SECTION 3 : DETAILED STUDY OF THE LANDSLIDE AT A PFA FILL SLOPE AT SIU LANG SHUI, TUEN MUN ON 9 JUNE 1998

Fugro Scott Wilson Joint Venture

This report was originally produced in October 1999 as GEO Landslide Study Report No. LSR 11/99

FOREWORD

This report presents the findings of a detailed study of three slope failures within an unauthorised pulverised fuel ash (PFA) fill slope at Siu Lang Shui, Tuen Mun, on 9 June 1998. The fill slope forms an L-shaped extension to a cut platform. The main landslide area is approximately 60 m wide, 30 m long, and 2 m deep, involving a failed mass of about 1,000 m^3 in volume. Debris from the landslide reached Lung Mun Road. No fatalities or injuries were reported.

The key objectives of the detailed study were to document the facts about the landslides, present relevant background information and establish the probable causes of the failures. The scope of the study comprised site reconnaissance, desk study and analysis of rainfall records.

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 J Hall and reviewed by Mr Y C Koo. The assistance of the GEO in the preparation of the report is gratefully acknowledged.

Y C Koo
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CONTENTS

1. INTRODUCTION

Landslide incidents, comprising one main and two smaller events (GEO Incident Report No. MW98/6/12) from an area above Lung Mun Road at Siu Lang Shui, Tuen Mun, were reported to the Geotechnical Engineering Office (GEO) on 10 June 1998. Some of the landslide debris was washed down onto Lung Mun Road but the incidents did not result in any injury.

Following the landslides, Fugro Scott Wilson Joint Venture (FSW), the 1998 Landslide Investigation Consultants, carried out a detailed study of the incidents for the GEO, 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 incidents, present relevant background information and establish the probable causes of the failures.

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

(a) a review of relevant documents pertaining to the site and the sequence of events leading up to the landslides,

(b) post-failure observations and measurements at the site, and

(c) analysis of rainfall records.

2. THE SITE

2.1 Site Description

The location of the site is shown in Figure 1, and the locations of the three landslides (referred to as Slips A, B and C in this report) are shown in Figure 2. An oblique aerial view of the main failure is shown in Plate 1.

The site comprises an L-shaped body of PFA fill (registered as slope No. 5SE-D/F17 in the Government's New Catalogue of Slopes), inclined at around 35°, some 150 m long and 50 m wide, skirting the southern and western margins of a cut platform which was formed as part of a borrow area during the construction of Tuen Mun New Town. The western section of the fill slope is up to 7 m high, whilst the maximum height of the main southern section is about 20 m.

The cut platform was leased to a building block manufacturer in 1984 under a short term tenancy (STT) agreement after formation. The STT ceased in April 1998, and the tenant subsequently vacated the site. The manufacture of the blocks involved the use of PFA, brought from the nearby Castle Peak Power Station, as a raw material. The platform was partly concrete paved over its original area, but was unsurfaced over the unauthorised PFA fill

extensions. At the time of the landslides, the platform had been levelled of all previous buildings.

The main cut platform is at an elevation of around 58 mPD, approximately 100 m north of the east-west trending Lung Mun Road, which runs adjacent and parallel to the coastline at an elevation of approximately 17 mPD. An ephemeral stream course runs from the eastern toe of the PFA fill slope, in a westerly direction diagonally in front of the slope (Figure 2).

The PFA fill slope was observed to be covered with scattered building debris (paving slabs, bricks, timber etc.) which had been tipped over the crest of the embankment. Elsewhere, dense vegetation had established on the slope.

2.2 Maintenance Responsibility

Land status documents obtained from the District Lands Office (DLO) indicate that the cut platform was leased under a STT Agreement from May 1984 to April 1998, by Kin Ching Besser Co Ltd (KCB) from Government, via DLO who acts as land manager. Records indicate that the tenant was obliged to hand back the site with all the PFA removed, and the site reinstated, including drainage rehabilitation, at the end of the agreement. Relevant extracts from the STT Agreement, including the plan delineating the leased area, dated 1 May 1984, are given in Appendix A.

According to the record of maintenance responsibility, which was compiled by the consultant of the Lands Department for the "Systematic Identification of Maintenance Responsibility of Registered Slopes in the Territory" (SIMAR) project, slope No. 5SE-D/F17 falls within unallocated Government land.

2.3 Water-carrying Services

Based on the information provided by the Water Supplies Department (WSD), the Drainage Services Department (DSD), and the Highways Department (HyD), together with FSW's field observations after the landslide, there are no water-carrying services in the vicinity of the landslide site.

3. SITE HISTORY AND PREVIOUS STUDIES/INSPECTIONS

3.1 Site Development History

The site development history has been established from a review of the available aerial photographs and relevant documentation, including files at the GEO and other Government Departments. The detailed aerial photograph interpretation (API) report is included in Appendix B and key observations from the API are shown in Figures 3a to 3f. The site development history is summarised below.

The earliest 1949 photographs show the area before any development in the region

took place. There were only tracks and footpaths linking scattered agricultural and fishing communities. The site of the platform is located within a spur between two converging southwest and west trending valleys. The major southwest trending valley is a permanent stream course, whereas its west flowing tributary, which cuts diagonally beneath the site area, is probably ephemeral. In general, the natural hillsides in the area are covered with grasses and scattered shrubs, with numerous boulders and rock outcrops. There were no significant changes between 1949 and 1964.

A coastal road had been constructed by 1973, and a haul road had been constructed along the southwest flowing valley, to the northwest of the site. Conditions in 1974 appear much the same as 1973, except that the haul road appears to have been extended. This is the last photographic evidence of the site in its natural state prior to borrowing works.

Lung Mun Road had been constructed by 1984, and formation of the cut platform had been completed. The factory was under construction in this year close to the crest of the cut platform. A drainage channel had been constructed around the edge of the cut platform, which discharged via catchpits down to the natural stream courses below.

The 1985 photograph shows that the cut platform had been extended, outside the area covered by the STT Agreement, towards the southwest by end tipping of fill material (predominantly PFA), to give an area in front of the factory of around 40 m wide. PFA had also been stockpiled against the rock cut face, behind the factory at this time. The drainage channel around the original crest of the slope was apparently infilled following extension of the cut platform.

By 1987, the area created at the front of the platform by filling (predominantly PFA) was being used as a storage area for blocks probably produced using PFA at the factory. No significant changes occurred between 1987 and June 1988. In the November 1988 photographs, a washout or possibly shallow landslip, delineated by an area of flattened vegetation, can be seen on the natural hillside below and to the southwest of the main slope. The upper portion of this scar was noted to be covered with fill material (predominantly PFA).

The May 1992 photographs show that the edge of the cut platform had been significantly extended such that the toe of the fill slope covered the ephemeral stream course. However, by November 1994, a sidelong track had been formed diagonally across the main slope, and the fill (predominantly PFA) above the track level had been excavated to form a steepened face.

Fill was removed from the main slope between 1994 and 1996, and during this time a track was formed along the ephemeral stream course towards Lung Mun Road. Fill (predominantly PFA) was placed on to the central and eastern portions of the main slope between 1996 and 1997, and at the same time, a small waste tip developed in the area associated with Slip C.

The November 1997 photographs represent the last available prior to the landslides. These photographs show that the slope in front of the factory has been extended again by end tipping predominantly PFA with building rubble (between October 1996 and

November 1997). The small waste tip observed on the site of Slip C was also extended, occupying approximately the same area as the 1998 slip identified on site.

No evidence of maintenance of the slope or the drainage provisions is apparent in any of the aerial photographs studied.

3.2 Past Landslides

Based on GEO's landslide database, no previous landslides in the vicinity of the 1998 landslide sites have been reported to the GEO.

3.3 Previous Studies and Inspections

The earliest information relating to this site in the GEO files is a memo dated 11 April 1986 to DLO requesting that KCB be advised to investigate the stability of the unauthorised PFA stockpiles, and take any necessary action to rectify and protect the slopes. DLO relayed the request to the tenant on 23 May 1986, and emphasised that removal of "PFA and debris should commence immediately".

During a meeting between GEO and KCB on 2 June 1986, KCB was advised of GEO's requirements with regard to engaging a geotechnical consultant whilst the slopes were to be flattened as an immediate precautionary measure.

DLO further instructed KCB via a letter dated 14 August 1986 to "remove all PFA and other debris which is presently deposited outside of the premises and reinstate to my satisfaction" within a period of sixty days. Another letter was sent to reinforce this instruction on 9 October 1986, adding that a schedule for the PFA removal was required within seven days. It also advised that a geotechnical consultant should be appointed immediately.

KCB engaged L G Mouchel & Partners (Asia) Consulting Engineers (LGM) in October 1986 to carry out a stability assessment of the unauthorised PFA fill slope.

The subsequent report by LGM (1986) concluded that the minimum factor of safety for the main fill slope at the front of the platform (at the location of the main landslide) was 1.26, and that the chance of a large-scale failure was extremely low, as was the likelihood of a mud-flow type failure. It noted that the PFA was relatively dense and weakly cemented, and that the critical slip surface would probably be at the PFA/ natural ground interface.

This report based its recommendations on the findings of a previous testing report, also prepared by LGM (1985), for China Light and Power (CLP) on PFA fill from Castle Peak Power Station (the same source as the subject fill), which included triaxial tests on samples compacted at optimum moisture content. Based on in-situ density measurements made by the tenant along the access track on the northern PFA stockpile only, LGM chose triaxial test results from similarly compacted specimens to determine the design strength parameters of $c' = 25$ kPa and $\phi' = 34°$. GCO probing had also been carried out at the in-situ density test

locations, and these, together with visual observations of the PFA in these particular locations, were considered by LGM to confirm the dense, weakly cemented nature of the PFA fill. The shear strength of the PFA/ natural ground interface was assumed to be $c' = 0$ kPa and $\phi' = 30°$ to 34°.

GEO, in a memo to DLO dated 16 December 1986, considered that the overall stability assessment of the PFA fill slope (a large portion of which was subsequently removed by October 1996) was acceptable. They commented however that should steepening of the slopes take place, a re-assessment should be made and that KCB should be responsible for reinstating any damaged drains beneath the slopes, and within the site, on removal of all the PFA.

In 1992, the GEO initiated the consultancy agreement entitled "Systematic Inspection of Features in the Territory" (SIFT) which, inter alia, aimed to update information on existing registered slopes in the 1977/78 Catalogue of Slopes, based on studies of aerial photographs and limited site inspections. The SIFT report prepared for the fill slope in January 1997 identified slope No. 5SE-D/F17 as Sift No. 5SE-18D/S17, and classified it as a "B2" slope (i.e. "Have been formed or substantially modified after 30 June 1978).

In 1994, the GEO initiated the consultancy agreement entitled "Systematic Identification and Registration of Slopes in the Territory" (SIRST) to update the 1977/78 Catalogue of Slopes and to prepare the New Catalogue of Slopes. A SIRST inspection report dated May 1997 describes the fill slope as 80% vegetated with a poor surface condition. It records no seepage from the face, but notes that "multiple minor" past instability has occurred.

4. DESCRIPTION OF THE LANDSLIDE

4.1 Field Mapping and Observations After the Landslide

The failures were reported to the GEO at 10:00 hours on 10 June 1998, having occurred at some unknown time before. Given the likely correlation of the rainstorm of 9 June 1998 and the landsliding, it is probable that the landslides occurred late on 9 June 1998.

The extent and profile of Slips A, B and C were determined by field inspection by FSW staff on 18 June 1998. The extent of the landsliding is shown in Figure 2, and a cross-section through the main landslide (i.e. Slip A) is given in Figure 4c. General views of the landslide site are shown in Plates 1 to 6.

The largest landslide (Slip A) occurred within the main body of end-tipped PFA on the south-facing embankment. It comprised an approximately 60 m wide, 30 m long and 2 m deep mass with an estimated volume of about 1,000 m^3 (Plates 1 and 2). The mode of debris movement involved a sliding failure. The failed mass comprised a number of bulging and discrete blocks, which were typically 6 m wide and 10 m long in a downslope direction. Erosion gullies up to 2 m deep had formed, probably due to the action of concentrated surface water flow between the blocks (Plate 2). PFA debris had been washed out along the stream

course as far as the Lung Mun Road and attained an average thickness of around 0.5 m along the stream course.

When inspected on 18 June 1998 by FSW, the PFA body of Slip A was generally loose and moist, and a steady seepage was observed from the base of the fill, which entered the natural stream course at the toe of the embankment and flowed down into a catchpit bordering Lung Mun Road some 90 m away.

The two smaller landslides (Slips B and C) occurred in the western section of the slope. Slip B occurred at the southwestern corner of the platform and the scar was 8 m wide, 10 m long and 4 m (maximum) deep, corresponding to a volume of approximately 80 m^3 (Plates 3, 4 and 5). Severe erosion was apparent around the crest and margins of this slip suggesting that washout by surface water flows had occurred.

Slip C occurred at the northern end of the western section. This part of the slope exhibited sign of distress with severe settlement in the order of 500 mm together with numerous tension cracks at the slope crest (Plate 6). The disturbed area measured about 7 m wide and 10 m long, involving a volume of about 20 m^3.

In the oblique aerial photographs taken on 29 June 1998 (Plate 1), it is apparent that a low area exists on the site platform, around the line of the original slope crest, some 25 m back from the crest of the main slope, above Slip A. This area was seen to be ponded on the oblique aerial photographs (Plate 1). The photograph also shows a stream of water, emanating from the cut slope at the back of the platform, running towards the location of Slip B.

4.2 Consequences of the Landslide

After the incidents, the Highways Department (HyD) undertook urgent repair works, which comprised regrading the slope and covering the surface with shotcrete. A new drainage channel at the crest of the slope was constructed. The cost of the urgent repair works totalled about $4.4 million.

The main consequence of the landslides was that PFA fill was washed out of the failed areas, particularly that of Slip A, and debris was deposited as far as Lung Mun Road. No one was injured in the failures.

In principle, uncontrolled washing out of the PFA could potentially lead to adverse environmental impact. The principal concern relates to the dissolving of heavy metals from the PFA by surface water flows, and possible local contamination of seawater or water supply sources. However, although the environmental impact of PFA is still being assessed by authorities such as the Environmental Protection Department (EPD) on a case by case basis, available evidence (Ho & Chen, 1995) suggests that the susceptibility of PFA giving rise to leachate with unacceptably high heavy metal concentrations is minimal. In particular, monitoring of leachate from the Siu Lang Shui Coal Ash Disposal Site (CLP, 1988) near to the subject site, and using PFA from the same source, showed that the relevant parameters measured were within the threshold limits laid down by the Guidelines for Drinking Water Quality (WHO, 1984).

5. SUBSURFACE CONDITIONS OF THE SITE

5.1 General

The subsurface conditions at the site were determined using information from past ground investigations in the vicinity, API and observations made during post-failure inspections.

The available information suggests that the PFA slope was built up by at least two stages of end tipping with no compaction. The first stage of end tipping reached a maximum extent at around 1992 before it was cut back, reaching a temporarily regressed limit in around October 1996. During late 1996 and 1997, the unauthorised fill slope was again extended by end tipping of PFA from the slope crest, with building rubble also deposited over the PFA surface.

5.2 Geology and Previous Ground Investigations

Sheet 5 of the Hong Kong Geological Survey 1:20 000 scale Map Series HGM20 (GCO, 1986) indicates that the landslide site is underlain by fine-grained and fine- to medium-grained megacrystic granite of Mesozoic age.

Three previous site investigations by Vibro HK Ltd. (1985), Lam Geotechnics (1986) and GCE (1988) were carried out near the site. These boreholes encountered completely decomposed granite (CDG) within about 0.5 m of the ground surface.

The newly extended PFA fill which was dumped during 1996 and 1997 had not been subjected to any investigation.

5.3 Groundwater Conditions

Of the three previous investigations in this area, only one drillhole had a water monitoring instrument installed (1614D by Vibro (HK) Limited in 1983). This was located on the natural hillside just beyond the western boundary of the site. The 8 m deep standpipe was monitored for one week after installation in August 1983, and it remained dry throughout this period.

The potential for perching within the PFA fill has been assessed by comparing the likely permeabilities of the PFA and the underlying top soil and CDG. The permeability from eight triaxial tests on compacted PFA specimens carried out for LGM (1985) ranged from 4.9×10^{-4} to 6.3×10^{-7} m/s, with an average of 1.8×10^{-6} m/s. The typical mass permeability for CDG is quoted as 1×10^{-5} to 1×10^{-7} m/s (GEO, 1993). Given the loose nature of the end-tipped PFA fill, its mass permeability will likely be at the higher end of test results. In addition, the CDG is capped by a top soil layer which usually has a higher fines content (i.e. with a permeability lower than that of CDG). There is the potential for development of perched water table at the PFA/natural ground interface.

At the time of FSW's inspection on 18 June 1998, a steady seepage was noted issuing from the base of the main PFA slope at around 38 mPD, in the vicinity of Slip A. This would tend to support the postulation that there is a barrier of lower permeability at the natural ground level. It is therefore considered that although the main groundwater table is probably below the natural ground level, there is the potential for development of perched water table in the uncompacted PFA fill with building rubble.

As the PFA fill was end-tipped from the slope crest, there is also the potential for development of seepage pressure along the interfaces between different "lifts" of the PFA fill. In addition, the incorporation of building rubble near the surface of the PFA fill also facilitated water ingress, thus promoting the development of transient elevated water pressure within the fill during rainstorms.

6. ANALYSIS OF RAINFALL RECORDS

The nearest GEO automatic raingauge is No. N07, which is located at Tuen Mun Technical Institute, Tsing Wun Road, about 4.2 km to the north-east of the site. The raingauge records and transmits rainfall data at 5-minute intervals via a telephone line to the GEO.

Daily rainfall for one month preceding the event, and seven days following the landslides, are shown in Figure 5, together with the hourly rainfall 48 hours before the landslides. The daily rainfall figure shows that the rain was concentrated around the day of 9 June 1998 (the presumed day of the landslide), with the hourly data indicating peaks from 03:00 to 05:00 hours, 10:00 to 11:00 hours and 13:00 to 17:00 hours ranging from about 40 mm/hr to 70 mm/hr.

Isohyets of rainfall for the 24-hour period preceding the landslides are shown in Figure 6, based on an assumed failure time of midnight on 9 June 1999.

Table 1 presents the estimated return period for the maximum rolling rainfall for various durations based on historical rainfall data at the Hong Kong Observatory (Lam & Leung, 1994). The 4 hour, 12 hour and 24 hour-rainfall (170.0 mm, 243.5 mm and 322.5 mm respectively) were the most severe with a corresponding return period of about 6 years. The rainstorm was relatively moderate and not particularly severe. As the PFA involved in the main failure was dumped only as recently as late 1996 and 1997, this rainstorm was probably the most severe experienced by this recent PFA fill on the slope.

7. SURFACE WATER DRAINAGE

The API has confirmed that a surface drainage system was installed around the platform by the time the tenant took possession the site (January 1984). This comprised a U-channel around the crest of the hillside on the southern margin to the platform, and toe drains immediately beneath the cut slope forming the northern boundary. The crest drain flowed in westerly and easterly directions from a central point along the length of the crest,

terminating in catchpits from which flows were fed via stepped channels into the natural stream courses to the south and west of the site.

This system was effectively destroyed as soon as PFA stockpiling commenced according to the 1985 aerial photograph. At the time of the 1998 landslides, no effective surface drainage provisions were in place.

The oblique aerial photograph taken on 30 June 1998 (Plate 1) shows water ponding along the line of the former cut slope crest possibly resulting in water ingress and subsurface seepage towards the area of Slip A. It also shows a stream draining from the northern stockpile of PFA towards the south-western corner of the cut platform, in the direction of Slip B. An ad-hoc drainage channel has been cut, possibly in an attempt to drain the ponded area to the back (north) of the platform, but as can be seen in the photograph, this has not prevented ponding.

8. DIAGNOSIS OF PROBABLE CAUSES OF THE LANDSLIDE

The failures involved PFA fill, which was placed by end-tipping mainly in the period between October 1996 and November 1997 with no record of geotechnical submission made to the GEO. The close correlation between the rainstorm on 9 June 1998 and the time that the landslides were reported indicates that the failures were probably triggered by rainfall.

The rainfall probably affected the unauthorised PFA fill slope at the three locations in different ways, and to a different extent. The sliding failure and slumping of debris at Slip A are likely to have been a result of direct infiltration of rainfall into the PFA slope, promoted by the presence of building rubble which rendered it more permeable, leading to the development of perched water table above the relatively impermeable natural ground or elevated water pressure within the PFA fill due to downslope subsurface groundwater flow. In addition, subsurface infiltration into the PFA from localised ponding of water behind the crest of the slope at platform level probably took place, which was exacerbated by lack of drainage provisions, leading to further build up of elevated water pressure.

The main cause of Slip B was predominantly concentrated surface water flow which, based on site observations, was channelised towards this area resulting in surface erosion.

The main cause of Slip C was probably the wetting up of loose PFA fill and building debris resulting in localised slope movement and erosion of the loose fill.

Contributory causes to the landslides include the loose nature of the fill and surcharging of the slope crest with building rubble after the demolition of the factory.

The landslides occurred on an unauthorised PFA fill slope primarily involving a portion which was dumped mainly in the period between October 1996 and November 1997 on Government land adjacent to an area leased to a tenant under a STT Agreement. The PFA fill was placed without apparent engineering input and construction control, and the stability of the portion of the slope that failed in June 1998 was not assessed previously by the tenant.

Concern over the stability of the unauthorised PFA fill was raised in 1986 by both the GEO and DLO. Although the tenant subsequently produced a geotechnical report on the stability of the fill slopes formed at the time, which was accepted by the GEO, he apparently did not remove the PFA fill, including that subsequently placed after October 1996, on Government land and did not reinstate the original drainage system on termination of the STT Agreement in April 1998.

9. CONCLUSIONS

It is concluded that the landslides that occurred on fill slope No. 5SE-D/F17 on 9 June 1998 were probably triggered by rainfall.

The large-scale landslides (about 1000 m^3 in volume) occurred on an unauthorised fill slope. The portions involved in the main failure was dumped mainly between October 1996 and November 1997. The fill material was probably in a loose state and susceptible to water ingress which became wetted up resulted in reduction in shear strength and hence the failure. The failure of the recently placed fill during a relatively moderate rainstorm (with a return period of about six years) demonstrated that the slope was substandard. The slope was vulnerable to failure because of absence of proper drainage provisions and lack of engineering input in its formation.

10. REFERENCES

Geotechnical Control Office (1984). Geotechnical Manual for Slopes (Second Edition). Geotechnical Control Office, Hong Kong, 295 p.

Geotechnical Control Office (1986). Solid and Superficial Geology. Hong Kong Geological Survey, Map Series HGM 20, Sheet 5, 1:20,000 scale. Geotechnical Control Office, Hong Kong.

Geotechnical Engineering Office (1993). Guide to Retaining Wall Design (Second Edition). Geotechnical Engineering Office, Hong Kong, 267 p.

Geotechnical and Concrete Testing Limited (1988). Site Investigation for Tuen Mun West Service Reservoir Phase 2. Geotechnical and Concrete Testing Limited.

Ho, K.S. & Chen, P.Y.M. (1995). Environmental Aspects of Using Fresh PFA as Fill in Reclamation. Geotechnical Engineering Office, Hong Kong, 44 p.

Lam Geotechnics Limited (1986). Site Investigation Report for Tuen Mun West Service Reservoir, EDD Contract No. GC/85/09. Lam Geotechnics Limited.

Lam, C. C. & Leung, Y. K. (1994). Extreme Rainfall Statistics and Design Rainstorm Profiles at Selected Locations in Hong Kong. Royal Observatory Technical Note No. 86, 51 p.

L. G. Mouchel & Partners (Asia) (1985). Castle Peak Power Station's PFA Disposal at Siu Lang Shui, plus Addendum Report. L G Mouchel & Partners (Asia).

L. G. Mouchel & Partners (Asia) (1986). PFA Stockpiles at Siu Lang Shui. L G Mouchel & Partners (Asia).

Mouchel Asia Limited (1997). PFA Landfill Site at Siu Lang Shui. Mouchel Asia Limited.

Vibro (H.K.) Limited (1983). Site Investigation for NTDD – Tuen Mun Additional Drillholes in Area 38, Contract No. 447/81. Vibro (H. K.) Limited.

WHO (1984). Guidelines for Drinking-Water Quality, Volume 1, Recommendations. World Health Organisation, Geneva. 130 p.

Wong, H.N. & Ho, K.K.S. (1996a). Travel distance of landslide debris. Proceedings of the Seventh International Symposium on Landslide, Trondhiem, Norway, vol. 1, pp 417 – 422.

Wong, H.N. & Ho, K.K.S. (1996b). Thoughts on the Assessment and Interpretation of Return Periods of Rainfall. Discussion Note DN 2/96, Geotechnical Engineering Office, Hong Kong, 19 p.

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Table 1 - Maximum Rolling Rainfall at GEO Raingauge No. N07 and Estimated Return Periods for Different Durations Preceding the Landslide of 9 June 1998

Duration	Maximum Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years)
5 Minutes	11	16:05 on 9 June 1998	2
15 Minutes	28.5	16:05 on 9 June 1998	2
1 Hour	71	16:05 on 9 June 1998	3
2 Hours	118	16:25 on 9 June 1998	4
4 Hours	170	16:20 on 9 June 1998	6
12 Hours	244	18:25 on 9 June 1998	6
24 Hours	323	18:25 on 9 June 1998	6
48 Hours	328.5	13:45 on 9 June 1998	4
4 Days	338	23:55 on 9 June 1998	3
7 Days	419.5	23:55 on 9 June 1998	3
15 Days	434	23:55 on 9 June 1998	1
31 Days	692	23:55 on 9 June 1999	3

Notes

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

(2) Maximum rolling rainfall was calculated from 5-minute data for durations up to 48 hours, and from hourly data for longer durations.

(3) The use of 5-minute data for durations between 2 hours and 48 hours results in better data resolution, but may slightly over-estimate the return periods using Lam & Leung (1994)'s data, which are based on hourly rainfall for these durations.

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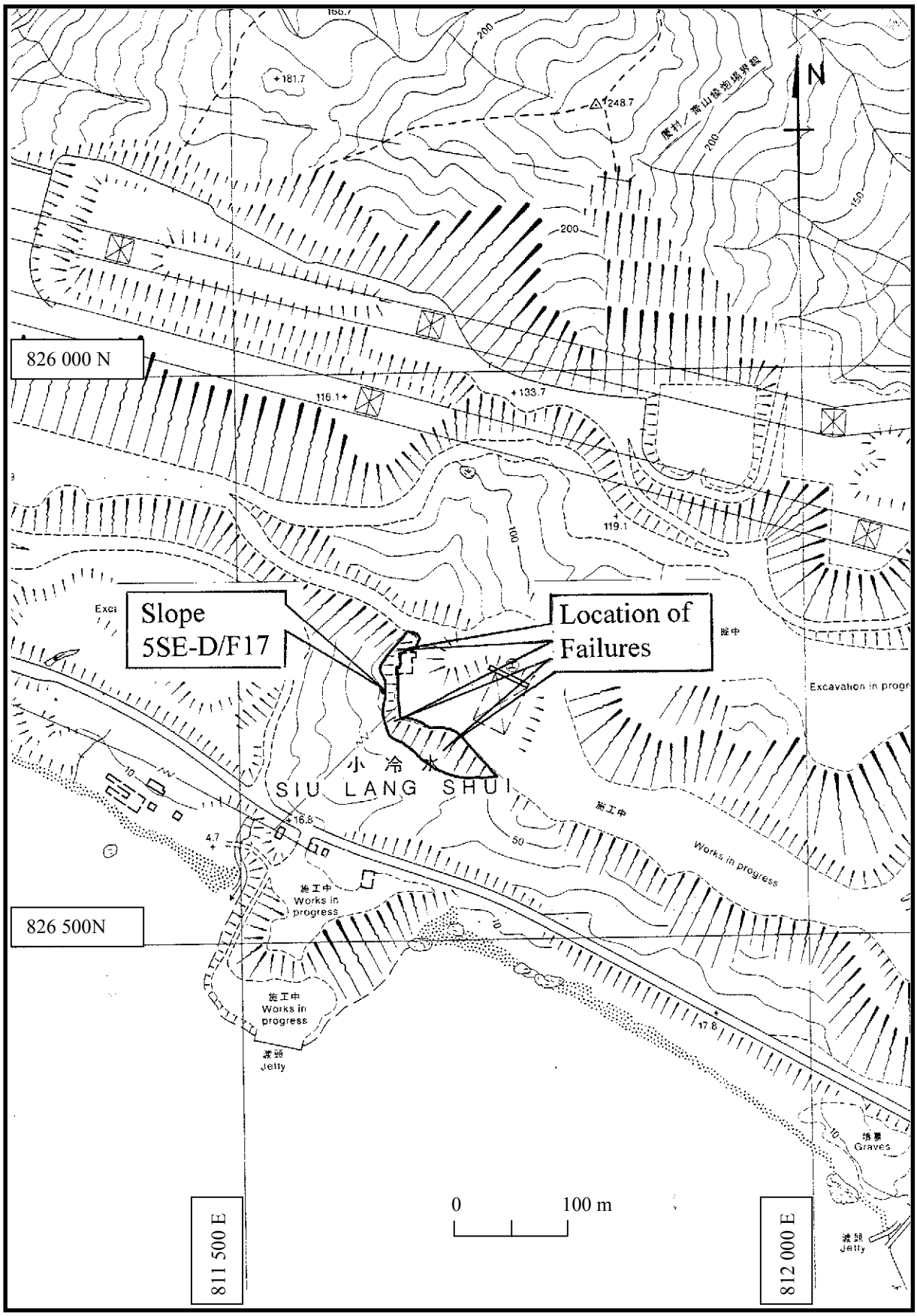


Figure 1 – Site Location Plan

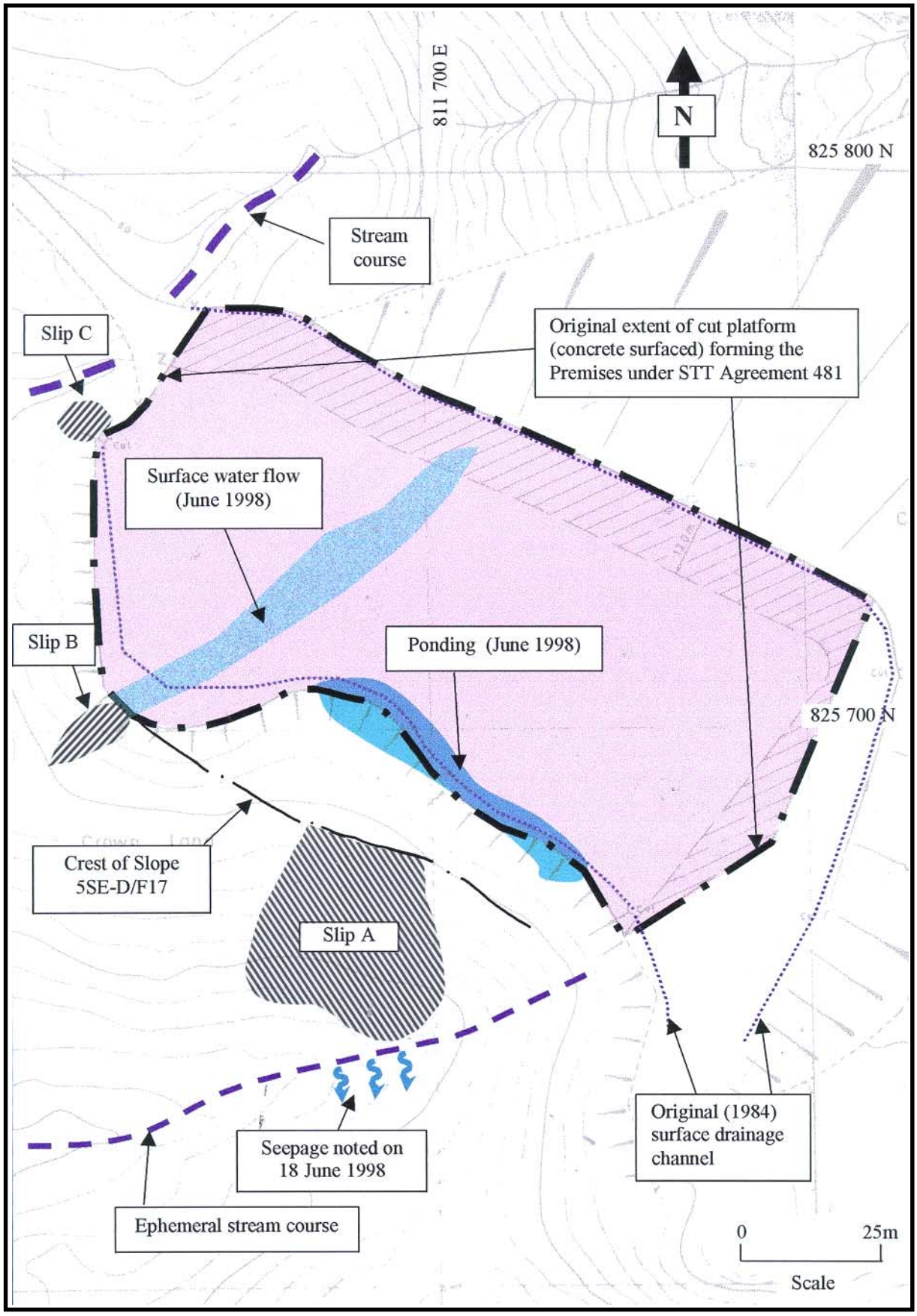
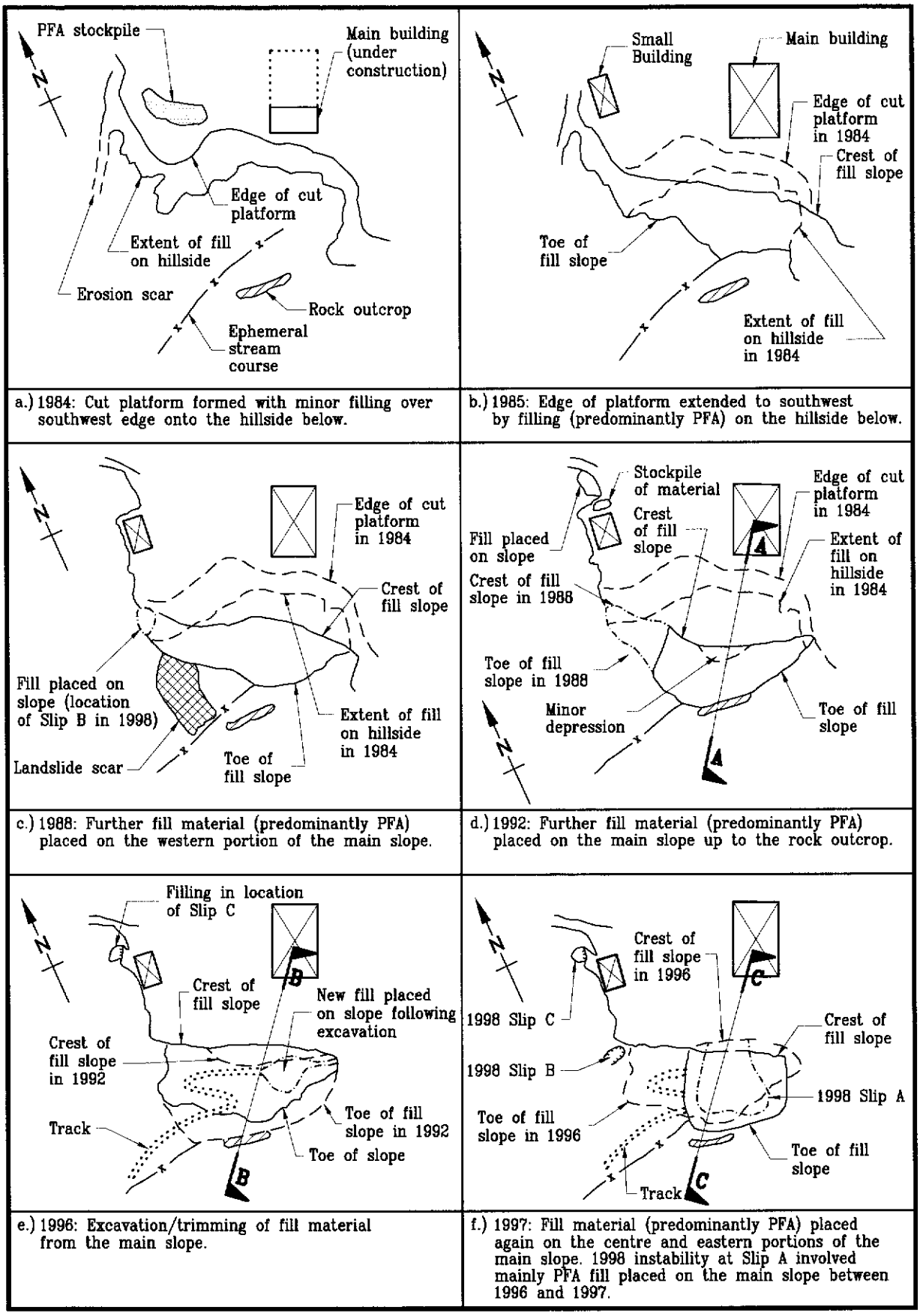


Figure 2 – Site Plan



a.) 1984: Cut platform formed with minor filling over southwest edge onto the hillside below.

b.) 1985: Edge of platform extended to southwest by filling (predominantly PFA) on the hillside below.

c.) 1988: Further fill material (predominantly PFA) placed on the western portion of the main slope.

d.) 1992: Further fill material (predominantly PFA) placed on the main slope up to the rock outcrop.

e.) 1996: Excavation/trimming of fill material from the main slope.

f.) 1997: Fill material (predominantly PFA) placed again on the centre and eastern portions of the main slope. 1998 instability at Slip A involved mainly PFA fill placed on the main slope between 1996 and 1997.

Figure 3 - Key Observations from API and Site Inspection in June 1998

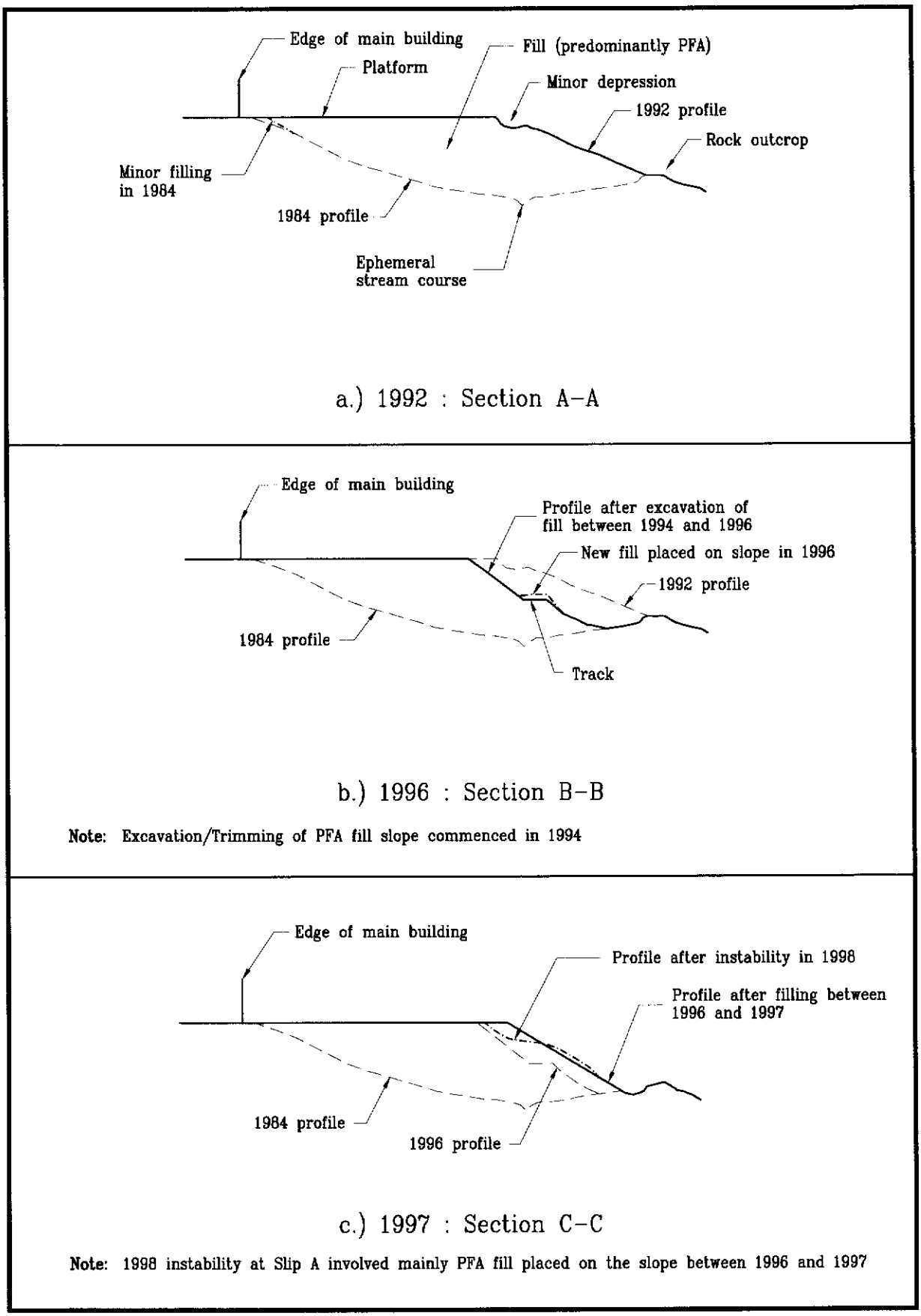
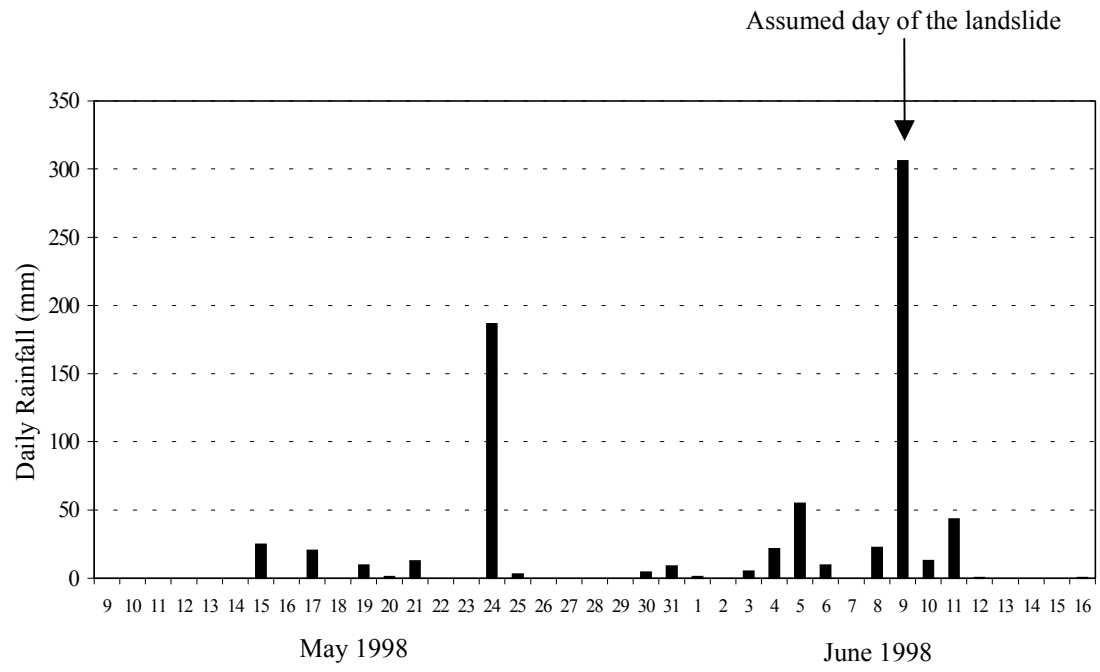
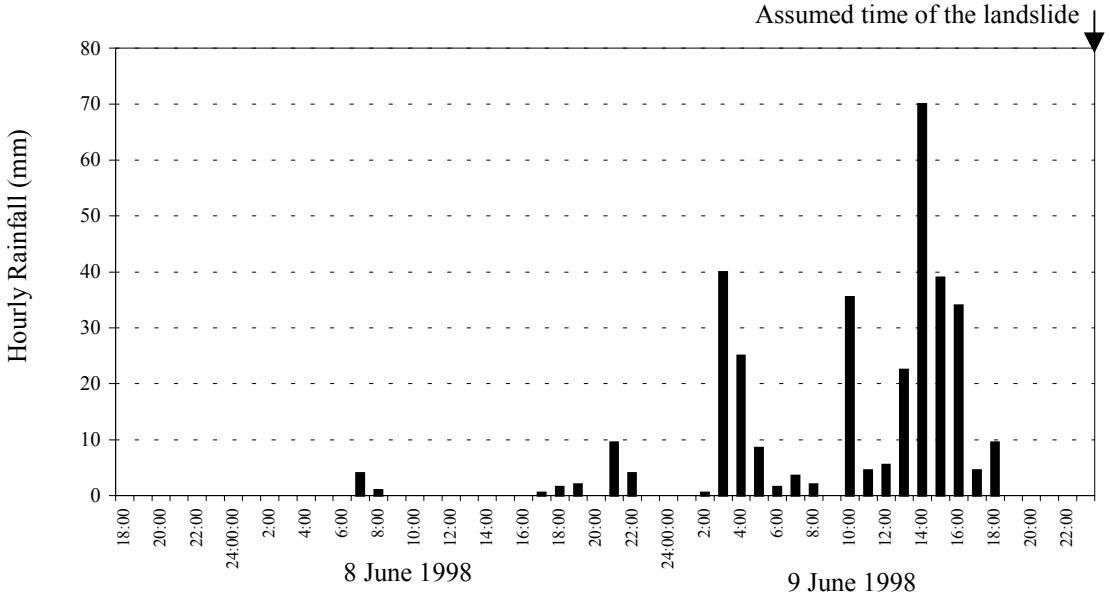


Figure 4 - Cross-sections through Landslide Slip A Location



(a) Daily Rainfall Recorded at GEO Raingauge NO7 from 9 May to 16 June 1998



(b) Hourly Rainfall Recorded at GEO Raingauge NO7 from 7 June to 9 June 1998

Figure 5 – Rainfall Records at GEO Raingauge No. N07

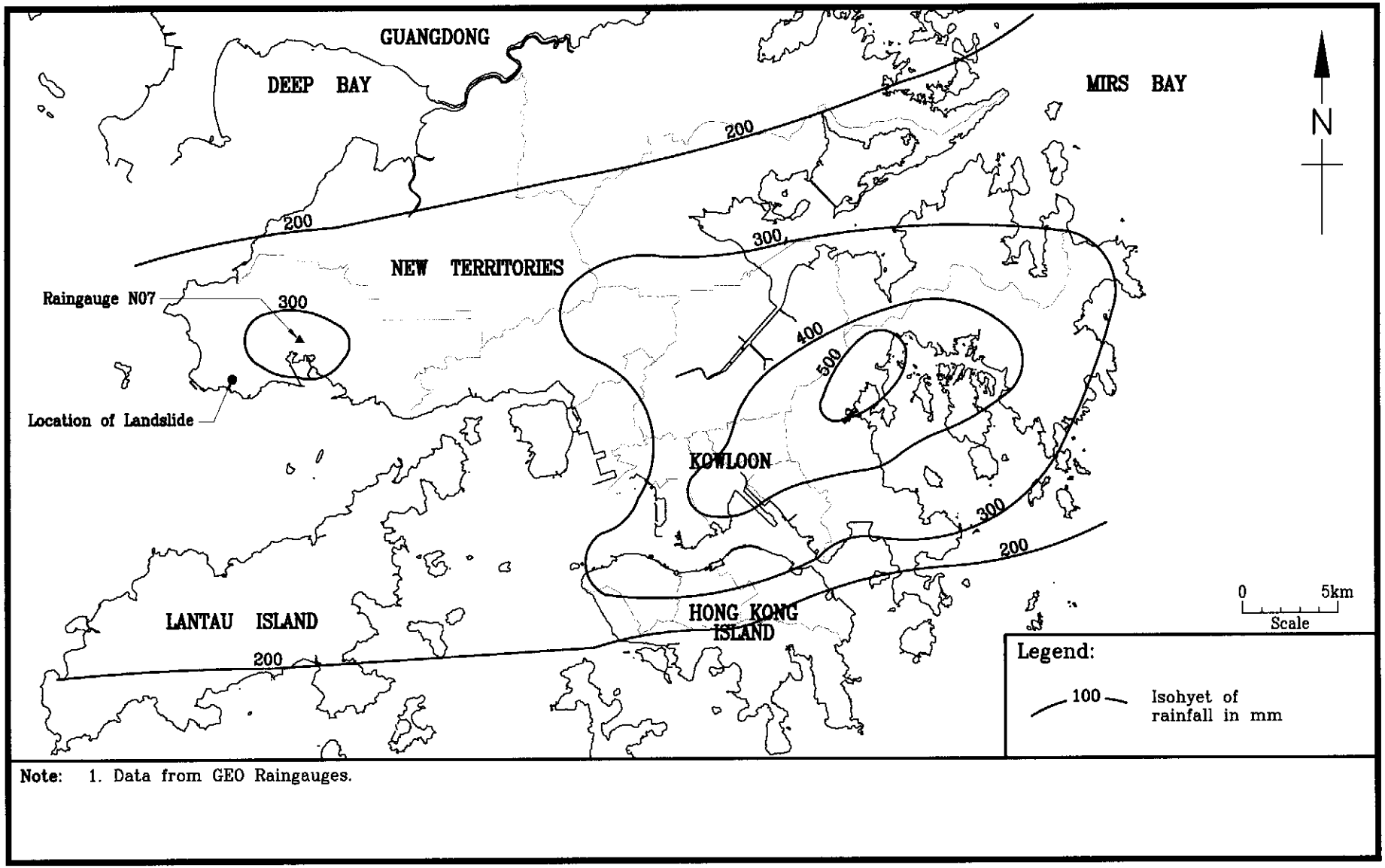


Figure 6 - Isohyets of Rainfall from 00:00 to 24:00 Hours on 9 June 1998

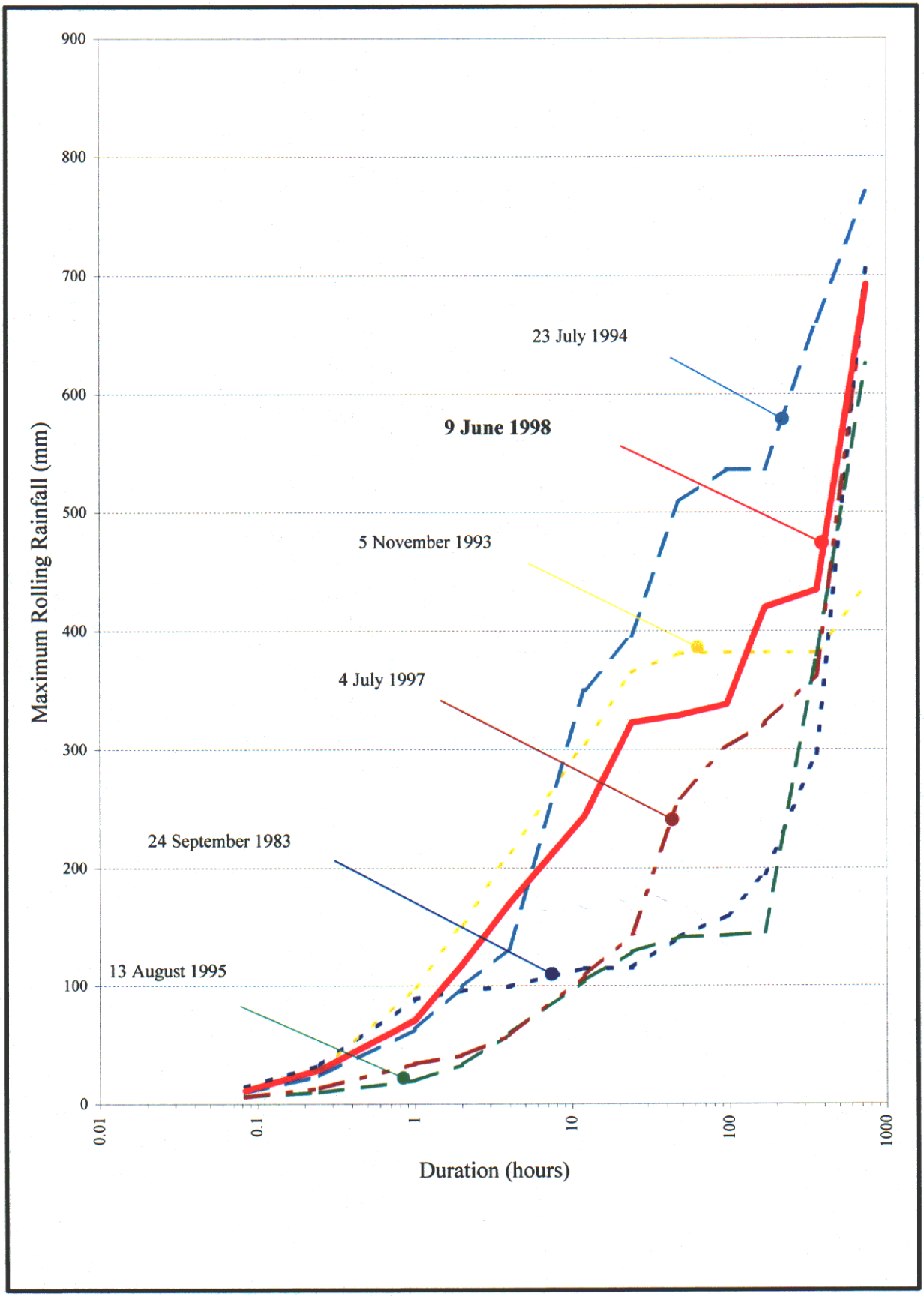


Figure 7 - Maximum Rolling Rainfall Preceding the Landslide of 9 June 1998 and that of Other Selected Major Rainstorms at GEO Raingauge No. N07

LIST OF PLATES

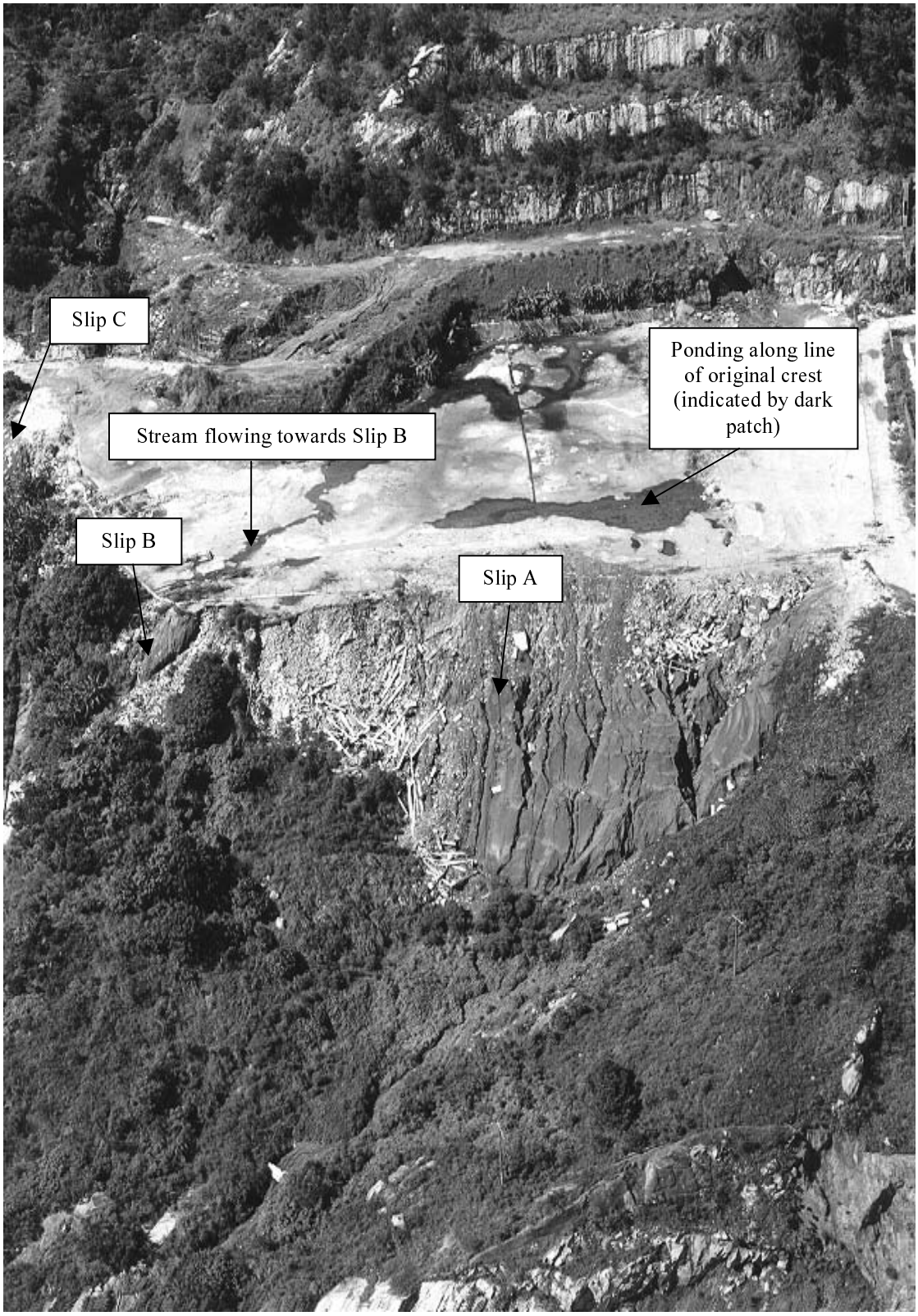


Plate 1 – Aerial View of Landslides (Photograph taken on 29 June 1998)

Plate 2 – View of Slip A from Slope Toe (Photograph taken on 18 June 1998)

Plate 3 – View of Slip B from North (Photograph taken on 18 June 1998)

Plate 4 – View of Slip B from South (Photograph taken on 18 June 1998)

Plate 5 – View of Slip B from North (Photograph taken on 18 June 1998)

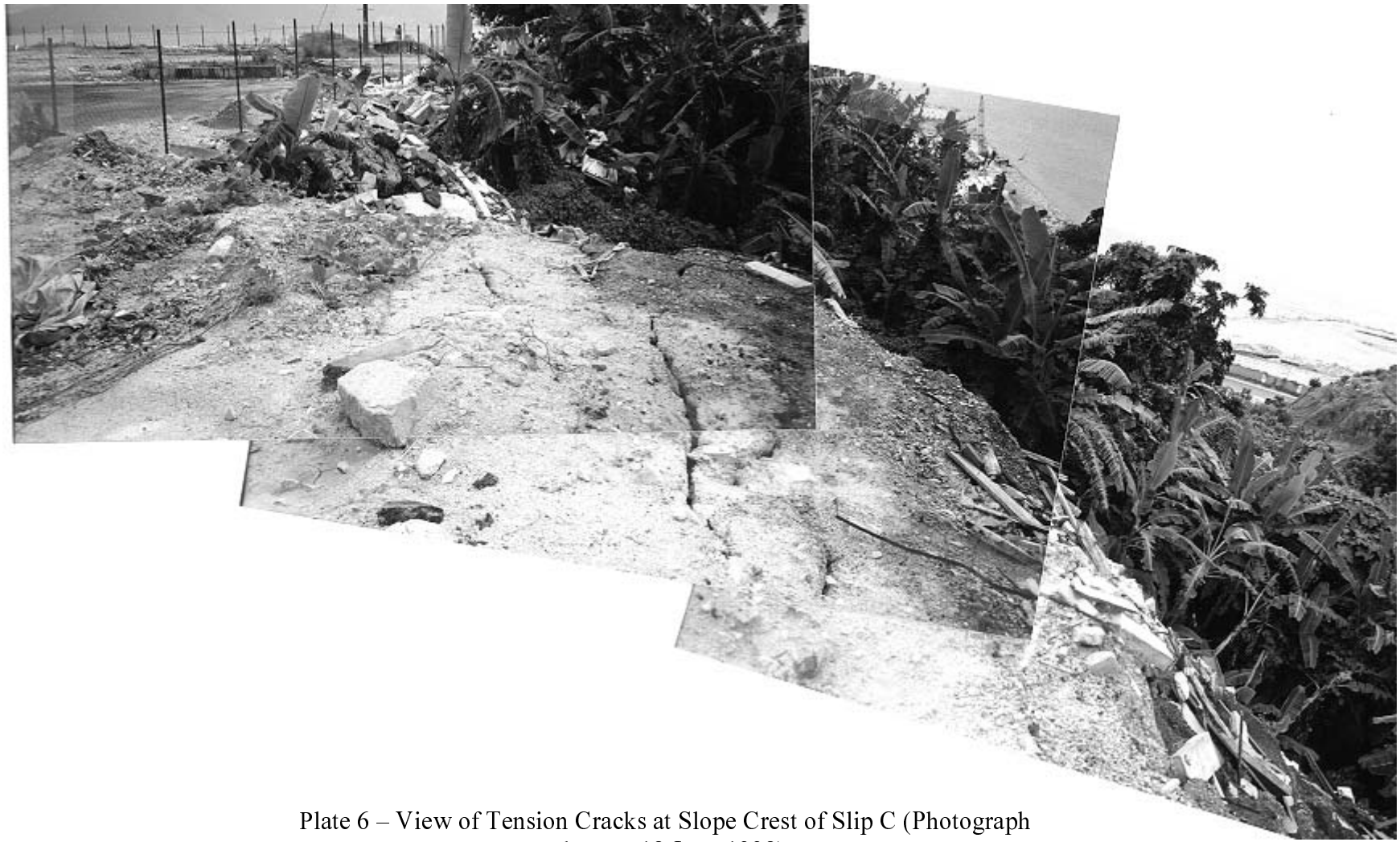


Plate 6 – View of Tension Cracks at Slope Crest of Slip C (Photograph taken on 18 June 1998)

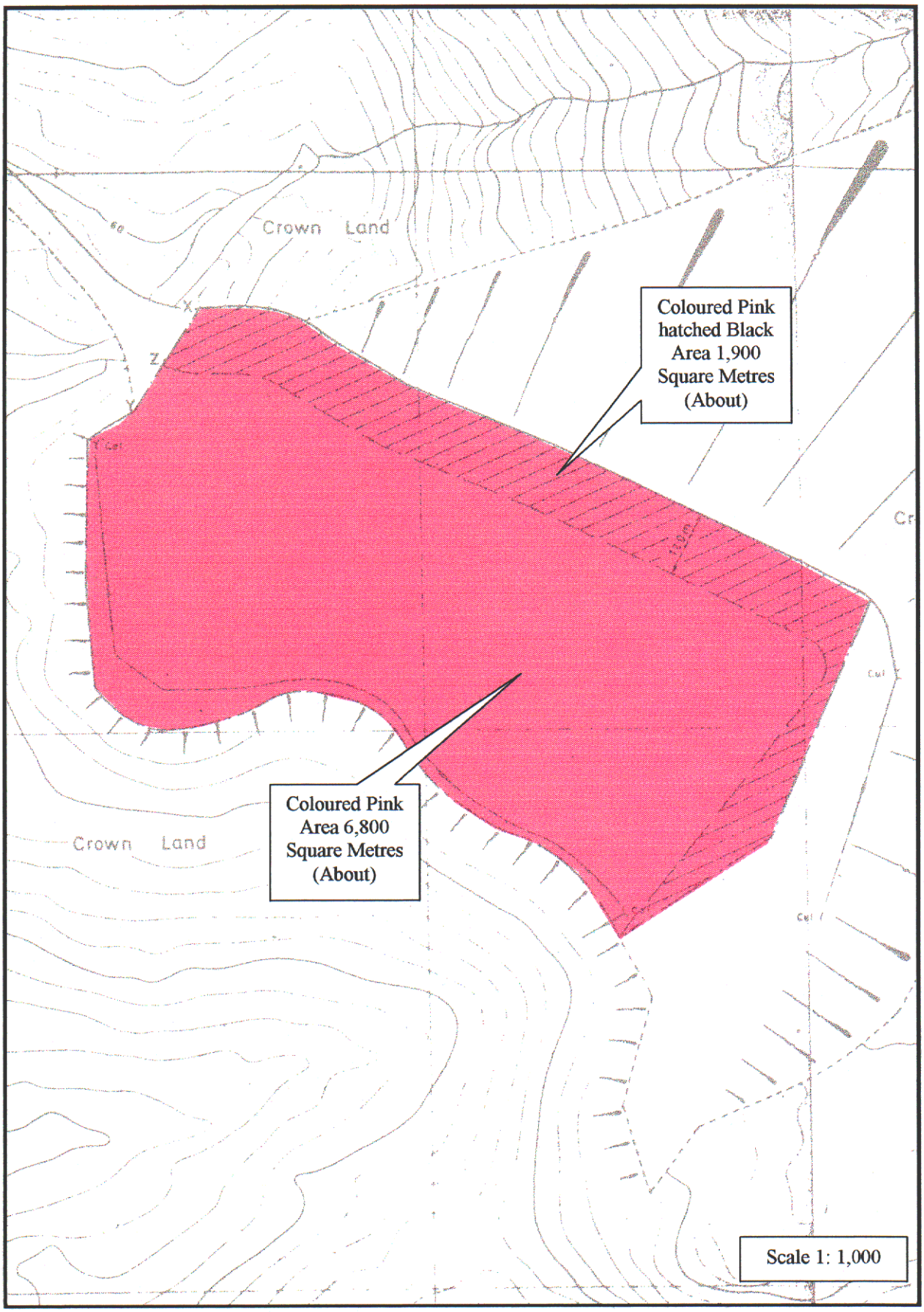
APPENDIX A

EXTRACTS FROM STT AGREEMENT 481

EXTRACTS FROM STT AGREEMENT No. 481

Clause No.	Clause
Clause 1	"THE LANDLORD LETS AND THE TENANT TAKES ALL THAT piece or parcel of ground the location of which are set forth in the First Schedule hereto and which is delineated and shown coloured pink and pink hatched black on the Plan hereto annexed……"
Clause 2 (i)	"(THE TENANT HEREBY AGREES WITH THE LANDLORD as follows:- ….) To take adequate precautions to prevent collapse of any earth banks sea walls or portions of hillside forming part of the Premises and in the event of any collapse occurring to be responsible for the repair of such collapse and removal of all silt to a Government dump to be nominated by the DLO and for any damage whatsoever which may result from any such collapse and to indemnify the Landlord from and against all costs claims demands and expenses in respect thereof;"
Clause 2 (j)	"(THE TENANT HEREBY AGREES WITH THE LANDLORD as follows:- ….) To construct and maintain at his own expense and to the satisfaction of the DLO such drains and channels, whether within the boundaries of the Premises or upon adjacent land, as the DLO may consider necessary to intercept and convey into the nearest stream-course, catchpit, channel or storm-water drain all storm-water or rain-water falling or flowing on to the Premises and to be solely liable for and to indemnify the Landlord and his officers from and against all actions claims and demands arising out of any damage or nuisance caused by such storm-water or rain-water;"
Clause 2 (k)	(THE TENANT HEREBY AGREES WITH THE LANDLORD as follows:- ….) No [sic] to do or cause or permit or suffer anything to be done at anytime in or upon the Premises or any part thereof which may be or become a nuisance or annoyance or which may cause damage or inconvenience to the Landlord or to the owners or occupiers of any adjoining or neighbouring lot or lots or premises;"
Clause 2 (l)	"(THE TENANT HEREBY AGREES WITH THE LANDLORD as follows:- ….) To permit the landlord his servants or agents at all reasonable times to enter upon the premises to view the state and condition thereof and of all defects and wants of repair or maintenance then and there found to give or leave on the Premises notice in writing to the Tenant who will within one month after such notice or sooner if required repair and make good the same in accordance with such notice and the Tenant's obligations in that behalf herein contained;"

Clause 2 (m)	"(THE TENANT HEREBY AGREES WITH THE LANDLORD as follows:-….) To indemnify and keep indemnified the Landlord, his officers, contractors and workmen against all actions suits costs claims demands and expenses whatsoever arising directly or indirectly out of or in connection with the occupation and use of the Premises by the Tenant"
Clause 4 (e)	"(IT IS HEREBY MUTUALLY AGREED BY AND BETWEEN THE PARTIES HERETO as follows:-…) That no compensation shall be payable by the Landlord to the Tenant in respect of any loss or damage caused to the Tenant or others by reason of any landslip or subsidence on or to or of or from the Premises;"
Third Schedule (19)	"The Tenant shall not dispose of any waste or surplus PFA or FBA from the Premises without the prior written consent of the DLO who may impose such directions on the Tenant as he deems necessary."
Third Schedule (23)	Any stockpiles on the premises shall be enclosed on three sides, with walls extending above the pile and 2 metres beyond the front of the pile.…
Third Schedule (34)	Any damage or obstruction caused by the Tenant, his servants or other Government properties within or adjoining the Premises shall be made good by the Government at the cost of the Tenant and the amount due in respect thereof shall be paid on demand to the Government by the Tenant…..
Third Schedule (36)	The Tenant shall not discharge or cause or permit or suffer to be discharged into any public sewer, storm-water drain, channel or stream-course any trade effluent or foul contaminated water or cooling water without the prior written consent of the DLO, who shall as a condition of granting his consent require the Tenant to provide, operate and maintain at his own expense and either within the Premises or otherwise and to the satisfaction of the DLO suitable works for the treatment and disposal of such trade effluent or foul or contaminated or cooling water."
Third Schedule (37)	"The Tenant shall take or cause to be taken all proper and adequate care skill and precautions at all times and particularly during any construction maintenance , renewal or repair work to avoid doing any damage to any Government or other existing drain, waterway or watercourse (including water main), footpath, sewer, nullah, pipe, cable, wire, utility service or any other works or installations …"
Third Schedule (38)	"The Tenant shall not interfere with any existing drain, waterway or nullah within or adjoining the Premises or have any right to the water therein."



Extract from Plan Appended to STT Agreement 481, 1 May 1984, Showing Pink and Pink Hatched Black Areas Included in the Agreement.

APPENDIX B

AERIAL PHOTOGRAPH INTERPRETATION

CONTENTS

B1. DETAILED OBSERVATIONS FROM AERIAL PHOTOGRAPH INTERPRETATION (API)

DATE	OBSERVATIONS
08.05.49	These earliest photographs show the area before any significant development in the region took place. Several tracks and footpaths are located on the natural terrain linking scattered agricultural and fishing communities. The platform site associated with the 1998 landslide events is part of a spur located between two converging southwest and west trending valleys. The major southwest trending valley is a permanent stream course whereas the west trending valley, located to the south of the platform, is probably ephemeral. In general the natural hillsides in the area are covered with grass and scattered shrubs, with numerous boulders and rock outcrops.
12.10.73	There were no significant changes in the area between 1949 and 1964. By 1973, a rough coastal track and a road along the southwest trending valley to the northwest of the platform site, have been formed.
17.12.74	The road along the southwest trending valley has been extended since 1973.
19.12.75	High level photographs indicate no significant change since 1974. A track has been formed in the area associated with the platform site.
23.11.76	Large cut slopes have been formed in connection with the construction of Lung Mun Road along the coastline to the south of the area associated with the platform site
25.03.77	No significant changes.
10.01.78	Lung Mun Road appears nearer to completion up to the agricultural area at Siu Lang Shui, to the west of the area associated with the platform site.
28.11.79	Lung Mun Road has been extended to the west to link with the large site formation/reclamation works for the power station at Tap Shek Kok.
10.10.82	The cut platform associated with the 1998 landslide events (Slips A, B and C) and the cut slope at the rear of the platform are mostly formed. The platform has been cut into the spur to the east of the southwest trending valley and to the north of the west trending valley. Another platform is also under formation in the area currently occupied by the service reservoir to the east of the landslide site. Lung Mun Road has been further extended beyond the power station.
22.12.83	The formation of the cut platform has been completed. Minor filling is noted on the southwest facing slope below the platform (referred to as the main slope). The fill has a light tone and comprises some boulders.

DATE	OBSERVATIONS
11.07.84	A building is under construction about 10 m from the crest of the main slope at the edge of the cut platform. A drainage channel has been constructed around the perimeter of the crest, which discharges via a catchpit down a stepped channel into the west trending valley below the platform. There is a stockpile of material on the platform, which is dark in tone and as such may be composed of pulverised fuel ash (PFA). Several smaller buildings/containers are located to the west of the building under formation.
03.10.85	The construction of the building beyond the crest of the main slope has been completed. The cut platform has been extended to the southwest by filling on the main slope. The platform is mostly covered with stockpiles of blocks (probably produced using PFA at the factory). The fill material placed on the main slope has a streaky appearance, with strips of fill perpendicular to the slope crest and varying between a light and mid-grey tone, which suggests that it was end-tipped from the crest of the slope at the platform edge. As a result of the filling, the catchpit and stepped channel are no longer visible. The slope surface has been severely affected by rill erosion and two relatively shallow landslide/washout scars can be seen towards the western end of the slope. Fill can also be seen within the drainage line below the fill slope. Fill has been placed on the slope associated with the location of the 1998 landslide Slip B, i.e. at the corner of the west and south facing fill slopes below the platform. Some fill has also been placed on the slope associated with Slip C since 1984. A large erosion scar is noted below and to the southwest of the west facing slope. The small buildings/containers noted in 1984 have been removed. Another building has been erected at the crest of the west facing slope close to the location of Slip C. A stockpile of material, located at the eastern end of the slope crest, is under excavation. Fill has also been stockpiled at the northern end of the building on the platform. The drainage channel located along the crest of the main slope in 1984 is no longer visible. A drainage channel has been formed on the west facing slope. This discharges directly onto the spur to the southwest of the main building.
09.09.87	The platform has been extended slightly, and the main slope surface has a different tone (mid- to dark grey) to that noted in 1985. The stockpiled material at the main slope crest noted in the 1985 photographs has been removed. A conveyor belt and a hopper/crusher unit have been set up on the edge of the platform at the western end of the main slope. There are erosion/landslide scars towards the centre of the slope and in the eastern corner immediately below the crest, and the slope surface has been affected by rill erosion.

DATE	OBSERVATIONS
	A stockpile of material can be seen at the top of the western end of the main slope above the location of Slip B. Vegetation covering the slope associated with Slip C and the west facing fill slope is denser than in 1985.
02.06.88	A small amount of fill has been placed on the main slope since 1987 as indicated by the streaky appearance of the slope surface.
21.11.88	A large, shallow landslide scar is located on the natural hillside below and to the southwest of the main slope. The upper half of this scar, which extends to the drainage line below, is covered with fill which has been placed over that noted in 1987, further extending the edge of the platform to the southwest. The fill has a uniform mid-grey tone and covers the western half of the slope. More filling is also noted in the area associated with landsliding/erosion towards the east of the slope in 1987. Rill erosion has produced deep erosion scars towards the centre of the slope, and the erosion/landslide scar noted in 1987 at the centre of the slope can still be observed. Fill characterised by a lighter tone than that comprising the main slope has been placed in the area associated with Slip B on the corner between the main slope and the west facing slope.
23.02.89	Minor extension of the platform as indicated by fill, characterised by a lighter tone, which has been placed on the western and eastern parts of the main slope. The central portion of the slope remains unchanged from 1988.
13.05.92	The central and eastern portion of the main slope has been extended significantly. Again, the streaky nature of the fill suggests that it has been end-tipped from the crest of the slope. The slope is affected by rill erosion. Material, with a light tone, has been stockpiled at the eastern end of the slope. A depression is noted at the centre of the slope immediately below the crest, which may suggest localised slumping and/or erosion of the fill. The area associated with Slip B at the western end of the main slope has not been affected by the extension of the fill. Some fill has been placed on the slope to the north of the area associated with Slip C, and a stockpile of material characterised by a light tone can be seen adjacent to the north end of the small building.
05.12.93	High altitude photographs with poor resolution. No significant changes apparent.
08.11.94	A track has been excavated diagonally across the upper to middle portion of the main slope. Part of the fill above this track has also been excavated.

DATE	OBSERVATIONS
08.11.94	Several small erosion scars are noted close to the area associated with Slip B. However, this area has not been affected by the excavation to the main slope.
23.11.95	High level photographs with good resolution. Much more of the fill from the main slope has been excavated. A single track is located diagonally across the middle portion of the slope. A small amount of grey fill has been placed on the slope in the area associated with Slip B. Filling is also noted in the area associated with Slip C.
22.10.96	The track now extends from the top of the main slope in the east to the southern end of the ephemeral stream course, above Lung Mun Road. At the southern end a small pile of fill has been tipped. The track does not appear to connect with the road in any way, and the reason for its formation is not clear. The track now zigzags across the slope and its elevation has been lowered since 1994/5. Boulders and blocks of material characterised by a light tone can be seen towards the toe of the main slope. More recent fill has been placed over the eastern portion of the main slope. The fill is dark grey in colour. At the top of this more recent fill, a track has been formed. Grey coloured fill is exposed in the area associated with Slip B, as noted in 1995. Fill has been placed on the slope in the area associated with Slip C.
21.11.96	More fill has been placed over the previously excavated portion of the main slope.
16.05.97	The extent of the track and more recent fill has now been increased across the main slope. The fill has a lighter grey colour than in 1996. There are deep erosion scars in the eastern corner of the slope. The area associated with Slip B appears the same as in 1996. However, more material has been placed in the area associated with Slip C.
01.11.97	The majority of the track formed on the main slope is now covered with more recent, grey fill. The fill is located on the central and eastern portion of the slope. The slope has been affected by rill erosion. The main and small buildings and associated stockpiles of blocks are still present on the platform. The areas associated with Slips B and C appear to be unchanged from 1996 and May 1997 respectively.

B2. LIST OF AERIAL PHOTOGRAPHS USED IN THIS STUDY

DATE	PHOTOGRAH NUMBER	FLYING HEIGHT (Feet)
08.05.49	Y1885/6	20000
18.11.54	Y2721/2	29200
31.01.63	Y8967/8	3900
13.12.64	Y12960/1	12500
12.10.73	5011/2	1600
17.12.74	10423/4	2000
19.12.75	11806/7	12500
23.11.76	16564/5	12500
25.03.77	17960/1	12500
10.01.78	20737/8	12500
28.11.79	28119/20	10000
10.10.82	44551/2	10000
22.12.83	52162/3	10000
11.07.84	55179/80	2500
03.10.85	A2325/6	4000
09.09.87	A10183/4	4000
02.06.88	A12861/2	4000
21.11.88	A15782/3	4000
23.02.89	A16652/3	4000
13.05.92	A31281/2	4000
05.12.93	CN5398/9	10000
08.11.94	A39911/2	4000
23.11.95	CN12334/5	10000
22.10.96	CN15144/5	3500
21.11.96	CN16206/7	10000
16.05.97	CN17024/5	4000
01.11.97	CN19040/1	10000