SECTION 4: DETAILED STUDY OF THE LANDSLIDE NEAR LIDO BEACH, CASTLE PEAK ROAD ON 2 JULY 1997

Halcrow Asia Partnership Ltd

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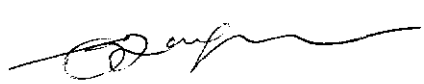
FOREWORD

This report presents the findings of a detailed study of a landslide (GEO Incident No. MW97/7/10) which occurred on 2 July 1997 near Lido Beach, Castle Peak Road. The landslide occurred on a partly modified natural hillside above Castle Peak Road and affected an adjacent registered fill slope. Approximately 750 m^3 of landslide debris completely blocked Castle Peak Road and an access road to six abandoned properties. Debris also spread downslope below Castle Peak Road into the gardens and swimming pool of the "Riviera Apartments". No fatalities were reported but eight people were injured and taken to hospital. Two of the injured were detained and the others were discharged after treatment.

The key objectives of the detailed study were to document the facts about the landslide, present relevant background information and establish the probable causes of the landslide. 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. It is one of a series of reports produced during the consultancy by Halcrow Asia Partnership Limited (HAP). The report was written by Mr R J Simonds and reviewed by Dr R Moore and Mr H Siddle. The assistance of the GEO in the preparation of the report is gratefully acknowledged.



G. Daughton
Project Director/Halcrow Asia Partnership Ltd

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1. INTRODUCTION

On the morning of 2 July 1997, a landslide occurred between No. 370 "Edinburgh Villas" and No. 372 "Villa Mar", above an access road leading from Castle Peak Road, near Lido Beach, to six abandoned properties (Figure 1). The landslide occurred on a 15 m high partly modified natural hillside and affected an adjacent registered fill slope (No. 6SE-C/F3). Approximately 750 m^3 of debris from the landslide completely blocked Castle Peak Road and the access road to the abandoned properties. Debris spread downslope below Castle Peak Road into the gardens and swimming pool of No. 369 "Riviera Apartments" (Figure 2). No fatalities were reported but eight people were injured and taken to hospital. Two were detained and the others were discharged after treatment.

At sometime prior to the above failure, a minor landslide occurred on a 7 m high cut slope (No. 6SE-C/C5) above the access road, about 50 m upslope from the main landslide (Figure 2). The two landslides are shown on an aerial photograph (Plate 1) taken on 4 July 1997. This report concentrates on the main landslide which resulted in blockage of Castle Peak Road and only refers to the minor landslide where considered relevant.

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

The key objectives of the study were to document the facts about the landslide, present relevant background information and establish the probable causes of the landslide. 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 relevant documents relating to the history of the site,

(b) analysis of rainfall records,

(c) interviews with eye-witnesses and injured persons,

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

(e) preliminary theoretical stability analysis, and

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

2. THE SITE

2.1 Site Description

The location of the landslide is shown in Figures 1 and 2. The landslide occurred within a development of six abandoned properties, which are linked to Castle Peak Road by an access road. The properties are situated on platforms with intervening cut and fill slopes. A number of streams on the natural hillside were diverted around the platforms during their construction (Figure 3). The landslide occurred on a 15 m high, partly modified natural hillside above Castle Peak Road. The slope is located below the abandoned property No. 374, between No. 370 Edinburgh Villas and 372 Villa Mar. The crest of the slope forms part of the fill platform at Villa Mar that contained an overgrown garden and a swimming pool. The slope was heavily vegetated prior to the landslide and had no surface protection (Plate 2). At the toe of the slope, there is an access road up to the abandoned properties. A 2 m to 3 m high chunam covered soil cut slope is present between the access road and a lay-by on Castle Peak Road.

A 300 mm stepped channel was present running down the hillside on which the landslide occurred. The channel appears to have collected surface water flows from a U-channel behind property No. 374 via a culvert under the access road. The condition of the surface channels and culvert prior to the landslide are not known. After the landslide, the broken end of the stepped channel was visible in the dense vegetation at the crest of the main scarp. During site inspections by HAP no drainage channels were found along the crest or the toe of the slope on which the landslide occurred.

The fill platform around Villa Mar is supported by a low masonry retaining wall (No. 6SE-C/R77) and two adjacent fill slopes (Nos. 6SE-C/F135 and 6SE-C/F3). The fill slopes had no surface protection and were constructed with two berms which had U-channels connected to the 300 mm stepped channel.

The minor landslide occurred on a cut slope (No. 6SE-C/C5) between an abandoned platform and the access road, about 50 m upslope of the main landslide (Figures 1 and 2).

Upslope to the north of the landslides, the construction of a new link road between Ting Kau Bridge and Tuen Mun Road was in progress at the time of inspection. The works included a 20 m deep cutting in rock and a rock fill embankment in the natural drainage line to the west of the cutting (location W, Figure 2). Surface drainage from the fill embankment was collected by a slope drainage system and discharged into a natural streamcourse west of the area of the landslides.

The landslide occurred mostly within unallocated Government land although the western flank of the landslide affected a fill slope (No. 6SE-C/F3) within private Lot No. 417 (Figure 3). The minor landslide also occurred within private Lot 417, although the cut slope (No. 6SE-C/C5) on which the failure occurred extends into unallocated Government land.

2.2 Site History

The site history was traced from a sequential series of aerial photographs of the site spanning the period 1954 to 1996 and a review of other available documentary information (Tables 1 and 2).

Aerial photographs show that site formation work for the development had been substantially completed by 1954 and that the six properties, including No. 372 Villa Mar and No. 374, had been constructed by 1963 (Figure 3).

The original extent of the platform around Villa Mar, as indicated by aerial photographs, is shown on Figure 3. An out-building below the bend in the access road appears to be on an extension of the main fill platform. Aerial photographs show that the platform around Villa Mar was modified by two extensions between 1963 and 1969. The southern end of the platform was extended to form a rectangular garden supported by a low retaining wall. Near the eastern end of the platform, another low retaining wall was added to extend the platform to the south of the swimming pool. The fill slopes downslope of the two extensions do not appear to have been modified.

Between 1969 and 1979 there was no apparent change to the slope on which the landslide occurred. However, there was evidence in 1975 and 1978 of seepage from the toe of the cut slope (No. 6SE-C/C5) on which the minor landslide occurred.

The aerial photographs taken in 1981 show that dense vegetation had been cleared from the partly modified natural hillside. By the following year a narrow terrace had been constructed along the southeastern edge of the platform of Villa Mar, to create a garden between the two previous extensions.

The 1985 aerial photographs show that the out-building in the garden of Villa Mar had been refurbished and there may have been some minor modifications or maintenance work to the cut slope (No. 6SE-C/CR462) on the downslope side of the access road above the out-building. There also appears to have been some minor repair work to the northeast corner of the platform around Villa Mar in 1987.

Apart from a general increase in the vegetation cover on the platform of Villa Mar and the partly modified natural hillside, aerial photographs indicate no apparent change at the site between 1992 and 1996.

2.3 Previous Studies

2.3.1 Slope Registrations and Stage 1 Studies

The partly modified natural hillside was not registered in the 1977/78 Catalogue of Slopes or in the New Catalogue of Slopes.

The eastern flank of the landslide affected part of Slope No. 6SE-C/FR3, which was registered in the 1977/78 Catalogue of Slopes. The first recorded inspection of the slope was

in May 1983 by the Geotechnical Control Office (GCO, 1983). At this time no proposed works or further actions were recommended.

In 1992, the GEO initiated a consultancy agreement entitled 'Systematic Inspection of Features in the Territory' (SIFT) which aims to, inter alia, update information on existing registered slopes based on studies of aerial photographs. In August 1996, the SIFT study divided slope No. 6SE-C/FR3 into two fill slopes and a retaining wall. The masonry retaining wall at the crest of the slope was allocated No. 6SE-C/R77, the western part of the slope was allocated No. 6SE-C/F135 and the eastern part of the slope, which was affected by the landslide, was allocated No. 6SE-C/F3 (Figure 3).

In 1994, the GEO commenced the project 'Systematic Identification and Registration of Slopes in the Territory' (SIRST), to systematically update the 1977/78 Catalogue of Slopes and to prepare the New Catalogue of Slopes. The SIRST programme confirmed the division of slope No. 6SE-C/FR3 into three features, following inspections in April 1997. Field sheets prepared for the three features recommended no follow-up actions and noted that "the whole area to be demolished and redeveloped in the near future".

The cut slope (No. 6SE-C/C5) above the access road, on which the minor landslide occurred, was registered in the 1977/78 Catalogue of Slopes. The first recorded inspection of the slope was undertaken in March 1978 by the consultants, Binnie & Partners (B&P) appointed to prepare the Catalogue. The inspection report recorded no signs of distress and maintenance works to the chunam cover were recommended (B&P, 1978). No records of subsequent maintenance works have been located within the GEO.

An inspection of Slope No. 6SE-C/C5 was undertaken in November 1994 by the SIRST consultants. The inspection report recorded blocked drainage, signs of distress and major cracking near the crest and mid-slope. As a result of these observations, a Stage 1 Study Report was prepared. The report specified no immediate action, however further study was recommended (see Section 2.3.3).

In August 1996, SIFT gave the classification 'Class C1' to Slope No. 6SE-C/C5 as it was "formed or substantially modified before 30.6.78" and satisfied the criteria for slope registration. It was noted that the slope was "constructed before 1963".

The debris from the main landslide inundated the fill slope (No. 6SE-C/F52) below Castle Peak Road which was registered in the 1977/78 Catalogue of Slopes. The SIFT study undertaken in August 1996 proposed Slope No. 6SE-C/FR52, due to the presence of a 1 m high retaining wall at the toe (Figure 3).

The masonry retaining wall (No. 6SE-C/R77) supporting the fill platform at the crest of the slope was inspected on 3 June 1996 by HAP as part of the programme of 'Thickness Gauging of Masonry Retaining Walls' (HAP, 1997). At the time of the inspection, no structural distress was apparent and no seepages were reported.

2.3.2 Dangerous Hillside Order

In August 1982, two landslides 'C' and 'D' (see Figure 1 and Section 2.4), occurred to the west of the 1997 landslides in private Lot No. 417 on cut Slope Nos. 6SE-C/C84 and 6SE-C/C6, respectively. The owner of private Lot No. 417 commissioned a report in November 1982 by Tang, K.F. & Associates (T & A, 1982). In addition to describing the two landslides, the report noted that cut Slope No. 6SE-C/C5 was "covered with chunam plaster and there was evidence that seepage had taken place at holes at the toe of the slope". The report recommended that "at the location where seepage was observed additional weepholes or toe drains should be installed. These works are required to maintain the access road in working condition". It is noted that seepages from the toe of cut Slope No. 6SE-C/C5 were visible on aerial photographs taken in 1975 and 1978 (see Section 2.2).

The lot owner was subsequently served with a Dangerous Hillside Order (DHO) in March 1983 to take action as a result of landslides 'C' and 'D'. The owner commissioned a geotechnical report (T & A, 1983). The report recommended repair works at the two landslide sites, however no recommendations were made concerning Slope No. 6SE-C/C5. The repair works commenced in November 1983, and in September 1984 the Buildings Development Department (BDD) confirmed to the owner of private Lot No. 417 that the works required by the DHO had been complied with (BDD, 1984). The drainage works recommended by T & A in 1982 on slope No. 6SE-C/C5 were not undertaken as part of these works.

2.3.3 Nominations to the Landslip Preventive Measures Programme

In June 1995, the GEO prepared a Landslip Preventive Measures Selection Nominated Features Study Report (GEO, 1995) for Slope No. 6SE-C/C5. The slope was subsequently included in the 1996/97 Landslip Preventive Measures (LPM) selection exercise. However, LPM works were not pursued as site formation plans for a proposed residential development at Lot No. 417 had been submitted to the BDD and the GEO in 1995. The plans indicated that Slope No. 6SE-C/C5 would be substantially modified by the proposals (Greg Wong & Associates, 1995).

In October 1996, Slope No. 6SE-C/FR3 was included in the LPM Programme. Fugro (HK) Limited (FHL) were appointed by the GEO to study the slope. In April 1997, FHL commenced a search of background information, however, in May 1997 the slope was deleted from the LPM Programme by the GEO as it was included within the area of the Castle Peak Road Improvement Project.

2.3.4 Castle Peak Road Improvement Project

A feasibility study for the Castle Peak Road Improvement Project was undertaken by Maunsell Consultants Asia Limited (MCAL, 1996) for the Highways Department (HyD). The study provided an outline design which would entail:

(a) the demolition of Villa Mar,

(b) the complete alteration of Slope Nos. 6SE-C/F3, 6SE-C/F135, 6SE-C/R77, 6SE-C/CR462 and the partly modified natural hillside on which the landslide occurred, to accommodate a cutting for the re-aligned Castle Peak Road, and

(c) the modification of Slope No. 6SE-C/C5.

The northern clearance limit for the proposed project, which is scheduled to commence in 2000, is shown in Figure 3.

2.4 Previous Landslides

GEO's Landslide Incident Report database contains no records of previous landslide incidents in the area of the 1997 landslides. GEO's Natural Terrain Landslide Inventory (NTLI) indicates there were two natural terrain landslides 'A' and 'B' on the hillside upslope of the 1997 landslides (Figure 1).

Landslide 'A' occurred in August 1982 and was inspected by a geotechnical engineer from BDD who noted that "large quantities of boulders up to 0.5 m^3 in size had travelled downhill along a small stream course and spread over the platforms occupied by the bungalow structures" (BDD, 1983). It is not known when landslide 'B' occurred, but it was first observed on aerial photographs taken in 1981. The debris from landslides 'A' and 'B' entered the natural streamcourse which passes about 120 m to the west of the landslide.

In August 1982, two landslides 'C' and 'D' occurred about 60 metres and 80 metres to the west of the landslide, respectively (Figure 1). Landslide 'C' occurred on cut Slope No. 6SE-C/C84 below the access road to "Rock Villa" and landslide 'D' occurred at the far western end of cut Slope No. 6SE-C/C6 above "Rock Villa" (Figure 3). The landslides resulted in a DHO being served on the owner of private Lot No. 417 (see Section 2.3.2).

2.5 Subsurface Conditions

The geological memoir (Langford et al, 1989) and sheet 6 of the Hong Kong Geological Survey 1:20 000 Map series (GCO, 1988) indicate that the site is underlain by megacrystic fine-grained granite.

A report prepared by Greg Wong & Associates (GW&A, in 1995) includes records of three boreholes (BH7, BH9 and BH19) in the vicinity of the landslide (Figure 3). The borehole records and groundwater level data were used to prepare the geological cross-section shown in Figure 4.

The boreholes (BH7 and BH9), upslope of the landslide, encountered 12.7 m and 15.9 m, respectively, of completely decomposed granite which was recovered as a silty fine sand, overlying moderately to slightly decomposed granite. Groundwater was encountered at a depth of 5 m in both boreholes. Borehole BH19, sunk in the access road below the landslide

encountered similar materials, although the thickness of completely decomposed granite was only 6.7 m. Groundwater was encountered at a depth of 5.5 m in borehole BH19. The boreholes were sunk at the end of the dry season and the water strikes at depths of about 5 m suggest that the groundwater table is shallow. This was confirmed by observation of groundwater seepages from the base of the rupture surface after clearance of landslide debris.

3. THE LANDSLIDE

3.1 Sequence of Events

The sequence of events has been established from eye-witness accounts and interviews with various persons involved in the emergency rescue. The Case Report and the Incident Log of the Hong Kong Police Force (HKPF, 1997a,b), a report by the Hong Kong Fire Services Department (HKFSD, 1997) and a report by the Safety Manager of Ting Kau Bridge Contractors Limited (TKBC, 1997) have also been consulted.

A landslip warning was issued at 06:25 hours on 2 July 1997. At about 08:00 hours a large washout of sand fill occurred from the Ting Kau Bridge construction site, about 200 m east of the landslide. The fill material was washed onto Castle Peak Road and partially blocked one lane. At sometime prior to 09:00 hours there was a second large washout of sand fill from the construction site. On this occasion both lanes of Castle Peak Road were blocked and debris spread as far as Edinburgh Villas (Figure 1), accumulating to a depth of around 300 mm. At 09:05 hours, a double decker bus was immobilised by the debris on Castle Peak Road near "Edinburgh Villas". As a result, the police closed both lanes of Castle Peak Road at 09:40 hours and diverted traffic onto Tuen Mun Road.

The police requested the assistance of TKBC plant and personnel to clear the road. An excavator and a 6-wheel dump truck together with five workmen from TKBC were mobilised to undertake the clearance work. By 11:45 hours, the TKBC workmen had cleared the majority of the debris from Castle Peak Road and were clearing up in front of "Edinburgh Villas". Two senior police officers arrived on site to inspect the condition of the road in advance of the road being re-opened.

The following account of what happened at 11:45 hours was given by two TKBC workmen, "there was a loud 'crack' and a landslide occurred beneath the property on the crest. About one minute later, a further loud 'crack' and a second landslide brought the power cables down, debris carried over the access road and lifted the truck and carried it downslope towards the swimming pool of Riviera Apartments. There was no forewarning, no unusual noises and no visible sign of surface water running off the slope on which the landslide occurred."

At around 11:55 hours eye-witnesses observed "slumping" within the landslide debris in the main scarp, however, the run-out from the "slumped" material did not reach the access road above Castle Peak Road.

Police officers who had left the site prior to the landslide, returned to the scene at 11:50 hours and undertook the rescue of a watchman who was partially buried in a wooden

hut which had been destroyed by landslide debris on Castle Peak Road (Figure 2). In addition, the police officers together with fire officers who arrived at the scene at 11:58 hours, rescued seven people from within the landslide debris which had accumulated in the garden area and swimming pool of "Riviera Apartments". Five of the seven people had been engulfed by the landslide debris and were swept down the slope below Castle Peak Road. All eight people rescued from the landslide debris were injured. Six of the injured people were discharged from hospital after treatment and two were detained for further treatment. Castle Peak Road was re-opened to one-way traffic at 03:45 hours on 7 July 1997 and was re-opened to two way traffic at 06:00 hours on 12 July 1997.

3.2 Description of the Landslide

Eye-witness accounts (see Section 3.1) and the morphology of the main scarp of the landslide indicate two phases of movement:

(a) An initial movement from the northwest end of the platform below Villa Mar, where the main scarp was within 3 m of the property and 1 m of the swimming pool. The run-out of debris from this failure did not reach the access road.

(b) A second movement during which the main scarp was widened to the northeast as far as the boundary fence of the private Lot No. 416 and to the north to within 3 m of the out-building in the garden of Villa Mar (Figure 2). The run-out of debris from this failure swept across the access road and Castle Peak Road.

The rupture surface of the landslide was 25 m wide, 20 m long and up to 3 m deep. The estimated volume of displaced material was 750 m^3, of which approximately two-thirds was completely decomposed granite and the remaining third was a mixture of residual soil and fill (Plate 3). The landslide debris was affected by minor slumping and secondary washout as a result of subsequent rainfall and surface water run-off (Plates 4 and 5).

The main scarp was near-vertical at the crest and 40° to the horizontal at mid-height. Landslide debris covered the lower part of the main scarp which was at about 20° to the horizontal. The material exposed in the main scarp of the landslide comprised about 1.2 m of fill, consisting of brown silty fine to medium sand. The fill overlay 1.5 m to 2 m of residual soil, composed of orange brown silty fine to coarse sand, below which orange brown completely decomposed, fine- to medium-grained granite was exposed. The majority of the main scarp was located on the partly modified natural hillside, however, the western 5 m of the main scarp and the western flank of the landslide affected fill Slope No. 6SE-C/F3. A 1 m high masonry wall (part of feature No. 6SE-C/R77) around the edge of the garden area was undermined and collapsed during the landslide.

The landslide completely demolished a watchman's hut which was located on the access road at the toe of the slope (Figure 3). The landslide debris inundated the access road and ran-out down a 3 m high cut slope onto Castle Peak Road, where it completely blocked

both lanes. A fully-laden stationary dump truck parked on Castle Peak Road was carried by the debris down a 5 m high fill slope (No. 6SE-C/FR52) into the garden of Riviera Apartments (Plate 6). A 5 m long section of the pavement above the fill slope was undermined around a service access chamber as a result of washout and surface water run-off after the landslide. The debris on Castle Peak Road was about 30 m wide and up to 1.5 m deep (Plate 7).

The travel angle of the landslide, measured from the crest of the main scarp to a point on top of the debris on the downslope side of Castle Peak Road was 20°. This excludes the extreme distal portion of the debris where the gradient of fill slope (No. 6SE-C/FR52) below Castle Peak Road and secondary washout are considered to have resulted in greater travel distance.

The landslide debris was observed to be very wet when inspected after the landslide on 2 July 1997 (Plate 8). The debris comprised silty fine to coarse sand, tree roots, vegetation, blocks of masonry retaining wall, sections of stepped channel, and debris from the destroyed watchman's hut. No obvious seepages were noted in the main scarp during inspections made on 2 and 3 July 1997. However, on 7 July 1997 when the debris had been removed from the lower part of the rupture surface and rockfill had been placed, moderately strong seepage was observed at two locations, approximately 5 m upslope from the access road (Figure 2).

A severed 75 mm diameter steel pipe was observed at a depth of about 1.2 m below ground level, protruding from the fill near the centre of the main scarp (Plate 9). Immediately after the landslide this pipe was observed to be discharging water onto the debris below the main scarp. Observations made on 3 July 1997 (the day after the landslide) indicated that water discharge from the pipe had ceased. Contractors working for HyD reported that when they trimmed back the main scarp the pipe was found to be connected to the base of the swimming pool in the garden of Villa Mar. The swimming pool was subsequently removed during the trimming back of the main scarp.

Inspections of the surrounding area by HAP about 2 hours after the main landslide on 2 July 1997, found that the upper platform Y (Figure 2) was waterlogged and provided the source of the surface water, which was observed flowing down the rupture surface of the minor landslide on cut Slope No. 6SE-C/C5 and onto the access road below. The surface water was diverted over the edge of cut Slope No. 6SE-C/C6 by landslide debris deposited on the access road, into an area of hardstanding around the abandoned property No. 374. There was an accumulation of silt and water on the hardstanding, which suggests that the drainage system around No. 374 and its connection to the 300 mm stepped channel might not have been functioning or had become blocked as a result of siltation. Surface water drained from the hardstanding onto the access road and flowed down the road. After the landslide it was diverted by the debris on the access road down the cut slope onto Castle Peak Road (Figure 2).

At the time of the inspection there was no evidence of surface run-off onto the main landslide from the access road above (location Z, Figure 2) or from the area between the access road and Edinburgh Villas. The U-channels on the fill slope below Villa Mar were found to be blocked with silt and leaf litter and would not have been capable of transmitting any significant water flow towards the landslide area.

The drainage system around the rock fill embankment associated with the link-road construction works north of the landslide was also inspected by HAP. At the time of inspection, about 2 hours after the landslide, the surface water drainage system on the rock fill embankment was found to be working satisfactorily. There was no evidence that overflow of surface water down the access road had occurred from the drainage system (location X, Figure 2).

Following the landslide the GEO advised HyD to carry out urgent repair works, comprising clearance of the debris, placement of rockfill to support the lower portion of the failure surface, trimming back the main scarp, soil nailing and provision of surface protection with weepholes. The works were largely completed ahead of the re-opening of Castle Peak Road on 12 July 1997.

4. RAINFALL

The nearest GEO automatic raingauge No. N10 is located at Sham Tseng Emmanuel Primary School, about 2 km west of the landslide site. The daily rainfall recorded in June and July 1997 is shown in Figure 5a. There was 492.5 mm and 208.5 mm of rainfall in the 31 days and 15 days before the landslide respectively. The hourly rainfall from 29 June to 2 July 1997 is shown in Figure 5b. There was 186 mm and 181.5 mm of rainfall in the 24 hours and 12 hours before the landslide respectively. Isohyets of rainfall prior to the landslide on 2 July 1997 are shown in Figure 6. The figure shows that the distribution of peak intensity of rainfall was centered about 14.5 km east northeast of the site.

The estimated return periods for maximum rolling rainfall for selected durations based on historical rainfall data at the Hong Kong Observatory (Lam & Leung, 1994) are presented in Table 3. The maximum rolling 15-minute rainfall between 08:35 hours and 08:50 hours was the most severe, with a corresponding return period of about 6 years.

The rainfall recorded at GEO raingauge No. N10 at 5-minute intervals on 2 July 1997 is shown in Figure 7. The figure shows that there was a lag of about 2.5 hours between the end of the rainstorm and the reported time of the landslide at 11:45 hours on 2 July 1997.

5. PROBABLE CAUSES OF FAILURE

The rainfall that preceded the landslide, although heavy, was not extreme having an estimated return period of only about 6 years. Significantly, the landslide occurred about 2.5 hours after the end of the rainstorm. The occurrence of a lag-time and the absence of significant surface water flow onto the landslide, indicates that the landslide was not a washout and was most probably triggered by an increase in groundwater level.

The eye-witnesses describe the landslide as being quick-moving, at least in the second phase of movement. The mobility of the debris was high as demonstrated by a travel angle of 20°, which is lower than the range typically associated with rain-induced landslides in Hong Kong (Wong & Ho, 1996). There was no significant outburst of water reported during the

failure and no evidence of deep erosion of the debris and the main scarp that would have resulted from such an outburst.

Theoretical stability analysis was undertaken to ascertain the role of groundwater in promoting the failure. The analysis was carried out for a range of groundwater levels using shear strength parameters derived from the ground investigation for the proposed re-development of the site (GW&A, 1995) and other published data. The analysis demonstrated that a groundwater level at or above mid-height in the slope would result in a factor of safety of unity or less.

Four sources of water that may have contributed to a rise in the groundwater level have been considered :

(a) Direct infiltration into the steep, vegetated and unsurfaced partly modified natural slope during the rainstorm.

(b) Infiltration of water that accumulated around the abandoned property No. 374 above the landslide.

(c) Water introduced into the slope from the drain pipe from the swimming pool, although this is considered unlikely to have introduced a large volume of water in view of the small surface area of the swimming pool.

(d) Extensive rock excavation for the roadworks upslope of the landslide site may have increased infiltration into the ground. However, the distance of the excavation from the landslide probably precludes any significant contribution to the rise in the groundwater level at the landslide from this source on the day of the incident.

There were no significant surface water flows onto the landslide itself to contribute to infiltration and it was noted during inspection by HAP that the platform of Villa Mar drains in a westerly direction, away from the landslide. It is likely, therefore, that the landslide was triggered by a rise in groundwater level caused by the combined effects of direct infiltration of rainfall at the site and ponded water from around the abandoned property No. 374. Significantly, surface water released from the waterlogged platform by the minor landslide upslope continued to reach the area around No. 374 after the end of the rainstorm and hence the groundwater level would have continued to rise in that area. It is significant that the area of ponded water is almost directly upslope of the landslide. Triggering of the landslide by progressively rising groundwater is consistent with observations of eye-witnesses of a sudden movement without prior warning.

At sometime after the construction of the platform for Villa Mar, fill was placed adjacent to the northeast edge of the platform at the crest of the slope on which the 1997 landslide occurred. It is considered that this placement of fill would have imparted additional shear stresses within the slope, which would have contributed, at least in part, to the reduction in stability of the slope.

The high mobility of the landslide debris was probably due to any or all of the following:

(a) The landslide occurred under a relatively high groundwater pressure condition, which implies that the effective stress and hence the shear strength of the soil that failed was low.

(b) The drainage of surface water from the access road into the path of the landslide.

(c) The presence of surface water and a thin layer of wet soil on Castle Peak Road following the earlier washout (Plate 8). It is considered that this may have created a buoyancy effect on the landslide debris due to undrained loading as the debris passed over the road. The second phase of movement of the slope may also have involved collapse of the slope onto the loose debris of the initial phase of movement resulting in undrained loading and development of positive porewater pressures.

6. CONCLUSIONS

It is concluded that the failure was a highly mobile debris slide which occurred on a partly modified natural hillside. The failure occurred within completely decomposed granite and was triggered by an increase in the groundwater level within the slope caused by the combined effects of direct infiltration of rain and surface water that was ponded around the abandoned property directly upslope of the landslide.

The landslide was more mobile than other failures in completely decomposed granite commonly observed in Hong Kong. The mobility was probably related to the landslide occurring at a relatively high groundwater pressure condition and hence involved failure of soil at low effective stress and shear strength. The high mobility of the landslide may also be attributed to the presence of surface water and wet soil on Castle Peak Road in the travel path of the landslide which may have resulted in undrained loading on impact.

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LIST OF TABLES

Table 1 – Summary of Site Development from Aerial Photograph Interpretation (Sheet 1 of 2)

Year	Photographic Reference No.	Altitude	Observations
1954	Y02680/81	29,200 ft	Site formation works appear to have been completed at Villa Mar. The slope between Villa Mar and Edinburgh Villas was vegetated.
1963	Y08913/14 Y08948/49	3900 ft 3900 ft	The six properties in private Lot No. 417 had been constructed. The original edge of the platform follows the natural topography in a smooth curve around Villa Mar. The surface of the fill slope was pale-toned, had a thin grass cover and showed signs of slight soil erosion. There were two U-channels on two narrow berms at 1/3 and 2/3 height of the fill slope below Villa Mar. The U-channels follow the contours round the slope into the drainage channel running down the slope between Villa Mar and Edinburgh Villas.
1964	Y11182/83	1800 ft	An area of bare soil was visible at the northeastern end of the fill slope below the platform around Villa Mar.
1969	Y15364 Y15365	5000 ft 3500 ft	Two extensions supported by retaining walls had been constructed on fill at the southeastern edge of the platform around Villa Mar.
1972	1732	1400 ft	No changes were apparent.
1975	11340/41	1500 ft	Cut Slope No. 6SE-C/C5 appears to have had a chunam surface protection. There was a dark toned area at the toe of the northeastern corner of cut Slope No. 6SE-C/C5 and the access road showed evidence of previous water flow.
1976	13210/11	4000 ft	No changes were apparent.
1977	20062/63	4000 ft	No changes were apparent.
1978	24039/40	4000 ft	There was a dark-toned area visible at the toe of the northeastern corner of cut Slope No. 6SE-C/C5. It is considered that this dark toned area was due to seepage.
1979	28109/10	10,000 ft	The vegetation had been cleared on the fill slope below the southeastern edge of the fill platform around Villa Mar.

Table 1 – Summary of Site Development from Aerial Photograph Interpretation (Sheet 2 of 2)

Year	Photographic Reference No.	Altitude	Observations
1981	36288	4000 ft	The vegetation had been cleared on the slope between Villa Mar and Edinburgh Villas.
1982	43111	3000 ft	A narrow rectangular terrace had been constructed between the two platform extensions below the southeastern edge of the fill platform around Villa Mar.
1983	52152/53	10,000 ft	The slope between Villa Mar and Edinburgh Villas was densely vegetated.
1984	56525/26	4000 ft	The terrace below the southeastern edge of the platform was clearly visible. The fill slope below Villa Mar was densely vegetated.
1985	67628/29	4000 ft	The platform around Villa Mar was clearly visible in its present configuration.
1986	A05733/34	4000 ft	No changes were apparent.
1987	A10525/26	4000 ft	The maintenance work on the platform below cut Slope No. 6SE-C/CR462 in the garden of Villa Mar appears to have been completed.
1988	70304/05	4000 ft	The maintenance work on the terrace area between the platform extensions around Villa Mar appears to have been completed.
1989	A18352	4000 ft	The platform around Villa Mar was highly vegetated.
1990	A20976/77	4000 ft	Vegetation on the fill slope below Villa Mar had been partially cleared. The terrace between the platform extensions around Villa Mar was visible.
1991	A27578/79	4000 ft	A low wall was visible around the edge of the platform around Villa Mar.
1992	A31211/12	4000 ft	No changes were apparent.
1993	A36010/11	4000 ft	The vegetation had been cleared from the cut Slope No. 6SE-C/CR124 behind Edinburgh Villas.
1994	A39963/64	4000 ft	There had been surface protection applied to the upper part of Slope No. 6SE-C/CR124.
1995	CN14256/57	4000 ft	Slope No. 6SE-C/CR124 had become re-vegetated.
1996	A44143/44	4000 ft	No changes were apparent. The whole area was densely vegetated.

Table 2 – Summary of Information Sources (Sheet 1 of 2)

Source	Information Obtained
Geotechnical Information Unit (GIU) at the Civil Engineering Department (CED) Library.	Re-resubmission Project No. P1323. Geotechnical Report of Site Formation for Proposed Residential Development at Lot 417 in D.D. 399, Ting Kau, Tsuen Wan, New Territories. Greg Wong & Associates Limited.
Slope Files and District Files from Mainland West Division and Files from Design Division of the GEO.	(a) Stage 1 Study Reports on Slope Nos. 6SE-C/C5 and 6SE-C/C6. (b) Field Sheet for Slope No. 6SE-C/FR3. (c) LPM Selection Nominated Features Study Report for Slope No. 6SE-C/C5.
GEO Publications, Reports, Maps, and Memoirs.	(a) Yuen Long : Solid and superficial geology, Hong Kong Geological Survey Map Series HGM20, Sheet 6, 1:20 000 scale. (b) Geology of the Western New Territories, Hong Kong, Geological Memoir No. 3.
GEO Planning Division.	Aerial Photographs 1954, 1963, 1964, 1972, 1976, 1978, 1983, 1985, 1988, 1990, 1992, 1993, 1994 and 1996.
GEO Slope Safety Division.	SIRST Reports for Slope Nos. 6SE-C/F3, 6SE-C/R77, 6SE-C/CR462 and 6SE-C/F135.
GEO Landslide Incident Report Database.	Details of past landslides reported to the GEO.
Lands Department, and District Lands Office (DLO).	(a) Land Status. (b) Maintenance Responsibility.
Water Supplies Department (WSD).	Existing Utility Information.
Drainage Services Department (DSD).	Existing Utility Information.

Table 2 – Summary of Information Sources (Sheet 2 of 2)

Source	Information Obtained
LPM / SIRST / SIFT Databases.	Registration status of Slope Nos. 6SE-C/F3, 6SE-C/R77, 6SE-C/F135, 6SE-C/CR462, 6SE-C/C6 and 6SE-C/C5.
Fugro (Hong Kong) Limited.	In relation to Slope No. 6SE-C/FR3 the following was obtained: (a) A record sheet indicating that no files were found on the slope in the Buildings Department. (b) Planning Department Drg No. 97294/RF/009 showing the proposed improvements to Castle Peak Road. (c) A letter from the GEO deleting the slope from the LPM Programme.
Halcrow Asia Partnership Limited (HAP) Archives.	Old Masonry Wall Field Inspection Sheet for the retaining wall at the crest of Slope No. 6SE-C/FR3.
Hong Kong Police Force (HKPF).	(a) Police Case Report no. 97017354. (b) Police Incident Log no.1997/08/16. (c) Completed questionnaires from four Police officers.
Hong Kong Fire Services Department (HKFSD).	Report on Special Services at Roadside Opposite No. 369 Castle Peak Road on 2 July 1997 at 11:50 hours.
Ting Kau Bridge Contractors Limited (TKBC).	(a) Report by Safety Manager. (b) A completed questionnaire from two eye-witnesses. (c) Drawing No. TKB/SRS/BC/1353 showing the alignment of the new link road to the west-bound carriageway of the Tuen Mun Road and the location of the fill embankment.
Hong Kong Observatory (HKO).	Isohyets of rainfall between 00:00 hours and 11:45 hours 2 July 1997.

Table 3 – Maximum Rolling Rainfall at GEO Raingauge No. N10 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	13.5	08:40 hours on 2 July 1997	2
15 minutes	35	08:50 hours on 2 July 1997	6
1 hour	89	09:00 hours on 2 July 1997	5
2 hour	120	09:00 hours on 2 July 1997	4
4 hours	129.5	10:00 hours on 2 July 1997	3
12 hours	182	12:00 hours on 2 July 1997	2
24 hours	187.5	11:00 hours on 2 July 1997	2
2 days	264	12:00 hours on 2 July 1997	2
4 days	277	12:00 hours on 2 July 1997	2
7 days	286.5	12:00 hours on 2 July 1997	1
15 days	365.5	12:00 hours on 2 July 1997	1
31 days	671	12:00 hours on 2 July 1997	2

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 from 5-minute data for durations up to one hour and from hourly data for longer rainfall durations.

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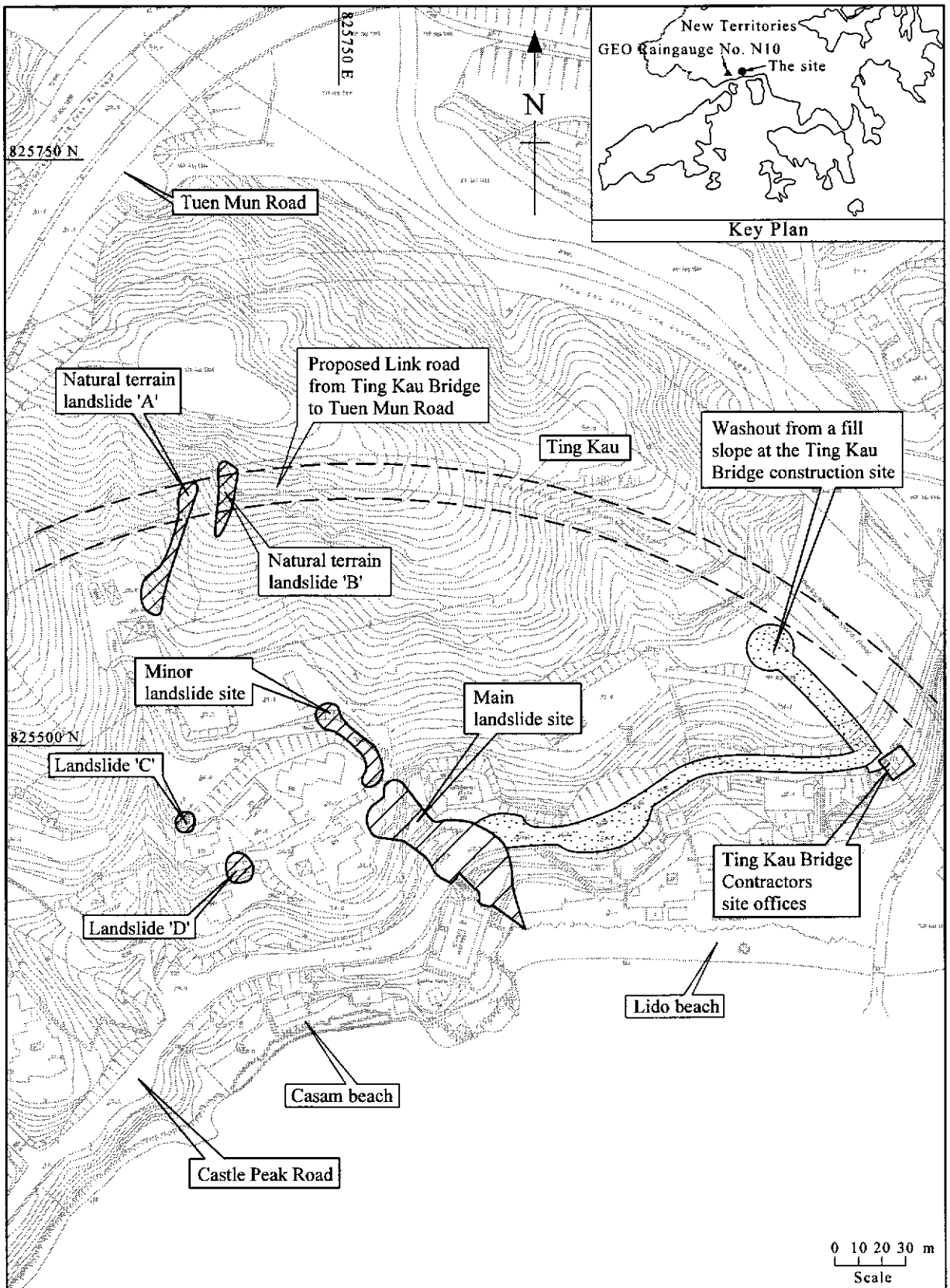


Note : Base map is extracted from Survey Sheet Nos. 6SE-18A and 6SE-18C dated October 1992 (Scale 1:1 000).

Figure 1 - Site Location Plan

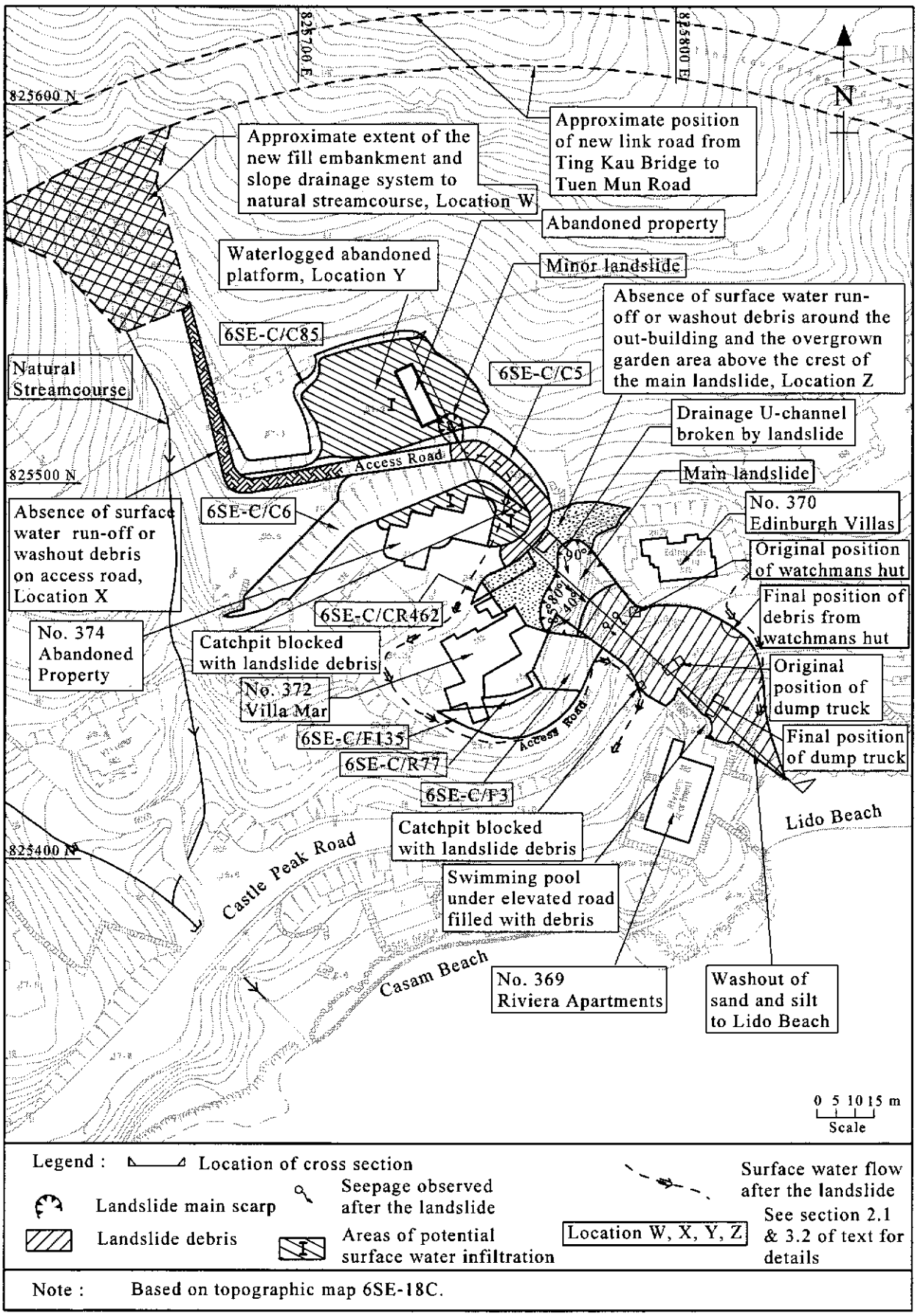


Figure 2 - Plan of the Landslide Site

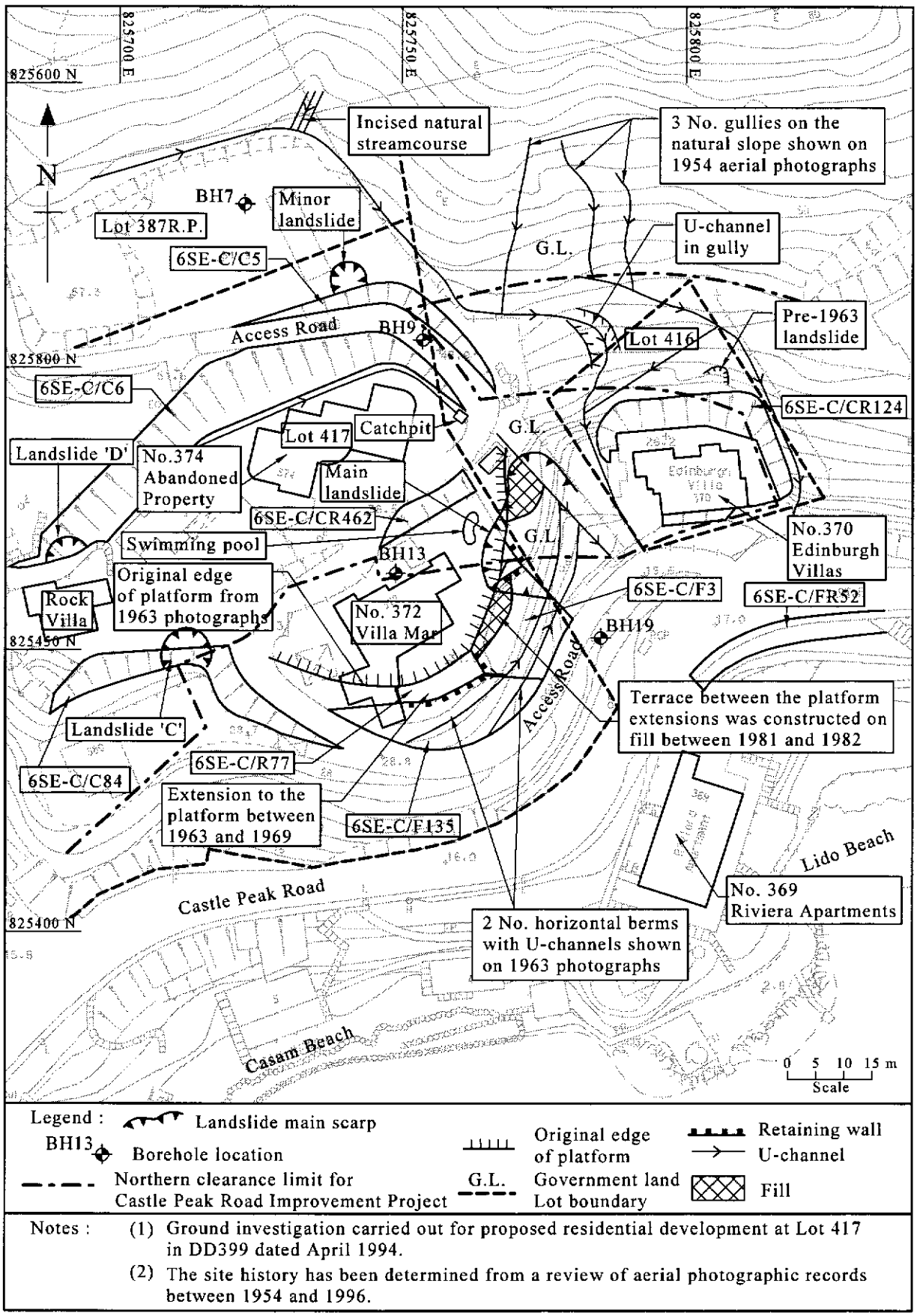


Figure 3 - Land Status and Site History

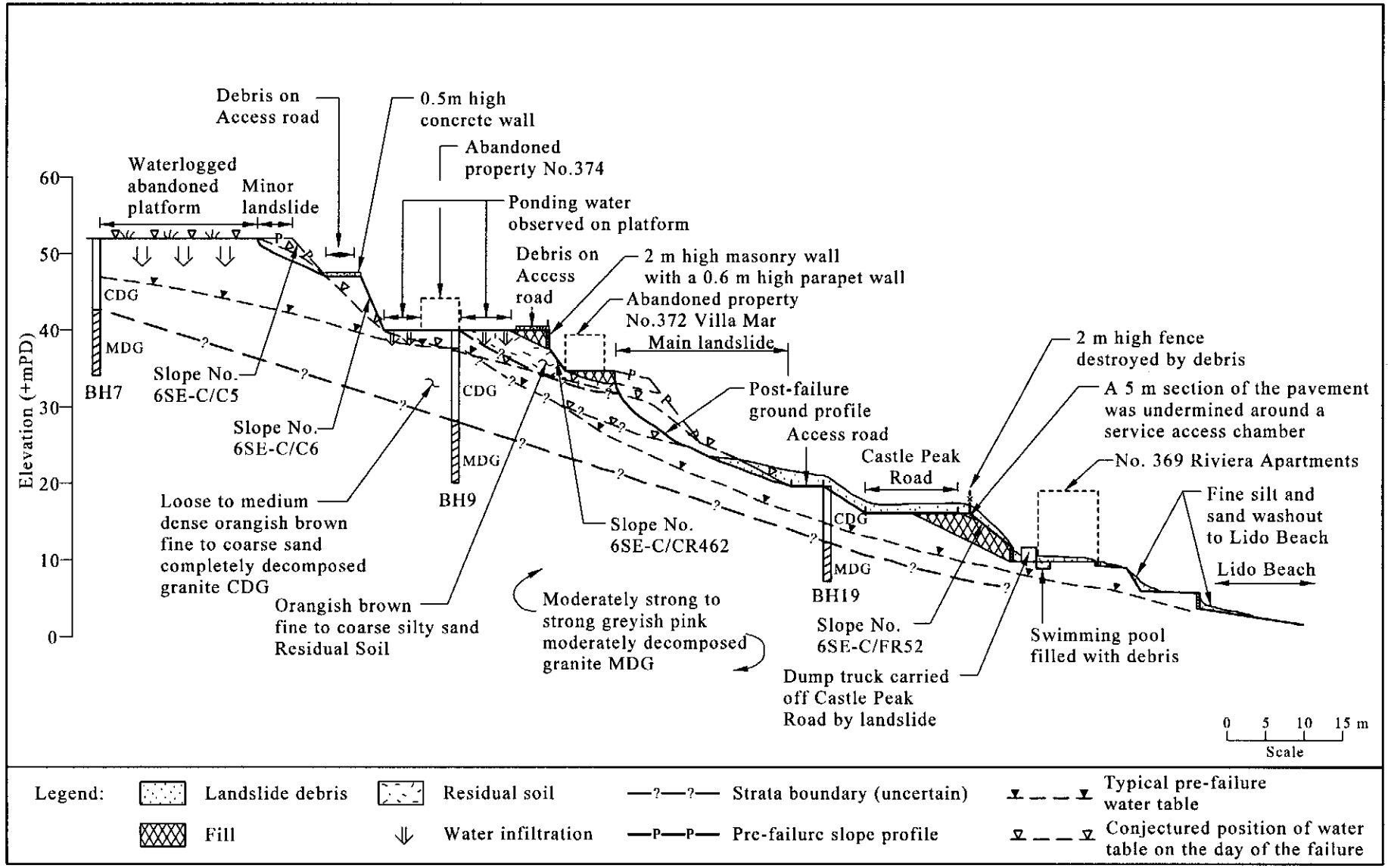
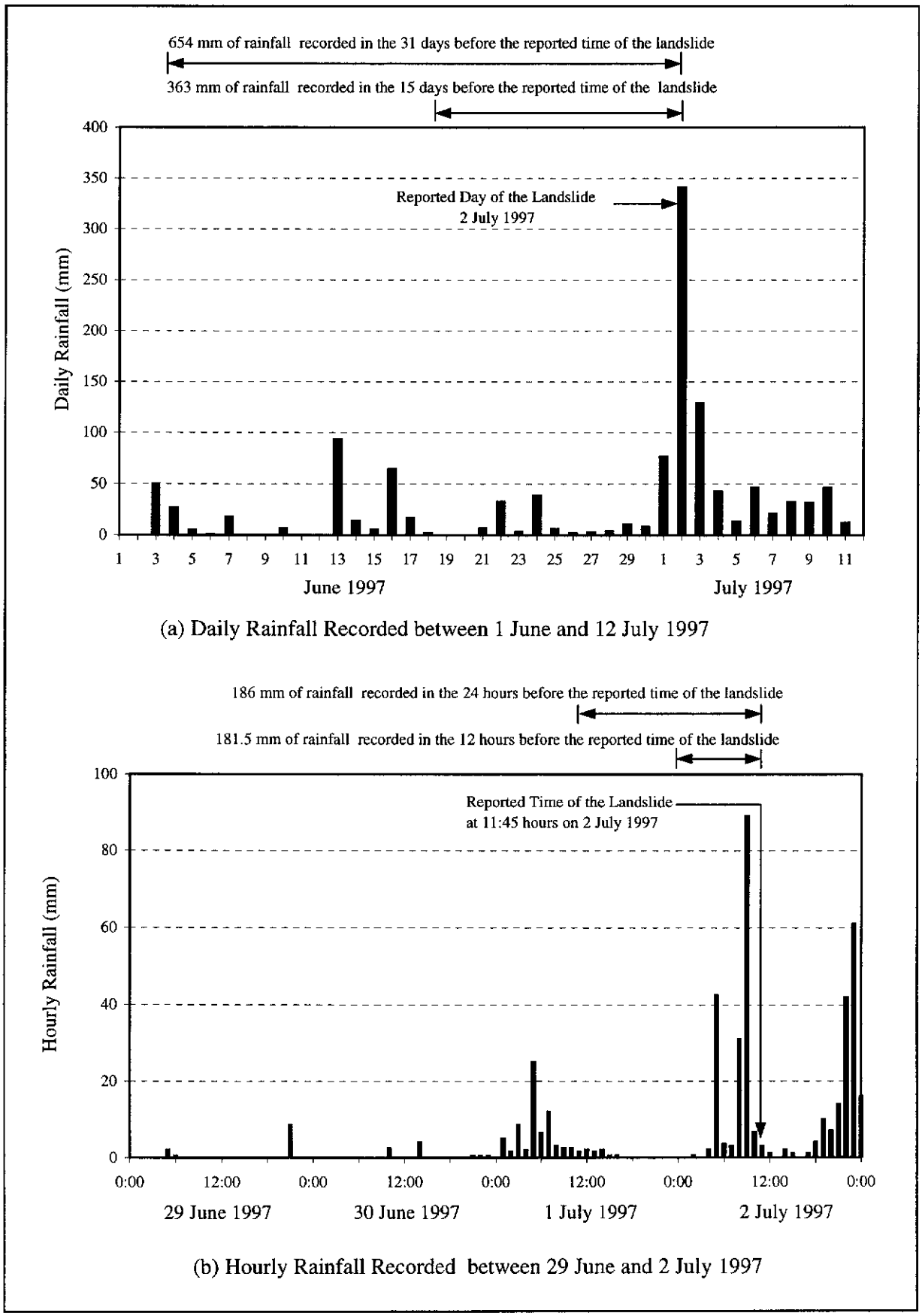


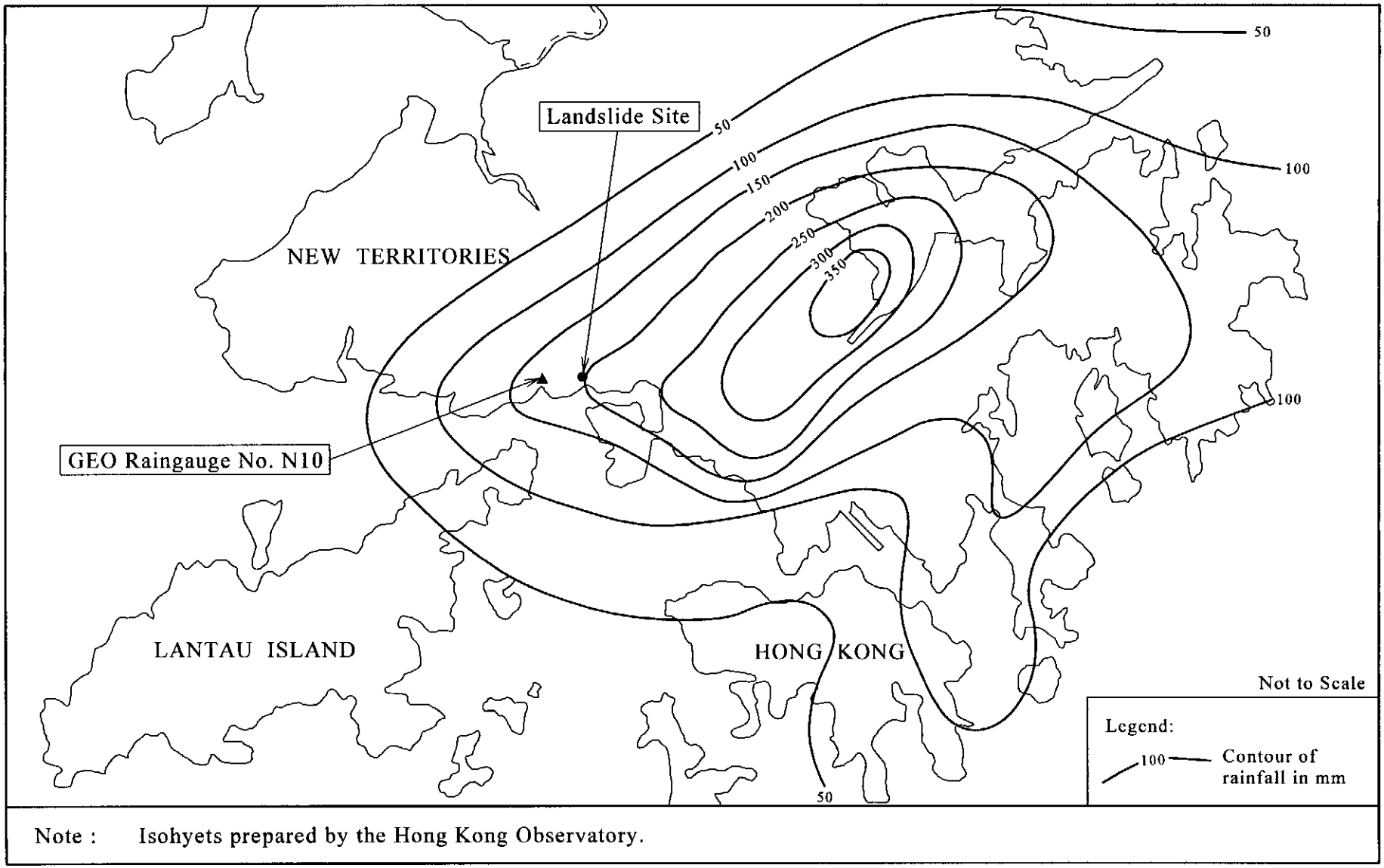
Figure 4 - Geological Cross-section



(a) Daily Rainfall Recorded between 1 June and 12 July 1997

(b) Hourly Rainfall Recorded between 29 June and 2 July 1997

Figure 5 - Rainfall Recorded at GEO Raingauge No. N10



Note : Isohyets prepared by the Hong Kong Observatory.

Figure 6 - Isohyets of Rainfall between 00:00 Hours and 11:45 Hours on 2 July 1997

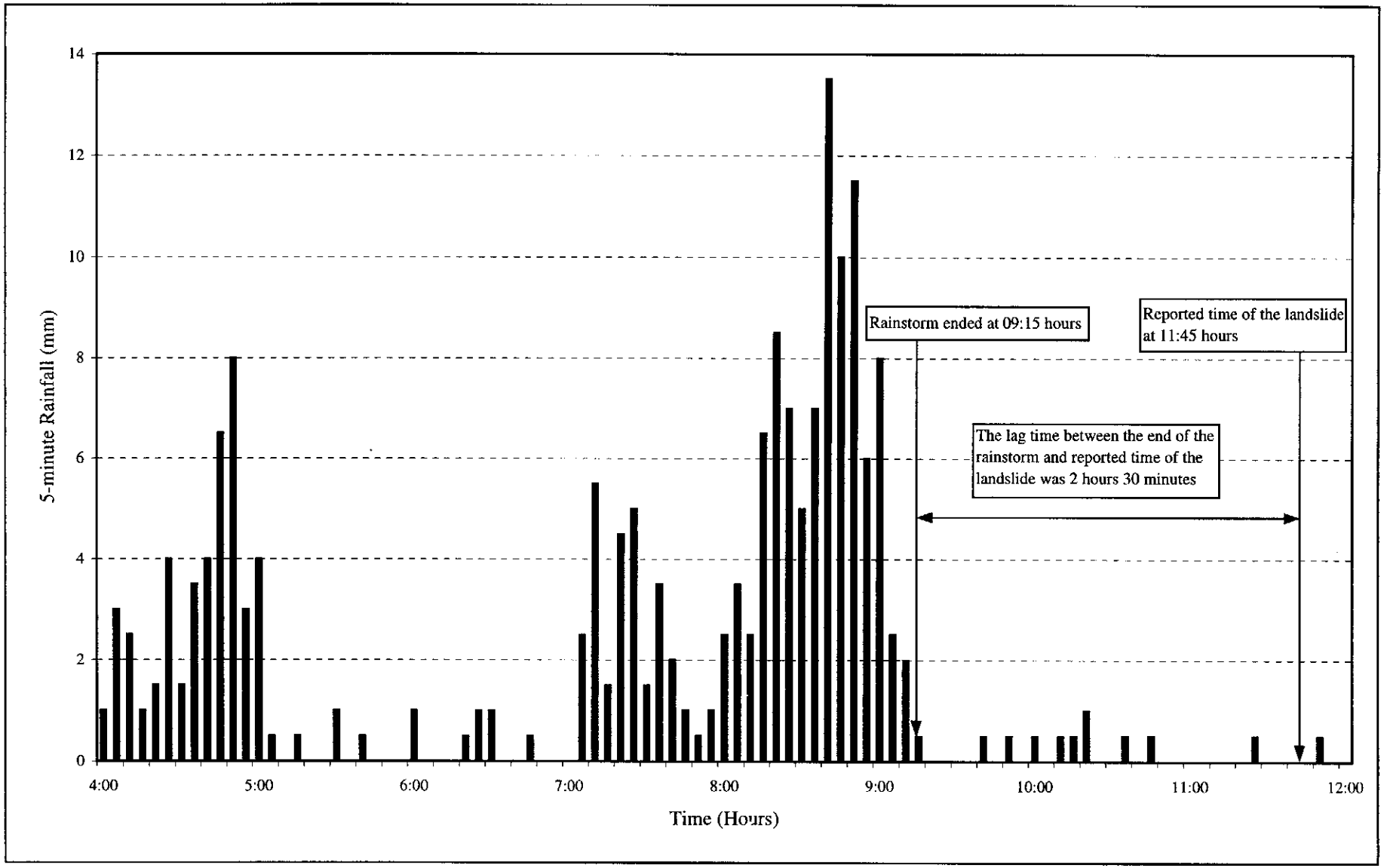


Figure 7 - Rainfall Recorded at GEO Raingauge No. N10 at 5-minute Intervals on 2 July 1997

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Plate 1 - An Aerial Photograph Showing the Main Landslide on the Slope between No. 372 Villa Mar and No. 370 Edinburgh Villas above Castle Peak Road near Lido Beach (Photograph Taken on 4 July 1997)
(Note the Minor Landslide on the Slope above the Access Road)

Plate 2 - View of No. 370 Edinburgh Villas (Photograph Taken on 3 June 1997) (Note the Slope on which the Main Landslide Occurred is Visible on the Left-hand side of the Photograph)

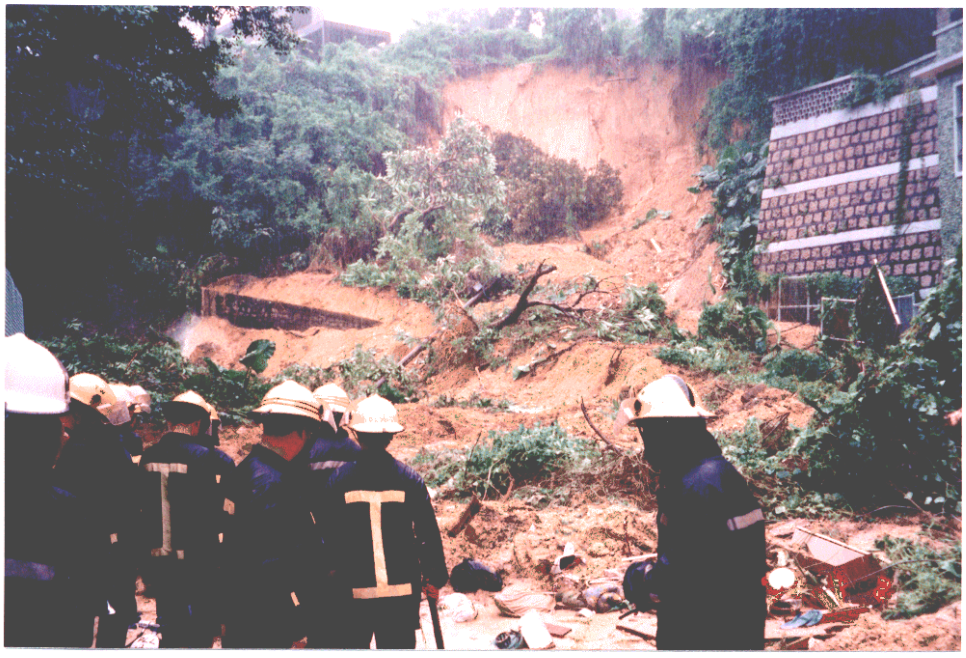

Plate 3 - General View of the Main Landslide between No. 370 Edinburgh Villas and No. 372 Villa Mar at the Crest of the Slope (Photograph Taken on 2 July 1997)

Plate 4 - View of the Eastern Flank of the Main Landslide Showing a Fallen Electricity Pole within the Landslide Debris (Photograph Taken on 2 July 1997)

Plate 5 - View of the Western Flank of the Main Landslide Showing a Section of Masonry Retaining Wall within the Landslide Debris (Photograph Taken on 2 July 1997)

Plate 6 - View from the Elevated Road to No. 369 Riviera Apartments Showing the Dump Truck which was Carried by the Landslide down the Slope below Castle Peak Road (Photograph Taken on 2 July 1997)

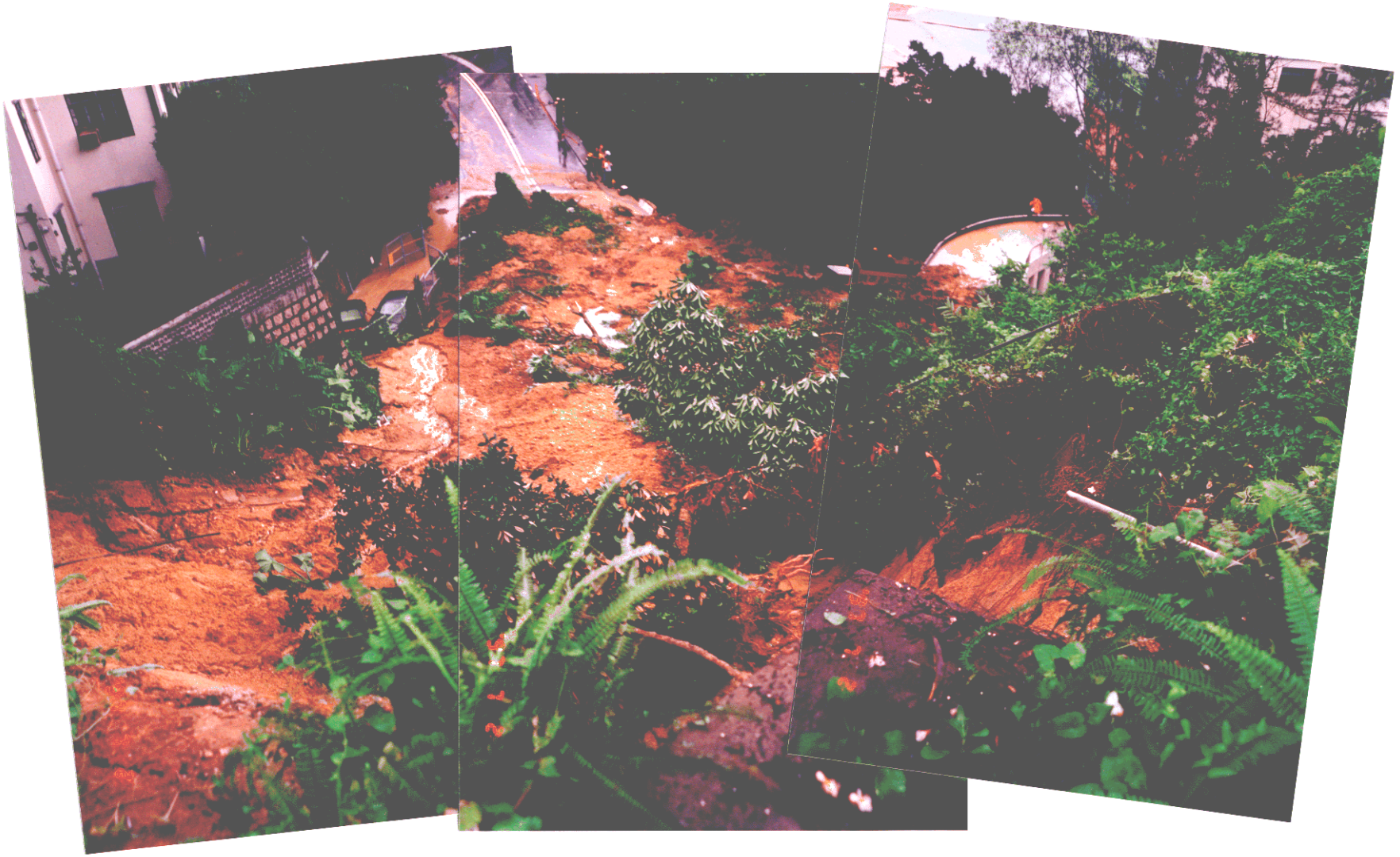

Plate 7 - View from the Crest of the Main Landslide (Photograph Taken on 2 July 1997)

Plate 8 - View of the Landslide Debris on Castle Peak Road adjacent to No. 370 Edinburgh Villas (Photograph Taken on 2 July 1997) (Note the Wet Condition and the Silt and Sand on the Surface of Castle Peak Road and Surface Water flowing around the Debris)

Plate 9 - General View of the Main Landslide (Photograph Taken on 2 July 1997)
(Note the Drain Pipe from the Swimming Pool at the Crest of the Slope discharging Water onto the Debris)