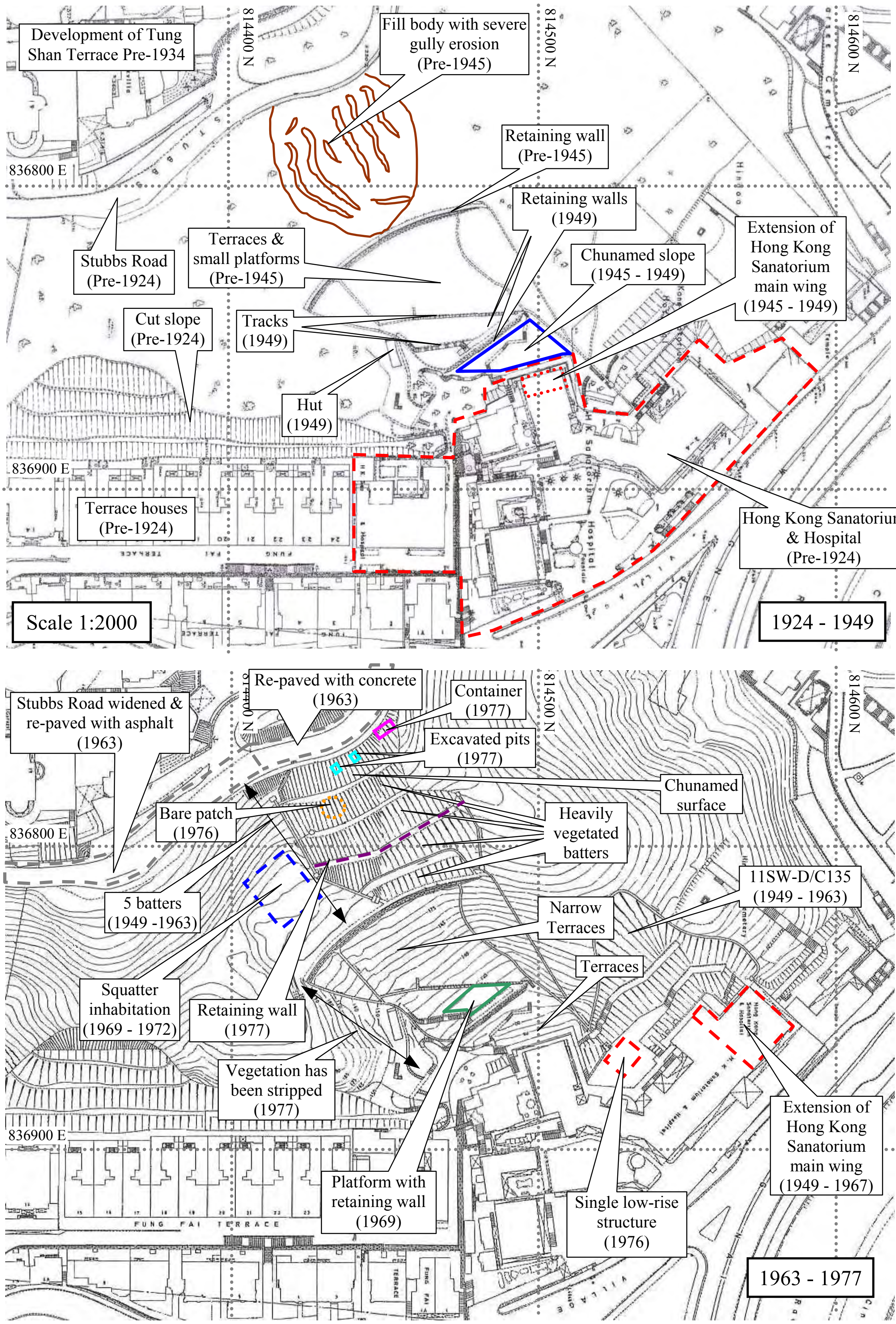
- A No.2 Re-developed between 1964 - 1972
- B No.3 Re-developed between 1994 - 1997
- C No.4 Re-developed between 1993 - 1994
- D No.5 Re-developed between 1980 - 1985
- E No.6 Re-developed between 1964 - 1972
- F No.7 Constructed between 1964 - 1972
- G No.7A Re-developed between 1994 - 1996
- H No.7B-C Re-developed work in progress (2002)
- I No.8 Re-developed betwwen 1974 - 1975
- J No.8A-B Constructed between 1949 - 1963
- K No.9 Constructed between 1949 - 1963
- L No.10 Constructed between 1949 - 1963
- M No.15 Re-developed betwwen 1991 - 1993
- N No.16 Re-developed between 1972 - 1974
- O No.17 Re-developed between 1981 - 1982
- P No.18 Re-developed between 1994 - 1998
- Q No.19 Re-developed between 1994 - 1998
- R No.20 Re-developed work in progress (2002)
- S No.21 Re-developed between 1999 - 2002
- T No.22 Re-developed between 1994 - 1997
- U No.23 Re-developed between 1988 - 1990
- V No.24 Re-developed between 1978 - 1979
- W No.28 - 30 Constructed between 1949 - 1963

Notes :

(1) Base Map is extracted from survey sheet No. 11SW-15C, scale 1 : 1000.
(2) General arrangement of the subject slope based on detailed topographic survey by CED Survey Division in May 2004.
(3) Geomorphology interpreted from 1924 aerial photographs.
(4) Estimated date of construction/demolition based on aerial photograph record.
(5) Sections 1 - 1 and 2 - 2 analysed by B & P in Phase II Landslide Study Report (B & P, 1978 b) shown for reference purposes.

Figure 4 - Development of Tung Shan Terrace

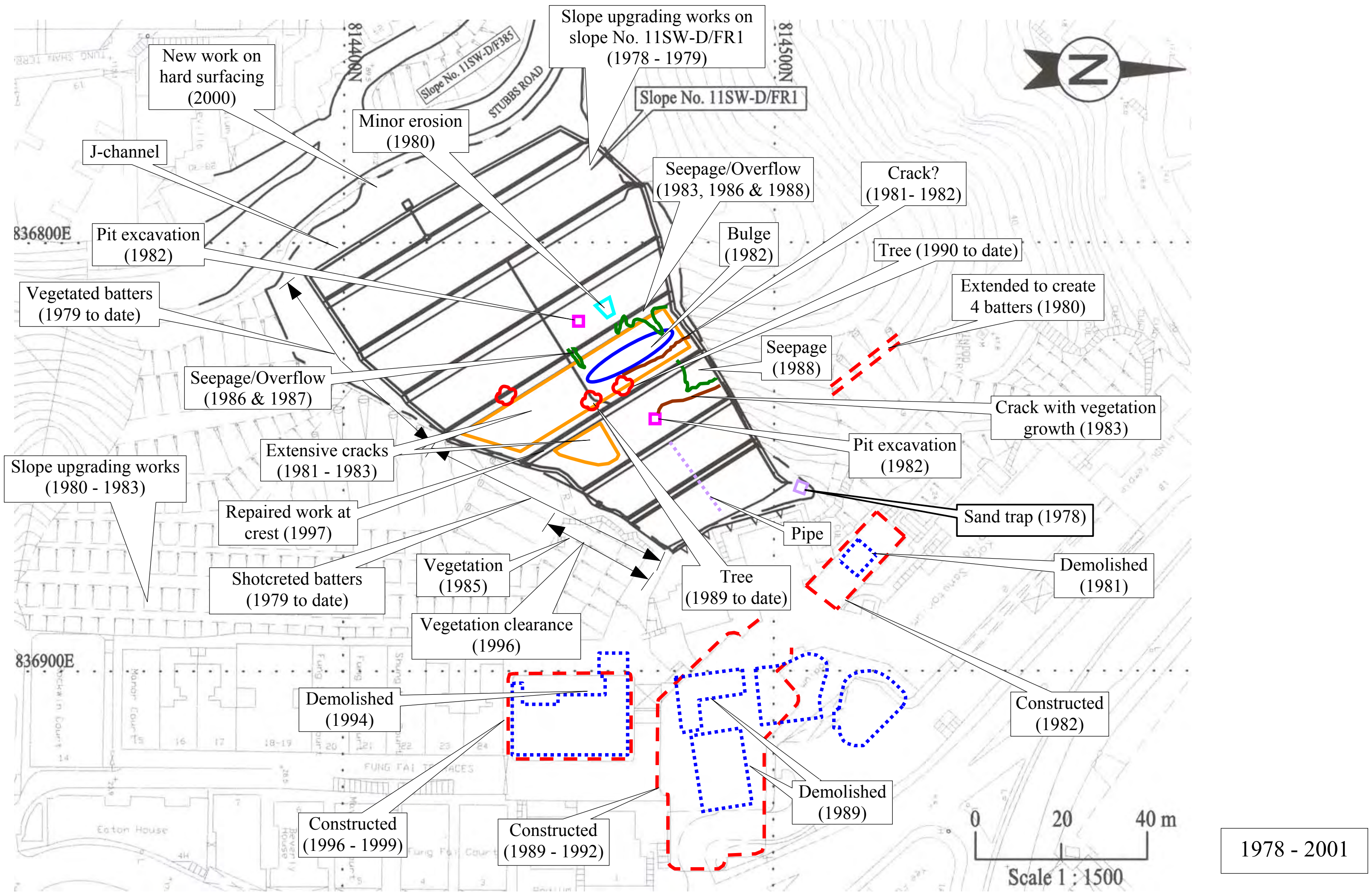
Table of Contents
Table of Contents
Table of Contents
Table of Contents



Notes: (1) Site History interpreted from aerial photograph record and factual account.
(2) Base map for 1945 - 1949 extracted from survey sheet nos. 213-NE-7, NE-8 & NE-12 (1959 ver.) & 213-NE-11 (1960 ver.) with scale 1:600.
(3) Base map for 1963 - 1977 extracted form survey sheet nos. C-213-NE-7 & NE-12 (1974 ver.) & C-213-NE-8 & NE-11 (1973 ver.) with scale 1:600.

Figure 5 - Site History (Sheet 1 of 2)

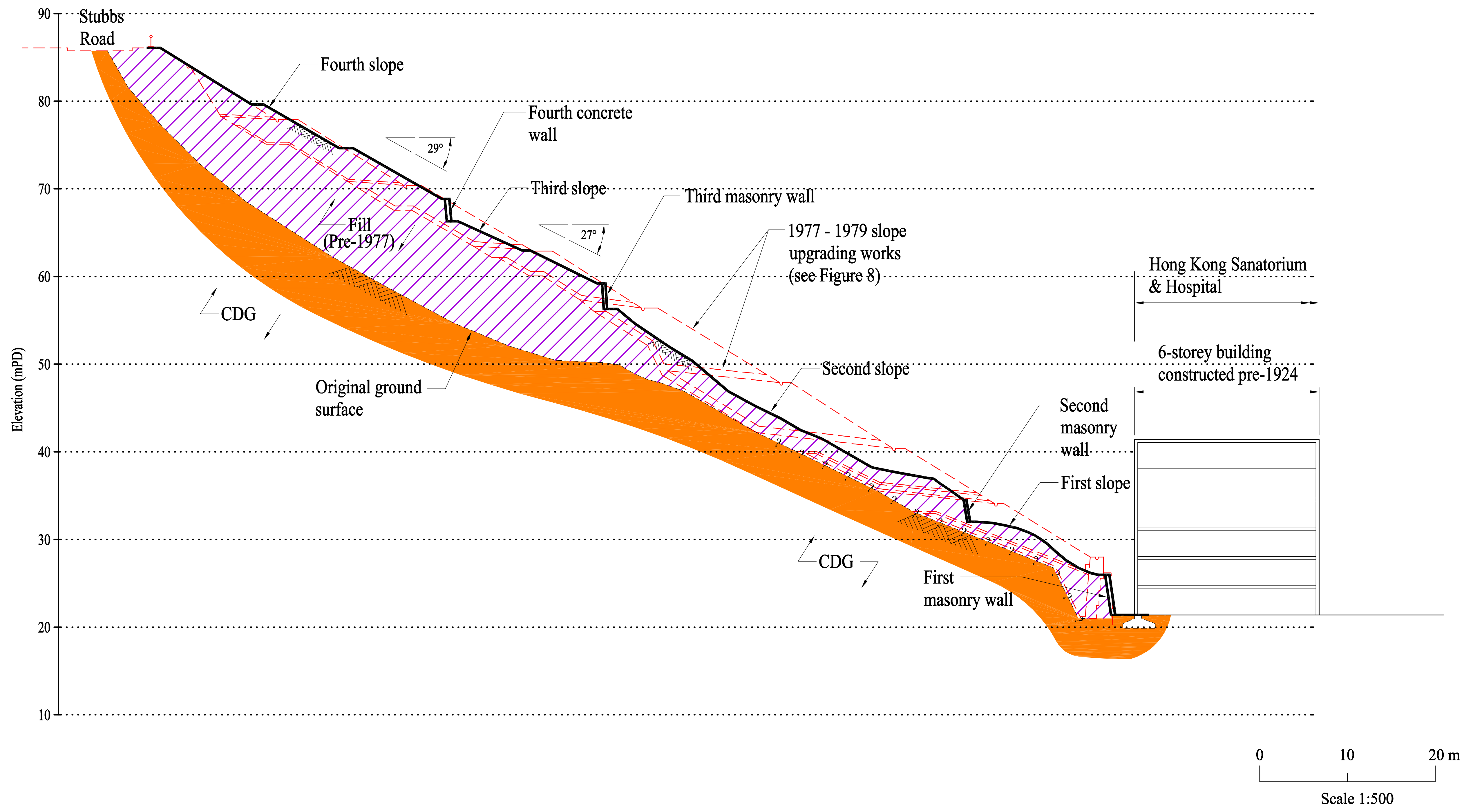
Table of Contents
Table of Contents
Table of Contents
Table of Contents



Notes:
(1) Site History interpreted from aerial photograph record and factual account.
(2) Base map extracted from survey sheet No. 11SW-15C scale 1:1000

Figure 6 - Site History (Sheet 2 of 2)

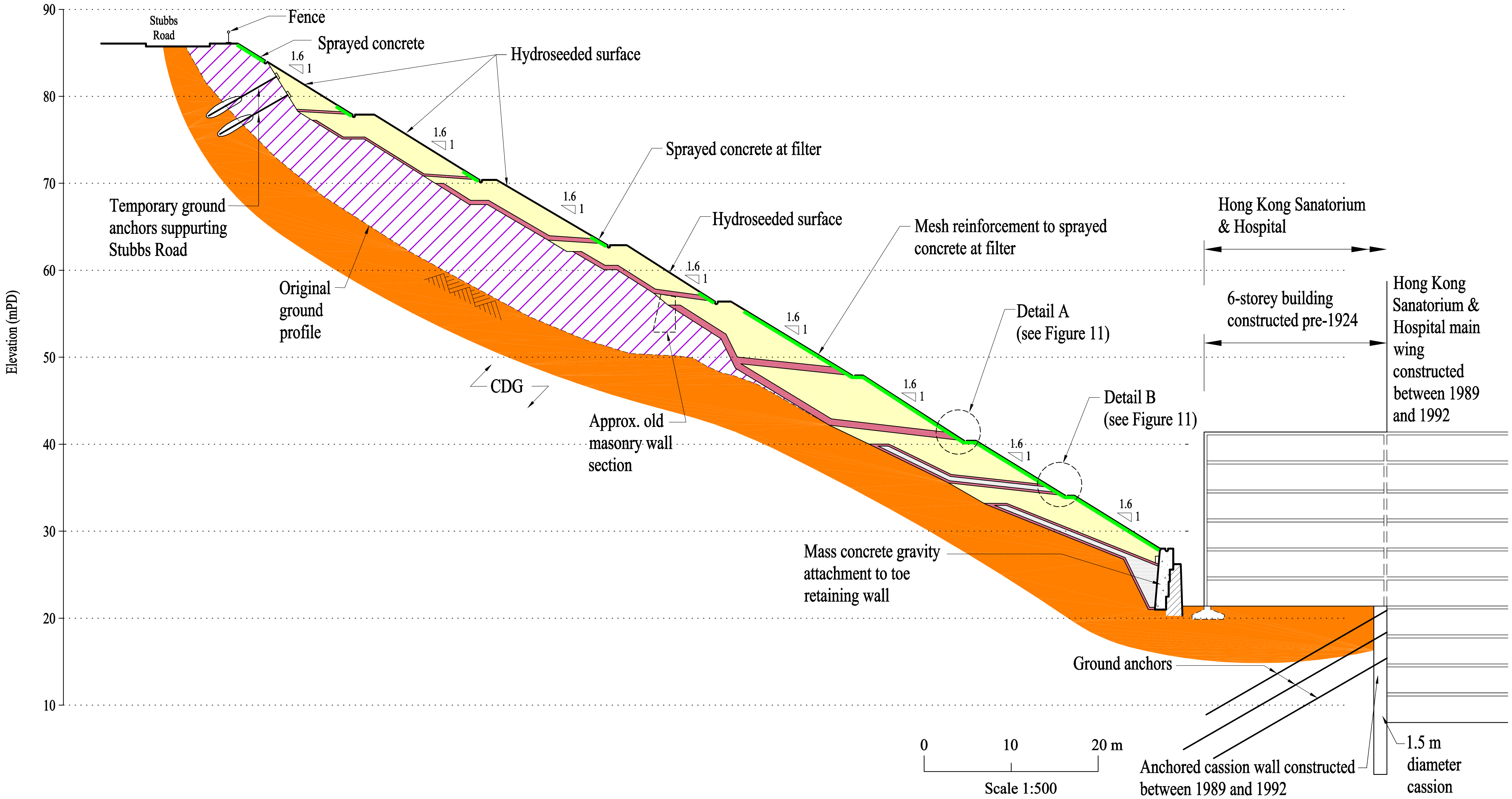
Table of Contents
Table of Contents
Table of Contents
Table of Contents



Notes :
(1) Cross-section based on pre-construction profile indicated in B & P (1980 b)
(2) As-constructed profile based on drawing no. H119/688/02R (B & P, 1980 C).
(3) Structure details of Hong Kong Sanatorium based on ref. 2/3047/88.
(4) For section location, see Figure 1.

Figure 7 - Cross-section A - A Through the Slope Prior to Upgrading Works in 1977

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



Legend :

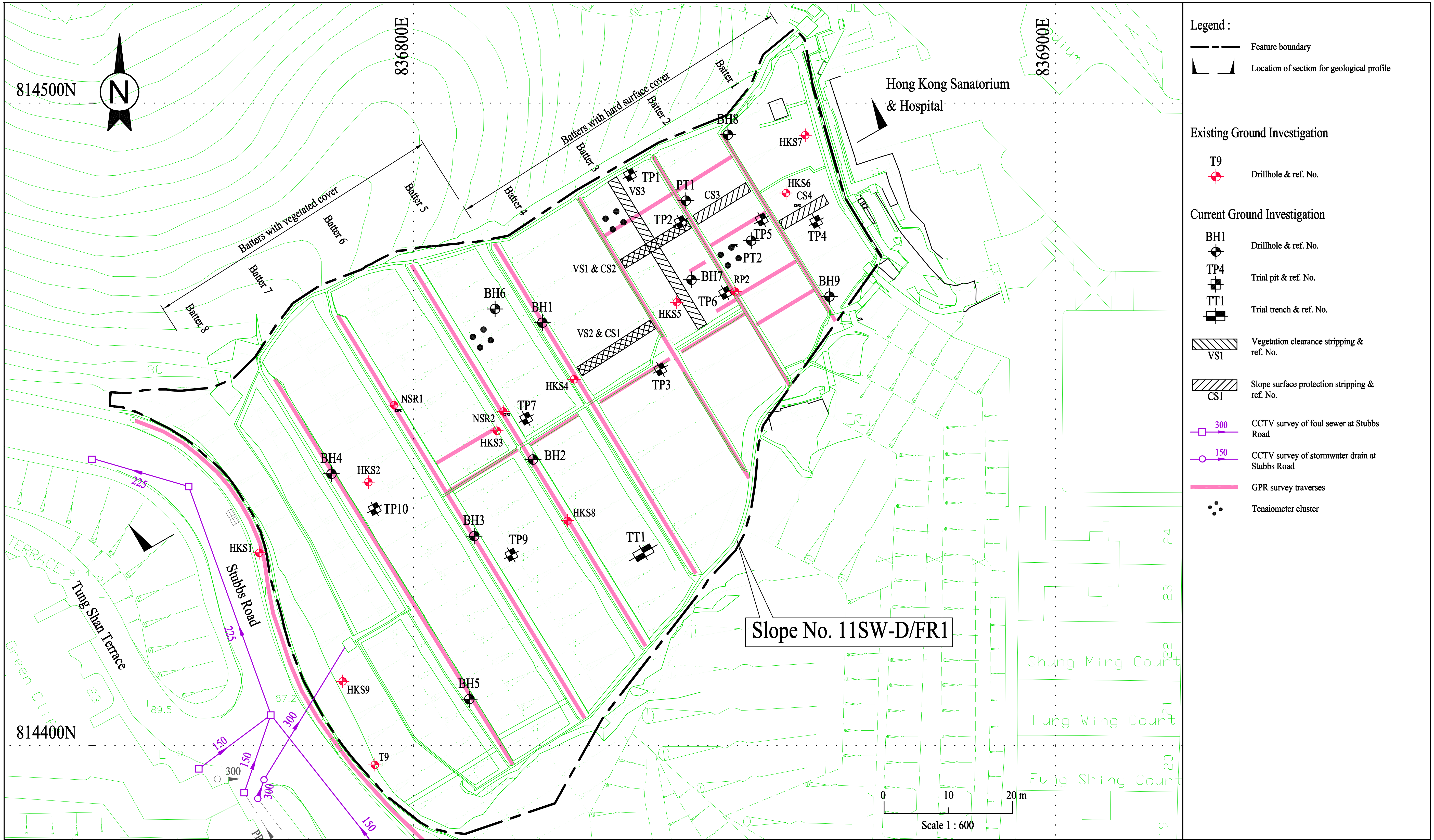
- Fill (1977 Re-construction)
- Fill (Pre-1977)
- Filter "A" (1977 Re-contruction)
- Filter "B" (1977 Re-contruction)
- Hard surface cover
- Completely decomposed granite

Notes :

(1) Cross-section based on as-built drawing no. H119/688/02 R (B & P, 1980).
(2) Struture details of Hong Kong Sanatorium & Hospital based on BD ref. 4/3047/88.
(3) For section location, see Figure 1.

Figure 8 - Cross-section A - A Through the Slope Following Upgrading Works

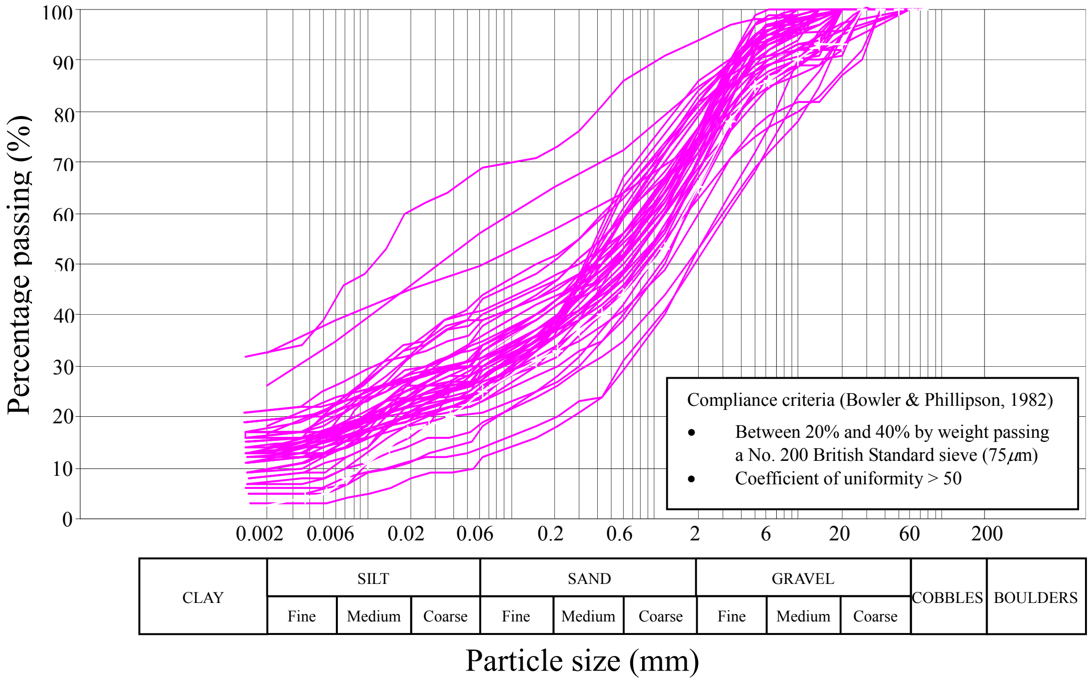
Table of Contents
Table of Contents
Table of Contents
Table of Contents



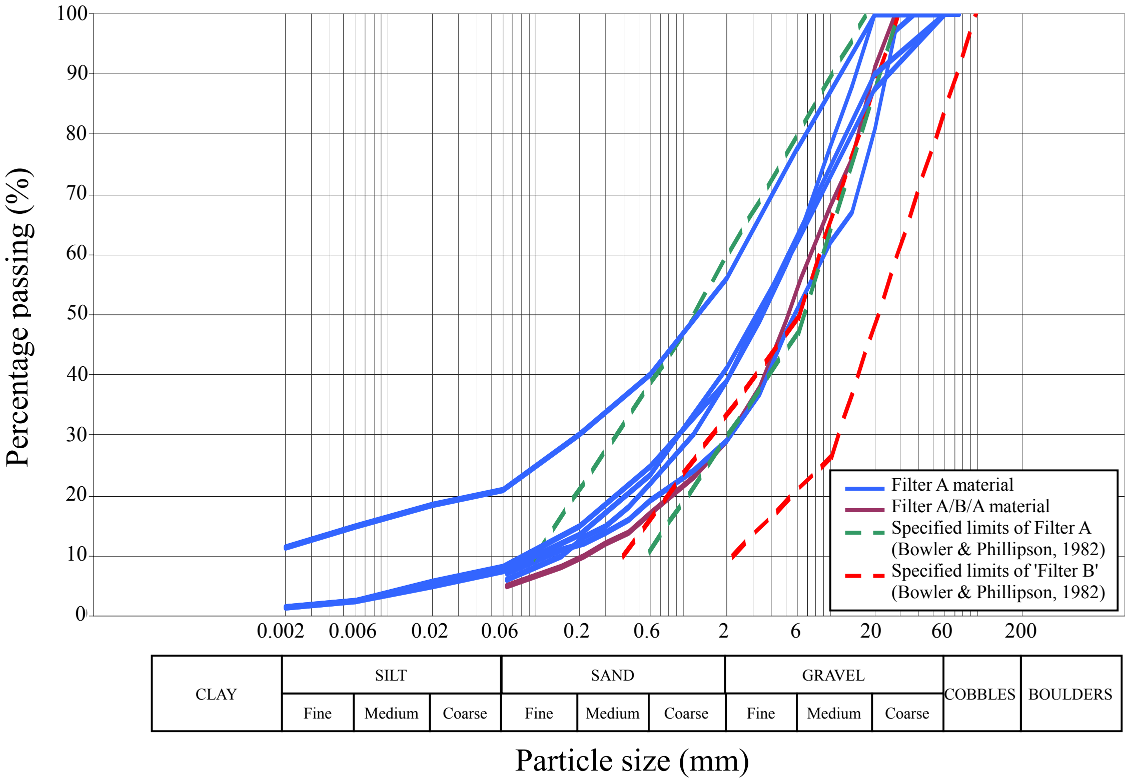
Notes :
(1) Base Map is extracted from survey sheet No. 11SW-15C, scale 1 : 1000.
(2) General arrangement of the subject slope based on detailed topographic survey by CED Survey Division in May 2004.
(3) Refer Figure 15 for geological profile.

Figure 9 - Location of Ground Investigation Stations

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



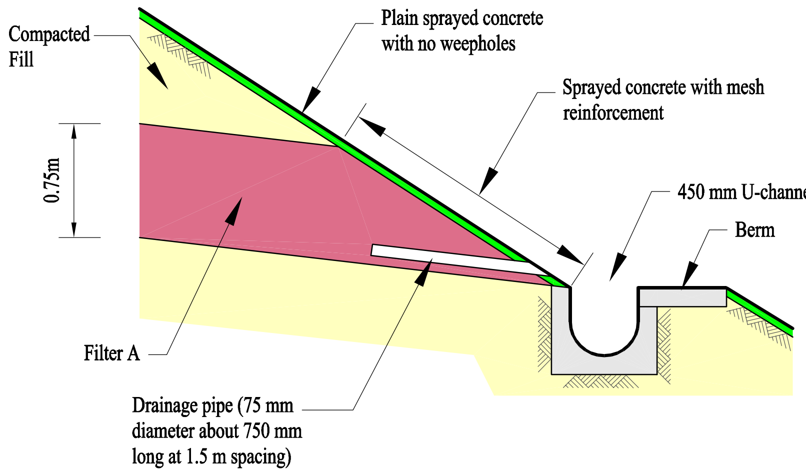
(a) Particle Size Distribution - Compacted Fill



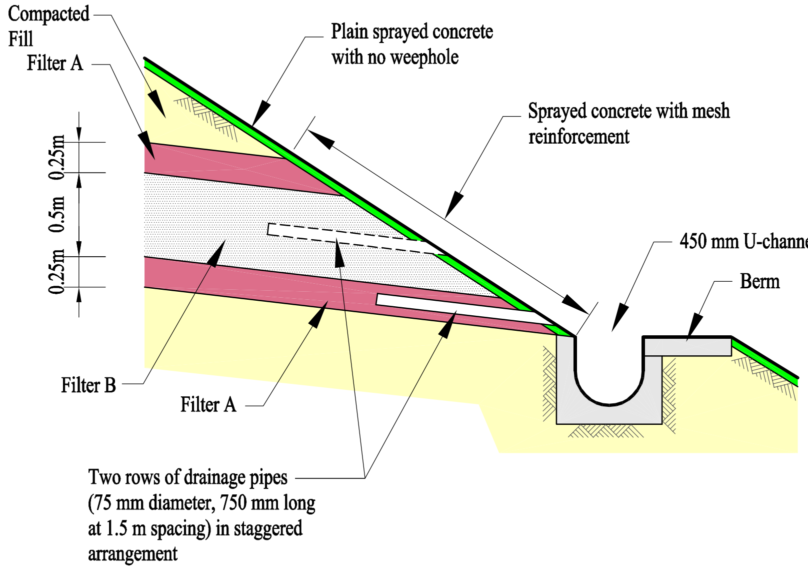
(b) Particle Size Distribution - Filter Materials

Figure 10 - Particle Size Distribution Plots - Compacted Fill and Filter

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



Detail A (Section)
Scale 1 : 50

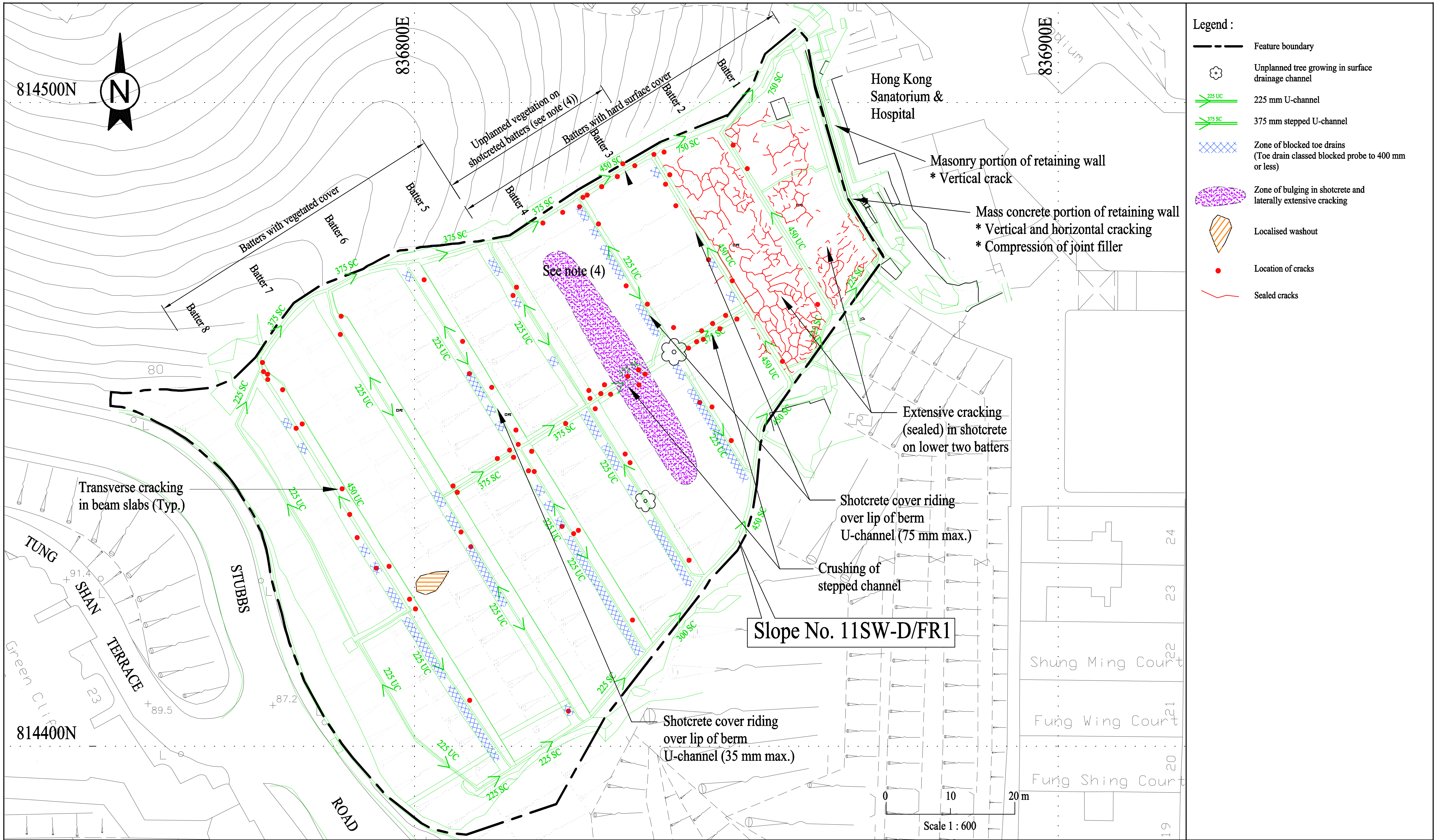


Detail B (Section)
Scale 1 : 50

Notes: (1) Refer to Figure 8 for locations of Details A & B.
(2) Details extracted from as-built drawings no. H119/688/02 R (B&P, 1980)

Figure 11 - Berm Drainage Details

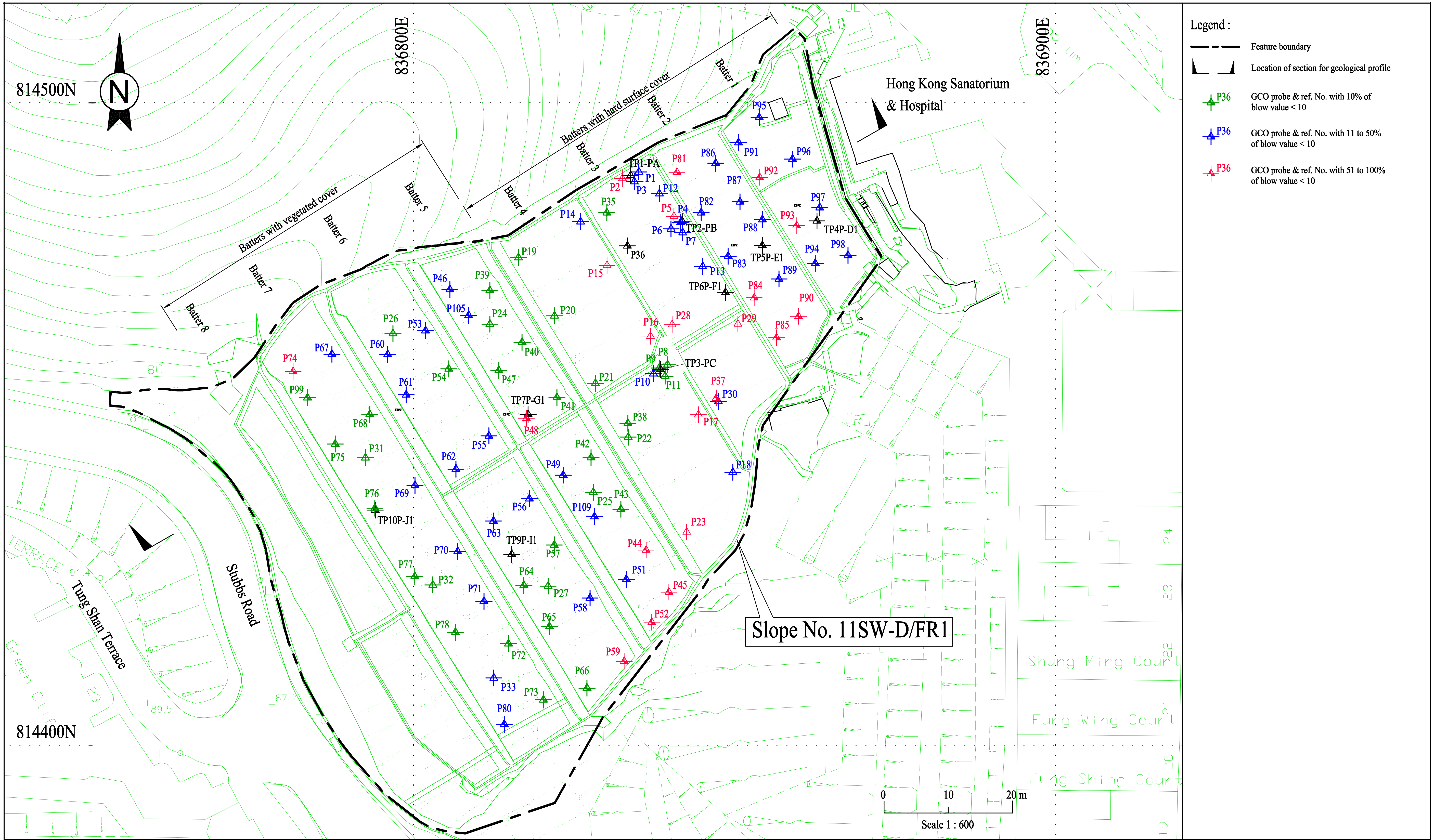
Table of Contents
Table of Contents
Table of Contents
Table of Contents



Notes :
(1) Base Map is extracted from survey sheet No. 11SW-15C, scale 1 : 1000.
(2) General arrangement of the subject slope based on detailed topographic survey by CED Survey Division in May 2004.
(3) Toe drains classed blocked able to be probed < 400 mm.
(4) Cracking on third and fourth batters above toe unable to be mapped in detail due to heavy growth of unplanned vegetation.

Figure 12 - Generalised Distress Map

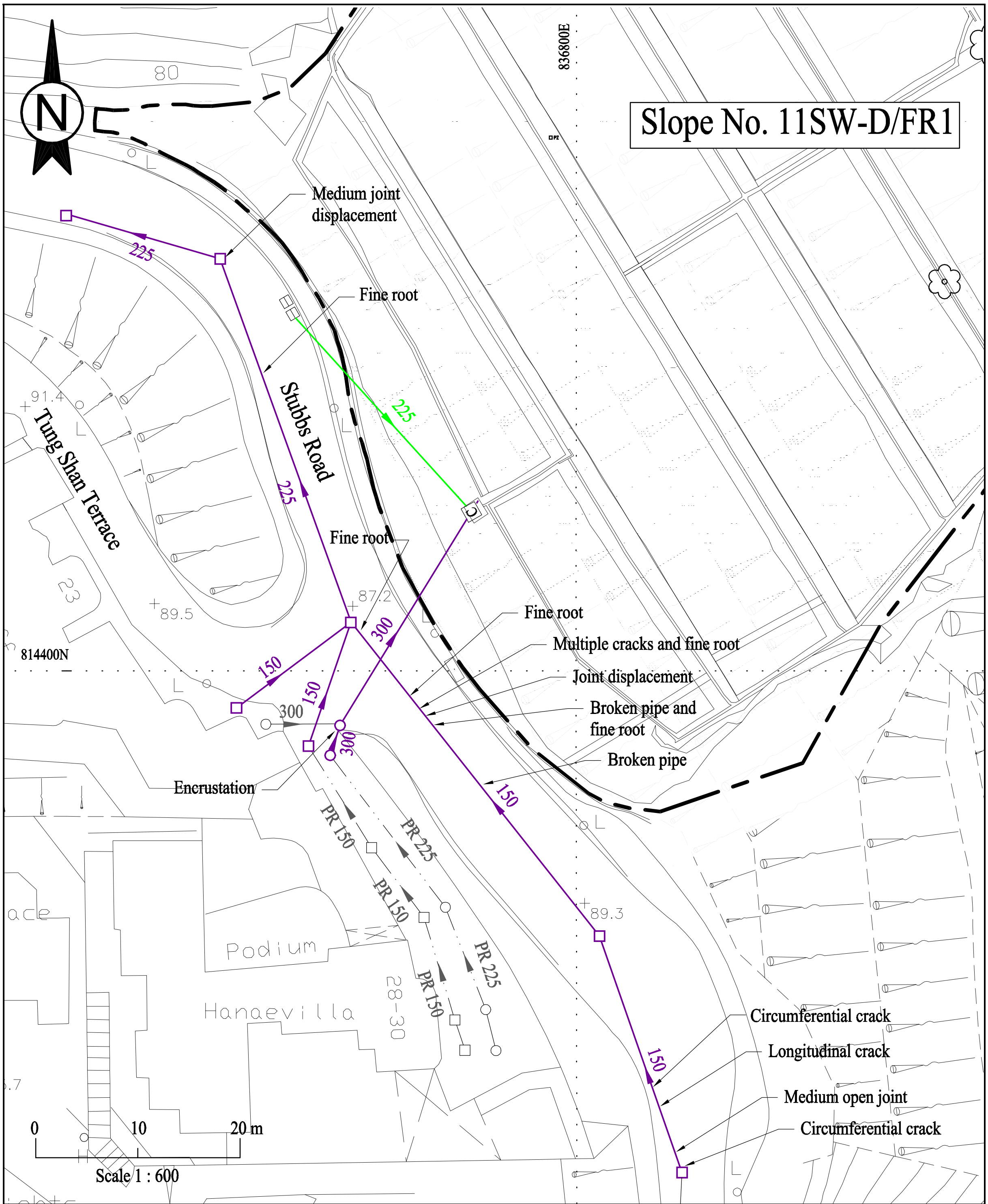
Table of Contents
Table of Contents
Table of Contents
Table of Contents



Notes :
(1) Base Map is extracted from survey sheet No. 11SW-15C, scale 1 : 1000.
(2) General arrangement of the subject slope based on detailed topographic survey by CED Survey Division in May 2004.
(3) Refer Figure 15 for geological profile.

Figure 13 - Locations of GCO Probe Tests

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



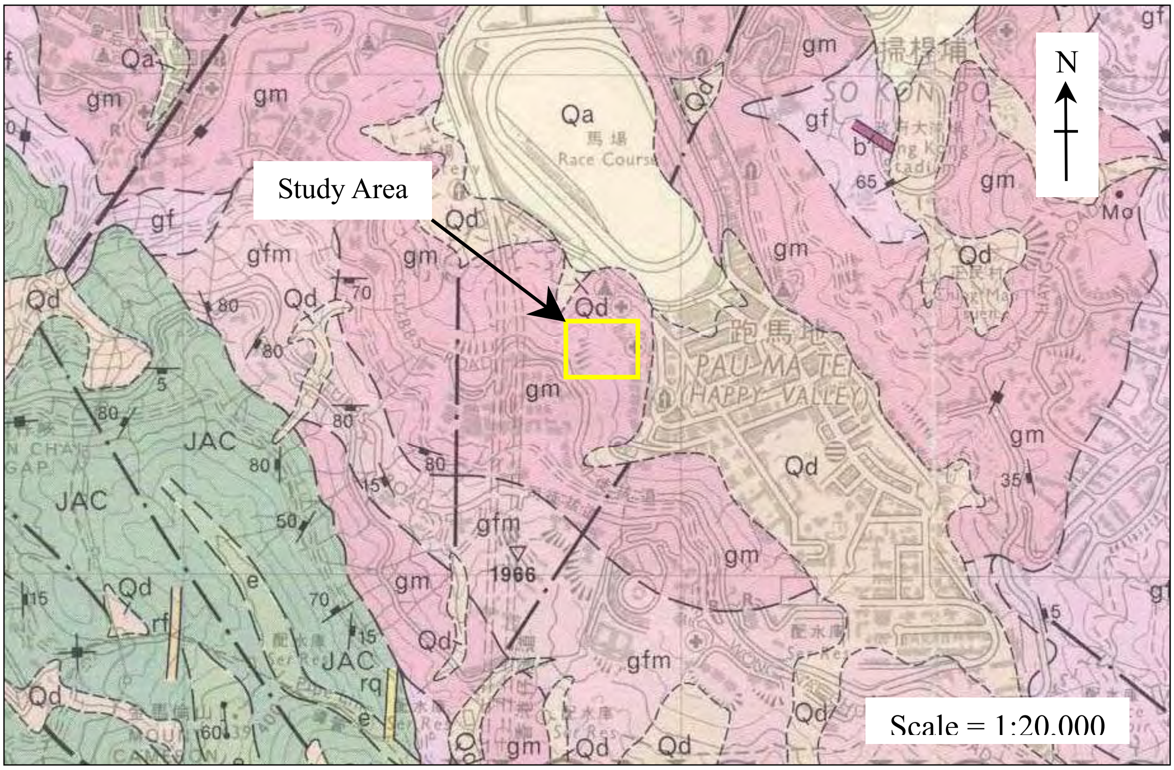
Legends :

Feature boundary	300 CCTV survey by FSW at existing public foul sewer (size indicated)	PR 225 Existing private stormwater drains (size indicated)	Roadside gully
150 CCTV survey by FSW at existing public stormwater drains (size indicated)	300 Existing public stormwater drains (size indicated)	PR 150 Existing private foul sewer (size indicated)	C Catchpit
	225 CCTV survey carried out by Highways Department at existing roadside stormwater drains on 3 June 2004		

Notes : (1) Base Map is extracted from survey sheet No. 11SW-15C, scale 1 : 1000.
(2) General arrangement of the subject slope based on detailed topographic survey by CED Survey Division in May 2004.

Figure 14 - Results of CCTV Survey on 2 August 2004

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



Legend:

Quaternary Superficial Deposits (Onshore)

	Fill; Sanitary Fill (Qfs)-Natural Earth and Waste
Qa	Alluvium - Clay/silt, Sand and Gravel; Well-sorted to Semi-sorted
Qd	Debris Flow Deposits - Unsorted Sand, Gravel, Cobbles and Boulders; Clay/Silt Matrix

Solid Geology

JAC	Fine Ash Vitric Tuff	b	Basalt
e	Eutaxite	rq	Quartzphyric Rhyolite
gf	Fine-grained Granite, < 2mm	rf	Feldsparphyic Rhyolite
gfm	Fine- to Medium-grained Granite	gm	Medium-grained Granite, 2-6mm

Geological Lines

- Geological Boundary, Superficial Deposits
- Geological Boundary, Solid Rock
- Fault (Crossmark indicates Downthrow Side)
- Photogelogical Lineament
- * Broken Lines on Map Face denote Uncertainty

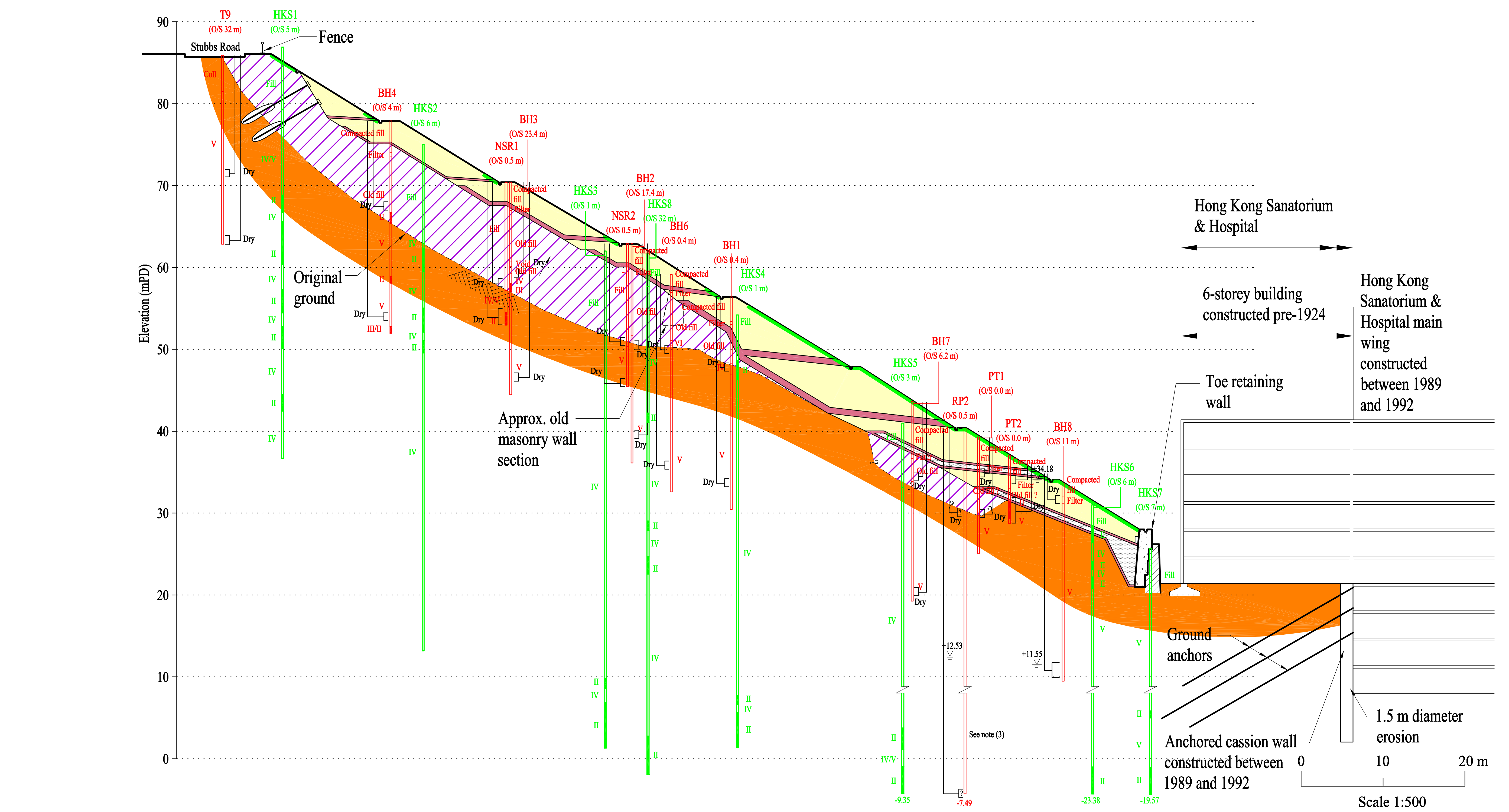
Other Symbol

- ▽ 1983 Important Slope Failure, with Date

Notes: (1) Geology relevant to study area shown bold.
(2) Extract from Sheet 11 of the Hong Kong Geolgoical Survey 1:20,000 scale Map Series HGM20 (GCO, 1986).

Figure 15 - Solid and Superficial Geology of the Study Area

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



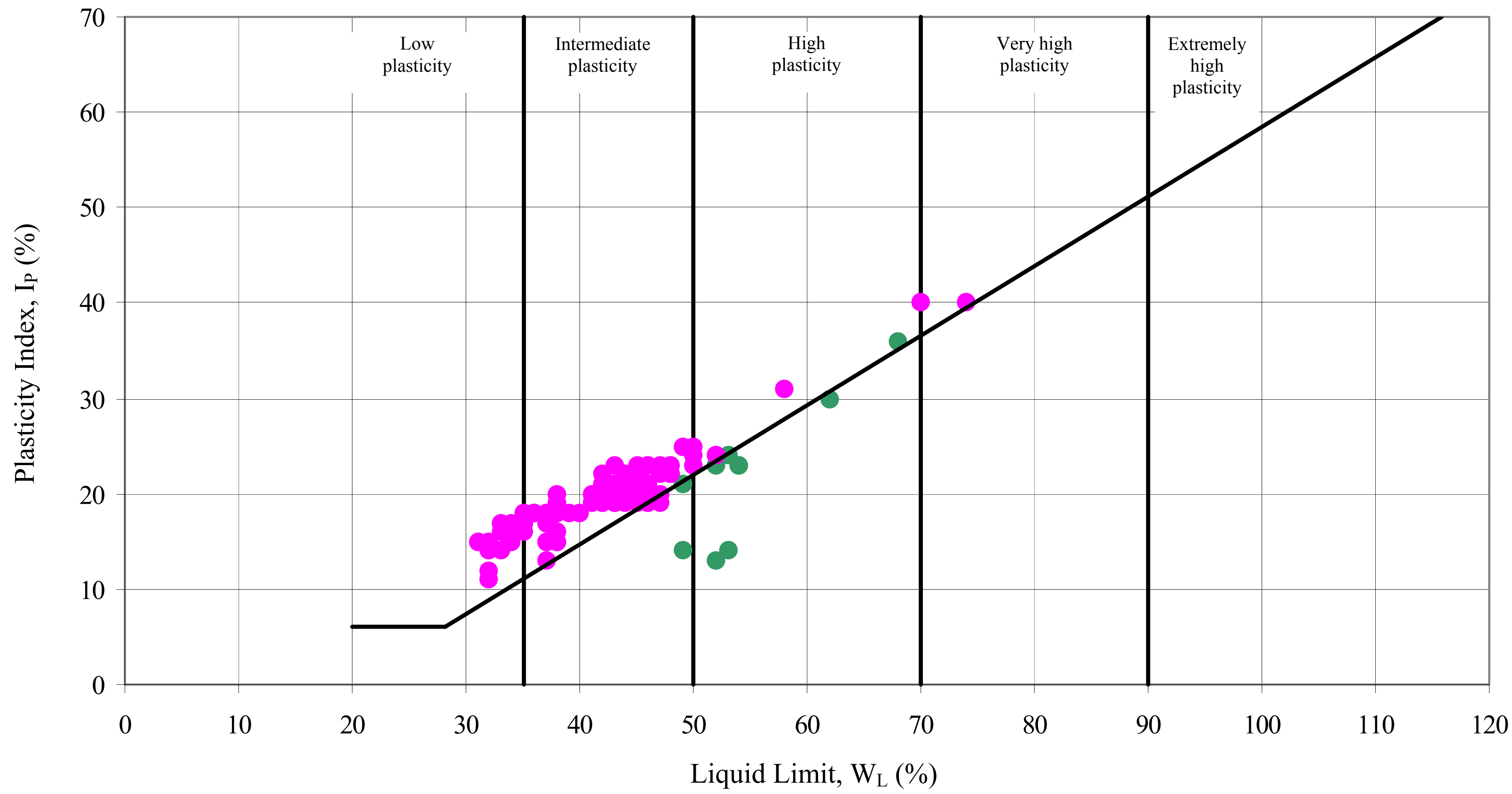
Legend :

Fill	Fill	Compacted Fill (1977 Re-construction)	Filter "A" (1977 Re-contruction)	T9 Drillhole (with existing piezometer)	Piezometer response zone	+12.53 Ground water level as measured on 15 Oct 2004
COLL	Colluvium	Fill (Pre-1977)	Filter "B" (1977 Re-contruction)	HKS1 Drillhole (without existing piezometer)	Piezometer response zone not known	
V/IV/III/II	Completely/Highly/Moderately/Slightly Decomposed Granite	Hard surface cover	Completely decomposed granite			

Note :
(1) Cross-section based on as-built drawing no. H119/688/02 R (B & P, 1980).
(2) Structure details of Hong Kong Sanatorium based on BD ref. 4/3047/88.
(3) For section location, see Figure 1.
(4) Details of soil strata not known.

Figure 16 - Geological Profile

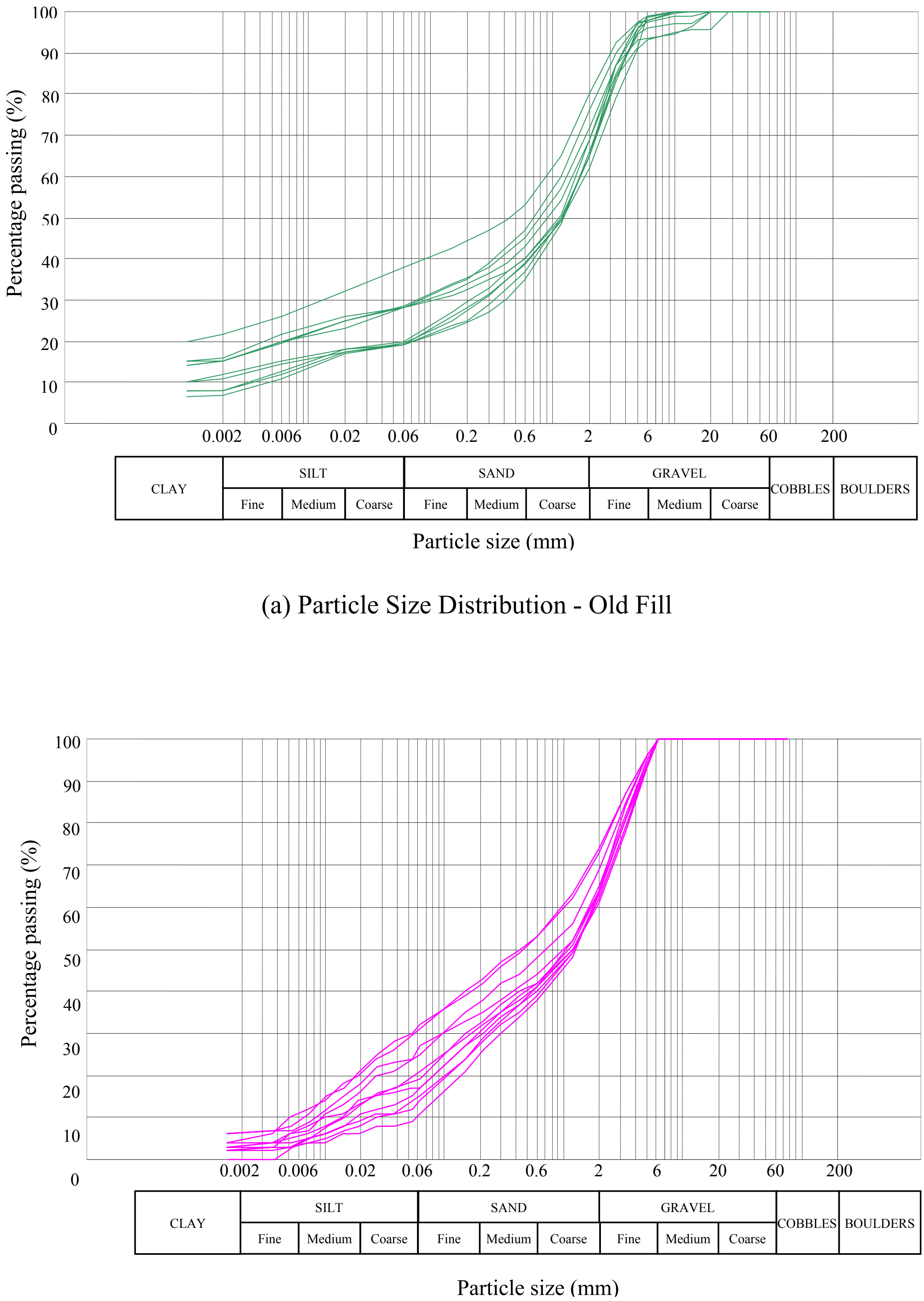
Table of Contents
Table of Contents
Table of Contents
Table of Contents



Legend:
Compacted fill
Old fill

Figure 17 - Plasticity Chart - Compacted Fill and Old Fill

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

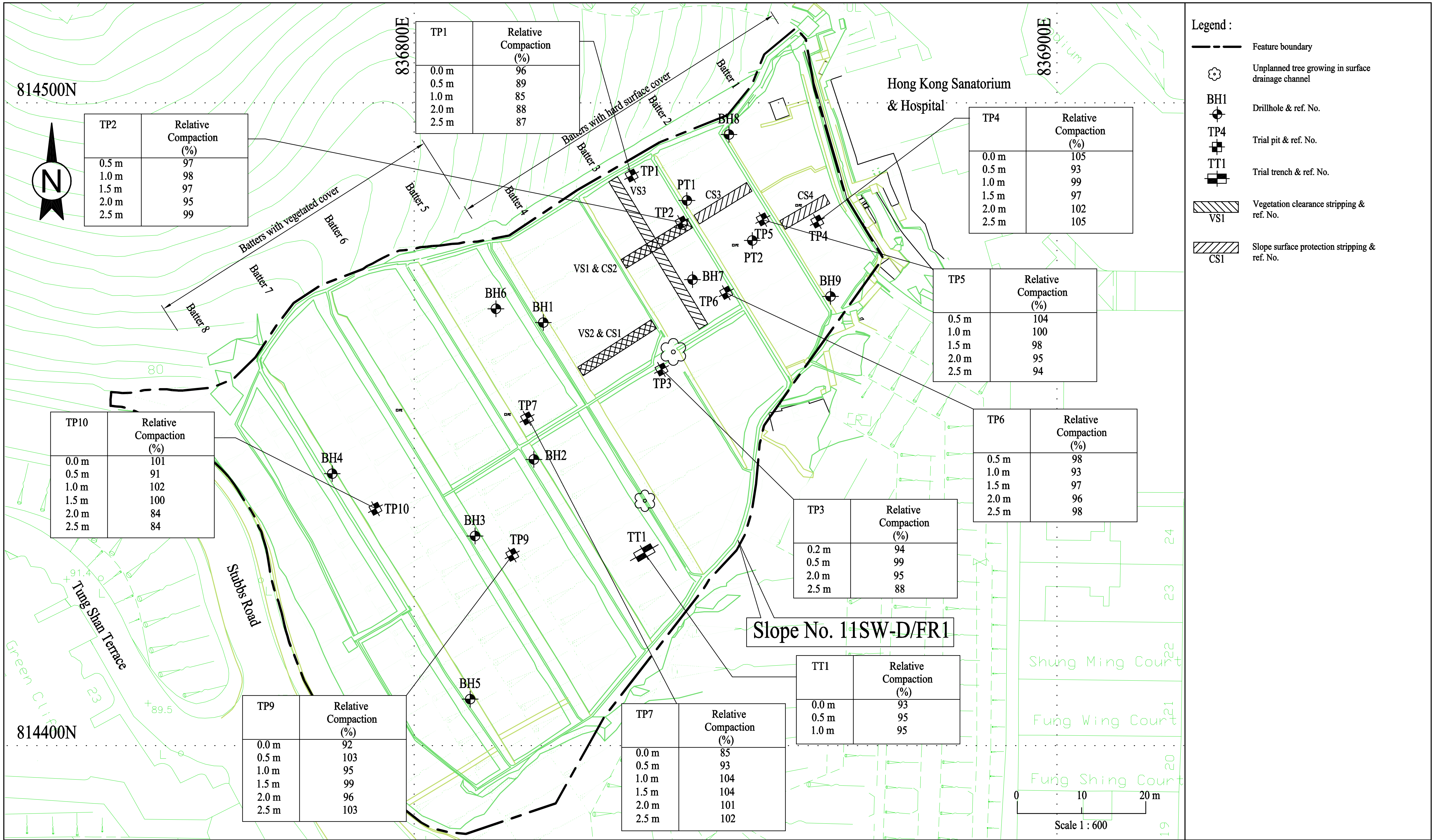


(a) Particle Size Distribution - Old Fill

(b) Particle Size Distribution - CDG

Figure 18 - Particle Size Distribution Plots - Old Fill and CDG

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



TP1	Relative Compaction (%)
0.0 m	96
0.5 m	89
1.0 m	85
2.0 m	88
2.5 m	87

TP2	Relative Compaction (%)
0.5 m	97
1.0 m	98
1.5 m	97
2.0 m	95
2.5 m	99

TP4	Relative Compaction (%)
0.0 m	105
0.5 m	93
1.0 m	99
1.5 m	97
2.0 m	102
2.5 m	105

TP5	Relative Compaction (%)
0.5 m	104
1.0 m	100
1.5 m	98
2.0 m	95
2.5 m	94

TP6	Relative Compaction (%)
0.5 m	98
1.0 m	93
1.5 m	97
2.0 m	96
2.5 m	98

TP10	Relative Compaction (%)
0.0 m	101
0.5 m	91
1.0 m	102
1.5 m	100
2.0 m	84
2.5 m	84

TP3	Relative Compaction (%)
0.2 m	94
0.5 m	99
2.0 m	95
2.5 m	88

TT1	Relative Compaction (%)
0.0 m	93
0.5 m	95
1.0 m	95

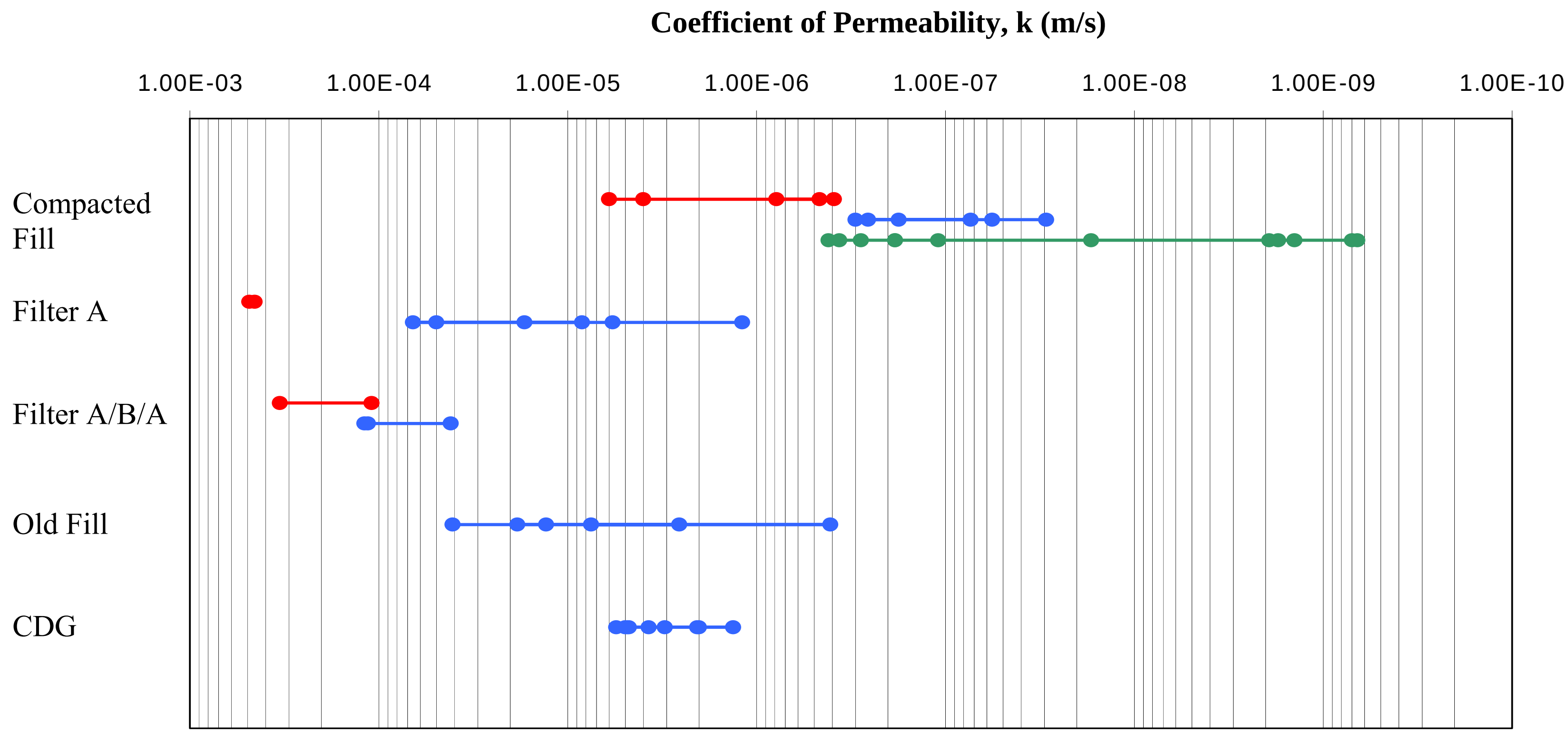
TP9	Relative Compaction (%)
0.0 m	92
0.5 m	103
1.0 m	95
1.5 m	99
2.0 m	96
2.5 m	103

TP7	Relative Compaction (%)
0.0 m	85
0.5 m	93
1.0 m	104
1.5 m	104
2.0 m	101
2.5 m	102

Notes :
(1) Base Map is extracted from survey sheet No. 11SW-15C, scale 1 : 1000.
(2) General arrangement of the subject slope based on detailed topographic survey by CED Survey Division in May 2004.

Figure 19 - Distribution of Relative Compaction on Slope

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



Legend:

Range of permeability constant, k (m/s) calculated from Constant Head Permeability Tests in drillhole

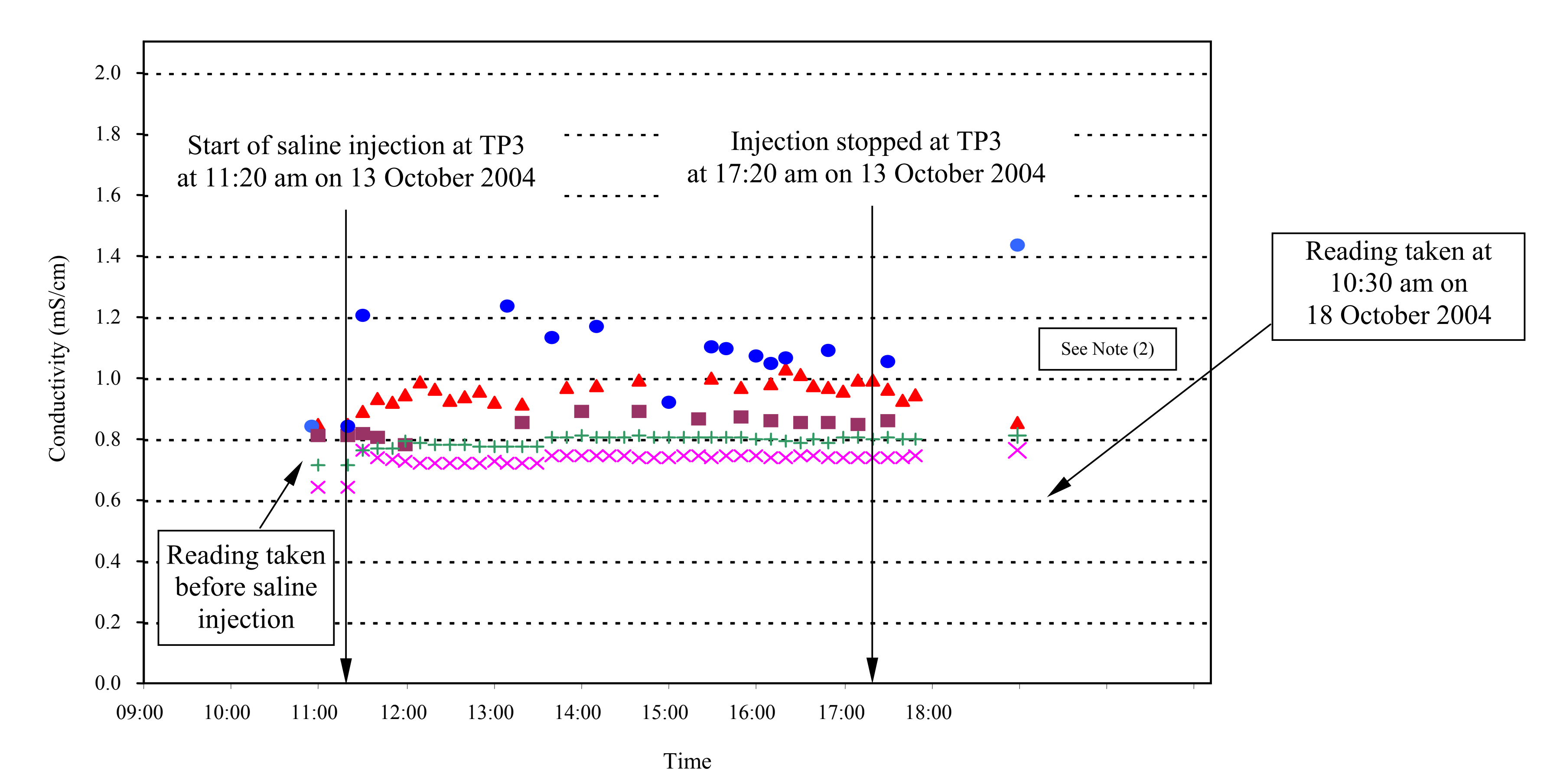
Range of permeability constant, k (m/s) calculated from double-ring infiltrometer permeability tests in trial pits

Range of saturated permeability constant, k_s (m/s) calculated from laboratory tests on undisturbed samples

, , Data point

Figure 20 - Results of Permeability Tests

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



Legend:
Conductivity Monitoring Points

× TP2	▲ TP5 (Lower)	■ TP6 (Upper)
+ TP6 (Lower)	● PT2 (Upper)	

Notes: (1) Conductivity of injected saline solution > 100 mS/cm.
(2) The piezometer TP6 (Upper) was dry on 18 October 2004.

Figure 21 - Results of Saline Tracing Tests

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

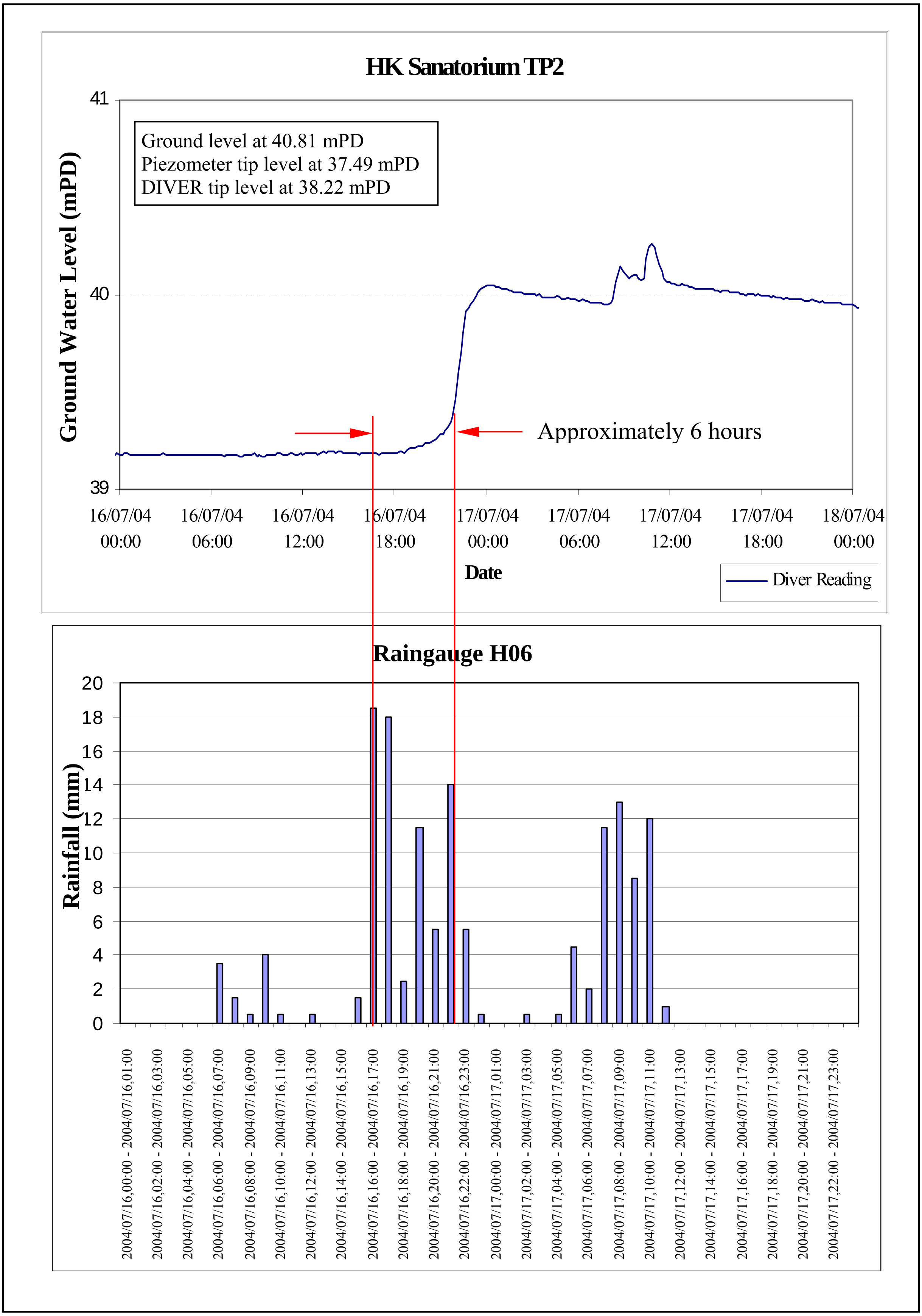


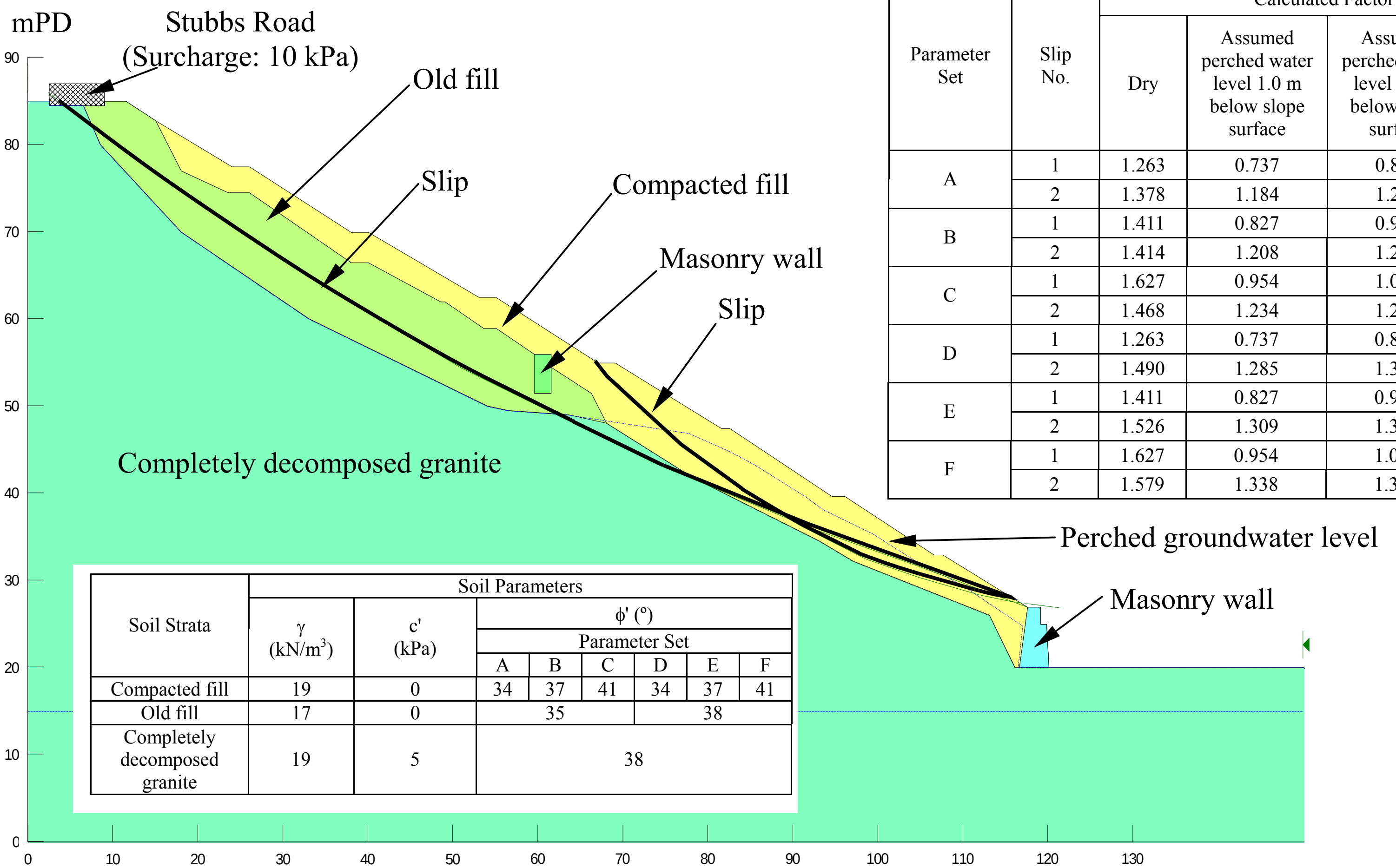
Figure 22 - Groundwater Response to Rainfall

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

Notes : (1) Base Map is extracted from survey sheet No. 11SW-15C, scale 1 : 1000.
(2) General arrangement of the subject slope based on detailed topographic survey by CED Survey Division in May 2004.

Figure 23 - Ground Penetrating Radar Survey

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



Parameter Set	Slip No.	Calculated Factor of Safety: Dry	Assumed perched water level 1.0 m below slope surface	Assumed perched water level 1.5 m below slope surface	Assumed perched water level 2.0 m below slope surface
A	1	1.263	0.737	0.820	0.885
	2	1.378	1.184	1.211	1.224
B	1	1.411	0.827	0.916	0.988
	2	1.414	1.208	1.229	1.249
C	1	1.627	0.954	1.056	1.140
	2	1.468	1.234	1.264	1.287
D	1	1.263	0.737	0.820	0.885
	2	1.490	1.285	1.313	1.334
E	1	1.411	0.827	0.916	0.988
	2	1.526	1.309	1.334	1.354
F	1	1.627	0.954	1.056	1.140
	2	1.579	1.338	1.368	1.391

Soil Strata	Soil Parameters: γ (kN/m^3)	c' (kPa)	ϕ' (°) Parameter Set A	B	C	D	E	F
Compacted fill	19	0	34	37	41	34	37	41
Old fill	17	0	35			38		
Completely decomposed granite	19	5	38					

Notes: (1) General arrangement of the subject slope is based on detailed topographic survey by CED Survey Division in May 2004.
(2) Geological ground profile of the subject slope is based on the as-constructed drawing by Binnie & Partners in Nov 1980 and recent ground investigation.
(3) The properties of the compacted fill are based on the recent laboratory testing results. The range of the parameter sets considered in the analysis covers lower bound to best fit values obtained form undisturbed samples and remoulded samples at insitu relative compaction.

Figure 24 - Theoretical Stability Analyses

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

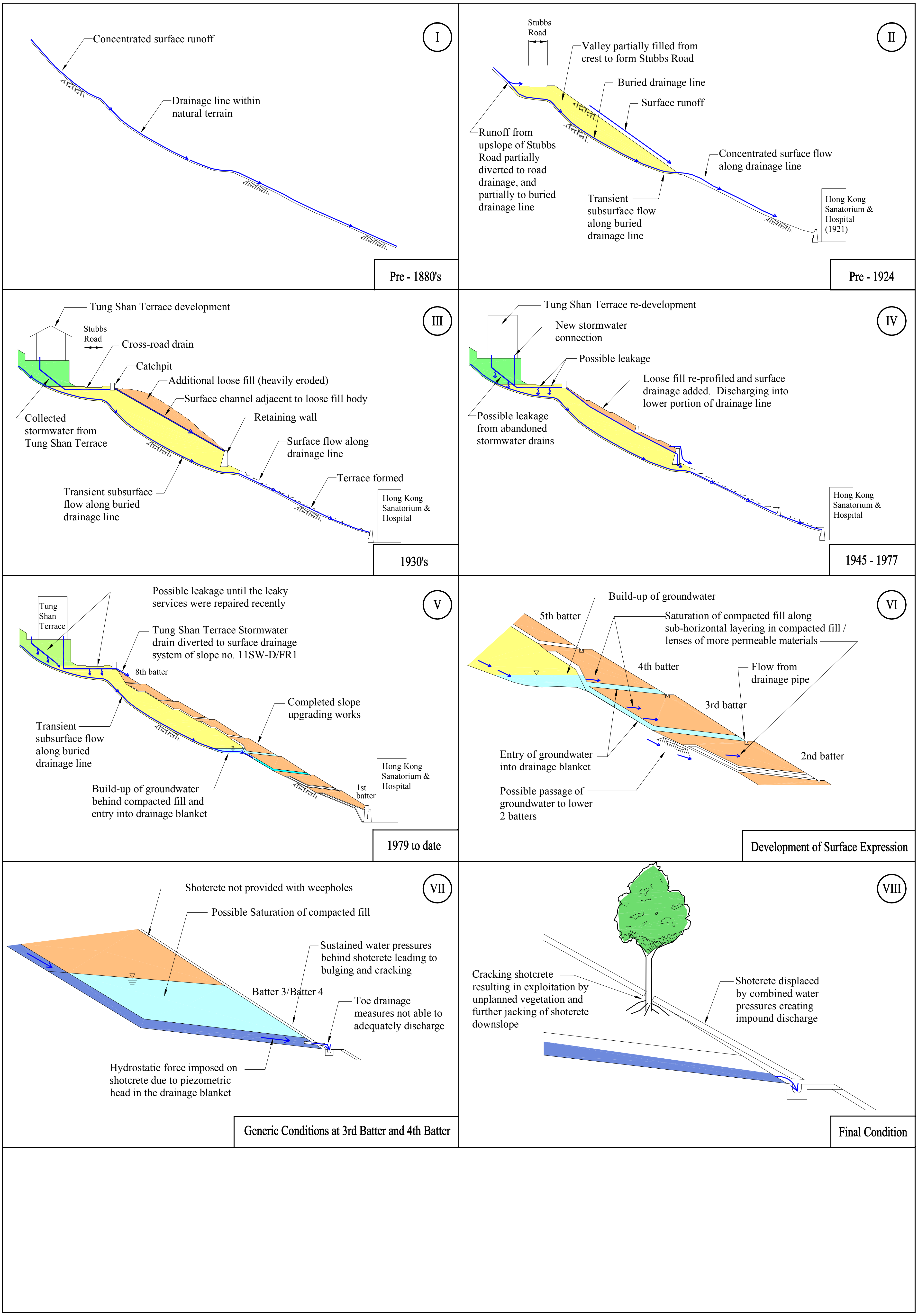


Figure 25 - Postulated Sequence of Event

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

LIST OF PLATES

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

Table of Contents
Table of Contents
Table of Contents

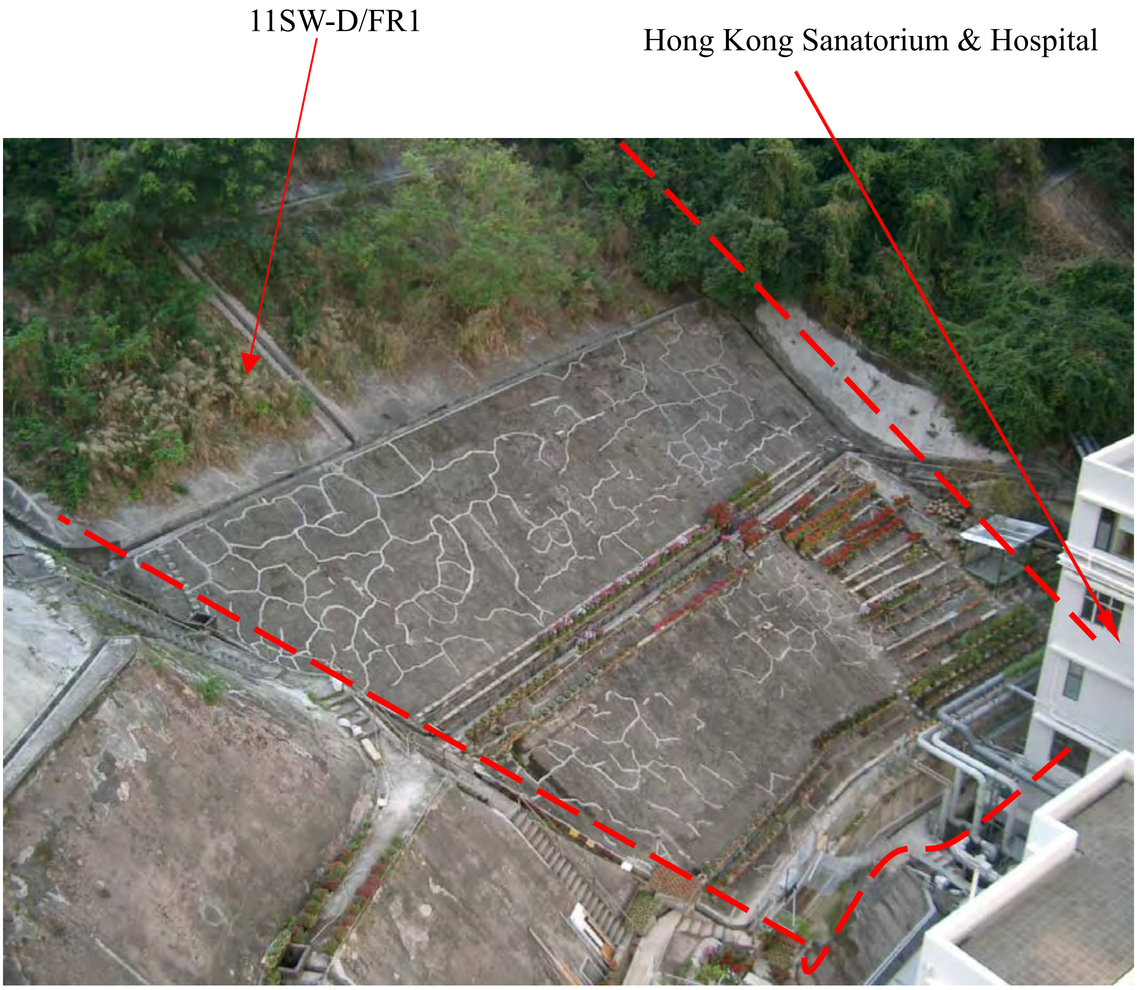


Plate 1 - General View of Lower Portion of Slope No. 11SW-D/FR1
(Photograph taken on 12 March 2004)

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

Plate 2 - General View of Hong Kong Sanatorium and Hospital Complex
(Photograph taken on 29 October 2004)

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

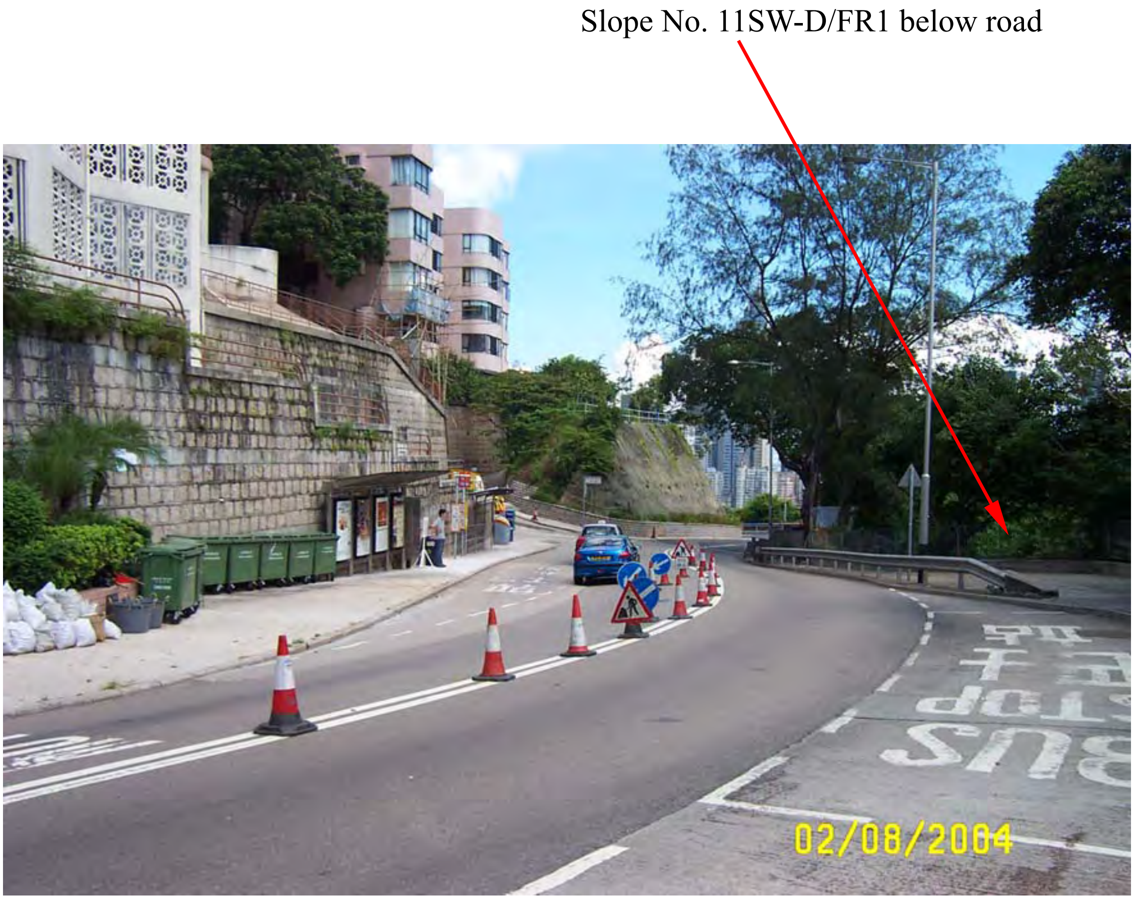


Plate 3 - General View Northwest along Stubbs Road at Crest of Slope No. 11SW-D/FR1
(Photograph taken on 02 August 2004)

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

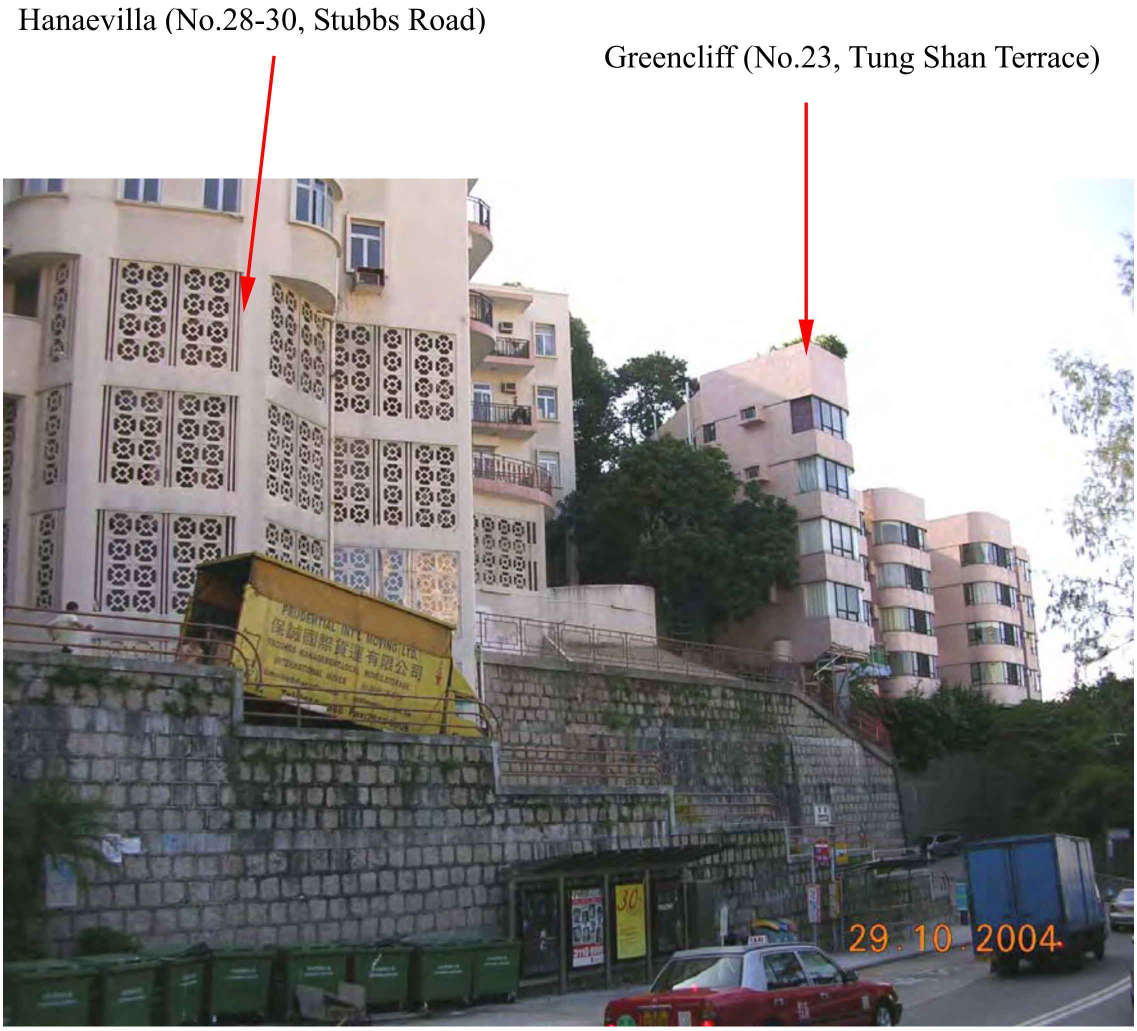


Plate 4 - General View Towards Tung Shan Terrace from Stubbs Road
(Photograph taken on 29 October 2004)

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

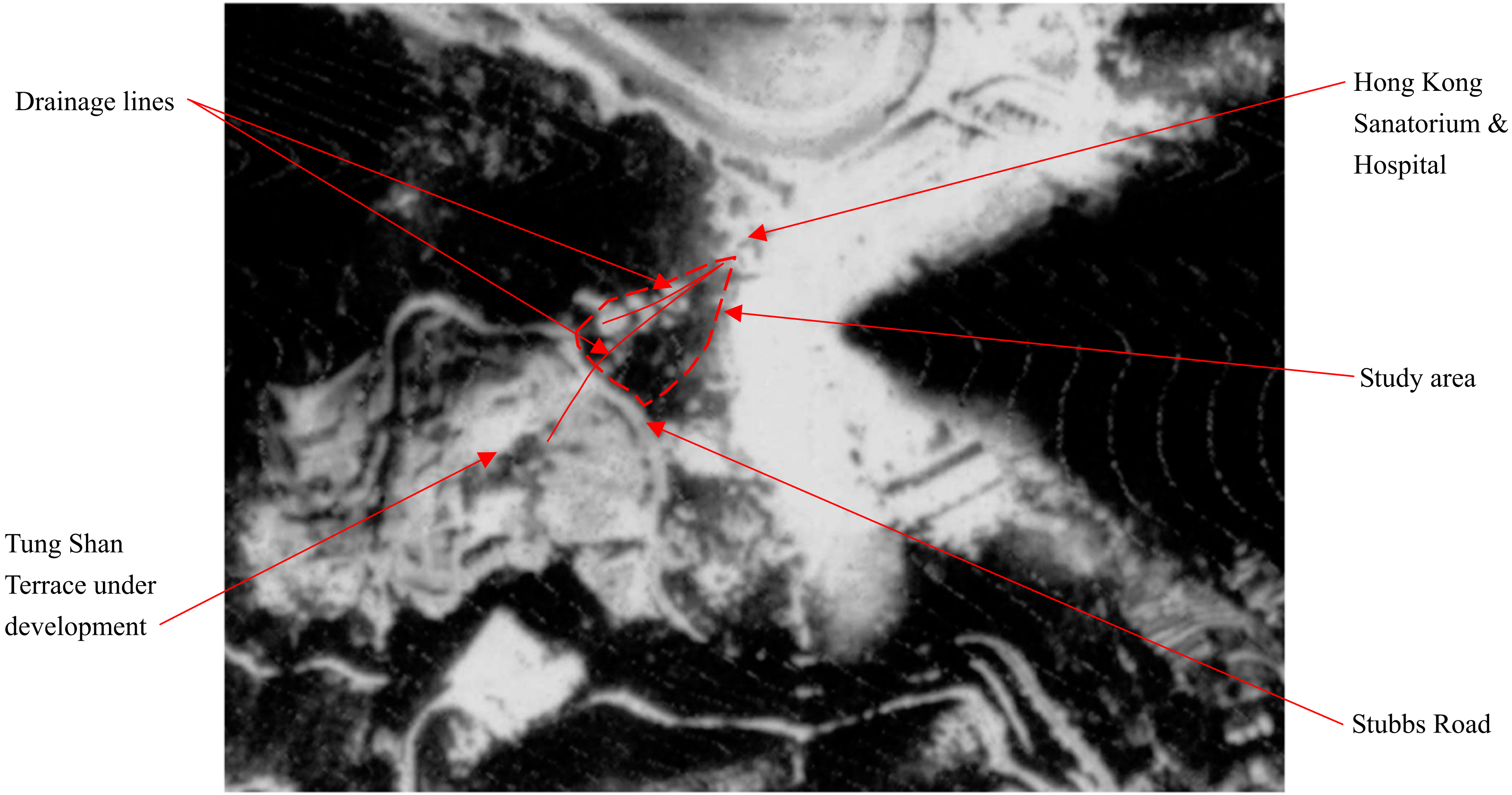


Plate 5 - Aerial View of Study Area in 1924

Note: Plate extracted from aerial photograph ref Y00037.

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

Plate 6 - Aerial View of Study Area in 1945

Note: Plate extracted from aerial photograph ref Y00470.

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

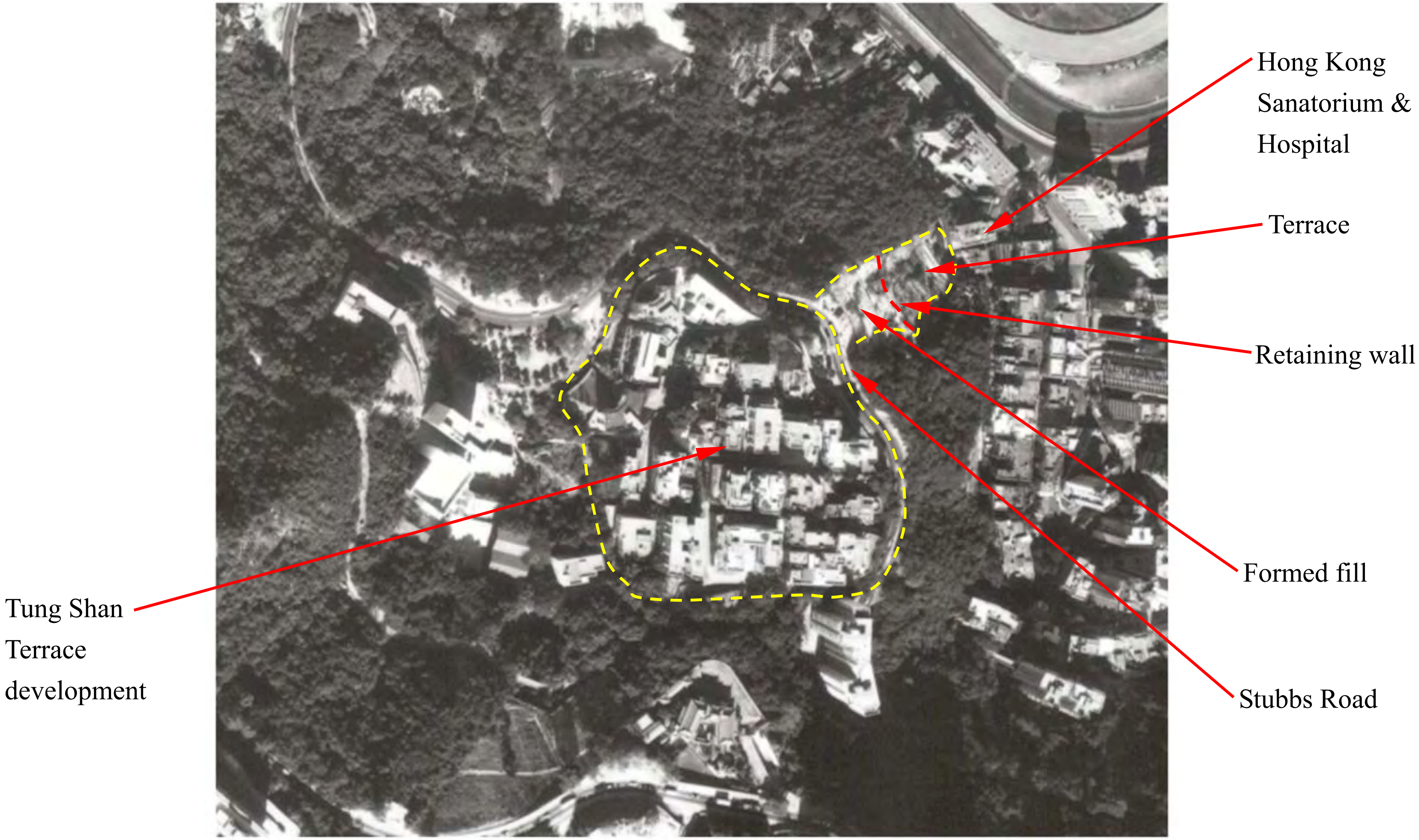


Plate 7 - Aerial View of Study Area in 1977

Note: Plate extracted from aerial photograph ref 20460.

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

Plate 8 - Aerial View of Study Area in 1978

Note: Plate extracted from aerial photograph ref 23870.

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

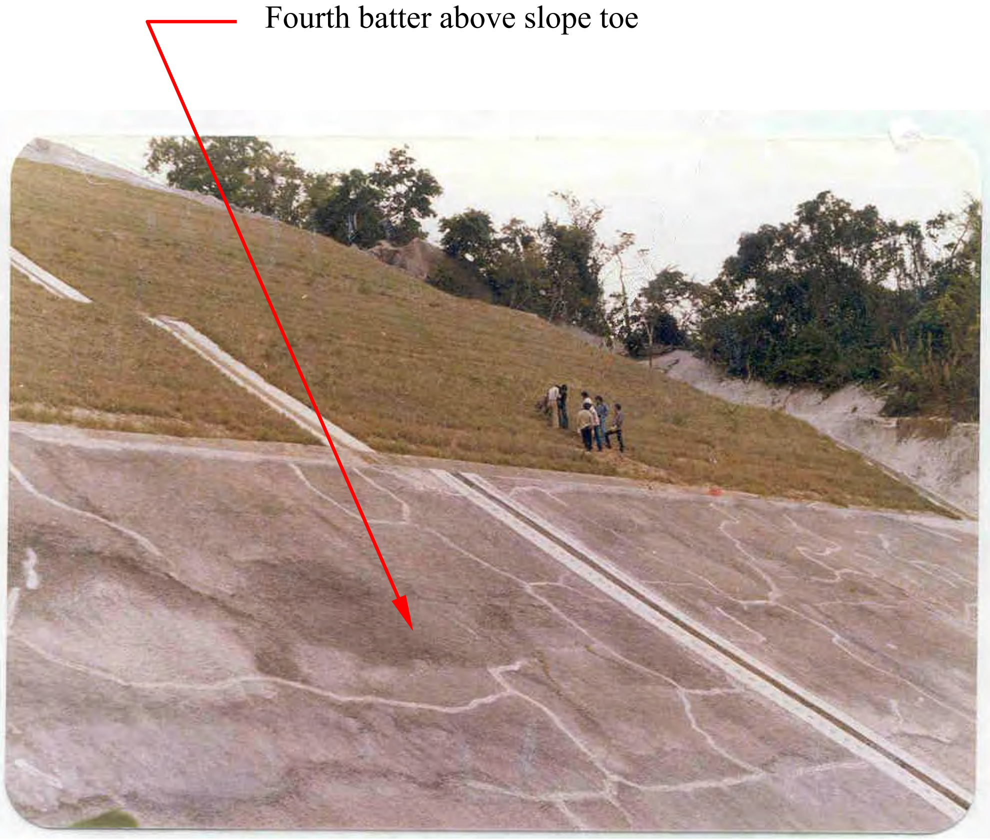


Plate 9 - View Northwest across Fourth Batter above Slope Toe showing Extensive Cracking on Shotcreted Surface in 1980

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

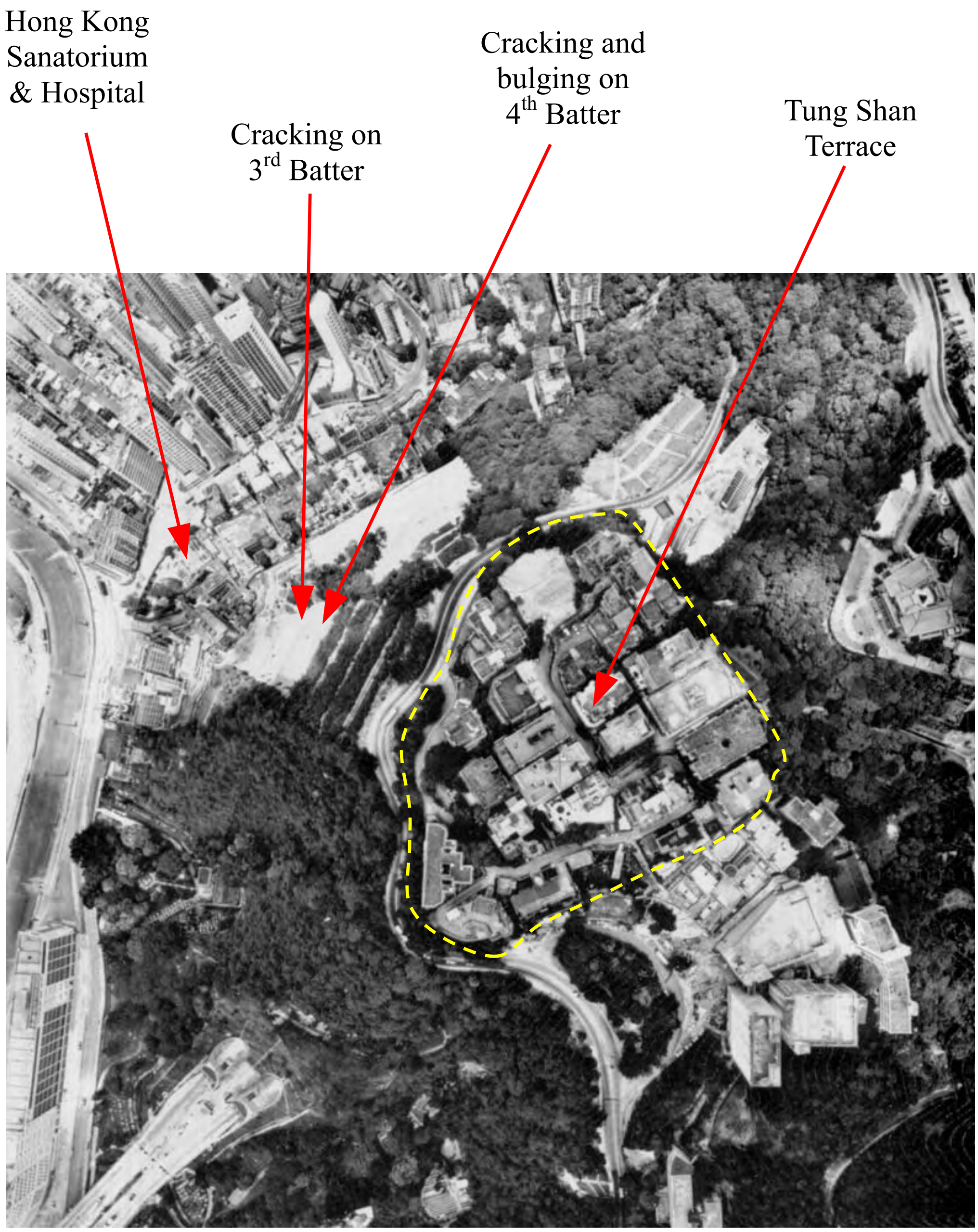


Plate 10 - Aerial View of Study Area in 1983

Note: Plate extracted from aerial photograph ref 49248

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

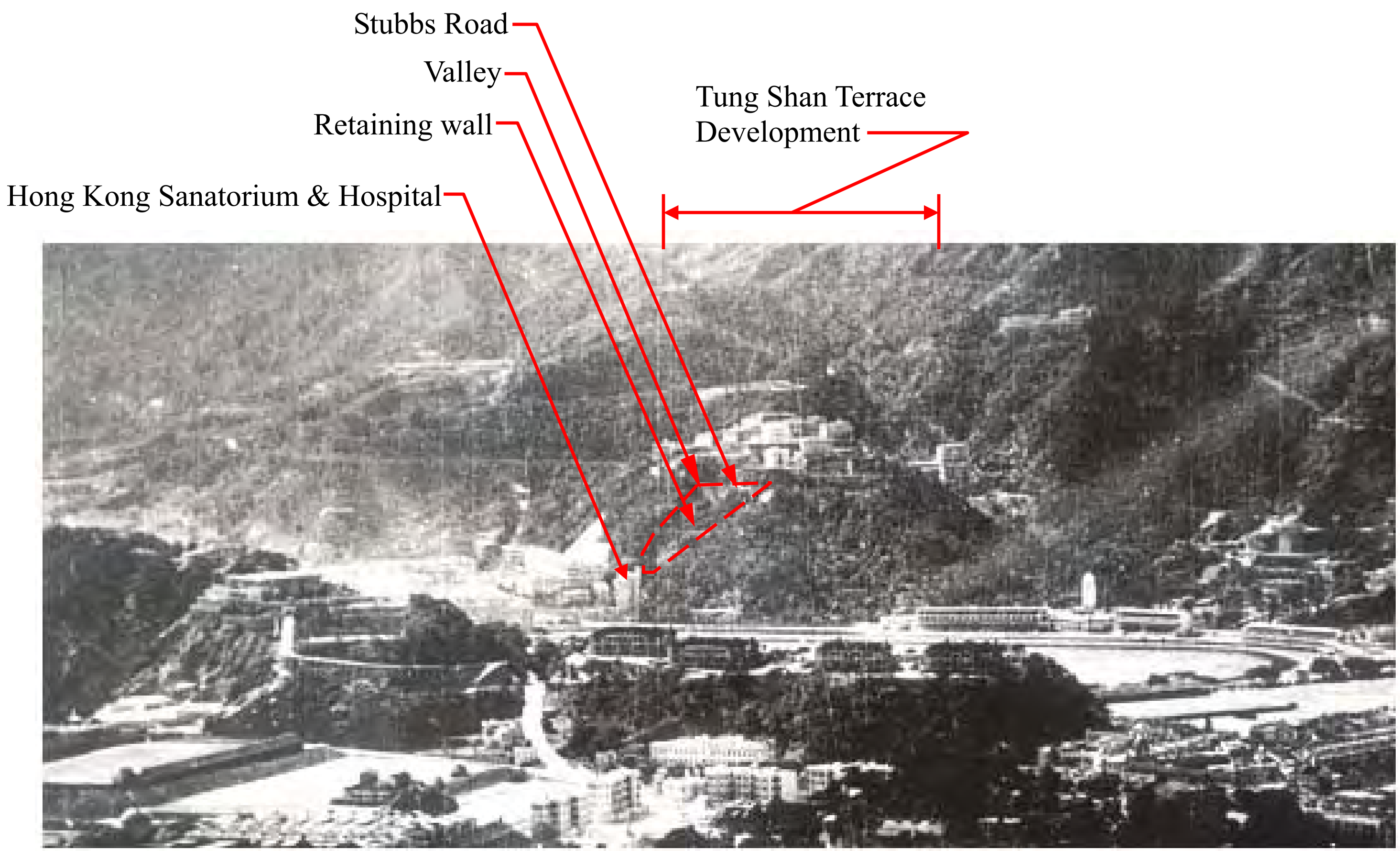


Plate11 - Low Angle Oblique View of Happy Valley in 1934

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

Plate 12 - View Southwest towards Hillside above Hong Kong Sanatorium and Hospital in 1978 (Photograph taken by Binnie & Partners in early 1978)

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

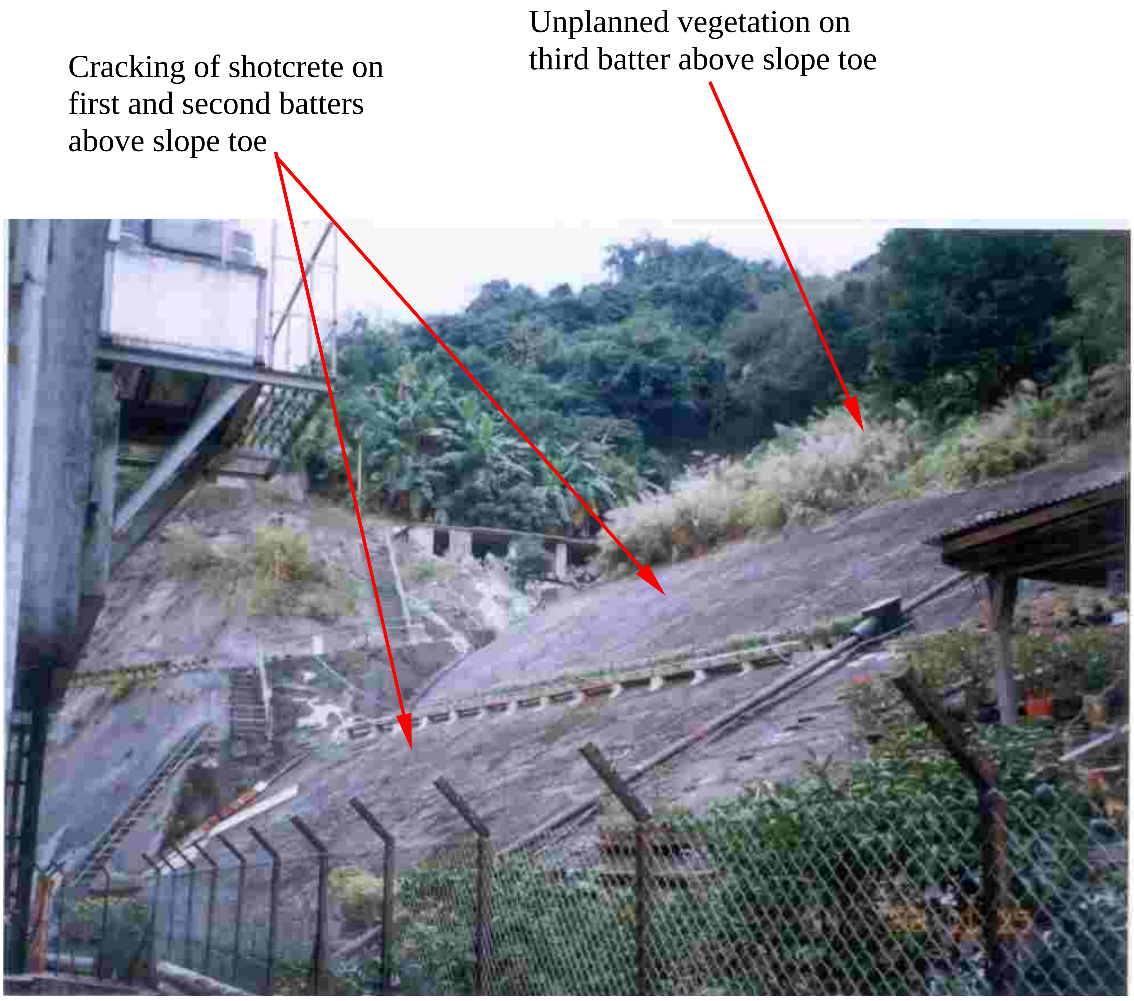


Plate 13 - View South across Lower Batters of Slope No. 11SW-D/FR1 (Photograph taken by Highways Department on 25 November 1998)

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

Cracking in mass concrete gravity retaining wall

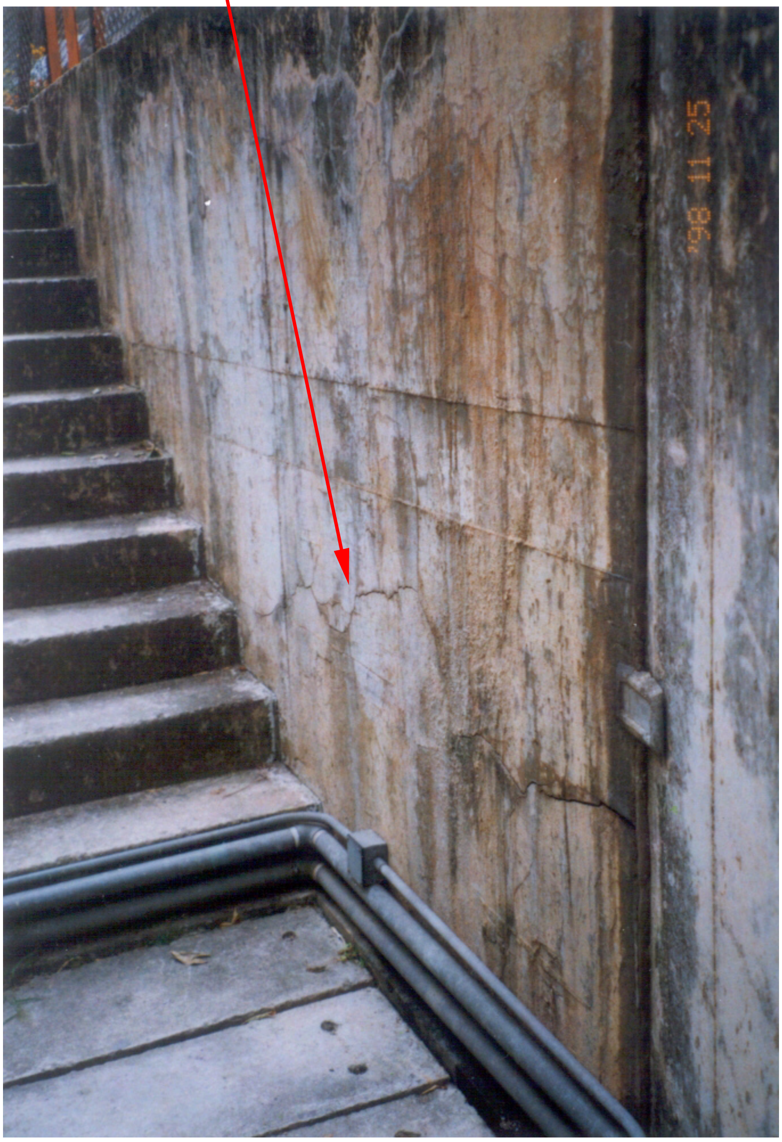


Plate 14 - Cracking in Mass Concrete Gravity Retaining Wall near Access Stairs
(Photograph taken by Highways Department on 25 November 1998)

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

Plate 15 - View Down Stepped Channel on 4th Batter above Slope Toe Showing Severe Cracking between Channel Apron and Adjacent Shotcrete and Growth of Unplanned Vegetation (Photograph taken by Maunsell Geotechnical Services in July 1999)

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

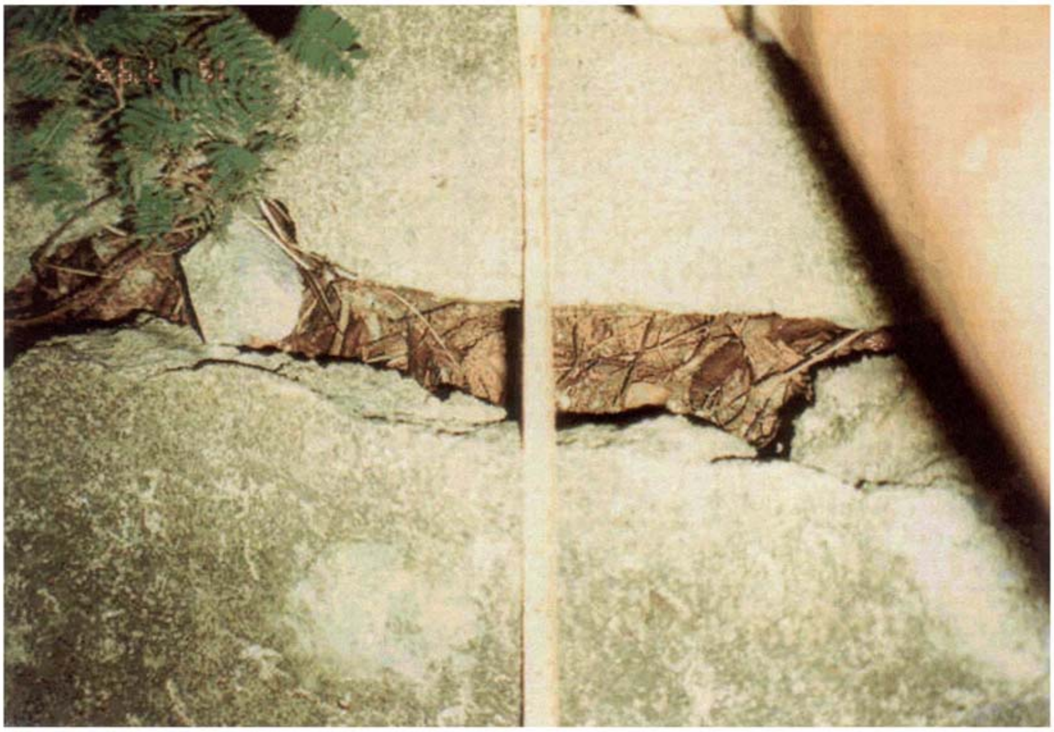


Plate 16 - Close View of Cracking between Stepped Channel Apron and Shotcrete on 4th Batter above Slope Toe (Photograph taken by Maunsell Geotechnical Services in July 1999)

Table of Contents

Table of Contents

Table of Contents

Table of Contents

Plate 17 - Typical Example of Transverse Crack in Berm Slab
(Photograph taken on 28 February 2004)

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

Plate 18 - Example of Shotcrete Surfacing Overhanging Berm U-channel
(Photograph taken on 1 March 2004)

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

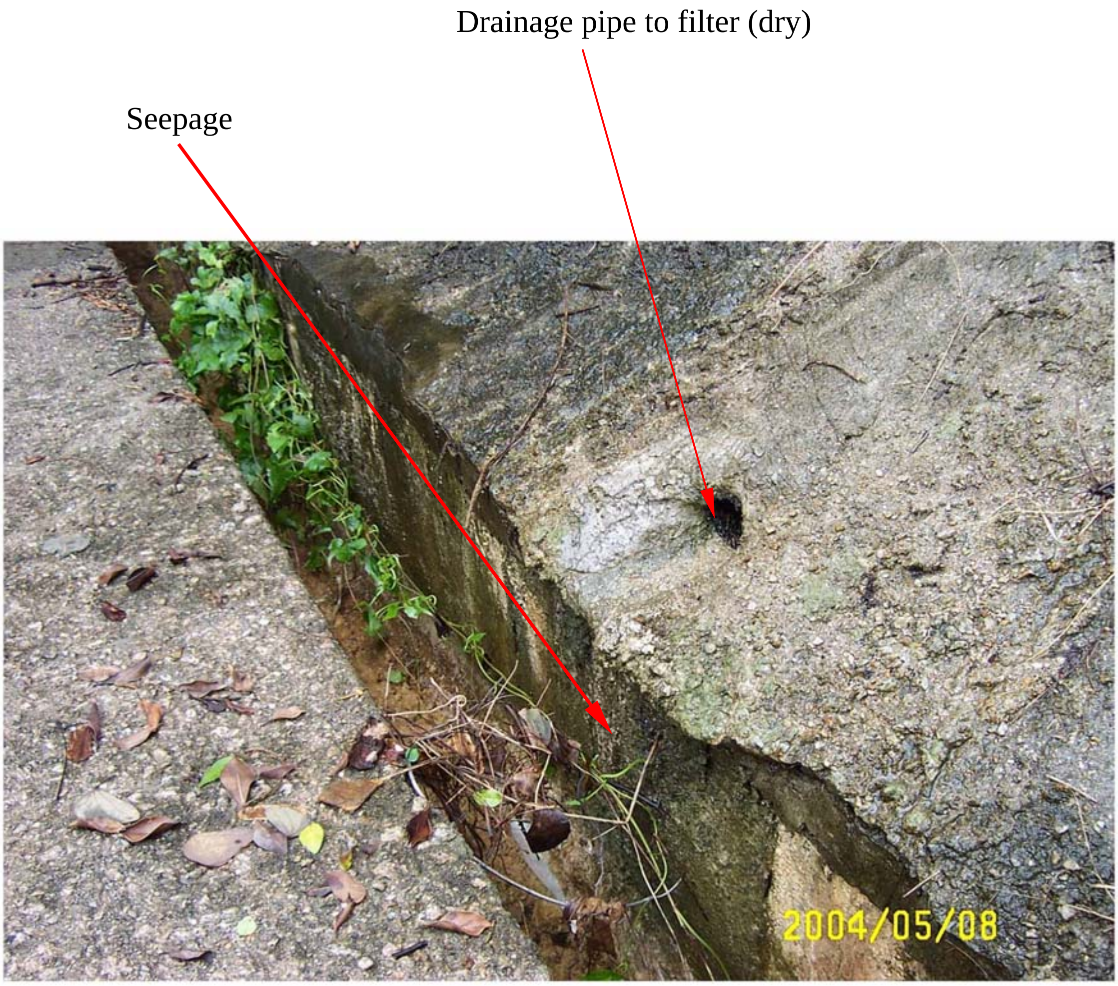


Plate 19 - Seepage Observed Flowing from Beneath Shotcrete Surfacing Following Light Rainfall on 8 May 2004 (Photograph taken on 8 May 2004)

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

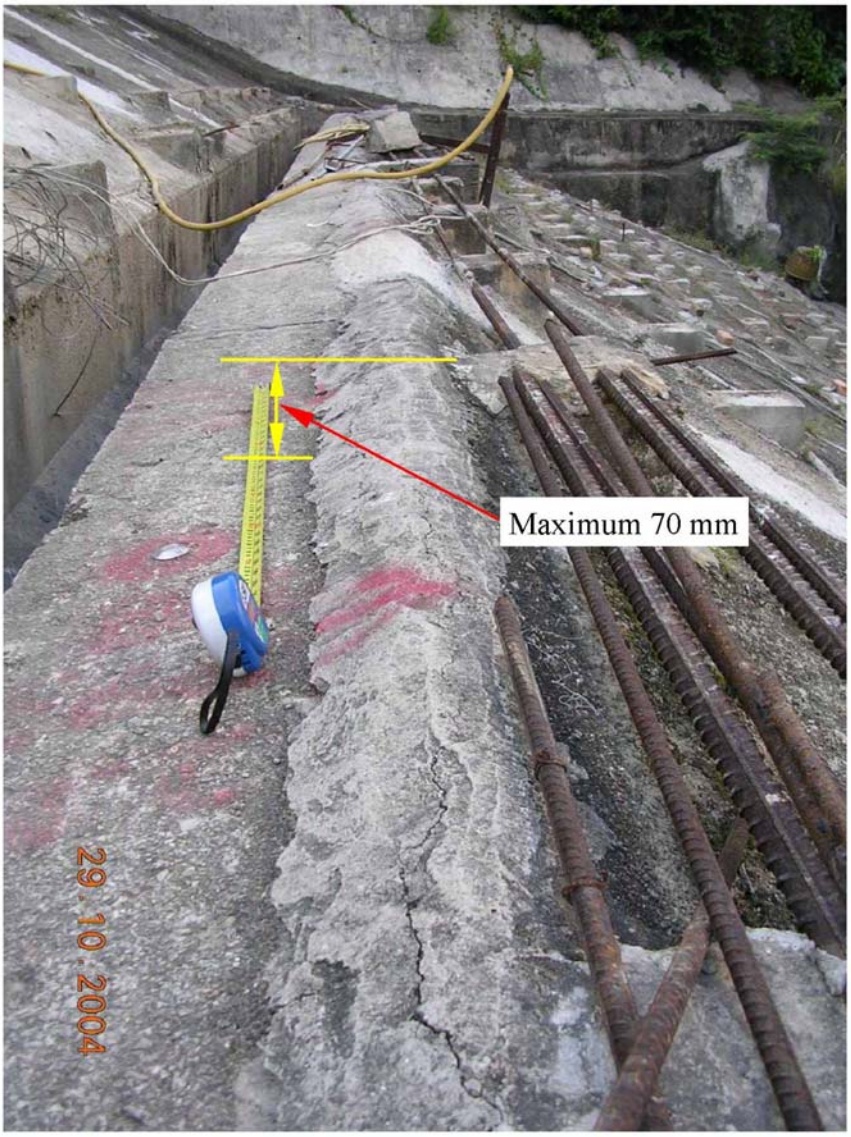


Plate 20 - Lip Formed at Crest of First Batter above Slope Toe through Differential Movement between Shotcrete and Berm Slab (Photograph taken on 30 August 2004)

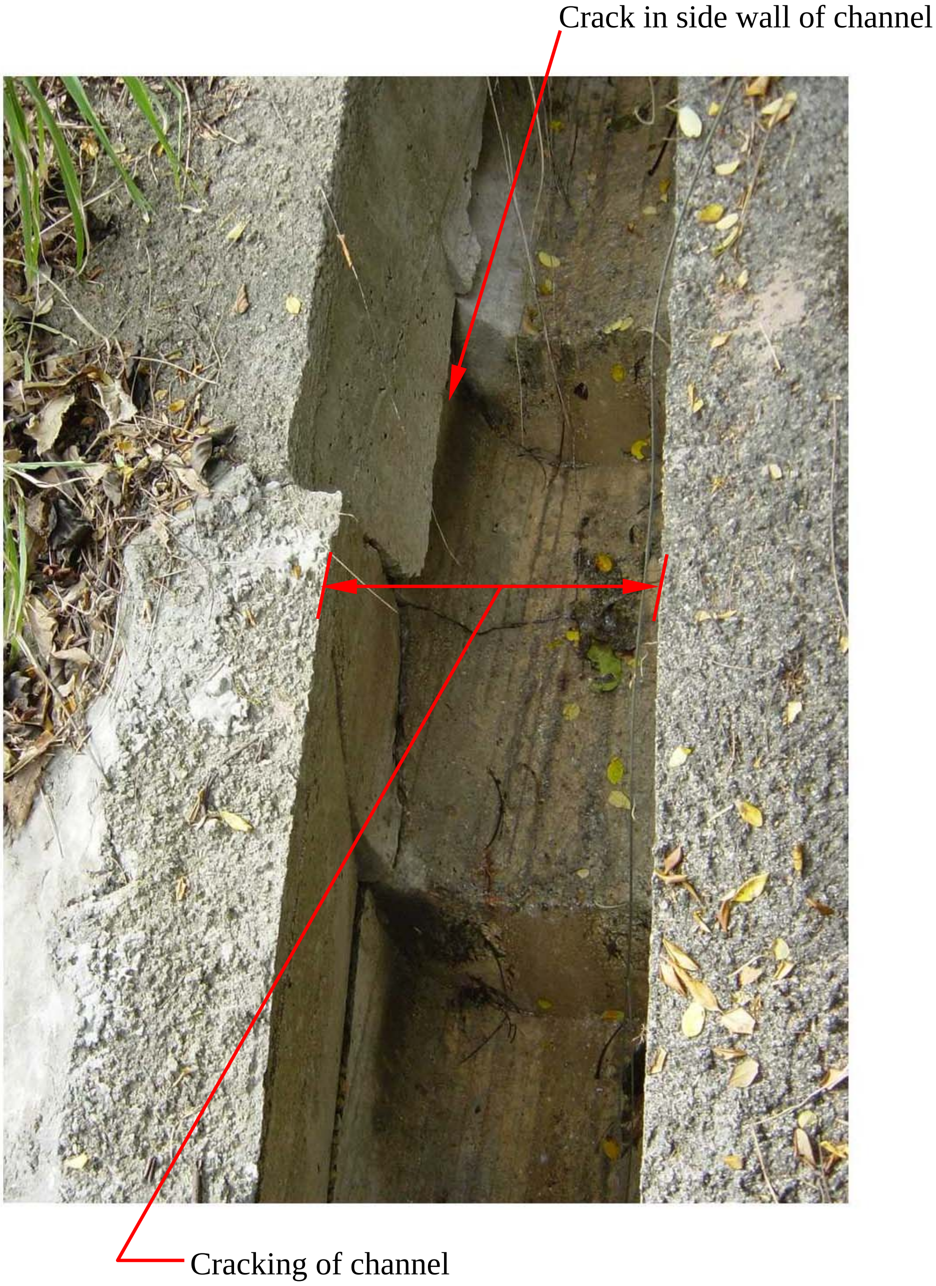


Plate 21 - Example of Cracked and Crushed Stepped U-channel
(Photograph taken on 28 February 2004)

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

Plate 22 - Example of Blocked 75 mm Diameter Drainage Pipe Exploited by Unplanned Vegetation (Photograph taken on 15 March 2004)

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

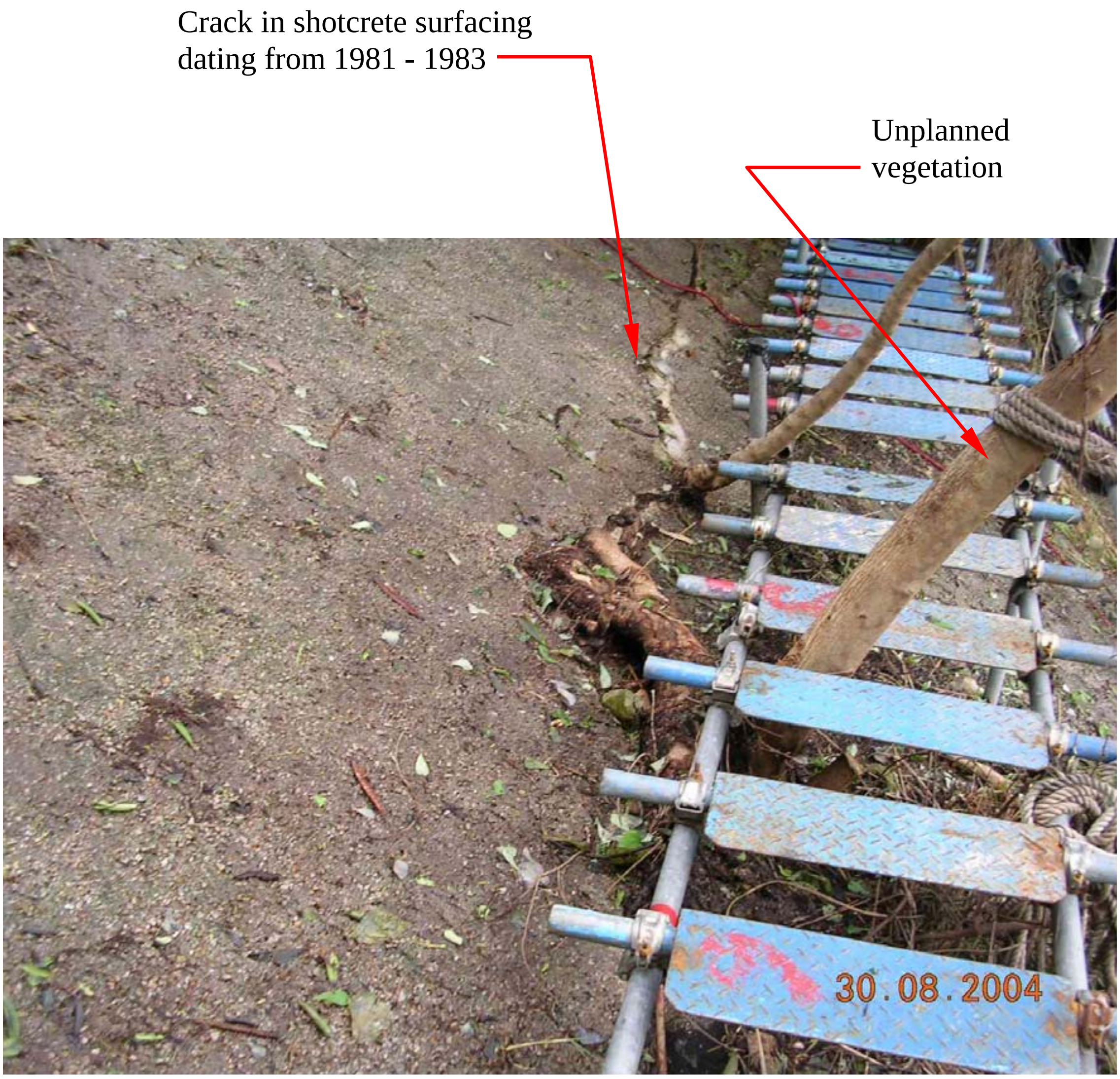


Plate 23 - Example of Unplanned Vegetation Exploiting Cracks in Shotcrete Surfacing on Third Batter above Slope Toe (Photograph taken on 30 August 2004)

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

Plate 24 - Unplanned Vegetation Blocks Surface Drainage System
(Photograph taken on 1 March 2004)

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

Plate 25 - Sustained Seepage Observed Issuing from Crack in Mass Concrete Gravity Retaining Wall (Photograph taken on 8 September 2004)

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

Plate 26 - Expansion Joint in Mass Concrete Gravity Retaining Wall
(Photograph taken on 25 February 2004)

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

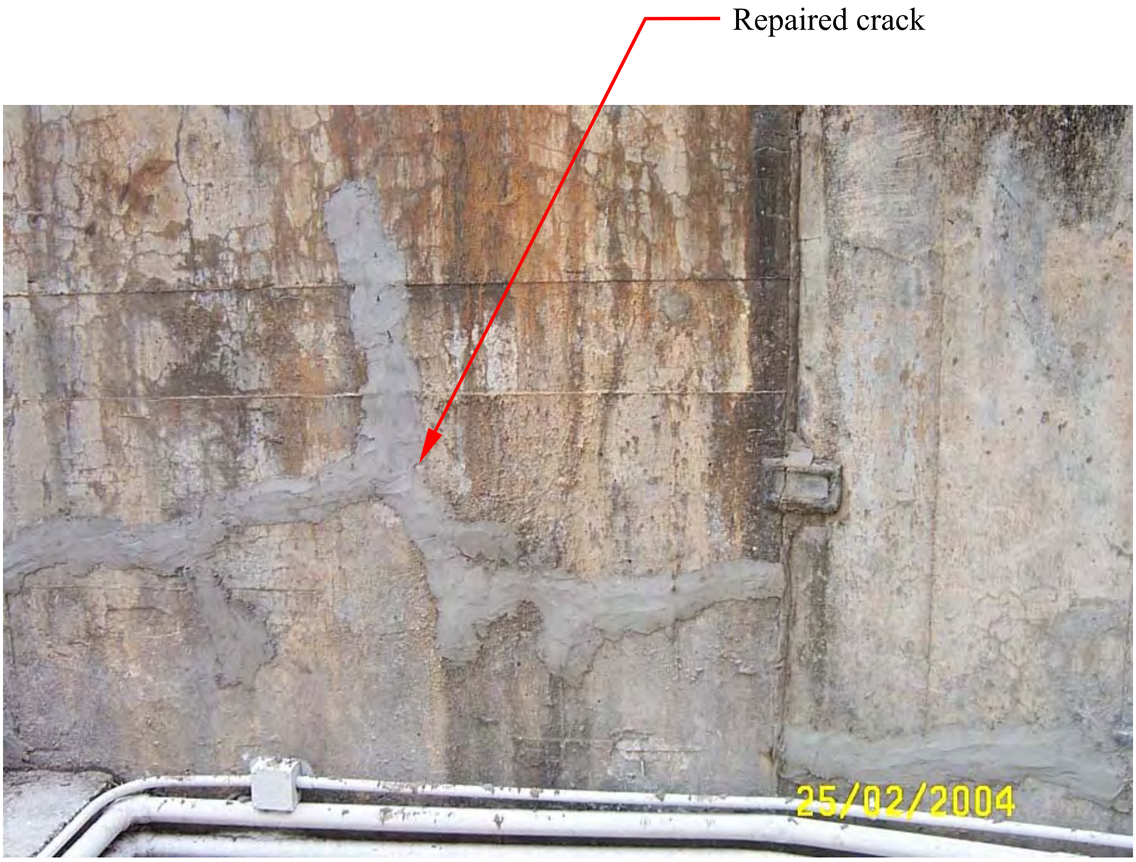


Plate 27 - Example of Repaired Cracking in Mass Concrete Gravity Retaining Wall
(Photograph taken on 25 February 2004)

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

Oversize rock blocks
exposed in face of trial pit

Plate 28 - Example of Rock Blocks Exposed within Compacted Fill Layer in Trial Pit TP4 (Photograph taken on 9 August 2004)

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

Plate 29 - Remains of Plastic Shoe Exposed within Compacted Fill Layer in Trial Pit TP6 (Photograph taken on 25 August 2004)

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

Plate 30 - Layer of Plastic Silty Clay Exposed within Compacted Fill Layer in Trial Pit TP4 (Photograph taken on 25 August 2004)

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

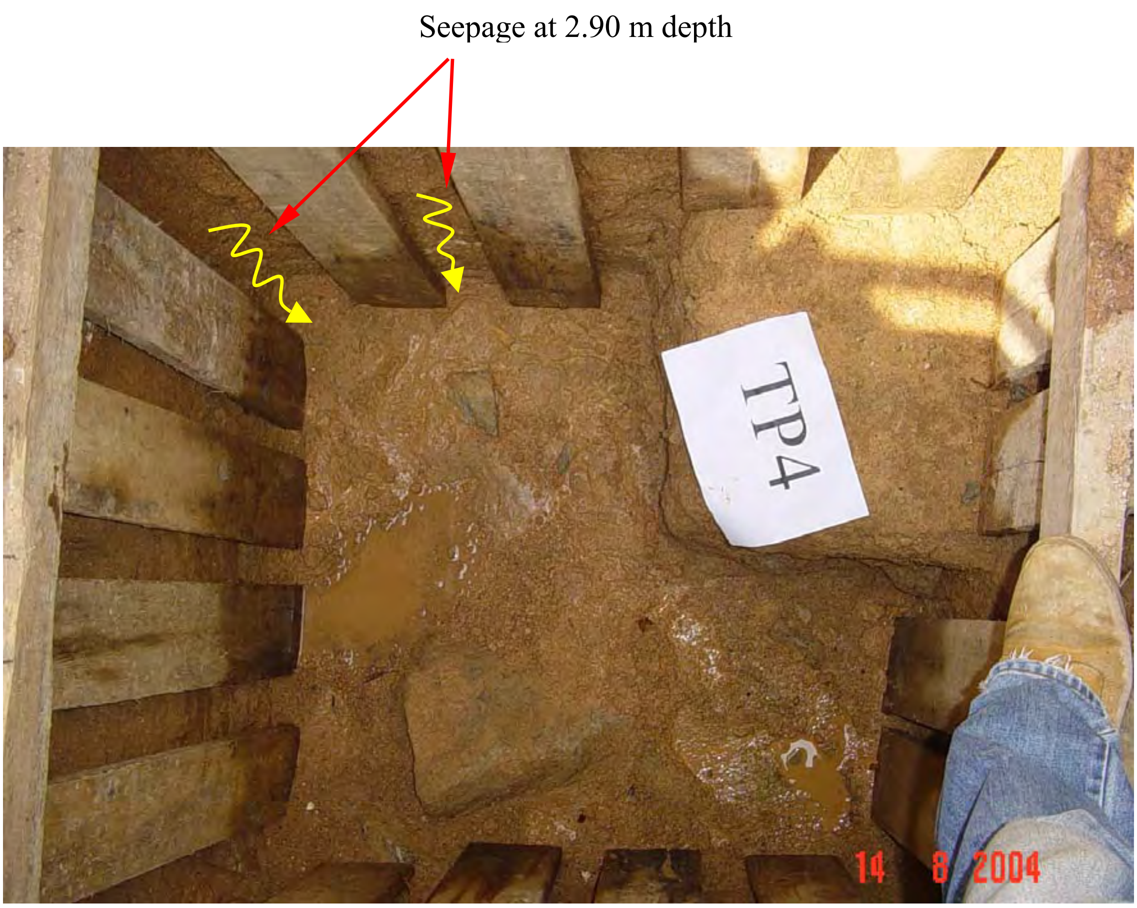


Plate 31 - Seepage Observed in Trial Pit TP4 during Excavation
(Photograph taken on 14 August 2004)

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

Plate 32 - Seepage Observed in Trial Pit TP5 during Excavation
(Photograph taken on 11 August 2004)

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

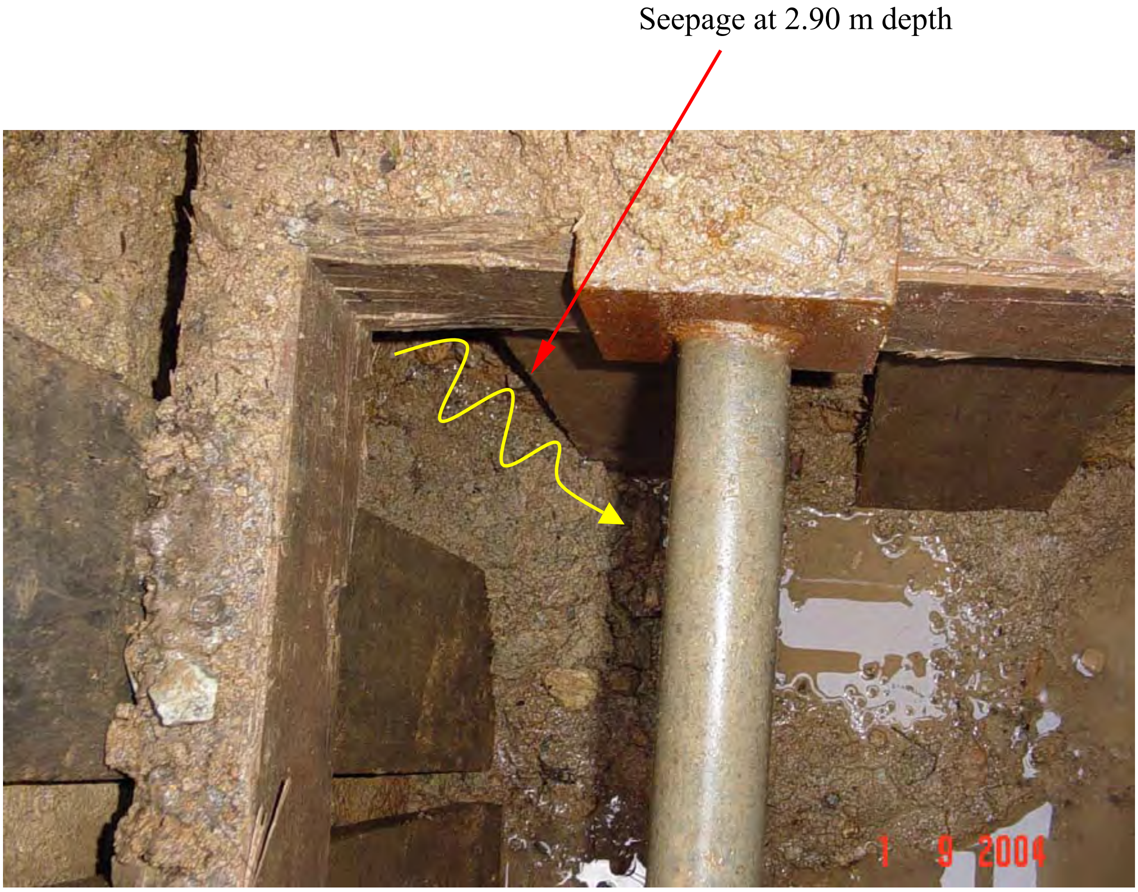


Plate 33 - Seepage Observed in Trial Pit TP6 during Excavation
(Photograph taken on 1 September 2004)

Table of Contents

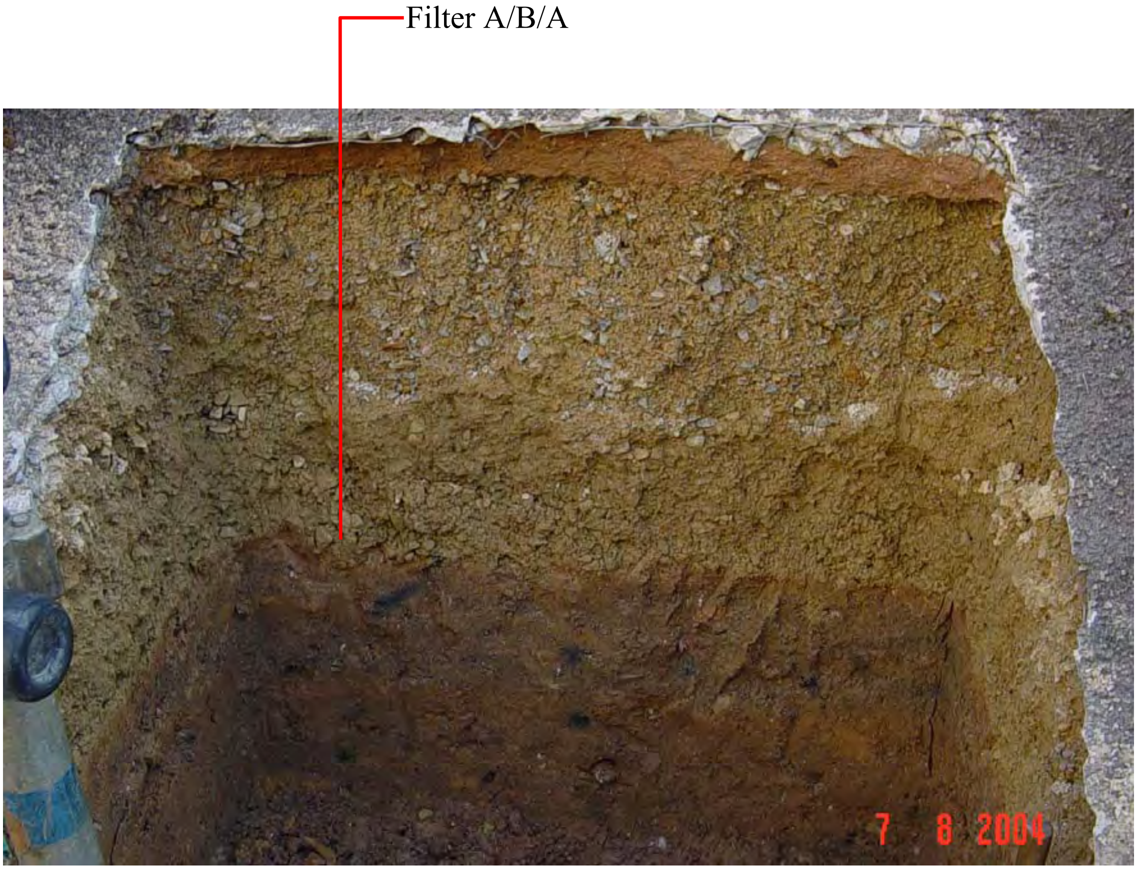


Plate 34 - Close View of Filter A/B/A Arrangement Exposed in Trial Pit TP5
Showing Lack of Definition between Individual Filter Layers
(Photograph taken on 7 August 2004)

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

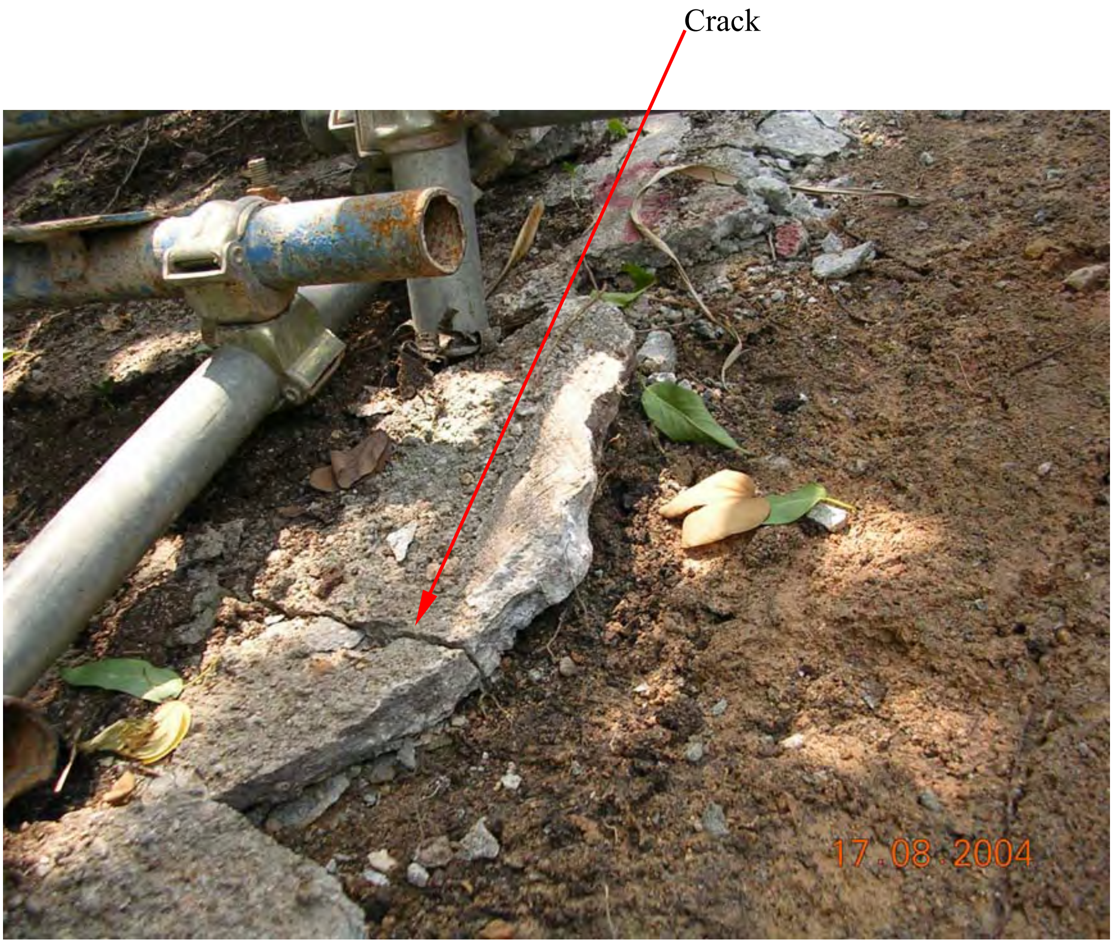


Plate 35 - Example of Surface Strip (CS1) across Cracking in Shotcrete
(Photograph taken on 17 August 2004)

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

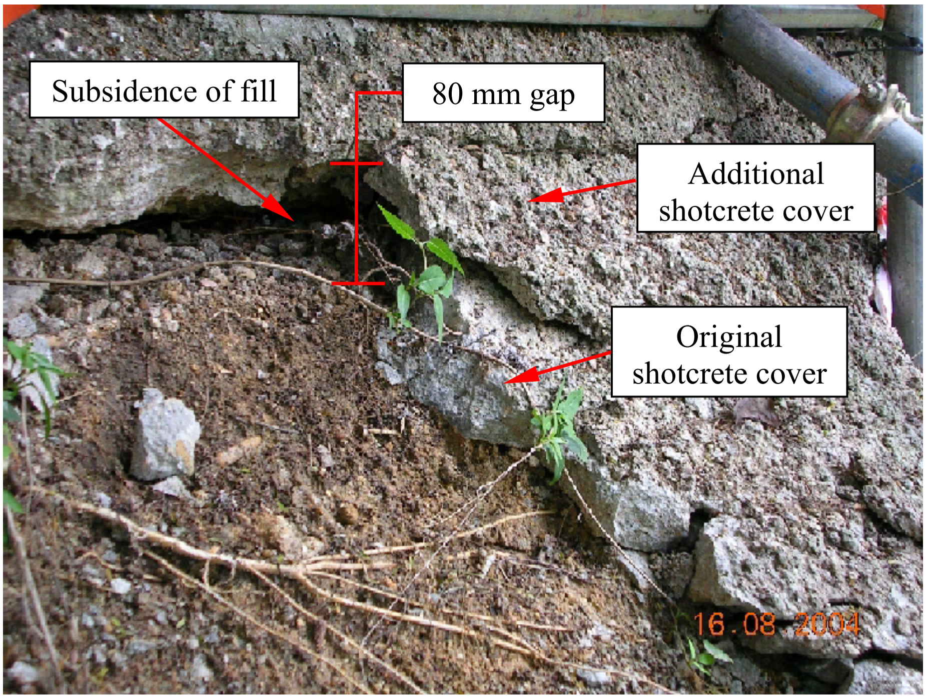


Plate 36 - Local Arrangement at Crest of 4th Batter above Slope Toe in SurfaceStrip CS1 (Photograph taken on 16 August 2004)

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

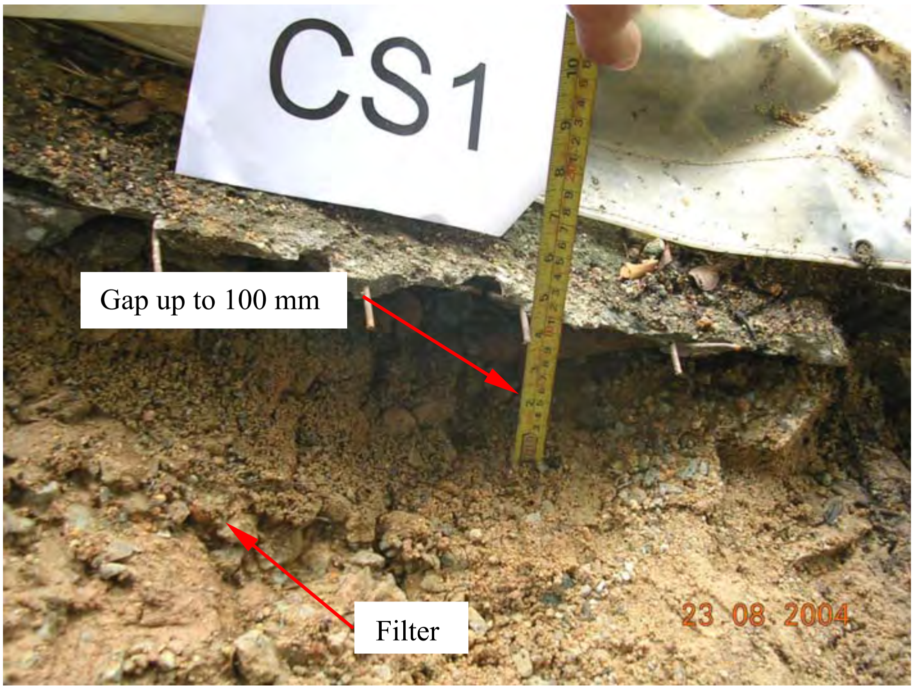


Plate 37 - Local Arrangement at Toe of 4th Batter above Slope Toe in Surface Strip CS1 (Photograph taken on 23 August 2004)

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

Plate 38 - Anomalous Flow of Foamy Water Observed at Stormwater Outlet Entering Surface Drainage System of Slope No. 11SW-D/FR1 at Slope Crest (Photograph taken on 23 August 2004)

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

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

APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

A.1 DETAILED OBSERVATIONS

The following comprise the detailed observations made from the aerial photographs studied. A list of aerial photographs used in this study is given in Section A.2.

Year	Observations
1924	No stereo pair. General area partially obscured by cloud. The Hong Kong Sanatorium complex is present above Wong Nai Chung Road and a row of terrace houses with a cut slope extending above are visible along the western side of Fung Fai Terrace to the south. Stubbs Road is present and follows current alignment. The Tung Shan Terrace area appears to be under development with general site clearance and bulk earthworks underway.
	The area presently occupied by feature No. 11SW-D/FR1 comprises a bowl-shaped valley with axis trending NE-SW between Stubbs Road to the southwest and the Hong Kong Sanatorium complex at the northeastern extent. The ground within the valley appears to be disturbed, particularly on the northern side. Two drainage lines are visible within the valley and converge about mid-slope on the northern side. The southern of the two drainage lines appears to extend above Stubbs Road into the Tung Shan Terrace development.
1945	Stubbs Road and Tung Shan Terrace are visible and follow the respective present-day alignments. Stubbs Road appears to be in cut on the eastern side as well as the western side in the local vicinity, except for the section along the present crest line of feature No. 11SW-D/FR1.
	The valley presently occupied by slope no. 11SW-D/FR1 can be seen with greater clarity than in 1924 aerial photographs. The valley has very steep flank on southeastern side and narrows considerably at the lower extent immediately above the Hong Kong Sanatorium complex.
	A curvilinear feature (retaining wall) spanning the valley is visible about mid-way between Stubbs Road and the Hong Kong Sanatorium. The ground immediately above the retaining wall is initially flatter than that occurring downslope; however steepens towards Stubbs Road. A body of fill with severe gully erosion occupies the northwestern half of the area above the retaining wall and the spur line immediately adjacent to the fill has been disturbed (possible excavated platforms).
	The ground extending below the retaining wall to the Hong Kong Sanatorium complex comprises a number of randomly placed terraces and small platforms.

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

Year	**Observations**
1949	The main wing of the Hong Kong Sanatorium complex has been extended to the southwest as far as the present toe of feature No. 11SW-D/FR1. Stubbs Road remains unchanged. The general arrangement in the valley above the Hong Kong Sanatorium complex is similar to that indicated by the 1945 photographs. The ground above the retaining wall located mid-way up the valley is much the same as previous; however, the condition of the fill body appears to have deteriorated, with the eroded gullies further developed. A chunamed slope extends above the Hong Kong Sanatorium complex and occupies about one quarter of the area between the slope toe and the retaining wall mid-way up the valley. The ground between the slope and the retaining wall is completely occupied by narrow terraces and small retaining structures, and a retaining wall extends continuously along the toe. The terraced area is traversed by two narrow tracks extending diagonally up the slope towards the south, one to a hut located on a cut platform on the spur ridge on the southeastern flank of the valley, the second extending as far as the retaining wall mid-way up the valley.
1963	The main wing of the Hong Kong Sanatorium complex has been extended to the northwest along Wong Nai Chung Road and a cut slope is visible in the hillside behind. Stubbs Road has possibly be widened and re-paved, with asphalt extending to the south of the junction with Tung Shan Terrace and concrete extending to the north. A number of sites along Tung Shan Terrace have been redeveloped, and slope Nos. 11SW-D/C385 and 11SW-D/C386 have been altered and recently surfaced with chunam. The general arrangement in the valley above the Hong Kong Sanatorium complex is similar to that indicated by the 1949 photographs. The fill body above the retaining wall located mid-way up the valley has been formed into four batters separated by berms incorporating drainage channels. The uppermost batter immediately below Stubbs Road has been covered with chunam and repairs in the chunam surface are visible. The lower three batters have a heavy cover of vegetation. The ground below the retaining wall remains occupied by the narrow terraces, with the addition that the slope feature extending above the Hong Kong Sanatorium complex has also been terraced.
1967	The main wing of the Hong Kong Sanatorium complex has been extended further to the northwest along Wong Nai Chung Road and the cut slope in the hillside behind is also extended. No obvious changes are evident along Stubbs Road.

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

Year	**Observations**
1967 cont'd	No major changes observed in the valley above the Hong Kong Sanatorium complex. The vegetation cover on the ground above the retaining wall located mid-way up the valley is heavier.
1969	No major changes observed at the Hong Kong Sanatorium complex. Some alteration evident in the forecourt/carpark area off Wong Nai Chung Road. No major changes observed along Stubbs Road. No major changes observed in the valley above Hong Kong Sanatorium complex. There are possible signs of squatter inhabitation on the ground above the retaining wall located mid-way up the valley, to the southeast of the fill body, with a number of tracks and possible structures visible. The upper half of the terraced area appears overgrown and untended, while the lower half remains unchanged. A small platform with a retaining wall along the northeastern edge has been formed between the two tracks in the lower portion of the terraced area.
1972	No major changes observed at the Hong Kong Sanatorium complex. No major changes observed along Stubbs Road. No major changes observed in the valley above the Hong Kong Sanatorium complex. Squatter inhabitation still present. Upper portion of terraced area remains overgrown.
1976	No major changes observed at the Hong Kong Sanatorium complex. Assembly of small roofed structures on northwest side of main wing replaced by single low-rise structure extending to northwest. No major changes observed along Stubbs Road. No major changes observed in the valley above the Hong Kong Sanatorium complex. Possible bare batch on fill body below Stubbs Road visible on second batter below crest. New paths cut across upper portion of terraced area.
1977	No major changes observed at the Hong Kong Sanatorium complex. No major changes observed along Stubbs Road. Vegetation stripped from fill body and ground above retaining wall located mid-way up valley and slope face mostly covered with chunam. Retaining wall visible separating third and fourth batters of fill body below Stubbs Road. Excavated pits are open on the upper batter and a container has been placed at the slope crest to the northwest. Vegetation has also been stripped from the terraced area below the retaining wall, leaving trees standing only.

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

Year **Observations**

1978 No major changes observed at the Hong Kong Sanatorium complex. No major changes observed along Stubbs Road.

Slope upgrading works to form the present-day geometry of feature No. 11SW-D/FR1 are underway, and filling works and finished slope face formation incorporating surface drainage are complete to the crest of the fourth batter above the slope toe. Earthmoving plant is visible on the platform at the crest of the completed portion.

The fill body above the area of filling has been re-worked to create a haul road from Stubbs Road, and the existing retaining structure separating the third and fourth batters of the previous slope works observed in the 1977 photographs remains visible.

Uncertain whether completed batters have been surfaced, as slope face and filling area have same tone.

1979 No major changes observed at the Hong Kong Sanatorium complex. Possible change in roof line on northwest section of main wing. No major changes observed along Stubbs Road.

Slope upgrading works forming present-day geometry of feature No. 11SW-D/FR1 are complete and comprise a total of eight batters separated by berms incorporating surface drainage channels. The upper four batters are vegetated, with the exception of the uppermost batter, which incorporates a J-channel at mid-height, and has a hard surfacing between the channel and Stubbs Road. A hand railing is visible along the slope crest.

The lower four batters have a hard surfacing; however, the third and fourth batters above the slope toe are much lighter in tone than the lower two batters, which are of similar tone to the vegetated batters above.

1980 No major changes observed at the Hong Kong Sanatorium complex. Cut slope above northern wing facing Wong Nai Chung Road (slope No. 11SW-D/C15) extended to create 4 batters. No major changes observed along Stubbs Road.

No major changes observed observed on feature No. 11SW-D/FR1. Minor erosion observed along linear features in lower portions of vegetated batters. Two large trees present at crest of feature No. 11SW-D/FR1.

Slope works commenced on northern portion of cut slope behind terrace houses facing Fung Fai Terrace comprising reprofiling of slope face.

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

Year	Observations
1981	Low-rise roofed structure on northwest side of main wing of the Hong Kong Sanatorium complex first observed in the 1976 aerial photographs demolished. No major changes observed along Stubbs Road
	No major changes observed observed on feature No. 11SW-D/FR1. Vegetation becoming heavier on upper four batters. Erosion long linear features still visible. The third and fourth batters above the slope toe are still lighter in tone than the lower two. A narrow linear feature (possible crack) is visible at about one-third height on the northwestern portion of the fourth batter above the slope toe.
	Slope works continuing on northern portion of cut slope behind terrace houses facing Fung Fai Terrace. Crest line extended further upslope.
1982	New extension to northwestern side of main wing of Hong Kong Sanatorium complex at location of demolition observed in 1981 aerial photographs. Possible change in roof line on northwest section of main wing. No major changes observed along Stubbs Road.
	No major changes observed observed on feature No. 11SW-D/FR1. Vegetation heavier on upper four batters. Appears to be some activity (possible pit excavation) ongoing in northwestern portion of third and fifth batters above slope toe. Large trees at crest not obvious.
	Linear feature on fourth batter above slope toe more pronounced and possible bulge in slope face visible along this feature.
	Slope works on northern portion of cut slope behind terrace houses facing Fung Fai Terrace appear to be complete. Surface strip visible in southern portion of cut slope.
1983	No major changes observed on feature No. 11SW-D/FR1. Upper four batters of feature overgrown with vegetation to obscure berms. Lower four batters are now of similar tone. Large trees at slope crest again visible.
	Fourth batter above slope toe is extensively cracked. Laterally extensive crack following linear feature at one-third height. Cracking also visible on southeastern portion of third batter above slope toe, but not as severe. Lighter toned area also visible on this portion of the batter.
	Vegetation visible along line of cracking on face of third batter above slope toe and also along northwestern portion of batter toe. Vegetation also visible along toe of northwestern portion of fourth batter above slope toe, but not as heavy.

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

Year	**Observations**
1983 cont'd	Possible seepage or overflow of surface drainage observed at crest of fourth batter above slope toe at northwestern end. Present-day tensiometer and piezometer surface boxes are visible on slope face. Major slope works completed on southern portion of cut slope behind terrace houses facing Fung Fai Terrace and hillside above to create continuous series of batters from Fung Fai Terrace to Stubbs Road. Minor resurfacing on northern portion of cut slope adjacent to feature No. 11SW-D/FR1.
1984	Vegetation appears to have been trimmed on upper four batters of feature No. 11SW-D/FR1 and possible erosion is visible at the northwestern end of the fifth batter above the slope toe. Vegetation visible growing along lines of cracking in third and fourth batters above slope toe and along toe of batters in northwestern portions. Additional vegetation clearance underway at northern end of previously completed slope works above Fung Fai Terrace observed in 1983 aerial photographs adjacent to fourth and fifth batters of feature No. 11SW-D/FR1.
1985	No major changes observed. Vegetation becoming heavier on upper four batters of feature No. 11SW-D/FR1. Erosion visible on fifth batter above slope toe to northwest of center and at crest of seventh batter above slope toe at the northwestern end. Vegetation also becoming heavier along lines of cracking on third and fourth batters above slope toe. Vegetation also now visible on lower two batters, but more spread out and randomly located.
1986	No major changes observed. Vegetation becoming heavier on upper four batters of feature No. 11SW-D/FR1. Vegetation heavier along lines of cracking on third and fourth batters above slope toe. Seepage visible at crest of fourth batter above slope toe in central portion and at northwestern end.
1987	No major changes observed. Vegetation becoming heavier on upper four batters of feature No. 11SW-D/FR1. Vegetation heavier along lines of cracking on third and fourth batters above slope toe. Seepage observed on fourth batter above slope toe in 1986 photographs still visible and northwestern end of batter generally darker in tone. Linear feature (pipe) visible on slope face extending from slope toe to crest of second batter above slope toe in northwestern portion.

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

Year	Observations
1988	No major changes observed. Vegetation becoming heavier on upper four batters of feature No. 11SW-D/FR1. Vegetation heavier along lines of cracking on third and fourth batters above slope toe, particularly on fourth batter. Slope face below cracking on fourth batter generally darker in colour and seepage observed since 1986 at northwestern end of fourth batter now extends to northwestern end of third batter.
1989	Two buildings located on the southern edge of the forecourt/carpark forming part of the original Hong Kong Sanatorium complex have been demolished and carpark has been extended. No major changes observed on Stubbs Road. No major changes observed on feature No. 11SW-D/FR1. Vegetation becoming heavier on upper four batters. Vegetation heavier along lines of cracking on third and fourth batters above slope toe. Tree established in stepped U-channel at toe of fourth batter above slope toe. Vegetation now well-established on lower two batters, but remains randomly located and less prominent compared to third and fourth batters above slope toe. Features visible at northwestern end of third and fourth batters above slope toe, which are possibly a combination of vegetation and staining from seepage, but are essentially identical in form.
1990	Building construction works underway within Hong Kong Sanatorium complex in footprint of carpark/forecourt. No major changes observed on Stubbs Road. No major changes observed on feature No. 11SW-D/FR1. Features at northwestern end of third and fourth batters above slope toe observed in 1989 photographs appear to be related to vegetation. Tree established in stepped U-channel at toe of fourth batter above slope toe is larger, and a second tree is established at the toe of the third batter above the slope toe immediately above the location of the pipe extending to the crest of the second batter.
1991	Building construction works observed in 1990 aerial photographs progressing within Hong Kong Sanatorium complex. Local widening of southbound lane of Stubbs Road to south of junction with Tung Shan Terrace to accommodate bus stop. No major changes observed on feature No. 11SW-D/FR1. Vegetation heavier on third and fourth batters above slope toe and now encroaching onto upper portion of second batter.

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

Year	**Observations**
1992	Building construction works underway within Hong Kong Sanatorium complex appear to be mostly complete with major new extension to main wing extending to the southeast in the footprint of the two structures demolished between 1988 and 1989 and forecourt redeveloped. No major changes observed on Stubbs Road.
	No major changes observed on feature No. 11SW-D/FR1. Angle of light in photographs clearly show vegetation growing along two horizontal lines across fourth batter above slope toe and single line at mid-height across third batter above slope toe.
	Vegetation heavier on lower two batters, but remains randomly spaced.
1993	No major changes within the Hong Kong Sanatorium complex. No major changes on Stubbs Road.
	No major changes observed on feature No. 11SW-D/FR1. Vegetation on lower four batters appears less prominent than in preceding years.
1994	First colour photographs. Building located at southern extent of the original Hong Kong Sanatorium complex facing Fung Fai Terrace has been demolished. No major changes on Stubbs Road.
	No major changes observed on feature No. 11SW-D/FR1. Breaks in vegetation observed on upper two batters in central-southeastern portions.
	Lower four batters have extensive cover of vegetation, which appears to be in phase of dry season die-back. Only the trees located on the third and fourth batters above the slope toe retain a green canopy in this portion of the slope.
1995	No major changes observed within Hong Kong Sanatorium Complex. No major changes on Stubbs Road. Yellow hazard hatching painted on northbound lane of Stubbs Road at junction with Tung Shan Terrace.
	No major changes observed on feature No. 11SW-D/FR1.
1996	Building construction works in progress within Hong Kong Sanatorium complex in footprint of previously demolished structure facing Fung Fai Terrace (refer observations for 1994 aerial photographs). No major changes at Stubbs Road.
	No major changes observed on feature No. 11SW-D/FR1. The lower two batters have been cleared of vegetation to expose hard surfacing. Heavy vegetation still present on third and fourth batter above slope toe

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

Year	**Observations**
1997	Building construction works progressing on new wing within Hong Kong Sanatorium complex facing Fung Fai Terrace. No major changes at Stubbs Road. No major changes observed on feature No. 11SW-D/FR1. Some repair work on berm at crest of third batter above slope toe at southeastern end visible.
1999	New wing within Hong Kong Sanatorium complex facing Fung Fai Terrace complete. No major changes at Stubbs Road. No major changes observed on feature No. 11SW-D/FR1.
2000	No major changes within Hong Kong Sanatorium complex. No major changes at Stubbs Road. No major changes observed on feature No. 11SW-D/FR1. New work on hard surfacing on upper portion of uppermost batter visible. Fine horizontal lines observed at northwestern end of lowest batter (supports for planters).
2001	No major changes within Hong Kong Sanatorium complex. No major changes at Stubbs Road. No major changes observed on feature No. 11SW-D/FR1.

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

A.2 List of Photographs

Date	Reference No.	Altitude
1924	Y00037	8000'
11/11/1945	Y0470, Y00471	20,000'
8/05/1949	Y01421, Y01422	8600'
1/02/1963	Y07363, Y07364	2700'
6/02/1963	Y07463, Y07518	3700'
16/05/1967	Y13281, Y13282	6250'
1969	Y14706, Y14707	Unknown
24/06/1972	1832, 1833,	2500'
28/01/1976	12643, 12644	4000'
21/12/1977	20460, 20461	4000'
5/12/1978	23869, 23870	4000'
28/09/1979	27147, 27148	5500'
28/11/1979	27870, 27871	4000'
16/04/1980	29836, 29837	4000'
18/05/1981	37401	4000'
4/01/1982	40665, 40666	4000'
21/06/1983	49246, 49247, 49248, 49249	1700'
3/02/1983	47696, 47697	4000'
2/03/1984	53669, 53670	4000'
6/12/1985	A03785	4000'
20/09/1986	A06007, A06008	4000'

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

Date	Reference No.	Altitude
9/09/1987	A10356	4000'
27/09/1988	A14492, A14493	4000'
16/08/1989	A17787, A17788	4000'
14/11/1990	A23800, A23801	4000'
4/10/1991	A28060, A28061	4000'
12/05/1992	A30941, A30942	4000'
5/12/1993	A36993	4000'
17/11/1994	CN8103, CN8104	4000'
7/12/1995	CN12704, CN12705	3500'
7/6/1996	CN14129	4000'
23/07/1997	CN17564	4000'
3/01/1999	CN24036	5000'
27/07/2000	CN27555, CN27556	4000'
21/11/2001	CW36537, CW26538	8000'

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

Table of Contents

Table of Contents

APPENDIX B

DISTRESS MAPPING

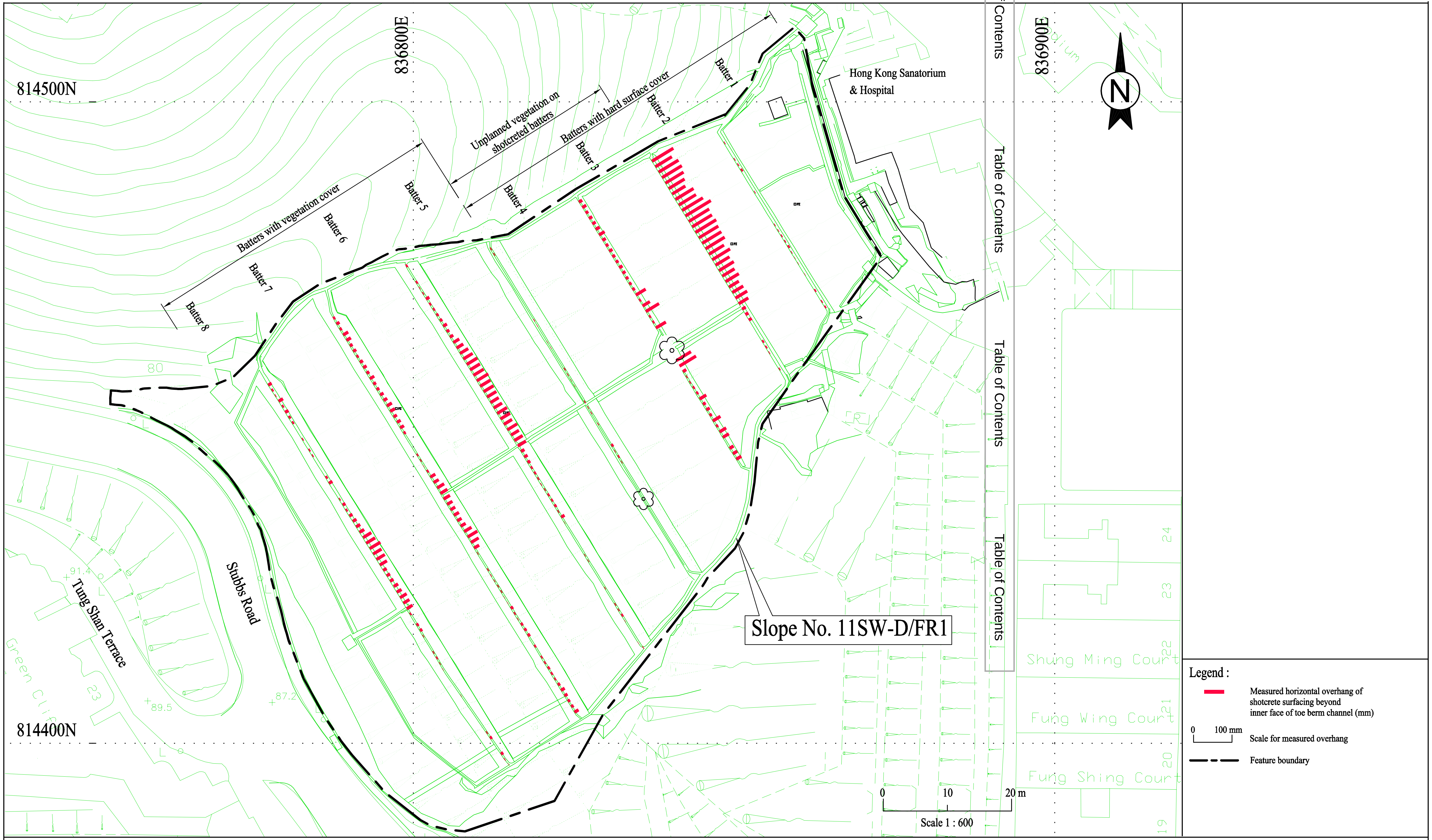
Table of Contents

Table of Contents

Notes : (1) Base Map is extracted from survey sheet No. 11SW-15C, scale 1 : 1000.
(2) General arrangement of the subject slope based on detailed topographic survey by CED Survey Division in May 2004.

Figure B1 - Mapping of Signs of Distress/Movements on the Slope Surface

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



Notes : (1) Base Map is extracted from survey sheet No. 11SW-15C, scale 1 : 1000.
(2) General arrangement of the subject slope based on detailed topographic survey by CED Survey Division in May 2004.

Figure B2 - Measured Horizontal Overhang of Shotcrete Surfacing

Table of Contents

Notes : (1) Base Map is extracted from survey sheet No. 11SW-15C, scale 1 : 1000.
(2) General arrangement of the subject slope based on detailed topographic survey by CED Survey Division in May 2004.

Figure B3 - Distress Mapping of Slope No. 11SW-D/FR1 - Height of Shotcrete above Crest Berm Slab

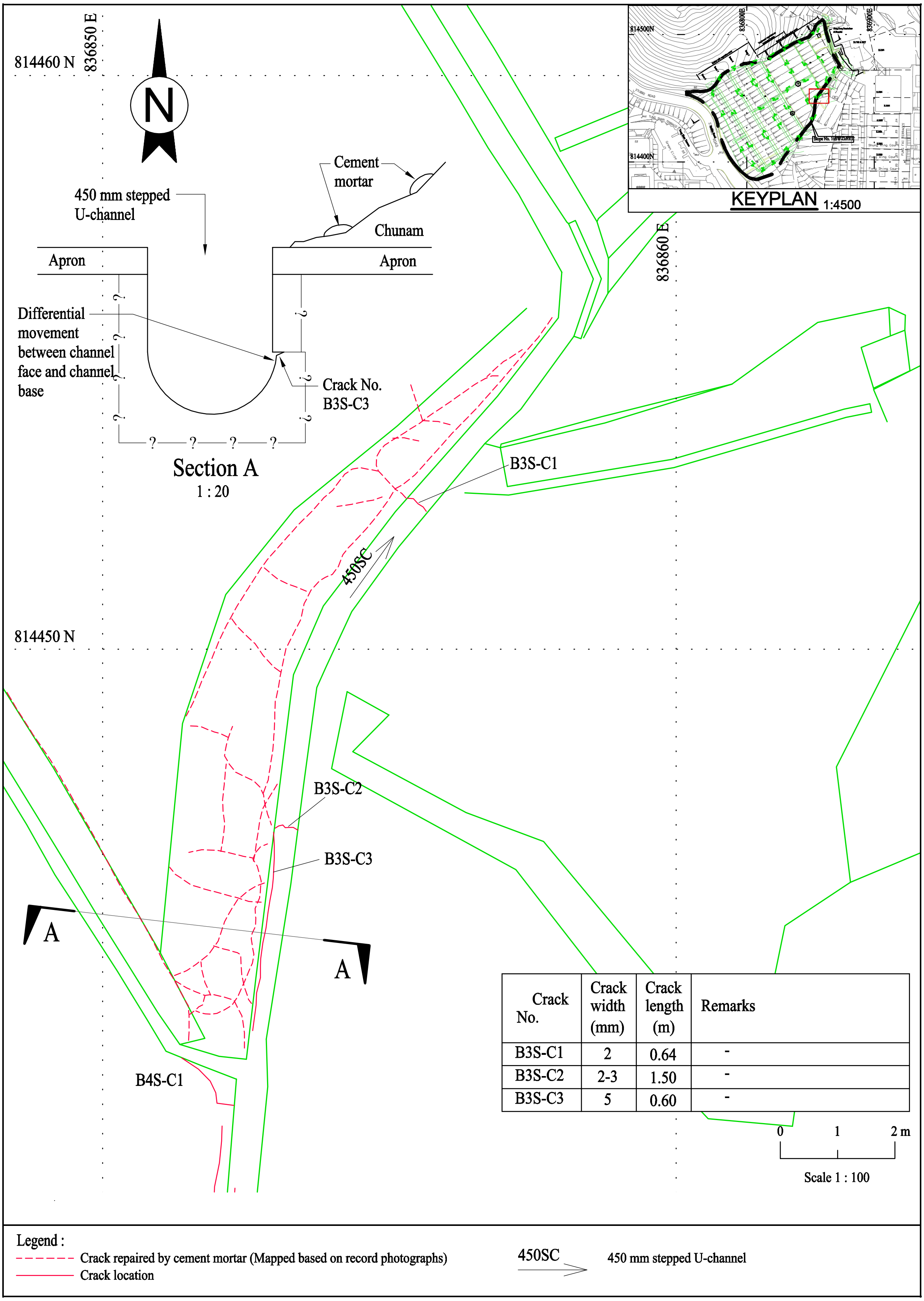
Table of Contents Table of Contents Table of Contents Table of Contents

Notes : (1) Base Map is extracted from survey sheet No. 11SW-15C, scale 1 : 1000.
(2) General arrangement of the subject slope based on detailed topographic survey by CED Survey Division in May 2004.

Figure B4 - Distress Mapping of Slope No. 11SW-D/FR1 - Relative Distress in Stepped Channels

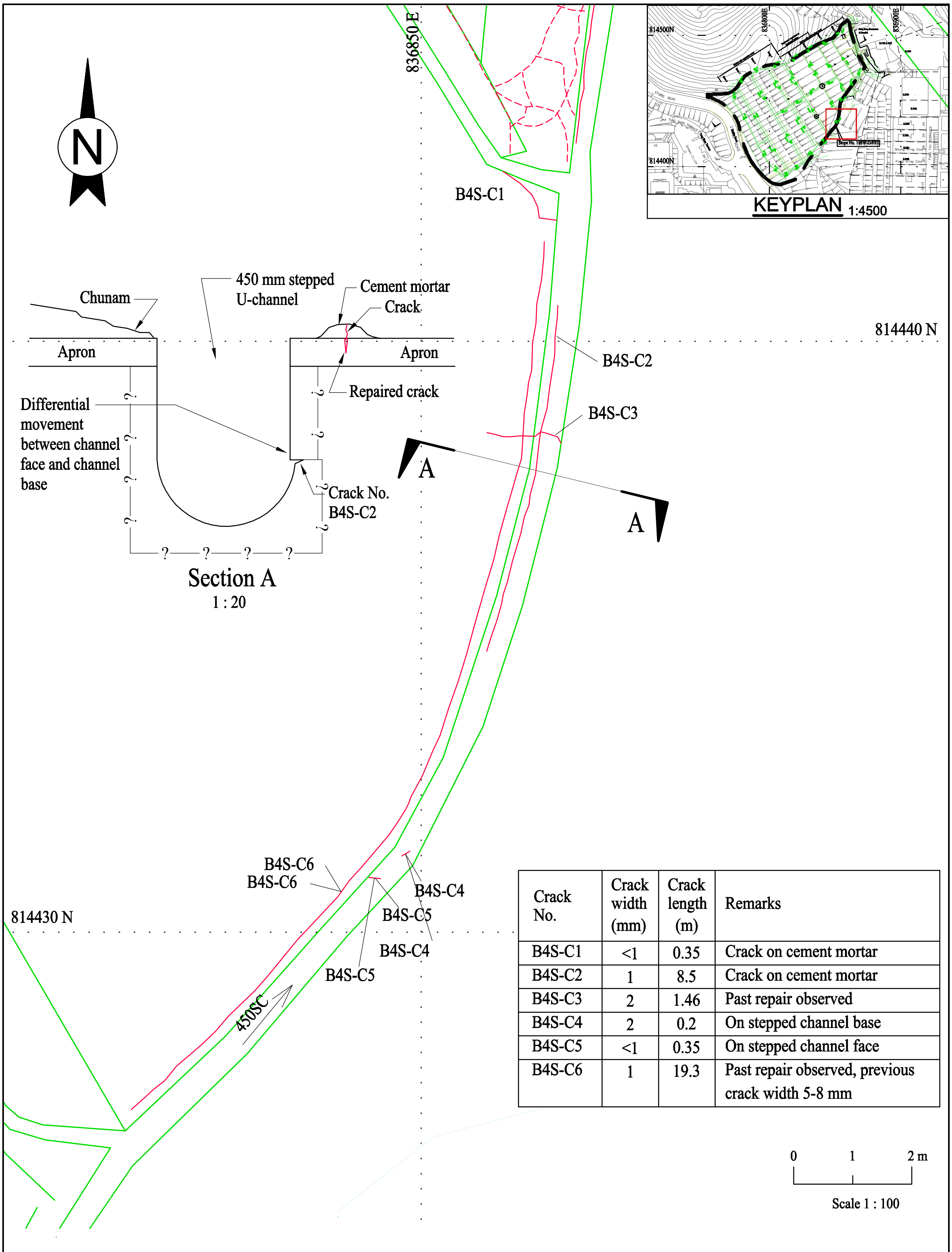
Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents



Crack No.	Crack width (mm)	Crack length (m)	Remarks
B3S-C1	2	0.64	-
B3S-C2	2-3	1.50	-
B3S-C3	5	0.60	-

Figure B5 - Distress Mapping of Slope No. 11SW-D/FR1 - Stepped U-channel at Southern End of 3rd Batter

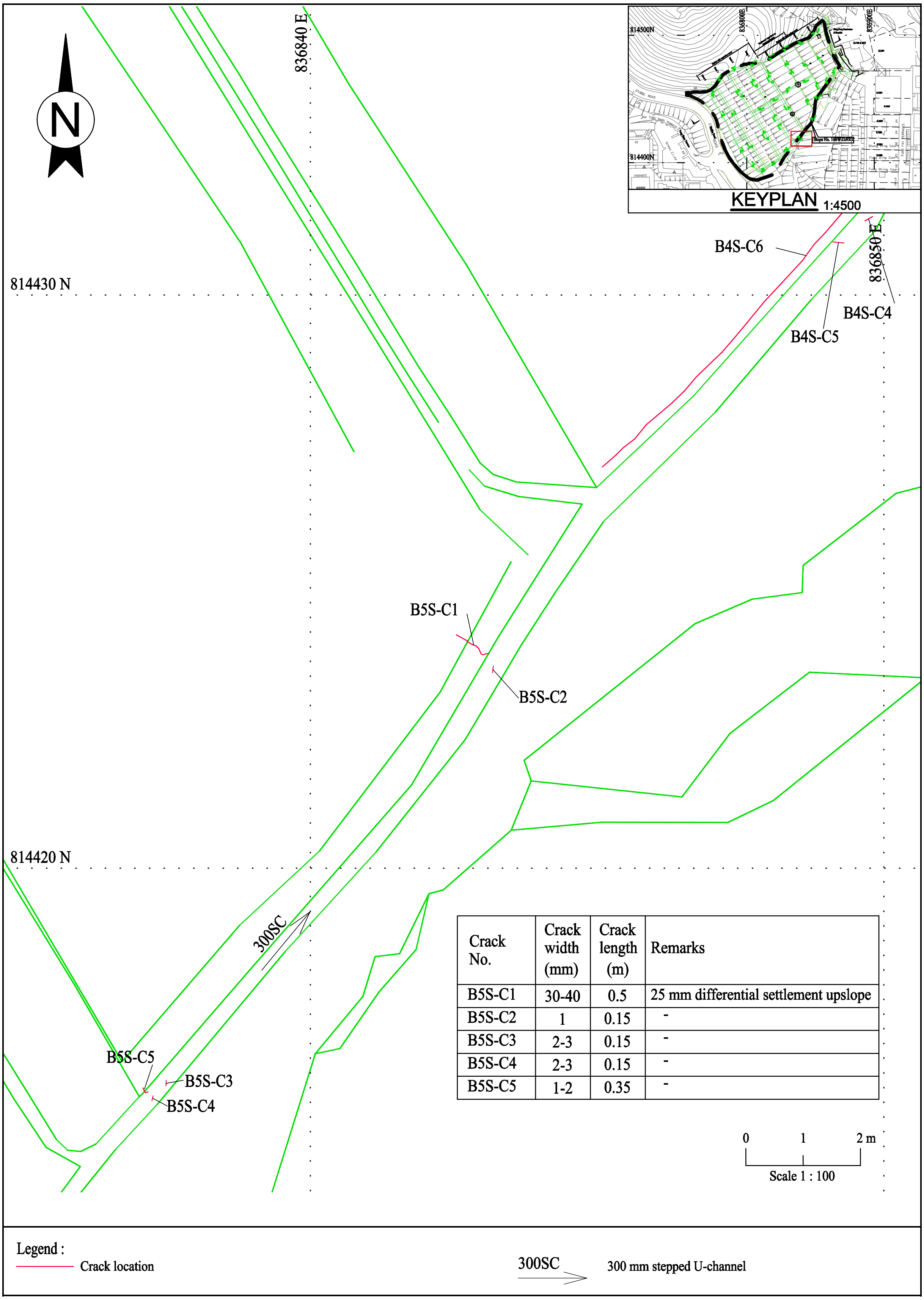


Crack No.	Crack width (mm)	Crack length (m)	Remarks
B4S-C1	<1	0.35	Crack on cement mortar
B4S-C2	1	8.5	Crack on cement mortar
B4S-C3	2	1.46	Past repair observed
B4S-C4	2	0.2	On stepped channel base
B4S-C5	<1	0.35	On stepped channel face
B4S-C6	1	19.3	Past repair observed, previous crack width 5-8 mm

Legend :
- - - - - - Crack repaired by cement mortar (Mapped based on record photographs)
——— Crack location
450SC → 450 mm stepped U-channel

Figure B6 - Distress Mapping of Slope No. 11SW-D/FR1 - Stepped U-channel at Southern End of 4th Batter

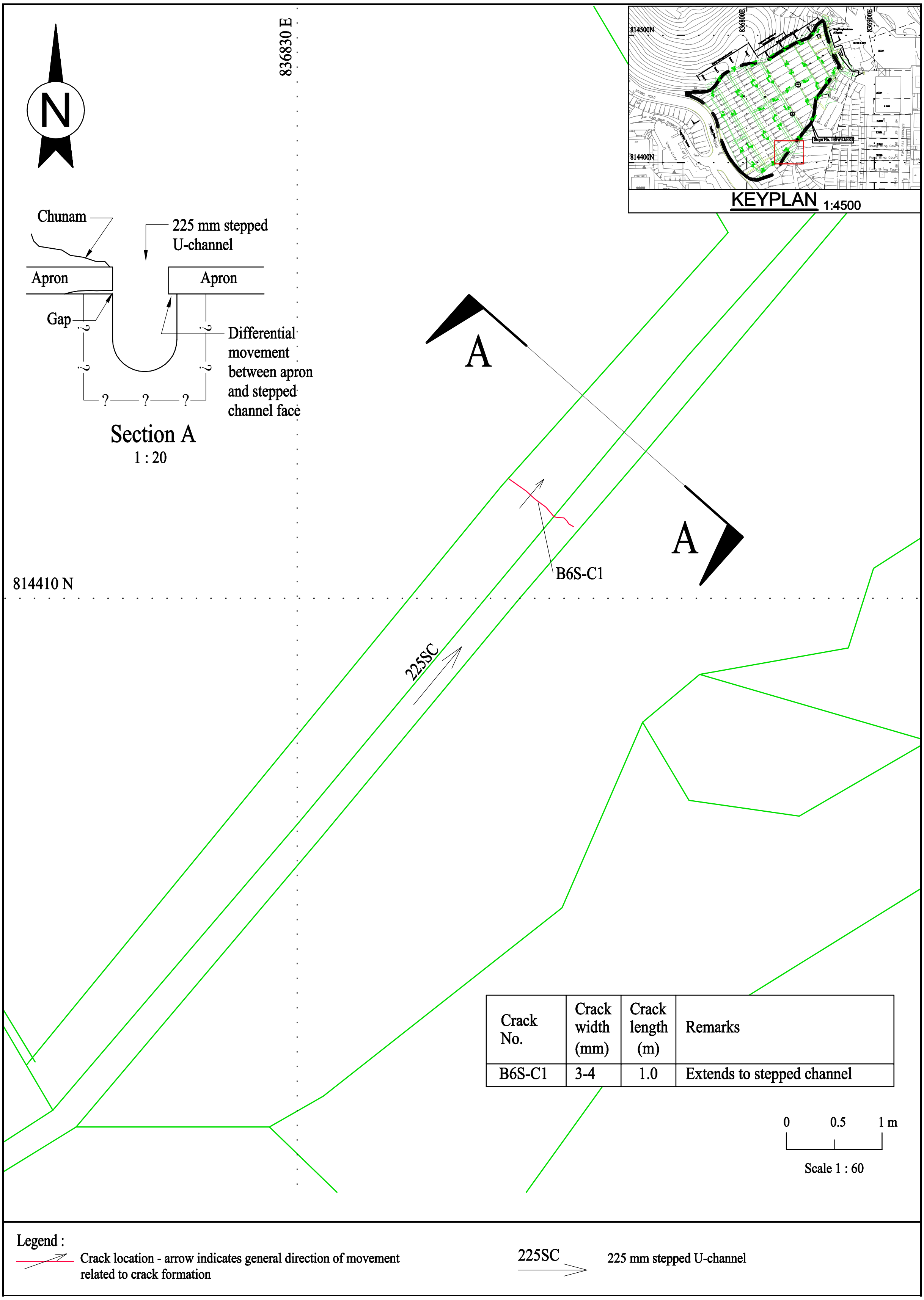
Table of Contents
Table of Contents
Table of Contents
Table of Contents



Crack No.	Crack width (mm)	Crack length (m)	Remarks
B5S-C1	30-40	0.5	25 mm differential settlement upslope
B5S-C2	1	0.15	-
B5S-C3	2-3	0.15	-
B5S-C4	2-3	0.15	-
B5S-C5	1-2	0.35	-

Figure B7 - Distress Mapping of Slope No. 11SW-D/FR1 - Stepped U-channel at Southern End of 5th Batter

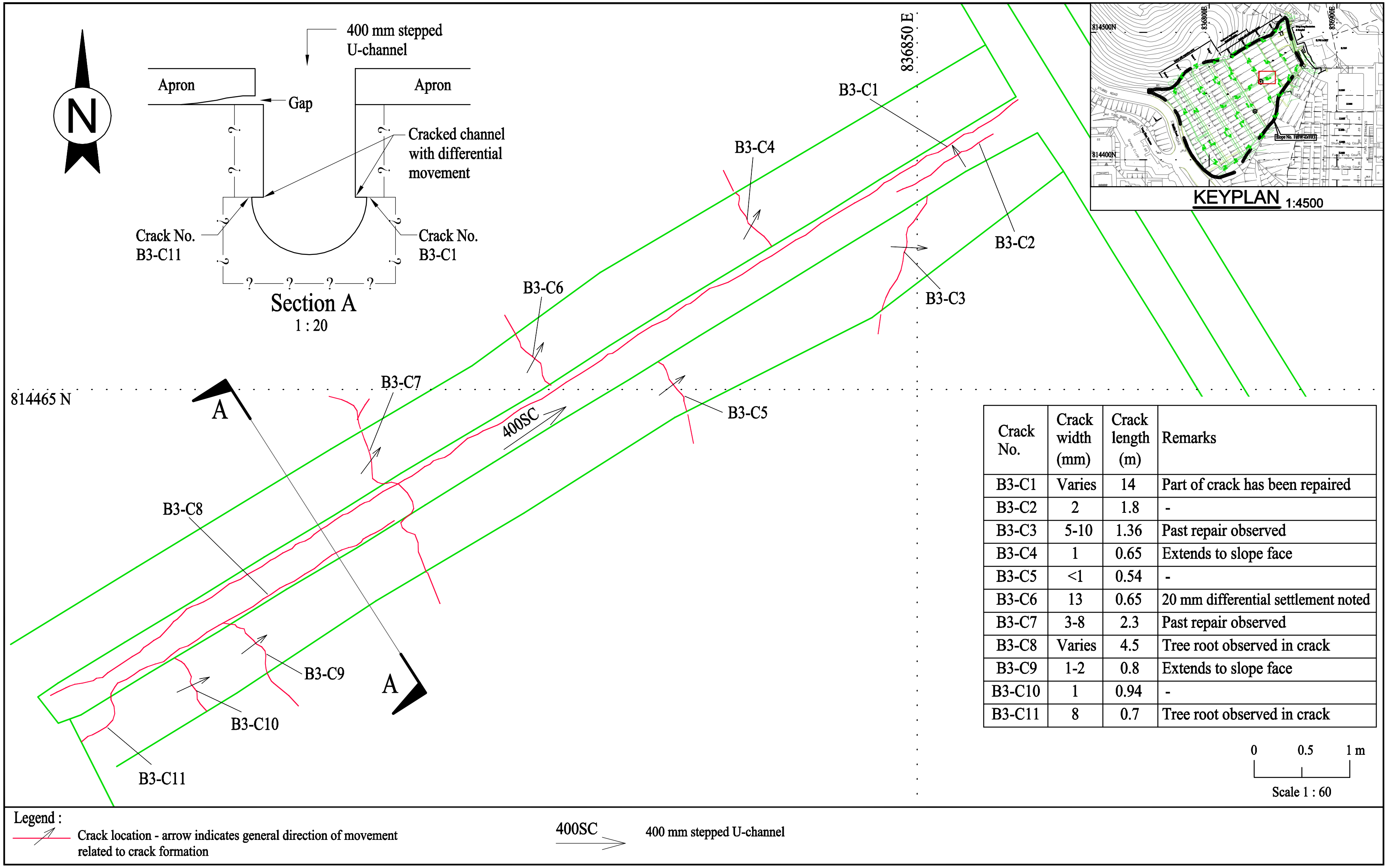
Table of Contents
Table of Contents
Table of Contents
Table of Contents



Crack No.	Crack width (mm)	Crack length (m)	Remarks
B6S-C1	3-4	1.0	Extends to stepped channel

Figure B8 - Distress Mapping of Slope No. 11SW-D/FR1 - Stepped U-channel at Southern End of 6th Batter

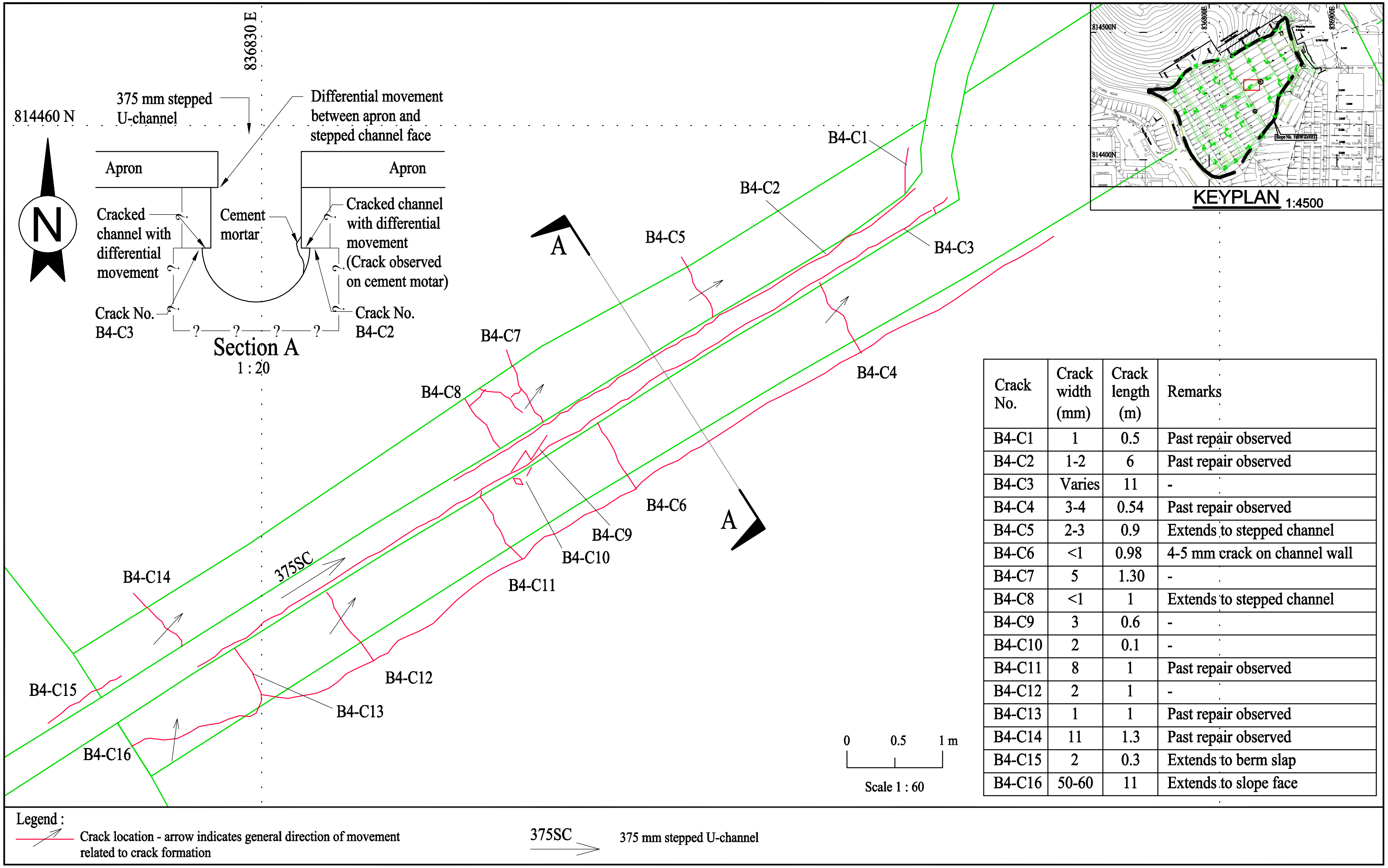
Table of Contents
Table of Contents
Table of Contents
Table of Contents



Crack No.	Crack width (mm)	Crack length (m)	Remarks
B3-C1	Varies	14	Part of crack has been repaired
B3-C2	2	1.8	-
B3-C3	5-10	1.36	Past repair observed
B3-C4	1	0.65	Extends to slope face
B3-C5	<1	0.54	-
B3-C6	13	0.65	20 mm differential settlement noted
B3-C7	3-8	2.3	Past repair observed
B3-C8	Varies	4.5	Tree root observed in crack
B3-C9	1-2	0.8	Extends to slope face
B3-C10	1	0.94	-
B3-C11	8	0.7	Tree root observed in crack

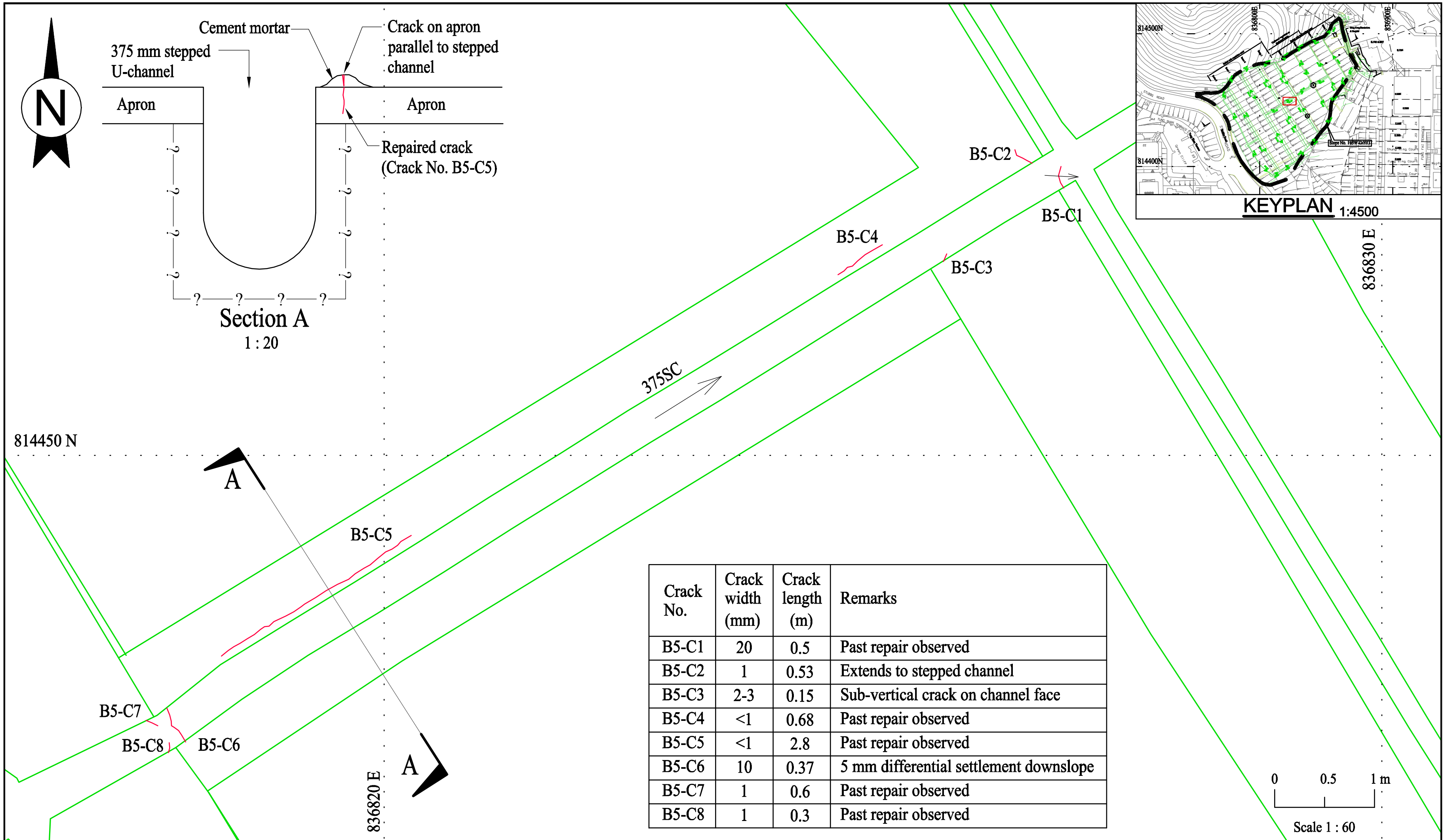
Figure B9 - Distress Mapping of Slope No. 11SW-D/FR1 - Stepped U-channel at the Centre of 3rd Batter

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



Crack No.	Crack width (mm)	Crack length (m)	Remarks
B4-C1	1	0.5	Past repair observed
B4-C2	1-2	6	Past repair observed
B4-C3	Varies	11	-
B4-C4	3-4	0.54	Past repair observed
B4-C5	2-3	0.9	Extends to stepped channel
B4-C6	<1	0.98	4-5 mm crack on channel wall
B4-C7	5	1.30	-
B4-C8	<1	1	Extends to stepped channel
B4-C9	3	0.6	-
B4-C10	2	0.1	-
B4-C11	8	1	Past repair observed
B4-C12	2	1	-
B4-C13	1	1	Past repair observed
B4-C14	11	1.3	Past repair observed
B4-C15	2	0.3	Extends to berm slap
B4-C16	50-60	11	Extends to slope face

Figure B10 - Distress Mapping of Slope No. 11SW-D/FR1 - Stepped U-channel at the Centre of 4th Batter



Crack No.	Crack width (mm)	Crack length (m)	Remarks
B5-C1	20	0.5	Past repair observed
B5-C2	1	0.53	Extends to stepped channel
B5-C3	2-3	0.15	Sub-vertical crack on channel face
B5-C4	<1	0.68	Past repair observed
B5-C5	<1	2.8	Past repair observed
B5-C6	10	0.37	5 mm differential settlement downslope
B5-C7	1	0.6	Past repair observed
B5-C8	1	0.3	Past repair observed

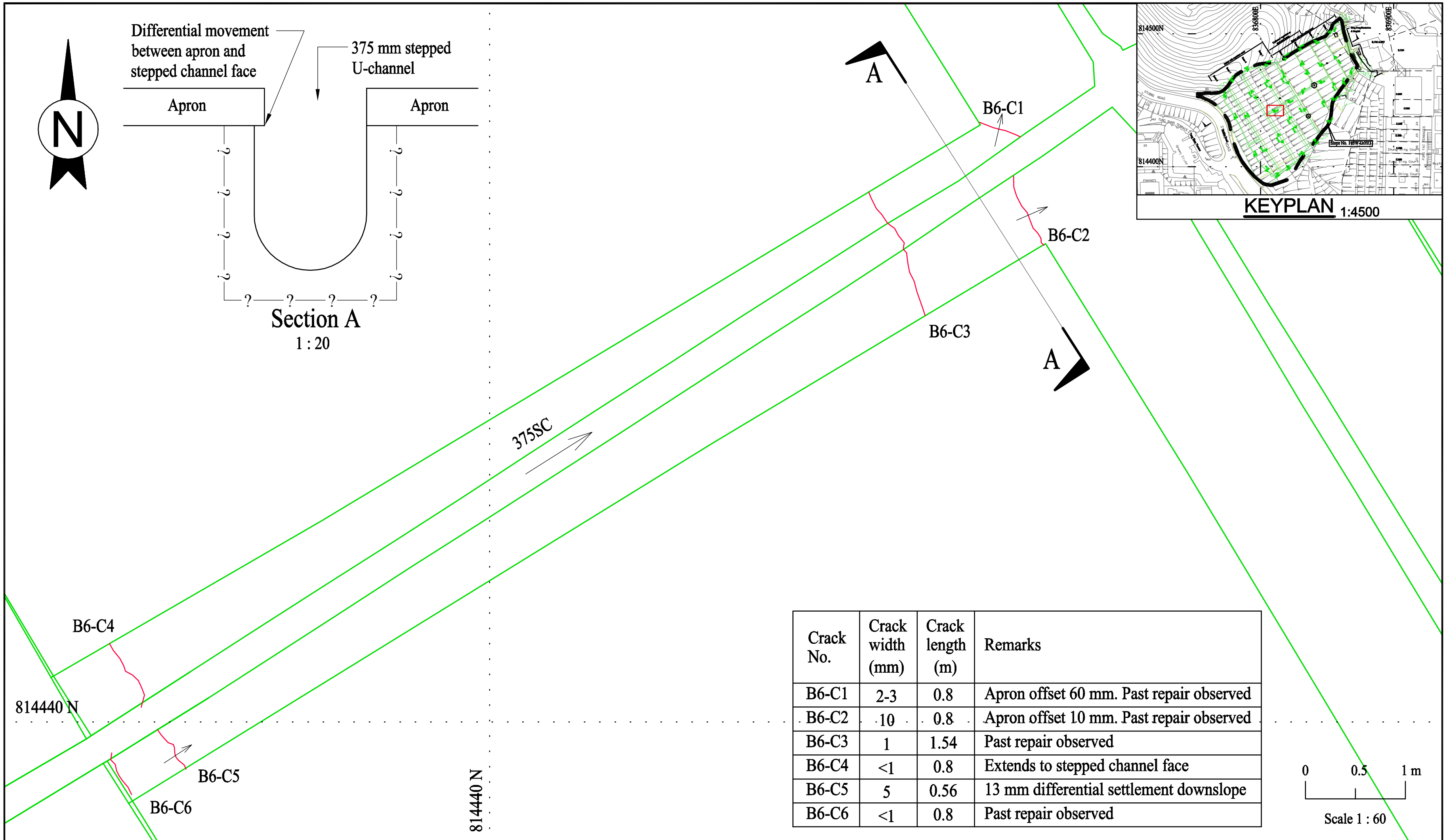
Legend :

Crack location - arrow indicates general direction of movement related to crack formation

375SC — 375 mm stepped U-channel

Figure B11 - Distress Mapping of Slope No. 11SW-D/FR1 - Stepped U-channel at the Centre of 5th Batter

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

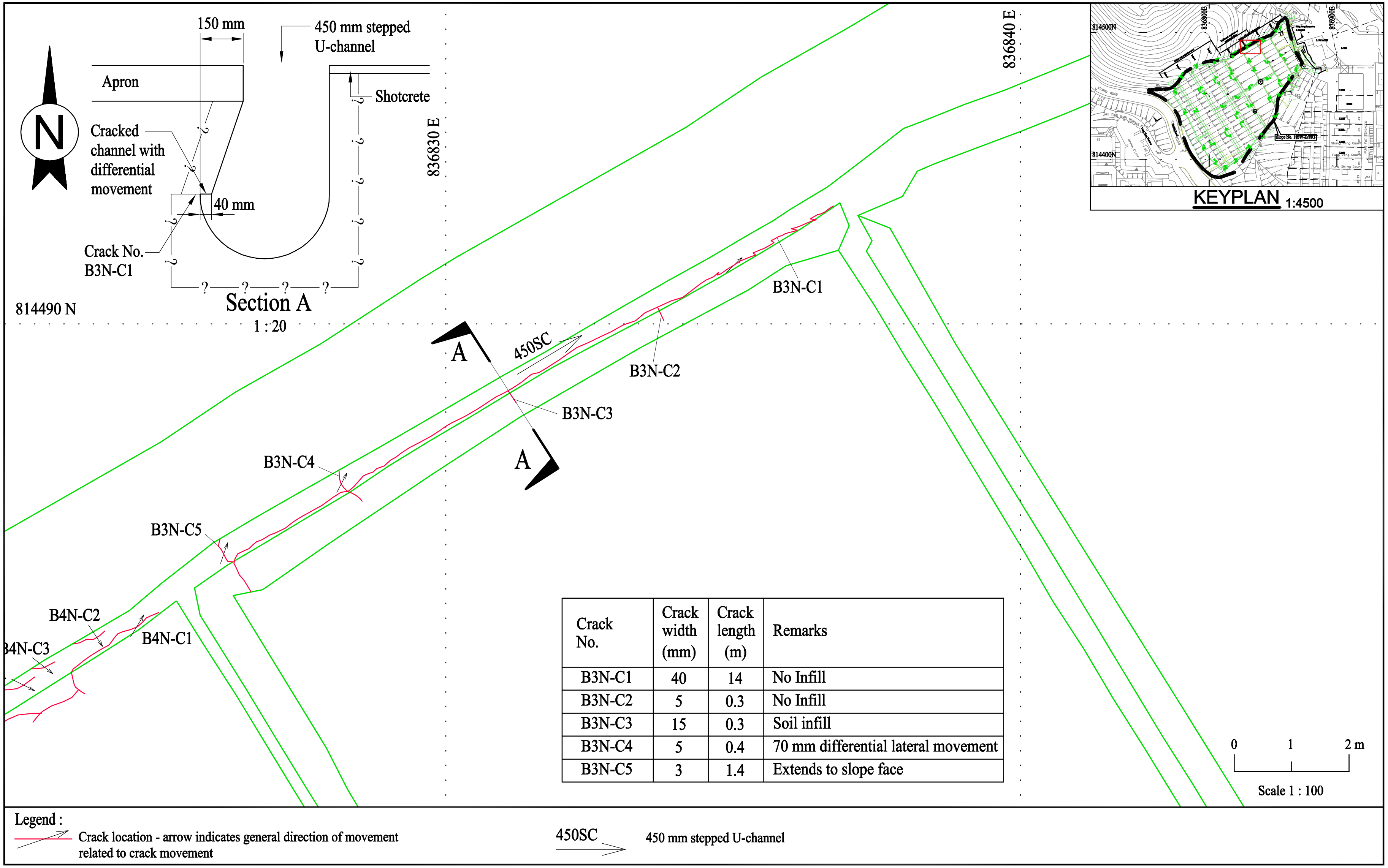


Crack No.	Crack width (mm)	Crack length (m)	Remarks
B6-C1	2-3	0.8	Apron offset 60 mm. Past repair observed
B6-C2	10	0.8	Apron offset 10 mm. Past repair observed
B6-C3	1	1.54	Past repair observed
B6-C4	<1	0.8	Extends to stepped channel face
B6-C5	5	0.56	13 mm differential settlement downslope
B6-C6	<1	0.8	Past repair observed

Legend :
Crack location - arrow indicates general direction of movement related to crack movement
375SC 375 mm stepped U-channel

Figure B12 - Distress Mapping of Slope No. 11SW-D/FR1 - Stepped U-channel at the Centre of 6th Batter

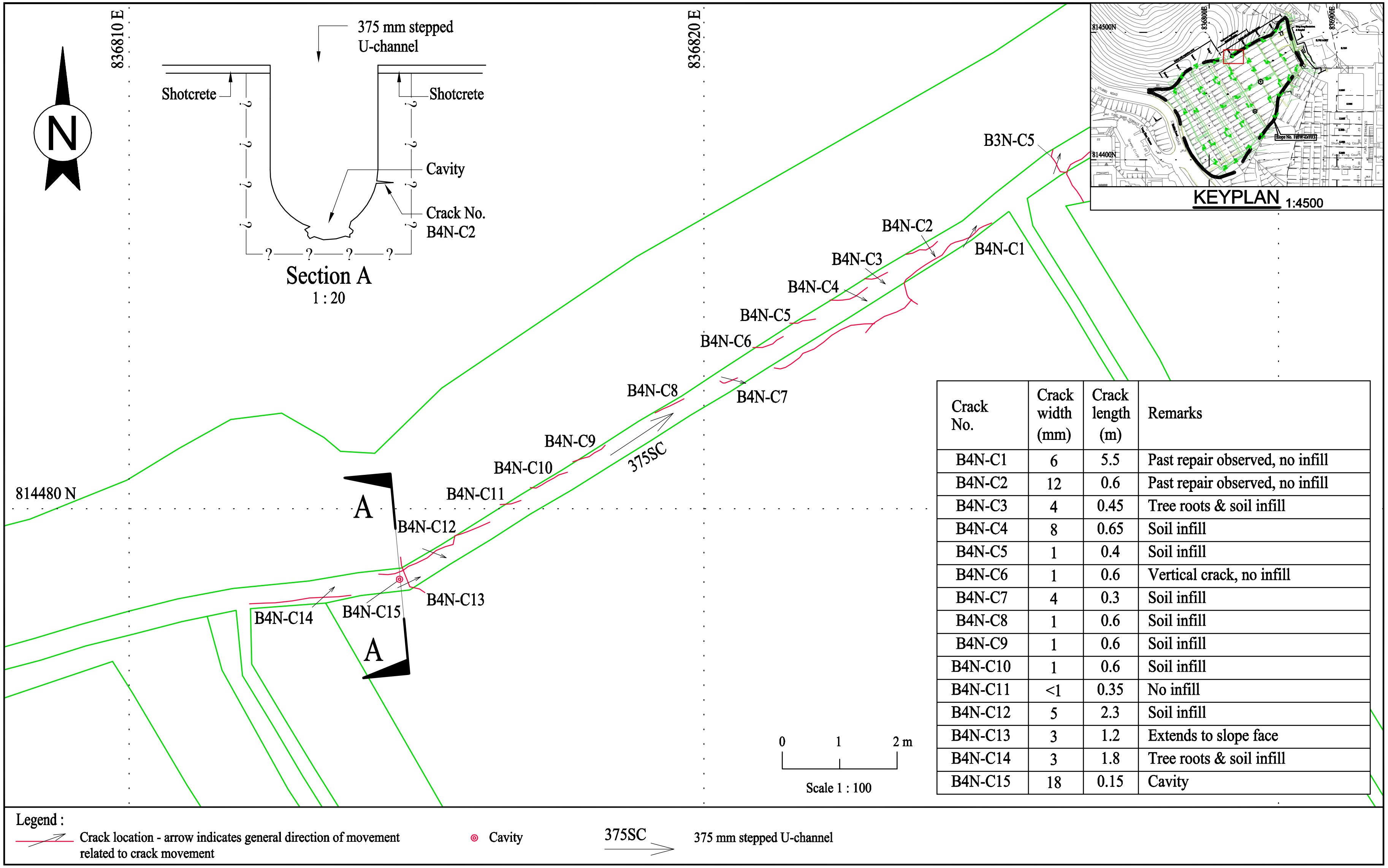
Table of Contents
Table of Contents
Table of Contents
Table of Contents



Crack No.	Crack width (mm)	Crack length (m)	Remarks
B3N-C1	40	14	No Infill
B3N-C2	5	0.3	No Infill
B3N-C3	15	0.3	Soil infill
B3N-C4	5	0.4	70 mm differential lateral movement
B3N-C5	3	1.4	Extends to slope face

Figure B13 - Distress Mapping of Slope No. 11SW-D/FR1 - Stepped U-channel at Northern End of 3rd Batter

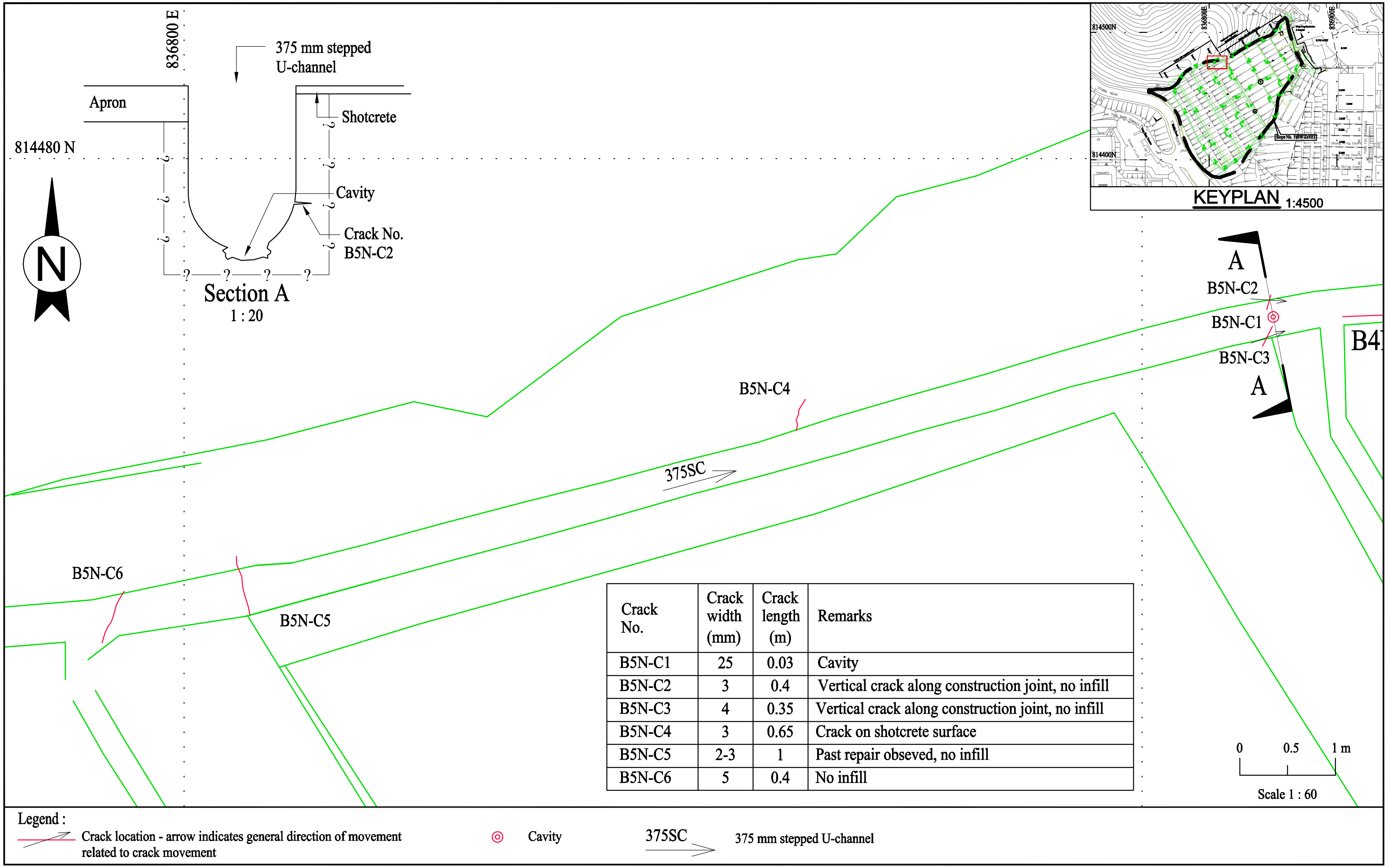
Table of Contents
Table of Contents
Table of Contents
Table of Contents



Crack No.	Crack width (mm)	Crack length (m)	Remarks
B4N-C1	6	5.5	Past repair observed, no infill
B4N-C2	12	0.6	Past repair observed, no infill
B4N-C3	4	0.45	Tree roots & soil infill
B4N-C4	8	0.65	Soil infill
B4N-C5	1	0.4	Soil infill
B4N-C6	1	0.6	Vertical crack, no infill
B4N-C7	4	0.3	Soil infill
B4N-C8	1	0.6	Soil infill
B4N-C9	1	0.6	Soil infill
B4N-C10	1	0.6	Soil infill
B4N-C11	<1	0.35	No infill
B4N-C12	5	2.3	Soil infill
B4N-C13	3	1.2	Extends to slope face
B4N-C14	3	1.8	Tree roots & soil infill
B4N-C15	18	0.15	Cavity

Figure B14 - Distress Mapping of Slope No. 11SW-D/FR1 - Stepped U-channel at Northern End of 4th Batter

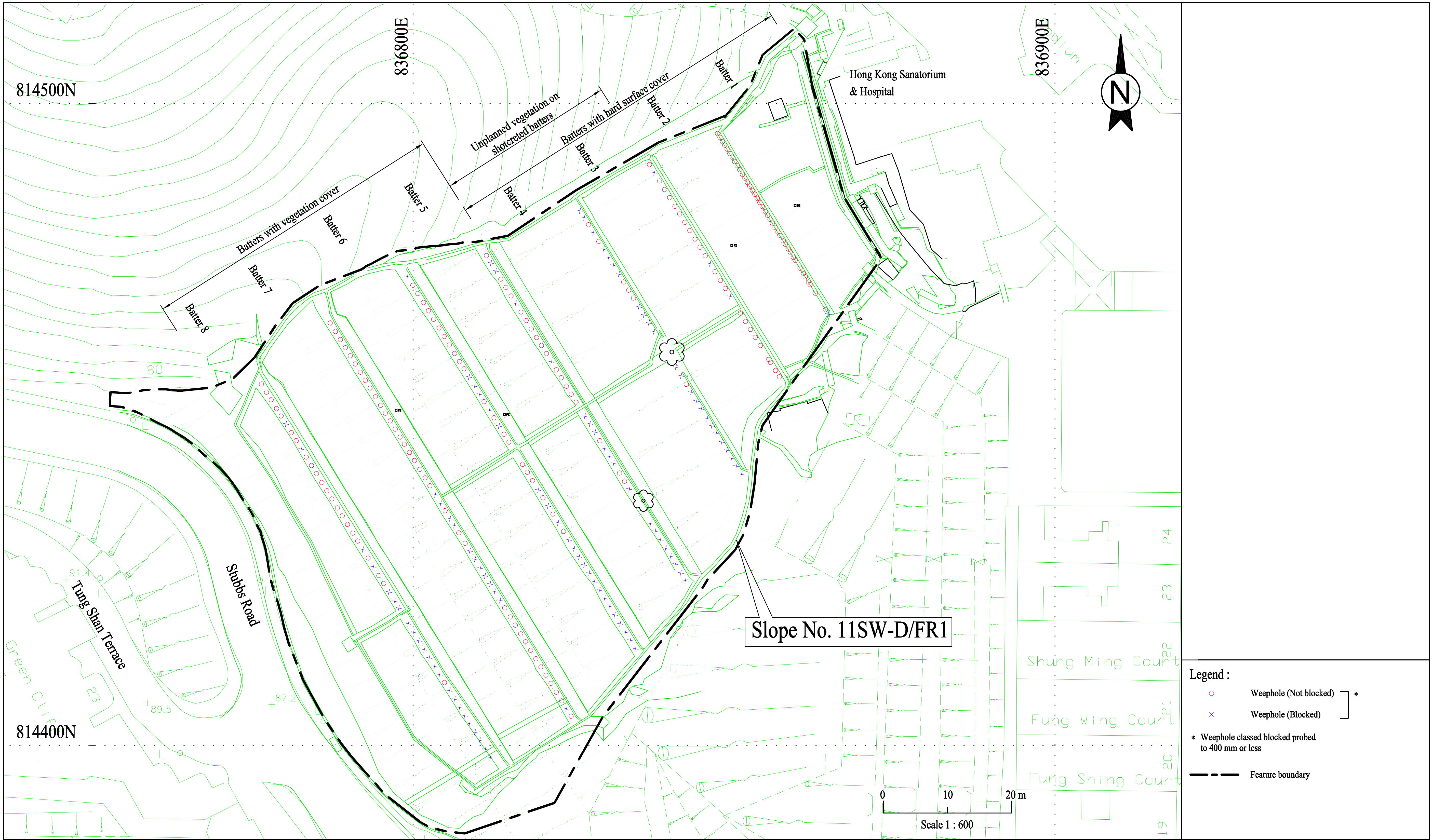
Table of Contents
Table of Contents
Table of Contents
Table of Contents



Crack No.	Crack width (mm)	Crack length (m)	Remarks
B5N-C1	25	0.03	Cavity
B5N-C2	3	0.4	Vertical crack along construction joint, no infill
B5N-C3	4	0.35	Vertical crack along construction joint, no infill
B5N-C4	3	0.65	Crack on shotcrete surface
B5N-C5	2-3	1	Past repair obseved, no infill
B5N-C6	5	0.4	No infill

Figure B15 - Distress Mapping of Slope No. 11SW-D/FR1 - Stepped U-channel at Northern End of 5th Batter

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



Notes :
(1) Base Map is extracted from survey sheet No. 11SW-15C, scale 1 : 1000.
(2) General arrangement of the subject slope based on detailed topographic survey by CED Survey Division in May 2004.

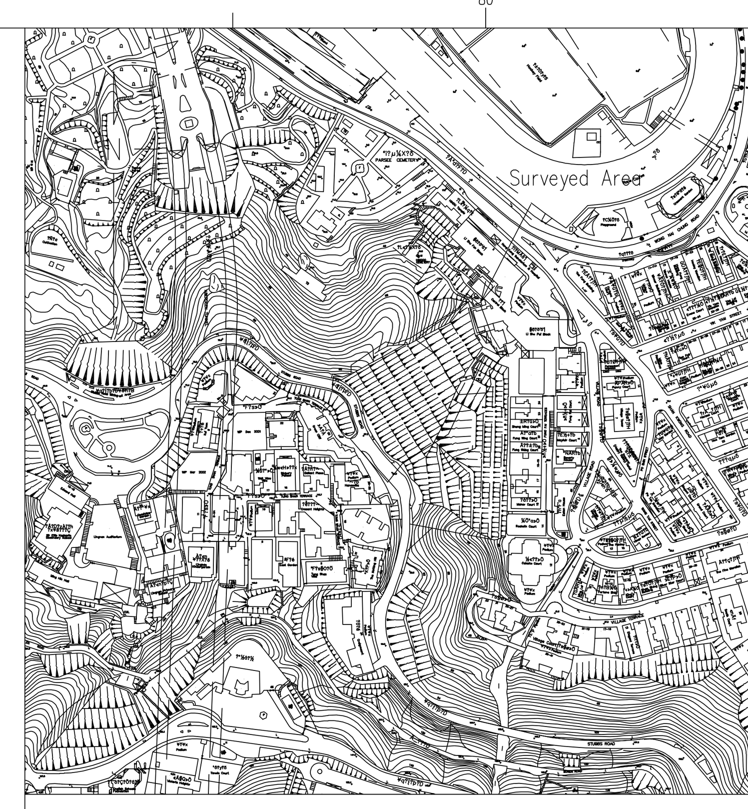
Figure B16 - Results of Probing Survey of 75 mm Diameter Drainage Pipes at Filter

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

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

APPENDIX C

TOPOGRAPHIC SURVEY



KEY PLAN SCALE 1 : 2000

NOTES :

1. ALL LEVELS ARE IN METRES ABOVE HONG KONG PRINCIPAL DATUM.
2. CO-ORDINATES ARE OF HONG KONG 1980 GRID SYSTEM.
3. ALL LEVELS ALONG KERB ARE BOTTOM LEVELS.
4. FOR SECTIONS, REFER TO DWG. GCS 3067/IX.

LEGEND :

●–●	STREET NAME POST
300 UC	300mm U-CHANNEL
300 SC	300mm STEPPED-CHANNEL
BW	BAFFLE WALL
	ROCK / ROCK SURFACE
29 66	SPOT LEVEL BENEATH STRUCTURE
	CRACK LINES
CH.F 0	CHAINAGE F 0+00 @ BERM F

SECTIONS DATA :

SECTION	NORTHING	EASTING
1 – 1'	814432.41	836771.73
	814500.00	836883.74
2 – 2'	814386.21	836795.48
	814434.80	836860.50

No.	date	description	initial
REVISION			

	name	date
surveyed	CY WONG, KW FAN, CY CHEUNG	12-05-2004
drawn	CY WONG, KW FAN	15-05-2004
checked	CY HO	

approved

K.S.TAM (LS/G2) Date

contract no.	CE 95/2002 (GE)
file no.	GCLI 2/A2/44-13
job no.	E 040033

contract

LANDSLIP PREVENTIVE MEASURES

drawing title

11SW-D/FR1
STUBBS ROAD
TOPOGRAPHICAL SURVEY PLAN

drawing no.	scale
GCS 3067/VIII	1 : 250

office

SURVEY DIVISION

CIVIL ENGINEERING
DEPARTMENT
HONG KONG

B1 1000x707

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

Table of Contents

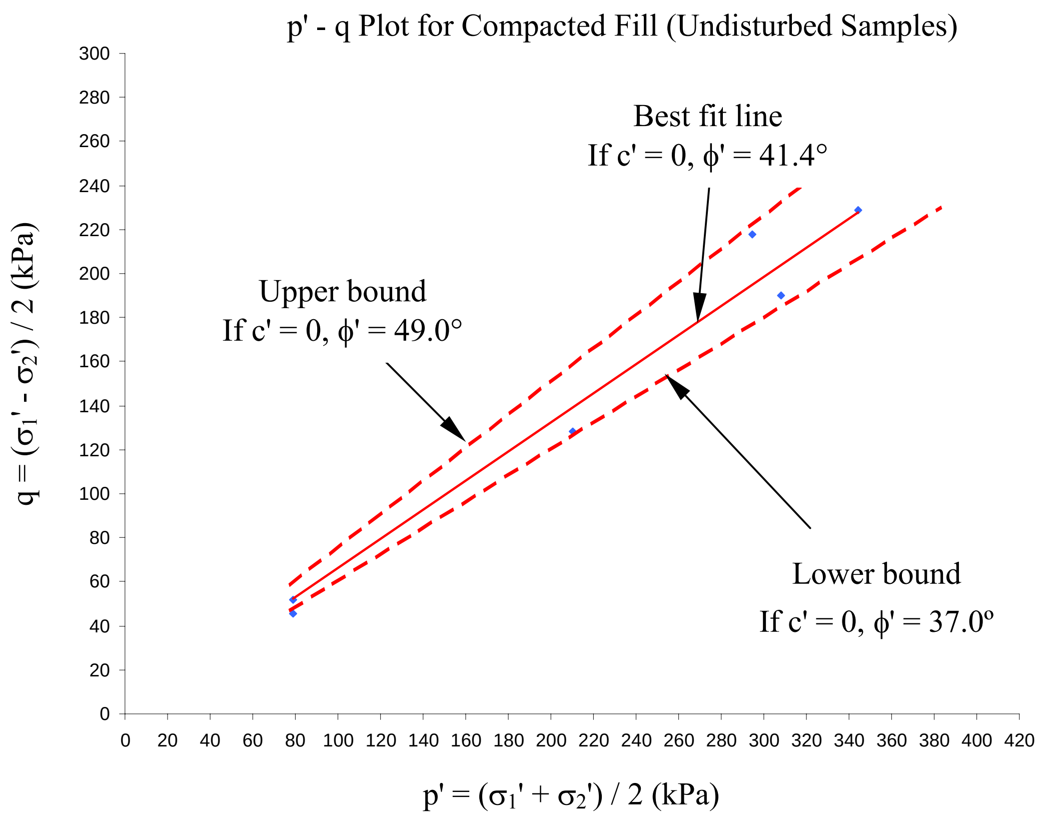
Table of Contents

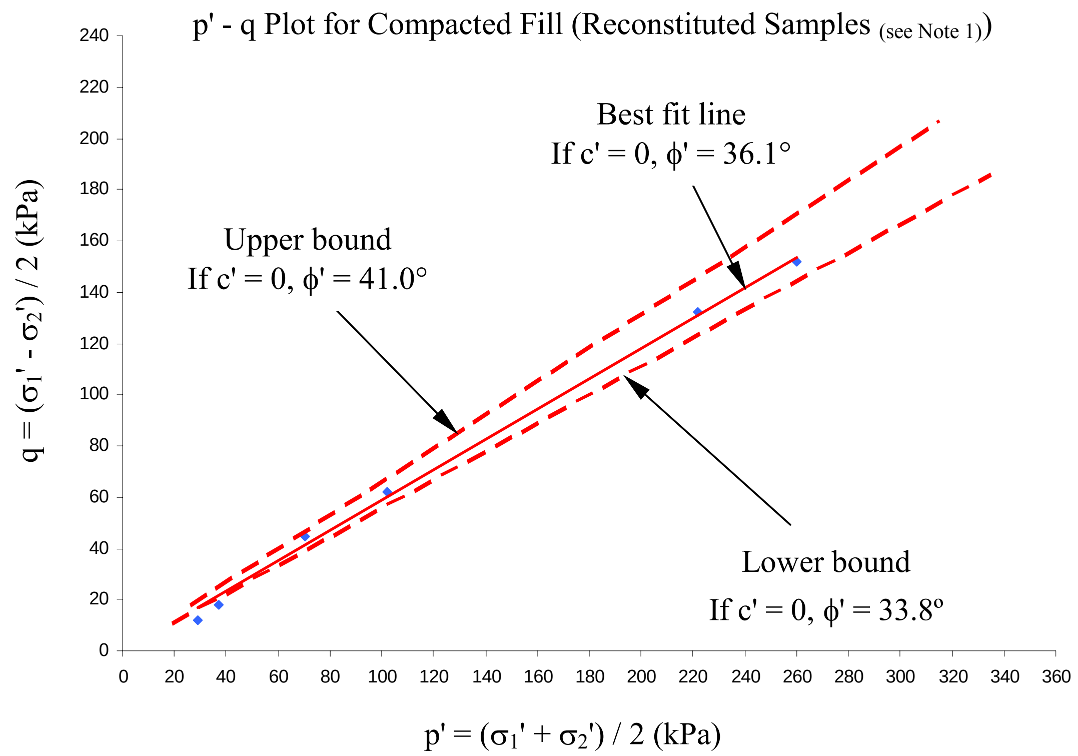
APPENDIX D

RESULTS OF TRIAXIAL TESTING

Table of Contents

Table of Contents

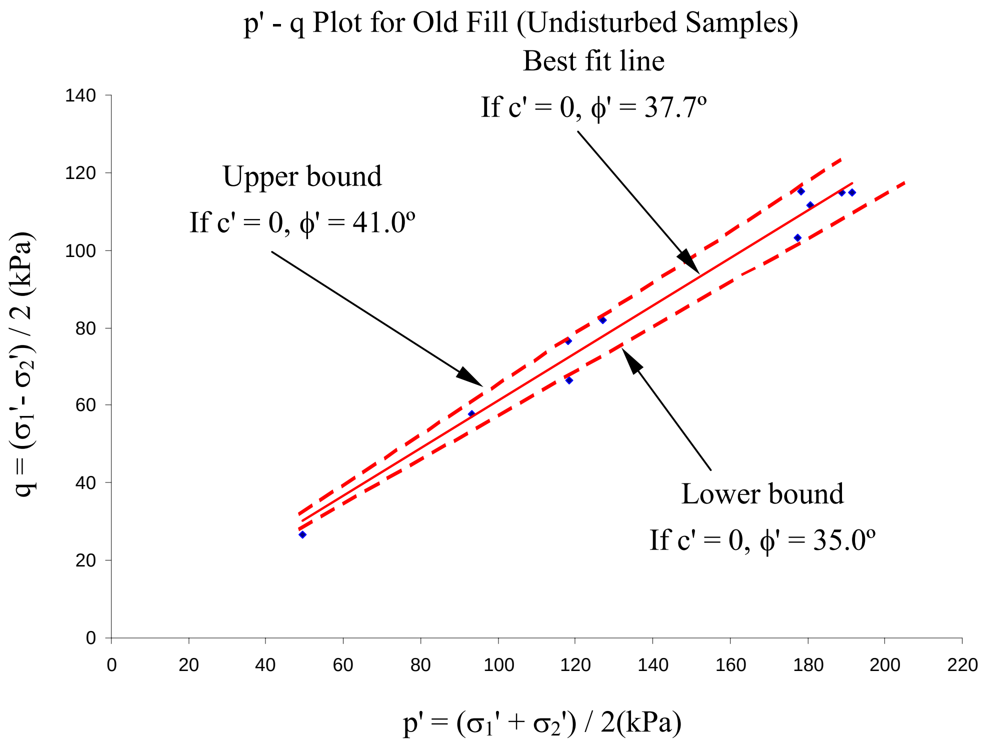




Note: (1) Samples reconstituted to relative degree of compaction close to in-situ condition.

Figure D1 - p' – q plot for Undisturbed Compacted Fill and Reconstituted Compacted Fill

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



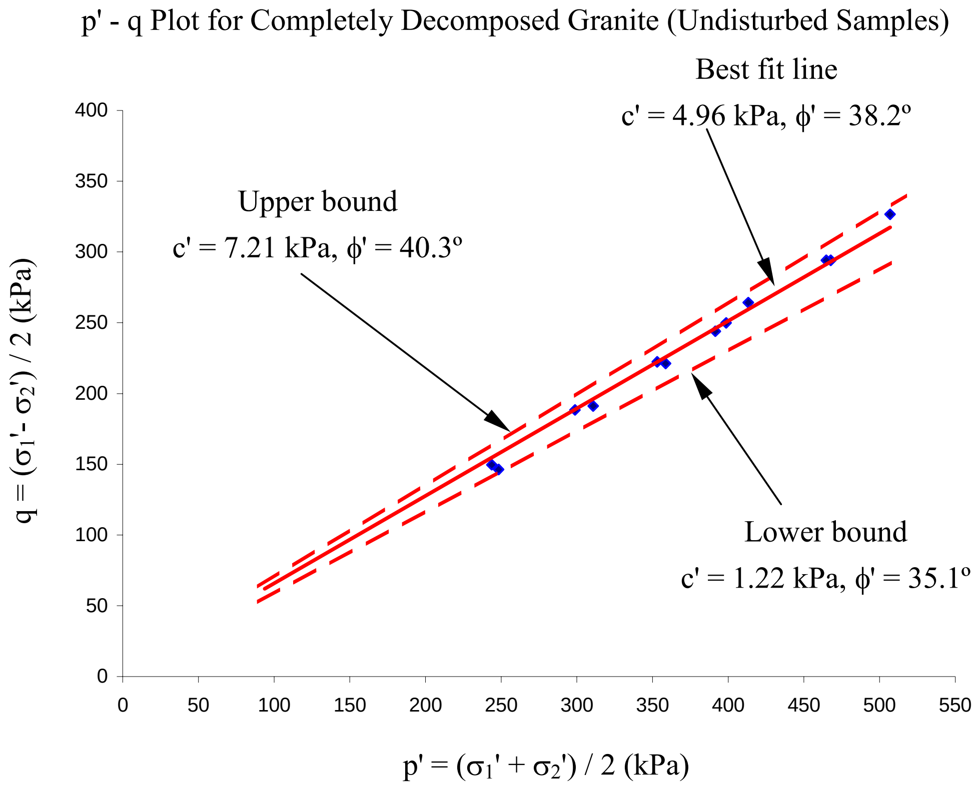


Figure D2 - p' - q plot for Old Fill and CDG

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

Table of Contents

Table of Contents

APPENDIX E

GROUNDWATER MONITORING

Table of Contents

Table of Contents

Table E1 - Summary of Groundwater Monitoring Data (Sheet 1 of 3)

Piezometer No		Co-ordinate Northing	Co-ordinate Easting	Ground Level (mPD)	Top of pipe above Ground Level (m)	Piezometer Tip Level (mPD)	Piezometer Tip Level (m)	Response Zone Level (mPD)	Response Zone Level (m)	22/03/2004 GW Depth (mPD)	22/03/2004 Halcrow Bucket (m)	06/04/2004 GW Depth (mPD)	06/04/2004 Halcrow Bucket (m)	16/04/2004 GW Depth (mPD)	16/04/2004 Halcrow Bucket (m)	06/05/2004 GW Depth (mPD)	06/05/2004 Halcrow Bucket (m)	14/05/2004 GW Depth (mPD)	14/05/2004 Halcrow Bucket (m)	25/05/2004 GW Depth (mPD)	25/05/2004 Halcrow Bucket (m)	27/05/2004 GW Depth (mPD)	27/05/2004 Halcrow Bucket (m)	28/05/2004 GW Depth (mPD)	28/05/2004 Halcrow Bucket (m)	29/05/2004 GW Depth (mPD)	29/05/2004 Halcrow Bucket (m)	31/05/2004 GW Depth (mPD)	31/05/2004 Halcrow Bucket (m)	01/06/2004 GW Depth (mPD)	01/06/2004 Halcrow Bucket (m)	02/06/2004 GW Depth (mPD)	02/06/2004 Halcrow Bucket (m)	03/06/2004 GW Depth (mPD)	03/06/2004 Halcrow Bucket (m)	04/06/2004 GW Depth (mPD)	04/06/2004 Halcrow Bucket (m)
T9	Upper	814397	836794	86.30	0.00	71.21	15.09	71.06 - 71.97	14.33 - 15.24	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	Lower				0.00	62.98	23.32	62.83 - 65.88	20.42 - 23.47	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	67.70	18.50	67.67	18.50	67.67	18.50	67.65	18.50	67.50	18.50	67.50	18.50	67.70	19.00	67.67	19.00	67.63	19.00
NSR1	Upper	814453	836797	70.60	0.05	57.00	13.15	57.30 - 58.30	12.45 - 13.45	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	Lower				0.15	52.80	17.80	52.63 - 54.65	15.95 - 17.97	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	53.95	Dry	53.94	Dry	53.92	Dry	53.92	Dry	Dry	Dry	Dry	Dry	53.89	Dry	Dry	Dry	Dry	Dry
NSR2	Upper	814452	836814	63.10	0.10	50.30	12.80	50.15 - 51.15	11.95 - 12.95	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-
	Lower				0.10	45.25	17.85	45.10 - 46.10	17 - 18	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
RP2	Upper	814469	836830	40.57	0.05	31.97	9.20	32.22 - 31.22	8.35-9.35	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	Lower				0.07	-6.62	47.19	(-5.77)-(-6.77)	46.34-47.34	13.47	-	13.70	-	13.83	-	13.83	-	14.19	-	14.10	26.00	14.09	26.00	14.18	26.50	14.26	26.50	14.35	26.00	14.35	26.00	14.35	26.00	14.35	26.00	14.35	26.00
BH1	Upper	814465.81	836820.08	56.44	0.08	47.24	9.20	48.24 - 46.74	8.20-9.70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower				0.08	32.14	24.30	33.14 - 31.64	23.30-24.80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BH2	Upper	814455.41	836844.90	47.80	0.08	35.15	12.65	36.15 - 34.65	11.65-13.15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower				0.08	24.00	23.80	25.00 - 23.50	22.80-24.30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BH3	Upper	814432.61	836809.46	70.44	0.10	58.74	11.70	59.74 - 58.24	10.70-12.20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower				0.10	46.54	23.90	47.54 - 46.04	22.90-24.40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BH4	Upper	814442.30	836787.25	77.97	0.14	67.67	10.30	68.67 - 67.17	9.30-10.80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower				0.14	54.47	23.50	55.47 - 53.97	22.50-24.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BH5	Upper	814407.22	836808.71	79.40	0.14	74.70	4.70	75.70 - 74.20	3.70-5.20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower				0.14	54.10	25.30	55.10 - 53.60	24.30-25.80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BH6	Upper	814467.96	836812.71	58.84	0.08	49.84	9.00	50.84 - 49.34	8.00-9.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower				0.08	34.74	24.10	35.74 - 34.24	23.10-24.60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BH7	Upper	814472.49	836843.29	42.92	0.08	33.22	9.70	34.72 - 32.72	8.70-10.20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower				0.08	19.32	23.60	20.32 - 18.82	22.60-24.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BH8	Upper	814495.07	836848.96	33.99	0.08	31.39	2.60	32.39 - 30.89	1.60-3.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower				0.08	10.39	23.60	11.39 - 9.89	22.6-24.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BH9	Upper	814469.88	836864.76	33.75	0.07	30.15	3.60	31.15 - 29.65	2.60-4.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower				0.07	10.45	23.30	11.45 - 9.95	22.30-23.80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PT1	Upper	814484.81	836842.42	40.14	0.07	36.14	4.00	37.14 - 35.64	3.00-4.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower				0.08	30.44	9.70	31.94 - 29.94	8.20-10.20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PT2	Upper	814478.58	836852.59	36.80	0.04	34.00	2.80	34.80 - 33.30	2.00 - 3.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower				0.04	29.55	7.25	32.30 - 29.35	4.50 - 7.45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TP1		814488.69	836833.83	42.69	0.10	40.19	2.50	40.19 - 41.19	1.50 - 2.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TP2		814481.37	836841.59	40.81	0.17	37.66	3.15	37.66 - 38.66	2.15 - 3.15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TP3		814458.51	836838.47	49.485	0.085	46.25	3.24	46.34 - 47.34	2.15 - 3.15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TP4		814480.83	836862.62	31.23	0.13	28.53	2.70	29.36 - 28.36	2.00 - 3.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TP5	Upper	814482.15	836853.20	35.02	0.16	34.46	0.56	34.88 - 34.38	0.50 - 0.80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower	814480.82	836853.97	35.07	0.15	31.79	3.28	32.72 - 31.73	2.50 - 3.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TP6	Upper	814469.41	836848.28	41.24	0.09	39.34	1.90	40.33 - 39.33	1.00 - 2.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower	814470.74	836847.51	41.24	0.17	38.44	2.84	39.41 - 38.41	2.00 - 3.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TP7		814451.06	836817.04	62.04	0.18	59.76	2.28	60.72 - 59.72	1.50 - 2.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TP9		814429.84	836814.62	68.94	0.13	65.75	3.19	2.50 - 3.50	2.50 - 3.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TP10		814437.17	836973.32	76.83	0.12	73.96	2.87	74.85 - 73.85	2.10 - 3.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TT1		814429.92	836834.13	59.99	0.12	57.20	2.79	58.01 - 57.33	2.10 - 3.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

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

Table E1 - Summary of Groundwater Monitoring Data (Sheet 2 of 3)

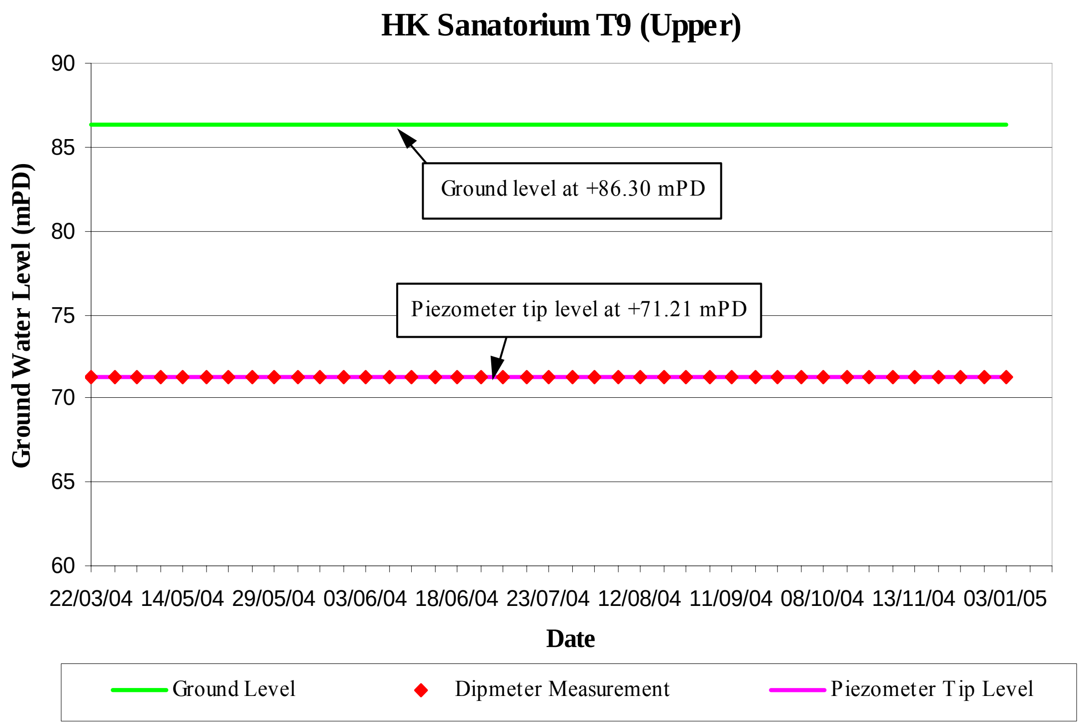
Piezometer No		Co-ordinate		Ground Level (mPD)	Top of pipe above Ground Level (m)	Piezometer Tip Level		Response Zone Level		Date																											
										05/06/2004		11/06/2004		18/06/2004		25/06/2004		29/06/2004		02/07/2004		09/07/2004		23/07/2004		26/07/2004		30/07/2004		06/08/2004		09/08/2004		12/08/2004		20/08/2004	
		Northing	Easting			(mPD)	(m)	(mPD)	(m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)
T9	Upper	814397	836794	86.30	0.00	71.21	15.09	71.06 - 71.97	14.33 - 15.24	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	-	-	Dry	Dry	Dry	Dry	Dry	Dry	-	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	Lower				0.00	62.98	23.32	62.83 - 65.88	20.42 - 23.47	67.62	19.00	67.54	19.00	67.50	19.00	67.52	19.00	-	-	67.39	19.00	67.40	19.00	67.19	19.00	-	-	67.13	19.50	66.08	19.50	66.08	19.50	67.08	19.50	66.97	19.50
NSR1	Upper	814453	836797	70.60	0.05	57.00	13.15	57.30 - 58.30	12.45 - 13.45	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	-	-	Dry	Dry	Dry	Dry	Dry	Dry	-	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	Lower				0.15	52.80	17.80	52.63 - 54.65	15.95 - 17.97	Dry	Dry	53.84	Dry	53.85	Dry	53.85	Dry	-	-	53.85	Dry	53.81	Dry	53.79	Dry	-	-	53.77	Dry	53.77	Dry	53.77	Dry	53.77	Dry	53.74	53.74
NSR2	Upper	814452	836814	63.10	0.10	50.30	12.80	50.15 - 51.15	11.95 - 12.95	Dry	-	Dry	-	Dry	-	Dry	-	-	-	Dry	-	Dry	-	Dry	-	-	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-
	Lower				0.10	45.25	17.85	45.10 - 46.10	17 - 18	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	-	-	Dry	Dry	Dry	Dry	Dry	Dry	-	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
RP2	Upper	814469	836830	40.57	0.05	31.97	9.20	32.22 - 31.22	8.35-9.35	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	-	-	Dry	Dry	Dry	Dry	Dry	Dry	-	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	Lower				0.07	-6.62	47.19	(-5.77)-(-6.77)	46.34-47.34	14.35	26.00	14.32	26.00	14.31	26.50	14.31	26.00	-	-	13.71	27.00	13.33	Dry	12.97	Dry	-	-	12.85	Dry	12.78	Dry	13.09	Dry	12.98	Dry	12.68	Dry
BH1	Upper	814465.81	836820.08	56.44	0.08	47.24	9.20	48.24 - 46.74	8.20-9.70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower				0.08	32.14	24.30	33.14 - 31.64	23.30-24.80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BH2	Upper	814455.41	836844.90	47.80	0.08	35.15	12.65	36.15 - 34.65	11.65-13.15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower				0.08	24.00	23.80	25.00 - 23.50	22.80-24.30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BH3	Upper	814432.61	836809.46	70.44	0.10	58.74	11.70	59.74 - 58.24	10.70-12.20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower				0.10	46.54	23.90	47.54 - 46.04	22.90-24.40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BH4	Upper	814442.30	836787.25	77.97	0.14	67.67	10.30	68.67 - 67.17	9.30-10.80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower				0.14	54.47	23.50	55.47 - 53.97	22.50-24.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BH5	Upper	814407.22	836808.71	79.40	0.14	74.70	4.70	75.70 - 74.20	3.70-5.20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower				0.14	54.10	25.30	55.10 - 53.60	24.30-25.80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BH6	Upper	814467.96	836812.71	58.84	0.08	49.84	9.00	50.84 - 49.34	8.00-9.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower				0.08	34.74	24.10	35.74 - 34.24	23.10-24.60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BH7	Upper	814472.49	836843.29	42.92	0.08	33.22	9.70	34.72 - 32.72	8.70-10.20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower				0.08	19.32	23.60	20.32 - 18.82	22.60-24.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BH8	Upper	814495.07	836848.96	33.99	0.08	31.39	2.60	32.39 - 30.89	1.60-3.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower				0.08	10.39	23.60	11.39 - 9.89	22.6-24.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BH9	Upper	814469.88	836864.76	33.75	0.07	30.15	3.60	31.15 - 29.65	2.60-4.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower				0.07	10.45	23.30	11.45 - 9.95	22.30-23.80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PT1	Upper	814484.81	836842.42	40.14	0.07	36.14	4.00	37.14 - 35.64	3.00-4.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower				0.08	30.44	9.70	31.94 - 29.94	8.20-10.20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PT2	Upper	814478.58	836852.59	36.80	0.04	34.00	2.80	34.80 - 33.30	2.00 - 3.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower				0.04	29.55	7.25	32.30 - 29.35	4.50 - 7.45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TP1		814488.69	836833.83	42.69	0.10	40.19	2.50	40.19 - 41.19	1.50 - 2.50	-	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-
TP2		814481.37	836841.59	40.81	0.17	37.66	3.15	37.66 - 38.66	2.15 - 3.15	-	-	39.30	-	39.65	-	39.65	-	39.50	-	39.49	-	39.38	-	39.79	-	39.79	-	39.35	-	40.09	-	39.87	-	39.80	-	39.73	-
TP3		814458.51	836838.47	49.485	0.085	46.25	3.24	46.34 - 47.34	2.15 - 3.15	-	-	47.03	-	46.87	-	46.90	-	46.71	-	46.67	-	46.51	-	47.45	-	-	-	47.52	-	47.49	-	47.38	-	47.30	-	47.07	-
TP4		814480.83	836862.62	31.23	0.13	28.53	2.70	29.36 - 28.36	2.00 - 3.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TP5	Upper	814482.15	836853.20	35.02	0.16	34.46	0.56	34.88 - 34.38	0.50 - 0.80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower	814480.82	836853.97	35.07	0.15	31.79	3.28	32.72 - 31.73	2.50 - 3.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TP6	Upper	814469.41	836848.28	41.24	0.09	39.34	1.90	40.33 - 39.33	1.00 - 2.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Lower	814470.74	836847.51	41.24	0.17	38.44	2.84	39.41 - 38.41	2.00 - 3.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TP7		814451.06	836817.04	62.04	0.18	59.76	2.28	60.72 - 59.72	1.50 - 2.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TP9		814429.84	836814.62	68.94	0.13	65.75	3.19	2.50 - 3.50	2.50 - 3.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TP10		814437.17	836973.32	76.83	0.12	73.96	2.87	74.85 - 73.85	2.10 - 3.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TT1		814429.92	836834.13	59.99	0.12	57.20	2.79	58.01 - 57.33	2.10 - 3.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

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

Table E1 - Summary of Groundwater Monitoring Data (Sheet 3 of 3)

Piezometer No		Co-ordinate		Ground Level (mPD)	Top of pipe above Ground Level (m)	Piezometer Tip Level		Response Zone Level		Date																													
										27/08/2004		03/09/2004		11/09/2004		17/09/2004		24/09/2004		30/09/2004		08/10/2004		15/10/2004		27/10/2004		06/11/2004		13/11/2004		20/11/2004		27/11/2004		22/12/2004		03/01/2005	
		Northing	Easting			(mPD)	(m)	(mPD)	(m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)	GW Depth (mPD)	Halcrow Bucket (m)
T9	Upper	814397	836794	86.30	0.00	71.21	15.09	71.06 - 71.97	14.33 - 15.24	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	Lower				0.00	62.98	23.32	62.83 - 65.88	20.42 - 23.47	66.92	19.50	66.86	19.50	66.78	19.50	66.72	19.50	66.68	19.50	66.63	20.00	66.57	20.00	66.55	20.00	66.50	20.00	66.47	20.00	66.45	20.00	66.41	20.00	66.39	20.00	66.29	20.00	66.25	20.00
NSR1	Upper	814453	836797	70.60	0.05	57.00	13.15	57.30 - 58.30	12.45 - 13.45	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	Lower				0.15	52.80	17.80	52.63 - 54.65	15.95 - 17.97	53.74	Dry	53.74	Dry	53.74	Dry	53.72	Dry	53.72	Dry	53.70	Dry	53.70	Dry	53.70	Dry	53.66	Dry	53.66	Dry	53.66	Dry	53.65	Dry	53.65	Dry	53.65	Dry	53.59	Dry
NSR2	Upper	814452	836814	63.10	0.10	50.30	12.80	50.15 - 51.15	11.95 - 12.95	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-
	Lower				0.10	45.25	17.85	45.10 - 46.10	17 - 18	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
RP2	Upper	814469	836830	40.57	0.05	31.97	9.20	32.22 - 31.22	8.35-9.35	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	Lower				0.07	-6.62	47.19	(-5.77)-(-6.77)	46.34-47.34	12.62	Dry	12.87	Dry	12.70	Dry	12.62	Dry	12.66	Dry	12.64	Dry	12.60	Dry	12.53	Dry	12.45	Dry	12.34	Dry	12.34	Dry	12.29	Dry	12.26	Dry	12.08	Dry	12.08	Dry
BH1	Upper	814465.81	836820.08	56.44	0.08	47.24	9.20	48.24 - 46.74	8.20-9.70	-	-	-	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	Lower				0.08	32.14	24.30	33.14 - 31.64	23.30-24.80	-	-	-	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
BH2	Upper	814455.41	836844.90	47.80	0.08	35.15	12.65	36.15 - 34.65	11.65-13.15	-	-	-	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	Lower				0.08	24.00	23.80	25.00 - 23.50	22.80-24.30	-	-	-	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
BH3	Upper	814432.61	836809.46	70.44	0.10	58.74	11.70	59.74 - 58.24	10.70-12.20	-	-	-	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	Lower				0.10	46.54	23.90	47.54 - 46.04	22.90-24.40	-	-	-	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
BH4	Upper	814442.30	836787.25	77.97	0.14	67.67	10.30	68.67 - 67.17	9.30-10.80	-	-	-	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	Lower				0.14	54.47	23.50	55.47 - 53.97	22.50-24.00	-	-	-	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
BH5	Upper	814407.22	836808.71	79.40	0.14	74.70	4.70	75.70 - 74.20	3.70-5.20	-	-	-	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	Lower				0.14	54.10	25.30	55.10 - 53.60	24.30-25.80	-	-	-	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
BH6	Upper	814467.96	836812.71	58.84	0.08	49.84	9.00	50.84 - 49.34	8.00-9.50	-	-	-	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	Lower				0.08	34.74	24.10	35.74 - 34.24	23.10-24.60	-	-	-	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
BH7	Upper	814472.49	836843.29	42.92	0.08	33.22	9.70	34.72 - 32.72	8.70-10.20	-	-	-	-	-	-	-	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	Lower				0.08	19.32	23.60	20.32 - 18.82	22.60-24.10	-	-	-	-	-	-	-	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
BH8	Upper	814495.07	836848.96	33.99	0.08	31.39	2.60	32.39 - 30.89	1.60-3.10	-	-	-	-	-	-	-	-	-	-	31.39	-	31.39	-	31.39	-	31.39	-	31.39	-	31.39	Dry	31.39	Dry	31.39	Dry	31.39	Dry	31.39	Dry
	Lower				0.08	10.39	23.60	11.39 - 9.89	22.6-24.10	-	-	-	-	-	-	-	-	-	-	11.66	-	11.62	-	11.55	-	11.47	-	11.39	-	11.28	22.30	11.25	22.30	11.22	22.80	11.09	22.80	11.05	22.80
BH9	Upper	814469.88	836864.76	33.75	0.07	30.15	3.60	31.15 - 29.65	2.60-4.10	-	-	-	-	-	-	-	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	Lower				0.07	10.45	23.30	11.45 - 9.95	22.30-23.80	-	-	-	-	-	-	-	-	12.54	-	12.47	-	12.41	-	11.32	-	12.18	-	12.08	-	11.98	21.20	11.93	21.20	11.90	21.20	11.78	21.20	11.72	21.70
PT1	Upper	814484.81	836842.42	40.14	0.07	36.14	4.00	37.14 - 35.64	3.00-4.50	-	-	-	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	Lower				0.08	30.44	9.70	31.94 - 29.94	8.20-10.20	-	-	-	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
PT2	Upper	814478.58	836852.59	36.80	0.04	34.00	2.80	34.80 - 33.30	2.00 - 3.50	-	-	-	-	-	-	-	-	34.40	-	34.39	-	34.38	-	34.16	-	34.35	-	34.35	-	34.35	Dry	34.34	Dry	34.33	Dry	34.33	Dry	34.31	Dry
	Lower				0.04	29.55	7.25	32.30 - 29.35	4.50 - 7.45	-	-	-	-	-	-	-	-	30.58	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
TP1		814488.69	836833.83	42.69	0.10	40.19	2.50	40.19 - 41.19	1.50 - 2.50	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-
TP2		814481.37	836841.59	40.81	0.17	37.66	3.15	37.66 - 38.66	2.15 - 3.15	40.12	-	40.01	-	40.08	-	39.89	-	39.93	-	39.69	-	39.69	-	38.74	-	38.74	-	38.74	-	38.69	-	38.65	-	38.62	-	38.50	-	38.35	-
TP3		814458.51	836838.47	49.485	0.085	46.25	3.24	46.34 - 47.34	2.15 - 3.15	47.43	-	47.37	-	47.49	-	47.10	-	47.16	-	46.98	-	46.46	-	47.36	-	46.91	-	46.71	-	46.61	-	46.52	-	46.49	-	46.42	-	46.42	-
TP4		814480.83	836862.62	31.23	0.13	28.53	2.70	29.36 - 28.36	2.00 - 3.00	-	-	-	-	-	-	-	-	-	-	29.03	-	28.77	-	28.59	-	28.45	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
TP5	Upper	814482.15	836853.20	35.02	0.16	34.46	0.56	34.88 - 34.38	0.50 - 0.80	-	-	-	-	-	-	-	-	-	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-
	Lower	814480.82	836853.97	35.07	0.15	31.79	3.28	32.72 - 31.73	2.50 - 3.50	-	-	-	-	-	-	-	-	-	-	33.22	-	33.13	-	32.30	-	32.68	-	32.64	-	32.58	Dry	32.51	Dry	32.36	Dry	32.16	Dry	32.01	Dry
TP6	Upper	814469.41	836848.28	41.24	0.09	39.34	1.90	40.33 - 39.33	1.00 - 2.00	-	-	-	-	-	-	-	-	-	-	39.91	-	39.61	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	Lower	814470.74	836847.51	41.24	0.17	38.44	2.84	39.41 - 38.41	2.00 - 3.00	-	-	-	-	-	-	-	-	-	-	39.88	-	39.58	-	39.23	-	38.95	-	38.76	-	38.61	Dry	38.43	Dry	38.28	Dry	Dry	Dry	Dry	Dry
TP7		814451.06	836817.04	62.04	0.18	59.76	2.28	60.72 - 59.72	1.50 - 2.50	-	-	-	-	-	-	-	-	-	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
TP9		814429.84	836814.62	68.94	0.13	65.75	3.19	2.50 - 3.50	2.50 - 3.50	-	-	-	-	-	-	-	-	-	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
TP10		814437.17	836973.32	76.83	0.12	73.96	2.87	74.85 - 73.85	2.10 - 3.10	-	-	-	-	-	-	-	-	-	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
TT1		814429.92	836834.13	59.99	0.12	57.20	2.79	58.01 - 57.33	2.10 - 3.10	-	-	-	-	-	-	-	-	-	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry

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



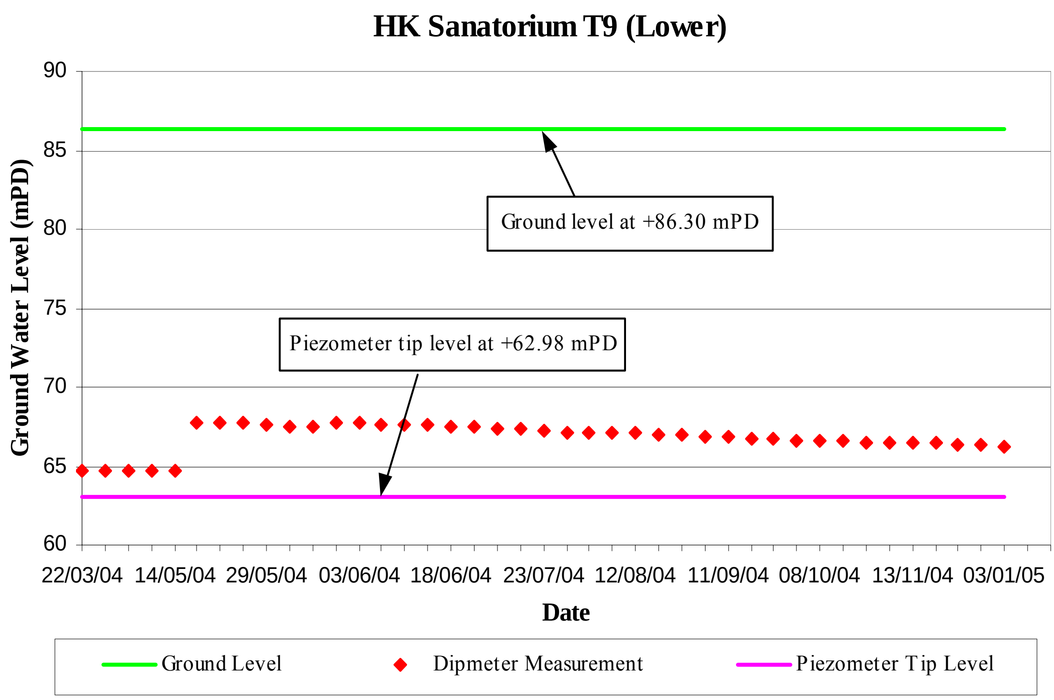
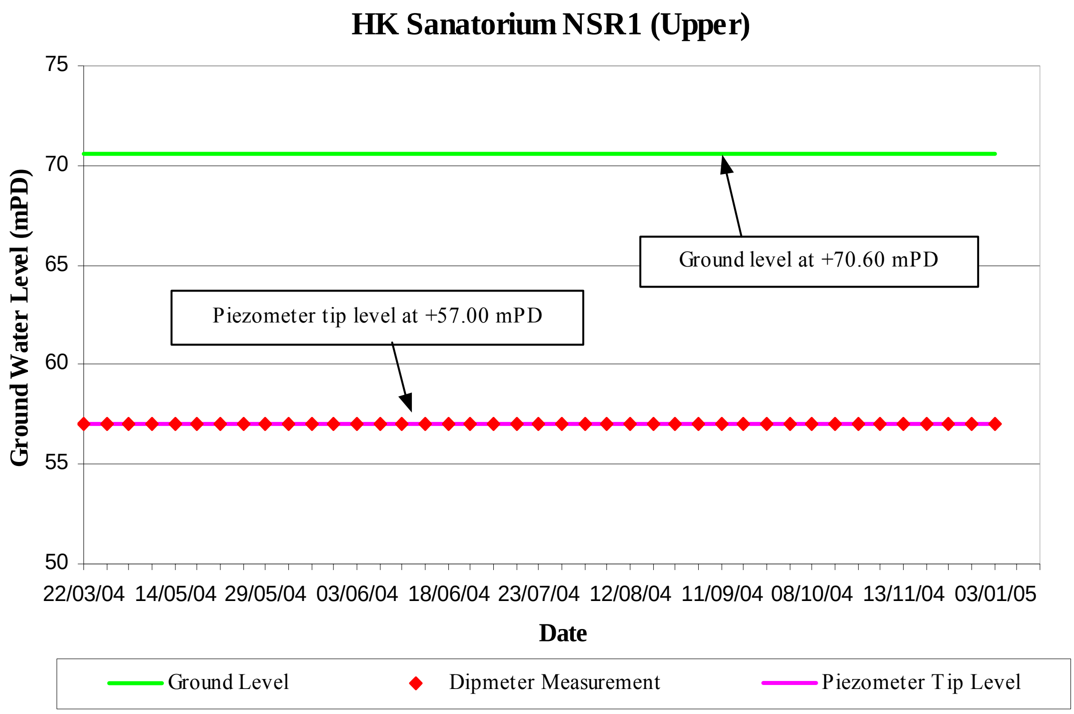


Figure E1 - Graphical Plot of Groundwater Data (Sheet 1 of 21)

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



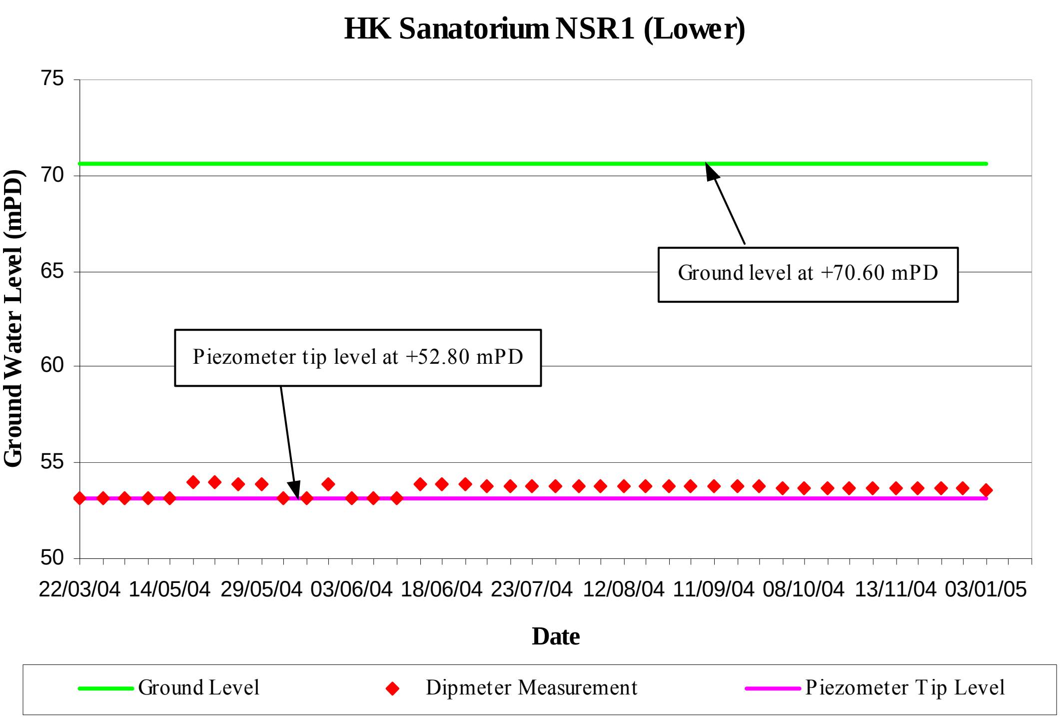
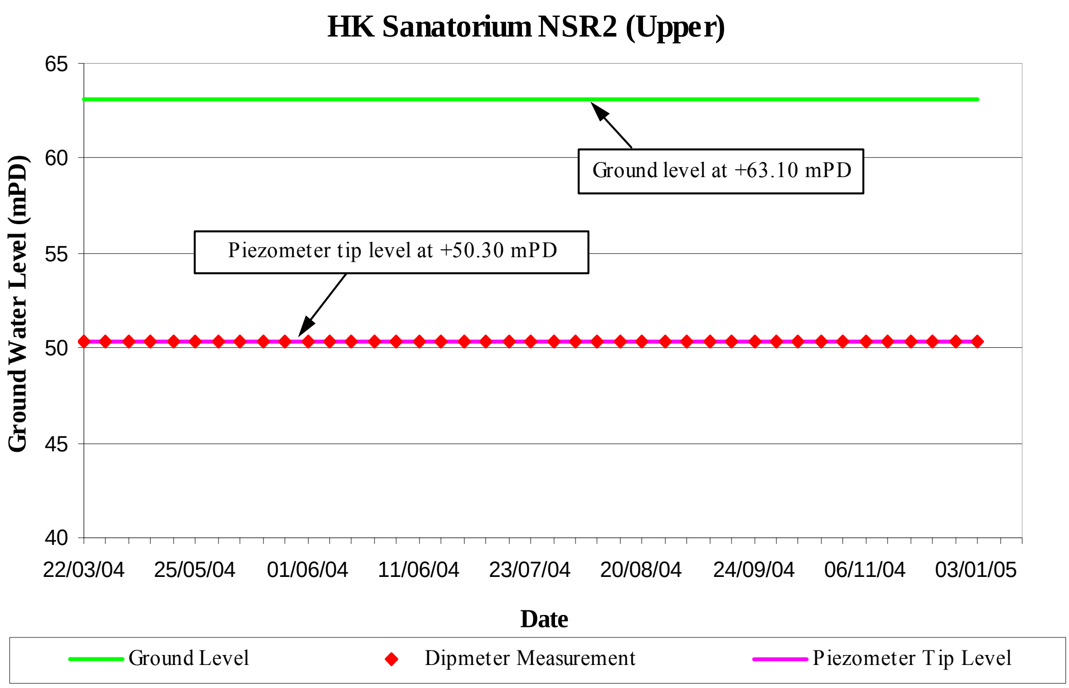


Figure E1 - Graphical Plot of Groundwater Data (Sheet 2 of 21)

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



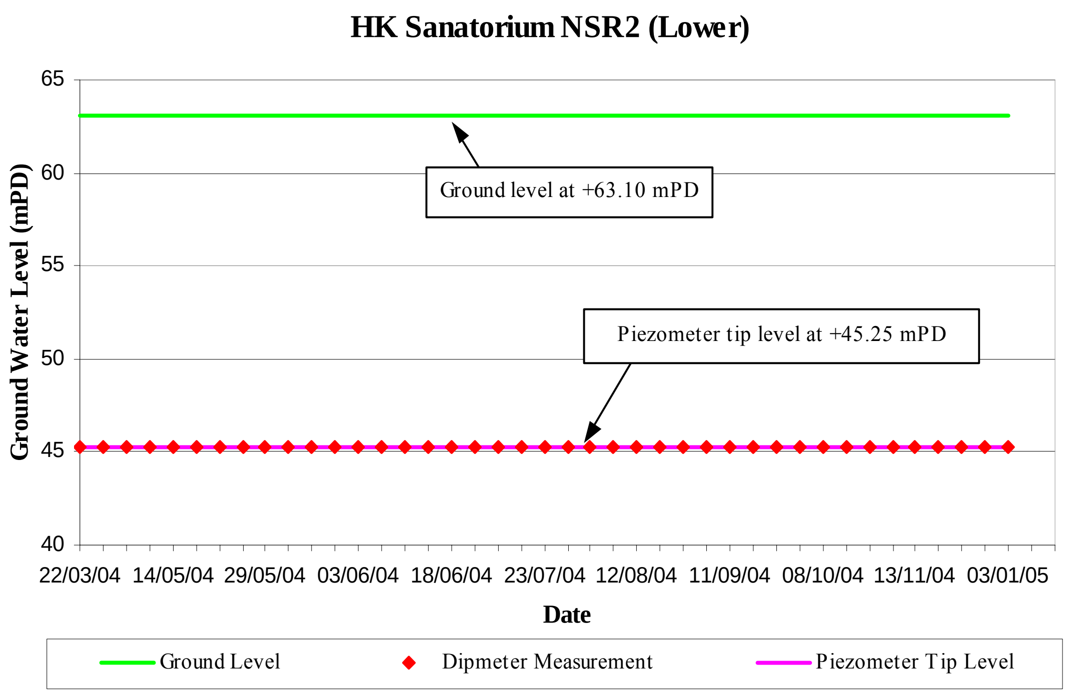
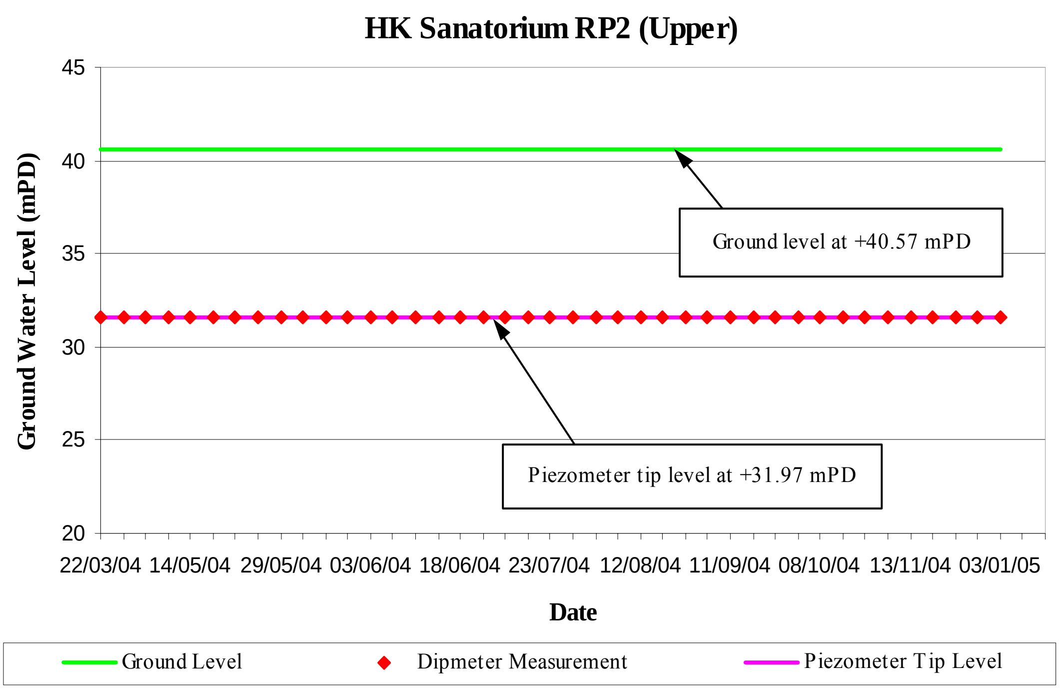


Figure E1 - Graphical Plot of Groundwater Data (Sheet 3 of 21)

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



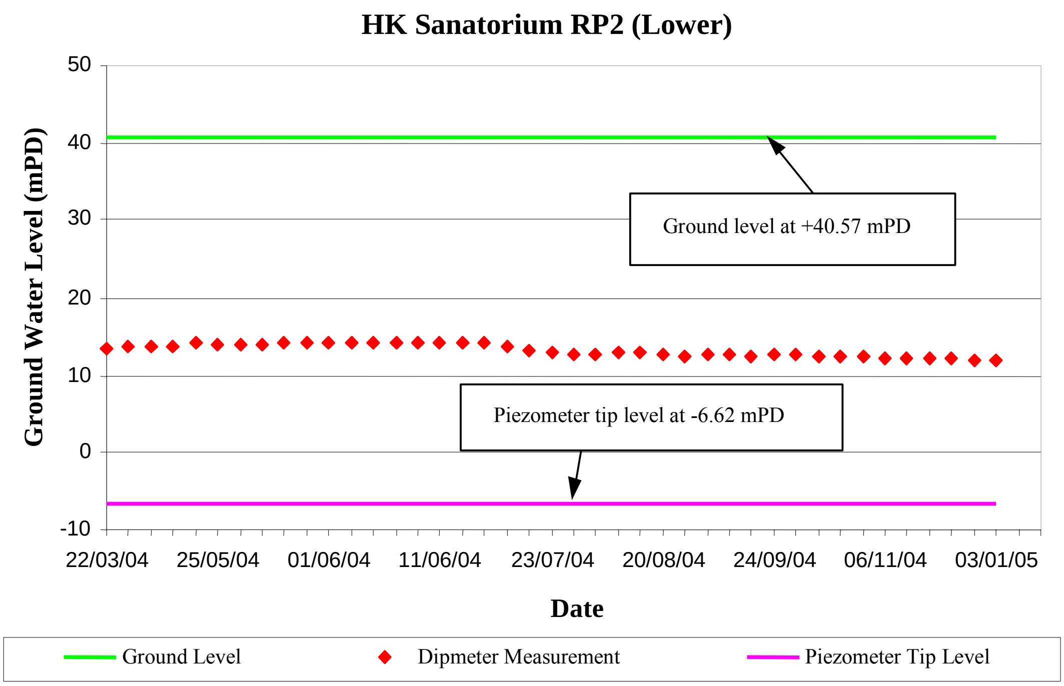
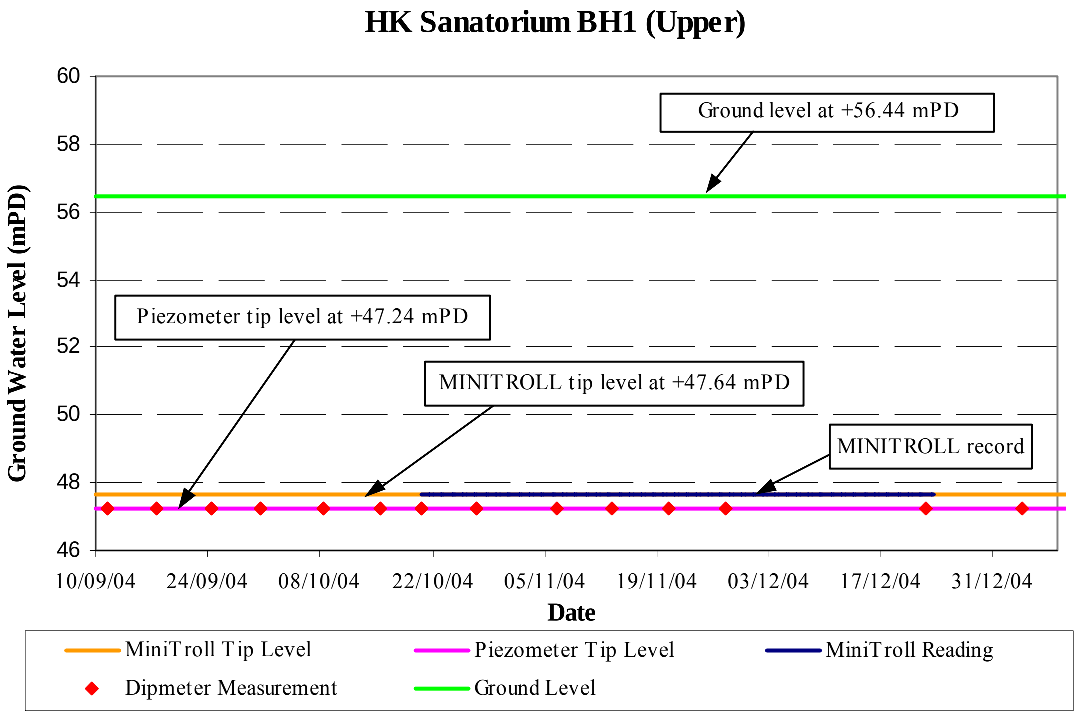


Figure E1 - Graphical Plot of Groundwater Data (Sheet 4 of 21)

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



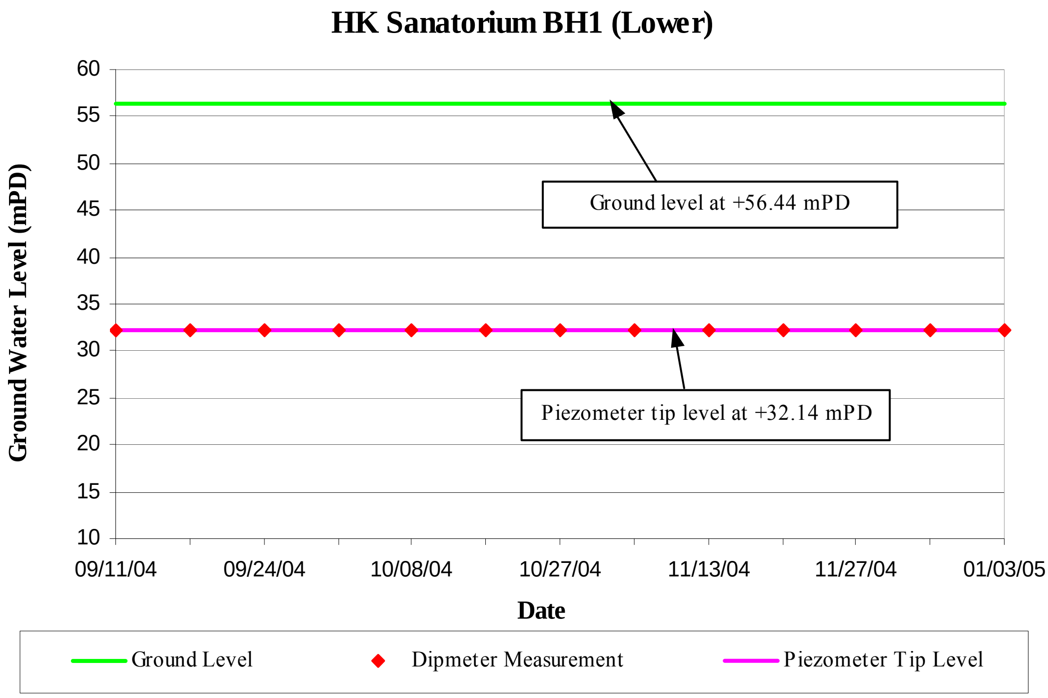
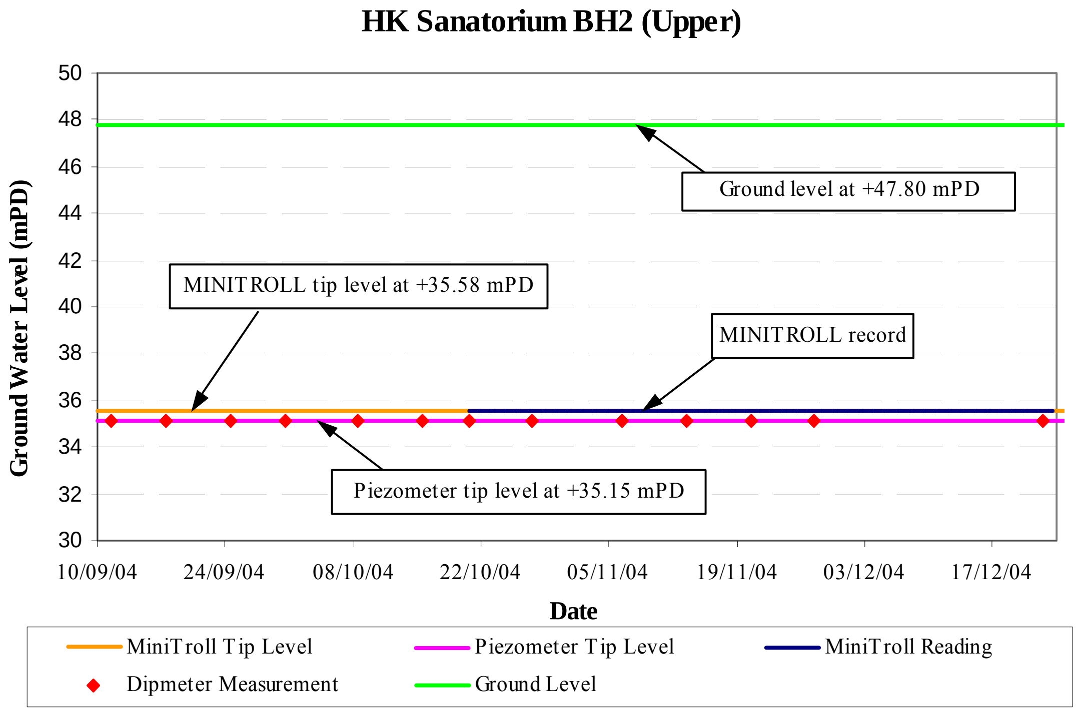


Figure E1 - Graphical Plot of Groundwater Data (Sheet 5 of 21)

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



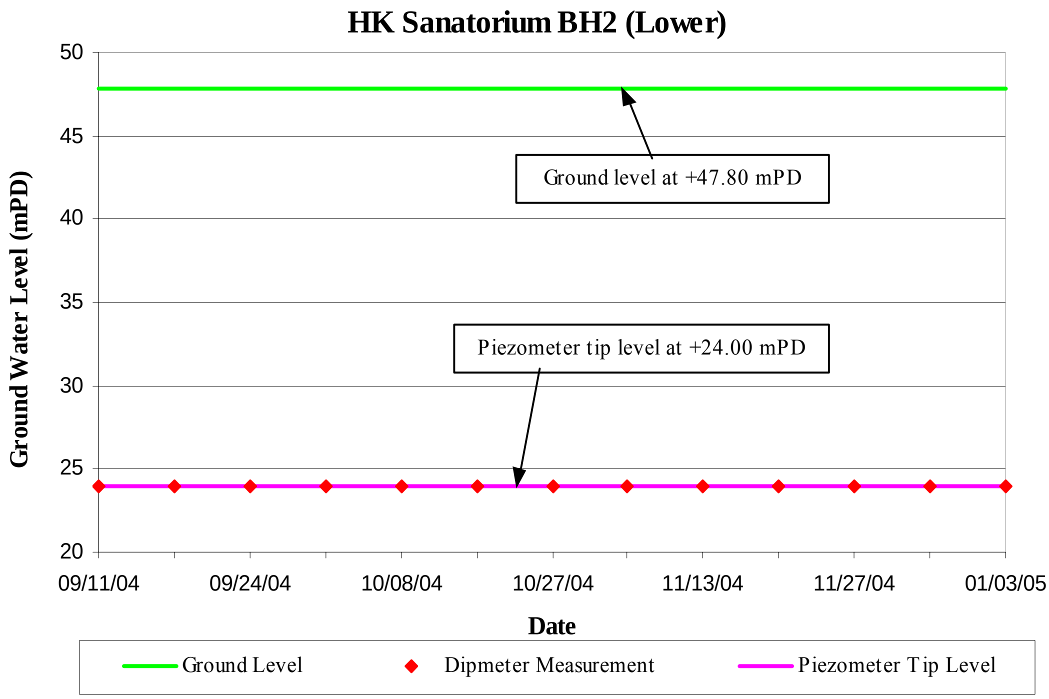
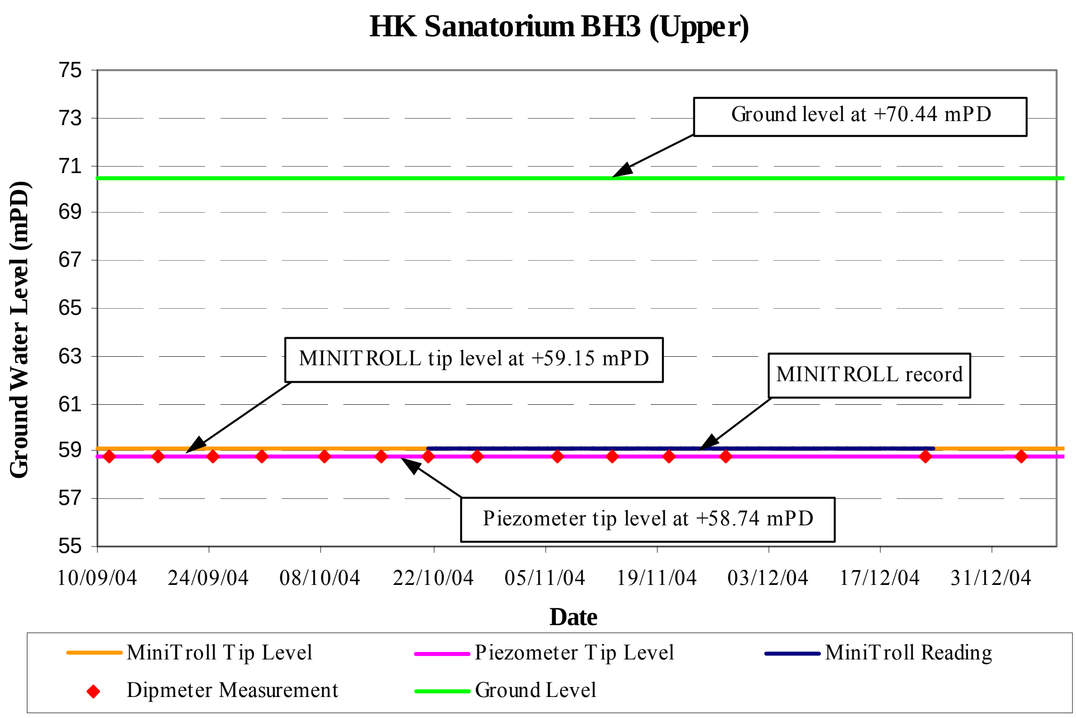


Figure E1 - Graphical Plot of Groundwater Data (Sheet 6 of 21)

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



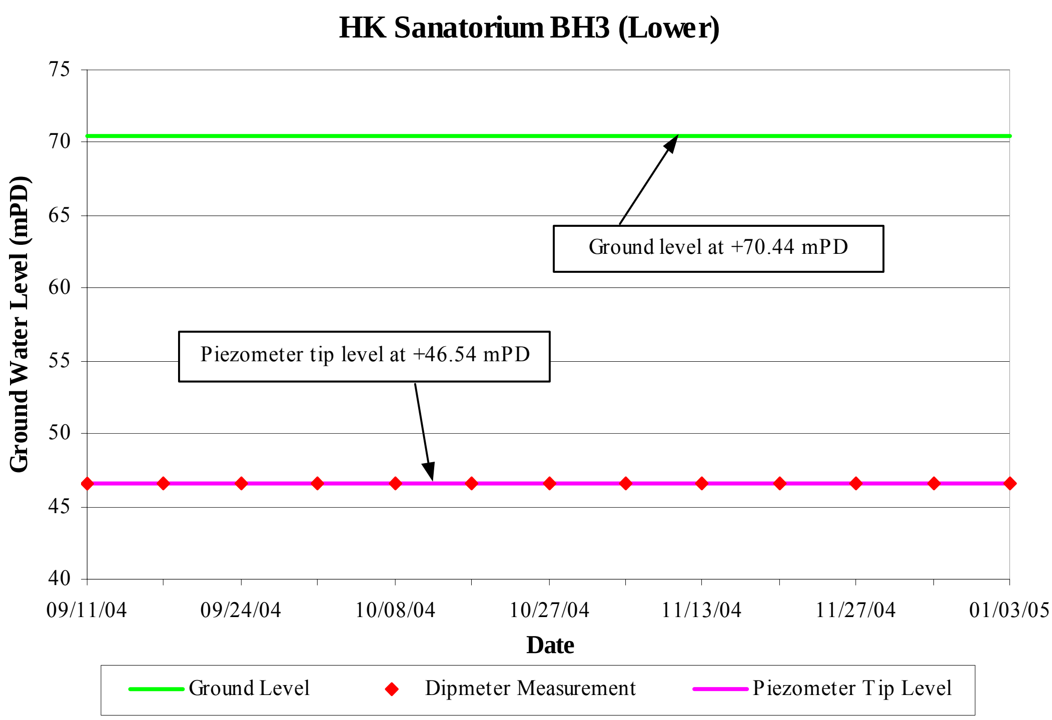
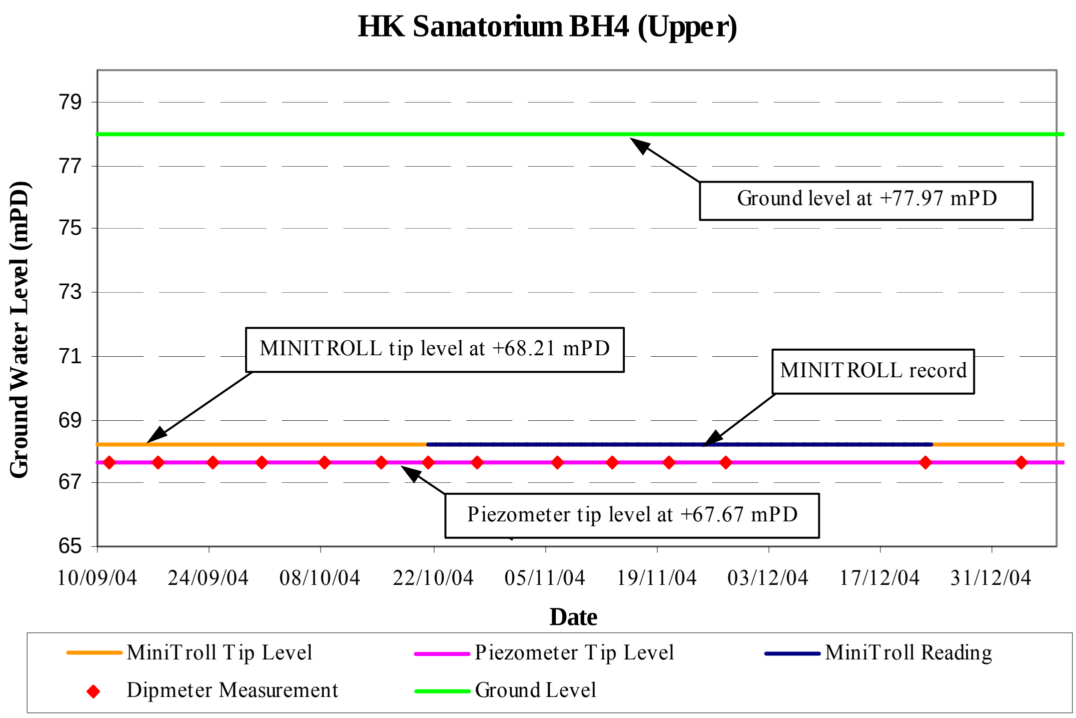


Figure E1 - Graphical Plot of Groundwater Data (Sheet 7 of 21)

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



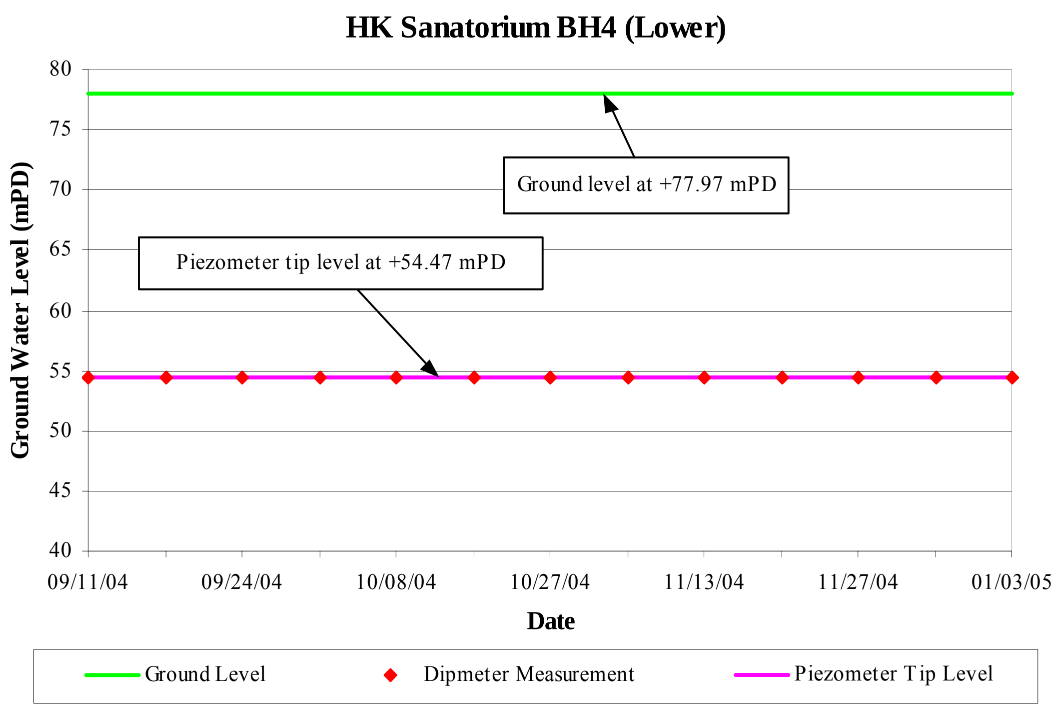
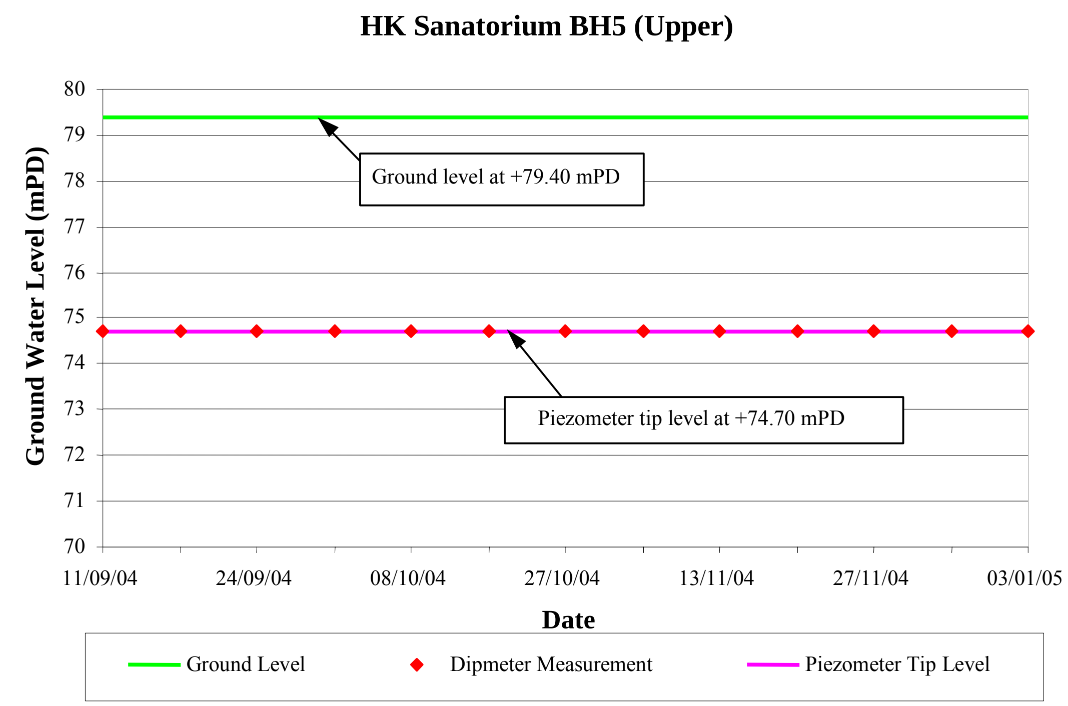


Figure E1 - Graphical Plot of Groundwater Data (Sheet 8 of 21)

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



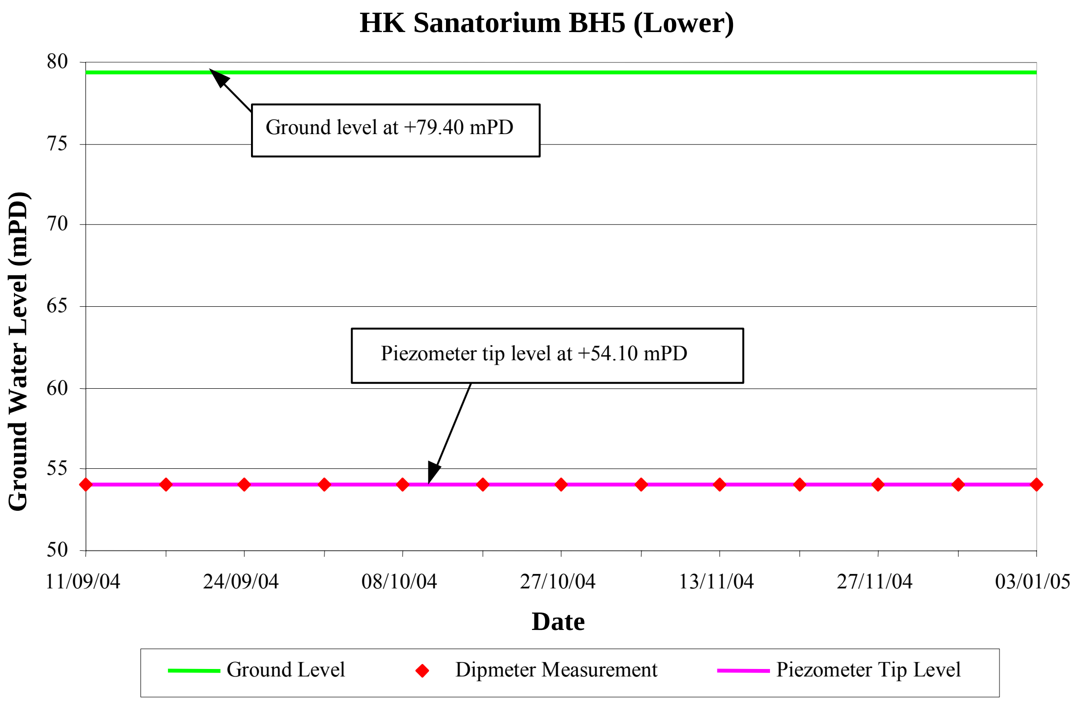
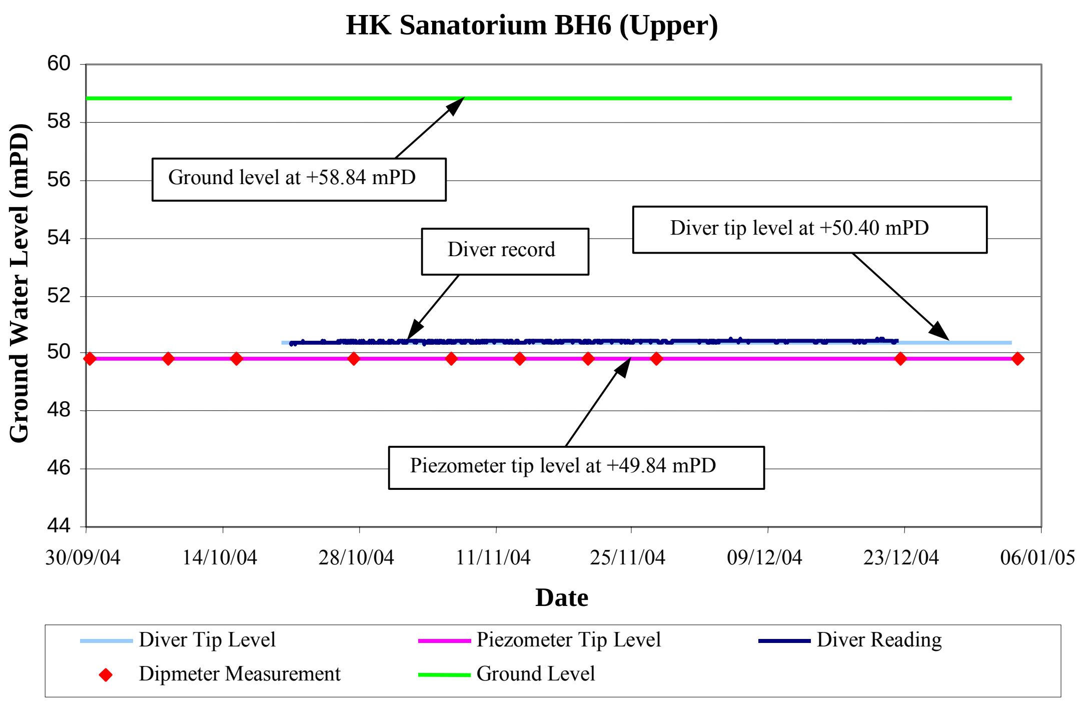


Figure E1 - Graphical Plot of Groundwater Data (Sheet 9 of 21)

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



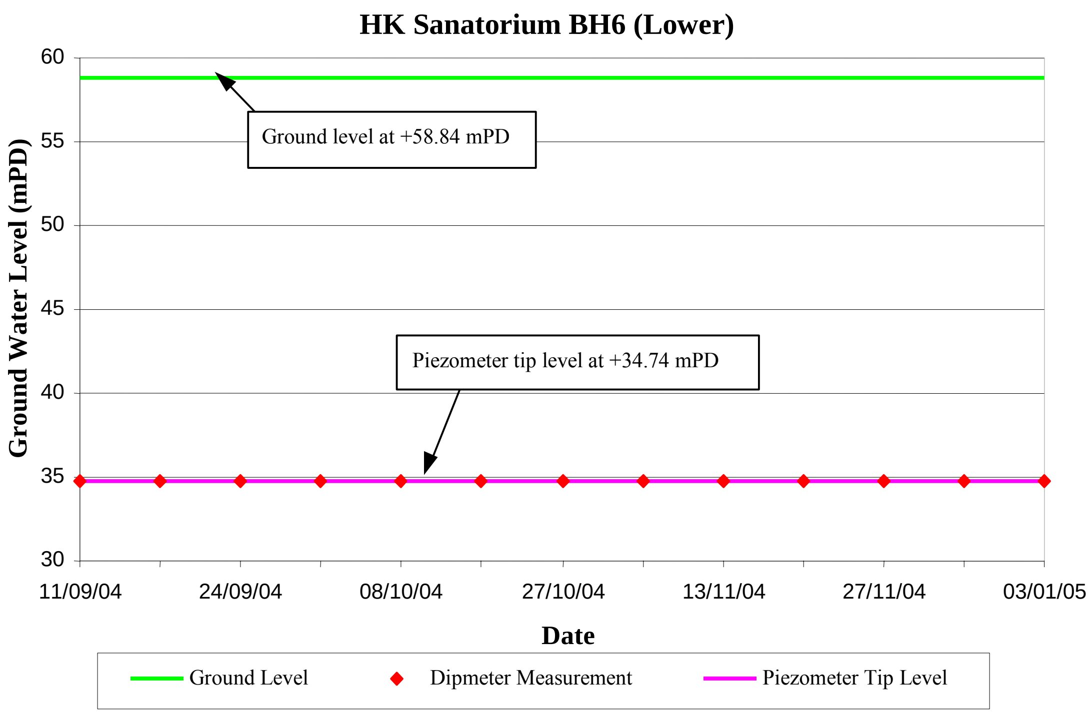
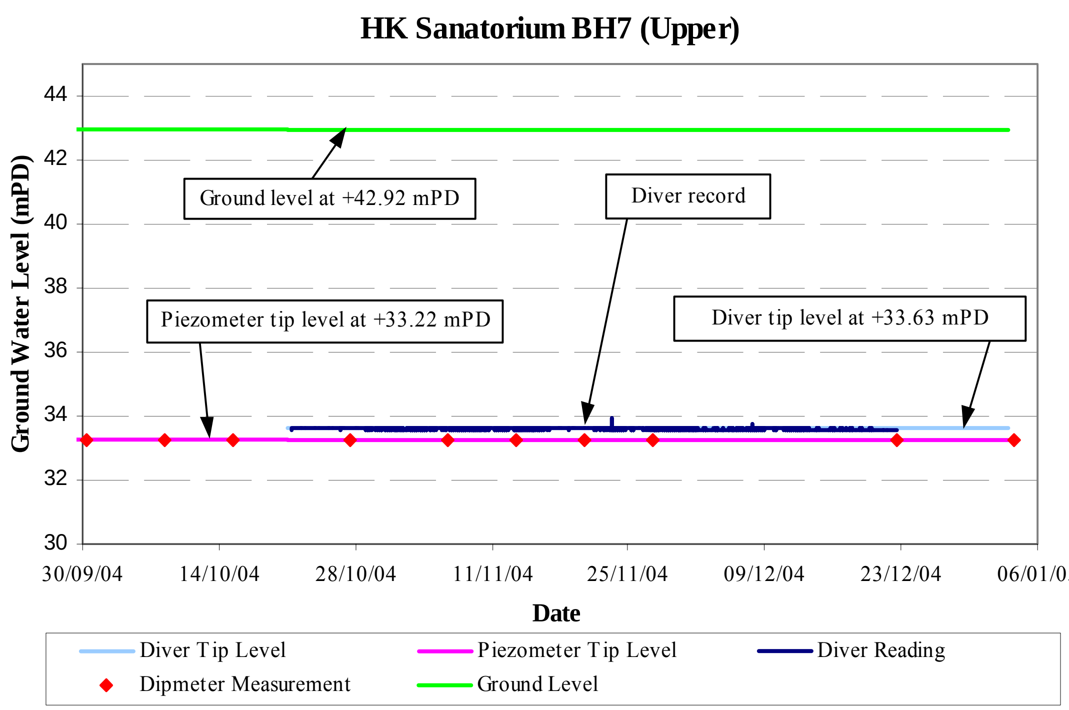


Figure E1 - Graphical Plot of Groundwater Data (Sheet 10 of 21)

Table of Contents
Table of Contents
Table of Contents



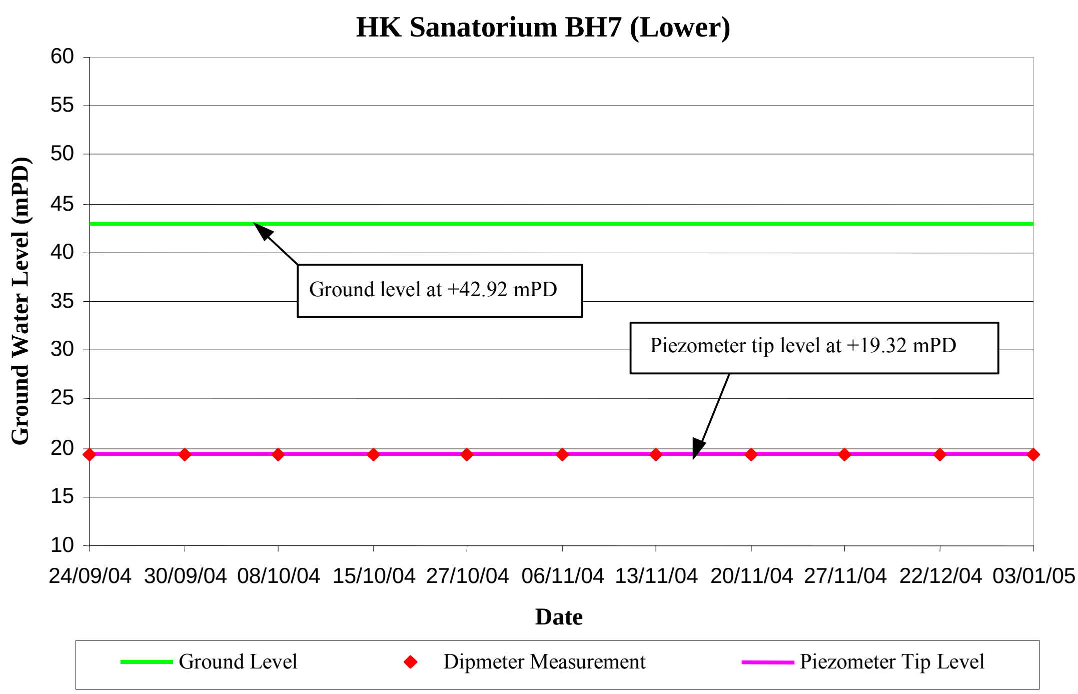
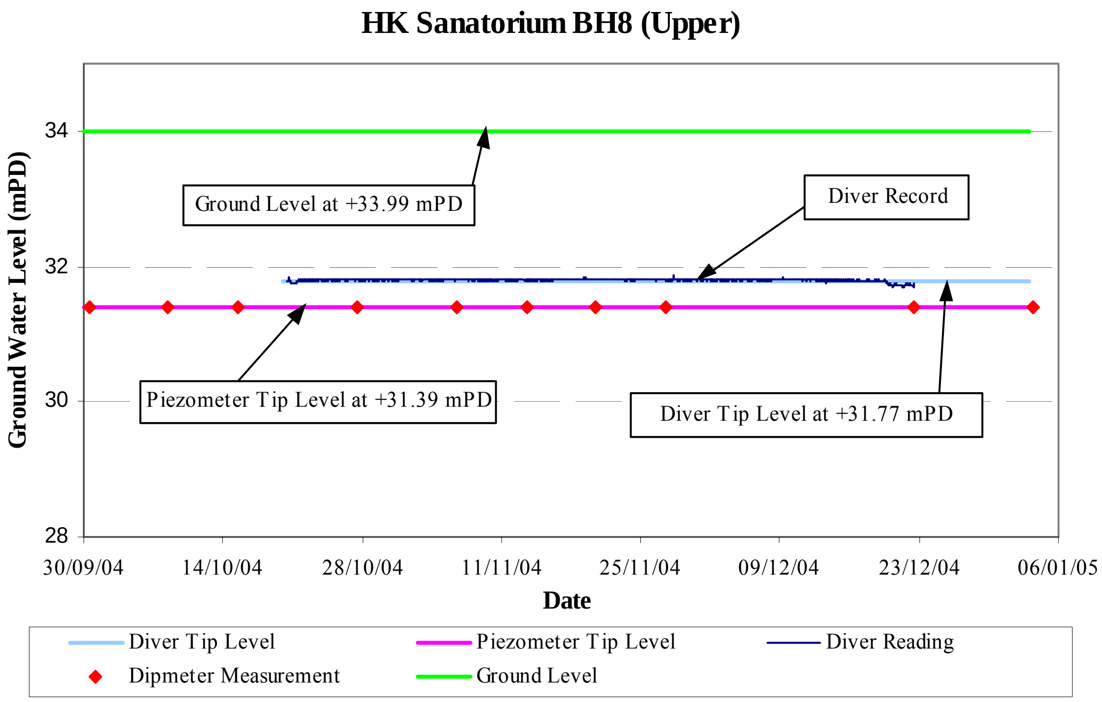


Figure E1 - Graphical Plot of Groundwater Data (Sheet 11 of 21)

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



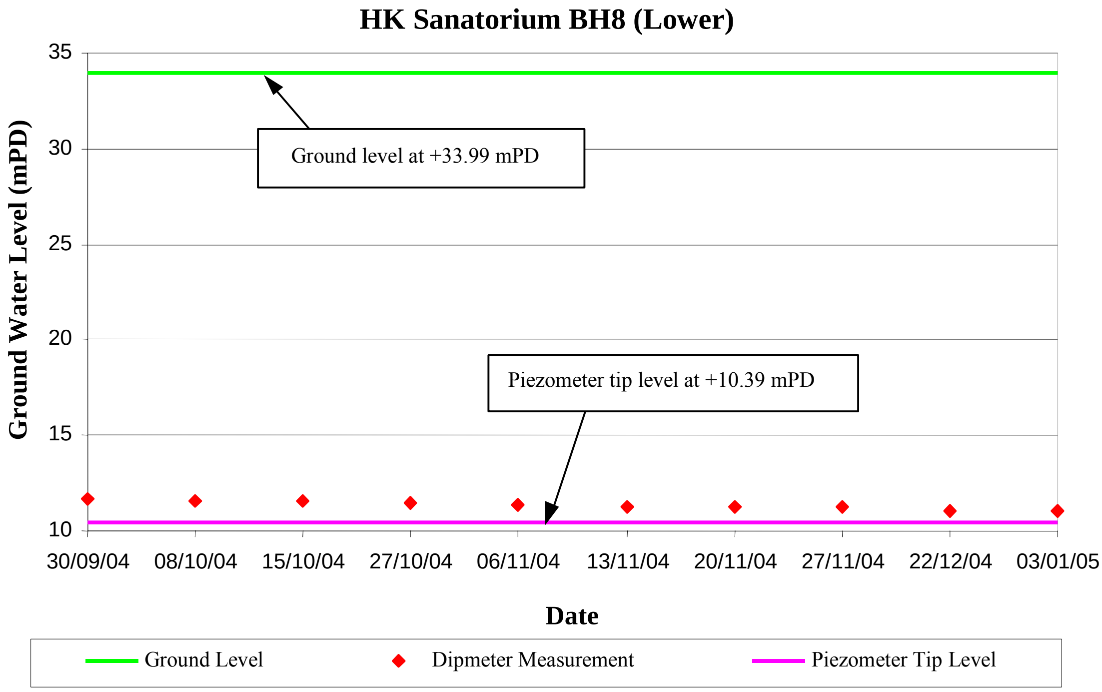
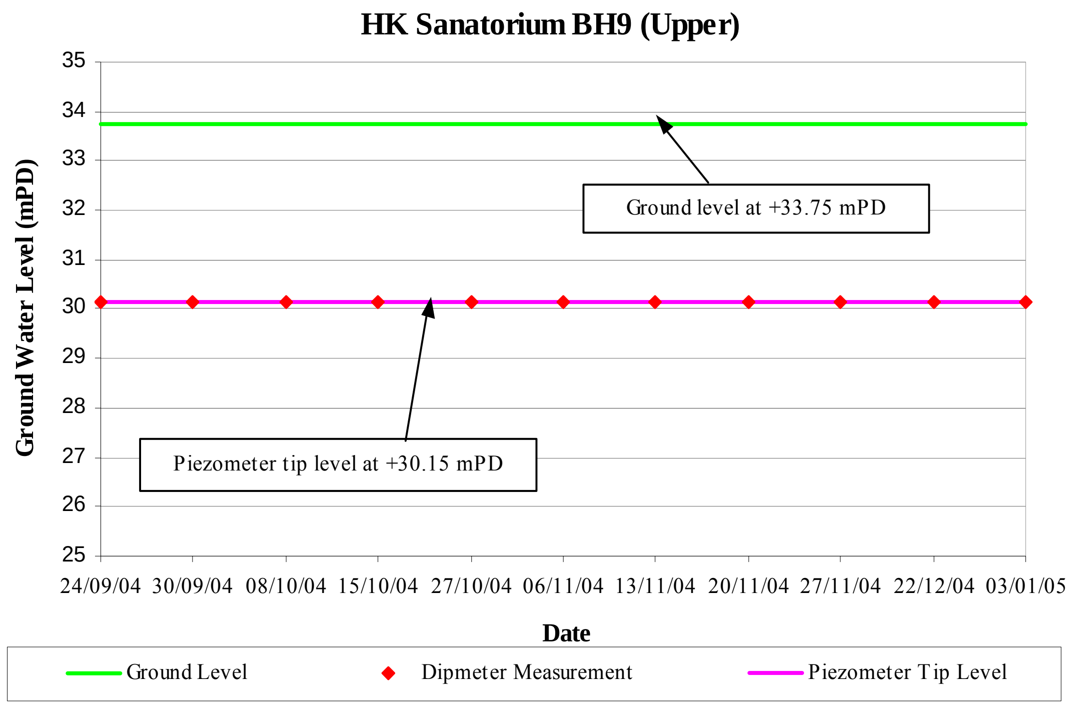


Figure E1 - Graphical Plot of Groundwater Data (Sheet 12 of 21)

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



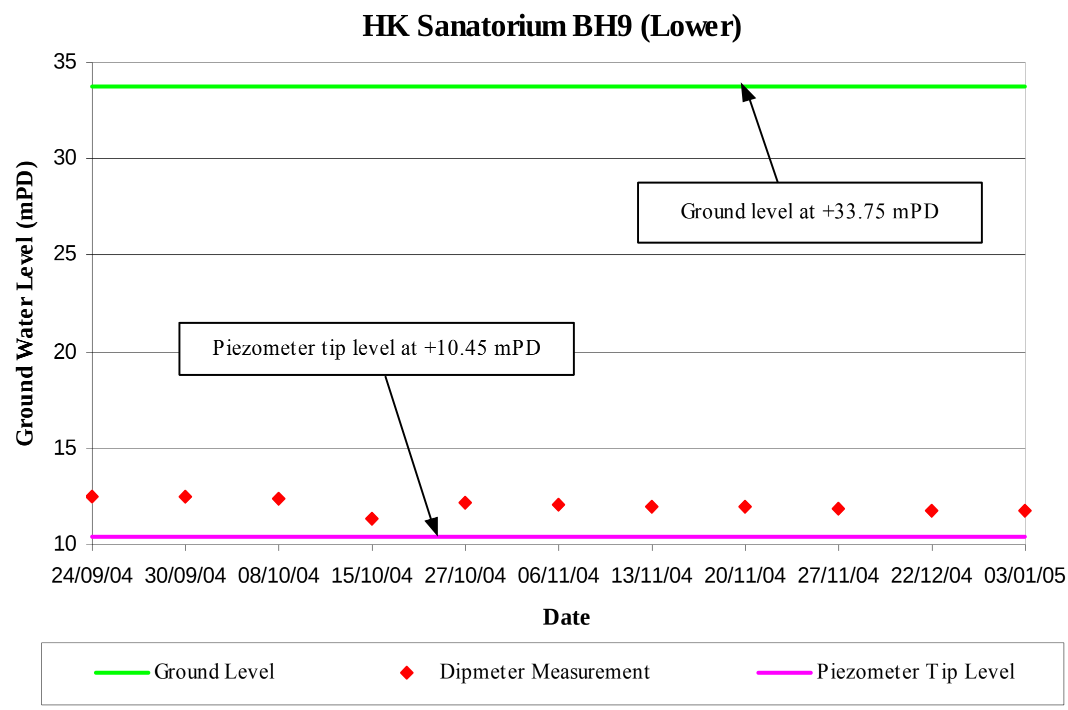
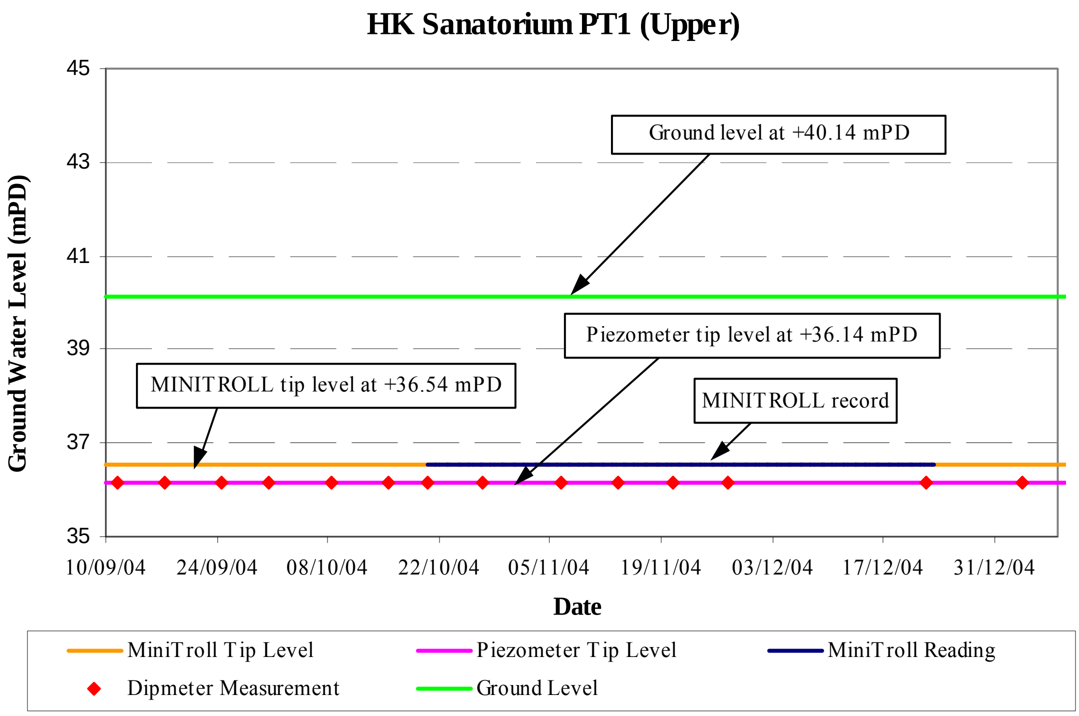


Figure E1 - Graphical Plot of Groundwater Data (Sheet 13 of 21)

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



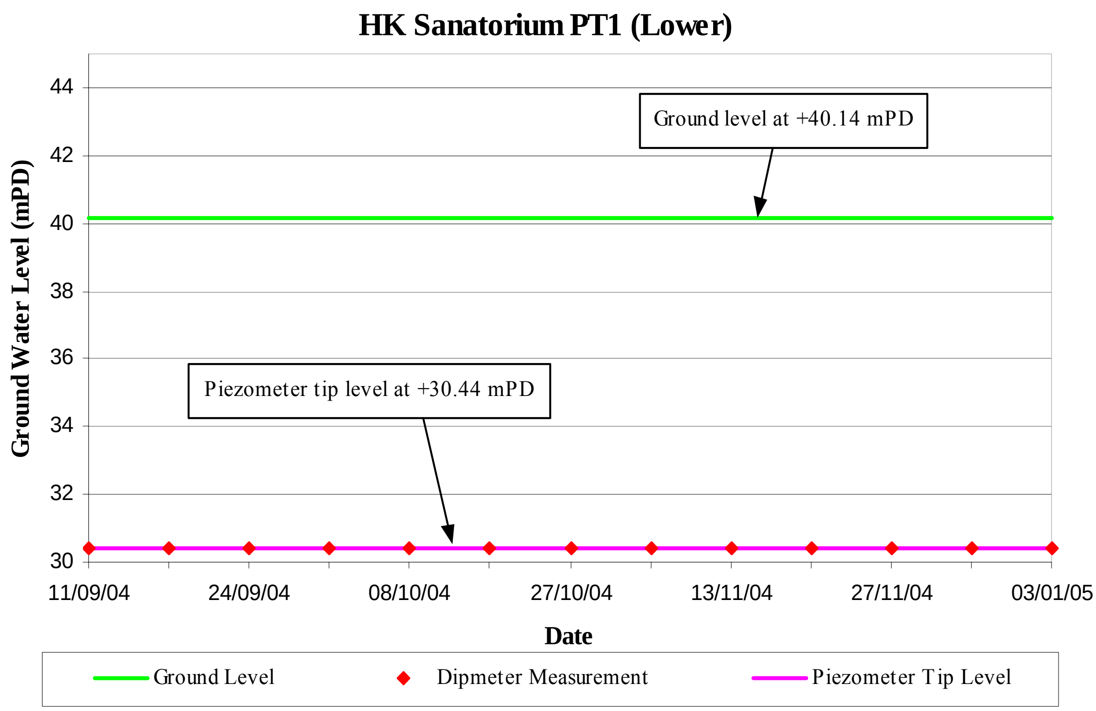
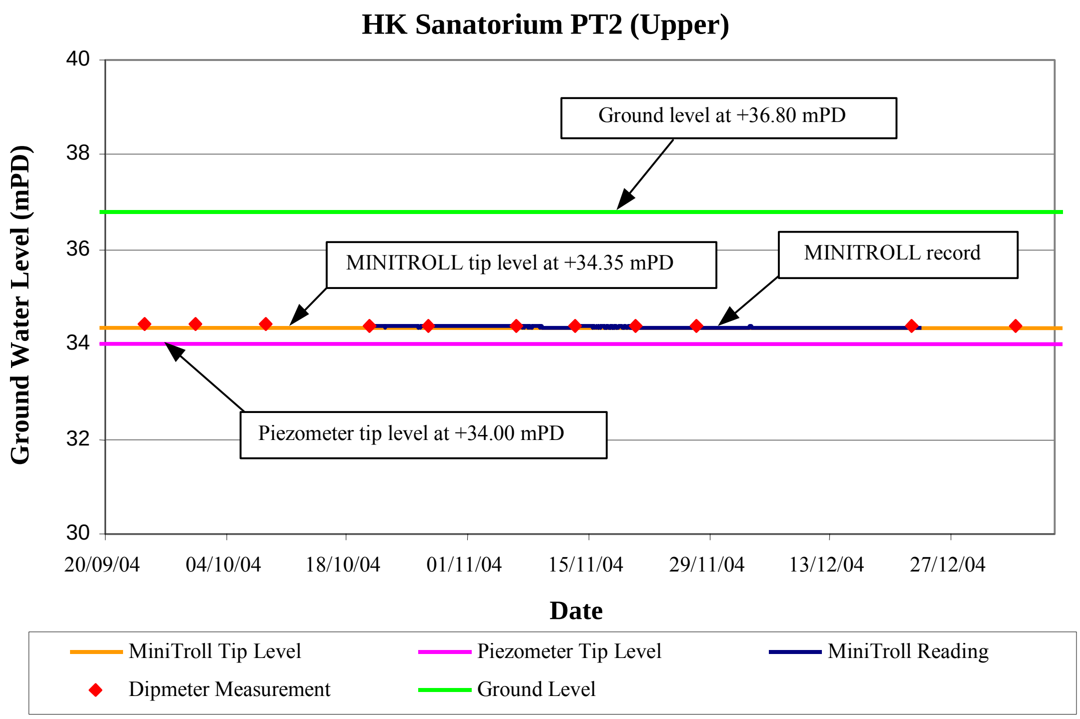


Figure E1 - Graphical Plot of Groundwater Data (Sheet 14 of 21)

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



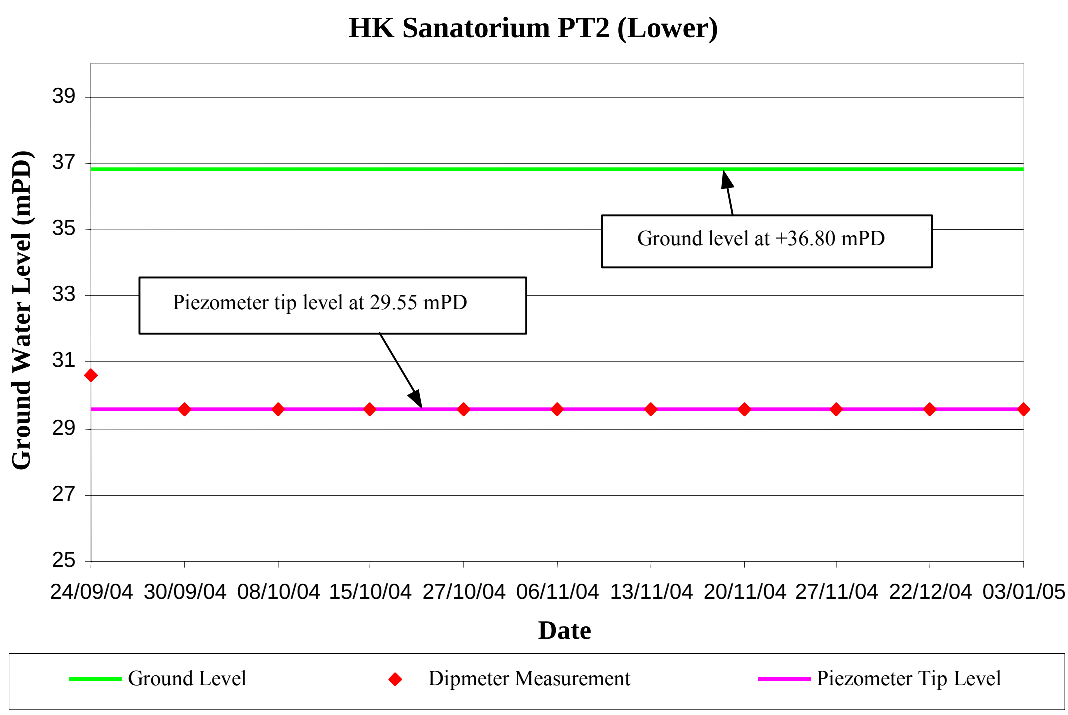
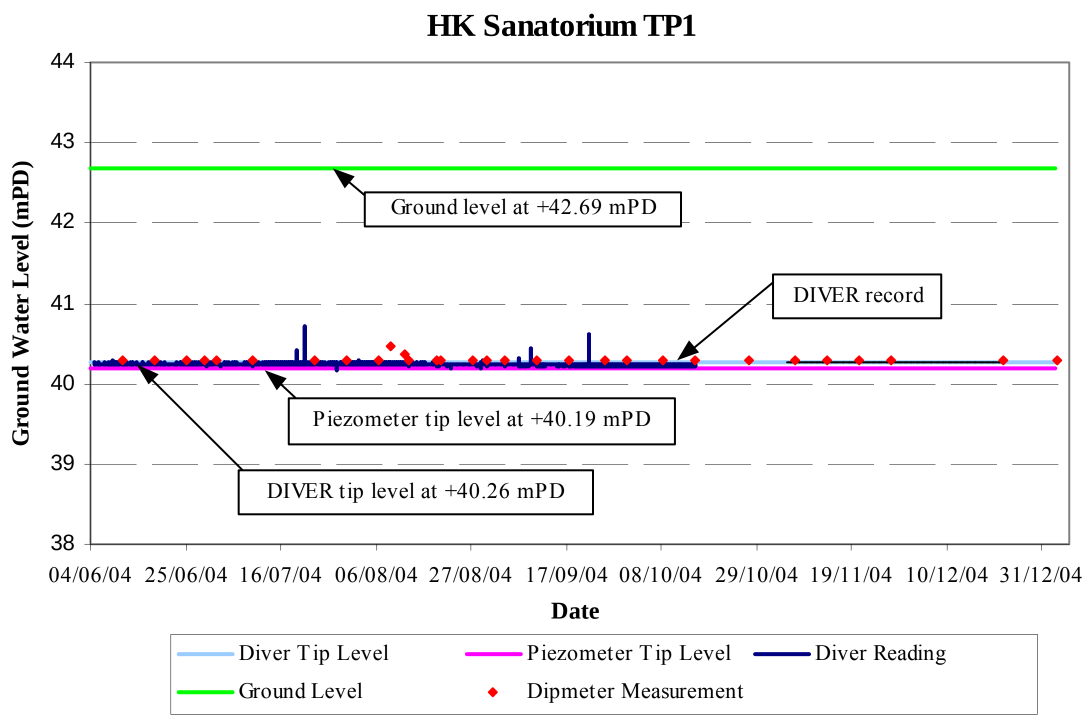


Figure E1 - Graphical Plot of Groundwater Data (Sheet 15 of 21)

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



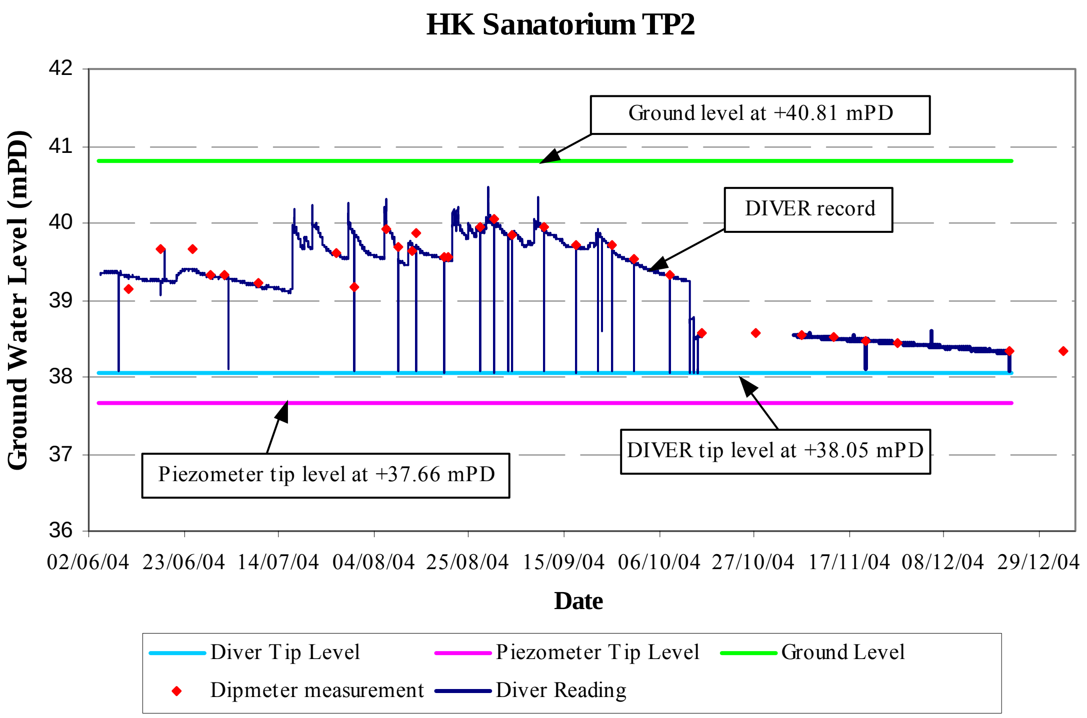
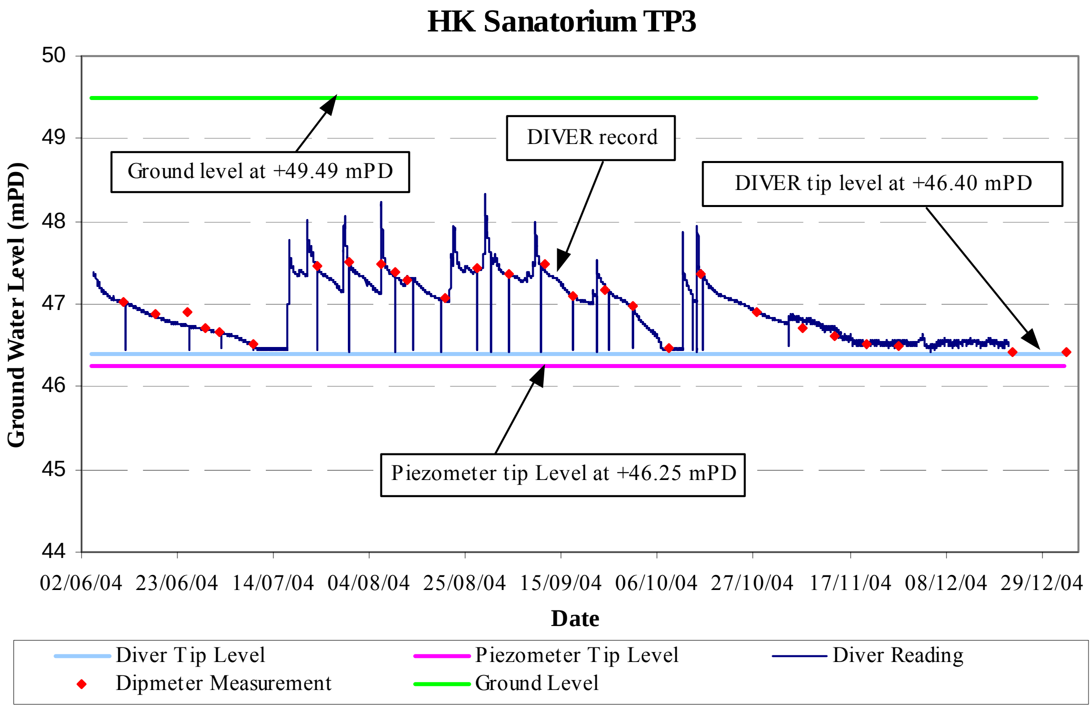


Figure E1 - Graphical Plot of Groundwater Data (Sheet 16 of 21)

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



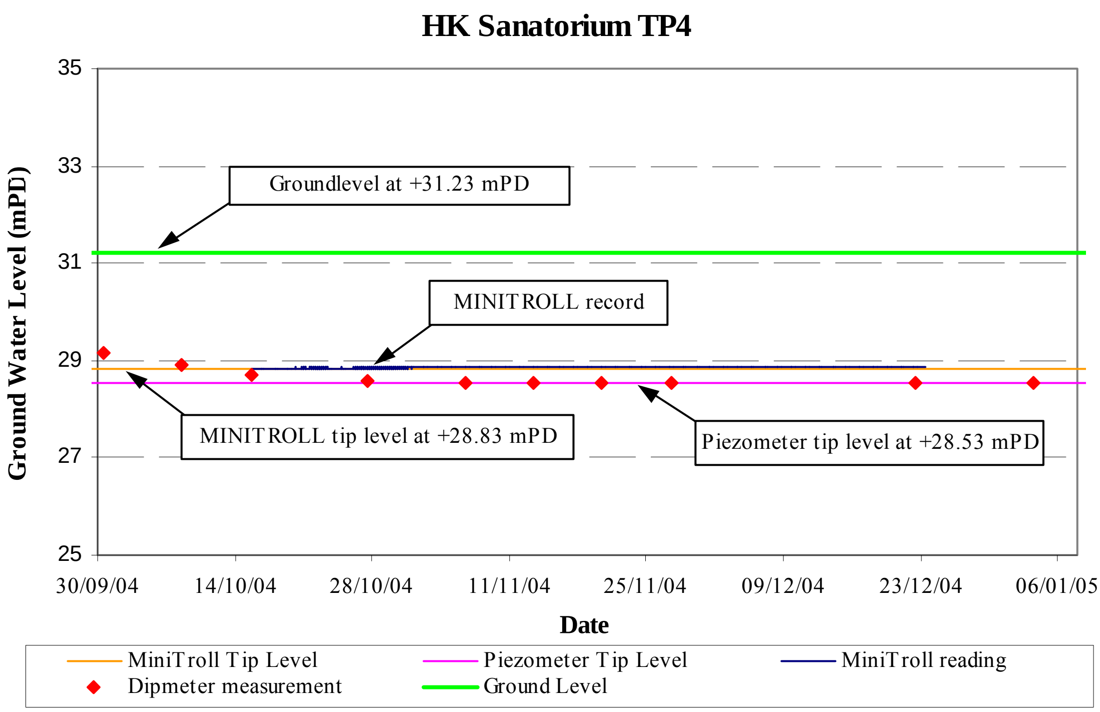
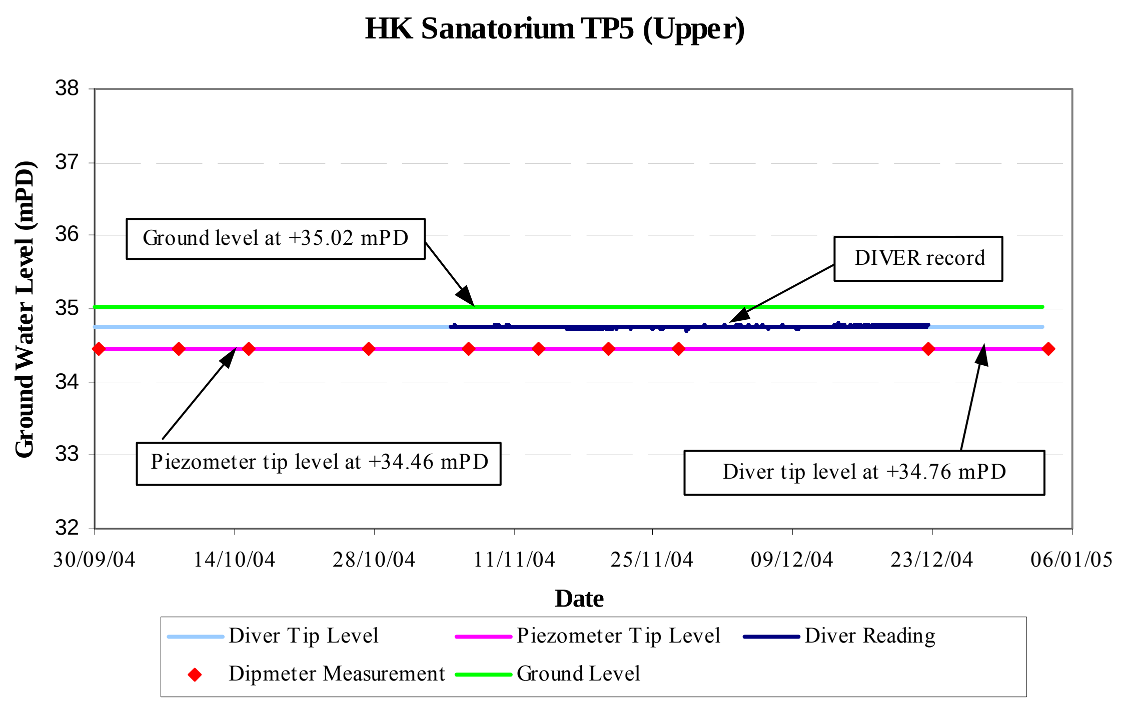


Figure E1 - Graphical Plot of Groundwater Data (Sheet 17 of 21)

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



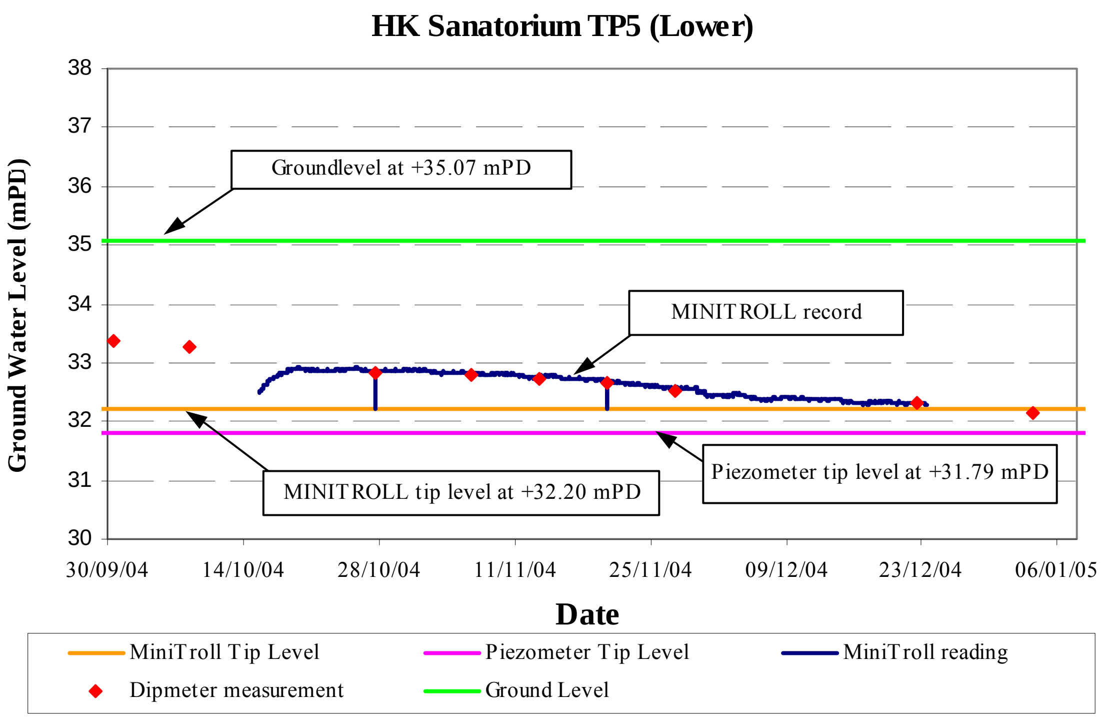
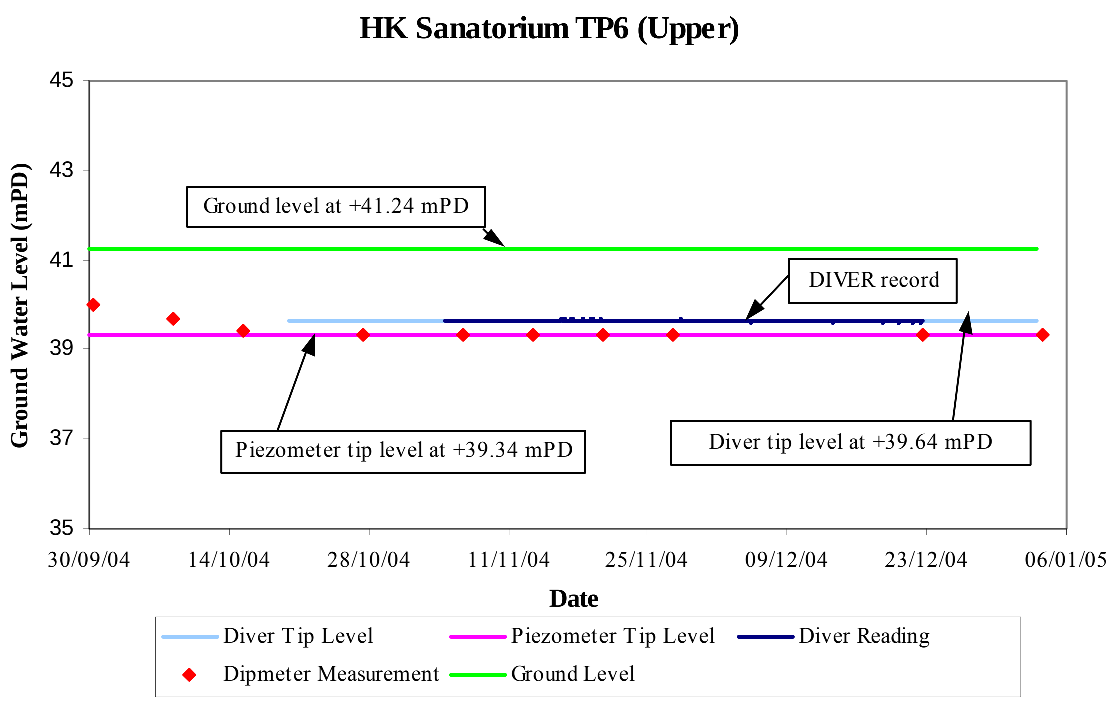


Figure E1 - Graphical Plot of Groundwater Data (Sheet 18 of 21)

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



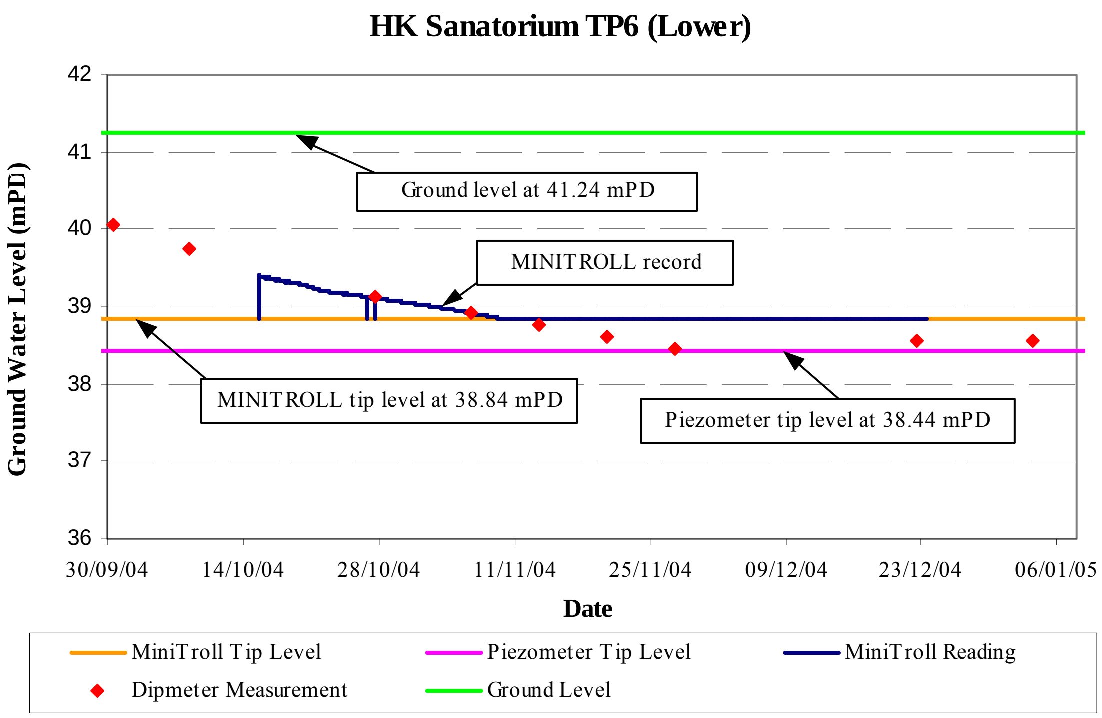
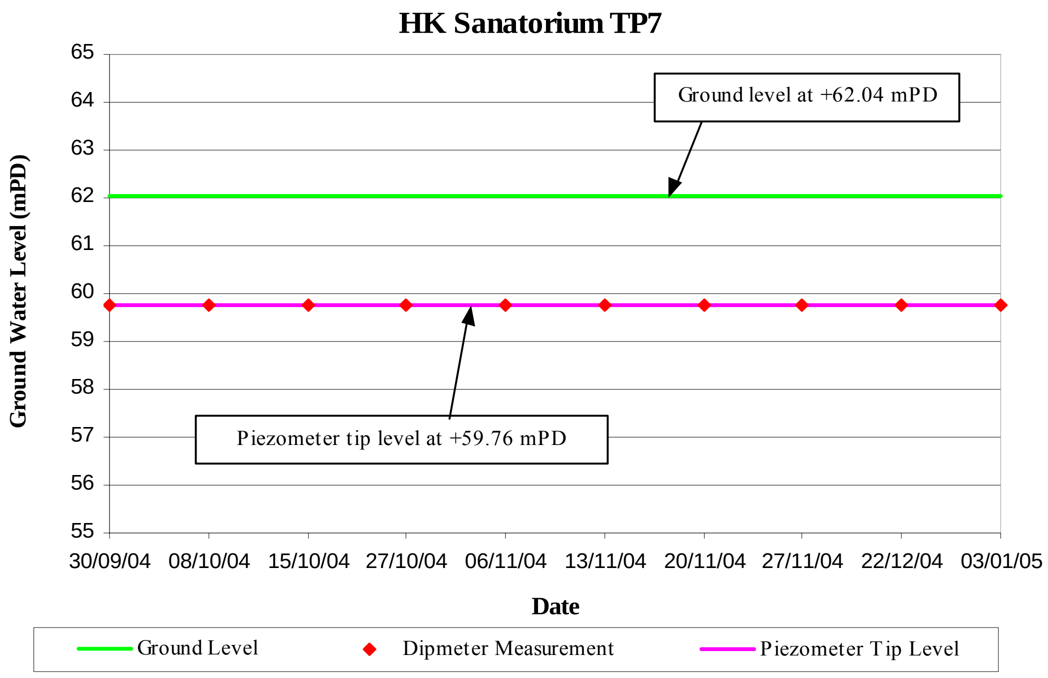


Figure E1 - Graphical Plot of Groundwater Data (Sheet 19 of 21)

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



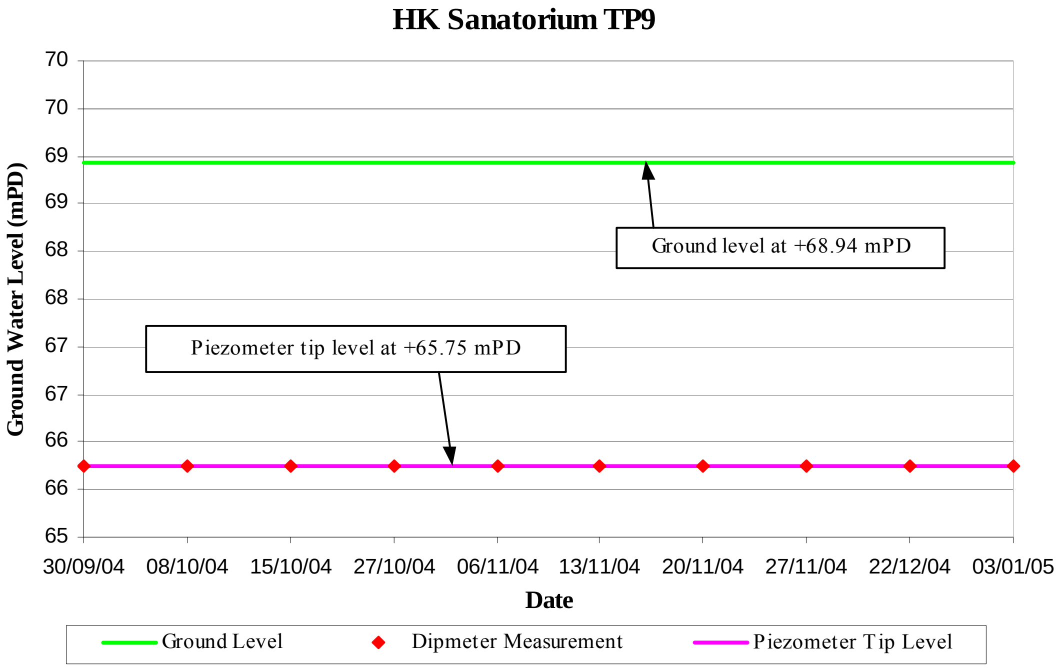
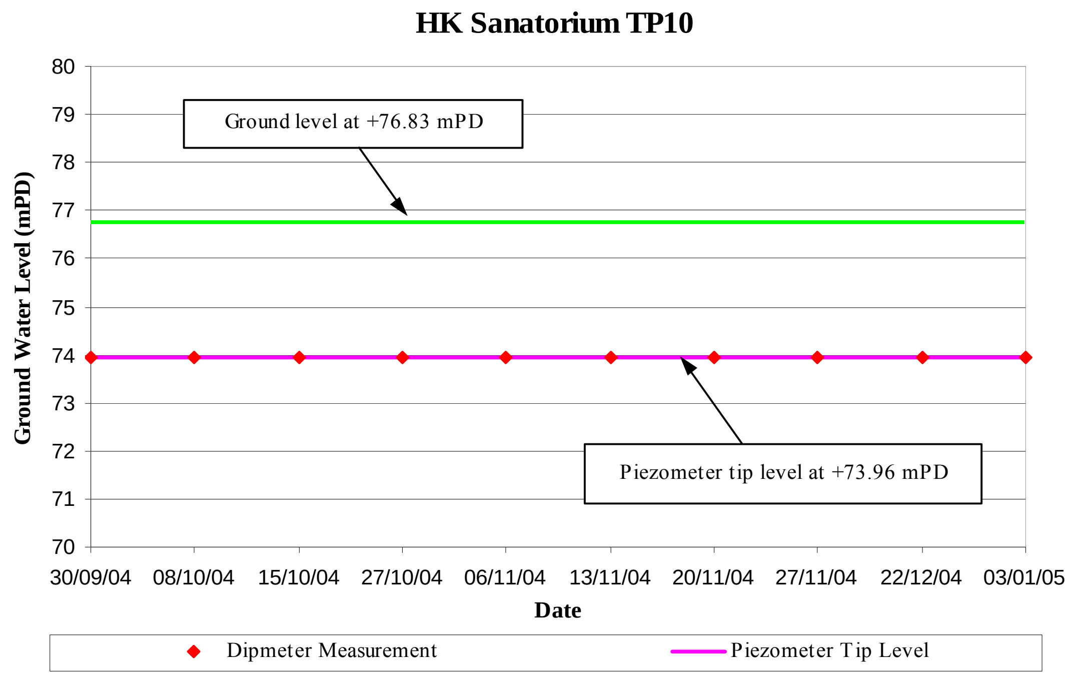


Figure E1 - Graphical Plot of Groundwater Data (Sheet 20 of 21)

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



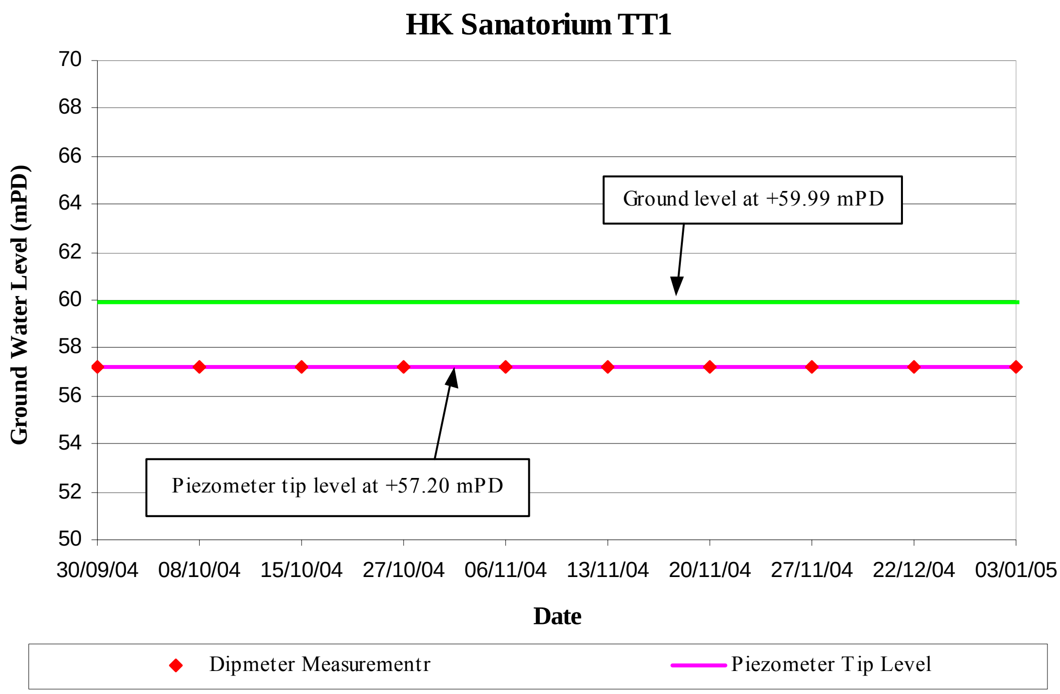


Figure E1 - Graphical Plot of Groundwater Data (Sheet 21 of 21)

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

APPENDIX F

SUCTION MEASUREMENTS

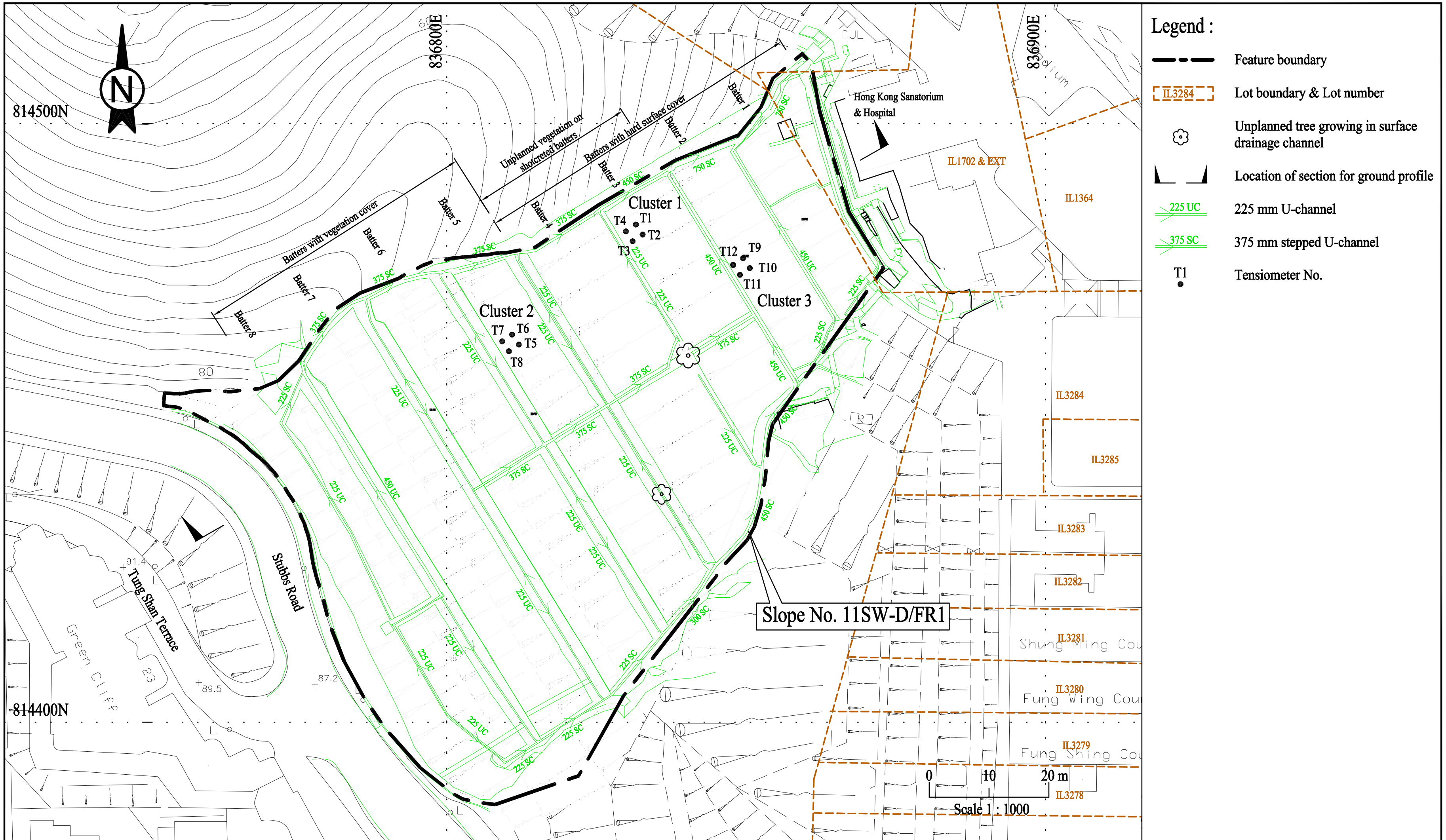
Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table F1 - Summary of Tensiometer Monitoring Data

Tensiometer		Depth of tip below ground level	Installation Data	Matrix Suction (or Negative Pore Water Pressure) (kPa)																																																																	
				Rainy	Rainy	Fine	Fine	Cloudy	Rainy	Sunny	Fine	Fine	Rainy	Rainy	Sunny	Sunny	Sunny	Sunny	Cloudy	Cloudy	Cloudy	Rainy	Rainy	Rainy	Fine	Rainy	Rainy	Rainy	Rainy	Rainy	Fine	Sunny	Rainy	Cloudy	Rainy	Rainy	Rainy	Cloudy	Fine	Fine	Fine	Sunny	Sunny	Fine	Cloudy	Sunny	Sunny	Rainny	Sunny	Fine	Fine	Fine	Fine	Fine	Fine	Fine	Fine	Fine	Fine	Fine	Fine	Fine	Fine	Fine	Fine	Fine	Fine	Fine	Fine	Fine	Fine
				15-Jun-04	16-Jun-04	17-Jun-04	18-Jun-04	05-Aug-04	06-Aug-04	07-Aug-04	09-Aug-04	10-Aug-04	11-Aug-04	12-Aug-04	13-Aug-04	14-Aug-04	16-Aug-04	17-Aug-04	18-Aug-04	19-Aug-04	20-Aug-04	21-Aug-04	23-Aug-04	24-Aug-04	25-Aug-04	26-Aug-04	27-Aug-04	28-Aug-04	30-Aug-04	31-Aug-04	1-Sep-04	2-Sep-04	3-Sep-04	6-Sep-04	7-Sep-04	8-Sep-04	9-Sep-04	10-Sep-04	11-Sep-04	13-Sep-04	14-Sep-04	15-Sep-04	16-Sep-04	17-Sep-04	18-Sep-04	20-Sep-04	21-Sep-04	22-Sep-04	23-Sep-04	24-Sep-04	25-Sep-04	27-Sep-04	28-Sep-04	30-Sep-04	2-Oct-04	4-Oct-04	6-Oct-04	7-Oct-04	8-Oct-04	11-Oct-04	14-Oct-04	15-Oct-04	20-Oct-04	21-Oct-04	27-Oct-04	5-Nov-04	13-Nov-04	20-Nov-04	27-Nov-04	22-Dec-04	3-Jan-05
Cluster 1	**T1**	0.42	04-Aug-04					3	-3	2	5	7	-1	1	5	7	9	8	8	8	5	-1	1	0	5	-1	-1	1	-1	0	2	7	-2	-2	5	-1	-3	1	2	3	7	7	6	4	2	4	7	2	5	4	6	6	7	8	8	10	13	15	20	29	47	53	74	75	68	74	76	75	73	67	68
	T2	0.86	04-Aug-04					2	-5	-1	1	4	-4	-3	2	6	5	6	6	6	5	-1	-4	-3	1	-4	-4	-2	-5	-4	-2	1	-4	-2	1	-3	-5	-2	-2	0	5	4	3	1	-2	1	3	-1	0	0	2	3	4	5	6	8	15	17	24	48	65	70	73	76	77	72	71	70	68	62	64
	T3	1.40	04-Aug-04					-1	-8	-2	0	2	-6	-4	1	3	5	5	5	4	4	-3	-4	-3	-1	-7	-6	-4	-7	-6	-4	1	-6	-10	1	-7	-9	-5	-7	-5	-1	-1	-2	-3	-5	-3	3	-4	-2	-2	-1	-2	-1	0	0	0	1	1	4	5	10	13	34	34	-1	44	65	66	64	60	61
	T4	1.81	04-Aug-04					-3	-7	-4	-2	0	-5	-5	-2	0	5	1	1	1	0	-4	-6	-6	-2	-6	-6	-4	-8	-7	-5	2	-7	-5	-3	-6	-10	-6	-6	-5	1	0	-1	-4	-5	-2	0	-3	-1	-3	0	-1	-1	-1	-1	-2	-2	-2	1	-1	-1	-1	0	1	1	3	6	14	22	62	60
Cluster 2	**T5**	0.63	14-Jun-04	64	73	76	78	8	0	3	5	4	1	-1	0	3	-7	7	8	8	8	5	0	0	1	-1	-1	-1	-2	-1	1	2	0	3	2	-2	-3	-1	0	1	2	2	2	2	1	2	2	-1	0	1	1	2	4	4	5	6	6	8	8	8	8	8	10	12	14	21	35	36	36	36	36
	T6	0.9	17-Jun-04				84	15	10	9	12	14	10	8	16	17	18	20	22	22	22	10	12	10	12	8	10	10	9	10	12	14	12	14	13	9	8	9	13	15	15	15	14	15	14	14	16	11	13	14	13	16	16	16	16	17	18	18	19	20	20	21	24	25	30	42	58	32	52	54	53
	T7	1.24	14-Jun-04	37	53	59	64	10	6	3	6	4	2	1	3	6	10	11	11	12	13	12	12	12	13	3	3	2	2	1	2	2	2	2	3	3	2	1	0	1	1	1	5	1	0	6	4	4	4	5	4	5	5	5	6	7	1	7	7	7	9	9	10	9	14	20	30	39	52	68	57
	T8	1.63	14-Jun-04	62	66	70	72	30	25	19	25	26	24	22	26	42	44	30	36	27	43	43	30	33	25	27	27	25	0	8	11	13	10	11	10	7	5	5	4	5	6	6	5	5	4	5	6	5	5	6	4	7	7	7	7	8	10	11	12	16	20	23	37	40	52	64	64	64	64	60	62
Cluster 3	**T9**	1.77	17-Sep-04																																										-8	-7	-7	-7	-7	-6	-8	-6	-6	-7	-8	-8	-7	-8	-8	-8	-7	-8	-6	-6	-5	-5	-4	-4	-4	0	1
	T10	0.81	17-Sep-04																																										1	1	2	0	1	1	1	1	2	2	1	2	2	1	2	0	4	4	3	3	2	3	3	5	5	9	10
	T11	1.38	17-Sep-04																																										-2	-1	0	-1	-1	-1	-2	-2	-1	-1	-2	-2	-1	-2	-1	-1	0	-2	-1	-1	0	0	1	3	3	6	8
	T12	0.43	17-Sep-04																																										-4	-2	-2	-2	-2	-2	-2	-2	-1	-1	0	0	-2	2	2	-1	3	1	2	2	2	2	4	7	8	15	18

Notes: (1) Positive values represent suction in kPa.
(2) Negative values represent positive pore pressure in kPa.

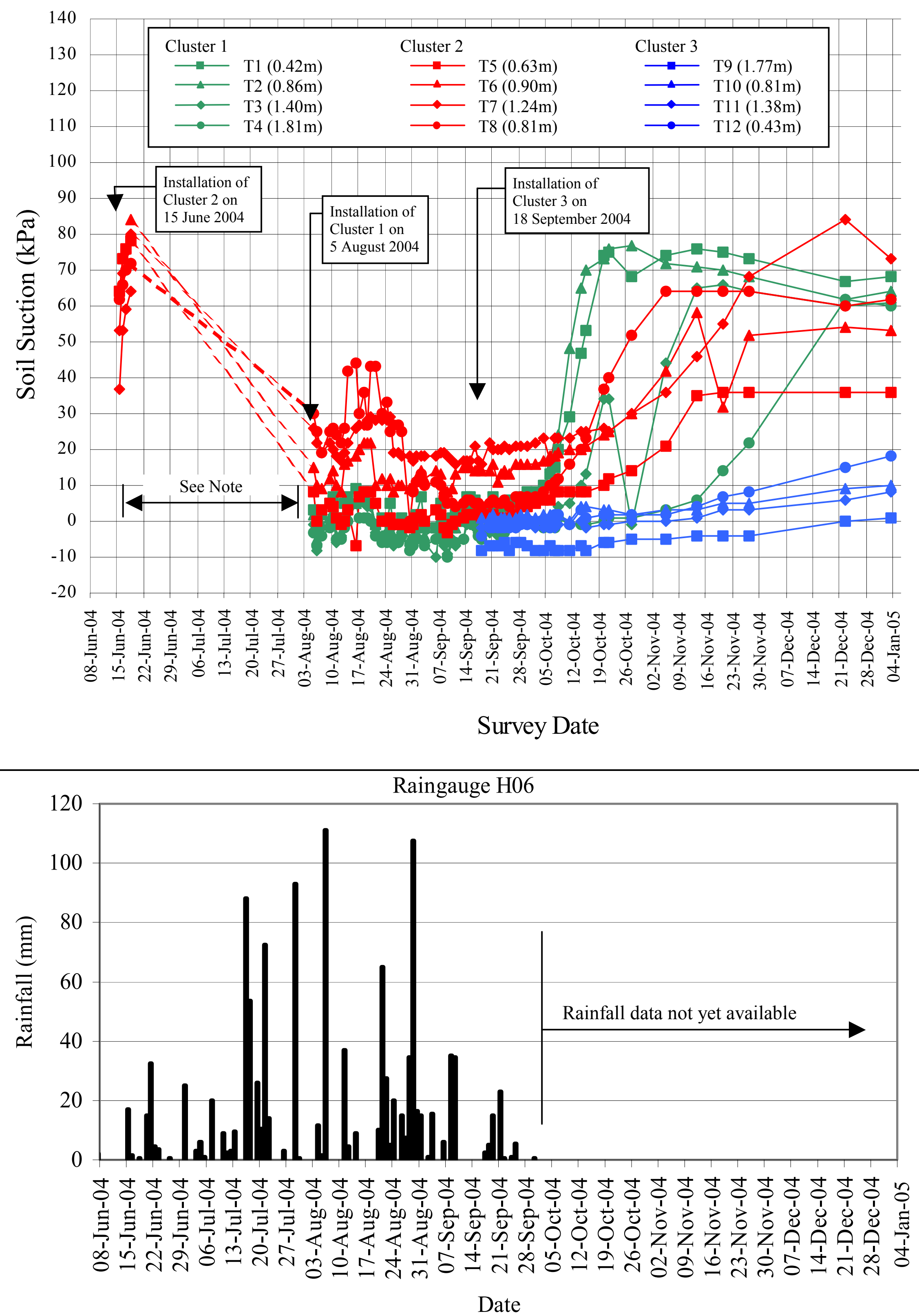
Table of Contents
Table of Contents
Table of Contents
Table of Contents



Notes :
(1) Base Map is extracted from survey sheet No. 11SW-15C, scale 1 : 1000.
(2) General arrangement of the subject slope based on detailed topographic survey by CED Survey Division in May 2004.

Figure F1 - Locations of Tensiometers

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



Note: Readings during this period for Cluster 2 only recorded by datalogger and subsequently found to be unreliable.

Figure F2 - Graphical Plot for Tensiometer Monitoring Data and Rainfall

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

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

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