INVESTIGATION OF SOME SELECTED LANDSLIDE INCIDENTS IN 1997 (VOLUME 6)

GEO REPORT No. 92

Halcrow Asia Partnership Ltd.

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

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PREFACE

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

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

R.K.S. Chan
Head, Geotechnical Engineering Office
June 1999

EXPLANATORY NOTE

This GEO Report consists of four Landslide Study Reports on the investigation of selected slope failures that occurred in 1997. The investigations were carried out by Halcrow Asia Partnership Ltd (HAP) for the Geotechnical Engineering Office as part of the 1997 Landslip Investigation Consultancy.

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

(a) establishment of an improved slope assessment methodology,

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

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

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

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

SECTION 1: DETAILED STUDY OF THE LANDSLIDES AT NO. 7 KENG HAU ROAD ON 4 JUNE 1997 AND NO. 5 KENG HAU ROAD ON 2 JULY 1997

Halcrow Asia Partnership Ltd

This report was originally produced in May 1998 as GEO Landslide Study Report No. LSR 9/98

FOREWORD

This report presents the findings of a detailed study of two landslides which occurred adjacent to Nos. 5 and 7 Keng Hau Road, Sha Tin on 4 June 1997 and 2 July 1997. The landslides destroyed a terraced garden area and partly undermined No. 5 Keng Hau 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 landslides. The scope of the study was 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. It is one of a series of reports produced during the consultancy by Halcrow Asia Partnership Limited (HAP).

G Daughton
Project Director/Halcrow Asia Partnership Ltd

CONTENTS

1. INTRODUCTION

On the morning of 4 June 1997, a landslide (GEO Incident No. MW97/6/22) occurred immediately to the east of No. 7 Keng Hau Road, Sha Tin (Figure 1). The failure destroyed the southern part of a terraced garden and some 150 m^3 of debris travelled down a natural gully and ran out onto a cultivated low-lying area. No fatalities or injuries were reported.

A second failure, involving the remaining section of the terraced garden adjacent to No. 5 Keng Hau Road, occurred early on 2 July 1997. The debris from this landslide was also constrained within the gully. No fatalities or injuries were recorded, but part of the structure of No. 5 Keng Hau Road was undermined. A separate incident number was not assigned to the landslide because it was not reported to the Geotechnical Engineering Office (GEO).

Following the landslides, Halcrow Asia Partnership Limited (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. It is one of a series of reports produced during the consultancy by Halcrow Asia Partnership Limited (HAP).

The key objectives of the 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 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 all known 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 observations and measurements at the landslide sites, and

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

2. THE SITE

2.1 Site Description

The buildings affected by the landslides are situated on the eastern side of Keng Hau Road, northwest of the head of a deep, northeast-trending gully (Figure 2). Each of the buildings has a swimming pool constructed on a podium that extends over the upper part of

the gully. A concrete U-channel, 330 mm wide and inclined at about 45°, is located adjacent to the south wall of No. 7 Keng Hau Road and extends down the slope towards the base of the natural gully (Figure 2). Stormwater pipes and overflow pipes from the swimming pool of No. 7 Keng Hau Road discharge into the U-channel.

The failures occurred on a chunam-surfaced cut slope (No. 7SW-D/C700), the crest of which was located between about 15 m and 20 m east of the buildings of Nos. 5 and 7 Keng Hau Road. The cut slope was about 6 m high, inclined at 60° to the horizontal and formed part of the terraced garden. Low masonry structures, less than 2 m high, existed at the toe and crest of the slope. Above the cut slope was a paved platform accessed from the south by pathways supported by at least three small masonry walls. A masonry-faced cut slope, inclined at about 70° and about 3 m high, formed the western boundary of the platform.

The slopes immediately below and to the east of the cut slope are inclined typically between about 30° and 40°, decreasing to 5° or less in the floor of the gully.

An unsurfaced superficial fill body, with a system of surface channels, was located to the north of the landslide sites, below Nos. 1 and 3 Keng Hau Road (Figure 2). Cut Slope Nos. 7SW-D/C701 and 7SW-D/C702 are located immediately to the south of the site below No. 9 Keng Hau Road.

The landslides affected both Government land and Short Term Tenancy (STT) Lot Nos. 858 and 859 (Figure 2) granted to the owners of Nos. 5 and 7 Keng Hau Road in 1991 respectively. Following the landslides, both owners have served a notice of termination of the tenancies.

2.2 Site History

The historical development of the site has been established from a review of the available aerial photographs and relevant documentation, including files held at the GEO. Key events in the history of the site are summarised below with reference to Figure 3.

The earliest aerial photographs taken in 1954, show that the sites of Nos. 5 and 7 Keng Hau Road and the 1997 landslides were undeveloped. Keng Hau Road had been constructed by this time. The 1969 aerial photographs show a lobe of fill deposited at the future location of Nos. 5 and 7 Keng Hau Road (Figure 3).

Slope No. 7SW-D/C700 and its associated masonry walls, together with the pathways, were formed sometime between 1969 and 1973 when Nos. 5 and 7 Keng Hau Road were built. The superficial fill body adjacent to Nos. 1 and 3 Keng Hau Road was deposited during the same period. Slope Nos. 7SW-D/C701 and 7SW-D/C702 were formed earlier, sometime between 1954 and 1963.

Between 1973 and 1976 the buildings of Nos. 1 and 3 Keng Hau Road were constructed. There were few changes to the site after this time except for the addition of podium structures and swimming pools at Nos. 5 and 7 Keng Hau Road between 1986 and 1988 and 1988 and 1990 respectively.

GEO's Landslide Incident Report (LIR) database contains no records of previously reported landslides in the vicinity of the 1997 incidents. Similarly, there are no recorded landslides in the GEO's Natural Terrain Landslide Inventory (NTLI). In the 1963 aerial photographs, surface depressions, which appear to be re-vegetated main scarps of relict landslides, are evident at about the same location as the 1997 incidents.

Following the recent failures, loose debris was removed and the landslide scars were shotcreted by the Buildings Department at the recommendation of GEO. Weepholes were also installed to facilitate drainage of water from the slope.

2.3 Previous Studies

None of the retaining walls or cut slopes below Nos. 1 to 9 Keng Hau Road were registered in the 1977/78 Catalogue of Slopes.

The man-made slopes and natural terrain below Nos. 1 to 9 Keng Hau Road were, however, included as Slope No. 7SW-D/N3 for assessment in the Sha Tin Area Phase IID Landslide Study carried out in 1980 (Binnie & Partners, 1980a, 1980b and Figure 3). The study included a detailed geotechnical assessment of the slope below No. 9 Keng Hau Road using site-specific information from ground investigation and laboratory testing.

The detailed assessment report (Binnie & Partners, 1980b) also included back analyses of a nearby slope which suggested the presence of "a pore suction of at least 13.5 kPa". This amount of suction was "adopted in design of preventive works for slopes in the area". Stability analyses of the slope below No. 9 Keng Hau Road indicated "a minimum factor of safety (FOS) of 1.11, requiring pore suction of 17.6 kPa to maintain FOS=1.4", the safety standard deemed necessary given the proximity of the residential buildings at the crest. As the calculated pore suction of 17.6 kPa was greater than the back analysed value, it was considered that "the stability of the slope (was) inadequate".

The report recommended that "an embankment be constructed at the toe of the slope" to improve its stability. In addition, the following measures were recommended for the slopes below Nos. 1 to 9 Keng Hau Road:

(a) "slopes and terraces be paved and bare slopes covered",

(b) installation of adequate U-channels and stepped channels "leading to a suitable outfall", and

(c) "low rubble walls in poor condition (should) be either removed or reconstructed, and any steep slopes formed in original ground should be no steeper than 50°".

Despite a thorough search of the available GEO files, it has not been possible to locate records that could confirm whether these measures were implemented as recommended. There is no evidence of a toe embankment on site.

In May 1995, the cut slope (No. 7SW-D/C700) affected by the landslide was identified by the GEO in the project entitled "Systematic Inspection of Features in the Territory" (SIFT). The project aimed to systematically search for sizeable man-made slopes not previously registered in the 1977/78 Catalogue of Slopes, based on studies of aerial photographs and limited site inspections. The SIFT report on Slope No. 7SW-D/C700 (SIFT No. 7SW-24B/S6) indicated that the slope was formed by cutting between 1969 and 1973. The slope was categorised as Class C1, (i.e. formed or substantially modified by cutting before 1978). No site inspection was possible for access reasons and the "consequence" of a landslide was not noted in the SIFT inspection report.

The fill body below Nos. 1 and 3 Keng Hau Road (Figure 3), evident on aerial photographs (see Section 2.2 above), was not identified by the SIFT study.

In July 1994, the GEO initiated a project entitled "Systematic Identification and Registration of Slopes in the Territory" (SIRST) to compile the New Catalogue of Slopes. In October 1996, the cut slope affected by the landslides was inspected by consultants appointed by the GEO to undertake the SIRST project, and was registered as Slope No. 7SW-D/C700. The SIRST field sheet recorded "partially blocked" weepholes, "signs" of seepage, "multiple minor inferred past instability" and "minor sign(s) of distress". The condition of the chunam cover was recorded as "poor" and no surface drainage channels were present on the slope.

The Stage 1 Study Report prepared for the slope by the SIRST consultants in October 1996 recommended further study.

2.4 Subsurface Conditions

Sheet 7 of the Hong Kong Geological Survey 1:20 000 scale series (Geotechnical Control Office, 1986) and the Geotechnical Area Studies Programme Engineering Geology Map (Geotechnical Control Office, 1987) indicate that the landslide sites are underlain by coarse-grained granite.

Ground investigations and analyses for the slope below No. 9 Keng Hau Road were carried out under the 1980 Landslide Study (Binnie & Partners, 1980b). The location of the section analysed and the positions of relevant exploratory holes are shown in Figure 3. Borehole ST3, drilled immediately west of No. 9 Keng Hau Road, identified 1.5 m of fill and 2 m of granitic residual soil overlying completely decomposed, coarse-grained granite. Moderately decomposed coarse-grained granite was encountered at about 22 m below ground level. Piezometers installed in the borehole at depths of 16.5 m and 21.1 m respectively, were monitored between August 1979 and December 1980. The results indicated that the main groundwater table was near the top of the moderately decomposed granite.

3. THE LANDSLIDES

3.1 The Landslide of 4 June 1997

3.1.1 Time of the Landslide

A resident of No. 7 Keng Hau Road first noticed the landslide "on the morning" of 4 June 1997, but was unable to recall the time of the observation. No other witnesses to the landslide were identified. The landslide was reported to the GEO at 14:30 hours on 5 June 1997 by the owner of No. 7 Keng Hau Road.

3.1.2 Description of the Landslide

Details of the failure are presented in Figure 4 and a representative cross-section through the landslide is given in Figure 5. Photographs of the landslide are shown in Plates 1 to 5.

The failure undermined the southern section of the level platform adjacent to No. 7 Keng Hau Road, and formed a rupture surface between about 10 m and 12 m wide extending from the original toe of the cut slope to the eastern wall of the building podium (Plates 1 and 2). The maximum depth of failure was typically between 1.5 m and 2 m and the estimated volume of failure was 150 m^3.

The landslide debris ran out down the slope and crossed the lower part of the stepped drainage channel that extended down the slope from near the south wall of No. 7 Keng Hau Road (Figure 4). The debris was deflected to the northeast by the opposing flank of the natural gully and came to rest on the low-lying cultivated area. The maximum horizontal travel distance was about 85 m. The travel angle of the debris, measured from the crest of the main scarp to the distal end of the main body of debris, was 19° (Figure 5). This angle is below the normal range for rain-induced failures in Hong Kong (Wong & Ho, 1996), indicating that the debris had relatively high mobility. The mobility of the debris was probably increased by stormwater flow discharged on to the slope from the main drainage channel near the toe of the main scarp.

The width of the debris track was between 10 m and 12 m and super-elevation of debris by about 3 m was observed at the elbow of the track (Plate 3). The depth of debris varied between 0.6 m and 0.8 m near the rupture zone and between 0.1 m and 0.3 m at the distal end of the slide. The debris was very wet when examined 13 days after the failure and evidence of significant re-working by surface water was seen in the lower reaches of the debris track.

The debris consisted mainly of pale orange, slightly clayey silty fine- to coarse-grained sand. Man-made artifacts including bricks, masonry, chunam and a section of hand railing, were found at the distal end of the debris track (Figure 4, Plates 4 and 5). A small tree originally located on the platform near the crest of the slope travelled about two-thirds of the way along the debris track.

Inspection of the main scarp identified about 0.5 m to 0.7 m of porous gravel-rich, granular fill overlying apparently undisturbed granitic residual soil (Figure 5). Highly to moderately decomposed fine- to medium-grained granite was exposed in the lower part of the rupture surface near the location of the chunamed section of slope prior to the failure. Variable, small thicknesses of fill were evident in association with the remaining sections of masonry walls and beneath the inclined channel along the southern margin of the first landslide (Figure 4).

A number of plastic pipes with diameters between about 40 mm and 80 mm, and an out-fall pipe were attached to the podium immediately above the main scarp of the landslides (Plate 2). The pipes were associated with the overflow and filtration system of the swimming pool and periodically discharged water into the main drainage channel adjacent to No. 7 Keng Hau Road. No water was seen to be issuing from the out-fall pipe during inspections of the landslide by HAP for the present study.

Groundwater was not observed during HAP's inspection of the landslide on 17 June 1997. However, minor erosion channels were observed below a void about 1 m below the central part of the main scarp, at the interpreted interface between the fill and in situ soil (Plate 1). It is possible that this feature is an erosion pipe associated with the throughflow of groundwater.

3.2 The Landslide of 2 July 1997

3.2.1 Time of the Landslide

The second landslide was first noticed between 06:00 hours and 07:00 hours on 2 July 1997 by the resident of No. 7 Keng Hau Road. No other witnesses were identified.

3.2.2 Description of the Landslide

Details of the failure are presented in Figure 6 and a representative cross-section through the landslide is given in Figure 7. Photographs of the landslide are shown in Plates 6 and 7.

The second landslide was slightly larger than the first with an estimated volume of about 210 m^3. The failure affected the remaining platform area adjacent to No. 5 Keng Hau Road and extended to the slope below Nos. 1 and 3 Keng Hau Road.

Two distinct failed masses were identified. The first, which had a volume of about 25 m^3, travelled furthest from the rupture area. The debris mainly consisted of pale orange, slightly clayey, silty fine- to coarse-grained sand with occasional man-made artifacts including bricks, masonry and chunam fragments. The failure involved the cut slope and part of the platform at its crest. The material was wet and was deposited in the gully as a thin layer. The failure undermined the higher parts of the slope near No. 5 Keng Hau Road. The second, larger failed mass travelled between about 15 m and 40 m from the rupture zone. The proportion of man-made artifacts was significantly higher than that of the initial failed mass

and the material accumulated near the main scarp as a thicker deposit, up to about 2 m deep.

The travel angle of the debris from the initial failure was about 25°. This angle is below the range for typical rain-induced failures in Hong Kong (Wong & Ho, 1996), indicating that the debris has a comparatively high mobility. Stormwater flow from the main drainage channel of No. 7 Keng Hau Road probably contributed to the increased mobility of the debris.

The morphology of the main scarp suggests that the movements which undermined part of No. 5 Keng Hau Road may have involved a third retrogressive failure. The slide involved a comparatively small volume and travelled only a short distance. This is clear from the location of the concrete steps which were originally attached to the podium of No. 5 Keng Hau Road. These were displaced by only about 15 m during this phase of the landslide. Application of shotcrete soon after failure prevented detailed inspection of the main scarp by HAP. The failure affected the remaining part of the cut slope and platform and would probably have involved fill and residual soil as observed in the main scarp of the landslide of 4 June 1997.

4. RAINFALL

4.1 General

Analysis of rainfall records was carried out to assess the influence of rainfall on the landslides. The analysis was based on rainfall readings taken at 5-minute intervals by a network of automatic raingauges located throughout Hong Kong and transmitted to HAP by the Hong Kong Observatory.

The nearest GEO automatic raingauge (No. N01) is located at the Administration Block of Sha Tin Water Treatment Works, about 450 m southwest of the landslide site (Figure 1). Rainfall recorded for the rainstorms on 4 June and 2 July 1997 are discussed separately below. The time of failure of the first landslide is not known and so the analysis presented in Section 4.2 includes all the rainfall for the rainstorm that ended at about 10:00 hours on 4 June 1997. The analysis presented in Section 4.3 is based on rainfall recorded prior to 07:00 hours on 2 July 1997 by which time the second failure is known to have occurred.

4.2 The Rainstorm of 4 June 1997

An isohyet map of rainfall recorded between 01:45 hours and 10:00 hours on 4 June 1997 is presented in Figure 8. The daily rainfall recorded between 5 May and 8 June 1997 and hourly rainfall intensities recorded between 1 June and 4 June 1997, are shown in Figure 9.

Rainfall began at about 01:00 hours and continued until around 12:00 hours on 4 June 1997. The storm was at its most intense between 06:00 hours and 09:00 hours, during which period 209 mm of rain was recorded. The maximum rolling hourly intensity of 81.5 mm was recorded between 06:15 hours and 07:15 hours. By 09:00 hours on 4 June 1997 a total of

305 mm of rain was recorded since the start of the storm.

Table 1 presents the estimated return periods for the maximum rolling rainfall, for selected durations, based on historical rainfall data recorded at the Hong Kong Observatory Principal Raingauge (Lam & Leung, 1994). The 4-hour rainfall was the most extreme, with a corresponding estimated return period of about 22 years.

The historical monthly maximum daily and hourly rainfall totals recorded at GEO raingauge No. N01 are shown in Figure 10. Figure 10a shows that the daily rainfall on 4 June 1997 was the highest on record. Figure 10b shows that the maximum hourly rainfall on 4 June 1997 (72 mm) was the fifth highest on record. It should be noted, however, that hourly and daily rainfall totals do not enable a direct comparison of absolute maximum rolling intensities of different rainfall events.

4.3 The Rainstorm of 2 July 1997

An isohyet map of rainfall recorded between 02:55 hours and 07:00 hours on 2 July 1997 is shown in Figure 11. The daily rainfall recorded at the raingauge between 1 June and 6 July 1997 and hourly rainfall intensities recorded between 29 June and 2 July 1997, are shown in Figure 12.

On 2 July 1997, rainfall began at about 01:00 hours and continued until around 13:00 hours. The maximum rolling hourly intensity occurred between 05:00 hours and 06:00 hours when 97.5 mm of rainfall was recorded. The 12-hour and 24-hour totals at 07:00 hours, by which time the second landslide is known to have occurred (Section 3.1), were 231 mm and 259 mm respectively.

Table 2 presents the estimated return periods for the maximum rolling rainfall, for selected durations, based on historical rainfall data at the Hong Kong Observatory Principal Raingauge (Lam & Leung, 1994). The 2-hour rainfall was the most extreme with a corresponding estimated return period of about 34 years.

Figure 10a shows that the daily rainfall recorded on 2 July 1997 was the highest on record. It should be noted, however, that only 231 mm of this total fell before 07:00 hours when the landslide was first observed. Figure 10b shows that the maximum hourly rainfall total on 2 July 1997 (97.5 mm) was the second highest on record.

5. PROBABLE CAUSES OF FAILURE

5.1 The Landslide of 4 June 1997

The shallow and comparatively broad shape of the main scarp, and parallel-sided nature of the debris track, suggest that the landslide occurred predominantly by sliding rather than by washout action. In addition, the majority of the debris had not been washed or sorted by surface water flow. There was, however, evidence of localised re-working of the debris by surface water at the distal end of the debris lobe (Figure 4).

The occurrence of the landslide "on the morning" of 4 June 1997, when there had been a significant rainstorm, indicates that intense short duration rainfall probably triggered the failure. Four possible sources of water at the landslide site were considered, namely:

(a) leakage or discharge of water on to the slope from pipes attached to the podium wall of No. 7 Keng Hau Road,

(b) surface water run-off from the platform of the podium,

(c) throughflow of subsurface water from the upslope area, and

(d) direct infiltration of rain and surface water through the platform above the cut slope.

The drain pipes attached to the front wall of the podium are associated with the overflow and filtration system of the swimming pool. According to the owner the swimming pool was empty at the time of the landslides and the pipes would not have been carrying water. No issue of water from the outfall pipe was observed during the investigation. It seems unlikely, therefore, that the pipes were a significant source of water.

Run-off from the platform of the podium is also considered unlikely, as the empty swimming pool would have collected much of the rainfall, and reduced the likelihood of accumulation and flow on to the landslide site. In addition, the owners have not previously seen water accumulating on the platform during heavy rainfall.

The presence of possible erosion pipes at the interface between the fill and residual soil indicates that throughflow of subsurface water into the landslide area may have occurred. The source of such water is, however, uncertain. The possibility that leakage of subsurface water-carrying installations associated with the buildings of No. 7 Keng Hau Road, or from the drainage system of Keng Hau Road itself, contributed to such flows cannot be discounted.

It is likely, therefore, that direct infiltration of rainfall on the platform above the cut slope, and on to the slope itself, was the principal source of water. The poor condition of the slope cover and absence of drainage channels, as noted during the SIRST inspection of the slope, would have made the slope more susceptible to infiltration. The front wall of the podium of No. 7 Keng Hau Road dictated the upslope extent of the failure and may have provided a line of concentrated infiltration of rainfall running down the face of the structure.

Infiltration of the near surface materials was likely to have resulted in saturation, counteracted soil suction through development of porewater pressure and increased bulk density leading to a reduction in shear strength and failure. The oversteep profile of the cut slope would have made it more susceptible to failure by these mechanisms.

It is possible that the mobility of the landslide debris was increased by discharge of stormwater from the drainage channel of No. 7 Keng Hau Road in the area near the toe of the main scarp.

5.2 The Landslide of 2 July 1997

The second landslide was also triggered by intense rainfall, probably involving similar mechanisms of failure and debris movement, but a contributory factor was the destabilising effect of the first landslide. The apparent less mobile nature of the subsequent, retrogressive failure masses suggests that loss of support of the upslope soil mass caused by the preceding movement, might have been the dominant causal factor in the later failure phases.

6. CONCLUSIONS

The failure behind No. 7 Keng Hau Road on 4 June 1997 was, most probably, the result of direct infiltration of surface water into a steep soil cut slope during intense rainfall. The failure was likely to have involved saturation of the slope-forming materials and the possible development of excess porewater pressures, or a change in the bulk density, leading to a reduction in shear strength and failure. The poor condition of the slope surfacing materials could be a major contributory factor in the failure.

The second failure at No. 5 Keng Hau Road on 2 July 1997 probably involved similar mechanisms, but loss of lateral support after the first landslide was likely to have been a significant contributory factor.

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Table 1 – Maximum Rolling Rainfall at GEO Raingauge No. N01 for Selected Durations Preceding the 4 June 1997 Landslide and The Corresponding Estimated Return Periods

Duration	Maximum Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years)
5 minutes	12.5	06:35 on 4 June 1997	2
15 minutes	28.5	06:45 on 4 June 1997	2
1 hour	81.5	07:15 on 4 June 1997	3
2 hours	144.0	08:00 on 4 June 1997	9
4 hours	225.5	09:00 on 4 June 1997	22
12 hours	306.5	10:00 on 4 June 1997	13
24 hours	308.5	09:00 on 4 June 1997	5
2 days	340.5	10:00 on 4 June 1997	4
4 days	342.5	10:00 on 4 June 1997	3
7 days	343.5	10:00 on 4 June 1997	2
15 days	347.5	10:00 on 4 June 1997	1
31 days	756.5	10:00 on 4 June 1997	3

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

(2) Maximum rolling rainfall was calculated using 5-minute data for durations up to 1 hour and from hourly data for greater rainfall durations.

Table 2 – Maximum Rolling Rainfall at GEO Raingauge No. N01 for Selected Durations Preceding the 2 July 1997 Landslide and The Corresponding Estimated Return Periods

Duration	Maximum Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years)
5 minutes	12.5	06:15 on 2 July 1997	2
15 minutes	36.5	06:20 on 2 July 1997	8
1 hour	125	06:30 on 2 July 1997	34
2 hours	176.5	07:00 on 2 July 1997	29
4 hours	224	07:00 on 2 July 1997	21
12 hours	231	07:00 on 2 July 1997	4
24 hours	259	07:00 on 2 July 1997	3
2 days	290.5	07:00 on 2 July 1997	3
4 days	296	07:00 on 2 July 1997	2
7 days	310.5	07:00 on 2 July 1997	2
15 days	453	07:00 on 2 July 1997	2
31 days	1083	07:00 on 2 July 1997	23

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

(2) Maximum rolling rainfall was calculated using 5-minute data for durations up to 1 hour and from hourly data for greater rainfall durations.

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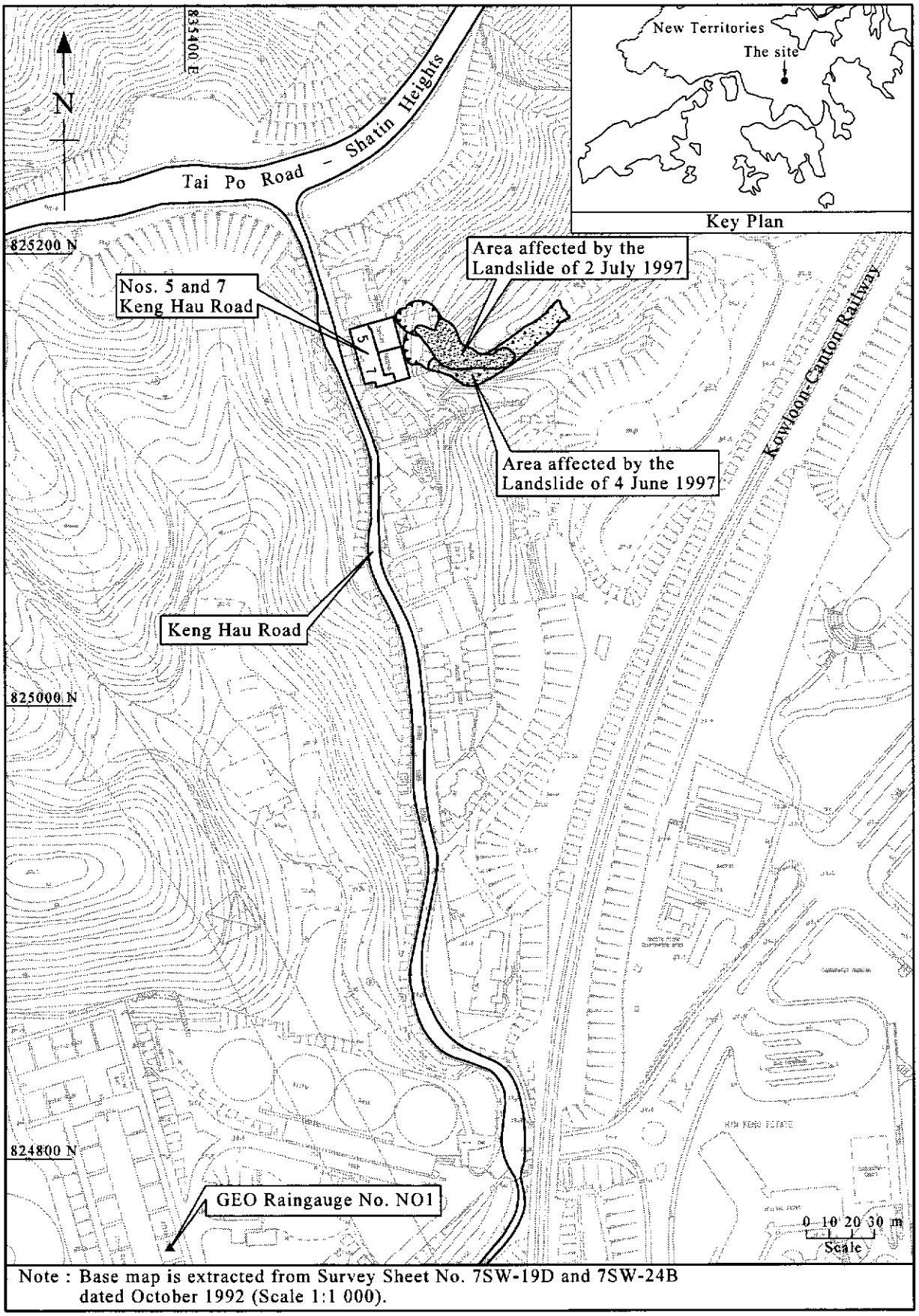


Figure 1 - Location Plan

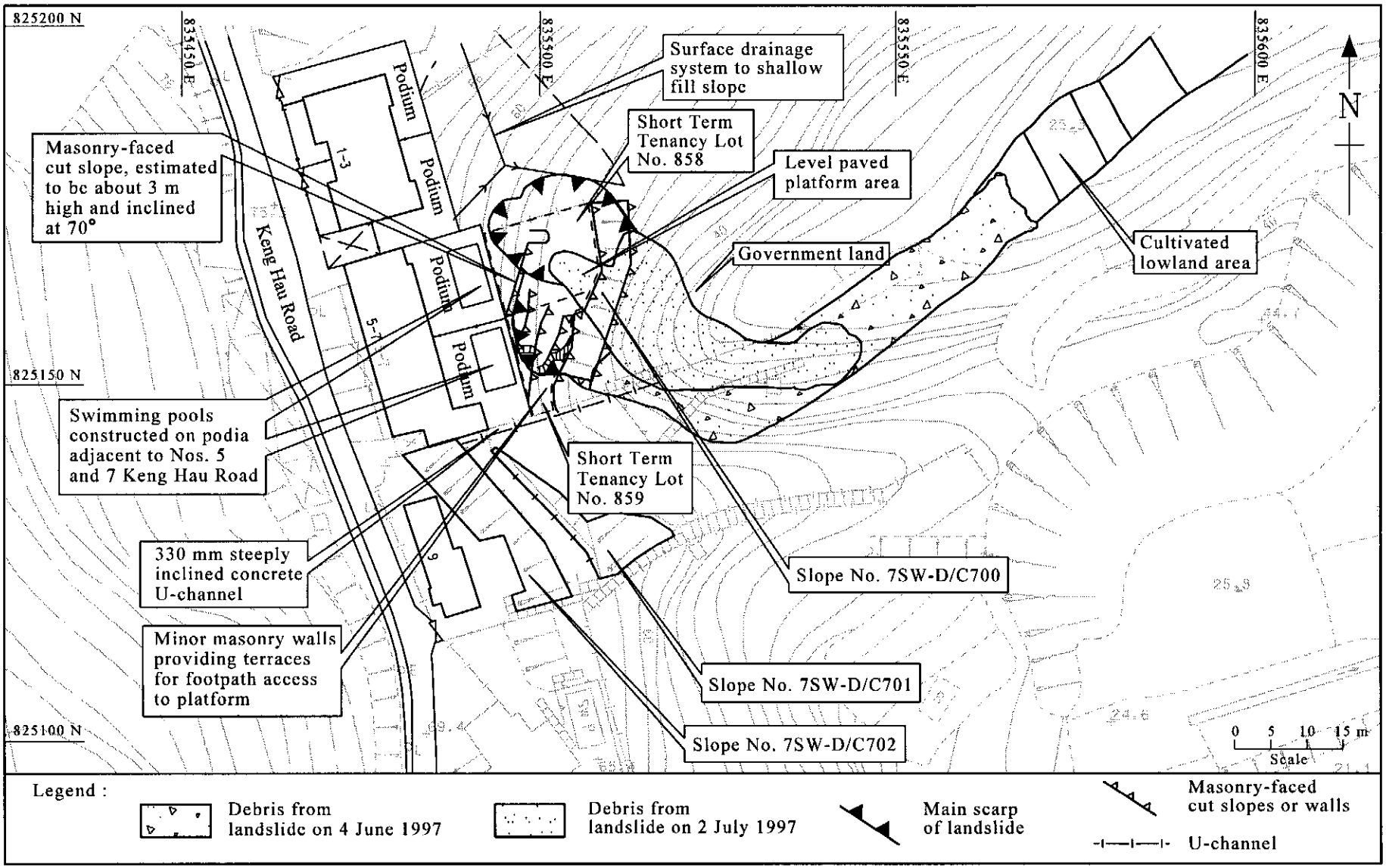


Figure 2 - Plan of the Landslide Site

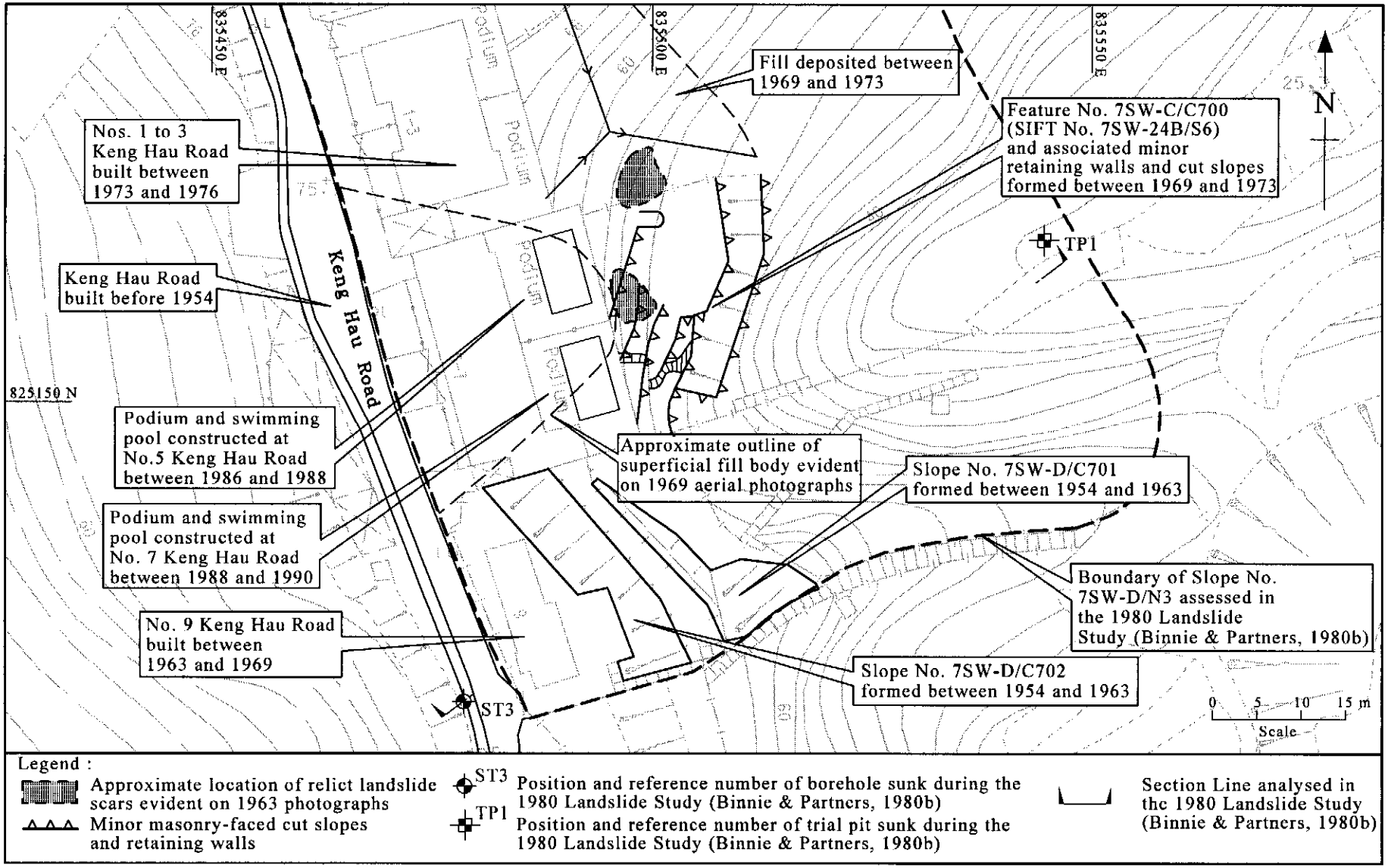


Figure 3 - Site History

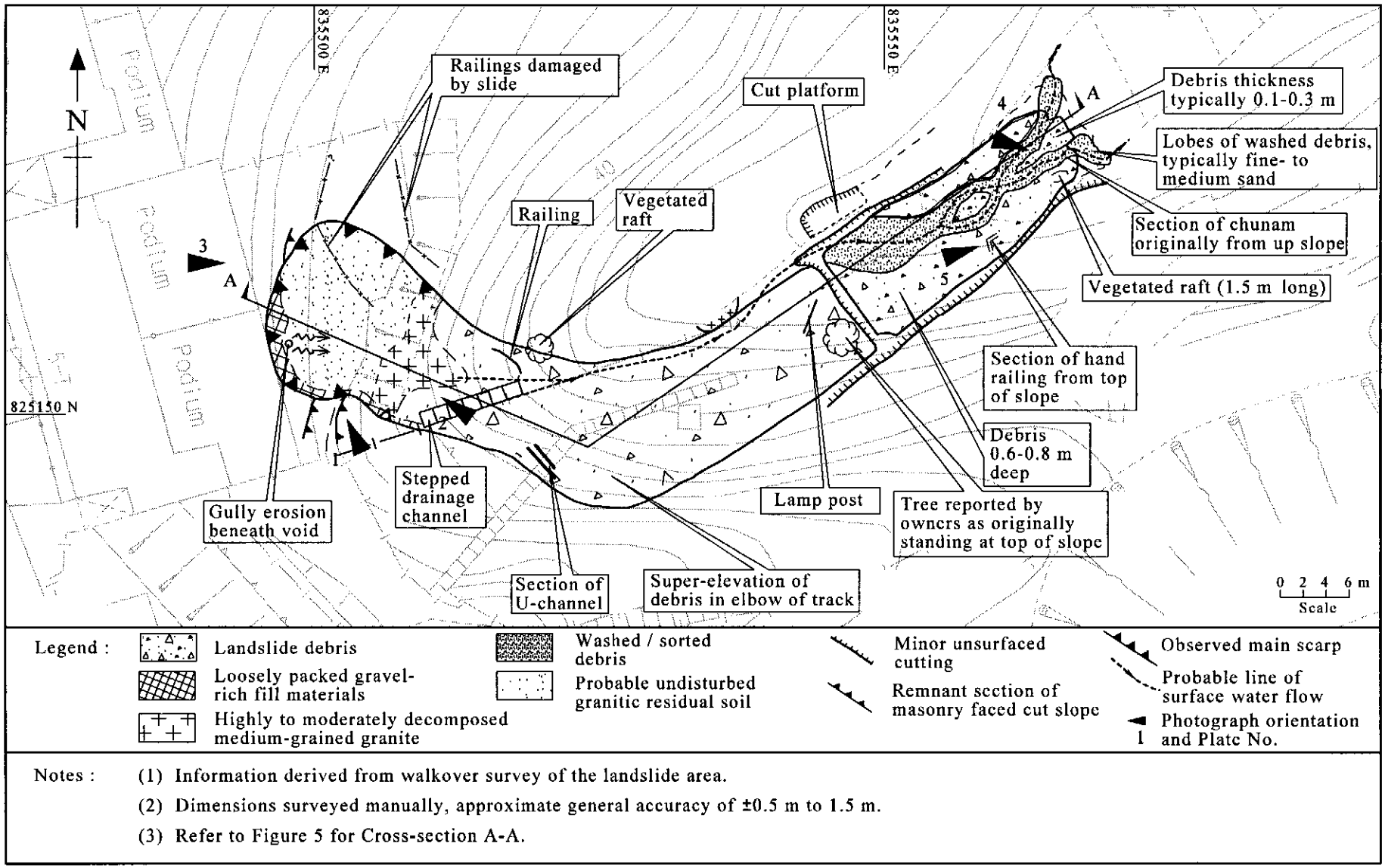


Figure 4 - Site Location Plan and Details of the Landslide of 4 June 1997

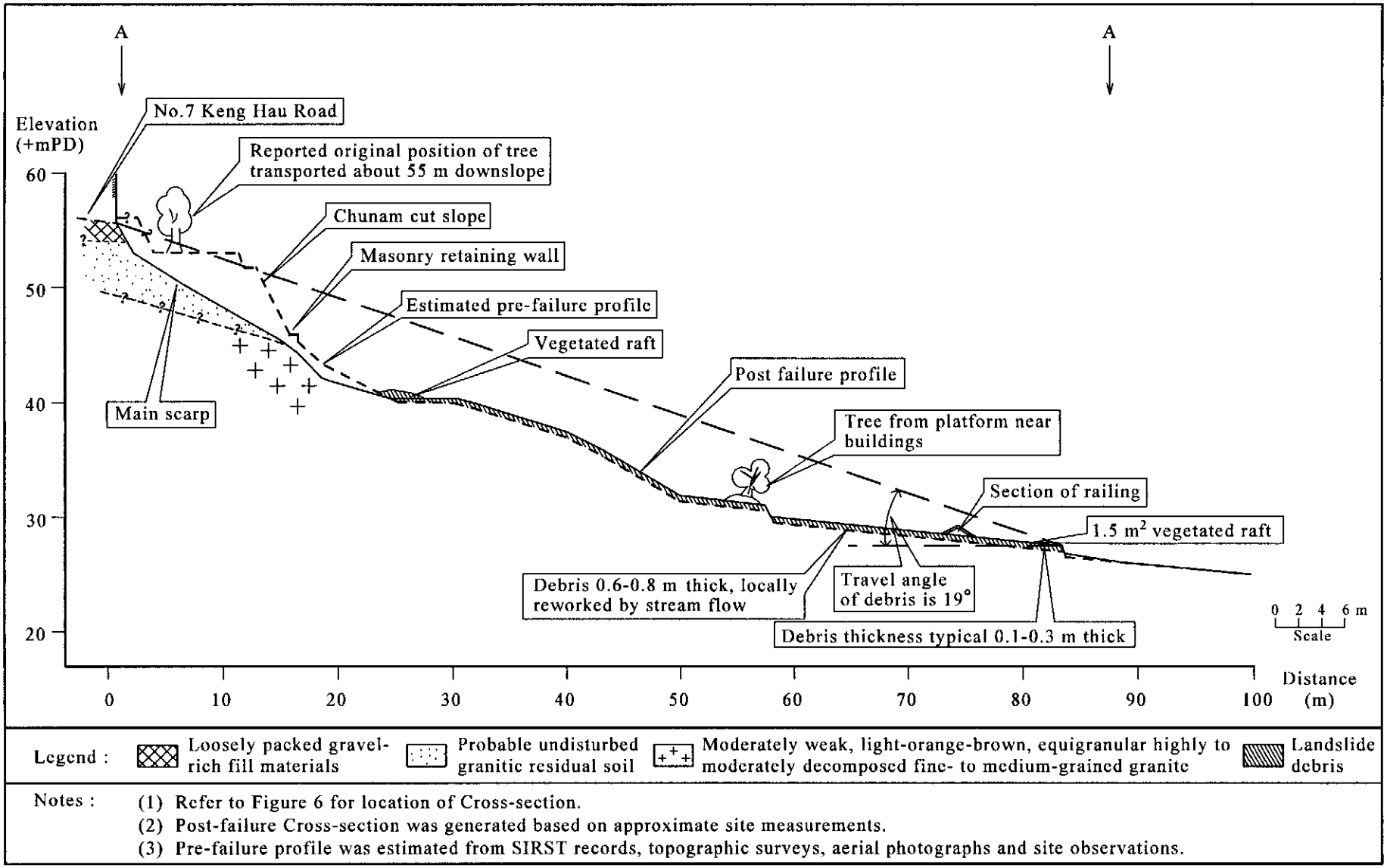
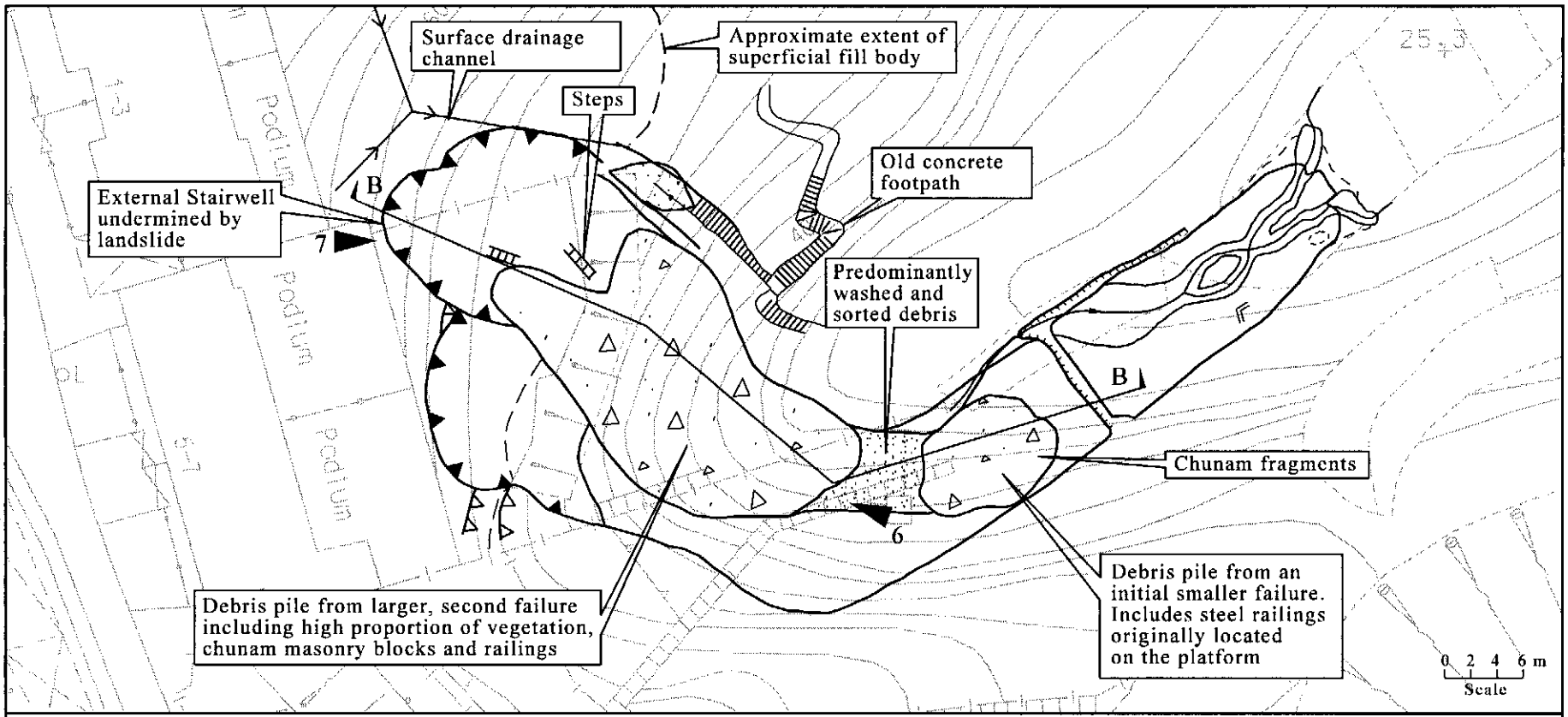
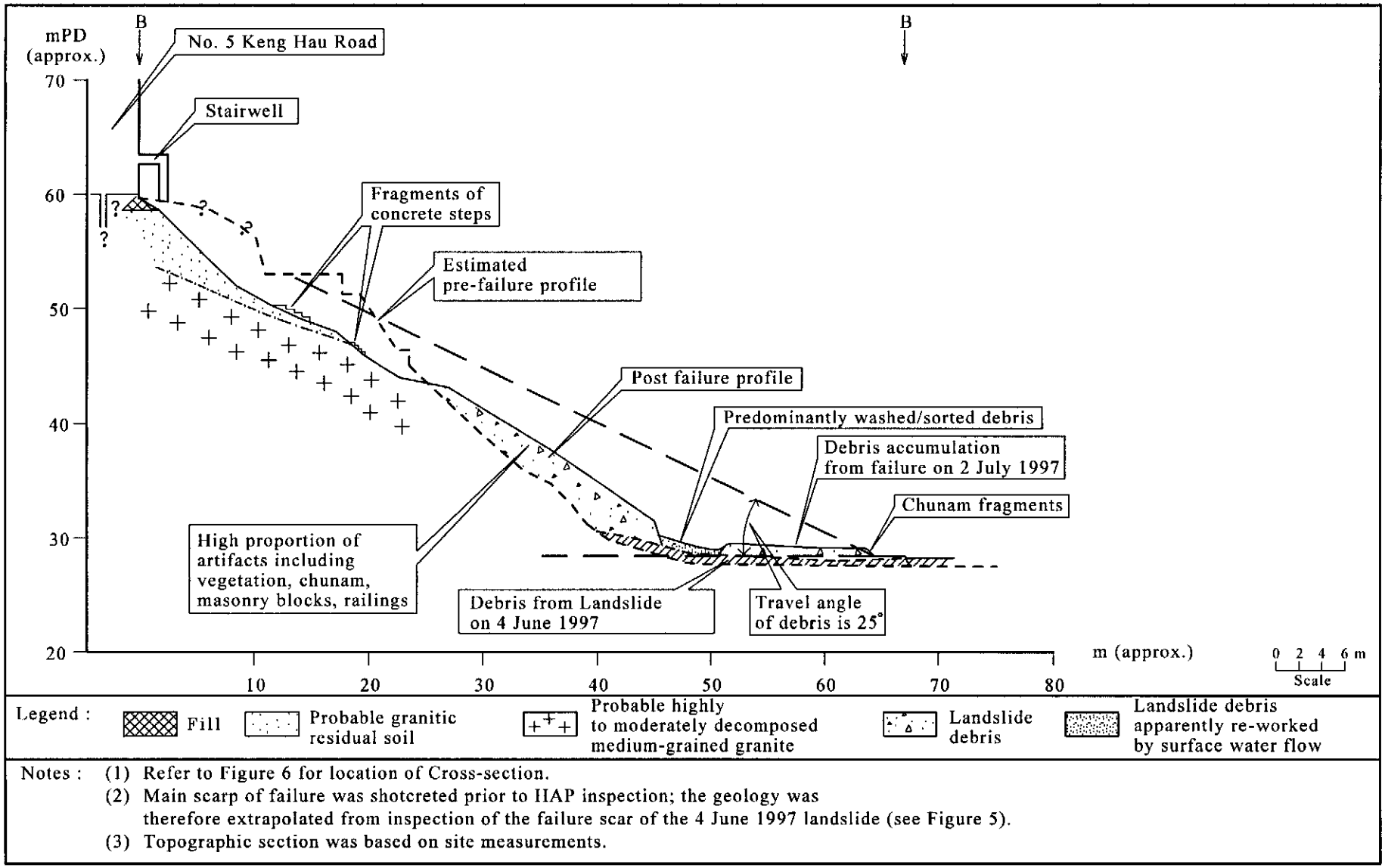


Figure 5 - Cross-section A-A Through the Landslide of 4 June 1997



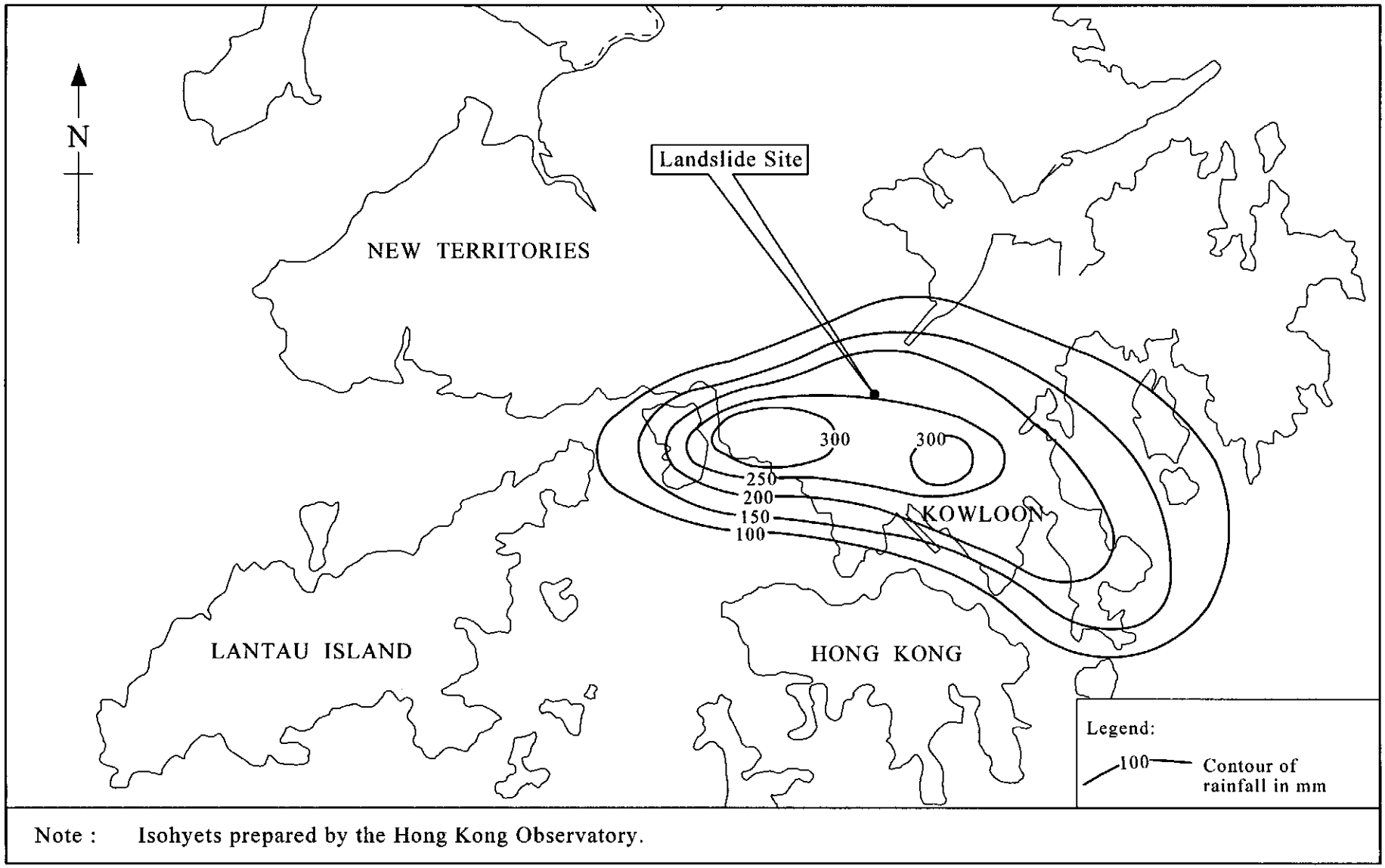
Notes :
(1) Information derived from walkover survey of the landslide area.
(2) Dimensions surveyed manually, approximate general accuracy of ±0.5 m to 1.5 m.
(3) Refer to Figure 7 for Cross-section B-B.
(4) Landslide main scarp was not inspected prior to application of shotcrete as part of emergency repair works.

Figure 6 - Site Location Plan and Details of the Landslide of 2 July 1997



Notes : (1) Refer to Figure 6 for location of Cross-section.
(2) Main scarp of failure was shotcreted prior to HAP inspection; the geology was therefore extrapolated from inspection of the failure scar of the 4 June 1997 landslide (see Figure 5).
(3) Topographic section was based on site measurements.

Figure 7 - Cross-section B-B Through the Landslide of 2 July 1997



Note : Isohyets prepared by the Hong Kong Observatory.

Figure 8 - Isohyets of Rainfall from 01:45 Hours to 10:00 Hours on 4 June 1997

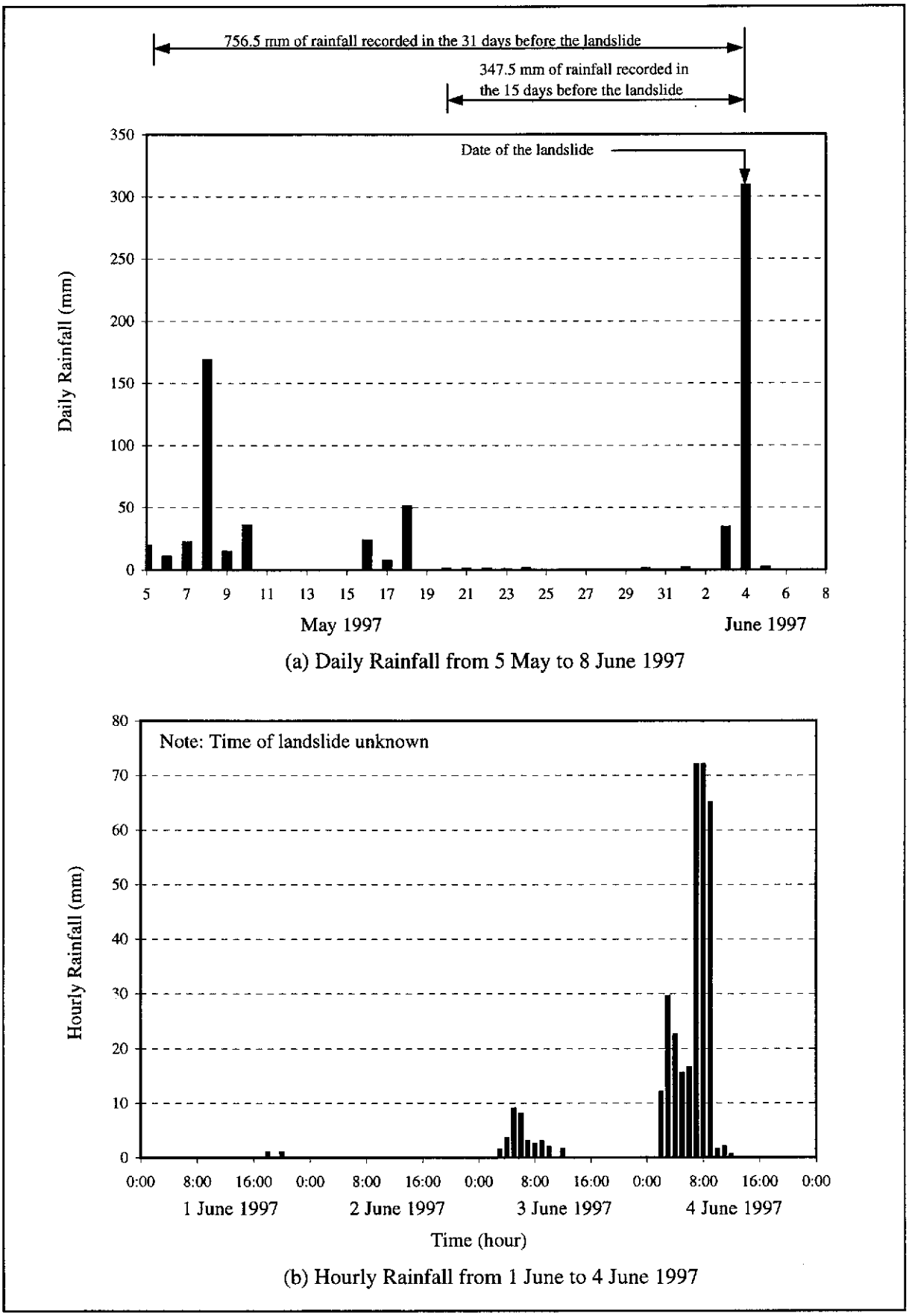


Figure 9 - Rainfall Records at GEO Raingauge No. N01 for the Rainstorm of 4 June 1997

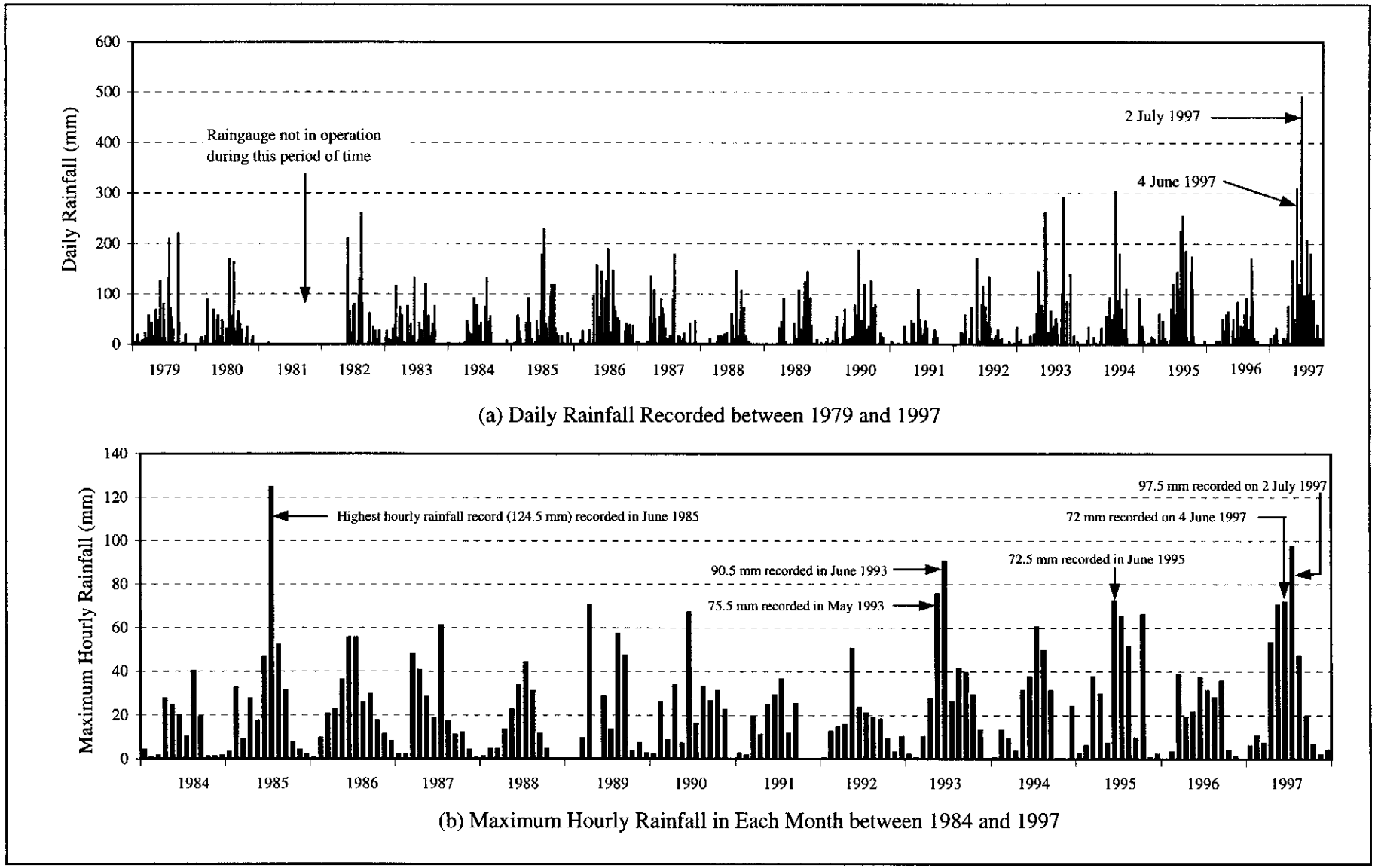
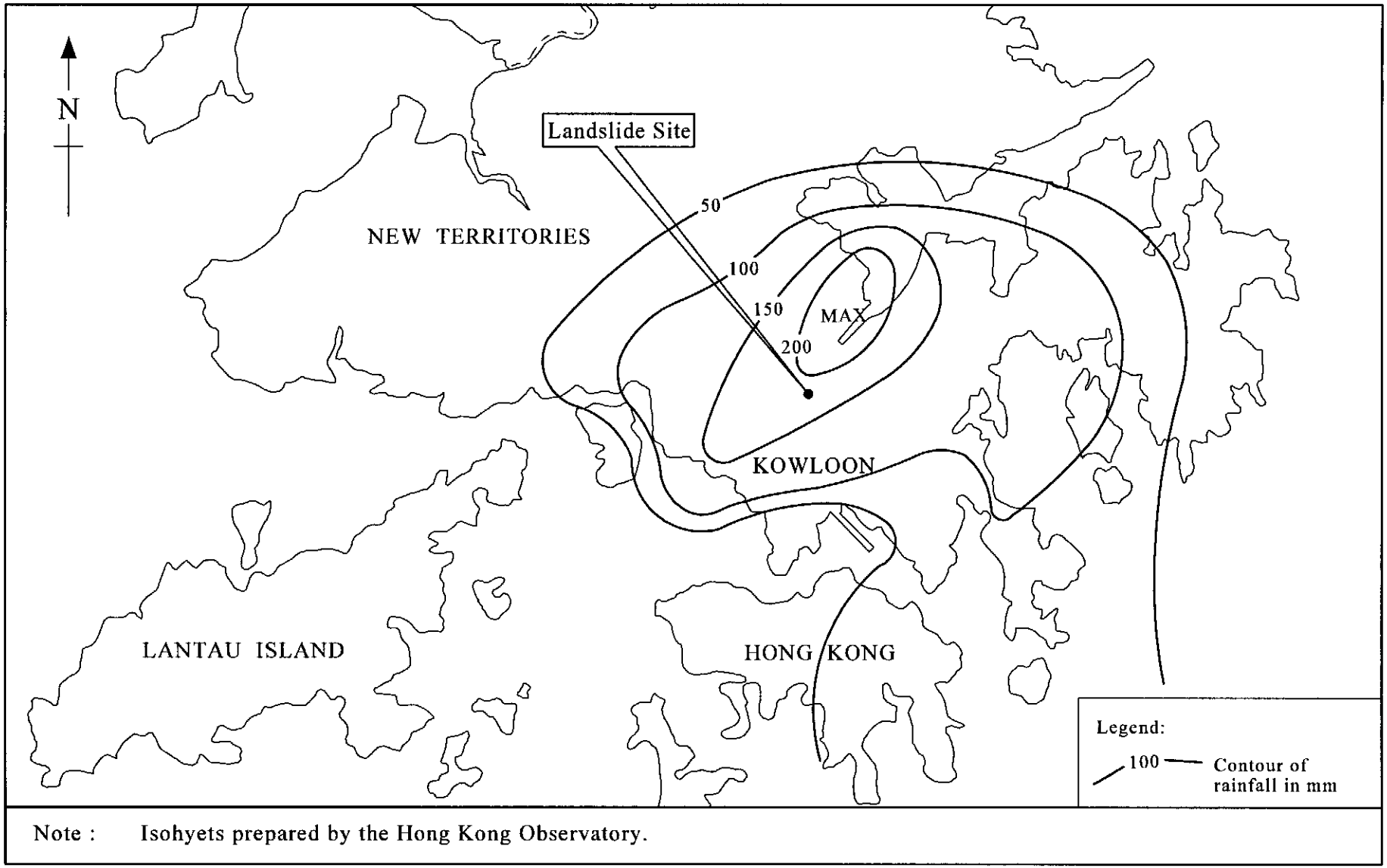


Figure 10 - Historical Rainfall Recorded at GEO Raingauge No. N01



Note : Isohyets prepared by the Hong Kong Observatory.

Figure 11 - Isohyets of Rainfall from 02:55 Hours to 07:00 Hours on 2 July 1997

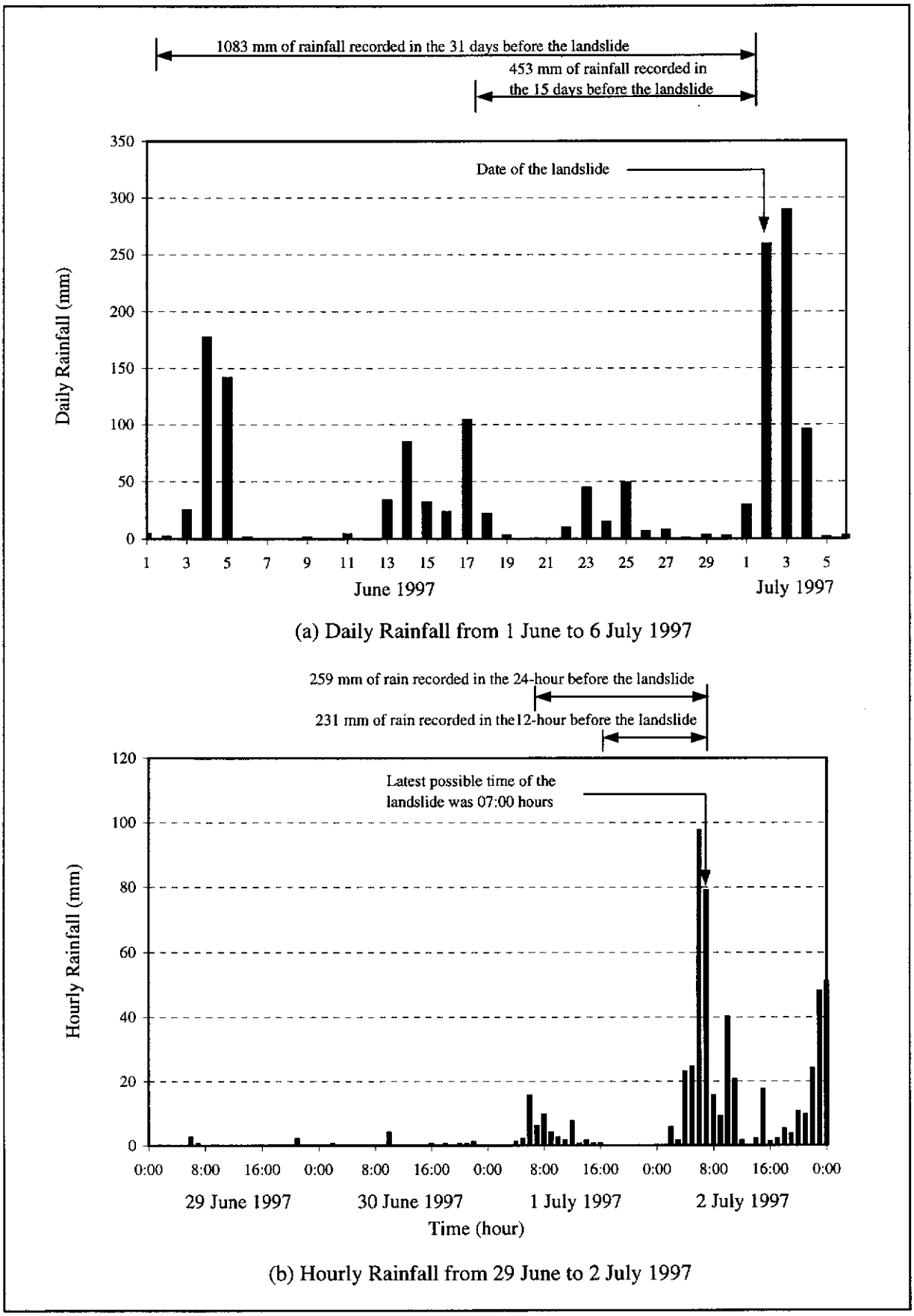


Figure 12 - Rainfall Records at GEO Raingauge No. N01 for the Rainstorm of 2 July 1997

LIST OF PLATES

Plate 1 - Northern Flank of the Landslide of 4 June 1997 (Photograph Taken on 17 June 1997)
(Note the Possible Erosion Pipe, Indicated by the White Arrow, and the Associated Minor Gullies, in the Upper Left Part of the Frame)

Plate 2 - View of the Main Scarp of the Landslide of 4 June 1997
(Photograph Taken on 17 June 1997)
(Note the Plastic Pipes Attached to the Front Wall of the Podia as Indicated by the White Arrow)

Plate 3 - View of the Track of the Landslide of 4 June 1997 (Photograph Taken on 17 June 1997)
(Note Super-elevation of Debris on the Right Hand Side of the Elbow in the Debris Track)

Plate 4 - Chunam Fragments Found at Toe of the Debris
(Photograph Taken on 17 June 1997)

Plate 5 - Hand Railings Found Near the Toe of the Debirs
(Photograph Taken on 17 June 1997)

Plate 6 - Upslope View of the Landslide Scars (Photograph Taken on 11 July 1997)
(Note the Undermining of the Stairwell in the Centre of the Photograph)

Plate 7 - Downslope View of the Landslide of 2 July 1997
(Photograph Taken on 11 July 1997)