INVESTIGATION OF SOME SELECTED LANDSLIDES IN 1998 (VOLUME 2)

GEO REPORT No. 109

Fugro Scott Wilson Joint Venture

GEOTECHNICAL ENGINEERING OFFICE

CIVIL ENGINEERING DEPARTMENT

THE GOVERNMENT OF THE HONG KONG SPECIAL ADMINISTRATIVE REGION

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Prepared by:

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

PREFACE

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. A charge is made to cover the cost of printing.

The Geotechnical Engineering Office also publishes guidance documents as GEO Publications. These publications and the GEO Reports may be obtained from the Government's Information Services Department. Information on how to purchase these documents is given on the last page of this report.

R.K.S. Chan
Head, Geotechnical Engineering Office
August 2001

EXPLANATORY NOTE

This GEO Report consists of three Landslide Study Reports on the investigation of selected slope failures that occurred in 1998. The investigations were carried out by Fugro Scott Wilson Joint Venture (FSW) for the Geotechnical Engineering Office as part of the 1998 Landslide Investigation Consultancy.

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

(a) establishment of an improved slope assessment methodology,

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

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

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

Section	Title	Page No.
1	Detailed Study of the Distress Observed in Slope No. 11NE-D/F10 below Hiu Kwong Street, Sau Mau Ping on 9 April 1998	5
2	Detailed Study of the Landslide below Au Tau Village Road, Tseung Kwan O on 9 June 1998	106
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The Landslip Investigation Division of the Geotechnical Engineering Office worked closely with the LI Consultants and provided technical input and assistance to the landslide studies.

SECTION 1 :
DETAILED STUDY OF THE DISTRESS OBSERVED IN SLOPE NO. 11NE-D/F10 BELOW HIU KWONG STREET, SAU MAU PING ON 9 APRIL 1998

Fugro Scott Wilson Joint Venture

This report was originally produced in August 1999
as GEO Landslide Study Report No. LSR 4/99

FOREWORD

This report presents the findings of a detailed study of distress observed in fill slope No. 11NE-D/F10 located below Hiu Kwong Street, Sau Mau Ping, on 9 April 1998. The distress comprised cracking, displacement and bulging of the shotcrete cover to the upper batter of the slope, and was observed following the reporting of seepage from the toe of the slope.

The key objectives of the detailed study were to document the facts about the incident, present relevant background information and establish the causes of the distress. The scope of the study included site reconnaissance, desk study, limited ground investigation and laboratory testing, movement monitoring and analysis. Recommendations for follow-up actions are reported separately.

The report was prepared as part of the 1998 Landslide Investigation Consultancy (LIC), for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 74/97. This is one of a series of reports produced during the consultancy by Fugro Scott Wilson Joint Venture (FSW). The report was written by Mr I Muir and reviewed by Mr Y C Koo. The assistance of the GEO in the preparation of the report is gratefully acknowledged.

Y C Koo
Project Director/Fugro Scott Wilson Joint Venture

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1. INTRODUCTION

Distress was observed in the upper portion of slope No. 11NE-D/F10 below Hiu Kwong Street, Sau Mau Ping (Figure 1) during an inspection by the Geotechnical Engineering Office (GEO) and Highways Department (HyD) on 9 April 1998, following an earlier report of seepage issuing from the slope toe and observation of distress of the slope on the same day by staff from Lui Kwok Pat Fung College, which is located at the toe of the slope. The distress was described as bulging and cracking of the shotcrete cover to the upper batter of the slope. An investigation of water-carrying services in the vicinity of the slope, instigated by HyD following the initial report of seepage, subsequently located a leaking saltwater supply main beneath the opposite side of Hiu Kwong Street. The seepage ceased following the repair of the main by the Water Supplies Department (WSD) on 14 April 1998.

Fugro Scott Wilson Joint Venture (FSW, the 1998 Landslide Investigation Consultants) carried out a detailed study of the distress for the GEO, Civil Engineering Department (CED), under Agreement No. CE 74/97. This is one of a series of reports produced during the consultancy by FSW.

The key objectives of the study were to document the facts about the incident, present relevant background information and establish the probable causes of the distress. The scope of the study included site inspection, desk study, limited ground investigation and laboratory testing, movement monitoring and analysis. Recommendations for follow-up actions are reported separately.

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

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

(b) limited ground investigation and laboratory testing,

(c) analysis of rainfall records,

(d) detailed observations and measurements at the site,

(e) engineering analysis of the slope, and

(f) diagnosis of the probable causes of the distress.

2. THE SITE

2.1 Site Description

Slope No. 11NE-D/F10 is located on the south-western side of Hiu Kwong Street at Sau Mau Ping (Figure 1 and Plate 1), approximately 250 m south-east of the intersection with Hip Wo Street.

The overall topography of the site and surrounding area slopes generally to the south-west, with individual slopes separated by areas of essentially levelled ground formed by fill and cut. Hiu Kwong Street falls longitudinally towards the north-west across the study area.

Slope No. 11NE-D/F10 comprises a fill slope approximately 70 m long and 25 m to 30 m high with three batters of roughly equal height and a batter slope angle of about 33°, separated by 1.5 m- to 2.5 m-wide berms. The slope cover comprises shotcrete with weepholes. The adjacent slope (No. 11NE-D/FR23) to the south-east supports a dense cover of vegetation, whilst the slope (No. 11NE-D/F374) to the north-west has a shotcrete cover with tree rings. The locations of the slopes are indicated on Figure 1.

The slope construction incorporates a surface drainage system on berms, which directs runoff towards a U-channel located along the slope toe and drains towards the south-east.

The area at and immediately above the crest is occupied by an open concrete paved area (an Urban Services Department (USD) "Rest Garden") approximately 5 m wide, which is separated from the Hiu Kwong Street footpath by a 1 m-high concrete parapet wall. The concrete paving incorporates a surface drainage system located close to and parallel with the parapet wall. A steel handrail has been provided along the crest of the slope.

The Hiu Kwong Street corridor has a conventional drainage system of kerb gutters draining into gully pits and is approximately 20 m wide, comprising a four-lane two-way carriageway with 3 m- to 4 m-wide footpaths on either side.

A masonry-faced retaining structure of maximum height of 5 m to 6 m is located along the north-eastern edge of Hiu Kwong Street. The area above the retaining wall comprises sloping ground leading up to a levelled platform occupied by high-rise residential structures of the Sau Mau Ping Housing Estate.

Liu Kwok Pat Fung College is located approximately 3 m beyond the toe of the slope to the south-west and the Kwun Tong Maryknoll College approximately 5 m to 6 m beyond the toe to the south-east. The ground surface is essentially level beyond the slope toe.

2.2 Geology

Sheet 11 of the Hong Kong Geological Survey 1:20,000 scale Map Series HGM20 (GCO, 1986), the relevant portion of which is reproduced in Figure 2, indicates that the solid geology of the study area and its surroundings is fine- to medium-grained granite. The study area also lies within a substantial area indicated as having superficial deposits of fill. Locations of "Important Slope Failures" are indicated in the fill bodies to the south-east (1972 events) and north-east (1976 events).

Debris flow deposits below the fill are indicated to the south-west of the slope extending along a north-west/south-east axis in what appears to be a buried drainage valley from the original landform. The fill body within which the study area is located would appear to have buried a tributary to the main valley. A geological fault (boundary uncertain) oriented NNE-SSW traverses the south-western portion of the slope.

2.3 Water-carrying Services

Water-carrying services located within the Hiu Kwong Street corridor are indicated on Figure 3. The layout of the services has been based on the relevant utility plans and visual confirmation of valve pits, manholes, etc.

Pressurised water-bearing services comprise two freshwater mains (400 mm diameter, installed in 1983, and 610 mm diameter with no record of installation), and one saltwater main (400 mm diameter installed in 1982). According to WSD, installation details and maintenance records are unavailable for these mains.

Gravity-fed services comprise two stormwater drains (900 mm and 1200 mm diameter) and a 1050 mm diameter foulwater sewer. The Drainage Services Department (DSD) have been unable to locate records on the date of installation of these services, and have indicated that there are no maintenance records.

2.4 Maintenance Responsibility

According to the consultant engaged by the Lands Department on the "Systematic Identification of Maintenance Responsibility of Registered Slopes in the Territory" (SIMAR) project, slope No. 11NE-D/F10 is under the maintenance responsibility of HyD.

The concerned slope was registered as No. 11NE-D/F10 in the 1977/78 Catalogue of Slopes, by consultants for the Government of Hong Kong, following slope reconstruction works in 1976/77. Prior to reconstruction and slope registration, it was referred to as slope No. SMP10. Figure 1 shows the boundary of this slope, and the adjacent slopes, as indicated on the New Catalogue of Slopes compiled by the GEO between 1992 and 1998.

3. SITE HISTORY AND PREVIOUS STUDIES

3.1 General

The site history of slope No. 11NE-D/F10 and details of previous studies have been compiled through a review of the available documentation and aerial photograph interpretation (API). Detailed findings of the API are summarised in Appendix A and Figures 4 and 5.

3.2 Site History

3.2.1 Events in the 1960's and 1970's

Major observations from initial slope formation until the slope reconstruction works carried out in 1977 are presented in Figure 4.

The 1963 aerial photographs show the site formation works for the Sau Mau Ping Estate under construction. The Hiu Kwong Street corridor was partially formed at this time

and the subject fill slope (No. SMP10) was under construction (the slope was completed under PWD Contract 134/1961). Available documentation indicates that the slope formation within the estate at this time was by end-tipping. The photographs show that the slope comprised a single batter between Hiu Kwong Street and a levelled platform at the slope toe, with surface drainage in a 'chevron' pattern. Available records indicate that the slope was 30 m high and inclined at 32°.

Aerial photographs taken in 1967 indicate erosion problems on the face of slope No. SMP10, with deep gullies visible on the south-east portion. The slope was re-surfaced over the lower two-thirds with stone pitching in 1968.

In June 1972, a major failure occurred in the fill slope immediately to the south-east of slope No. SMP10 resulting in 71 fatalities (Government of Hong Kong, 1976). This slope was subsequently reconstructed to its present form comprising a 40 m-high, 55 m-long face at 22° to 26°, with surface vegetation and a 4 m- to 13 m-high retaining wall along the slope toe, was registered as slope No. 11NE-D/FR23 in the 1977/78 Catalogue of Slopes.

A small local failure is visible mid-way along slope No. SMP10 in the 1973 aerial photographs, extending below the crest, with a narrow runout of debris to the slope toe. Further deterioration of the slope is visible in the 1974 aerial photographs, with additional localised erosion and minor instability observed in the upper portion of the slope, although the 1973 scar near the slope crest has been covered with a hard surfacing. Linear features indicating possible instability were also identified in the south-east portion of the slope at the crest and at the top of the stone pitching.

A large failure occurred in the south-east portion of slope No. SMP10 on 25 August 1976 following prolonged heavy rainfall (Binnie & Partners, 1976; Government of Hong Kong, 1976). The failure was one of four incidents that occurred in the Sau Mau Ping Estate. The landslide scar and urgent repair works, comprising removal of displaced material, are visible in 1976 aerial photographs (Plates 2 and 3).

Permanent slope stabilisation works were carried out during 1977 under PWD Contract 409/1977 (Binnie & Partners, 1977a). The works involved placement of new fill over the original slope profile resulting in the present day geometry, comprising three batters at a gradient of 1V:1.5H, separated by 1.5 m- to 2.5 m-wide berms. According to the as-constructed drawings (Binnie & Partners, 1980), the slope face was covered with a 40-mm thick chunam surfacing and incorporated a stone pitching detail extending above the toe of each batter (0.5 m mid-slope and 1.5 m at the toe), covering the drainage blanket behind. Other documentation (Binnie & Partners, 1979 & 1984) indicates a sprayed concrete surfacing instead of chunam. A general view of the slope in June 1978 is shown in Plate 4.

A typical section through the reconstructed slope, indicating the permanent stabilisation works, is presented in Figure 6. This indicates the thickness of the new fill, taken perpendicular to the slope face, to be approximately 3 m, 4.5 m and 6.5 m for the top, middle and lower batters respectively. The overall volume of additional fill is estimated to be in the order of 18 000 m^3.

A basal filter layer, labelled "Filter Type A", is shown to cover about 85% of the original slope face below the 1977 fill. This layer is isolated between batters and extends to

the toe of each batter respectively, incorporating the stone pitching details at the slope face. The filter thickness increases downslope, with 0.25 m indicated for the upper and middle batters and 0.5 m to 1.0 m for the lower batter. It is noted that the filter thickness along the base of the lower batter includes a 0.5 m-thick layer of "Filter Type B" between 0.5 m-thick layers of the "Filter Type A" material.

The surface drainage system is indicated as comprising 225 mm U-channels along the original crest line (boundary of old and new fill) and on intermediate berms, with a 450 mm U-channel along the toe. A series of 300 mm and 450 mm stepped channels discharges collected runoff from berms to the toe channel. Crest runoff is discharged to the slope toe along a 450 mm stepped channel at the north-eastern end of the slope.

The fill material was recompacted to "an average dry density of 1.8 t/m^3" (Binnie & Partners, 1978). The specification for recompaction of fill slopes at the time of these works required 95% (standard) maximum dry density (Government of Hong Kong, 1976).

The new slope formation in 1977 essentially represents the current condition of the study area and is presented in Figure 5, annotated with the main observations from the subsequent site history, as described below.

3.2.2 Events in the 1980's

A record photograph of slope No. 11NE-D/F10, taken in June 1983, shows the hard surfacing to be cracked and vegetation to be growing along berms and on the slope face (Plate 5).

On 3 April 1984, a slope failure occurred on the north-western portion of the upper batter of slope No. 11NE-D/F10 (GCO, 1984), which was described as a "washout failure" and attributed to a leaking water main at the slope crest, though available documentation does not positively identify the source of the leakage. The damage to the slope is shown in Plates 6 to 9, which suggests fill material having been removed from the slope, creating a void into which the hard surfacing collapsed. There appeared to be significant undermining of the hard surfacing, given the extent of the cracking, which extends beyond the crest of the slope (Plate 6). An area of subsidence in the eastbound lane of the Hiu Kwong Street carriageway is also indicated in Plate 6. Available records indicate that the volume of the failed material was of between 50 m^3 and 160 m^3.

The damage resulting from the 3 April 1984 incident was repaired by removal of the affected material (as determined by GCO probing – locations indicated on Figure 8) and the replacement and recompaction of fill in the excavated area (including the replacement of the filter layer, where encountered), and replacement of the hard surface cover. The remedial works are shown in Plate 10. The presence of surface drainage and hard surfacing from the pre-1977 slope formation beneath the excavated fill at the edge of the feature, as can be seen in Plate 9, suggests that these may have been left in place beneath the 1977 reconstruction works.

Between 1984 and 1985, Lui Kwok Pat Fung College was constructed adjacent to Maryknoll College at the toe of slope No. 11NE-D/F10.

Some distress of the slope face was observed by HyD in March 1985, which was reported to WSD on the basis of possible leakage from an adjacent fire hydrant. The nature of the distress was not elaborated. WSD apparently located minor leakage from the packing of an isolation valve to the hydrant and also in the packing on a sluice valve in Hiu Kwong Street. Repairs were carried out, but WSD stated that the level of leakage would be unlikely to have had much effect on the slope.

From 1985 to the present, relatively little change has been observed in slope No. 11NE-D/F10. At some time between 1985 and February 1994, a concrete parapet wall was constructed along the Hiu Kwong Street footpath and a hand railing placed at the crest of the slope.

The slope face is observed to have been subject to cycles of deterioration, with vegetation appearing over time and zones of erosion visible on the upper batter, and periodic maintenance comprising vegetation removal and repair of erosion. The deterioration appears to be most prevalent in the upper batter.

The term 'erosion' is based on interpretation of aerial photographs and is used in cognisance of the presence of a hard surfacing on the slope face. That the erosion, described as 'rilling' (debris on berm also observed, see Appendix A), is observed on the upper batter suggests the possibility of the hard surfacing breaking up at the slope crest. This is first visible in the 1985 photographs and may therefore be associated with the leaking services described above. Alternatively, overspilling of surface water from Hiu Kwong Street may have occurred. This latter possibility becomes less likely following the construction of the parapet wall.

3.2.3 Events in the 1990's

Maintenance works are visible in the 1990 and 1995 aerial photographs. Both have the appearance of re-surfacing of the entire slope. Documentary evidence has been located for the 1995 re-surfacing, which was carried out by HyD.

The condition of the upper batter in February 1994 is shown in Plates 11 to 13, which indicate vegetation and cracking in the hard surfacing (with repairs). Possible distortion in the hand railing at the slope crest is evident in Plate 13. A small patch of what appears to be erosion is visible on the upper batter, near the location of "bulging" described by the GEO in 1998 (see Section 4 and Figure 7), in the May 1994 aerial photographs. The patch is darker than the rest of the slope, the cause of which is not known. The October 1994 aerial photographs indicate noticeably heavier vegetation in this area.

The condition of the slope approximately one year later, in March 1995, is presented in Plates 14 and 15. Of note is the apparent convex deformation of the lower portion of the slope face of the upper batter at the interface between the hard surfacing and stone pitching (Plate 14) and the cracking along the interface (Plate 15).

Plates 16 and 17 show the 1995 re-surfacing works in progress. Both photographs, taken from the lower of the two berms, indicate a convex deformation near the slope toe.

Plate 18 shows the completed re-surfacing works in June 1995. The slope condition one year later is shown in Plates 19 and 20. Possible distortion of the hand railing at the slope crest is indicated in Plate 19. Plate 20 shows a feature in the shotcrete surfacing of the upper batter, which suggests only partial removal of the previous hard surfacing prior to the 1995 application of shotcrete.

A view of the upper batter of the slope is given in Plate 21, taken in May 1997, which indicates the presence of vegetation on the slope face.

3.3 Previous Studies

No information relating to the design of the original fill slope formation (slope No. SMP10) in the 1960's can be located.

Highways Office (HO) completed an assessment of the condition and stability of slope No. SMP10 in September 1972. The assessment was carried out in relation to the school building (Kwun Tong Maryknoll College) located at the slope toe, following the significant landslide incident on the adjacent slope (see Section 3.2.1). The assessment, which assumed shear strength parameters based on laboratory test results on samples from the adjacent failed slope ($c' = 22$ kPa, $\phi' = 30°$), a slip surface located along the fill/in-situ ground interface and an r_u value of 0.5, found the factor of safety to be 1.3.

Binnie and Partners were commissioned by the Hong Kong Government to report on the landslide incidents that occurred in the Sau Mau Ping Estate on 25 August 1976, which resulted in fatalities. Their report (Binnie & Partners, 1976) describes the landslide in slope No. SMP10 as a shallow slip caused by the loose state of the fill and triggered by rainfall. That the displaced mass “slumped”, rather than developing into a "flow slide", as with other incidents of 25 August 1976 in this locality, was attributed to the higher overall insitu density at this location.

Details of the proposed reconstruction works for slope No. SMP10 are given in Binnie & Partners (1977a). The report also recommended horizontal drains near the slope toe to “intercept any groundwater travelling from the buried valley”. Original ground contours indicating the valley feature are shown on Figure 4. Such drains, however, are not shown on the as-constructed drawings.

The slope was inspected by Binnie and Partners in June 1977 as part of the Preliminary Studies for the Investigation into Fill Slopes (Binnie & Partners, 1977b) and subsequently registered as slope No. 11NE-D/F10 on the 1977/78 Catalogue of Slopes.

A detailed study report for slope No. 11NE-D/F10, comprising a review of previous ground investigation and an assessment of the stability of two cross-sections of the reconstructed slope, was completed in January 1979 (Binnie & Partners, 1979). The ground investigation was carried out prior to the slope works. A “conservative assumption” was made for the groundwater level for the analysis of “Section 1”, where base groundwater levels were assumed to coincide with the “original ground surface”. The assumed strength parameters for analysis were as follows: “$c' = 0$ kPa, $\phi' = 36°$” for existing fill, “$c' = 0$ kPa,

$\phi' = 26°$" for existing fill base, "$c' = 0$ kPa, $\phi' = 39°$" for compacted fill and "$c' = 0$ kPa, $\phi' = 38°$" for insitu soil.

The analyses showed that the factors of safety "for deep seated failures passing beneath the recompacted fill" ranged from 1.4 to 1.65, for a 1-in-10 year design ground water level. The factor of safety for shallow slip surfaces within the recompacted fill was calculated to be about 1.2. The report notes that "provided the surface protection is maintained such slips will not occur".

The report includes details of water-carrying services located behind the crest, within the Hiu Kwong Street corridor. The layout of the services is much the same as that indicated on the current utilities plans (Figure 3). Three abandonments (most notably a 40 mm diameter saltwater main located beneath the southern footpath of Hiu Kwong Street and apparently connecting to the existing saltwater fire hydrant), the replacement of a 380 mm diameter saltwater main with the existing 400 mm diameter main and addition of the existing 400 mm diameter freshwater main on the northern side of Hui Kwong Street are indicated as having occurred since 1979.

The report recommends "that services layed in the fill are either relocated out of the fill or relaid in drained ducts". The services are indicated as being located in the fill material some 7 m from the crest of the slope, beneath Hiu Kwong Street. Comparison of the layout of utilities between 1979 and the current records suggests possible abandonment of the 40 mm diameter saltwater main may have been in response to this recommendation. However, on the basis of available records, there does not appear to have been any further action taken with respect to re-location or placement of services in ducts.

A geotechnical report was prepared by MAA Consultants (HK) Ltd in September 1982 in relation to the proposed "New Life School" at NKIL 5625 (now Lui Kwok Pat Fung College) which included a study of the stability of slopes associated with the development of the site. The analyses presented in the report repeat those of Binnie & Partners (1979) described above and produced the same results.

Slope No. 11NE-D/F10 was inspected by Binnie & Partners (1984) on 20 June 1983. The drainage channels and surface protection were found to be in a "fair condition". Seepage through cracks in the slope cover was noted but locations were not identified.

In 1992, the GEO initiated the consultancy agreement entitled "Systematic Inspection of Features in the Territory" (SIFT) which, inter alia, aims to identify features not registered in the 1977/78 Catalogue of Slopes and update information on registered slopes based on studies of aerial photographs and limited site inspections. Slope No. 11NE-D/F10 has been assigned class "B1" by SIFT, i.e. "Assumed not to have been checked by GEO (assumed formed pre-1978, or illegally formed)".

Reports on annual slope maintenance inspections carried out by HyD have been located for the years 1995, 1996 and 1997. The inspection carried out on 29 March 1995 recommended cleaning of surface drains, removal of vegetation from the slope surface and application of sprayed concrete, which were subsequently carried out.

The inspection carried out on 21 January 1996 by HyD did not recommend maintenance works. However, tell-tales were installed at the parapet wall "...as recommended by GEO". Specific reasons for the installation (HyD or GEO concerns) and the monitoring records have not been located.

The record for the 26 July 1997 inspection recommended routine maintenance works comprising clearing of drainage channels, removal of surface debris and vegetation "causing severe cracking of slope surface cover and drainage channels" and unblocking weepholes. No recommendation was made for repair of the surface cover and channels, and Engineer Inspection was indicated as "not required".

In June 1995, the slope was inspected by consultants appointed by HyD to undertake the "Roadside Slope Inventory and Inspections" project. The Engineer Inspection record (FMR Consultants, 1995) makes no adverse comment in relation to the slope condition and recommends Routine Maintenance and Engineer Inspections to be carried out on a yearly basis. The record photographs indicate a freshly shotcreted slope (i.e. inspection carried out immediately following maintenance works carried out by HyD in May 1995).

In late 1996 or early 1997 the slope was included in a study of the adjacent Liu Kwok Pat Fung College as part of the Architectural Services Department (ASD) School Improvements Programme (SIP), Phase III, because the study requires an assessment of all slopes with a potential to impact on the new works. Meinhardt Consulting Engineers (MCE) were engaged by ASD for the study (School S149). The MCE assessment of the slope has included ground investigation (drillholes and trial pits), which was completed in June 1998. It is understood that the school has now been transferred to Phase IV of the SIP. It is further understood that the slope no longer requires consideration by the consultant, as the new works involved are to be located away from the slope toe.

Slope No. 11NE-D/F10 was included in a review on the performance of recompacted loose fill slopes (Law et al, 1998). The review includes reference to the 1984 incident (washout failure) as one of four failures in the 128 recompacted fill slopes studied. However, the failure was not included statistically in the review because it was related to a burst water main and "...not due to weakness of the recompacted slope under the normal operating condition".

4. DESCRIPTION OF THE DISTRESS ON THE SLOPE

4.1 Description of the Distress

The following description has been compiled on the basis of desk study, discussion with various parties and site observations by FSW staff. A chronological sequence of events relating to the recent (i.e. post-January 1998) history of slope No. 11NE-D/F10 is presented separately in Appendix B.

The major distress to the slope observed by the GEO on 9 April 1998 was confined largely to the upper batter of the slope. The distress comprised localised "bulging" of the shotcrete surfacing and a single line of cracking (crack width 5 mm to 10 mm) following a semi-elliptical path from the crest of the slope near the centre of the feature down to berm

level at either end. The cracking extended across the berm and a short distance into the middle batter at the south-eastern end. The two zones of "bulging" observed (Plates 22, 23, 27 and 29) were located on the line of cracking. On the basis of the desk study (Section 3.3), the shotcrete surfacing in which the distress was observed is presumed to be that installed in 1995.

The term "bulging", as used here, refers to the shotcrete surfacing alone. A hole formed in the affected area by GEO during an inspection on 14 April 1998 revealed the shotcrete to have lifted off the underlying slope surface by 50 mm to 75 mm (Plate 24).

The shotcrete below the line of cracking was observed to have moved down-slope to extend beyond the lip of the berm U-channel to a maximum of 50 mm (Plates 30 and 31). Where this was the most pronounced, the rear channel wall had broken and leaned forward into the channel over a length of 2 m to 3 m. On either side of the broken section, the width of the channel was less than that of the unaffected sections.

Additionally, subsidence and movement of the ground surface behind the crest, in the USD "Rest Garden", was evident along the length of the slope and most pronounced near the centre (Plates 32 and 33), extending into the Hiu Kwong Street carriageway. Evidence of subsidence and lateral movement in this area included the following:

(a) cracking and separation of the concrete pavement in the slope crest area and between the pavement and a surface drainage channel (Plates 33 and 34),

(b) a concrete plinth (purpose not known) standing proud of the concrete pavement by 50 mm to 100 mm in the Rest Garden (Plate 25),

(c) deformation of the steel handrail along the crest of the slope (Plates 32, 33 and 35),

(d) deformation and cracking of the parapet wall behind the crest (Plates 32 to 34 and Plate 36), and

(e) a minor dip in the Hiu Kwong Street carriageway north-west of the centre of the feature, noticeable by observing passing vehicles.

The locations of the various items of distress are shown in Figure 7.

4.2 Observations Prior to Reporting of Distress

From approximately early February 1998 onward, seepage was observed by the ground staff of Lui Kwok Pat Fung College to be issuing from weepholes installed in the 450 mm U-channel located along the toe of the slope. The extent of the seepage is indicated in Figure 7. The heaviest seepage was described as 'gushing'. Some discrepancies exist between various accounts as to the extent of the seepage and the zone of maximum flow, but the differences are not so great as to affect the overall impression given by Figure 7.

The subsequent reporting of this seepage to HyD on 7 April 1998 by the school administrative staff initiated the series of joint inspections by HyD with various Government Departments, initially WSD and DSD. The slope was then inspected with GEO, following identification by school staff of the distress observed in the upper batter of the slope, on 9 April 1998 (Appendix B).

Past observation of ground movements at the crest of the slope is illustrated by the glass "tell-tales" installed across construction joints at four locations along the parapet wall by HyD in January 1996. No monitoring data has been located and all tell-tales are now destroyed. Discussions with the GEO have also suggested that concerns regarding movement may have dated back some years, although no supporting documentation has been located.

4.3 Observations Following Reporting of Distress

Subsequent to the initial inspection by HyD on 7 April 1998, WSD and DSD visited the site to check their services for leakage.

WSD initially performed a test on samples of the seepage at the slope toe to determine the chloride ion content, which confirmed that the seepage was saline (WSD, 1998a). Using leakage detection devices including a leakage noise correlator and stethoscope (WSD, 1998b) at the location of the freshwater and saltwater services, a leak was detected in the 400 mm diameter pressurised saltwater supply main on the northern side of Hiu Kwong Street, opposite the location of the toe seepage. An exploratory pit, excavated by WSD on 14 April 1998, exposed the leak (flow rate reported as 2.4×10^{-5} m^3/sec, pressure head in the main (taken on 22 August 1998) reported as 11.7 kg/cm^2 (WSD, 1998b)), which required the pit to be de-watered by a pump (Plate 26). The details of the leak (i.e. at joint or in the pipe itself) have not been supplied by WSD. Repairs to the leaking pipe were carried out by WSD.

DSD similarly performed checks on their services in the Hiu Kwong Street corridor. Closed Circuit Television (CCTV) inspections were carried out on 14 April 1998 and indicated that the two stormwater drains (900 mm and 1200 mm diameter) and the foulwater sewer (1050 mm diameter) were in "normal" condition, with "no signs of structural cracks or joint displacement ..observed". Dye tests carried out by DSD on 15 April 1998 did not result in any colour change in the seepage at the slope toe. The seepage was observed to have ceased during an inspection on 7 May 1998. This timing of cessation of the seepage compares well with observations by the school staff, who noted a marked reduction in seepage in the week following 14 April 1998, with a gradual reduction to zero flow over the next 3 to 4 weeks.

At the time of the initial inspection of the slope by the GEO on 9 April 1998, very minor seepage was observed as issuing from beneath the shotcrete surfacing on the upper batter into the berm U-channel. As described earlier (Section 4.1), an inspection hole formed at the main zone of bulging on 14 April 1998 revealed that the shotcrete had lifted off the slope surface and no seepage or free water was observed within the void.

GEO requested stripping of a panel of shotcrete from the slope crest to the upper berm level at the location of the most severe "bulging" and cracking, and GCO probing at four

locations in the exposed fill profile. These works were carried out by HyD between 16 April and 24 April 1998, and are discussed in Section 5.

FSW staff first visited the site on 30 April 1998 and again on 5 May 1998. A general view across the slope at this time is provided in Plate 35. Observations generally concurred with previous inspections and it was noted that the remainder of the slope below the top batter was in a better overall condition, the shotcrete surfacing displaying minor cracking and supporting a sparse cover of vegetation at crack locations and weepholes.

Pertinent observations made by FSW include the following:

(a) The bulging in the shotcrete at the south-eastern end of the slope, which had not been covered by the urgent repair works, involved an out-of-plane distortion of the shotcrete associated with the line of cracking (Plate 29).

(b) Vegetation was observed growing from the gaps between the shotcrete and the U-channel on the upper and middle batters, at locations where the shotcrete protruded beyond the lip of the channel (Plates 30 and 31).

(c) The shotcrete surfacing on the middle batter was observed to have moved downslope to protrude slightly beyond the lip of the berm U-channel, though to a much lesser extent than that observed on the upper batter.

(d) A vertical gap of up to 100 mm was observed between the shotcrete surfacing on the lower batter and the U-channel along the toe of the slope, though it was unclear as to whether this was due to movement of the shotcrete (no other observations in the lower batter), washout of a thin layer of loose material (shotcrete rebound) not properly cleared prior to application of the shotcrete, or subsidence of the U-channel.

(e) The upper batter was observed to have a pronounced ‘break’ in slope angle about 1 m to 2 m above berm level, with angles below the break of 45° to 50° and angles above of 30° to 33° (Plates 28, 37 and 38). Sympathetic cracking in the shotcrete was minor, suggesting possible application (in 1995) of the shotcrete surfacing after deformation had occurred.

(f) Immediately to the east of the shotcrete stripping, the lower portion of the slope surface was uneven (Plate 38), notwithstanding the break in slope angle and, again, the shotcrete surfacing appeared to have been applied to the distorted surface, as only minor sympathetic cracking was observed.

(g) The fill exposed below the stripped shotcrete was observed to be a decomposed granite material in a relatively compact state (Plates 37, 38 and 39). An older cement-based surfacing was observed beneath the shotcrete on the western edge of the strip (Plate 39) and the upper portion of the eastern edge, but was absent on the lower portion of the eastern edge (Plate 38), suggesting partial removal of previous surfacing(s) prior to the 1995 application of shotcrete.

(h) Mortared stone pitching was exposed beneath the shotcrete over the lower 1 m of the batter on either side of the stripping (Plate 37). The stone pitching incorporated stub drains (perforated PVC pipes), presumably providing discharge to a filter layer behind, which extended through the shotcrete surfacing (Plate 31).

(i) The stone pitching, where exposed (Plates 37), had a pronounced convex shape in section, and it was observed that the overlying shotcrete had separated from the stone pitching at the slope toe. The appearance was of an increase in the curvature of the stone pitching which had occurred since application of the shotcrete resulting in separation at the slope toe and an outward movement of the shotcrete over the lip of the berm U-channel.

(j) The cracking traversing the upper batter had been partially filled with a bitumen-based sealant (Plate 40). Repairs had also been carried out at the location of the concrete plinth behind the slope crest (Plate 32). The plinth had apparently been removed and the pavement repaired to match the surrounding area.

Urgent repair works to the upper batter were carried out by HyD during May 1998. Works comprised the removal of a significant proportion of the 1995 application of shotcrete (leaving older surfacing beneath generally intact), re-application of shotcrete to the entire batter and repair of the berm U-channel (Plate 41).

It is noted that GEO provided preliminary recommendations on repair works only, which consisted of the removal of the hard surfacing on the upper batter and had intended to base their final recommendations on the results of inspection of the exposed face. However, HyD completed the application of shotcrete without notifying GEO. Also, not all the hard surfacing was removed, as noted above.

5. SUBSURFACE CONDITIONS

5.1 General

The subsurface conditions within the study area have been assessed on the basis of the detailed desk study and results of a limited ground investigation carried out as part of the present study. The study has also included a topographic survey of the area and monitoring of ground movement and groundwater levels.

5.2 Previous Ground Investigations

A number of previous ground investigations, including the recent GCO probing requested by GEO, have been undertaken within or in close proximity to the concerned slope. The locations of previous investigation stations are presented in Figure 8.

5.3 Current Investigation

Limited ground investigation (Figure 8) was carried out between 25 August and 7 September 1998. This comprised a vertical drillhole located on the upper berm, in line with the observed location of "bulging" in the shotcrete, and extending 5 m into insitu ground, three 1.5 m deep trial pits and removal of the existing hard surfacing in four 0.5 m-wide strips.

Standard Penetration Tests (SPT's) with liner samples were carried out at 0.5 m intervals within the drillhole. Two falling head permeability tests were conducted at depths of 2.3 m to 3.5 m (new fill) and 6.8 m to 8.0 m (old fill) within the drillhole.

GCO probing was carried out at each of the trial pits prior to excavation. Insitu density testing was carried out in the trial pits and disturbed samples were recovered.

Details of the ground investigation are given in Bachy Soletanche (1998). Photographs detailing the shotcrete stripping and the various observations made during the investigation are presented in Plates 42 to 65.

Laboratory testing on recovered samples has included classification, moisture content determination and compaction tests (Chen, 1996). Additionally, selected soil samples have been tested for chloride ion content to identify contamination by saltwater, and dispersion tests have been carried out to assess the potential for migration of fines. The laboratory tests were carried out by the Public Works Central Laboratories (PWCL).

Piezometers and standpipes were installed in the drillhole and trial pits for groundwater monitoring purposes. Additionally, use was made of existing installation at the slope crest and toe to supplement the information on the groundwater regime. Plots of the recorded groundwater elevations during the study period are presented in Figure 9.

In addition to the subsurface investigation, a detailed topographic survey of the study area was completed. A number of survey nail markers were also installed along berms and at the crest and toe of the slope for movement monitoring purposes. The detailed survey plan, which indicates the locations of survey markers, is presented in Figure 10. Monitoring of the horizontal and vertical movement of the survey markers has been carried out on a weekly basis during the study period.

Tell-tales were installed across selected cracks in the hard surfacing on the middle and lower batters in early January 1999 to permit monitoring of crack widths. Tell-tale locations are indicated on Figure 10.

Probing of the toe drains at each batter and selected weepholes has also been carried out with the aim of assessing their general condition.

5.4 Deduced Conditions

5.4.1 Slope Surfacing

The present investigation has shown that the upper batter of the slope has been subjected to a considerable amount of post-construction repair works, with up to six distinct cement-based layers observed, in strips S1, S3 and S3A (Plates 45, 49, 52, 59 and 61), including the recent (1998) shotcrete layer. The maximum combined thickness of the layered surfacing is 250 mm to 350 mm. Elsewhere (strip S4 and trial pit TP2), the single layer of shotcrete applied in 1998 directly overlies the fill. Included in the cement-based layers, which generally comprised shotcrete, was a layer resembling cement stabilised fill and located immediately above the compacted fill in strip S3, which may be a replacement fill layer rather than a previous hard surfacing.

Strip S4 and trial pit TP3 in the middle batter revealed a less complex arrangement, with a single layer of older shotcrete present beneath the current (i.e. 1995) application of shotcrete (Plate 65). However, only a single strip and a trial pit have been completed on this batter, in close proximity to one another, and conditions may vary laterally across the slope.

Stone pitching was observed over the lower 1 m of the slope face above berm level in strips S2 in the upper batter and S4 in the middle batter (Plates 49 and 62 respectively). PVC weepholes/stub-drains were observed in the stone pitching (Plate 37). This detail is consistent with that indicated on the as-constructed details for the reconstruction works carried out in 1977.

Cracking was observed at numerous locations in the older layers of surfacing beneath the most recent application on the upper and middle batters (see Plates 42, 43, 44, 46, 50, 51, 54, 55, 57, 63 and 64). The path of the cracking on the upper batter appears to be in much the same location as that observed in the 1995 shotcrete at the commencement of the study, and has reflected through to the present (1998) surfacing in a number of locations with a crack width ranging from "hairline" to about 0.5 mm (Plate 58). The most pronounced cracking was observed in strips S3 and S3A, approximately 4 m below the slope crest. Crack width was approximately 20 mm to 30 mm, with a dark organic soil infill, suggesting development over time. Tension cracking and voiding was observed in the fill beneath the crack location on removal of the layers of previous surfacing (Plates 56, 57, 59 and 60). The crack width was of the order of 50 mm to 100 mm (Plate 59). The crack was present to at least a depth of approximately 300 mm (Plate 60) and it extended beyond the end of strip S3A. The voiding is in the form of a clear space between the underside of the hard surfacing and the slope face of the fill on either side of the crack, and was about 10 mm to 20 mm deep.

Organic infill was also observed in two old cracks in the hard surfacing located in strip S2 (Plates 52 and 53). However, tension cracking in the fill material could not be confirmed at either location. Voiding in the fill was also observed in strip S2 immediately above the stone pitching (Plate 48).

There was no indication of seepage or erosion of the fill surface in any of the surface strips.

The locations of cracks (width up to 25 mm, typically less than 7 mm) observed in the existing surface layer (1995 application) on the middle and lower batters have been superimposed on the survey plan in Figure 10. The age of the cracks probably varies, the presence of vegetation being the main indicator. It is considered that some of the cracks have formed or worsened since the initial FSW inspection. This is supported by fresh spalling along cracks and previously unobserved differential movements across cracks. The most recent monitoring information from tell-tale installations (April 1999) indicates movement of 1 mm or less since installation (January 1999).

Subsequent probing of the toe drains for each batter indicated that nearly all of these contain a sandy material and the probe only penetrated 100 mm to 200 mm. As the length of drains shown on the as-constructed drawings is 750 mm, blockage over a significant length is suggested.

Probing of selected weepholes on the slope face indicated penetrations of 50 mm to 100 mm. Sandy material was again encountered, though a 'hard' refusal of the probe occurred. It is therefore suggested that the weepholes may terminate at the older surfacing beneath the 1995/1998 applications (and not penetrate through to the fill beneath). As-constructed drawings do not indicate weepholes in the original surface cover.

The condition of the slope surfacing may be summarised as follows:

(a) Certain areas of the upper batter have a number of layers of hard surfacing, while other areas have only the present (1998) layer of shotcrete.

(b) The middle batter has received only two layers of hard surfacing comprising the 1995 application of shotcrete (uppermost) and another cement-based layer.

(c) PVC stub drains along the toe of the upper and middle batters and at the toe of the slope are apparently blocked or damaged.

(d) Some of the weepholes may only penetrate as far as an older slope surfacing present beneath the 1995 or 1998 application.

(e) Significant movement has occurred on the upper and middle batters as indicated by cracking in the older layers of hard surfacing which remain on the slope. The occurrence of movement prior to observing the most recent distress in April 1998 is evidenced by the presence of organic infill in the cracks. The more severe areas of cracking on the upper batter are accompanied by formation of voiding and tension cracking in the fill beneath. No indication of water infiltration/erosion between the surface cover and the fill is apparent.

(f) Significant movement has occurred in the stone pitching at the toe of the upper and middle batters (most pronounced on the upper batter), producing a convex shape in cross-section and resulting in separation of the shotcrete surfacing from the stone pitching. The occurrence of past movement prior to the most recent observation of distress is evidenced by the break in slope angle in the slope face for the individual batters.

(g) Further movement at the slope surface on the middle and lower batters during the study period has been observed, based on the apparent formation or worsening of cracks in the existing hard surfacing.

The occurrence of movement in the slope prior to the most recent distress is further confirmed by pre-1998 record photographs, presented in Plates 11 to 21.

5.4.2 Ground Conditions

The ground profile within the comprises two layers of fill separated by a layer of medium-grained gravel, overlying an insitu weathering profile of granitic bedrock.

Beyond the toe of the slope, the ground profile comprises a layer of fill, the lower boundary of which dips away rapidly from the toe to depths in excess of 16 m. This overlies insitu weathered granite which, according to one drillhole, is separated from the fill by a thin layer of colluvium. Two drillholes at the western extent of the slope indicate an isolated intrusion of basalt within the granite. The weathering profile of the granitic bedrock varies rapidly, with the thickness of completely weathered material ranging from 2 m to 11 m over a distance of 15 m from the slope toe.

A geological profile is presented in Figure 13. The upper fill layer encountered was the compacted fill layer, and the gravel layer the filter/drainage blanket. The lower zone of fill was probably placed during the original site formation in the 1960's.

A 'boulder' was encountered in drillhole DH1 at approximately the interface of the filter layer and the pre-1977 fill. It is thought that this may comprise part of the stone-pitched facing noted previously as being applied in 1968 (Section 3.2). This would correspond with photographic evidence, which implies that this old stone pitching was not removed prior to the placement of fill (Plate 9). However, boulders have also been recorded in two trial pits excavated in February 1991 (Bachy Soletanche, 1991), one of which terminates within the upper zone of fill and it is therefore possible that both fill strata contain oversized material.

The upper fill layer was about 4 m thick. This comprises a relatively uniform completely decomposed granite fill of predominantly sand-sized particles based on visual classification and PSD results from the current investigation. SPT N values range from 7 to 23, with an average value of 19 (from 9 results). GCO Probe results for this material vary from 2 to 48 blows per 100 mm. The average blow count per test ranges between 10 and 20, with the recent tests giving results at the lower end of the range. Tests carried out at the location of the current trial pits show the blow counts are initially low (2 to 3 blows per 100 mm) and increase gradually with depth, whereas many of the previous test results show a higher initial blow count (>10 blows per 100 mm), which is maintained, or increases, with depth. Insitu density tests carried out during the current ground investigation show relative compaction values of 83%, 90%, 93% and three at 98% (i.e. three results less than 95%). The fill has typically been described on investigation logs as being loose to medium dense. Whether the lower than specification results reflect the workmanship employed in the placement and compaction of the fill layer or are the result of post-construction influence, such as ground movement or washing out of fines by seepage, cannot be assessed given the available information.

Borehole permeability test results in the upper fill indicate a mass permeability value in the order of 10^{-7} m/s. This shows general agreement with published values (GEO, 1993) ranging from 10^{-6} to 10^{-7} m/s for a completely decomposed granite fill.

The older underlying fill deposit encountered was between 3 m and 11.8 m thick near the crest (increasing to 18.8 m to the west, in the valley area), between 2.5 m and 6 m thick at the intermediate berms and between 1.8 m and 4 m thick at the toe. It was similar in composition to the upper fill, except that limited laboratory test results indicate a lower fines content than in the upper fill. SPT N values range from 4 to 15 with an average value of 8 (from 23 results). GCO Probe results vary from 4 to 32 blows per 100mm, with an average of 10 blows per 100mm. It is noted that the boundary between the upper and lower fill layers was difficult to establish for many of the probe records. Generally, the results indicate that the pre-1977 fill layer is in a loose to medium dense state, which is consistent with the descriptions given on the investigation logs. Insitu density test results in this material, carried out by Binnie & Partners (1979), indicate dry density values in the range of 1.35 t/m^3 to 1.61 t/m^3. Details of any laboratory compaction testing could not be located.

Borehole permeability test results from the recent investigations in the pre-1977 fill indicate a mass permeability value in the order of 10^{-6} to 10^{-7} m/s. It is noted that past test results have varied considerably for this material, with permeability in the order of 10^{-4} m/s from a test carried out at the slope crest (Binnie & Partners, 1979). At the same time, permeability tests were "unsuccessful" at a location mid-slope because "the rate of water loss very slow". Conversely, tests undertaken in 1991, in piezometers installed along the eastern edge of the feature, indicate that the flow is too high to be measured. Overall, this highlights the potential variability of the pre-1977 fill, the possibility of preferential flow paths and the possible effects of layering resulting from end tipping.

The decomposed granite beneath the fill comprises an upper zone of predominantly Grade V medium-grained granite, described as a silty sand with fine to medium gravel. SPT N values range from 7 to over 200, with averages (excluding refusals) of 32 at the crest, 36 mid-slope and 70 at the toe.

Borehole permeability test results from investigations in 1991 and 1998 indicate a mass permeability value in the order of 10^{-6} to 10^{-7} m/s in the completely decomposed granite (CDG).

Pinhole dispersion testing (BSI, 1990) on samples of the upper fill, lower fill and CDG all proved inconclusive in determining the dispersability of fines. This was due to repeated collapse of the 1 mm diameter hole formed in the samples and zero flow through the samples being recorded as a result.

The results of chloride ion content determinations (PWCL, 1998b) shown in Table 1 indicate essentially background levels of contamination in the upper fill layer and upper portion of the lower fill. Trace levels only were indicated near the base of the lower fill (2 results) immediately above the fill/natural interface and high levels (1 result) indicating saline soil moisture within the upper 0.5 m of the insitu profile.

Little information is available on the condition of the filter drainage blanket. That the majority of toe drains have been blocked suggests the possibility of washing in of fines. It is

further noted that records from the current investigation indicate the gravel filter layer to be within a 2 m thick sand fill deposit with much fine to coarse gravel, suggesting also the potential contamination of the filter with fine material during construction.

5.4.3 Groundwater

Groundwater monitoring from 22 September 1998 to 5 February 1999 has only recorded a water table at the crest and toe of the slope, with installations located on the slope remaining 'dry' throughout (Figure 9). The installation at the crest of the slope (S149-SA) comprised a piezometer tip located within slightly decomposed granite (SDG), 15 m below the insitu horizon, and a standpipe extending, essentially, the full depth of the fill (11.7 m). The installation at the toe (S149-fd) comprised a piezometer tip located in CDG, 4.7 m below the insitu horizon. Installations on the slope face comprised three standpipes extending to a depth of 1.5 m (TP1, TP2 and TP3 of the current investigation) in the 1977 fill and two piezometer tips (DH1 of the current investigation), one at the base of the filter layer and one 1 m above the base of the pre-1977 fill layer. Locations of the installations are shown on Figure 8. The groundwater levels at the crest and toe have remained essentially constant during the monitoring period (approximately 32 mPD and 10.5 mPD, respectively). These elevations are around 6.5 m below (crest) and 1 m above (toe) the insitu horizon respectively. A postulated phreatic surface corresponding to the 1998 dry season, based on the current data, is indicated on Figure 13.

Comparison with historical records (Binnie & Partners, 1979 & Bachy Soletanche Group, 1991) only permits assessment of groundwater levels at the crest and upper berm (piezometer SM15 located at the slope toe was destroyed during the 1977 slope works). The installations at the crest of the slope (DH-1, HSM9 and SM14) each comprised two piezometers. One piezometer tip was located at the interface between the pre-1977 fill and the insitu material (DH-1), at a depth of 3 m. Of the remaining piezometer tips, three were located within CDG, 5.56 m, 11.5 m and 12.65 m below the insitu horizon (HSM9, DH-1 & SM14 respectively), and two were located within SDG, 10.44 m and 23.7 m below the insitu horizon (HSM9 & SM14, respectively). There is no indication in the available information of any of these installations having been filled with bucket strings. The installation on the upper berm (DH-2) comprised two piezometer tips located within CDG, 0.5 m and 12.28 m below the insitu horizon. Available results from mid-1977 to mid-1979 (Binnie & Partners, 1979) and February 1991 (Bachy Soletanche Group, 1991) show reasonable agreement with the present data. These indicate a base groundwater table located at between 30 mPD (piezometer HSM9) and 36 mPD (piezometer SM14) at the crest (with DH-1 shown to be dry at time of reading) and 26.5 mPD at the upper berm (DH-2). An apparent lack of storm response is noted. However, the possibility of short duration transient responses to particular rainstorm events cannot be discounted.

It is noted that two of the historical piezometers (SM14 and SM15) (Binnie & Partners, 1979) are located approximately along the line of the buried valley beneath the south-eastern portion of the slope. The available data for SM14 (SM15 destroyed, as noted above) indicates base groundwater level below the fill/natural ground interface.

There is no indication of perched water within the different fill layers, or along the fill/natural material interface, from the available information.

5.4.4 Ground Movement

An assessment of ground movement in slope No. 11NE-D/F10 has been made on the basis of the as-constructed survey levels, topographical survey data from the current study and data obtained from the monitoring of settlement markers and tell-tales during the study period.

The data from the recent topographic survey has been compared to as-constructed levels following the 1977 slope works (Binnie & Partners, 1980), see Figure 10.

Comparison of the two sets of data indicates poor correlation in terms of progression from the as-constructed condition to the present. Only about a third of the spot levels indicate settlement, while the remainder indicate a rise in ground elevation of up to 0.4 m to 0.6 m, with no particular trend in relation to location on the slope observed. The accuracy of the as-constructed levels may be open to question and no definite conclusion may be drawn regarding the cumulative ground movements.

Although no data has been located for the area extending behind the crest of the slope, an attempt has been made to estimate the magnitude of settlement which has visibly occurred within this area. Comparison of a straight line interpolation between spot levels at each end of the feature and the profile indicated by intermediate survey data points suggests a maximum out-of-plane settlement of approximately 200 mm along the crest and 150 mm within the USD Rest Garden adjacent to the parapet wall. It is noted that the parapet wall is located along the approximate boundary between the pre-1977 and 1977 fills. Out-of-plane settlement is not significant along the near-side kerb of Hiu Kwong Street. However, there appears to be a local sag of about 80 mm along the Hiu Kwong Street centreline.

Horizontal movement measurements of the present survey markers are erratic. While some markers indicate a certain bias along a particular axis (usually along a berm), the magnitude of movement is generally within the degree of accuracy of the survey method (prism on staff).

The plots of vertical movement presented in Figures 11 and 12 also indicate a degree of erratic behaviour on an individual station basis, although some consistency can be observed when comparing groups of plots from the same elevation to suggest a common levelling error, and general trends in the plots can be postulated.

Markers at the crest of the slope display a general trend of settlement with time, typically 2 mm to 4 mm (allowing for reinstatement of three markers), and a maximum of approximately 8 mm. Current magnitudes of movement were generally achieved by early November 1998 and have remained essentially constant since. No lateral trend along the slope crest (i.e. hog or sag) is indicated.

Markers on the upper berm display a similar trend to those along the crest with settlements of 5 mm to 9 mm. The current magnitudes were generally achieved by early November 1998, though some markers continued to settle beyond this date. A sag near the centre of the slope is indicated.

The monitoring plots for the lower berm indicate no consistent trend. In general the settlements are of the order of 0 to 3 mm, these being achieved early in the monitoring period and that an upward movement of 1 mm to 2 mm was indicated in early October, followed settlement of a similar magnitude in late November. No lateral trend along the berm (i.e. hog or sag) is indicated.

Markers at the slope toe indicate a slight upward movement of the order of 0 to 2 mm. Early data shows a high, though consistent, level of erratic behaviour becoming more uniform from mid-October when the current magnitudes of movement were achieved. Again, no trend in lateral movement is indicated.

Monitoring information for tell-tale installations indicates continuation of the trend of minor movements over the period January 1999 to April 1999, recording movements across selected cracks of 1 mm or less.

To summarise, the slope has experienced detectable settlement during the 6 month monitoring period to date of less than 10 mm and generally less than 5 mm. The upper berm has recorded the highest level of settlement ranging from 5 mm to 9 mm, with a sag towards the centre of the slope. A small heave of approximately 2 mm has been recorded along the slope toe. Vertical movements have generally tended to stabilise with time from late October to early November. No discernible trend for horizontal movement is indicated.

6. ANALYSIS OF RAINFALL RECORDS

The GEO automatic raingauge closest to the concerned slope is No. K03, which is located at the PMG Radio Monitoring Station off Hong Ning Road, about 400 m to the west of the slope. The raingauge records and transmits rainfall data at 5-minute intervals via a telephone line to the GEO.

Daily rainfall in the period from approximately one month preceding the initial observation of seepage (taken to be 1 February 1998), to the time the seepage was reported to HyD (7 April 1998), is presented in Figure 14.

Rainfall recorded during this period (approximately 3 months) is relatively low. There were two events with a 24-hour rainfall exceeding 50mm, i.e. 14 January 1998 and 17 February 1998, when 51 mm and 66 mm of rainfall were recorded, respectively.

Given that there appears to be no direct links between the timing of seepages and distress on the slope and the preceding rainstorms, only an approximate indication of the return period for the above storms has been assessed, as opposed to detailed rainfall analyses.

Charts based on historical data at the Hong Kong Observatory (Lam & Leung, 1994), which present estimated return period as a function of rainfall depth and duration, indicate that a rainfall of less than 10 mm for any single duration exceeding 5 minutes implies a return period of less than 2 years. A further check confirmed that all 5-minute readings were less than 10 mm.

Given that filling of the natural valleys was carried out in the vicinity of the concerned slope, and extends some distance to the north (extent of fill indicated in Figure 2), it is considered useful to compare rainfall data from the upper reaches of these valleys with that recorded in closer proximity to the site. This has been done in order to assess, in broad terms, the potential for more remote rainfall to influence conditions within the study area.

Daily rainfall data from GEO automatic raingauge No. K04, located in the Shun Lee Estate in the Clearwater Bay area, has been plotted against data from raingauge No. K03 in Figure 14. It can be seen that the rainfall records of raingauge Nos. K03 and K04 are comparable.

The analysis of rainfall records indicates that no significant rainstorms had occurred in the immediate vicinity of the concerned slope when the seepage and distress were reported.

7. SOURCES OF WATER

The sources of transient water flow considered to have potential to impact on slope No. 11NE-D/F10 are as follows:

(a) leakage from water supply mains (fresh and saltwater),

(b) leakage from stormwater drains,

(c) leakage from foul water sewer,

(d) surface runoff,

(e) rise in groundwater table, and

(f) subsurface seepage from upslope areas.

The leak identified in the 400 mm diameter saltwater supply main (Section 4.3) constitutes the most likely source of transient water flow to have influenced the recent distress. Results of tests by WSD confirm that the seepage issuing from the slope toe originated from the leaking main. Additionally, limited chemical testing of soil samples has indicated saline conditions near the fill/natural ground interface.

It is recognised that information on chloride ion concentration was obtained from a single location and that results may not be indicative of other locations on the slope. However, the information available suggests that, at least at the drillhole location, the flow of saltwater leakage from the main appears to have reached the base of the fill, and apparently did not contaminate the upper fill layer placed during the 1977 reconstruction of the slope. The leakage therefore may not necessarily have had a direct influence on the recent distress, although the possible reduced efficiency of the drainage layer due to blockages of the stub drains may have an adverse effect on the 1977 fill.

The upper batter of slope No. 11NE-D/F10 has reportedly been affected by transient groundwater flows from leaking supply mains (Section 3.2).

Stormwater and foulwater drainage may be considered together as potential sources, both being gravity fed water-carrying services. As previously mentioned, checks were carried out in April and May 1998, which confirmed the general integrity of the drains and absence of gross leakage from in the vicinity of the study area. However, these checks do not preclude occurrence of leakage from these services on previous occasions.

Direct surface runoff and direct infiltration are considered unlikely to have contributed greatly to the recent distress as the slope face and the area behind the crest, including Hiu Kwong Street, have been provided with both an impermeable surfacing and surface drainage system.

Transient seasonal responses in the groundwater table have also been considered. From the phreatic surface indicated in Figure 13, it can be seen that a rise of approximately 10 m to 12 m would be needed for the measured groundwater table to directly influence the 1977 fill comprising the upper batter of the slope. There is no evidence, from current and past monitoring, of significant transient rises in the base groundwater table.

Remote sources of significant transient water flow are unlikely due to the presence of the retaining structure located adjacent to the northern footpath of Hiu Kwong Street (Figure 1), which would likely act as a "cut-off". North-west of the wall, the original ground contours (Figure 4) indicate a buried valley feature, which should direct seepage away from the concerned slope towards the north-west.

In summary, it is considered that leakage from water-carrying services below Hiu Kwong Street are the likely source of transient groundwater flows to have influenced the condition of the slope.

8. PROBABLE CAUSES OF DISTRESS

8.1 Seepage at the Slope Toe

The seepage at the slope toe has been positively related to the leakage from the 400 mm diameter saltwater supply main located below Hiu Kwong Street. In support of this diagnosis are the following:

(a) chloride ion content testing of the seepage by WSD,

(b) chloride ion content testing of soil samples as part of this study,

(c) reduction and eventual cessation of seepage following repair of the leaking saltwater main,

(d) absence of significant rainstorms in the three month period prior to reporting of seepage,

(e) absence of leakage detected elsewhere in other pressure mains, and

(f) the general integrity of stormwater and foulwater sewer reported by DSD, based on CCTV survey, and negative results from dye tests performed on these mains.

8.2 Slope Distress

Distress has been observed in slope No. 11NE-D/F10 both in the area behind the slope crest and on the slope face, most noticeably on the upper batter. The available records indicate that problems with the slope have occurred since as early as 1985. There is evidence of recurrent repair to the upper batter in the form of multi-layering of shotcrete cover, which reflects problems with the slope. The slope has therefore been subject to deterioration and the distress has not occurred solely as a result of the most recent incidence of prolonged leakage from the saltwater main, with intermittent movements having probably taken place over a number of years.

Relatively minor slope movements have continued to be detected during the study period, though these have tended to stabilise with time. The likelihood of continuation of this trend is unknown at present.

The earliest indication of problems in the slope occurred in the year following the failure of 1984 due to the leaking main. This circumstantial evidence may suggest that the fill could have been affected to a larger extent than the area remediated by the removal and replacement of fill, or that leakage from defective drains may have taken place again.

The distress observed behind the slope crest in the form of differential movements and cracking in a concrete parapet wall, a sag and cracking in the paved area (USD "Rest Garden", Hiu Kwong Street carriageway and footpath), and deformation in the steel hand railing, is likely to be due to subsidence resulting from movement in the fill body forming the road embankment and slope.

A number of possible causes of the ground movements may be postulated, as follows:

(a) presence of disturbed material in the compacted cap,

(b) wetting up of the pre-1977 fill,

(c) shear deformation in the fill body.

The first postulated cause involves the presence of loose material locally within the compacted cap – the lowest insitu density measurement in the current investigation corresponds to a relative compaction of 83%. Such loose material may be a result of the 1984 failure. Alternatively, the construction method, involving the placement of the compacted cap directly on the prevailing ground profile without excavation, may have been a contributory factor. With this method, it may be possible that the portion of the compacted cap already constructed could be disturbed by further placement of fill inducing settlement of the underlying loose fill.

The second postulated cause involves the wetting up and settlement of the pre-1977 fill. The 1984 leakage incident could have contributed to wet up the underlying loose fill. Limited chemical analyses during the current investigation suggest that leakage from the saltwater main could have reached the base of the pre-1977 fill. Therefore, subsurface seepage arising from leaking water-carrying services may have contributed to ground movement by wetting up the loose fill that underlies the compacted cap.

The final postulated cause is possible deep-seated shear deformation of the loose fill body associated with the progressive development of instability. This could be exacerbated by the presence of locally weak zones or development of localised elevated water pressures along the likely layering in the end-tipped fill. There is currently insufficient information to assess the relative contribution of this mechanism to the observed distress at ground surface.

There is also inadequate information to assess whether the efficiency of the drainage blanket could have been impaired by "washing in" of fines, contamination with fine material during construction, or blockage of the stub drains. This could be a contributory factor to the ground movements by preventing effective drainage of the slope.

Continued distress of the slope is also evidenced by organic infill present in previous cracking to the pre-1995 hard surfacing which suggests sporadic movements as a result of ephemeral triggers, as opposed to a continual movement. Cracking and voids in the 1977 fill were also observed at one location below previous distress on the slope surfacing.

That the distress has manifested itself more severely on the upper batter compared to the lower two batters could be a result of disturbance of the compacted cap by the 1984 water main leakage incident and possibly exacerbated by the increased total thickness, and hence weight, of slope surfacing present on the former (up to six layers of hard surfacing locally), and lesser depth of the pre-1977 fill towards the slope toe.

9. DISCUSSION

The potential instability of the distressed slope poses a hazard to the school buildings of Lui Kwok Pat Fung College and Kwun Tong Maryknoll College below the slope and road traffic on Hiu Kwong Street at the slope crest. The hazard is exacerbated by a number of significant and old water-carrying services (with no provisions for ducting) located within, and underlain by, significant depths of fill material forming the slope, which are the most likely source of water ingress into the slope.

The history of the slope formation involves loose fill end-tipped into a buried valley which failed in 1976. Slope stabilisation works consisted of placement of compacted fill over the existing slope without significant excavation. Any partially developed failure surfaces formed during the 1976 failure could therefore still be present within the slope.

To date the slope has behaved in a relatively ductile manner (i.e. progressive development of signs of distress and ground movement). However, from the limited information presently available, it is not possible to be definitive as to whether the signs of distress represent surface expression of an essentially settlement-related mechanism or the

progressive development of a deeper-seated instability. Continued deterioration is liable to result in shallow failure of the compacted cap.

The liquefaction potential of the pre-1977 fill in the event of significant water ingress associated with gross leakage or bursting of water-carrying services is uncertain. Should this take place, the failure could be brittle (i.e. sudden detachment of material in an uncontrolled and 'fast-moving' manner) and mobile.

The unknowns associated with the sub-surface conditions of the distressed slope are considered sufficient to render the assessment of the stability of the slope by conventional analytical methods to be of limited value and potentially misleading. Consequently, stability assessments have not been attempted for the present landslide study.

Whilst there are no positive indications of immediate danger, the need for detailed assessment of the short and long-term stability of the fill slope through detailed investigation is emphasized, taking due account of the performance history of the slope and the possible effect of the water-carrying services.

10. CONCLUSIONS

Significant distress has been noted in slope No. 11NE-D/F10 located below Hiu Kwong Street at Sau Mau Ping in April 1998 following a report of heavy seepage issuing from the toe of the feature, which had continued since February 1998. The distress has included cracking and deformation of the shotcrete surfacing, predominantly in the upper batter of the slope and subsidence at the crest of the slope.

The source of the prolonged seepage has been determined to be leakage from a 400 mm diameter pressurised saltwater main located along the northern side of the Hiu Kwong Street carriageway.

The concerned slope was previously upgraded by the construction of a compacted fill overlay in 1977. The present study has established that the fill slope has undergone movement over a number of years to produce the subsidence and associated distress at the slope crest and the slope face. Distress on the upper batter of the slope has been more extensive than the lower two batters, probably because of the greater thickness of hard surfacing present in this location (locally with up to 6 layers of surfacing observed in trial pits) and the magnitude of ground movements experienced in this area.

A major failure of the slope occurred in 1984, reportedly as a result of leakage from a water main. Since then, the slope apparently started to suffer from distress and deteriorate. This suggests that the material within the slope could have been disturbed to a greater extent than that covered by the subsequent remedial works.

The integrity of the surface compacted cap appears to have been adversely affected with the presence of locally loose pockets, infilled tension cracks, voids, etc. The distressed slope is vulnerable to leakage from water-carrying services.

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Table 1 – Results of Water Soluble Chloride Ion ($C1^-$) Concentration Determination

Location	Depth (m)	Material	Moisture Content (%)	Measured Chloride Ion Content[1] (%)	Chloride Ion Content for Saline Soil Moisture[2] (%)	Remarks
TP1	0.50	1977 Fill	15.3	< 0.01	0.22 to 0.29	
TP1	1.50	1977 Fill	12.3	< 0.01	0.17 to 0.23	
TP2	0.50	1977 Fill	15.9	< 0.01	0.23 to 0.30	
TP2	1.50	1977 Fill	16.0	< 0.01	0.23 to 0.30	
TP3	0.50	1977 Fill	17.7	< 0.01	0.25 to 0.33	
TP3	1.50	1977 Fill	15.9	< 0.01	0.23 to 0.30	
DH1	3.00 to 3.45	1977 Fill	19.0	< 0.01	0.27 to 0.36	1.55 m to 2.0 m above base of stratum
DH1	5.00 to 5.95	Pre-1977 Fill	17.0	< 0.01	0.24 to 0.32	0.00 m to 0.45 m below top of stratum
DH1	6.50 to 6.95	Pre-1977 Fill	14.0	< 0.01	0.20 to 0.26	1.00 m to 1.45 m below top of stratum
DH1	7.50 to 7.95	Pre-1977 Fill	20.0	< 0.01	0.28 to 0.38	Approximately centre of stratum
DH1	8.50 to 8.95	Pre-1977 Fill	22.0	0.01	0.31 to 0.42	1.05 m to 1.50 m above base of stratum
DH1	9.00 to 9.45	Pre-1977 Fill	22.0	0.05	0.31 to 0.42	0.55 m to 1.0 m above base of stratum
DH1	10.00 to 10.45	CDG	12.0	0.14	0.17 to 0.23	0.00 m to 0.45 m below top of stratum

Notes:

1. Water Soluble Chloride Content measured as % dry mass of soil sample to BS1377 : Part 3 : 1990, Test 7.
2. Based on quoted range of chloride ion content of saltwater supply at Cha Kwo Ling Saltwater Pumping Station, April 1997 to March 1998, of 14 200 mg/1 to 18 900 mg/1 (WSD, 1998).

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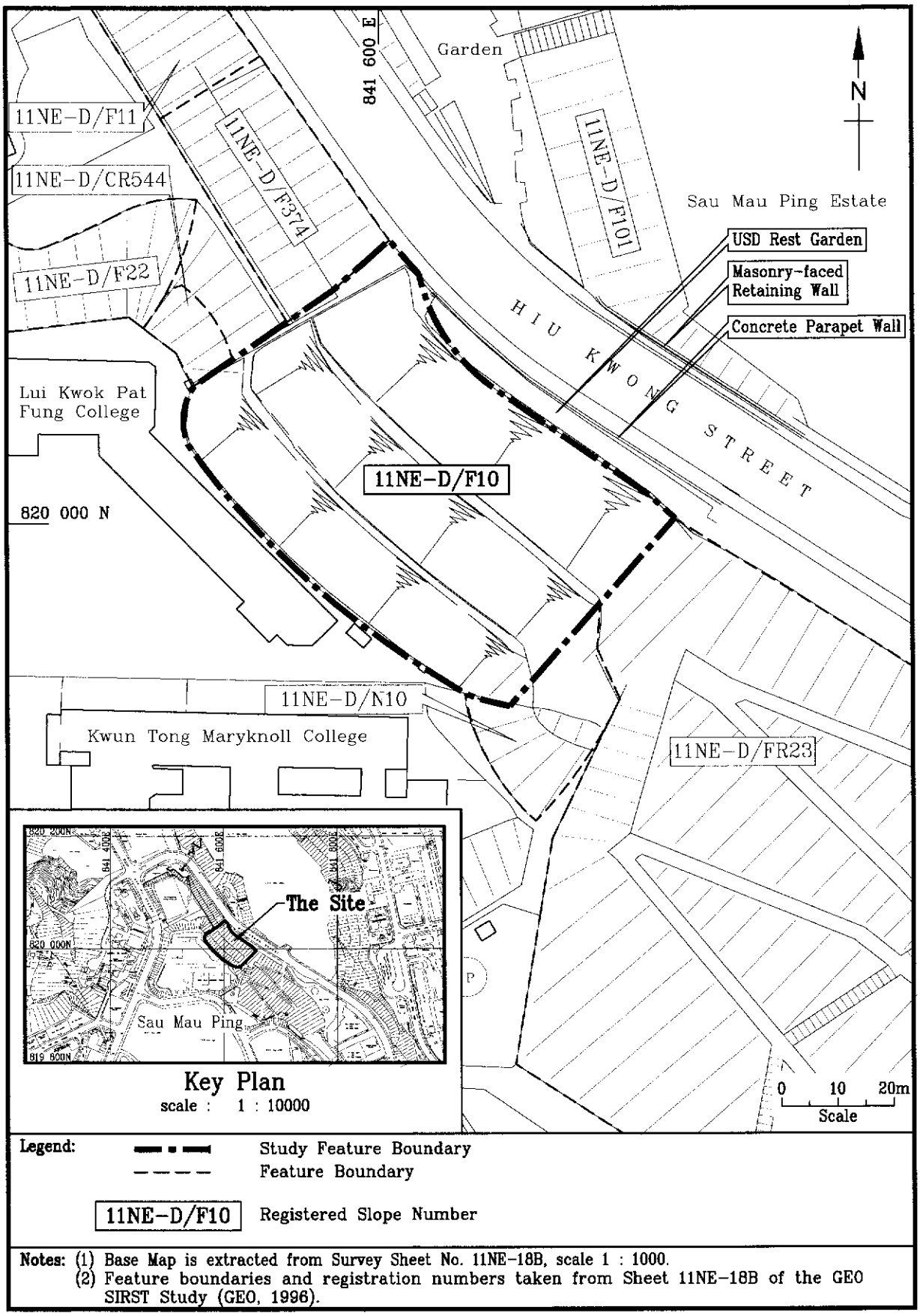
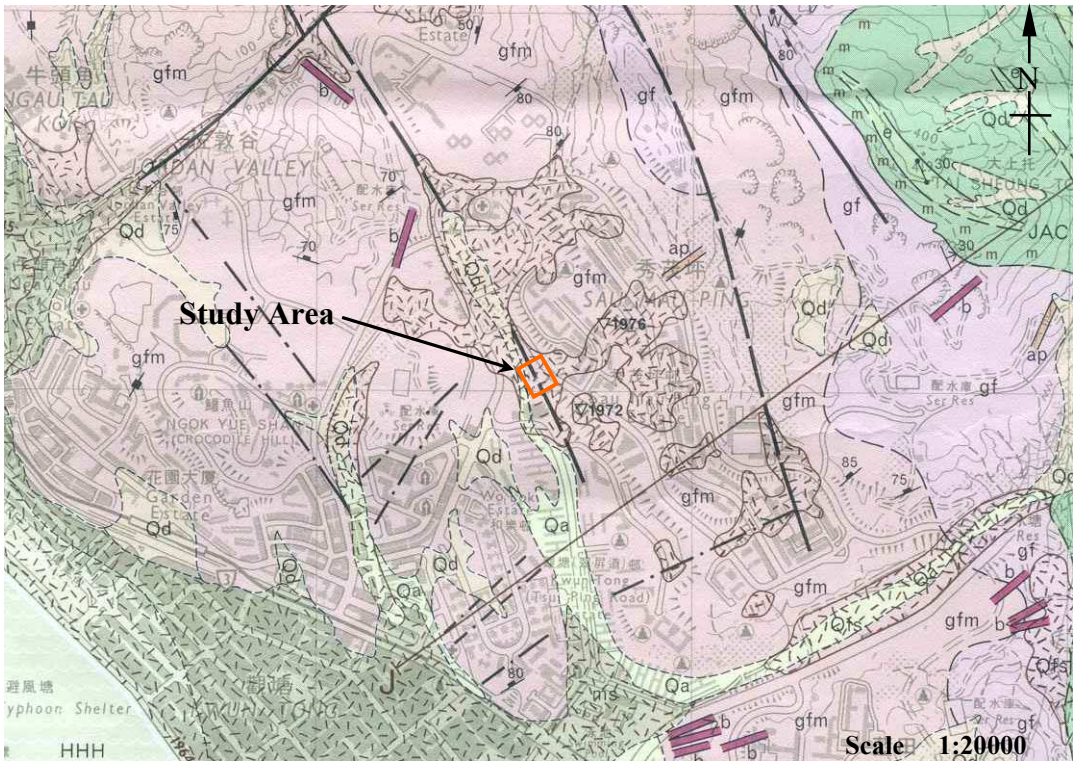


Figure 1 - Site Location Plan



Legend :

Quaternary Superficial Deposits (Onshore)

Qfs	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
e	Eutaxite
gf	Fine-grained granite
gfm	Fine- to medium-grained granite
b	Basalt
m m m	Hornfels

Quaternary Superficial Deposits (Offshore)

HHH	Undivided, mainly dark grey marine mud
ms	Marine sand, partly silty

Geological Lines

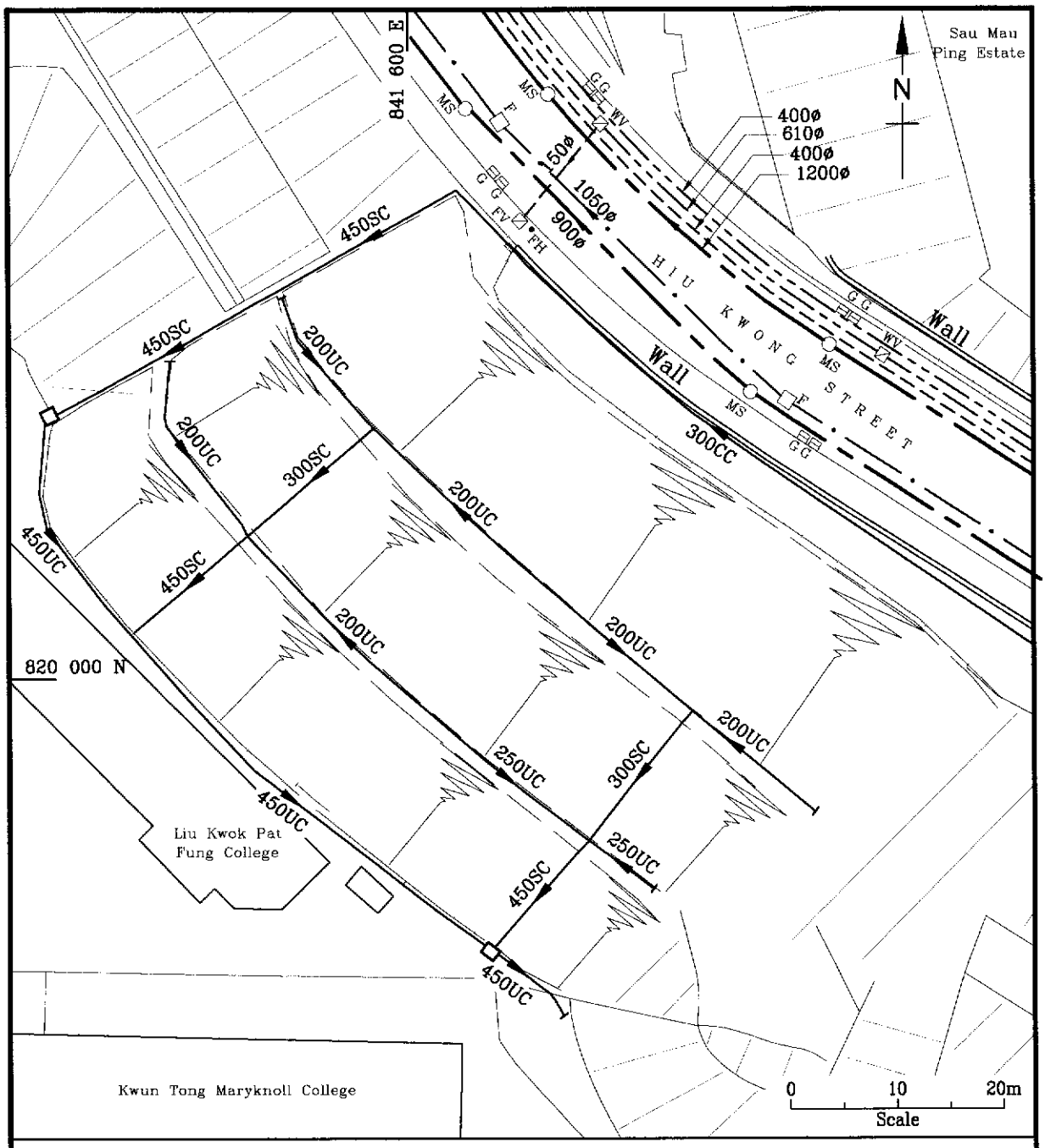
----------	Geological boundary, superficial deposits
_____ _ _ _ *	Geological boundary, solid rock (* Broken lines denote uncertainty)
——— ——— *	Faults (crossmark indicates downthrow side)
— · — · —	Photogeological lineament
*	Broken lines denote uncertainty

Other Symbol

▽ 1976	Important slope failure, with date

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

Figure 2 – Solid and Superficial Geology of the Study Area



Legend:

400ø	Freshwater Main and size (mm)
400ø	Saltwater Main and size (mm)
1050ø	Foulwater Main and size (mm)
1200ø	Stormwater Drain and size (mm)
300UC	Surface Drain and size (mm)

Symbols:

F	Foulwater Manhole
MS	Stormwater Manhole
FV	Fire Valve
WV	Water Valve
G	Gully / Grating
	Catchpit
UC	U-channel
SC	Stepped U-channel
CC	Covered U-channel
FH	Fire Hydrant

Notes: (1) Base Map is extracted from Survey Sheet No. 11NE-16B, scale 1 : 1000.
(2) Information is based on Water Services Department and Drainage Services Department utility plans.
(3) The alignments of water-carrying services are indicative only.

Figure 3 - Existing Water-carrying Services

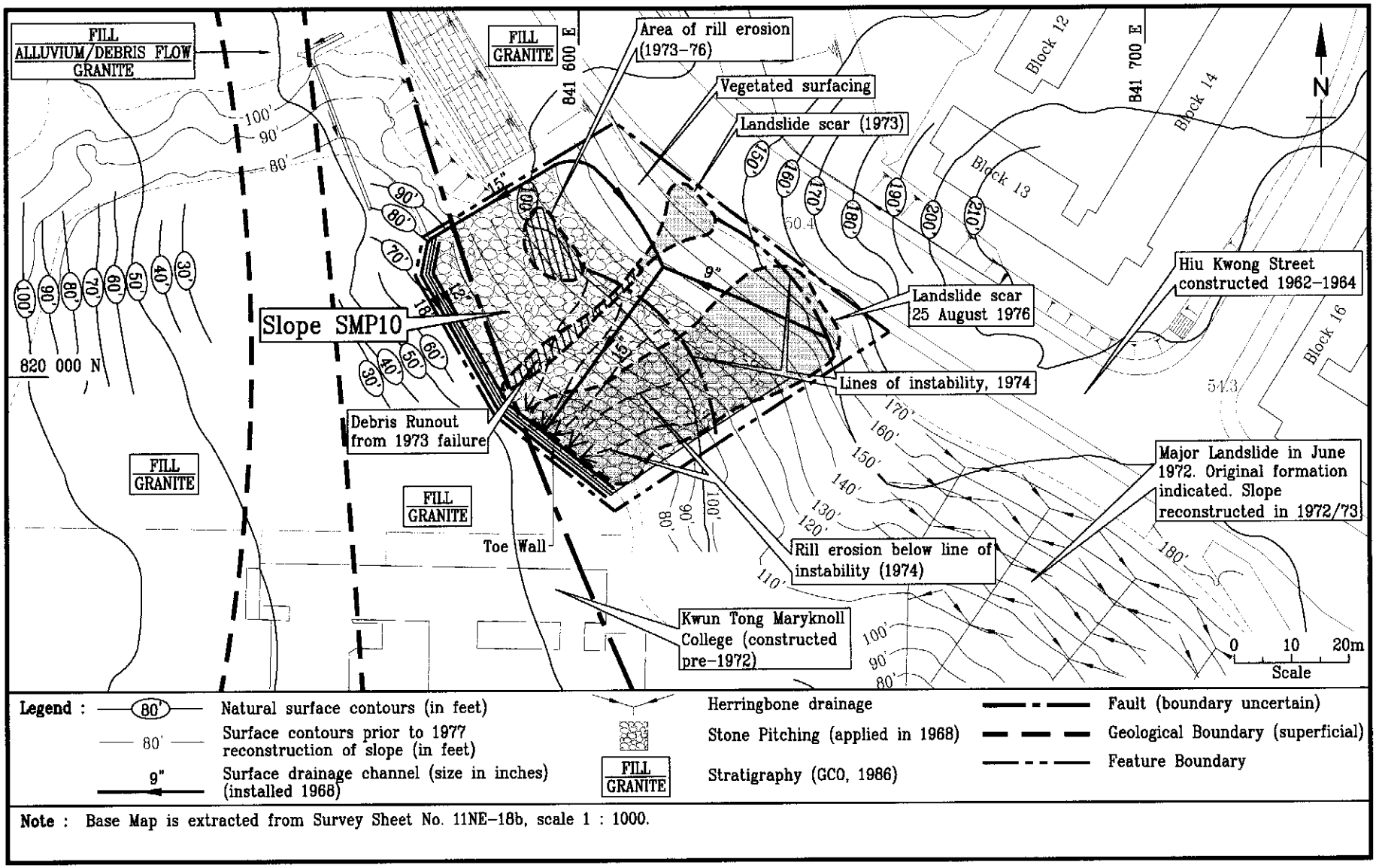


Figure 4 - Slope Formation Prior to 1977 Re-construction

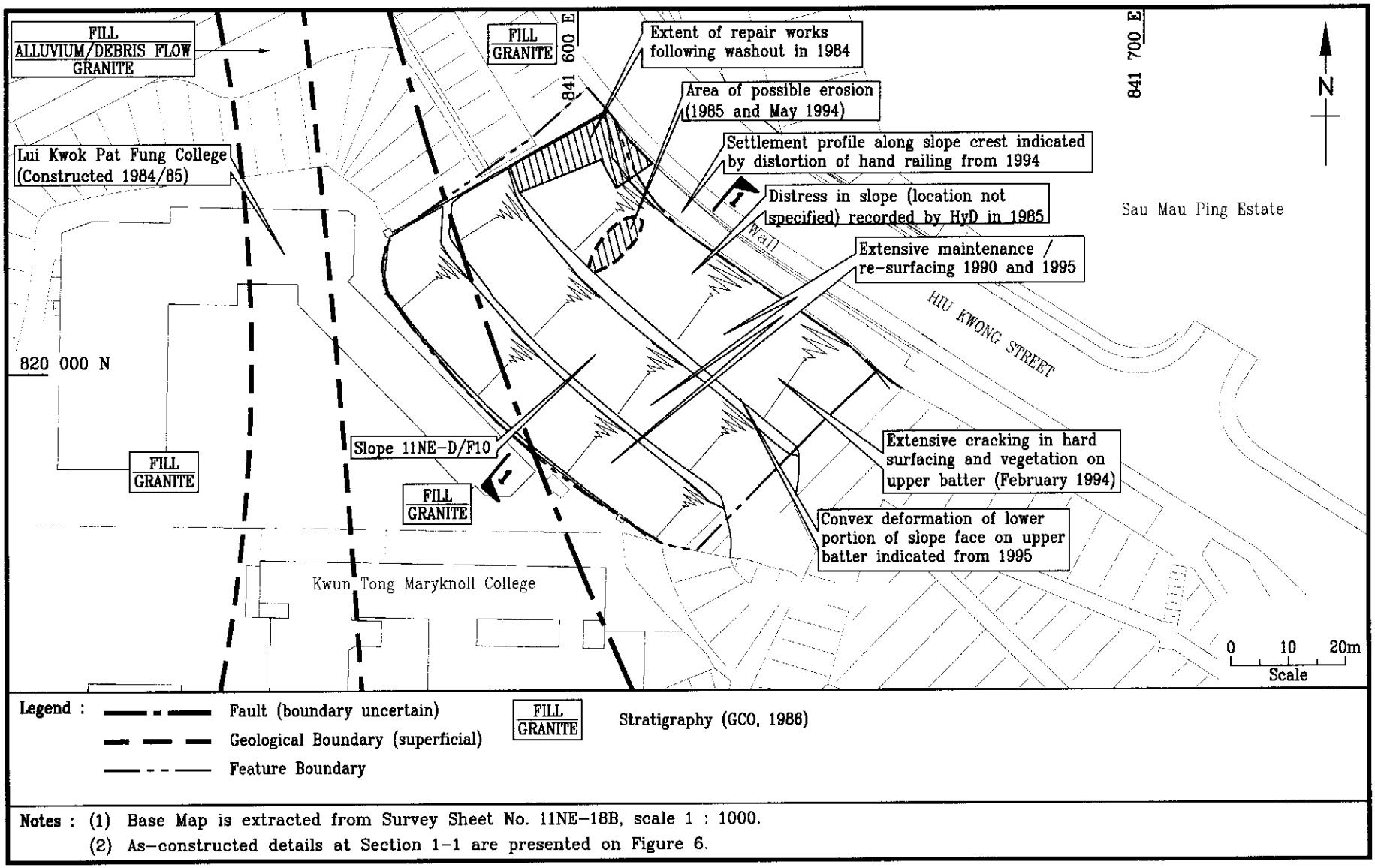
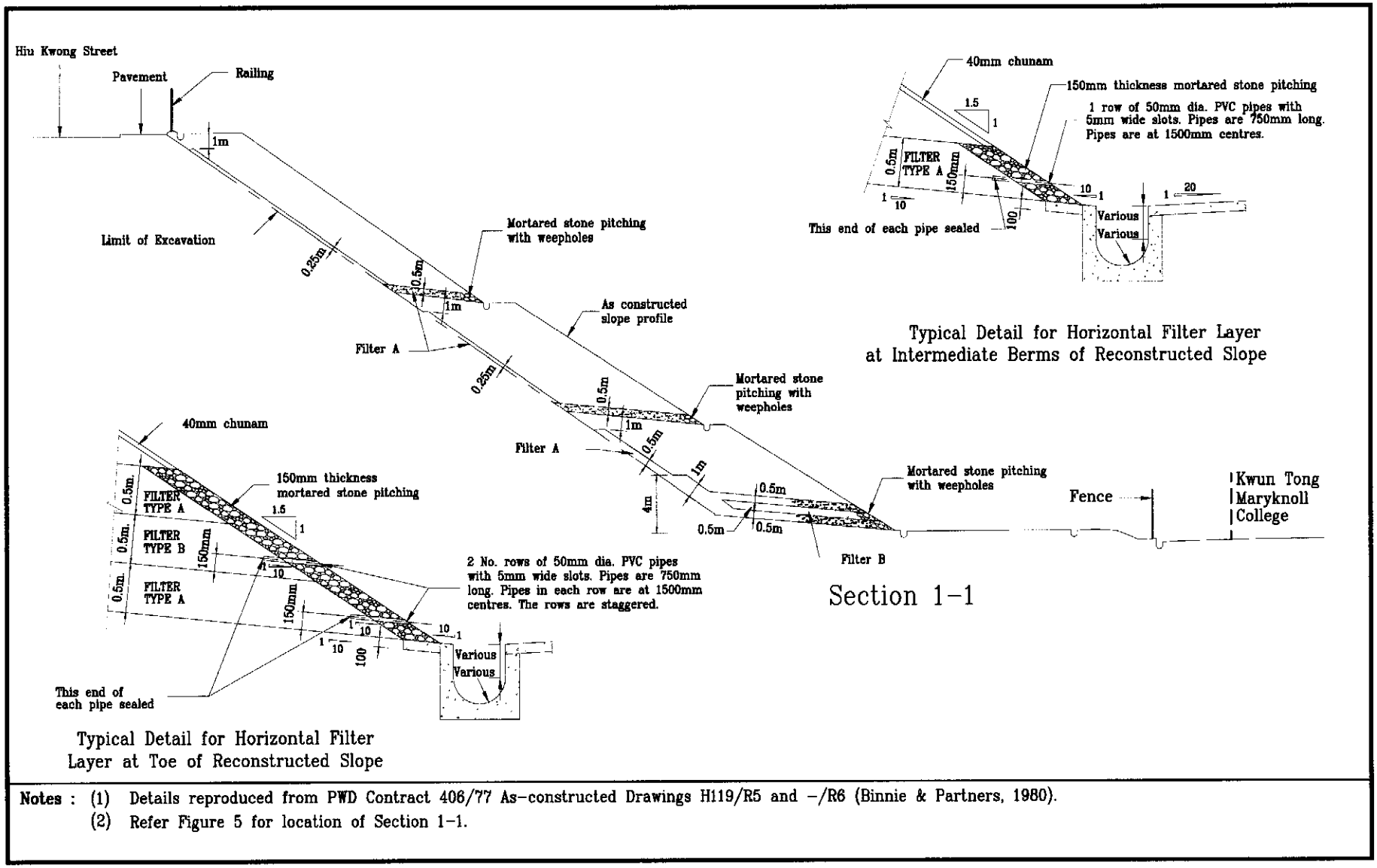


Figure 5 - Slope Formation Following 1977 Re-construction



Notes : (1) Details reproduced from PWD Contract 406/77 As-constructed Drawings H119/R5 and -/R6 (Binnie & Partners, 1980).
(2) Refer Figure 5 for location of Section 1-1.

Figure 6 - As-constructed Details of 1977 Re-construction

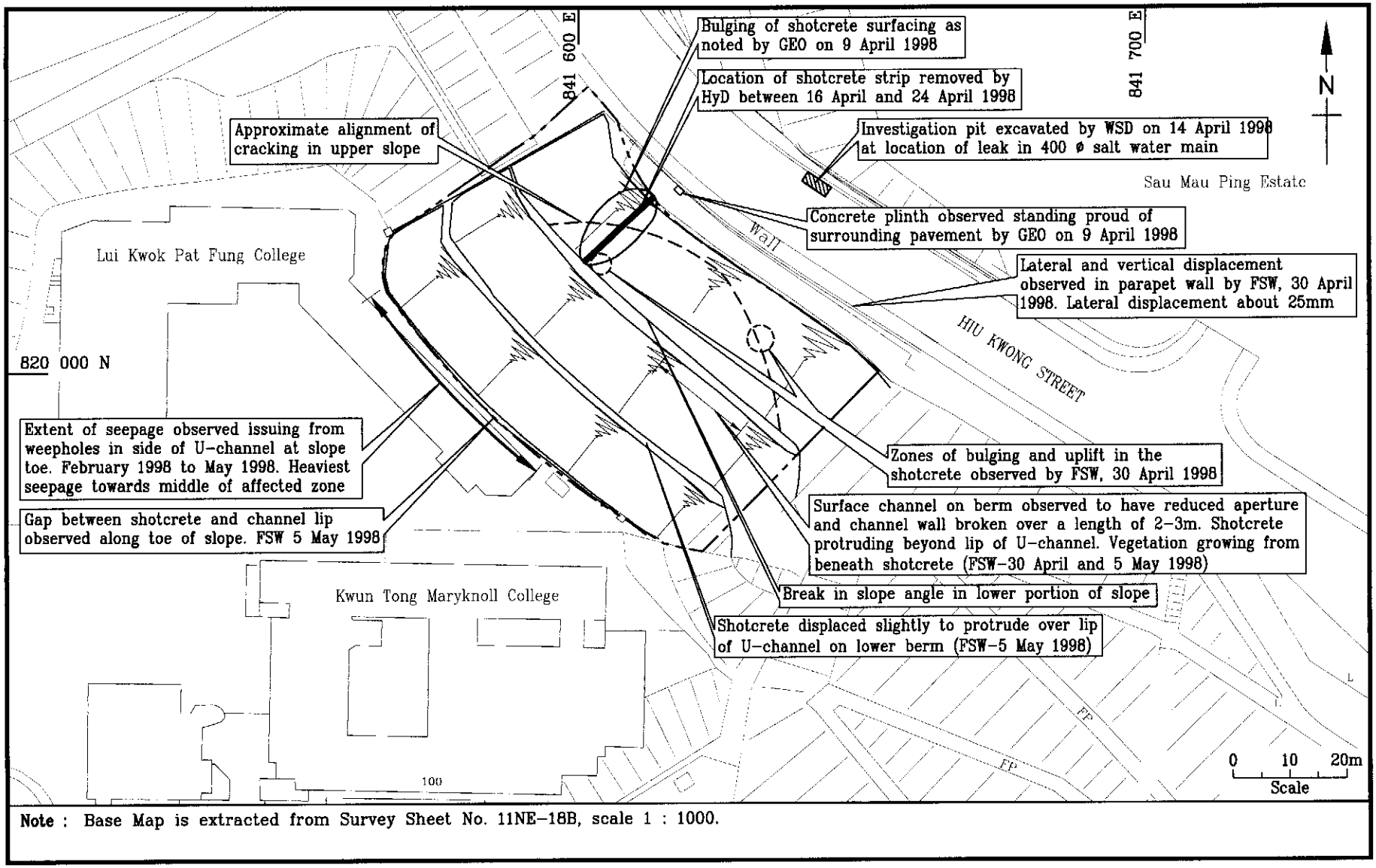
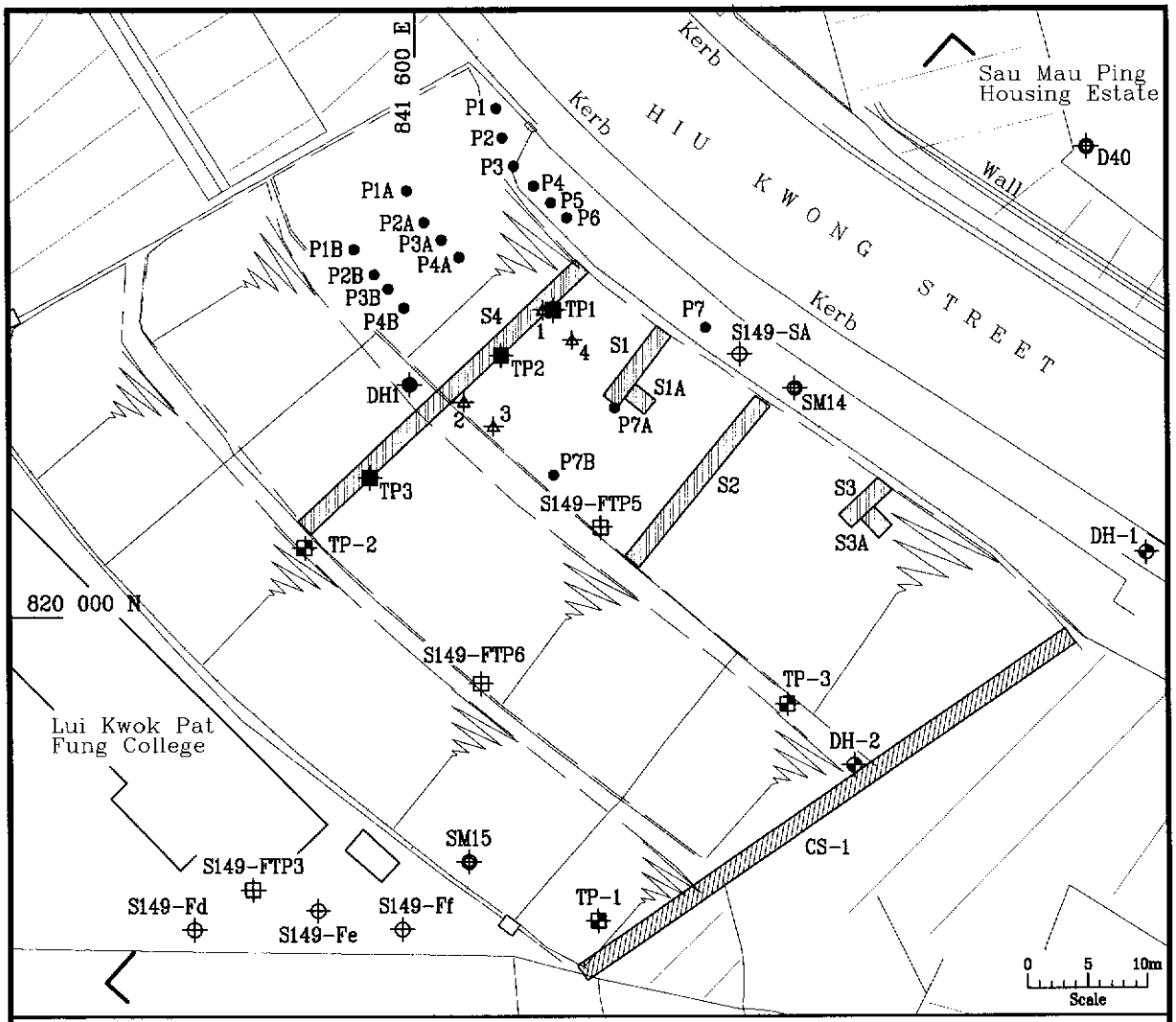


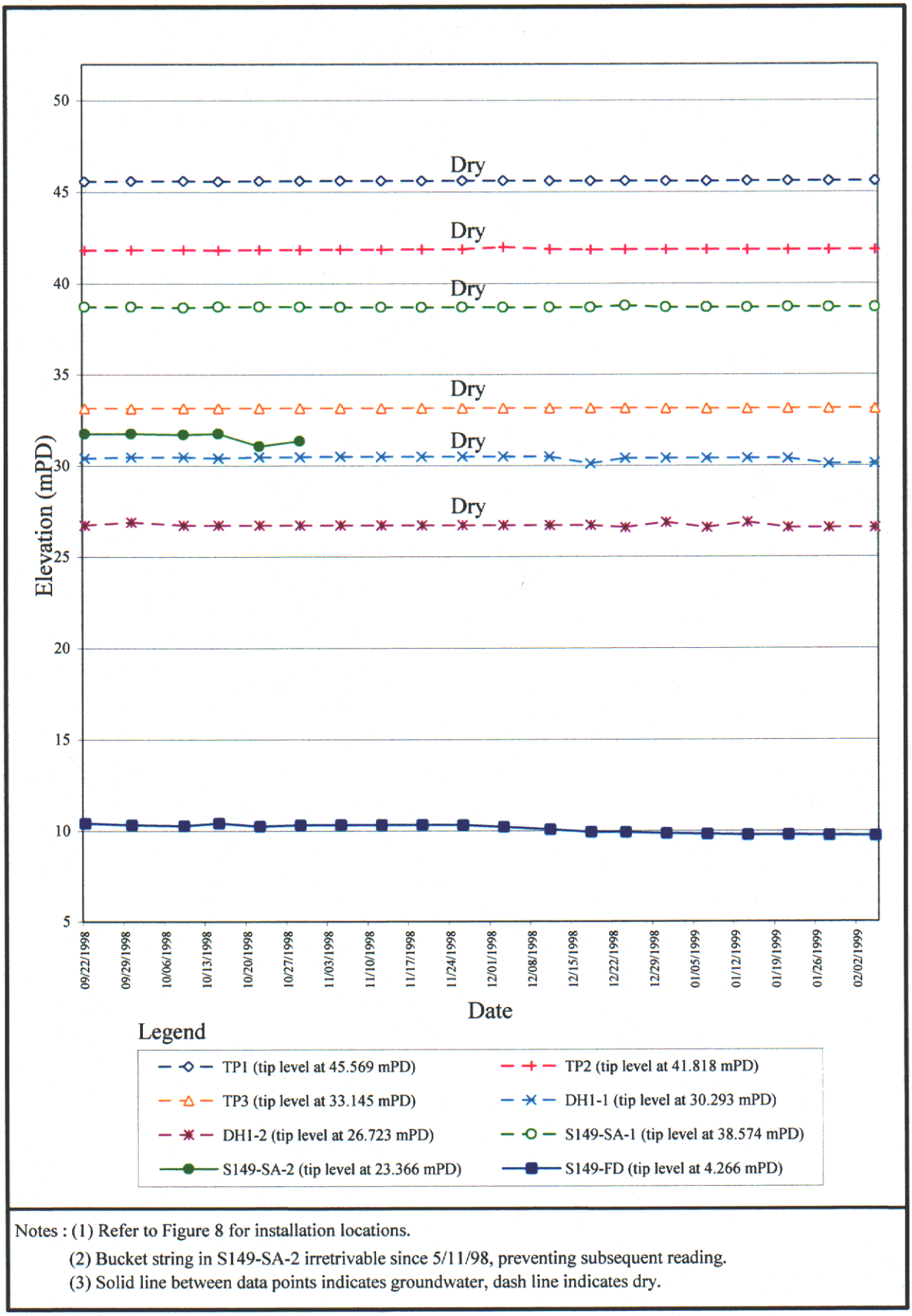
Figure 7 - Distress Observed in April and May 1998



Legend:

SM14	Drillhole location and reference number (Binnie & Partners, 1977) GIU ref. 15219	
P1	GCO probe location and reference number (GEO, 1984)	
DH-1	Drillhole	Location and reference number of GI stations (Bachy Soletanche, 1991) GIU ref. 14280
TP-1	Trial pit	
CS-1	Chunam stripping	
D40	Drillhole	Location and reference number of GI stations (Gammon Construction Ltd 1994) GIU ref. 19301
S149-Fd	Drillhole	Location and reference number of GI stations (I-P Foundations Ltd. 1997/98)
S149-FTP3	Trial pit	
4	GCO probe location and reference number (GEO, 1998)	
DH1	Drillhole	Location and reference number of GI stations (Bachy Soletanche, 1998)
TP1	Trial pit	
S1	Chunam stripping	
	Section	For Geological Profile along section line see Figure 13

Figure 8 - Ground Investigation Stations

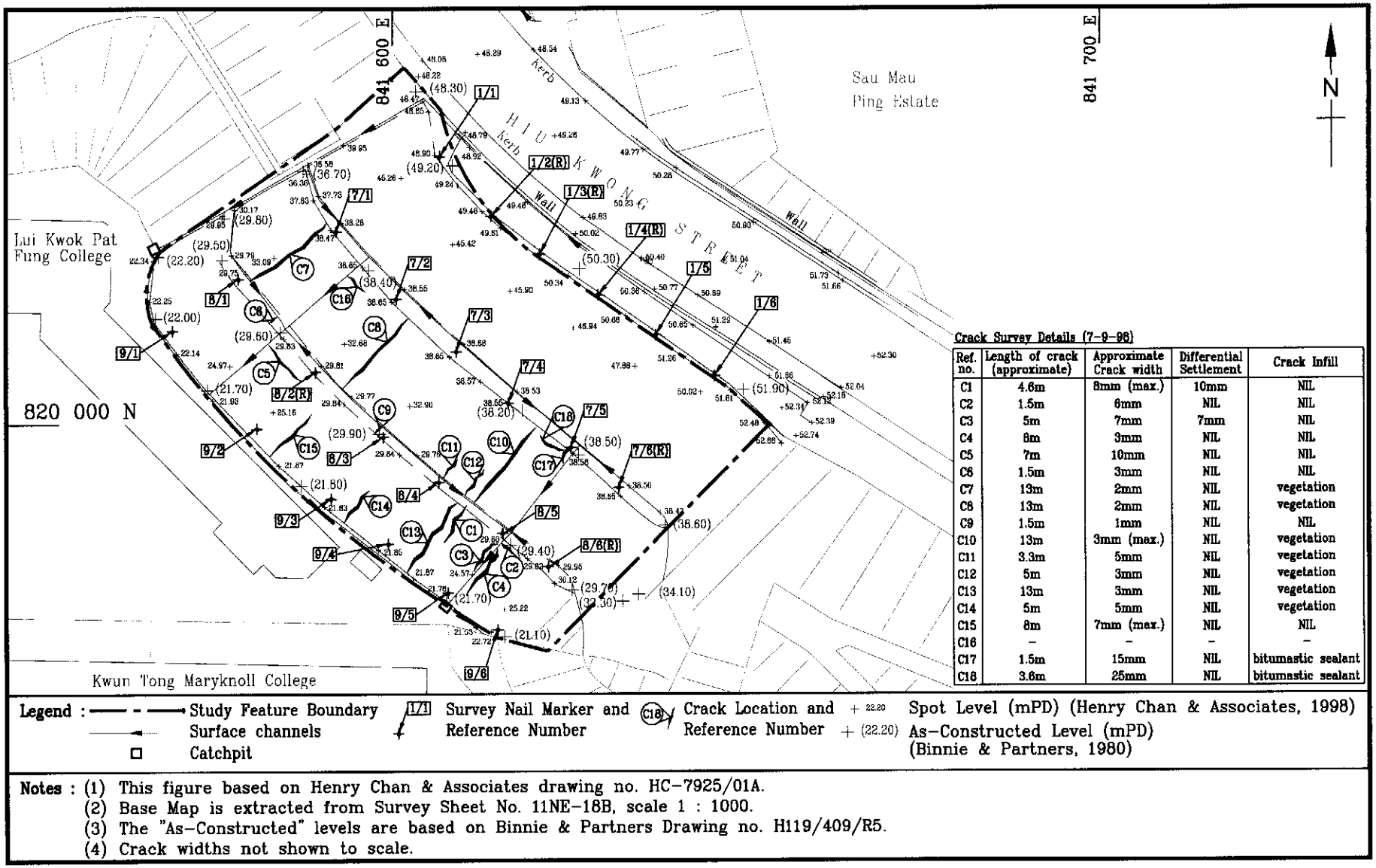


Notes : (1) Refer to Figure 8 for installation locations.

(2) Bucket string in S149-SA-2 irretrivable since 5/11/98, preventing subsequent reading.

(3) Solid line between data points indicates groundwater, dash line indicates dry.

Figure 9 - Piezometer Monitoring Records



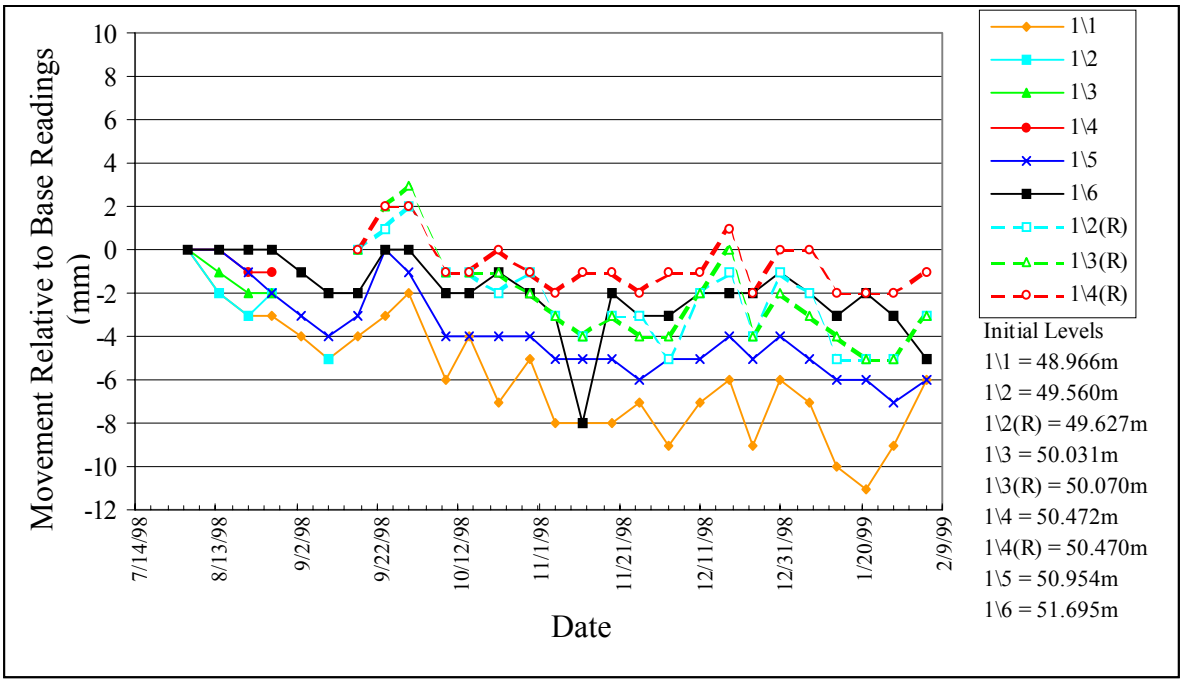
Crack Survey Details (7-9-98)

Ref. no.	Length of crack (approximate)	Approximate Crack width	Differential Settlement	Crack Infill
C1	4.6m	8mm (max.)	10mm	NIL
C2	1.5m	6mm	NIL	NIL
C3	5m	7mm	7mm	NIL
C4	8m	3mm	NIL	NIL
C5	7m	10mm	NIL	NIL
C6	1.5m	3mm	NIL	NIL
C7	13m	2mm	NIL	vegetation
C8	13m	2mm	NIL	vegetation
C9	1.5m	1mm	NIL	NIL
C10	13m	3mm (max.)	NIL	vegetation
C11	3.3m	5mm	NIL	vegetation
C12	5m	3mm	NIL	vegetation
C13	13m	3mm	NIL	vegetation
C14	5m	5mm	NIL	vegetation
C15	8m	7mm (max.)	NIL	NIL
C16	–	–	–	–
C17	1.5m	15mm	NIL	bitumastic sealant
C18	3.6m	25mm	NIL	bitumastic sealant

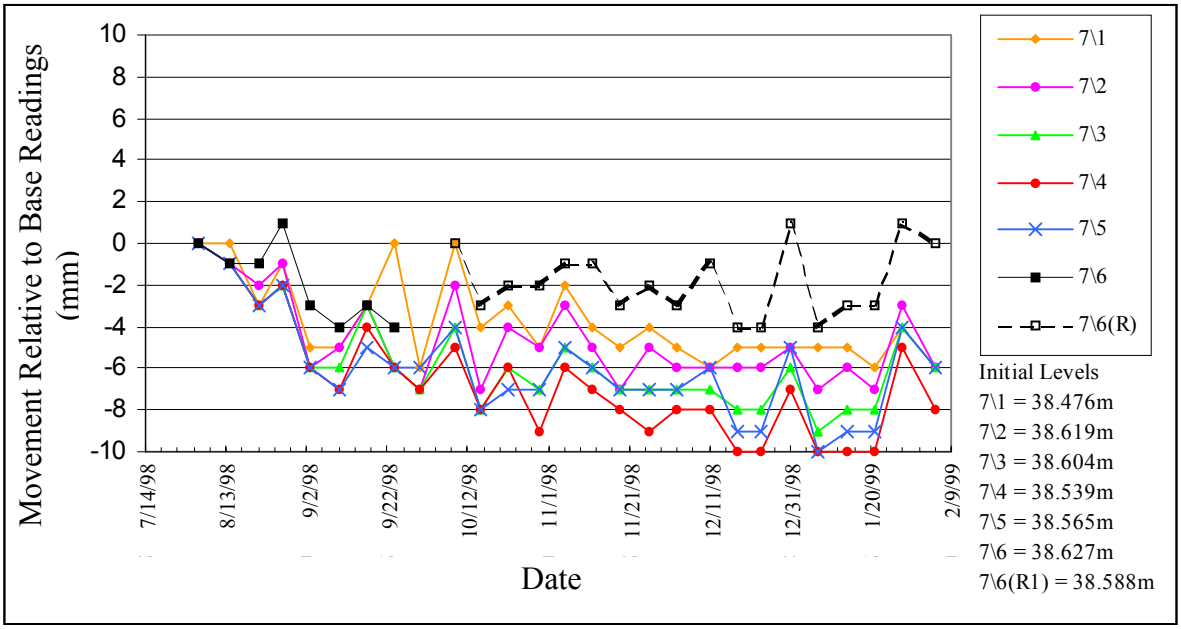
Legend : Study Feature Boundary; Surface channels; Catchpit; 1/1 Survey Nail Marker and Reference Number; C18 Crack Location and Reference Number; + 22.20 Spot Level (mPD) (Henry Chan & Associates, 1998); + (22.20) As-Constructed Level (mPD) (Binnie & Partners, 1980)

Notes : (1) This figure based on Henry Chan & Associates drawing no. HC-7925/01A.
(2) Base Map is extracted from Survey Sheet No. 11NE-18B, scale 1 : 1000.
(3) The "As-Constructed" levels are based on Binnie & Partners Drawing no. H119/409/R5.
(4) Crack widths not shown to scale.

Figure 10 - Survey Plan



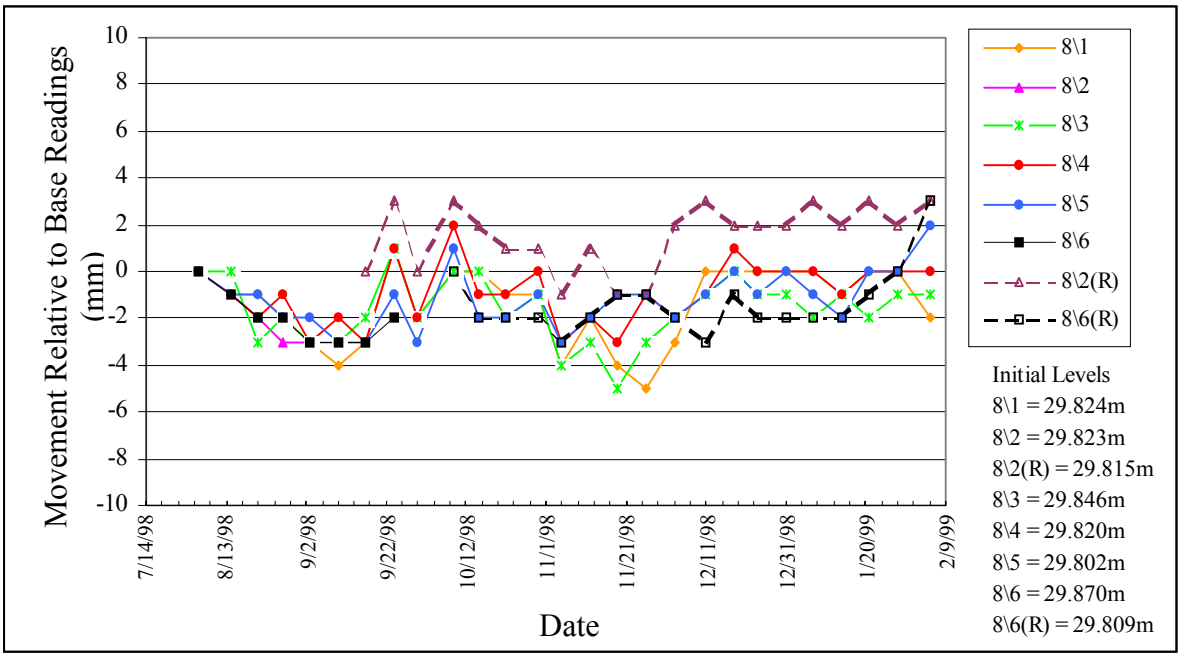
(a) Slope Crest



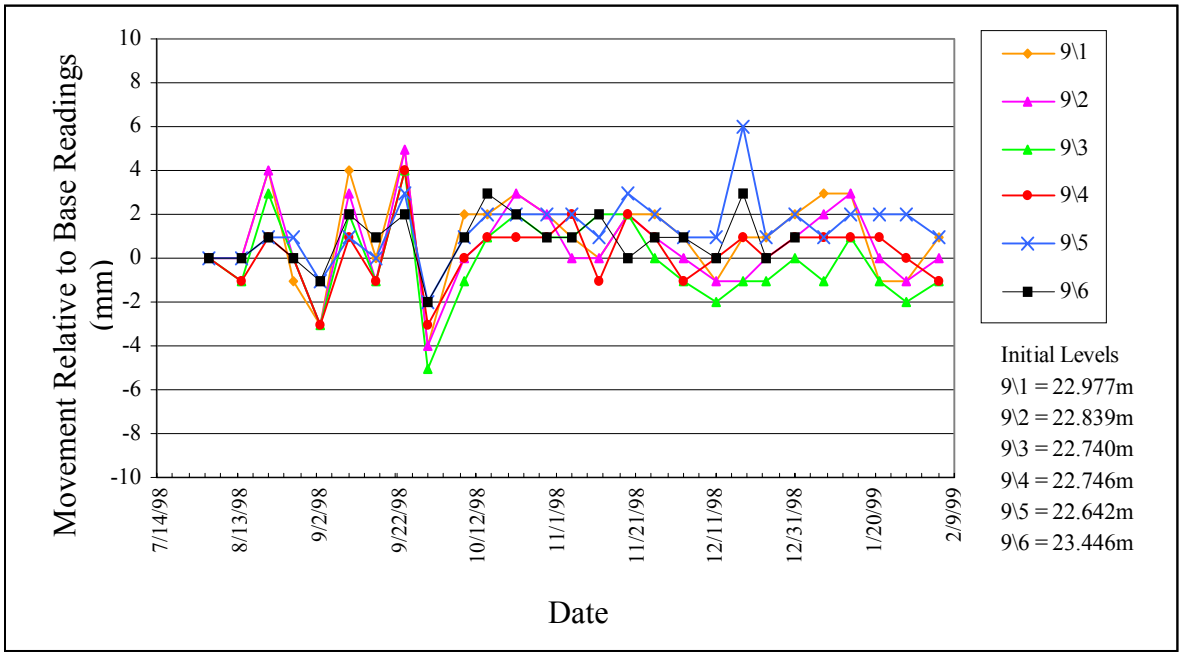
(b) Upper Berm

Notes : (1) Refer to Figure 10 for survey marker locations.
(2) "(R)" denotes re-installation of marker following damage to original.

Figure 11 – Vertical Movement Plots for Slope Crest and Upper Berm



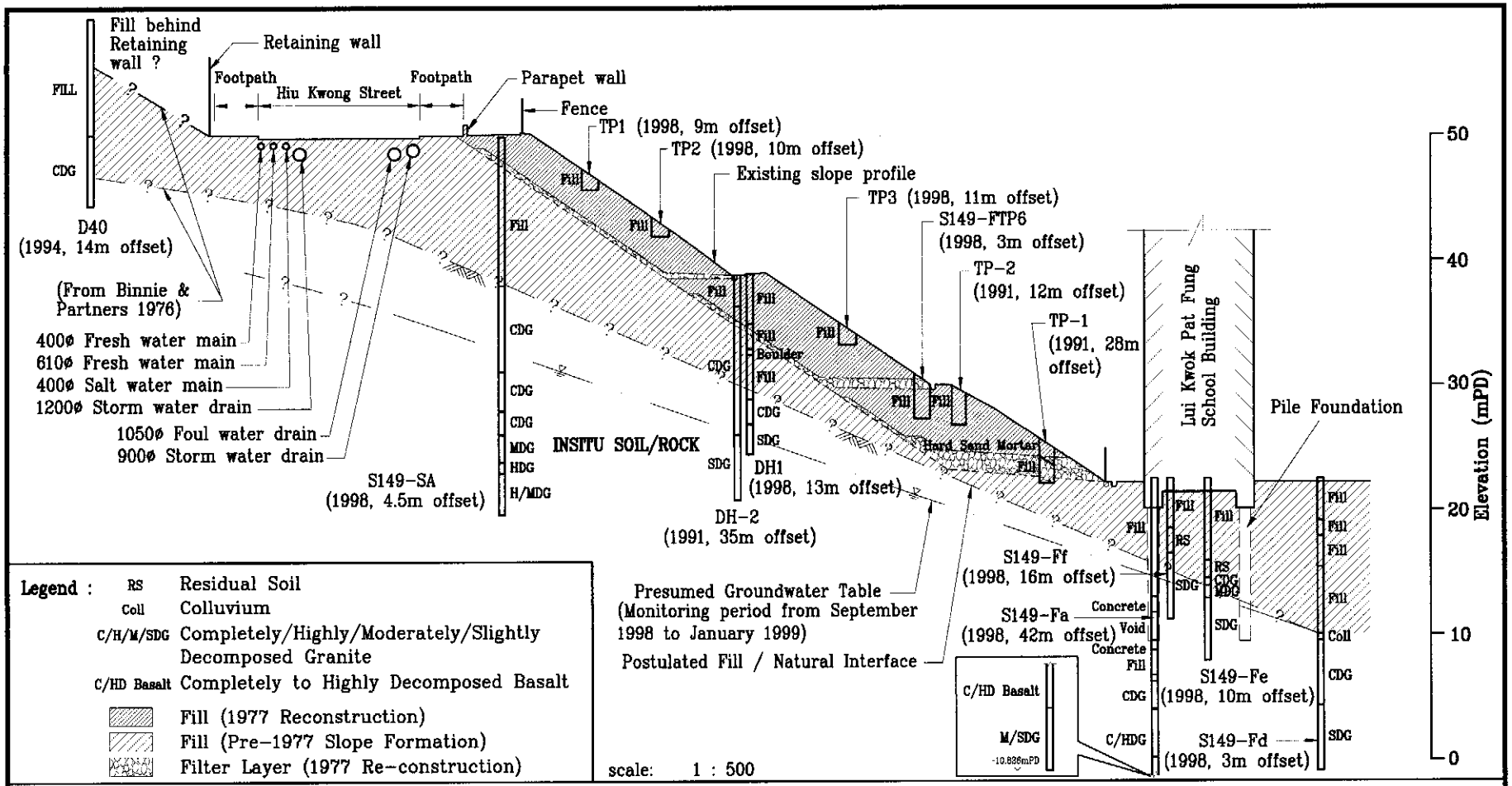
(c) Lower Berm



(d) Slope Toe

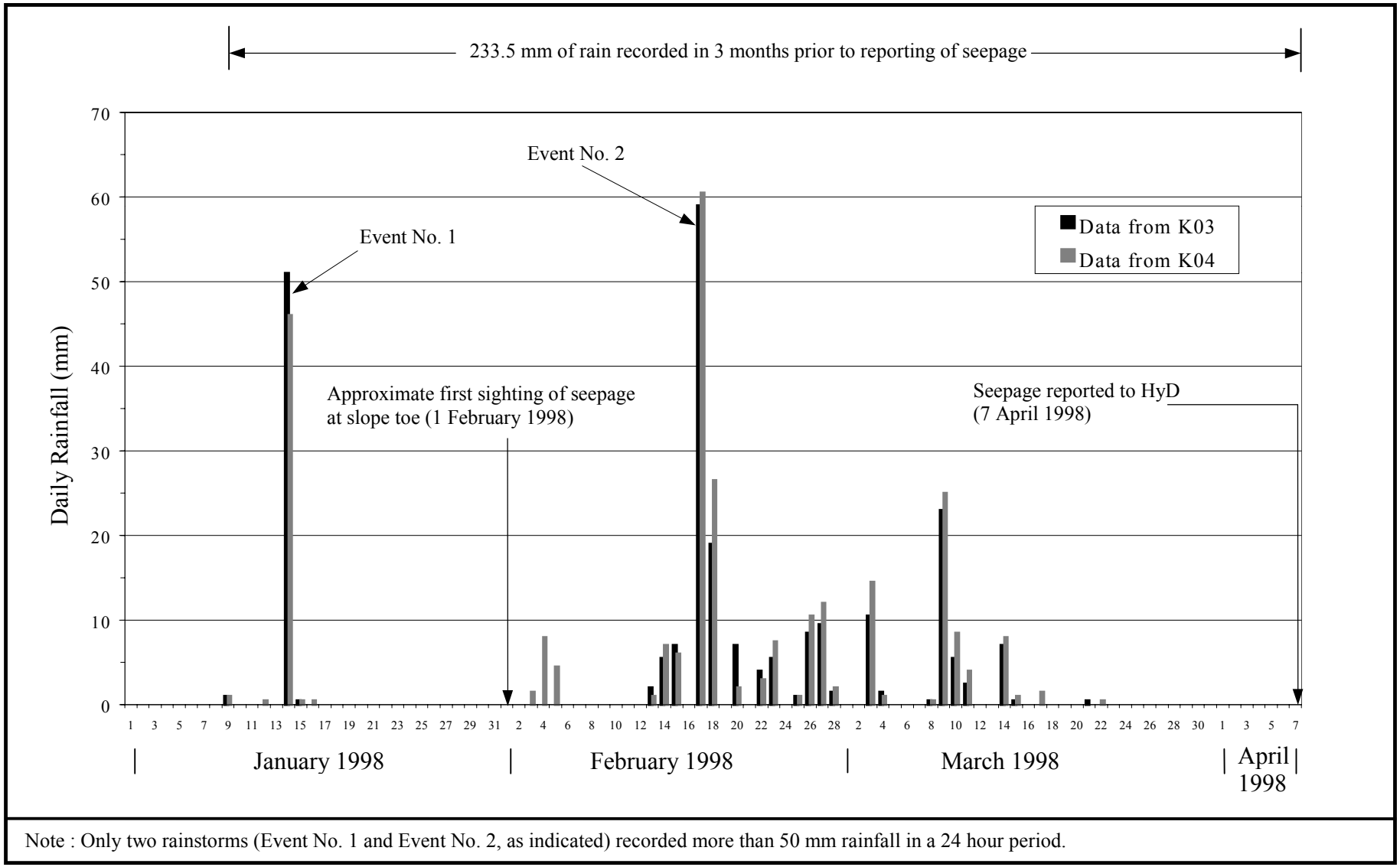
Notes : (1) Refer to Figure 10 for survey marker locations.
(2) "(R)" denotes re-installation of marker following damage to original.

Figure 12 – Vertical Movement Plots for Lower Berm and Slope Toe



Notes :
(1) The existing slope profile is based on the section survey carried out by Henry Chan & Associates (1998) Drg. ref. no. HC-7925/01A.
(2) The As-Constructed internal slope geometry is based on Binnie & Partner's drawing no. H119/409/R5.
(3) Locations of water-carrying services are based on information obtained from Water Supplies Department and Drainage Services Department ultility plans and are indicative only. Depth to invert not to scale.
(4) For location of section see Figure 8.
(5) Foundation details for Lui Kwok Pat Fung College from Building Department file reference 3/4286/81. Piles shown to be 635mmø insitu concrete. Founding levels are indicative (from proposed finished levels).

Figure 13 - Geological Profile



Note : Only two rainstorms (Event No. 1 and Event No. 2, as indicated) recorded more than 50 mm rainfall in a 24 hour period.

Figure 14 – Rainfall Recorded at GEO Raingauge Nos. K03 and K04 from 1 January 1998 to 7 April 1998

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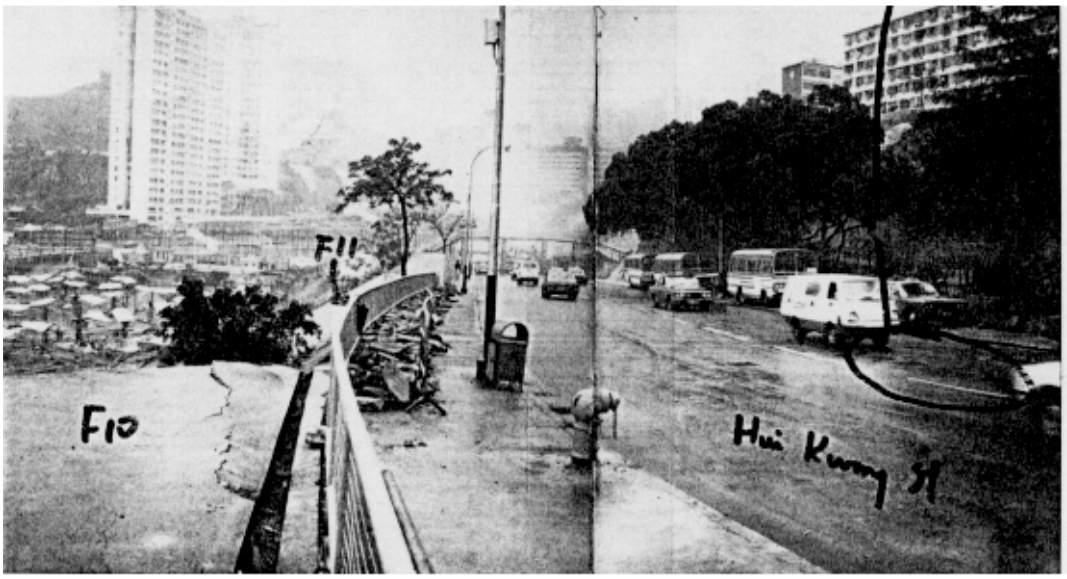
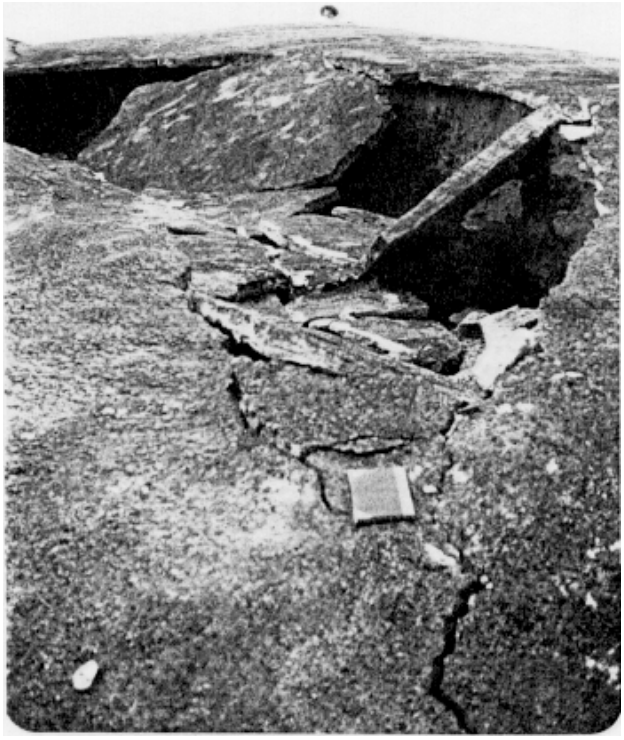


Plate 6 – View North-west Along Crest of Slope No. 11NE-D/F10 Following "Washout" of Fill Reportedly by Leaking Water Main (Photograph Taken on 5 April 1984)



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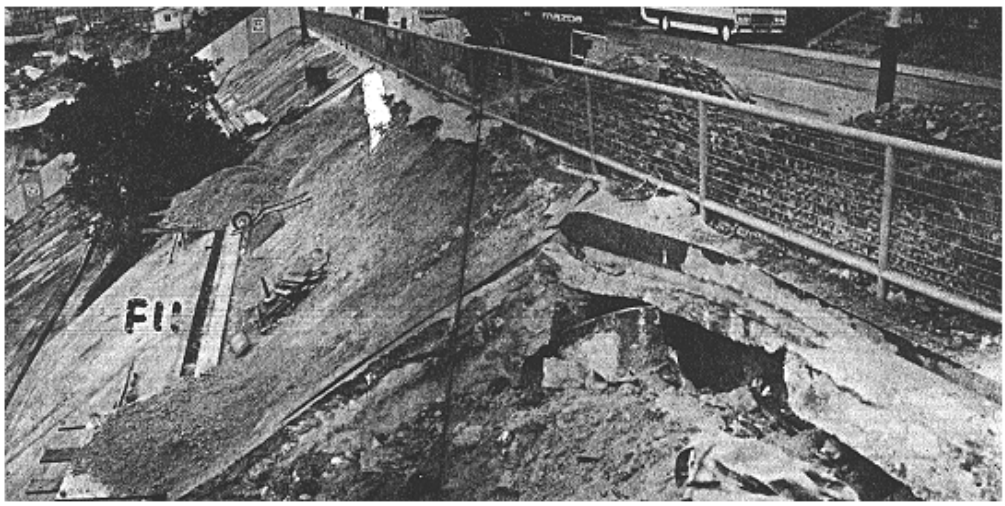


Plate 10 – View North-west Across 11NE-D/F10 and /F11 (Stepped Channel is the Separator) Indicating the Extent of Removal of 1977 Fill During 1984 Remedial Works (Photograph Taken on 25 April 1984)

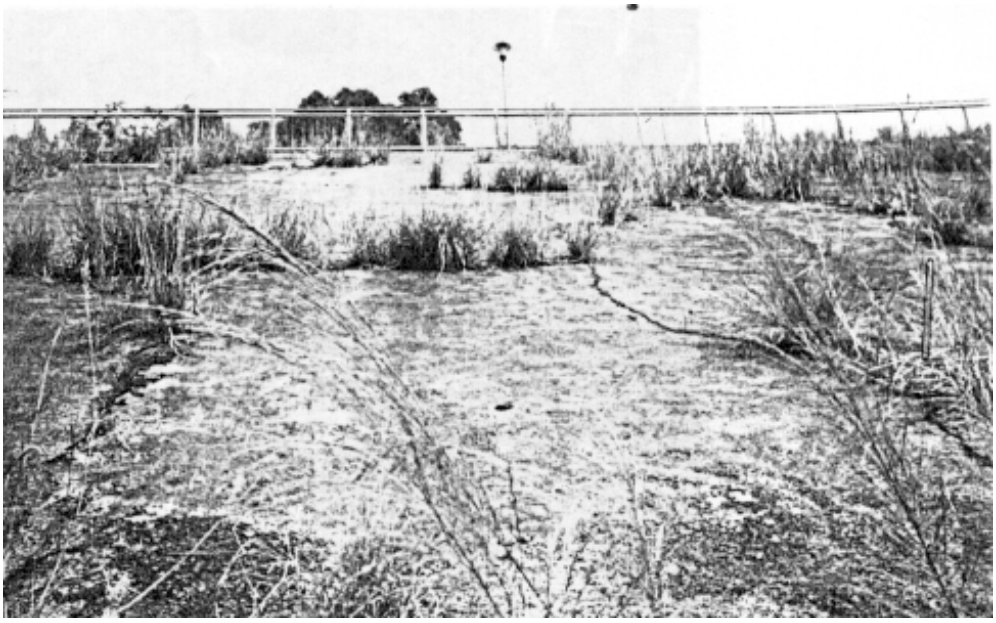


Plate 11 – View North-east From Toe of Slope Indicating Vegetation and Cracking on Hard Surfacing (Photograph Taken on 17 February 1994)

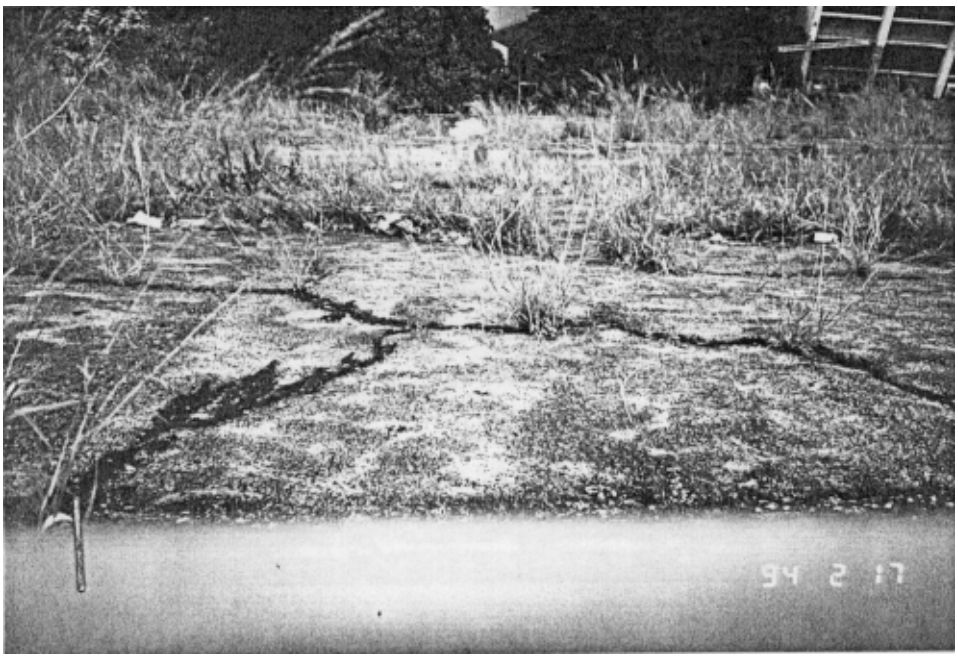


Plate 12 – View South-west From Crest of Slope Indicating Vegetation and Cracking on Hard Surfacing (Photograph Taken on 17 February 1994)

Slight Distortion on Hand Railing

Plate 13 – View North-west From Slope Crest Indicating Vegetation on Hard Surfacing. Note Also Slight Distortion in Hand Railing on Right (Middle Distance) (Photograph Taken on 17 February 1994)

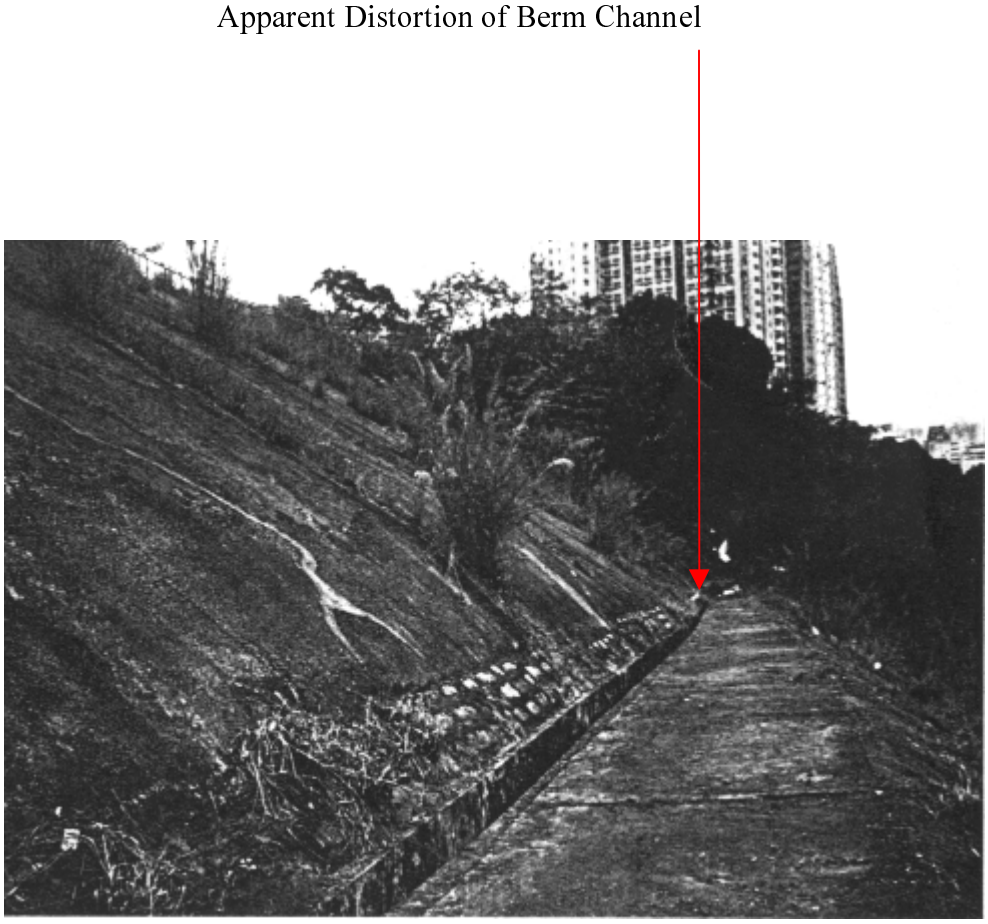


Plate 14 – View South-east Along Upper Berm. Note Repaired Cracking, Stone Pitching Above Berm Channel and Convex Shape of Lower Portion of Slope. Note Also Apparent Distortion of Berm Channel (Photograph Taken on 20 March 1995)

Crack Between Hard Surfacing and Stone Pitching

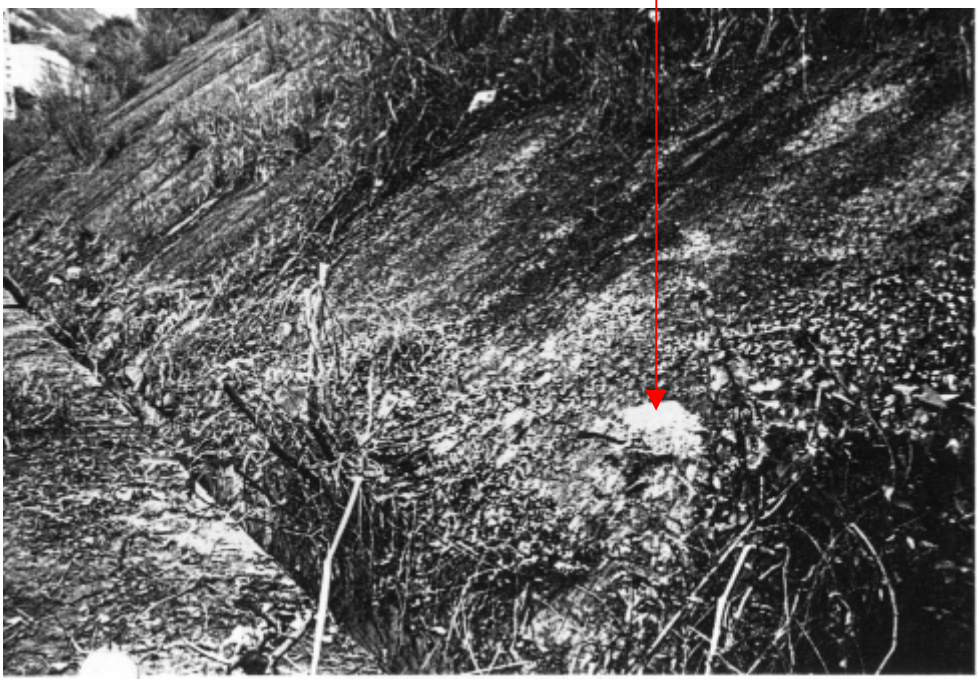


Plate 15 – View North-west Along Upper Berm. Note Vegetation on Slope Face and Apparent Crack Between Hard Surfacing and Stone Pitching in Foreground (Photograph Taken on 20 March 1995)

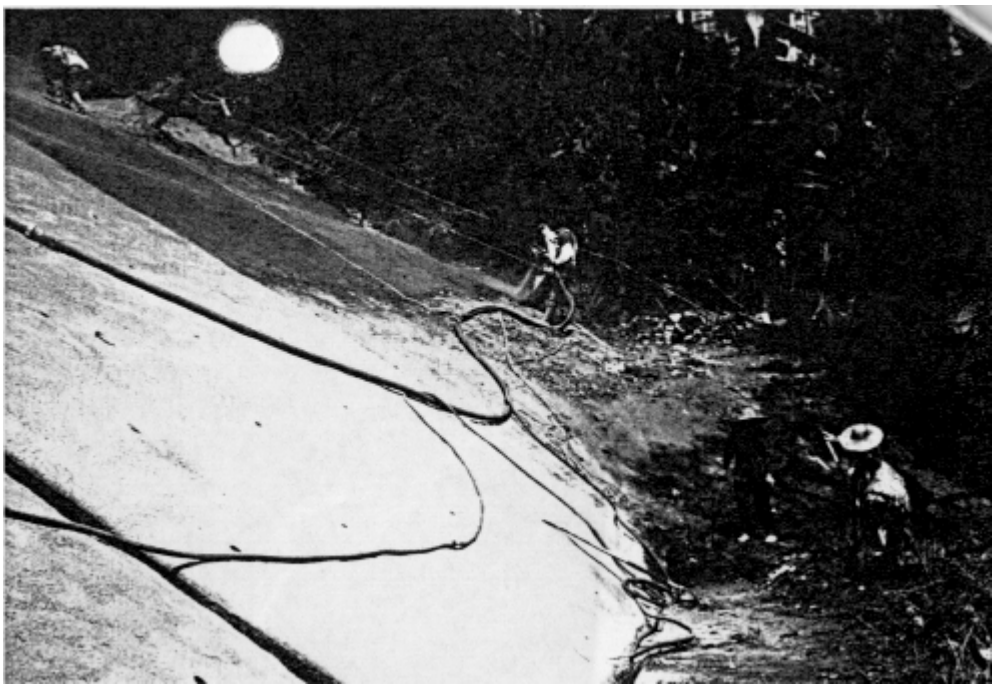


Plate 16 – View South-east Along Lower Berm. Re-Surfacing Works Underway (Photograph Taken on 26 May 1995)

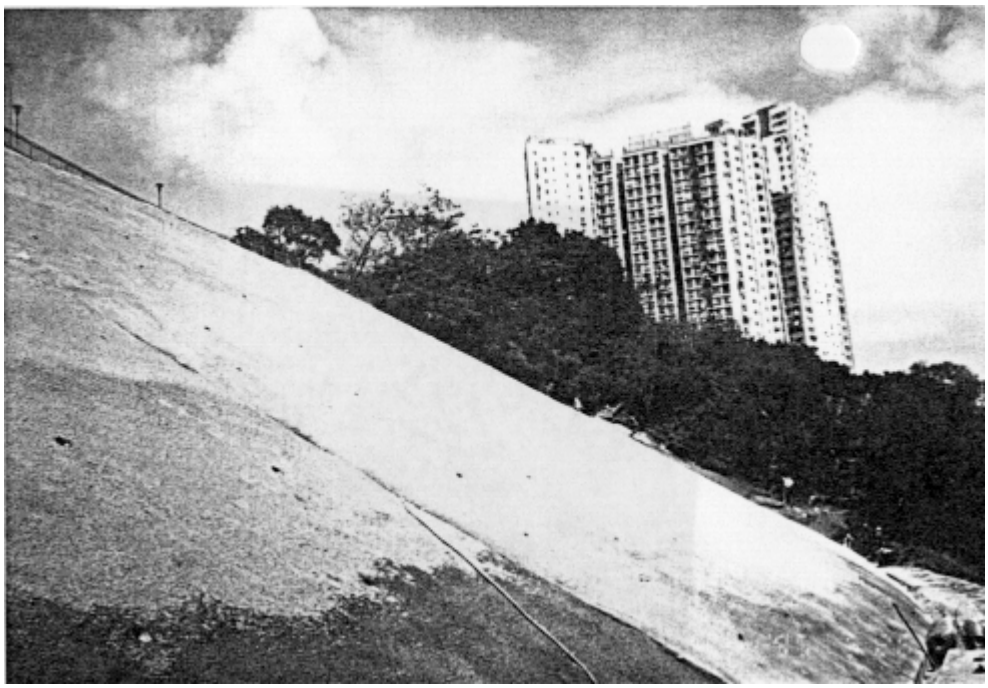


Plate 17 – View South-east Along Lower Berm. Re-Surfacing Works in Progress. Note Slight Convex Shape of Slope at Toe in Profile (Photograph Taken on 26 May 1995)

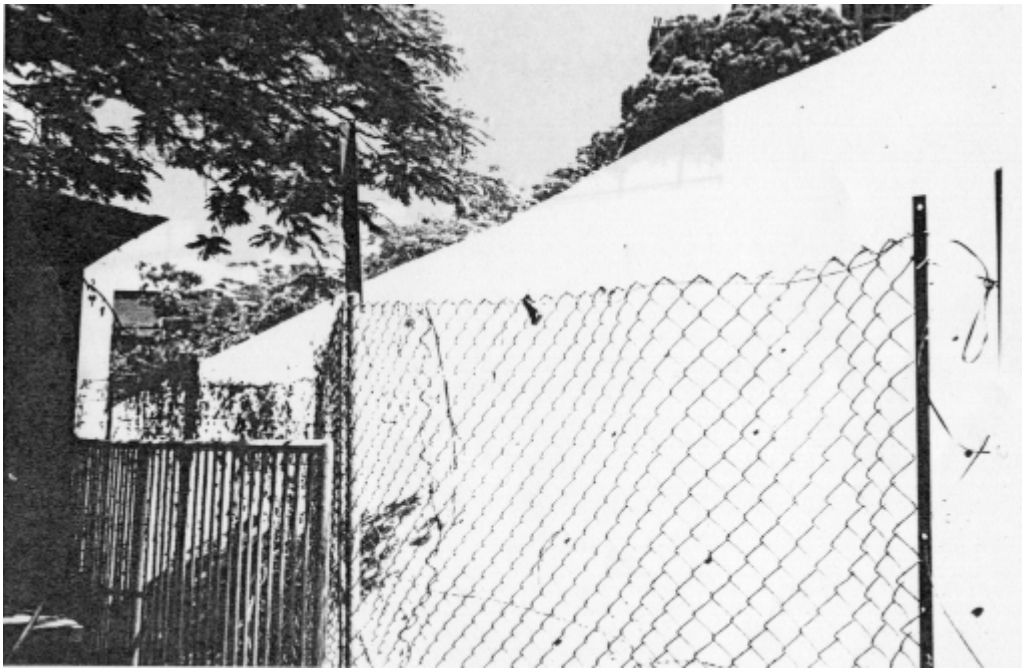
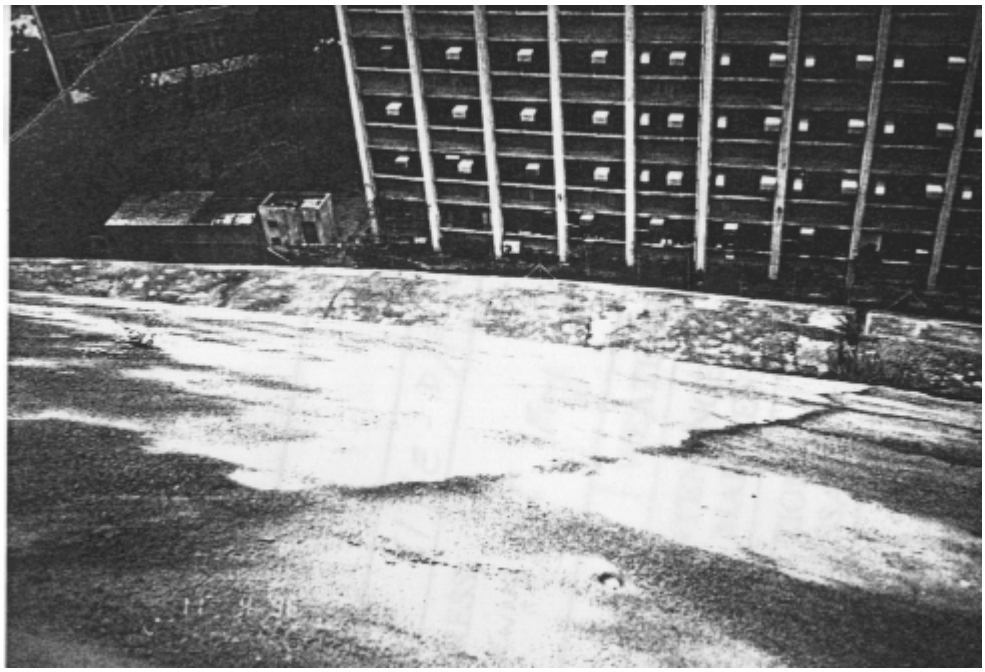


Plate 18 – View North-east From Toe of Slope Indicating Newly Shotcreted Slope. Weepholes Visible in Shotcrete (Photograph Taken on 13 June 1995)

Plate 19 – View North-west Along Crest of Slope. Note Possible Cracking in Foreground. Note Also Distortion in Hand Railing at Crest on Right (Photograph Taken on 11 April 1996)



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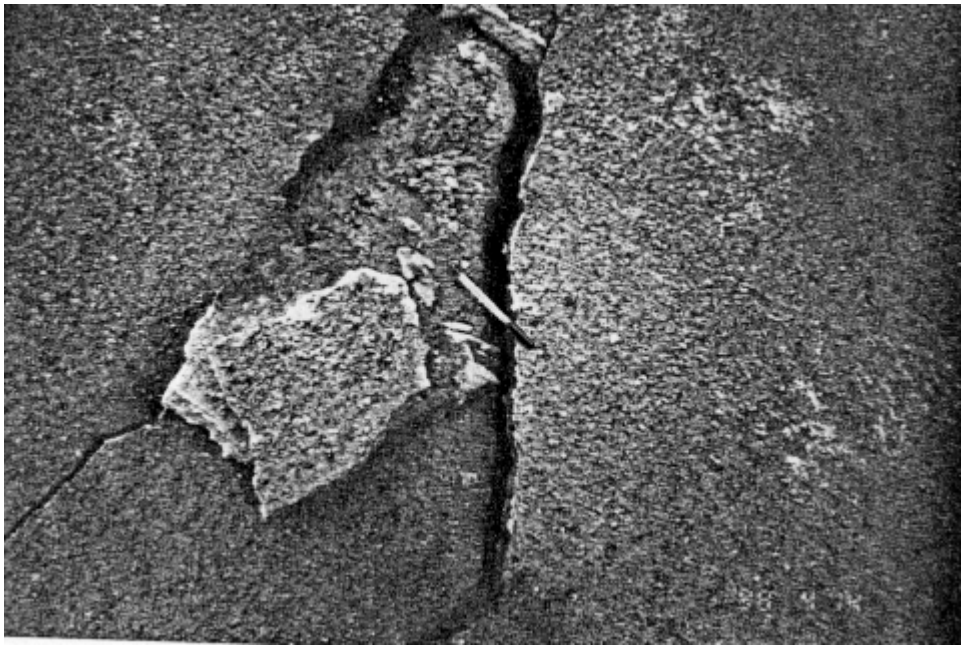

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Plate 23 – Cracking in Shotcrete at North-western Zone of Bulging (Photograph Taken on 14 April 1998)

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Plate 27 – View North-east From Upper Berm at Location of South-eastern Zone of Cracking and Bulging in Shotcrete (Photograph Taken on 14 April 1998)

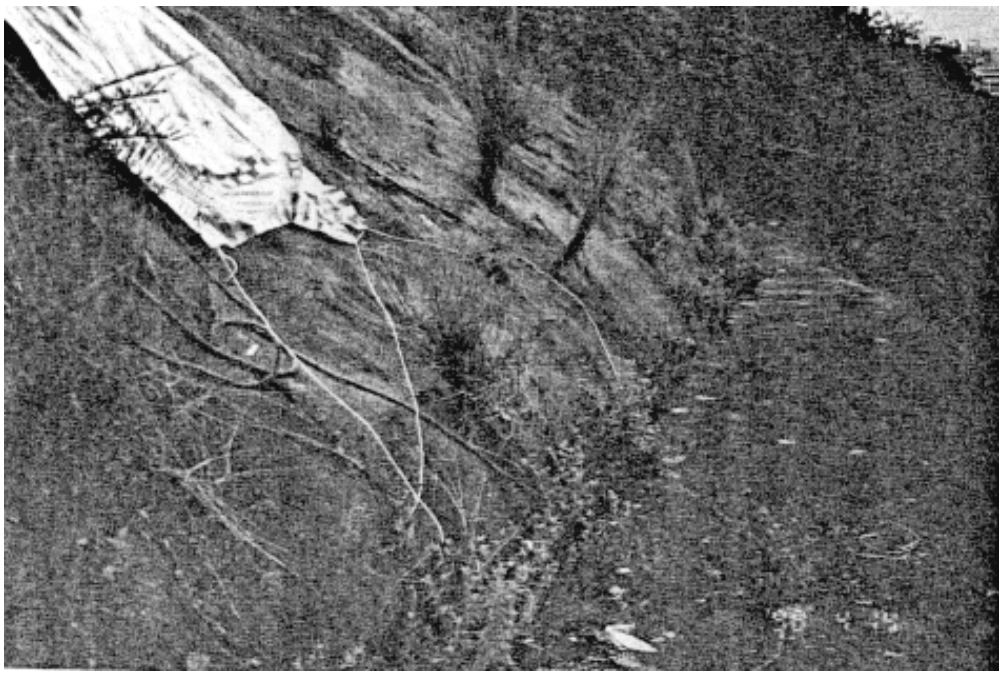

Plate 28 – View South-east Along Upper Berm. Note Break in Slope Angle and Cracking Along Break (Photograph Taken on 14 April 1998)

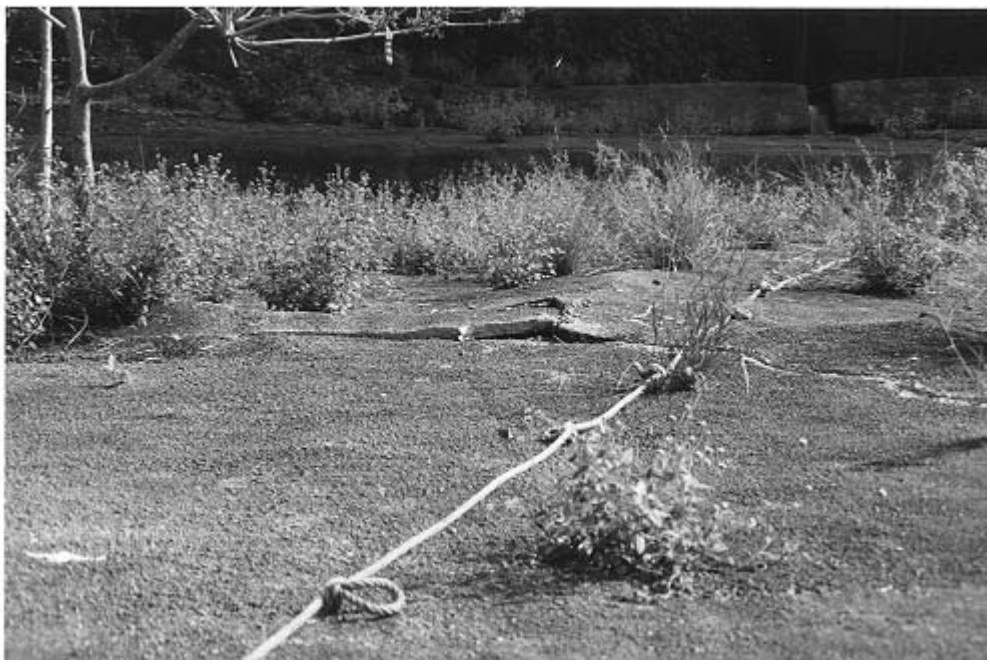

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Plate 39 – View of North-western Edge of Shotcrete Strip. Note Previous Application of Hard Surfacing Beneath Shotcrete (Photograph Taken on 5 May 1998)

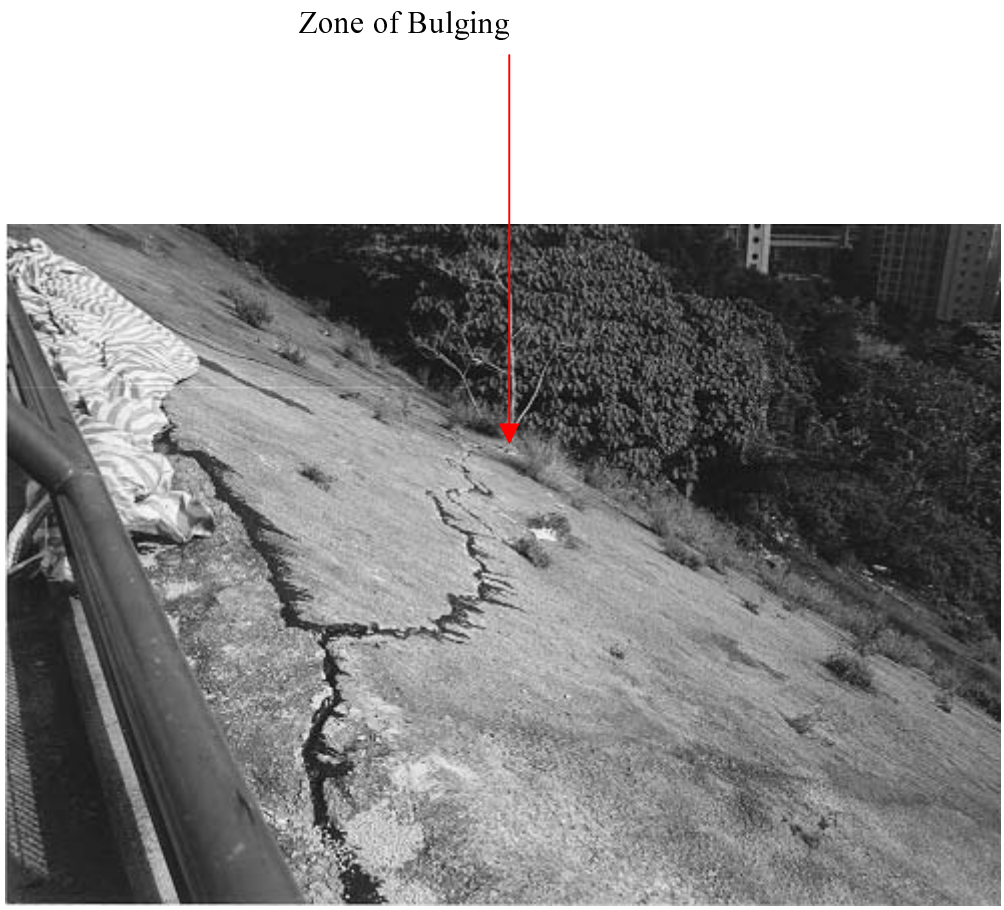

Plate 40 – View South Along Line of Cracking in Upper Batter at South-eastern End of Feature. Crack Has Been Filled. Zone of Bulging Visible in Distance (Photograph Taken on 5 May 1998)

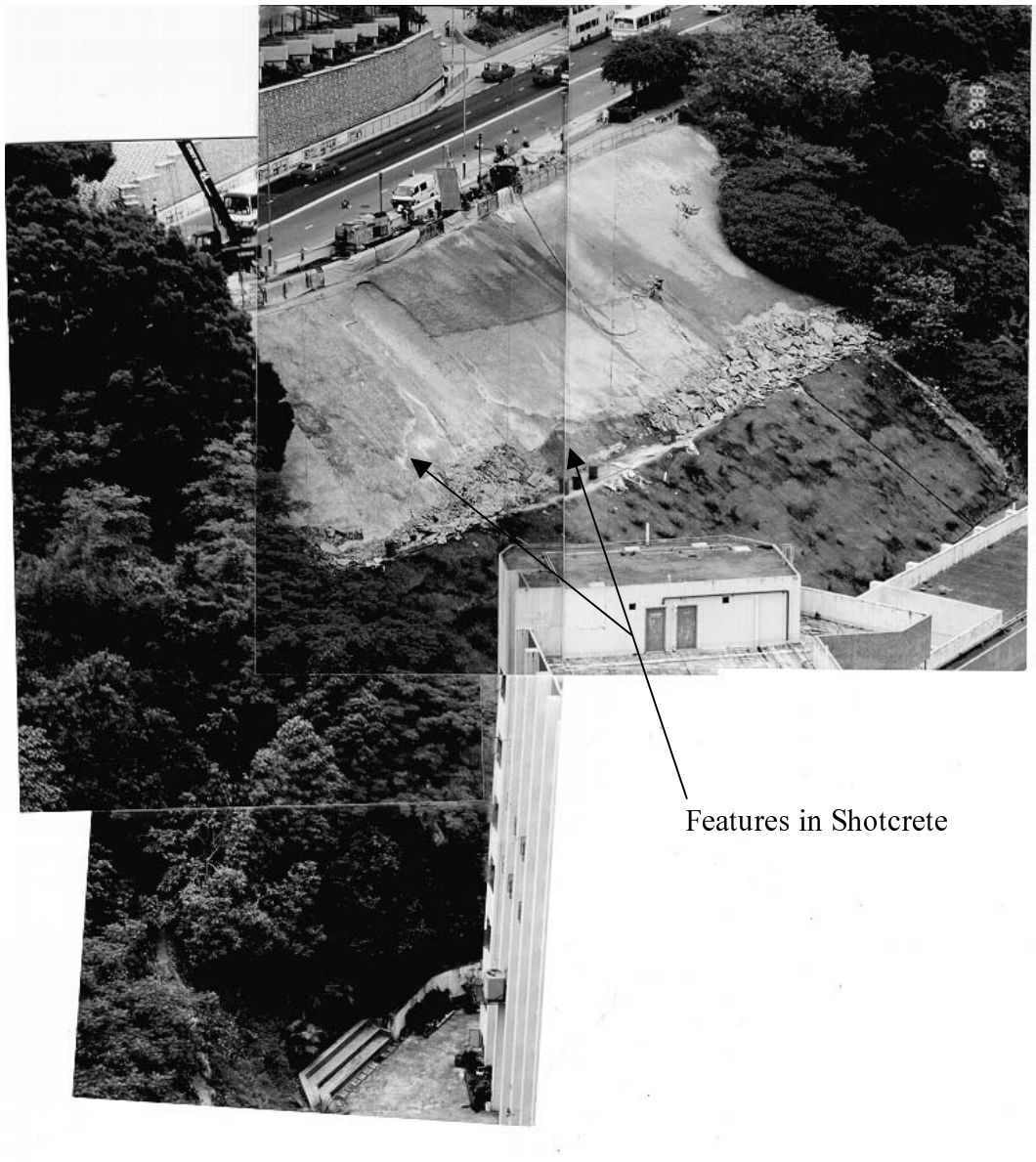

Plate 41 – View East Across Slope No. 11NE-D/F10 of Remedial Works in Progress. Some Indication is Given of Extent of Removal of 1995 Application of Shotcrete by Spoil on Berm and Extent of Removal of Previous Hard Surfacing by Features in Shotcrete. (Photograph Taken on 19 May 1998)

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Plate 43 –
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Plate 51 –
Strip S2 Showing Crack in Previous Hard Surfacing 17 m Above Upper Berm (Photograph Taken on 29 August 1998)

Plate 52 –
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Plate 53 – Strip S2 Showing Fill Exposed Beneath Hard Surfacing, 17 m Above Upper Berm. Note Apparent Extension of Crack into Fill (Area Chased, But No Sign of Cracking in Fill Observed) (Photograph Taken on 31 August 1998)

Plate 54 –
Strip S3 Showing Cracking Exposed in Previous Hard Surfacing. Crack in Foreground Approximately 0.2 m Below Crest. Crack in Middle Ground Approximately 4 m Below Crest (Photograph Taken on 31 August 1998)

Plate 55 – Strip S3 Showing Cracking Exposed in Previous Hard Surfacing Approximately 4 m Below Crest. Note Darker Organic Fill in Middle Ground (Photograph Taken on 31 August 1998)

Plate 56 – Strip S3 Showing Fill Exposed Behind Hard Surfacing at Crack Location. Note Staining of Fill Along Line of Crack in Hard Surfacing. Note Void Beneath Surfacing on Right Hand Side. Slot at Top of Exposure is Crack Infill (Photograph Taken on 31 August 1998)

Plate 57 – Strip S3(A) Showing Cracking in Previous Hard Surfacing and Voiding Beneath Exposed Below 1998 Application of Shotcrete, Approximately 4 m Below Crest (Photograph Taken on 4 September 1998)

Plate 58 – Strip S3(A) Showing Cracking in 1998 Application of Shotcrete Beyond Extent of Strip (Photograph Taken on 5 September 1998)

Plate 59 – Strip S3(A) Showing Voiding in Fill Exposed Beneath Hard Surfacing. Crack Width Approximately 100 mm Throughout, Soft Infill Between Voids (Note Multiple Layers of Hard Surfacing) (Photograph Taken on 5 September 1998)

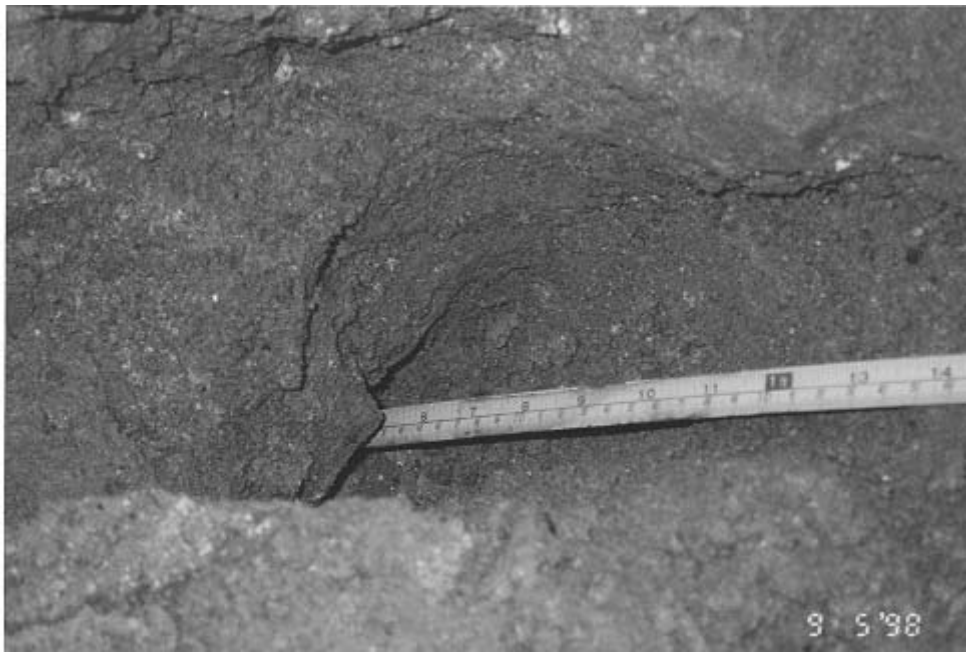

Plate 60 – Strip S3(A) Showing Close-Up of Void. Tape Measure Reads Approximately 300 mm (Photograph Taken on 5 September 1998)

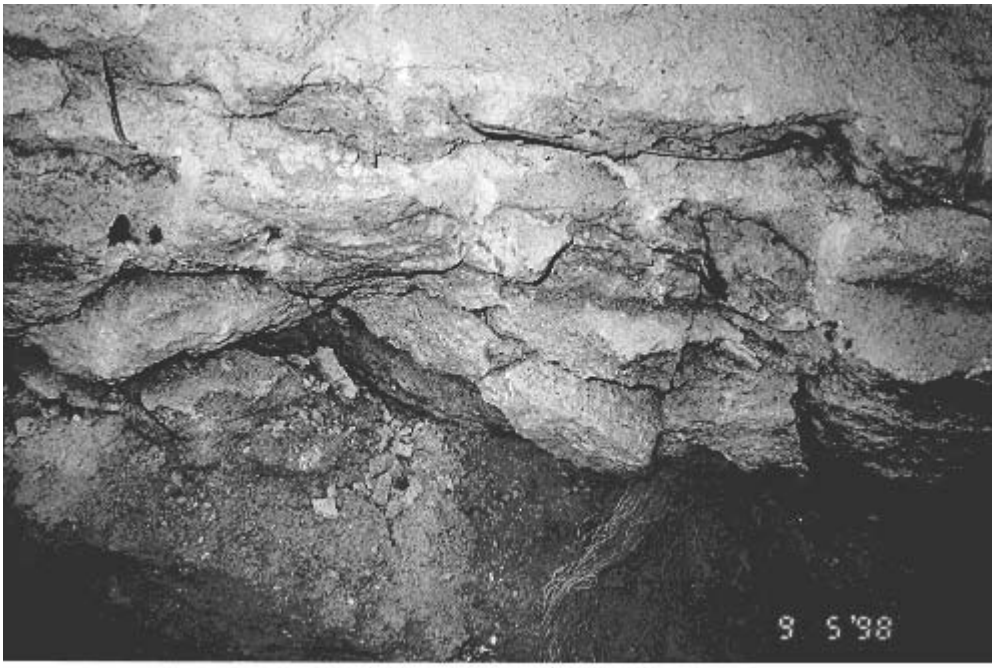

Plate 61 – Strip S3(A) Showing Close-Up of Multiple Layering of Hard Surfacing. Total Thickness Approximately 250–350 mm (Photograph Taken on 5 September 1998)

Plate 62 –
Strip S4 (Middle Batter) Showing Stone Pitching Exposed Below 1995 Application of Shotcrete at Toe of Batter. Note Differential Movement Between Previous Hard Surfacing and Stone Pitching at Interface (Photograph Taken on 26 August 1998)

Plate 63 –
Strip S4 (Middle Batter) Showing Cracking in Previous Hard Surfacing Below 1995 Application of Shotcrete Approximately 16 m Above Lower Berm. Note Organic Infill and Rootlets (Photograph Taken on 26 August 1998)

Plate 64 – Strip S4 (Middle Batter) Showing Cracking in Previous Hard Surfacing Approximately 16 m Above Lower Berm. Note Organic Fill and Rootlets (Photograph Taken on 26 August 1998)

Plate 65 –
Strip S4 (Middle Batter) Showing Fill Exposed Below Hard Surfacing 12 m Above Lower Berm. Note Single Layer of Hard Surfacing Below 1995 Application of Shotcrete (Photograph Taken on 27 August 1998)

APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

A1. DETAILED OBSERVATIONS

The following comprise the detailed observations made from the photographs studied. Relevant photographs are referenced in Section A2.

YEAR	OBSERVATIONS
1963	Hiu Kwong Street under construction. Fill slope under construction to the SW of this road (Originally labelled Slope No. SMP10. Slope registered in 1977/78 Catalogue of Slopes as slope No. 11NE-D/F10 following reconstruction in 1977. Details provided below) with chevron drainage, between the road corridor and the levelled platform below for Maryknoll College. No obvious surface cover. Drainage channels apparatus not lined at time of photograph, and have same appearance as rest of slope.
1967	Surface washout failure of slope No. SMP10, with deep gullies eroded on the SE portion of the slope in particular. Vegetated areas between gullies and rills visible. Fill slope with chevron drainage also formed to the SE of slope No. SMP10, later to be reconstructed as slope No. 11NE - D/FR 23. Rock outcrop separates the two fill slopes. Fill slope also formed to the NW of slope No. SMP10.
1972	Maryknoll College constructed at base of slope No. SMP10. Slope No. SMP10 reformed by filling with Y-shaped drainage line down the centre of the slope and surfacing placed over the lower 2/3 of the slope. Over the surfacing the vegetation is scattered and patchy whereas the upper portion of the slope is covered by a uniform layer of grass. There is a bare patch at the top of the surfaced area and some rill erosion on the fill slope to the NW of slope No. SMP10.
1973	Small local failure below the road on slope No. SMP10 with narrow runout of debris to toe of the slope. Vegetation mostly consists of a cover of grass as in 1972, but now more widespread over the slope, i.e. over the surfaced area. Some scattered low shrubs. A bare patch can be seen around mid-slope. Slope No. 11NE - D/FR 23 now formed to present construction.
1974	Rill erosion below possible line of instability located approx. 1/3 of the length from the road to the base of the slope, i.e. along the crest of the surfaced zone. Signs of slope distress below the road in SE portion of the slope. Erosion with rilling to the north and west of the centre of the slope. Vegetation as in 1973. Scar from 1973 local failure (the scar below the road only) has been covered with a hard surfacing.
1976	Large failure to SE portion of slope No. SMP10. Landslide scar has been covered with hard surfacing for possible temporary works. Resolution not sufficient to see any weepholes. Landslide appears to have been shallow. Vegetation over the remainder of the slope is denser than in 1974. Bare patch

YEAR	OBSERVATIONS
	still exists as in 1973 and 1974.
	Scar from 1973 landslide now vegetated and has a similar appearance to the rest of slope, i.e. no sign of the hard surfacing noted in 1974.
	Area used at the base of the slope and to the rear of Maryknoll College to clear debris from the landslide area. It has the appearance of runout from the landslide.
1977	Fill slope now reconstructed to the present form of slope No. 11NE-D/F10 following previous failure, and consisting of 3 batter slopes between 2 berms. Slope covered with hard surfacing. Formation apparently involved substantial filling over the previous feature.
	[Berms have been constructed consistent with the topographic survey maps produced later in 1994. The alignment of these berms generally appears to be the same as the alignment in 1997, i.e. no bulging can be seen (although the toe of the slope cannot be seen in the 1997 photographs).]
	Low wall/barrier extends for part of the SE portion of the feature, along the approximate location of the old crest line (i.e. adjacent to the Hiu Kwong Street footpath. From this point to the NW end of the slope, the feature is absent, but there is a short step-up from the footpath to the open space behind the crest.
	Resolution is insufficient to detect the presence of weepholes in the hard surfacing. There appears to be no patchiness or repair to the road surface. A dark patch can be seen on a panel in the NW corner of the upper batter (adjacent to the northern-most panel).
1978	No vegetation. Wall/barrier now extended the whole length of the feature.
1980	Edge of panels of hard surfacing noticeable. Evenly-spaced marks on the hard shoulder on either side of the road above slope No. 11NE-D/F10. These are interpreted as oil marks from parked vehicles. Scattered vegetation over the slope.
1982	Patches of vegetation concentrated along slope surface drainage channels only. Oil (?) works still noticeable as in 1982, but now faded.
1984	NW portion of the upper batter has been repaired with a hard surfacing. Sparse vegetation growing through the hard surfacing in lines parallel to the dip of the slope perhaps reflecting the joints between separate hard surface panels. This is most noticeable over the lower batter. No sign of any major cracking. No rilling. No indication of any preparation for the construction of the Lui Kwok Pat Fung College.

YEAR	OBSERVATIONS
1985	East wing of the Lui Kwok Pat Fung College constructed at the base of the fill slope, slope No. 11NE-D/F10, which may have involved some minor alteration to the toe of the slope. Some lined rill erosion despite hard surfacing) on the NW portion of the upper batter, notably in the area where bulging has been noted in 1998. Deposition of a small amount of debris onto the upper berm due to erosion along these lines which extend from the crest of the slope to the berm. Patchy vegetation along drainage channel lower berm only. No sign of any major cracking.
1986	Some lined rill erosion through hard surfacing on NW portion of the upper batter. No apparent settlement of open space behind crest. Vegetation as above.
1987	Some surface erosion to NW corner of the slope (repaired in 1984). Vegetation is sparse and scattered along the lower berm only. Rill erosion as above.
1988	NW portion of upper slope remains unrepaired. Rill erosion appears to have stopped, possibly due to some filling, but lines are still noticeable. Vegetation along middle batter especially along lines parallel to the dip of the slope. Lower batter shows no signs of distress and spare patchy vegetation. Horizontal lines of vegetation, parallel to the strike of the slope, on the SE portion of the top batter suggesting possible cracking to the hard surfacing. Road surface and parapet appear to be intact.
1989	Rills have been repaired by filling but are still visible. Most of the vegetation noted in 1988 over the middle and upper batters has been cleared.
1990	Slope has been tidied-up. Vegetation has been removed, drainage lines cleared. NW portion of the slope appears same as the rest of the slope. It is possible that the slope has undergone some form of spray cleaning or resurfacing.
09/1991	Vegetation concentrated along lines parallel to the dip of the slope and along the previous rill channels (repaired in 1989). Vegetation also along diagonal and horizontal lines on the SE portion of the upper batter. The diagonal lines may be a result of vegetation concentrated in weepholes. Crest of the slope and the road surfacing both appear intact.
04/1992	Vegetation as above but thinner, possibly due to the time of the year. Crest of the slope and the road surfacing both appear intact.
07/1993	Vegetation as above but slightly denser.
05/1994	Possible small erosion patch on the NW portion of the upper batter. There appears to be no debris associated with this erosion. The patch appears darker than the rest of the slope and is located at the position of present

YEAR	OBSERVATIONS
	bulging. Vegetation has been cleared from the whole slope.
10/1994	Vegetation now concentrated along lines parallel to the dip of the slope over all three batters and in most of the drainage channels. The vegetation is noticeably dense in the eroded (?) area noted in May of the same year. Some sparse vegetation also along horizontal lines parallel to the strike of the slope on the SE portion of the upper batter, along the central portion of the middle batter, and immediately below the parapet towards the centre of the slope.
1995	Surface covered with shotcrete. There are no signs of unevenness in the upper batter. Berms have same shape as previously. There are no signs of a settlement profile at the crest. No sign of development of the break of slope.
1996	Slope is in good condition. Some sparse vegetation along drainage channels and through weepholes. No sign of cracking to the upper batter. There are no signs of a settlement profile at the crest.
11/1997	As above.

A2. PHOTOGRAPHS

A full list of the photographs studies as part of the API is presented below:

YEAR	PHOTOGRAPHS
1963	Y7909 Y7910
1964	Y10714 Y10715 Y10716
1967	Y13356 Y13355
1972	32 33
1973	5263 5264
1974	10441 10442
1976	15338 15339
1977	20343 20344
1978	24179 24180
1980	30883 30884
1982	43013 43014
1984	56924 56925
1985	66948 66949
1986	A4313 A4314
1987	A9550 A9551
1988	A14639 A14640 A14324 A14325 (oblique)
1989	A17968 A17969
1990	A20881 A20882
1991	A27406 A27407 A27408

YEAR	PHOTOGRAPHS
1992	A30390 A30391
1993	A35608 A35609
1994	A38104 A38105 A39215 A39216
1995	CN11271 CN11272
1996	CN14349 CN14350
1997	CN18970 CN18971 CN18972

APPENDIX B

POST-JANUARY 1998 SEQUENCE OF EVENTS

Post-January 1998 Sequence of Events

Date	Event
February 1998	Ground staff of Lui Kwok Pat Fung College observe seepage issuing from toe of slope No. 11NE-D/F10. Observation not reported.
7 April 1998 (am)	Administration Officer from Lui Kwok Pat Fung College reported to HyD that "...a substantial quantity of water has been discharging from weepholes at the slope toe for about one week".
7 April 1998 (pm)	HyD inspected the site. HyD subsequently contacted WSD and DSD, requesting each department to investigate their respective services in order to identify the source of the seepage.
8 April 1998	WSD and DSD inspected the site.
9 April 1998	DSD made initial report to HyD that no drainage leakage had been located in the vicinity of the slope and that they had faxed their drainage record. WSD made initial report to HyD that their investigation was still underway and faxed their watermain records. Administration Officer from Lui Kwok Pat Fung College reported to HyD that distress in the shotcrete surfacing had been identified while viewing slope No. 11NE-D/F10 from an upper floor of the school building. HyD inspected the site and observed the distress in the shotcrete facing. An inspection of the area behind the crest (USD Rest Garden) located a "concrete block" (around 0.5m x 0.5m) which appeared to have lifted upwards relative to the surrounding concrete pavement. A joint site meeting (HyD, GEO and WSD) was held in the afternoon, during which the GEO District Engineer inspected the slope. GEO recommended further investigation and that USD be contacted in respect of buried services within their rest garden. HyD issued a fax to USD describing the situation and requesting details of buried facilities in the vicinity of the slope and to arrange a joint site inspection on 14 April 1998. HyD issued a Works Order to their maintenance contractor for the supply and maintenance of "canvas sheeting" to cover the area of the slope face exhibiting distress in accordance with GEO recommendations.
14 April 1998	HyD confirmed to GEO that the distressed portion of the slope had been covered as recommended. HyD requested that USD report on "repair works" carried out within their area

Date	Event
	at the crest and copy to GEO. HyD requested WSD and DSD to investigate leakage/damage of buried mains/drains in the vicinity of the slope. Testing of the seepage at the toe to identify the source was also requested. HyD confirmed the GEO appraisal of the situation that the slope was not posing any imminent danger to Lui Kwok Pat Fung College and that evacuation was not required. Early recommendations from GEO on repair works were requested. A joint site meeting was held (GEO, HyD) during which it was noted that WSD were excavating a trench along the far side of Hiu Kwong Street and that water was continuously flowing from the trench. Leakage from a 400 mm diameter saltwater main was apparently confirmed by WSD site personnel. In respect of the distress on the slope face, GEO recommended that a 2 m wide strip of shotcrete be removed at the location of bulging and cracking of shotcrete and GCO probing be carried out to "determine the insitu density of the fill". The exposed area was to be covered with "tarpaulin sheet", and HyD were recommended to urge WSD to repair the damaged pipe as soon as possible. DSD conducted CCTV survey of buried services, comprising 900 mm and 1200 mm diameter stormwater drains and 1050 mm diameter sewer.
15 April 1998	ASD (maintenance agent for USD) inspected the crest area in relation to the concrete block. Repair works were effected immediately and the concrete block was removed. A rusted and broken pipe (postulated by ASD as being an abandoned piezometer) extended vertically below the block. This was capped and the area was reinstated. DSD initiated dye tests on buried services, comprising 900 mm and 1,200 mm diameter stormwater drains and 1050 mm diameter sewer. Inspections were made over the course of the week following for traces of dye in the seepage at the toe of slope No. 11NE-D/F10.
16 April 1998	HyD confirmed to GEO that the investigative works as discussed on 14 April would be carried out. HyD requested WSD to repair the leakage from the 400 mm diameter saltwater pipe as detected on 14 April and to investigate for further damage to the water mains in the vicinity. HyD requested USD to investigate for any damage to buried services in the rest garden. ASD confirmed to HyD their findings from the site inspection of 15 April and that the area had been reinstated.

Date	Event
24 April 1998	Investigative works (shotcrete stripping and GCO probing) completed by HyD.
28 April 1998	USD requested ASD to investigate and rectify "uplifting of the footpath" and to take "necessary action for the suspected burst underground pipe inside the rest garden" (works already completed and reported to HyD).
30 April 1998	FSW inspected slope No. 11NE-D/F10 and completed a "Report on Landslide Incident", documenting the observed distress in the feature.
4 May 1998	GEO confirmed to HyD that, following a review of utility plans, the investigation of services should include stormwater drains and sewers, fresh and saltwater mains in the vicinity of Hiu Kwong Street above the slope. WSD and DSD were requested to conduct a thorough investigation of their services and to effect any repair works as soon as possible. It was further recommended that HyD remove "shotcrete cover and old chunam cover if found" from the uppermost section of the slope. Further repair works were to be determined following re-inspection by GEO.
5 May 1998	FSW inspected slope No. 11NE-D/F10 and commenced study of feature.
7 May 1998	DSD confirmed to GEO findings of their of check on services, namely: • CCTV survey completed on 14 April of 900 mm and 1200 mm stormwater drains and 1050 mm sewer drain, which indicated 'normal' condition, and no signs of structural cracks or joint displacement. • Dye test commenced on 15 April did not produce dye at toe of slope in the week following. • Inspection on 7 May indicated no signs of dye and that seepage had stopped.
End-May 1998	HyD completed repair works to upper batter of slope No. 11NE-D/F10 comprising partial removal of hard surfacing and application of shotcrete to entire batter. No inspection by GEO District Engineer prior to application of shotcrete (refer 4 May events).
30 June 1998	Completion of ground investigation by I-P Foundations Ltd for Meinhardt Consulting Engineers as School S149 (Lui Kwok Pat Fung College) consultants to ASD for Phase III of the School Improvement Programme, which incorporated slope No. 11NE-D/F10. (Ground Investigation commenced in 1997, investigation of slope commenced February 1998). Ground investigation relevant to slope comprised drillholes at crest and toe, and two trial pits located on intermediate berms.