SECTION 2: DETAILED STUDY OF THE LANDSLIDES AT NOS. 1 TO 5 CHUNG SHAN TERRACE LAI CHI KOK ON 4 JUNE 1997

Halcrow Asia Partnership Ltd

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FOREWORD

This report presents the findings of a detailed study of four landslides (reported in GEO Incident Report Nos. MW97/6/20 and MW97/6/30) which occurred on 4 June 1997 on cut slopes behind Nos. 1 to 5 Chung Shan Terrace, Lai Chi Kok. Debris from the landslides affected residential properties below the slopes. 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 landslides. The scope of the study was generally limited to site reconnaissance, desk study and analysis. Recommendations for follow-up actions are reported separately.

The report was prepared as part of the 1997 Landslip Investigation Consultancy (LIC), for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 68/96. This is one of a series of reports produced during the consultancy by Halcrow Asia Partnership Ltd (HAP). The report was written by Mr P Smith and reviewed by Dr R Moore and Dr X D Pan. The assistance of the GEO in the preparation of the report is gratefully acknowledged.

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CONTENTS

1. INTRODUCTION

On the morning of 4 June 1997, four landslides occurred on the cut slopes immediately northeast of Chung Shan Terrace, Lai Chi Kok, New Territories (Figure 1). Three of the landslides (A1 to A3 in Figure 1) affected an unregistered cut slope behind Nos. 2 and 3 Chung Shan Terrace. The fourth landslide (B in Figure 1) affected the cut slope, registered as Slope No. 11NW-A/CR261, behind Nos. 4 and 5 Chung Shan Terrace (Figure 1). Debris from the landslides came to rest in the open space between the toe of the slopes and the buildings of Chung Shan Terrace. No fatalities or injuries were reported.

Following the landslides, Halcrow Asia Partnership Ltd (the 1997 Landslip Investigation Consultants) carried out a detailed study of the failures for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 68/96. This is one of a series of reports produced during the consultancy by Halcrow Asia Partnership Ltd (HAP).

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 landslides. The scope of the detailed study was limited to site reconnaissance, desk study and analysis. Recommendations for follow-up actions are reported separately.

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

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

(b) analysis of rainfall records,

(c) interviews with witnesses and persons affected by the landslides,

(d) detailed site observations and measurements at the landslides, and

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

2. THE SITE

2.1 Site Description

The locations of the landslides are shown in Figure 2.

At the location of landslides A1 to A3, the cut slope is about 5 m high and inclined at about 70° to the horizontal. The slope is unsealed and essentially bare and there is no surface drainage provision at its crest.

At the location of landslide B, the cut slope is about 12 m high and inclined at about 50° to the horizontal. Its surface was predominantly covered with small shrubs and grass prior to the landslides. U-channels were present at its crest and toe. Prior to the landslide, the slope was crossed at about mid-height by a water-carrying pipe and further upslope by a group of pipes. All the pipes were above the slope surface (Figure 2, Plate 1).

The ground upslope of the cut slopes is lightly vegetated with trees and shrubs and inclined typically between 30° and 40° to the horizontal. It extends upslope towards an area of level ground used as a sitting-out area (Figure 2). The sitting-out area is covered with grass and provides a sizeable area through which infiltration of surface water may occur. Castle Peak Road is located beyond the sitting-out area, some 25 m from the crest of the cut slope.

A concrete retaining wall, about 1 m to 2 m high, is present along the toe of the cut slopes. There is a U-channel at the crest of the retaining wall along most of its length and a fence is present on the retaining wall behind Nos. 4 and 5 Chung Shan Terrace. The buildings of Nos. 1 to 5 Chung Shan Terrace are located typically between about 1.5 m and 4 m from the retaining wall.

Landslides A1 to A3 affected Private Lot Nos. KCTL 449 and 3326RP and adjacent Government land (Figure 3). Landslide B predominantly affected Private Lot Nos. 3326RP and KCTL 425RP but the main scarp extended upslope into Government land (Figure 3). At the time of preparing this report, the party responsible for maintenance of the Government Land affected by the failures was still being determined by the Lands Department.

2.2 Site History and Past Landslides

The history of the site was established from a review of aerial photographs (Table 1) and available documentary information. Information sources consulted during the detailed study are summarised in Table 2.

Photographs taken in 1949 show that the platform now occupied by Nos. 2 to 5 Chung Shan Terrace had been formed by cutting and filling of a natural hillside. Castle Peak Road had been constructed and at the time carried two lanes of traffic. The cut slopes, retaining walls and earlier buildings (subsequently demolished) were completed by 1954 (GCO, 1988a). Re-alignment and widening of the Castle Peak Road to its present four lanes were completed by 1963. Some filling above the crest of the cut slopes took place during these works to form the sitting-out area at the crest. No significant modifications to the slopes or the buildings are apparent on aerial photographs taken between 1963 and 1973.

Aerial photographs taken in 1973 show a small failure on the cut slope behind No. 5 Chung Shan Terrace, about 10 m north of the location of 1997 landslide B (Figure 3). The photographs indicate that surface protection was applied to the 1973 failure scar after the incident, along with improvement to the surface drainage system.

Between 1978 and 1984, the earlier buildings at the location of Nos. 4 and 5 Chung Shan Terrace were demolished. The platform remained vacant until sometime between 1988 and 1991 when the present buildings were constructed. Localised surfacing works to the

slope behind No. 4 Chung Shan Terrace, associated with the occurrence of a minor landslide (see below), were carried out in about 1992. The earlier buildings at Nos. 2 and 3 Chung Shan Terrace were demolished in 1992 and the subsequent construction of buildings that currently occupy the platform was completed by 1995.

According to GEO's landslide database, a landslide (GEO Incident Report No. MW92/5/68) occurred on the cut slope behind No. 4 Chung Shan Terrace on 8 May 1992. In the Incident Report prepared by the GEO, it is noted that approximately 3 m^3 of material failed from the middle part of the cut slope and came to rest behind the fence at the crest of the retaining wall. Infiltration was reported as the cause of failure. The 1992 minor landslide occurred at the same location as landslide B in 1997 (Figure 3).

Following the landslide incident in 1992, the GEO advised the Buildings Department (BD) that repair and maintenance works would be needed. On 14 September 1992, the BD issued an Advisory Letter to Sinotrade Development Ltd (SDL), who manage Nos. 4 and 5 Chung Shan Terrace, suggesting that they provide "surface protection to the slip surface" and relocate "the 50 mm water pipe away from the slope" (Figure 2). The slope protection works had been completed by November 1995. Reminders of the need to relocate the water pipe were sent to the owners by the BD on 11 December 1995 and 14 May 1996 respectively, but the relocation of the pipe had not been carried out prior to the 1997 failures.

2.3 Previous Studies and Assessments

In April 1978 Binnie & Partners (B & P), the consultants appointed by Government to prepare the 1977/78 Catalogue of Slopes, inspected the retaining wall at the toe of the cut slope behind Nos. 3 and 4 Chung Shan Terrace. The slope was registered as No. 11NW-A/R6 in the 1977/78 Catalogue of Slopes (Figure 3). In the field sheet prepared for the feature following the inspection (B & P, 1978a) it is recorded that there were no signs of seepage or distress associated with either the retaining wall or the cut slope above.

The retaining wall at the toe of the cut slope behind No. 5 Chung Shan Terrace was registered as No. 11NW-A/R7 in the 1977/78 Catalogue of Slopes (Figure 3). It is noted in the field sheet for the feature (B & P, 1978b), that there were no signs of distress and that weepholes positioned 1.5 m above the toe of the wall were wet. For the cut slope above the wall, no signs of seepage or distress were reported.

In the late 1980s, retaining wall No. 11NW-A/R7 and part of retaining wall No. 11NW-A/R6 and the associated cut slope, were upgraded as part of the site formation for the redevelopment of Nos. 4 and 5 Chung Shan Terrace. The 1997 landslide B affected this part of the cut slope. Fugro (Hong Kong) Ltd (FHKL) completed the design of the site formation works in 1988. The design included provision for constructing a retaining wall in front of the existing concrete retaining wall and cutting back the cut slope above to 50°. The geological model, the assumptions and the results of the stability assessment for the design at the location of landslide B are summarised in Figure A1 of Appendix A. The site formation submission was checked by the Geotechnical Control Office (GCO, renamed GEO in 1991) in 1988 (GCO, 1988a) and was approved by the Buildings and Lands Department (BLD, subsequently renamed BD) in August 1988.

In July 1988 the Planning Division of the GCO completed a detailed Stage 1 Study of the southern part of retaining wall No. 11NW-A/R6 (behind No. 3 Chung Shan Terrace) and the wall behind No. 2 Chung Shan Terrace (which was unregistered at the time) together with the cut slope above the walls (GCO, 1988a). The northern part of wall No. 11NW-A/R6 was excluded from the study because of the earlier assessment and upgrading works at Nos. 4 and 5 Chung Shan Terrace. The Stage 1 Study report indicated that the cut slope had an adequate factor of safety but that the stability of the walls was inadequate. In the study it was recommended that wall No. 11NW-A/R6 and the wall behind No. 2 Chung Shan Terrace should be registered as "CR-feature(s)", and that a Stage 2 Study be carried out. The retaining wall behind No. 2 Chung Shan Terrace was subsequently registered as No. 11NW-A/R12 in October 1988 (Figure 3).

The Stage 2 Study of the southern part of wall No. 11NW-A/R6, wall No. 11NW-A/R12 and the cut slope above included a stability assessment of a section about 5 m northwest of landslide A1, based on site-specific ground investigation that included boreholes (GCO, 1991). The location of the section together with the adopted geological model, assumptions and results of the assessment are summarised in Figure A2 of Appendix A.

The factor of safety of the potential failure surface, which most closely represents the rupture surface of landslide, A1 was about 1.5. It was also noted that "local slips in the residual soil" had a "marginally inadequate" factor of safety of 1.18. It was considered, however, that "the critical slip is quite small and shallow and (that) its failure would not affect the houses below". It was further noted that the stability of this part of the slope could "be maintained if adequate drainage is provided to minimise surface erosion and infiltration." The retaining walls were considered to have adequate factors of safety.

Following the Stage 2 Study, the BLD advised the owners of Nos. 2 and 3 Chung Shan Terrace in June 1992 to "provide (a) surface channel along (the) slope crest and behind the wall .... clear vegetation from the slope (and) .... protect the cleared slope surface with chunam plaster". The absence of surface protection and drainage on the slope, noted by HAP during the investigation of the landslides, suggests these works were not carried out before the 1997 failures occurred.

In 1992 John Connell & Associates Ltd (JCAL) were engaged as the consultants for the redevelopment of Nos. 2 and 3 Chung Shan Terrace. JCAL prepared a geotechnical report for the site formation works and assessed the stability of the existing cut slope. They reported that the cut slope had "a minimum factor of safety of 1.48" and was considered to be "adequately safe" (JCAL, 1992). The geological model, assumptions and results of the assessment are summarised in Figure A3. The geotechnical report and associated site formation drawings were submitted to the BLD in November 1992. The submission was checked by the GEO in December 1992 (GEO, 1992) and was approved by BLD in January 1993.

In 1992, the GEO initiated the consultancy agreement entitled "Systematic Inspection of Features in the Territory" (SIFT,) which, inter alia, aims to systematically search for features not registered in the 1977/78 Catalogue of Slopes and to update information on previously registered features, based on studies of aerial photographs and limited site

inspections. The part of the feature behind Nos. 1 to 3 Chung Shan Terrace was assigned a "Work in Progress" status in 1995, as at that time the area was being redeveloped. The part of the feature behind Nos. 4 and 5 Chung Shan Terrace was assigned to SIFT Class "C1", which is for slopes "assumed (to have been) formed pre-1978".

In July 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. The wall behind Nos. 4 and 5 Chung Shan Terrace (i.e. previously wall No. 11NW-A/R7 and the northern part of wall No. 11NW-A/R6) and the cut slope above were re-registered as Slope No. 11NW-A/CR261 (Figure 3). In the SIRST field sheet prepared in August 1995, it was noted that there were no signs of seepage or distress. The feature was not recommended for further study as it was considered to have been "checked by GEO" during the earlier redevelopment of Nos. 4 and 5 Chung Shan Terrace.

2.4 Subsurface Conditions

Sheet 11 of the Hong Kong Geological Survey 1:20 000-scale map series (GCO, 1986) and the Engineering Geology Map of the Geotechnical Area Studies Programme (GASP) for the Central New Territories (GCO, 1987) indicate that the site is underlain by coarse-grained granite.

Ground investigations for the Stage 2 Study of the retaining wall and cut slope behind Nos. 1 to 3 Chung Shan Terrace were carried out by Geotechnics & Concrete Engineering (GCE) in September 1990. The investigation included two vertical boreholes, two trial pits and two surface strips on the cut slope and six coreholes through the retaining wall. The locations of the exploratory holes are shown in Figure 3.

A geological section showing the ground conditions near the location of landslide A1, interpreted from GCE's borehole information (GCE, 1990), is presented in Figure 4. The information suggests that the crest of the slope has a cover of about 2 m of fill, overlying about 2 m of residual soil that comprised medium-dense to dense clayey sand. The residual soil overlies about 7 m of completely decomposed granite and below that, highly decomposed granite. The highest observed water level, based on monitoring of piezometers installed in boreholes at the site between July and October 1990, was well below the base of landslide A1 (Figure 4).

The ground investigations for the redevelopment of Nos. 4 and 5 Chung Shan Terrace (see Section 2.3 above) were carried out by Oriental Boring & Engineering Company Ltd (OBECL) in 1988. The investigation included four vertical boreholes, three horizontal boreholes and two trial pits (Figure 3).

A geological section showing the ground conditions near the location of landslide B, interpreted from the OBECL ground investigation data (1988), is presented in Figure 5. Borehole BH2 proved "completely weathered" granite to a depth of about 8 m, overlying about 7 m of "highly weathered" granite and below that, slightly "weathered" granite. According to the geotechnical report on the site formation aspects of the redevelopment of

Nos. 4 and 5 Chung Shan Terrace (FHKL, 1988), records of piezometers made between May 1988 and June 1988 "indicate that there is generally no groundwater table above rockhead in the hillside".

3. THE LANDSLIDES

3.1 Time of Failure

The time of failure of landslides A1 to A3 (GEO Incident Report No. MW97/6/30) behind Nos. 1 and 3 Chung Shan Terrace was reported to GEO to be at 07:00 hours on 4 June 1997. A resident of No. 4 Chung Shan Terrace witnessed landslide B (GEO Incident Report No. MW97/6/20) and reported the time of failure as 08:30 hours on 4 June 1997. A Landslip Warning was issued at 07:45 hours on 4 June 1997.

3.2 Description of the Landslides

A cross-section through landslide A1, the largest of the landslides affecting the cut slope behind Nos. 1 to 3 Chung Shan Terrace, is shown in Figure 4 and a photograph of the landslide taken after completion of urgent repair works is shown in Plate 2.

The rupture surface of landslide A1 was estimated to be about 8 m wide, 6 m long and 0.5 m deep. The volume of the displaced debris was estimated to be about 10 m^3. Landslide debris overtopped the retaining wall at the toe of the slope and accumulated behind Nos. 2 and 3 Chung Shan Terrace.

Landslides A2 and A3 were smaller (Plates 3 and 4). Landslide A2 was about 4 m wide, 2 m long and 0.5 m deep, and landslide A3 was about 2 m wide, 2 m long and 0.4 m deep (Plates 3 and 4). The total volume of these two landslides was about 4 m^3. According to GEO's Incident Report prepared following an inspection on 4 June 1997, the debris was deposited at the toe of the retaining wall behind Nos. 2 and 3 Chung Shan Terrace. There is no record of groundwater seepage in the main scarps on the incident report. Application of shotcrete to the landslide scars as part of the urgent repair works prevented HAP preparing detailed descriptions of materials involved in the failures. The geology of the site, established from previous ground investigations (Figure 4) and observation of nearby exposures on the cut slope, suggests that the failures would have involved predominantly completely decomposed granite.

The morphology of the landslide scars and debris suggests that the failures occurred principally by shallow sliding. There is insufficient reliable information on debris deposition to enable their mobility to be assessed.

HAP noted that there was no surface protection or drainage provision on the slope, during inspections carried out as part of the investigation. This suggests that the recommendation of the 1992 Advisory Letter (see Section 2.3 above) had not been carried out before the 1997 landslides.

A cross-section through landslide B is shown in Figure 5 and photographs taken soon after the failure are presented in Plates 5 and 6.

The rupture surface of the landslide was about 16 m wide, 7 m long and up to 1.5 m deep. The estimated volume of the landslide was about 85 m^3. The material exposed in the main scarp was completely decomposed granite consisting of predominantly medium-dense brown mottled light yellow silty fine- to coarse-grained sand. There was no evidence of adversely oriented discontinuities or groundwater seepage from the main scarp. Inspection of intact and broken sections of the U-channel near the crest of the main scarp found no evidence of blockage that may have caused overflow of surface water onto the slope before failure.

Landslide debris destroyed the fence on the retaining wall and piled up behind No. 4 Chung Shan Terrace. The landslide engulfed the slope protection put in place after the 1992 incident, destroyed a U-channel on the slope and displaced a catchpit associated with the U-channel (Plate 6). The landslide also severed the water pipes on the surface of the slope that caused water leakage and erosion of a channel through the landslide debris before the water flow was brought under control by installation of a stopcock on the pipe. Vegetation on debris rafts in the upper part of the landslide debris remained upright while vegetation on rafts at the toe toppled forward. The presence of the rafts suggests that this failure also occurred principally by shallow sliding. The travel angle of landslide B cannot be established because the run-out of the debris was constrained by a wall behind No. 4 Chung Shan Terrace.

Following the landslides, BD implemented urgent repair works including removal of landslide debris, reinstatement of the slope drainage and protection of the landslide scars, at the recommendation of GEO. BD served a DH Order on the owners of Nos. 4 and 5 Chung Shan Terrace on 3 November 1997 at the recommendation of GEO.

4. RAINFALL

The nearest GEO automatic raingauge No. N04 is located about 870 m northwest of the site at Kai Kwong Lau, Cho Yiu Estate, Lai King (Figures 1 and 7). The daily rainfall between 1 May and 10 June 1997 is shown in Figure 6a. A total of 296.5 mm of rainfall was recorded in the 15 days before 07:00 hours on 4 June 1997.

Hourly rainfall between 2 June 1997 and 5 June 1997 is presented in Figure 6b. Rainfall was continuous between 01:30 hours and 06:00 hours on 4 June 1997 and intensified between 06:00 hours and 07:00 hours immediately before the reported time of landslides A1 to A3. The isohyets of rainfall between 01:30 hours and 08:30 hours on 4 June 1997 are shown on Figure 7.

Tables 3 and 4 present the estimated return periods of maximum rolling rainfall recorded before landslides A1 to A3 and B1 respectively for selected durations, based on historical rainfall data at the Hong Kong Observatory (Lam & Leung, 1994). The analysis for Incident No. MW97/6/30 includes rainfall recorded before 7:00 hours, the time that the failure was reported to GEO. The analysis for Incident No. MW97/6/20, includes rainfall recorded before 08:30 hours, the time that the landslide was reported to have occurred. The 1-hour rainfall for Incident No. MW97/6/30, and the 4-hour rainfall for Incident No. MW97/6/20,

were the most severe, with corresponding estimated return periods of about 40 years and 50 years respectively.

Figure 8 shows the maximum rolling rainfall at raingauge No. N04 for selected major rainstorms. The rainfall was the highest recorded for durations of between 15 minutes and 9 hours for landslides A1 to A3 and between 15 minutes and about 15 hours for landslide B.

5. PROBABLE CAUSES OF FAILURE

5.1 Landslides A1, A2 and A3

The morphology and geology of the three landslide scars suggest that they were shallow sliding failures predominantly within completely decomposed granite. The close correlation of the severe rainstorm on 4 June 1997 and the reported time of the failures indicate that they were probably triggered by rainfall.

Based on the field observations, there was no evidence of unusually weak materials, discontinuities or other adverse geological features. The failures were not typical of major washout incidents resulting from concentrated surface water flow nor was there any evidence of a general rise in the base groundwater table. Rainfall on 4 June 1997 was particularly severe and rainfall falling on the cut slope and surface run-off from the upslope area (as there was no surface drainage provision at the slope crest) were probably the principal sources of water. It is postulated that the most likely cause of failure was infiltration into the vegetated slope followed by downslope seepage flow (i.e. non-vertical) along preferential flowpaths resulting in the development of local seepage pressures in the near-surface soils.

5.2 Landslide B

The morphology and geology of the landslide scar and debris suggest that the failure probably involved shallow sliding predominantly within completely decomposed granite. Landslide B occurred about 90 minutes after landslides A1 to A3, and was probably triggered by severe rainfall.

As with landslides A1 to A3, there is no evidence of unusually weak materials, discontinuities or other adverse geological features. The landslide was not typical of a major washout incident resulting from concentrated surface water flow nor was there any evidence of a general rise in the base groundwater table. Inspections of the broken and remaining sections of the crest U-channel by HAP immediately following the landslide did not reveal any evidence of blockage that may have resulted in overtopping of the U-channel.

There is no known observation or record of water pipe leakage prior to the failure. The coincidence of the time of the landslide occurrence and severe rainfall suggests that the failure was probably triggered by rain.

It is considered that the landslide was most probably caused by direct infiltration of rainwater into the predominantly unprotected cut slope followed by downslope seepage flow and the development of local seepage pressures in the near-surface soils.

6. DISCUSSION

Landslides A1 to A3, behind Nos. 2 and 3 Chung Shan Terrace, occurred on a cut slope which had been subjected to a detailed stability assessment in 1991, and the calculated safety margin against shallow failures in the upper part of the slope were only just below the required standard. However, slope works recommended in the Advisory Letter following the assessment were not carried out by the owners prior to the 1997 landslides.

The same cut slope behind Nos. 2 and 3 Chung Shan Terrace was assessed as being up to standard, as part of the site formation design for the redevelopment in 1992. The maximum slope angle considered in this assessment, however, appears to be lower than that considered in the 1991 study and observed on site. The reasons for this discrepancy are not known.

Landslide B occurred on a cut slope which was upgraded during the private redevelopment of Nos. 4 and 5 Chung Shan Terrace in 1990. This slope had a history of minor failures both before and after the upgrading works.

Monitoring of piezometers installed in the cut slopes, carried out for the above assessments and site formation design, indicated that the base groundwater table was well below the observed failure surfaces. The possible development of local seepage pressures in the near-surface soils resulting from surface infiltration was not considered in the assessments.

The previous assessments were based on the assumption of saturated shear strengths (determined from site-specific ground investigation and laboratory tests) and zero pore water pressure. The assumed shear strengths (Appendix A) seem reasonable in that they are consistent with parameters typically taken for similar materials and that no evidence of unusually weak materials, discontinuities or other adverse geological features was found. Hence, the shallow failures were likely to be due to the build-up of local positive pore water pressures. It is probable that these resulted from development of seepage pressure following direct infiltration or concentrated water ingress after localised erosion by surface water flow down the slope face.

7. CONCLUSIONS

It is concluded that the landslides that affected the cut slopes behind Nos. 1 to 5 Chung Shan Terrace were triggered by severe rainfall.

The failures were probably caused by direct infiltration of rainfall leading to downslope seepage flow and consequential development of seepage pressure in the near-surface soils. The lack of surface protection at the concerned slopes, together with the

absence of surface drainage at the crest of the cut slope at the location of landslides A1 to A3, were probably contributory factors to the failures.

The failures occurred at slopes that were previously subjected to detailed stability assessments.

8. REFERENCES

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Lam, C.C. & Leung, Y.K. (1994). Extreme rainfall statistics and design rainstorm profiles at selected locations in Hong Kong. Royal Observatory, Hong Kong, Technical Note no. 86, 89 p.

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LIST OF TABLES

Table 1 – Summary of Aerial Photograph Interpretation

Year	Observation
1949	Chung Shan Terrace under construction. Platforms created for the development, by cutting and filling. Cut slope formed to the rear of the platforms where Nos. 2 to 4 Chung Shan Terrace are to be constructed. Access road to properties is present and supported in sections by large fill bodies. The foundations for Nos. 2 to 4 Chung Shan Terrace are in place. Castle Peak Road (2-lane) constructed with vegetated slopes adjacent to the road. A verge is present above 1997 failure sites.
1963	Castle Peak Road widened to 4 lanes. The sitting-out area directly above the 1997 failures has been widened by the addition of fill. Nos. 1 to 5 Chung Shan Terrace have been constructed. A retaining wall can be seen at the rear of Nos. 4 and 5, and there is a lineament to the rear of Nos. 2 and 3 suggesting that a retaining structure has been built there also.
1973	Cut slope behind No. 5 Chung Shan Terrace has recently been re-surfaced. The configuration of the re-surfaced section indicates a minor failure may have previously occurred.
1978	The section of the slope previously re-surfaced appears more clearly in these photographs. A vertical lineament on the face of the failure suggests that surface drainage channels have been constructed. Additionally, a newly surfaced area is present just below the crest of the same slope (directly above the relict scar and below the verge).
1984	Nos. 4 and 5 Chung Shan Terrace have been demolished. The platforms upon which the buildings had been previously located remain unchanged.
1986	Site for building Nos. 4 and 5 remain vacant.
1991	Nos. 4 and 5 Chung Shan Terrace recently constructed. Dense vegetation on slope to rear of Nos. 1 to 5 Chung Shan Terrace.
1992	Slope to the rear of No. 4 Chung Shan Terrace locally re-surfaced. Nos. 2 and 3 Chung Shan Terrace demolished.
1994	Building Nos. 2 and 3 Chung Shan Terrace under construction.
1995	Construction of Nos. 2 and 3 completed.

Table 2 – Summary of Sources of Information

Source	Documents
GEO Planning Division	Aerial Photographs dated 1949, 1963, 1964, 1967, 1972, 1973, 1978, 1980, 1984, 1986, 1988, 1991, 1992, 1993, 1994, 1995, 1996, 1997
GEO Mainland West Division	(a) BOO File GCMW 9117/88 (b) BOO File GCMW 6/9268/91 (c) File DH507/92NT (d) File DH581/90NT (e) Slope File GCMd 2/E1/11NW-A/R6 (f) File GCMd 2/E2/92(W)
GEO Design Division	(a) Slope File GCD 2/A1/11NW-A/R6 (b) Cut Slope Master List
Civil Engineering Library (CEL)	(a) 1977/78 Catalogue of Slopes (b) SIFT Report Nos. 11NW-2D/S3 and 11NW-7B/S17
Geotechnical Information Unit (GIU) at CEL	(a) GIU Ref. 11003 Development of Nos. 4 to 5 Chung Shan Terrace, Fugro 1988 (b) GIU Ref. 13365 Site Investigation Report, Stage 2 Study 11NW-A/R6
GEO Slope Safety Division	SIRST Report for Slope No. 11NW-A/CR261

Table 3 – Maximum Rolling Rainfall Recorded at GEO Raingauge No. N04 for Selected Durations Preceding 07:00 Hours on 4 June 1997 and The Corresponding Estimated Return Periods (Landslides A1, A2 & A3)

Duration	Maximum Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years)
5 minutes	14	07:00 hours on 4 June 1997	3
15 minutes	38	07:00 hours on 4 June 1997	10
1 hour	128.5	07:00 hours on 4 June 1997	41
2 hours	162.5	07:00 hours on 4 June 1997	17
4 hours	205	07:00 hours on 4 June 1997	14
12 hours	252.5	07:00 hours on 4 June 1997	6
24 hours	263	07:00 hours on 4 June 1997	3
2 days	294	07:00 hours on 4 June 1997	3
4 days	294	07:00 hours on 4 June 1997	2
7 days	295	07:00 hours on 4 June 1997	2
15 days	296.5	07:00 hours on 4 June 1997	1
31 days	787.5	07:00 hours on 4 June 1997	4

Notes: (1) Return periods were derived from the Gumbel equation and data published in Table 3 of Lam and Leung (1994).

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

Table 4 – Maximum Rolling Rainfall Recorded at GEO Raingauge No. N04 for Selected Durations Preceding 08:30 Hours on 4 June 1997 and The Corresponding Estimated Return Periods (Landslide B)

Duration	Maximum Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years)
5 minutes	14	07:00 hours on 4 June 1997	3
15 minutes	38	07:00 hours on 4 June 1997	10
1 hour	128.5	07:00 hours on 4 June 1997	41
2 hours	180	08:00 hours on 4 June 1997	33
4 hours	224	08:00 hours on 4 June 1997	51
12 hours	304	08:00 hours on 4 June 1997	26
24 hours	314.5	08:00 hours on 4 June 1997	8
2 days	345.5	08:00 hours on 4 June 1997	7
4 days	345.5	08:00 hours on 4 June 1997	4
7 days	346.5	08:00 hours on 4 June 1997	3
15 days	348	08:00 hours on 4 June 1997	1
31 days	846.5	08:00 hours on 4 June 1997	6

Notes: (1) Return periods were derived from the Gumbel equation and data published in Table 3 of Lam and Leung (1994).

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

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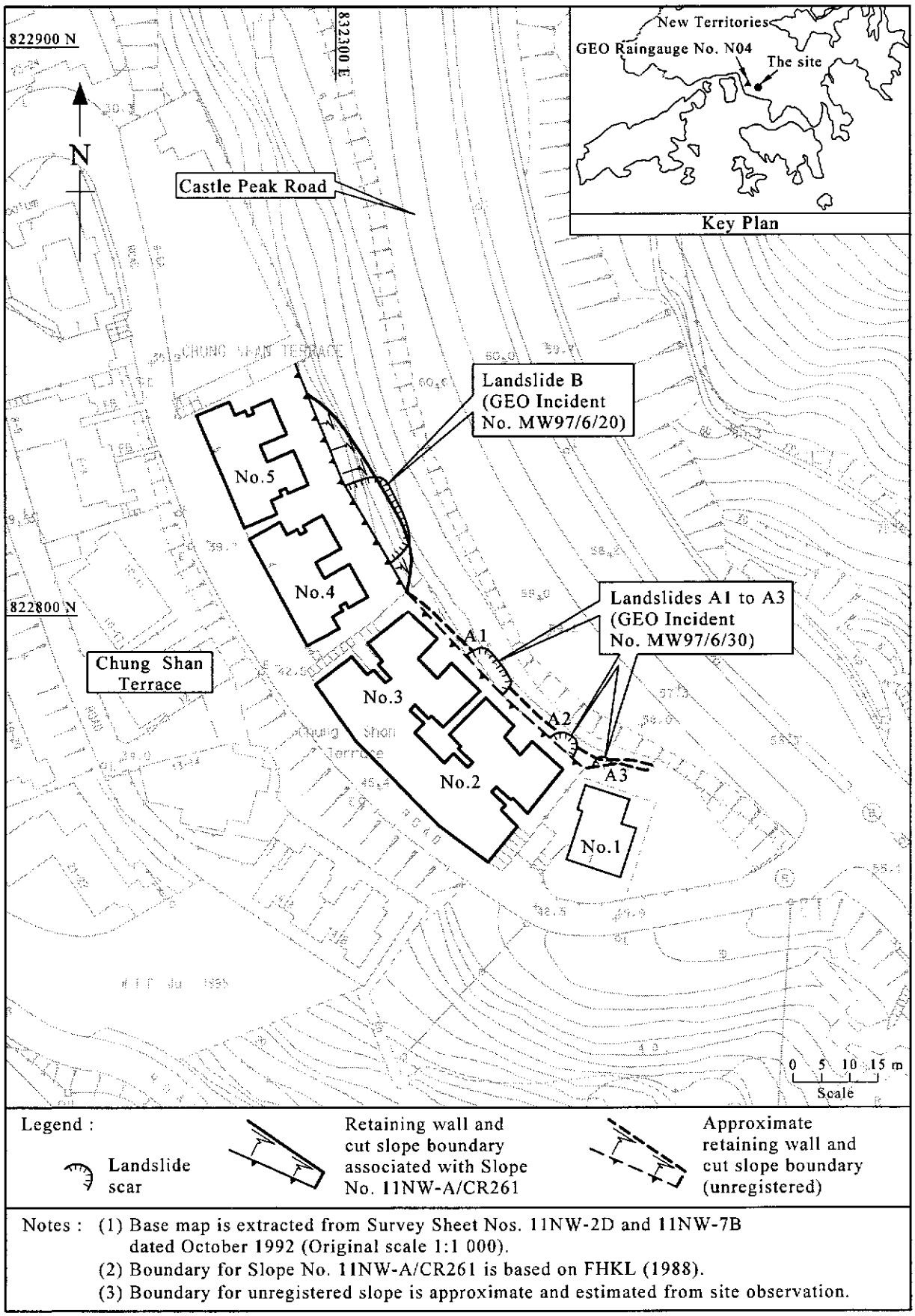


Figure 1 - Site Location Plan

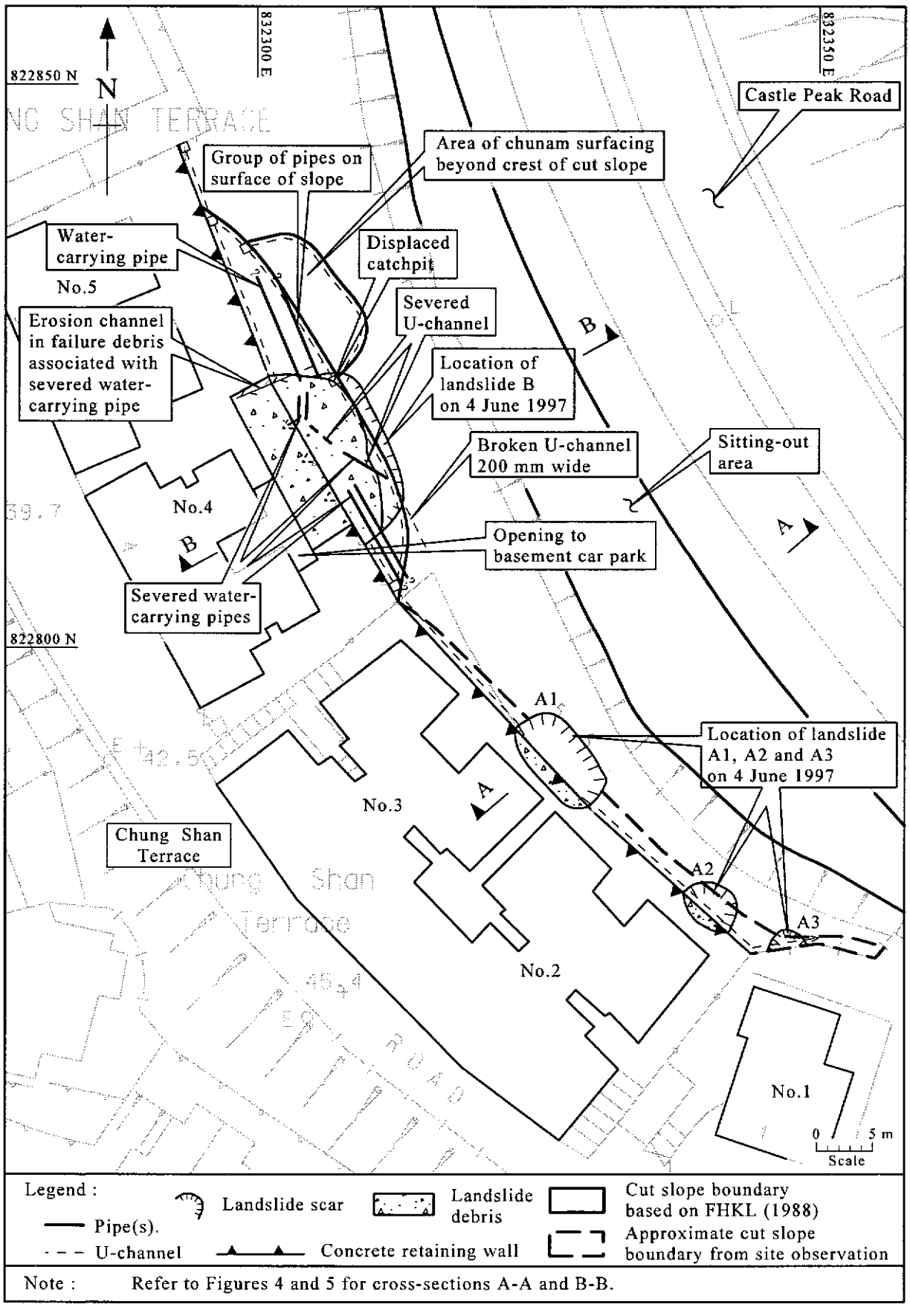


Figure 2 - Plan of the Landslide Sites

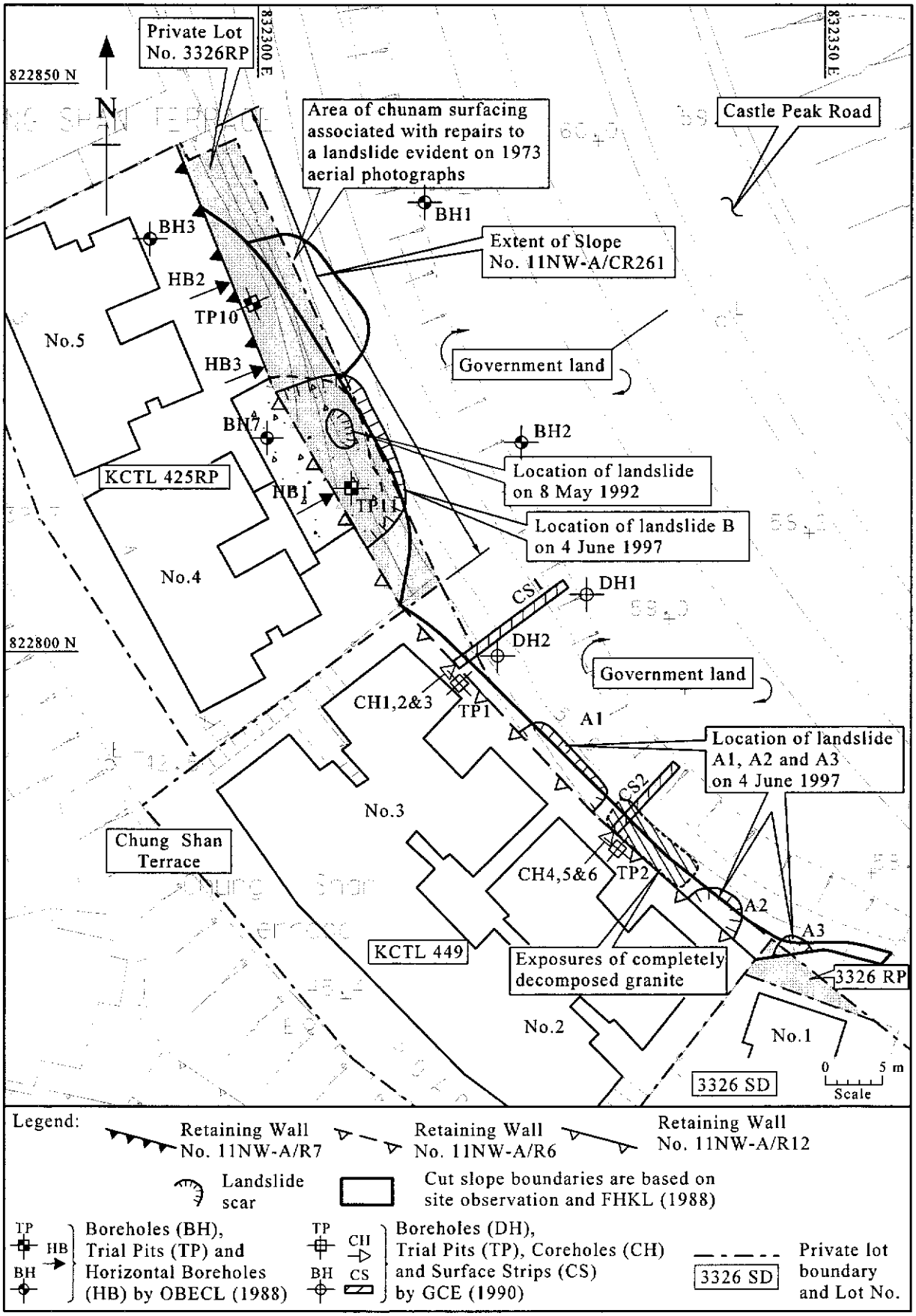
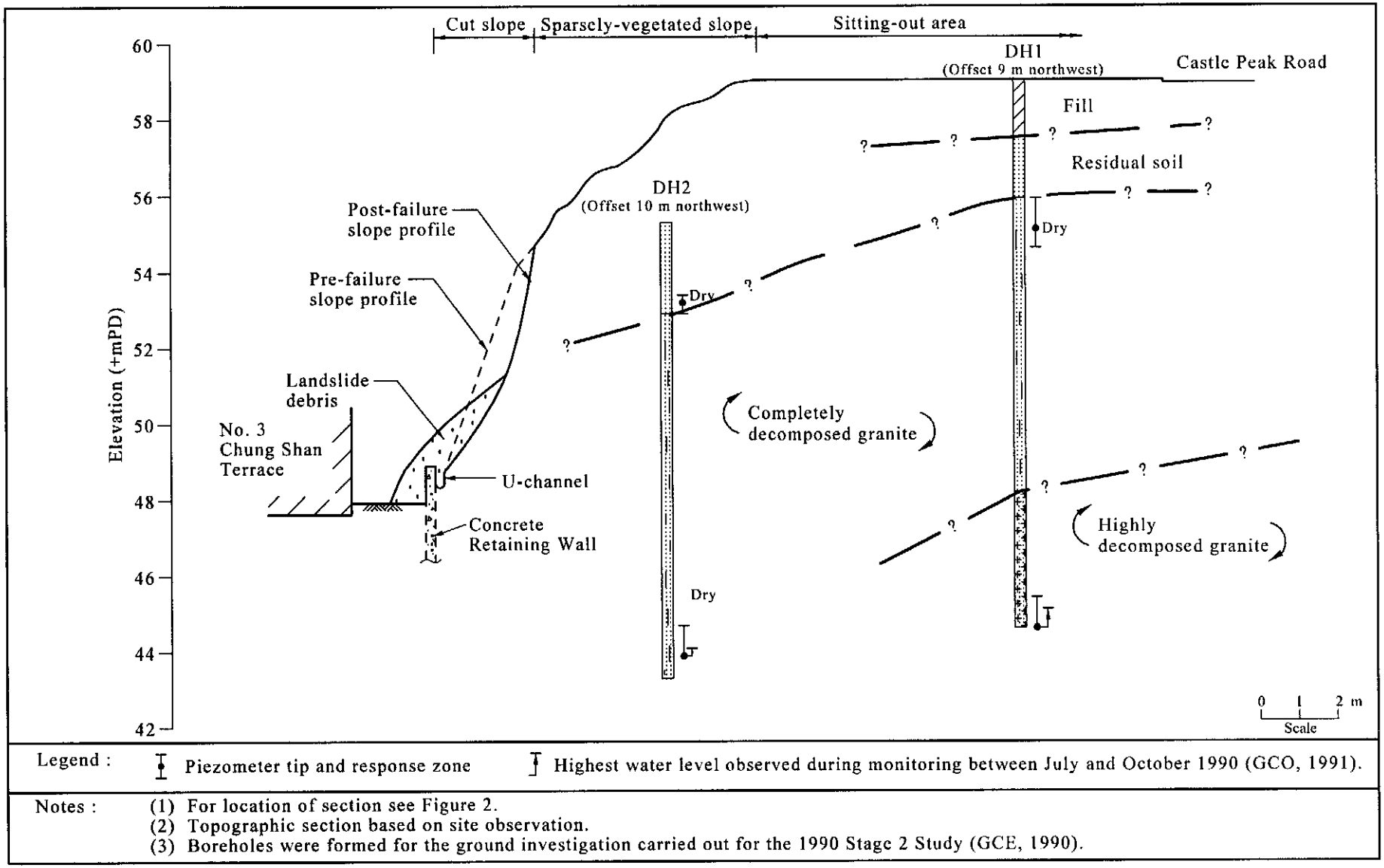


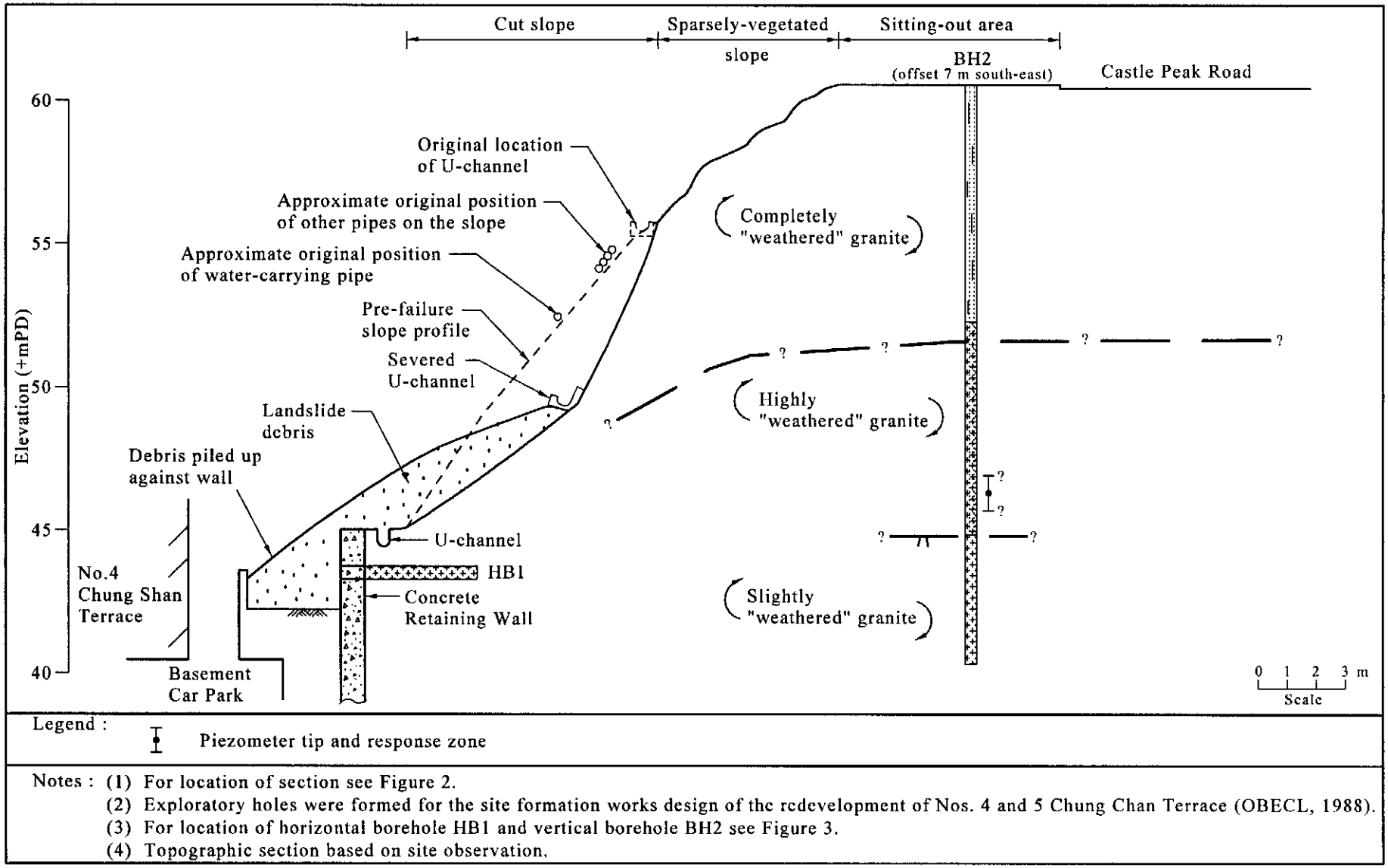
Figure 3 - Land Status and Site History



Legend : Piezometer tip and response zone Highest water level observed during monitoring between July and October 1990 (GCO, 1991).

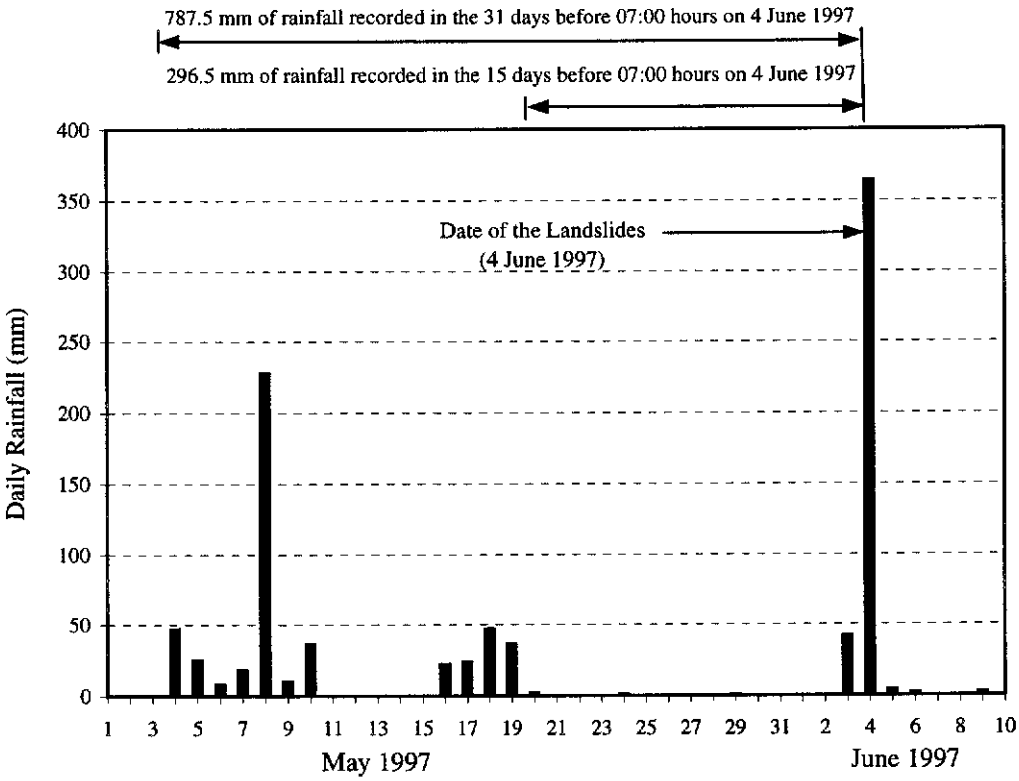
Notes :
(1) For location of section see Figure 2.
(2) Topographic section based on site observation.
(3) Boreholes were formed for the ground investigation carried out for the 1990 Stage 2 Study (GCE, 1990).

Figure 4 - Cross-section A-A through Landslide A1

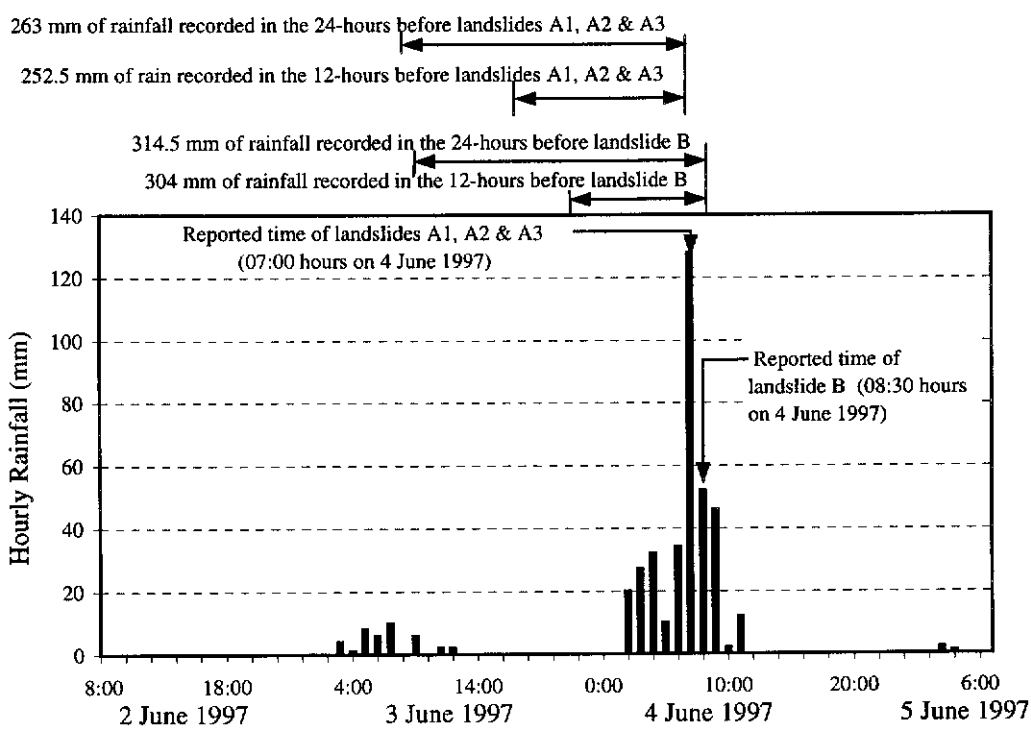


Notes : (1) For location of section see Figure 2.
(2) Exploratory holes were formed for the site formation works design of the redevelopment of Nos. 4 and 5 Chung Chan Terrace (OBECL, 1988).
(3) For location of horizontal borehole HB1 and vertical borehole BH2 see Figure 3.
(4) Topographic section based on site observation.

Figure 5 - Cross-section B-B through Landslide B

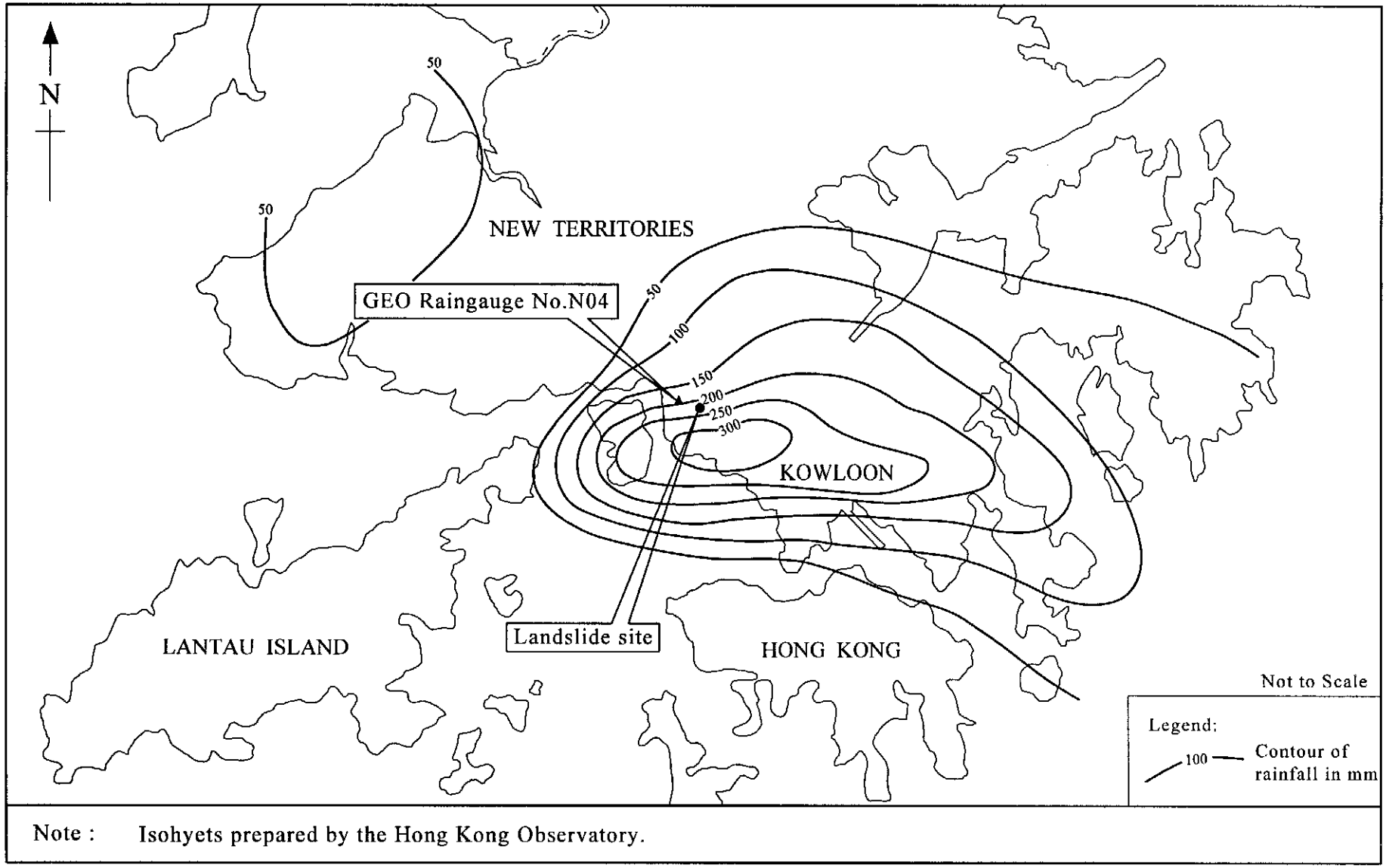


(a) Daily Rainfall recorded between 1 May and 10 June 1997



(b) Hourly Rainfall Recorded between 08:00 hours on 2 June and 06:00 hours 5 June 1997

Figure 6 - Rainfall Records at GEO Raingauge No. N04



Note : Isohyets prepared by the Hong Kong Observatory.

Figure 7 - Isohyets of Rainfall between 01:30 Hours and 08:30 Hours on 4 June 1997

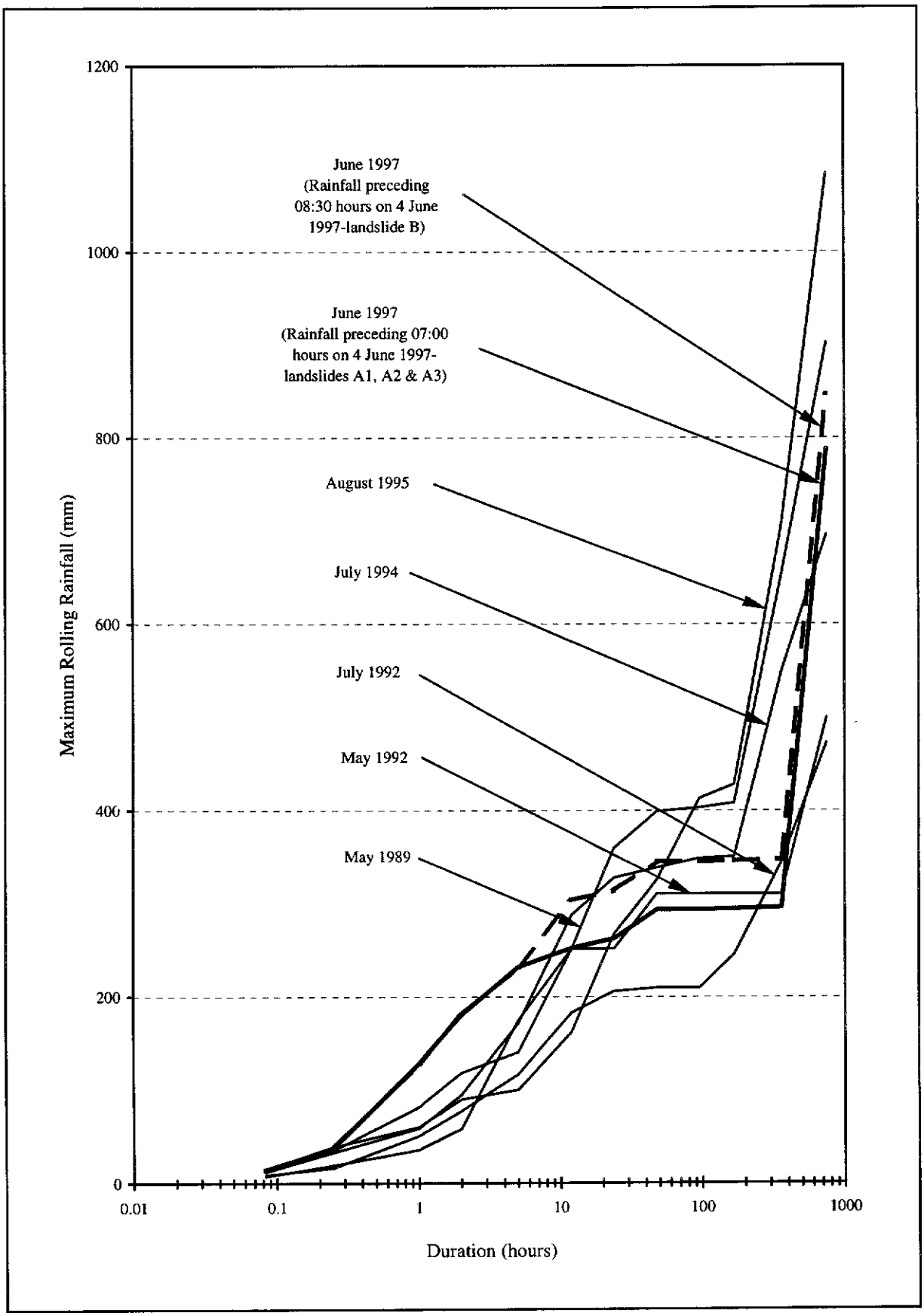


Figure 8 - Maximum Rolling Rainfall at GEO Raingauge No. N04 for Selected Major Rainstorms

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Plate 1 - Water-carrying Pipe and Other Pipes Ruptured by Landslide B

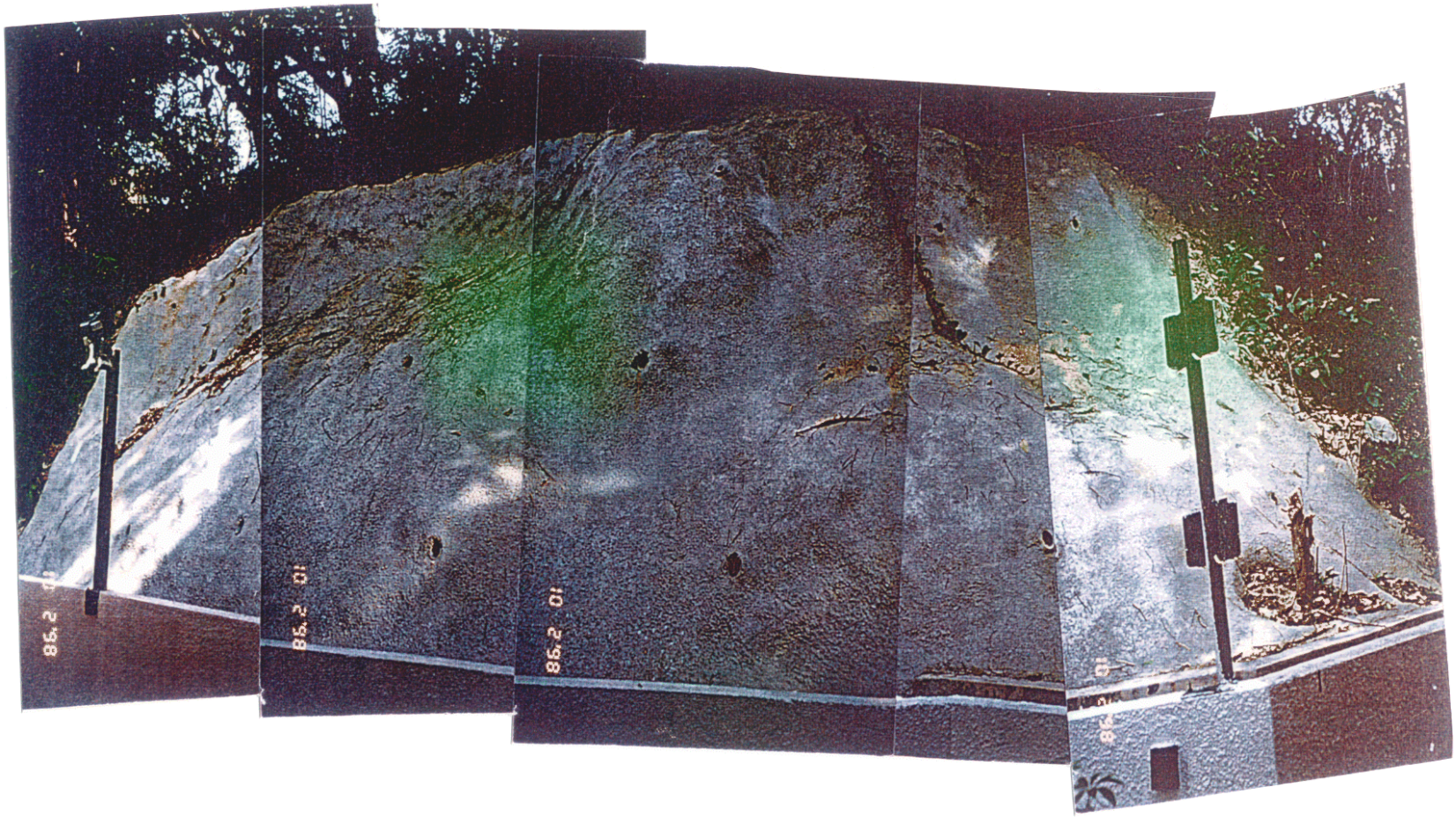


Plate 2 - General View of Landslide A1 after Urgent Repair Works (Photograph Taken on 10 February 1998)

Plate 3 - General View of Landslide A2 after Urgent Repair Works (Photograph Taken on 10 February 1998)

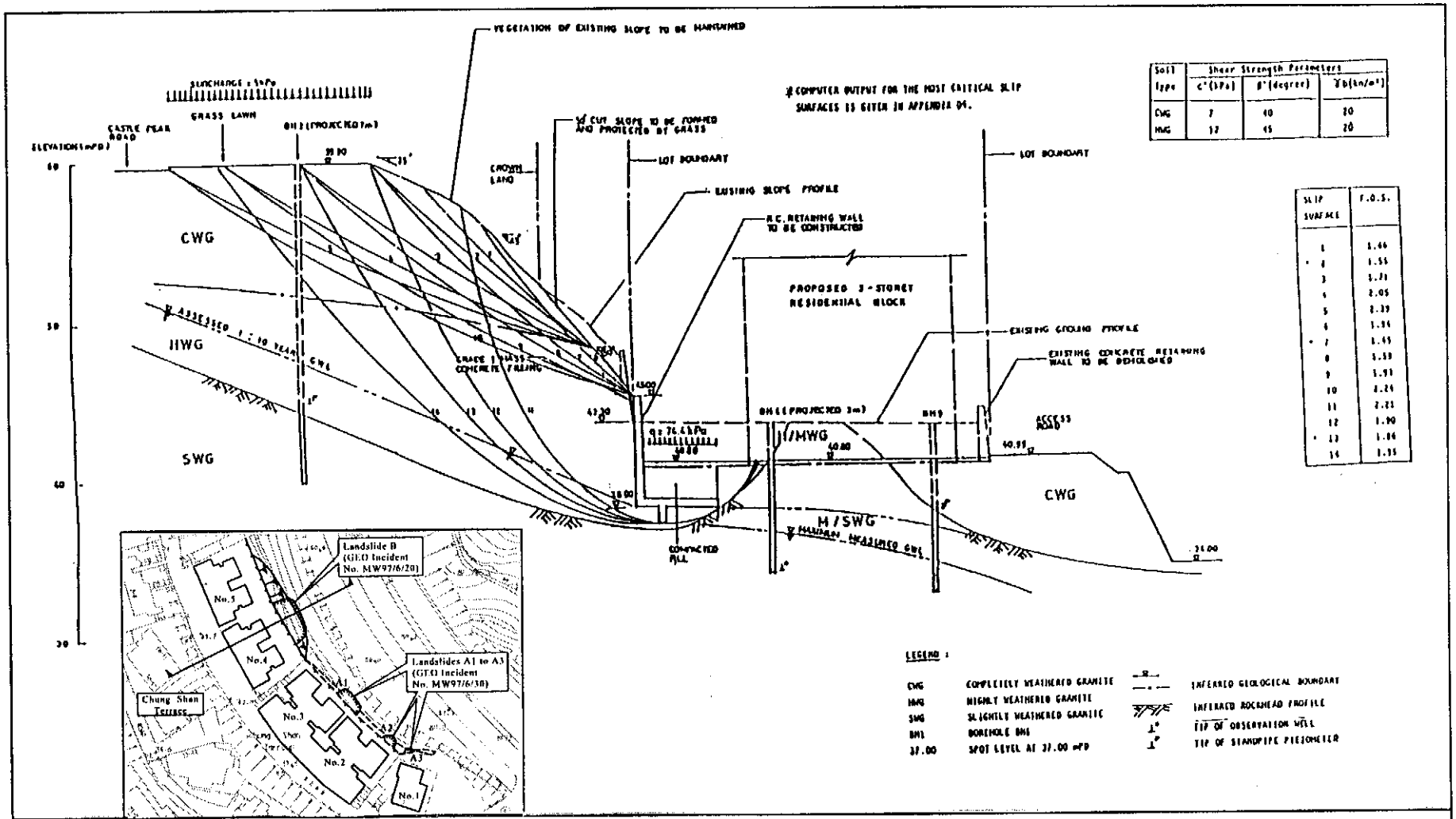
Plate 4 - General View of Landslide A3 after Urgent Repair Works
(Photograph Taken on 10 February 1998)

Plate 5 - General View of Landslide B (Photograph Taken on 5 June 1997)

Plate 6 - Broken U-channel and Displaced Catchpit at Landslide B
(Photograph Taken on 5 June 1997)

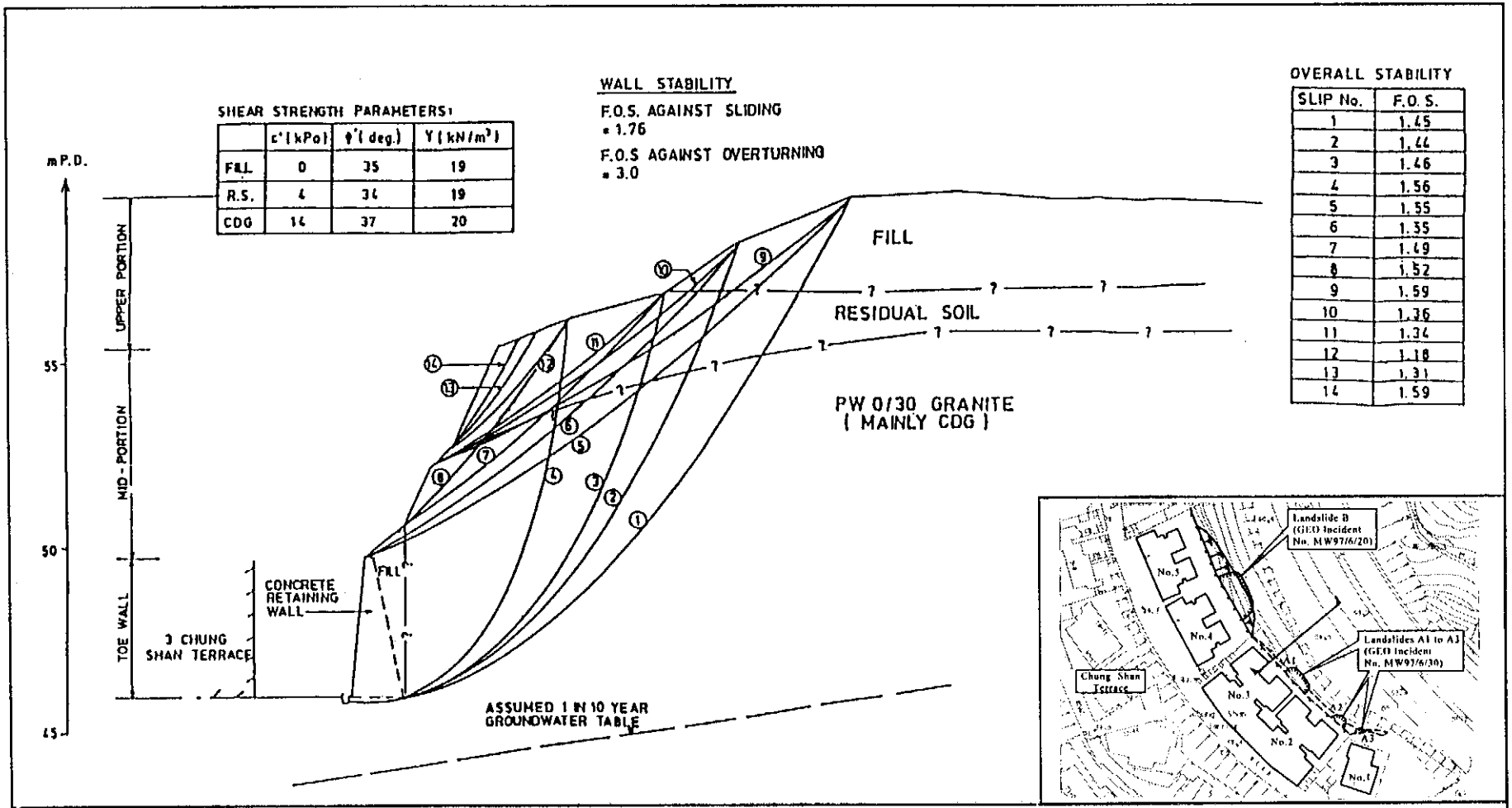
APPENDIX A

PREVIOUS STABILITY ASSESSMENTS



Notes: (1) See insert for location of section.
(2) Details of the stability assessment are extracted from FHKL (1988).
(3) The piezometer installed in BH2 was dry during monitoring in May 1988 and June 1988.
(4) Adopted shear strength parameters are based on site specific laboratory testing.

Figure A1 - Stability Assessment for Site Formation Works Design of the Redevelopment of Nos. 4 and 5 Chung Shan Terrace

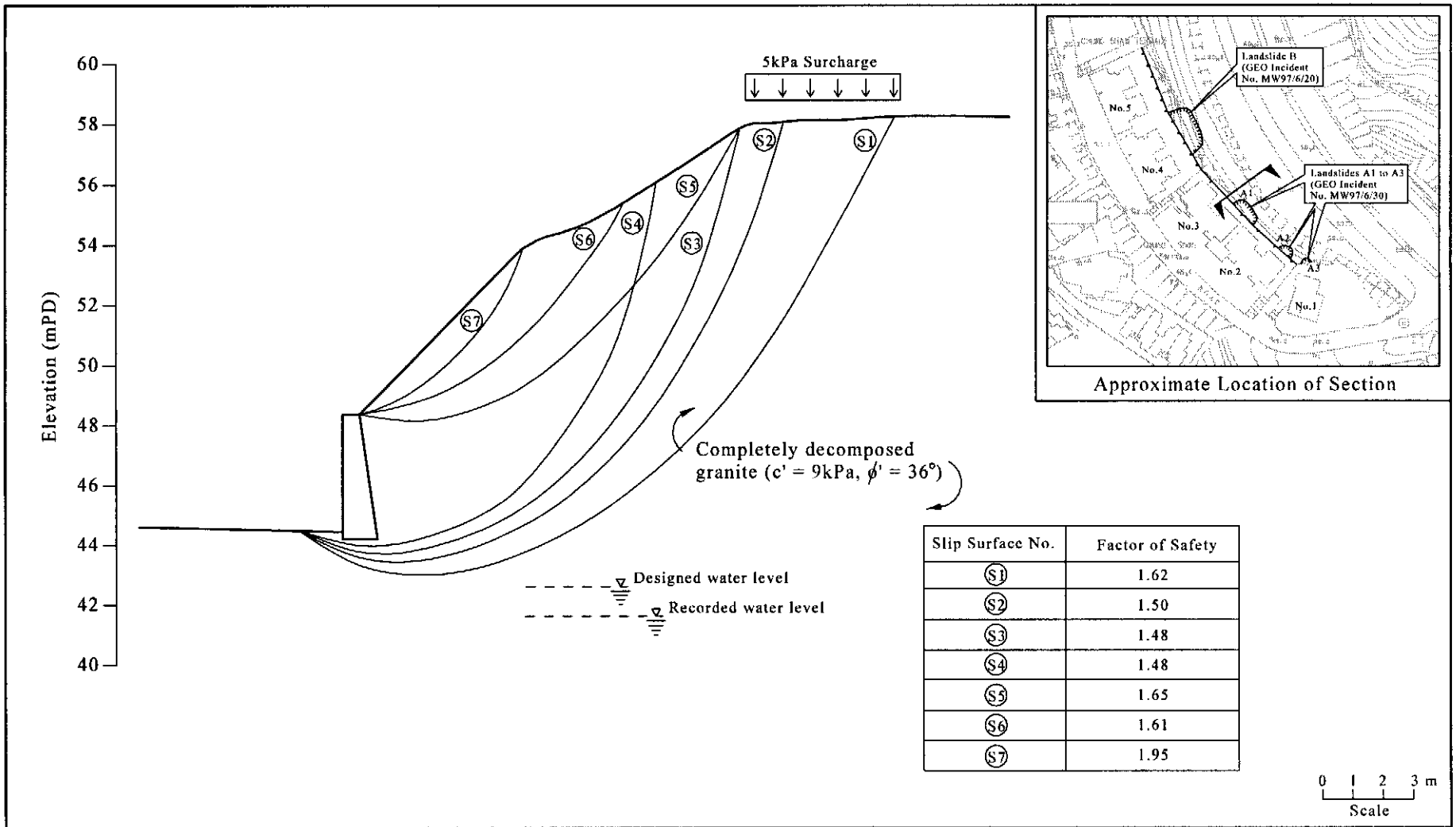


	c' (kPa)	φ' (deg.)	γ (kN/m³)
FILL	0	35	19
R.S.	4	34	19
CDG	14	37	20

SLIP No.	F.O.S.
1	1.45
2	1.44
3	1.46
4	1.56
5	1.55
6	1.55
7	1.49
8	1.52
9	1.59
10	1.36
11	1.34
12	1.18
13	1.31
14	1.59

Notes: (1) See insert for location of section.
(2) Details of the stability assessment are extracted from GCO (1991).
(3) Adopted shear stength parameters are based on site specific laboratory testing.
(4) The assumed 1-in-10 year groundwater table was derived from the height observed water levels (Figure 4) with "1 m rise allowed for any transient rainstorm effects" (GCO, 1991).

Figure A2 - Stability Assessment for the 1991 Stage 2 Study



Slip Surface No.	Factor of Safety
S1	1.62
S2	1.50
S3	1.48
S4	1.48
S5	1.65
S6	1.61
S7	1.95

Notes :
(1) Details of the assessment are extracted from JCAL (1992).
(2) The "recorded water level" appears to have been taken from monitoring of a piezometer installed at +37.97mPD (with a response zone between 39.97mPD and 39.07mPD) in borehole D1 (Figure 3) which was carried out between 10 August 1992 and 17 August 1992.

Figure A3 - Stability Assessment for Site Formation Works Design for the Redevelopment of Nos. 2 and 3 Chung Shan Terrace