

**SECTION 4:  
DETAILED STUDY OF THE  
LANDSLIDE AT  
TUEN MUN ROAD  
NEAR TING KAU  
ON 2 JULY 1997**

**Halcrow Asia Partnership Ltd**

**This report was originally produced in June 1998  
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## FOREWORD

This report presents the findings of a detailed study of a landslide (GEO Incident No. MW97/7/11) which occurred on 2 July 1997 and affected a fill slope on the approach to Telford Bridge below the west-bound carriageway of Tuen Mun Road, near Ting Kau. Debris from the landslide blocked an access road at the toe of the fill slope. In addition, the landslide undermined part of the verge of the Tuen Mun Road resulting in temporary lane closures and significant disruption to traffic throughout the day. No fatalities or injuries were reported.

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.



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## 1. INTRODUCTION

On the morning of 2 July 1997, a landslide (GEO Incident No. MW97/7/11) occurred on a fill slope on the approach to Telford Bridge below the west-bound carriageway of Tuen Mun Road, near Ting Kau (Figure 1). Debris from the landslide blocked an access road at the toe of the fill slope. The landslide also undermined part of the verge of Tuen Mun Road resulting in temporary lane closures and significant disruption to traffic throughout the day. No fatalities or injuries were reported.

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 produced 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) detailed observations and measurements at the landslide site, and
- (d) 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 on fill Slope No. 6SE-C/F10 below Tuen Mun Road. The debris from the landslide blocked the access road at the toe of the fill slope. Below the access road, there was another fill slope (No. 6SE-C/F9) which was unaffected by the landslide. The landslide was located between two bridge piers (D2/2 and D2/3) which had been constructed for a viaduct for the Country Park Section of the Route 3 Project (Figure 2 and Plate 1).

At the location of the failure slope No. 6SE-C/F10 was 11.5 m high and inclined at 30° to the horizontal. Prior to the landslide the slope was heavily-vegetated with grass and scrub, with the exception of the lower 2.5 m of the slope which had been cut-back to an angle of

about 50° to the horizontal and was unsurfaced. The surface of the fill slope had a herringbone drainage system, comprising 250 mm and 300 mm U-channels. At about 1.5 m from the crest of the slope there was a 300 mm U-channel with a slotted concrete cover at the roadside. The U-channel was present for about 75 m, upto the point where the road verge approached a low spot near Telford Bridge.

The fill Slope No. 6SE-C/F9 below the access road was 11 m high and inclined at 30° to the horizontal. The slope had a herringbone drainage system of U-channels which discharged water to a streamcourse at the toe of the slope. In addition, there was an outfall from a 900 mm diameter cross-road culvert which discharged water to a concrete-lined channel prior to entering the streamcourse below.

The landslide affected land covered by a Forestry Licence No. W6685. However, the licence states that "the licensee is not bound by the licence conditions to perform slope maintenance works" (District Lands Office, 1992). The slope on which the landslide occurred is Government Land maintained by the Highways Department (HyD). At the time of the landslide the site was within the works limit of the Country Park Section (CPS) of the Route 3 Project (Figure 2).

## 2.2 Site History

The site history was traced from a sequential series of aerial photographs of the site spanning the period 1924 to 1996, and a review of other available documentary information (Tables 1 and 2).

In 1924, the site was located within a valley with a vegetated natural hillside to the west and a natural streamcourse to the south. By 1963, an access road had been constructed from Castle Peak Road to a catchwater approximately 1.5 km to the north of the site.

The two fill slopes (Nos. 6SE-C/F9 and 6SE-C/F10) were formed between 1972 and 1975 during construction of Tuen Mun Road. A herringbone slope drainage system and a U-channel at the toe of Slope No. 6SE-C/F10 were evident on the 1975 photographs. At that time, a cut slope (No. 6SE-C/C76) was present near the abutment of Telford Bridge, and an unregistered cut slope was formed to the south of the bridge abutment. Areas of natural vegetation existed above the cut slope and between the cut slope and Slope No. 6SE-C/F10.

Minor gully erosion was visible on Slope No. 6SE-C/F10 in 1978. By 1980 there was no evidence of the previous gully erosion and Slope Nos. 6SE-C/F9 and 6SE-C/F10 were covered by dense vegetation.

The aerial photographs taken in 1982 indicate that there had been a minor landslide on the natural terrain above the unregistered cut slope (Figure 3). By 1984, this area had been subject to repair works. Between 1988 and 1989, further surface protection measures had been applied to the previously affected area and to the unregistered cut slope below. At this time repair works were also undertaken on an area of instability (GEO Incident No. MW86/6/1) on Slope No. 6SE-C/F9 (see Section 2.3).

Vegetation was cleared from both fill slopes between 1990 and 1991 after which there were no apparent changes until the commencement of construction works for the Route 3 Project.

An aerial photograph taken in January 1997 (Plate 1) shows that the toe area of Slope No. 6SE-C/F10 had been cut back to allow access for the construction of bridge piers for Route 3. The construction of Route 3 was undertaken by the Route 3 Contractors Consortium (R3CC). At this time, bridge pier D2/2 was under construction and the foundation excavation for bridge pier D2/3 was underway.

Contractors working for HyD last undertook clearance of the roadside U-channel above Slope No. 6SE-C/F10 on 24 December 1996 (HyD, 1997a).

### 2.3 Previous Studies

Slope Nos. 6SE-C/F9 and 6SE-C/F10 were registered in the 1977/78 Catalogue of Slopes. The first recorded inspection of the slopes was carried out by Binnie & Partners (B & P) in October 1977.

The following information was recorded for both slopes:

- (a) high potential risk,
- (b) blocked herringbone drainage,
- (c) surface erosion, and
- (d) squatter huts within 15 m of base of slope.

Immediate actions recommended were to warn occupants of the huts near the toe of Slope No. 6SE-C/F9 and to clear the blocked drainage channels. Checking of the liquefaction potential of the fill was a further proposed action.

In May 1979, Scott Wilson Kirkpatrick and Partners (SWKP) undertook geotechnical checking of the Tuen Mun Road earthworks, which included analysis of the compaction data for Slope No. 6SE-C/F10 (SWKP, 1979). The findings of SWKP indicated that the relative compaction of fill achieved for the slope varied from 86 % to 94 % and was:

- (a) "in excess of the average relative compaction which could be achieved using the Public Works Department specification", and
- (b) "in excess of the critical value below which liquefaction is likely" (B & P, 1980).

In June 1981, SWKP undertook a stability assessment of fill slopes constructed under Stage I of Tuen Mun Road (SWKP, 1981), which included Slope Nos. 6SE-C/F9 and

6SE-C/F10. The SWKP report concluded that "all the fill slopes under consideration have acceptable factor of safety" and they also stated that "the remedial measures recommended to these slopes are limited to minor surface treatments which include:

- (i) re-vegetating the grassed surface where gully occurred;
- (ii) clearing and making necessary repairs to the surface drainage channels".

In July 1986, an aerial photograph interpretation (API) report was prepared by the GCO following Incident No. MW86/6/1 (GCO, 1986). The incident was inspected by the GCO in May 1986 who reported a minor failure and collapse of part of the herringbone drainage on Slope No. 6SE-C/F9 (Figure 3). The API report indicated that Slope No. 6SE-C/F9 and the partly modified slopes below had a history of instability from 1980 to 1986, the extent of which is shown in Figure 3.

Repair works, including vegetation clearance, trimming back the slope and drainage improvements, were undertaken by HyD in the area affected by Incident No. MW86/6/1 between 1988 and 1990.

In April 1987, Slope No. 6SE-C/F9 was considered for, but not included in the 1988/89 Landslip Preventive Measures (LPM) Programme. The reasons for non-inclusion were given as follows:

"According to API, the slope suffered minor washouts in 1984 and has as yet not to be reinstated. The works so required are of remedial nature but not of Preventive nature. Furthermore, the only property at risk is at a distance of about 10 to 15 metres from the slip area and hence the consequence of failure which is shallow in nature will be low as compared to other slopes of higher priority" (GCO, 1987).

In November 1992, Stage 1 Study Reports and an LPM Selection Nominated Features Study Report were completed by GEO (GEO, 1992).

Slope Nos. 6SE-C/F9 and 6SE-C/F10 were included in the 1995/96 LPM Programme and ground investigation works were undertaken on the slopes between July and September 1995 by Lam Geotechnics Limited (LG, 1995). In December 1995 the slopes were deleted from the LPM Programme because they "were found to lie within the project boundary of the Route 3 development" (GEO, 1995a). The Route 3 Contractors Consortium (R3CC) were requested by GEO via HyD to "investigate the stability of and to carry out upgrading works to these slopes in conjunction with the Route 3 development" (GEO, 1995a).

In May 1995, Slope No. 6SE-C/F10 was inspected by consultants Fugro Mouchel Rendel (FMR) appointed by HyD in a project entitled 'Roadside Slope Inventory and Inspections' to carry out Engineer Inspections on about 4 000 HyD slopes which satisfy GEO's slope registration criteria. The Engineer Inspection Record for Slope No. 6SE-C/F10 recommended Engineer Inspections to be carried out every three years and the following actions:

- (a) Routine Maintenance: "Clear drainage channels in the vicinity of the feature, repair cracked and damaged channels and unblock weepholes".
- (b) Preventive Maintenance Works: "None".
- (c) Other Recommendations: "Geotechnical conditions not known, slope considered to be very steep – stability assessment required."

The Engineer Inspection Record stated that the overall state of maintenance of the slope was "good", although minor maintenance works were recommended (GEO, 1995b).

At sometime between March and April 1996, HyD carried out routine maintenance works which included "cleansing of slope surface drains and cutting of overgrown grass on slope surface" of Slope No. 6SE-C/F10.

In November 1996, R3CC submitted a slope stability assessment to HyD undertaken by their design consultants, a joint venture between Maunsell Consultants Asia Limited and SWKP which had been checked by an independent consultant, Ove Arup & Partners (OAP). The assessment concluded that "the stability of the existing fill slopes uphill of the pier locations has also been checked and has been found to have the required (Factor of Safety) FOS  $\geq 1.1$  as defined in Tables 5.2 and 5.4 of the Geotechnical Manual for Slopes" (R3CC, 1996). Slope No. 6SE-C/F10 was therefore considered to be up to current standards. The design checker, OAP, noted the assessment had been "carried out in accordance with the Geotechnical Manual of Slopes" (OAP, 1997).

In 1992, GEO initiated a consultancy agreement entitled 'Systematic Inspection of Features in the Territory' (SIFT) to systematically search for slopes not included in the 1977/78 Catalogue of Slopes, which aims to, inter alia, update information on existing registered slopes based on studies of aerial photographs. In August 1996, the SIFT report noted that "this feature is undergoing modifications during works associated with the widening of Tuen Mun Road" and was classified as "no longer exists" and given SIFT No. 6SE-18A/S65, pending inspection on completion of the works. As a result the slope was not advanced into the "Systematic Investigation and Registration of Slopes in the Territory" SIRST project which commenced in 1994 to update the 1977/78 Catalogue and prepare the New Catalogue of Slopes.

#### 2.4 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.

Two boreholes (CF9-DH1 and CF10-DH1) were drilled near the site of the landslide (Figure 2) during the 1995 ground investigation by Lam Geotechnics Limited (LG, 1995). A third borehole (BH46) was drilled near the site during a ground investigation between July



and October 1993 by Intrusion Prepakt (Far East) Limited (IP, 1993) for the proposed improvements to Tuen Mun Road. The boreholes have been used to prepare the geological cross-section (Figure 4).

Borehole CF9-DH1 was located on the access road between Slope No. 6SE-C/F10 and Slope No. 6SE-C/F9. The borehole encountered 11 m of fill, consisting of a loose to medium dense brownish yellow clayey silty fine to coarse sand. The fill materials were underlain by 1.3 m of completely to highly decomposed granite, below which moderately to slightly decomposed granite was encountered to the base of the borehole at 50.7 mPD. Groundwater was recorded in a piezometer at a depth of 8.6 m below ground level at about 57 mPD.

Borehole CF10-DH1 was located on the verge of Tuen Mun Road at the crest of Slope No. 6SE-C/F10. The borehole encountered 4.5 m of fill consisting of soft to firm brownish yellow clayey sandy silt and medium dense pinkish grey spotted grey slightly clayey silty sand. Underlying the fill the borehole encountered 4.25 m of material described as "fill/debris flow deposit" comprising firm to stiff, brownish yellow clayey sandy silt with occasional subangular fine quartz gravel and occasional cobble-size moderately weak to moderately strong rock fragments. These deposits materials were overlying 9.2 m of completely to highly decomposed granite to the base of the borehole at 59.24 mPD. Groundwater was recorded in a piezometer at a depth of 15.6 m below ground level at about 61 mPD.

Borehole BH46 encountered a 0.25 m thick concrete slab above 1.75 m of fill. The fill was underlain by 0.45m of residual soil and 21.2 m of completely decomposed granite, below which slightly to moderately decomposed granite was encountered to the base of the borehole at 43.45 mPD. There was no groundwater monitoring installation in BH46.

The report on the stability assessment of fill slopes (SWKP, 1981) was based on the results of GCO probing, trial pitting and in situ and laboratory testing. Five GCO probes (15A, 14A, 14B, 13A and 13B) together with one trial pit (14A/B) were undertaken in the area of the 2 July 1997 failure. The locations of the GCO probes and the trial pit are shown in Figure 2. Fill, described as a light brown slightly clayey sandy silt, was encountered in the trial pit to a depth of 2.5 m. The GCO probes (14A & 14B) that were undertaken within the fill which failed, indicated that it was of a uniformly low density to a depth of 5 m with an SPT blowcount ranging from 2 to 13 (SWKP, 1981).

### 3. THE LANDSLIDE

#### 3.1 Time of Failure

No eye-witnesses of the landslide could be identified. The landslide was first reported at 09:30 hours on 2 July 1997 by a workman from R3CC to GEO. A landslip warning was issued at 06:25 hours on 2 July 1997.

### 3.2 Description of the Landslide

The landslide affected the full height of Slope No. 6SE-C/F10 between Tuen Mun Road and the access road. The failure was up to 25 m wide, 13 m long and 1.2 m deep and had an estimated volume of about 200 m<sup>3</sup>. The debris blocked the access road at the toe of the fill slope. The travel angle of the landslide debris was 28°. The travel angle was 28°, which is at the upper end of the range commonly observed for sliding failures of fill slopes in Hong Kong (Wong & Ho, 1996). The majority of the landslide debris was deposited within the main scarp without travelling further downslope (Plates 1 and 2).

The fill exposed in the main scarp was loose orangish brown very silty fine to medium sand. During an inspection by HAP on 3 July 1997, no seepages were observed from the main scarp and the landslide debris was in a moist to wet condition. The debris comprised fill with artefacts of broken U-channel and chunam (Plates 3 and 4).

The main scarp undermined part of the verge of Tuen Mun Road, and a void was formed about 5 m wide, 1.2 m high and 1.5 m deep (Plate 3). A small water pipe and two steel cable conduits running in the verge were exposed by the landslide (Plate 5). There was no apparent leakage of water from the water pipe.

About five hours after the landslide the inner and middle lanes of the west-bound carriageway of Tuen Mun Road were closed by the police to allow engineers to inspect a crack in the road pavement. The crack was about 20 m-long and 5 mm wide, and was located upslope of the landslide on the inside lane of the west-bound carriageway, about 4 m from the crest of the slope on which the failure occurred (Plate 6). During the lane closure, HyD contractors and contractors working for R3CC inspected the roadside drainage channel and found that it "was totally blocked by silt and refuse" (Gammon Construction Limited (GCL, 1997). The landslide was located on Slope No. 6SE-C/F10 immediately below the blocked roadside drainage channel. HyD contractors and workmen from GCL undertook urgent repair works to the slope, in accordance with the recommendations of GEO. The west-bound carriageway was re-opened about 6 hours later, after completion of the urgent repair works (Plates 8 and 9).

## 4. RAINFALL

The nearest GEO automatic raingauge No. N10 is located at Sham Tseng Emmanuel Primary School, about 2.5 km west of the landslide site (Figure 1). The daily rainfall recorded in June and July 1997 is shown in Figure 5a. There was 664.5 mm and 364 mm of rainfall in the 31 days and 15 days before the landslide respectively. The hourly rainfall from 29 June 1997 to 2 July 1997 is shown in Figure 5b. There was 186 mm and 178 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 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 on 2 July 1997 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 is shown in Figure 7. The figure shows that the maximum intensity of the rainstorm (as indicated by the 5-minute rainfall) occurred between 08:35 hours and 08:40 hours on 2 July 1997.

## 5. PROBABLE CAUSES OF FAILURE

The landslide was a moderate-size (200 m<sup>3</sup>) rain-induced fill slope failure. The geometry of the failure and the mode of debris deposition suggest that the landslide was probably a shallow translation slide and not a washout caused by erosion and concentrated surface water flow. The debris was not particularly mobile and much of the debris was deposited in the main scarp without travelling further downslope. There were no indications that liquefaction of the fill material had occurred.

The landslide was probably triggered by heavy, though not especially unusual, rainfall on 2 July 1997. The fill slope had an overall gradient of about 30° and was not oversteep. Given the nature of the fill material and lack of evidence of washout and liquefaction, the sliding failure probably occurred due to wetting of the fill, together with development of positive porewater pressures, as a result of water infiltration into the slope.

The landslide was located immediately below a blockage of the surface water drainage channel alongside Tuen Mun Road. In addition, the ground topography in the vicinity was such that stormwater run-off from the west-bound carriageway of the road collected by the channel would have been diverted onto the fill slope below, as a result of the blockage. It is considered probable that the concentrated discharge of surface water onto the slope from the blocked drainage channel, during the period of heavy rainfall, which commenced from about 07:00 hours on 2 July 1997, was the principal source of water contributing to the failure. The water would have wetted the fill, and possibly also led to local erosion and hence increased infiltration. Infiltration would have resulted in the development of local seepage pressures, and a reduction in the effective stress and shear strength of the fill due to elevated porewater pressure which triggered the sliding failure. A further contributory factor was the removal of support from the toe of the fill slope, due to cutting into the slope by construction activities.

An assessment was undertaken on the adequacy of the capacity of roadside drainage channel using published design formulae (GCO, 1984). The check determined that, in a clean state, the roadside drainage channel would have been of a sufficient capacity to accommodate stormwater run-off from the west-bound carriageway of Tuen Mun Road. A blockage however, would have significantly reduced the capacity of the channel and led to overflowing of the channel.

Based on the information collected from this detailed study, it is considered that the following is the probable sequence of events which led to failure of Slope No. 6SE-C/F10 on the morning of 2 July 1997:

- (a) the roadside drainage channel, which is at a low point in the road verge, became completely blocked with oily debris and litter at sometime prior to 2 July 1997,

- (b) the channel overflowed during heavy rain on 2 July 1997 and a large volume of stormwater was discharged onto the fill slope below,
- (c) the stormwater infiltrated into the slope which was not sealed with a protective cover,
- (d) as more water entered the slope, the soil became partly saturated and water pressures and seepage forces developed leading to a reduction in the effective stress and shear strength, and
- (e) a shallow sliding failure occurred within the fill.

## 6. CONCLUSIONS

The failure on 2 July 1997 was probably caused by stormwater run-off onto the fill slope from Tuen Mun Road due to the blockage of a roadside drainage channel. The roadside drainage channel became blocked with oily debris and litter sometime after it was last cleared in December 1996. The concentrated discharge of a large quantity of surface water onto the fill will have resulted in rapid infiltration of water, wetting up of the fill, development of seepage pressures and reduction in shear strength leading to slope failure.

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Table 1 – Summary of Site Development from Aerial Photograph Interpretation  
(Sheet 1 of 4)

Year	Photographic Reference No.	Altitude	Observations
1924	Y00122 Y00129	-	The site was within a small valley with a minor streamcourse at the bottom. There was a heavily vegetated hillslope to the west of the site and the minor storm course fed into a major streamcourse to the south of the site.
1963	Y8914/15	3900 ft	An access road had been constructed about 500 m to the east of the site from Castle Peak Road to a catchwater. A track from the access road crossed the valley upstream from the site and followed around the hillside at approximately 2/3 slope height, to an area of spoil tipping. A U-channel was visible through the dense vegetation on the hillside above the track.
1964	Y11182/83	1800 ft	No changes were apparent.
1972	1723	1300 ft	The access road to the area of spoil tipping had become overgrown and there was some minor surface erosion below a bend in the road to the west of the site.



Table 1 – Summary of Site Development from Aerial Photograph Interpretation  
(Sheet 2 of 4)

Year	Photographic Reference No.	Altitude	Observations
1975	11410/11	1500 ft	Tuen Mun Road was under construction. The valley had been infilled and a culvert had been constructed under Tuen Mun Road. The culvert had an outfall on the lower part of the lower fill slope which entered a lined open channel prior to discharging to the streamcourse. The adjacent hillslope had been significantly reduced in height. Slope Nos. 6SE-C/F9 and 6SE-C/F10 had been formed together with Slope No. 6SE-C/C76. There was an unregistered cut slope to the east of Slope No. 6SE-C/C76 around the south western flank of the hill. The catchwater access road had been diverted to its present alignment between Slope Nos. 6SE-C/F9 and 6SE-C/F10. Slope 6SE-C/F10 had a herringbone slope drainage system and a toe drain. A naturally vegetated slope remained between the western edge of Slope No. 6SE-C/F10 and the eastern edge of the unregistered cut slope.
1976	15635 13210/11	1500 ft 4000 ft	Natural vegetation remained between Slope No. 6SE-C/F10 and the unregistered cut slope. The bridge piers for Telford Bridge were under construction. There was minor gully erosion on Slope No. 6SE-C/F9.
1977	20062/63	4000 ft	Traffic was evident moving east and west on what is now the east-bound carriageway of Tuen Mun Road, i.e. Tuen Mun Road Stage I was completed. The west-bound carriageway was unsurfaced. There was increased vegetation cover on Slope Nos. 6SE-C/F9 and 6SE-C/F10.

Table 1 – Summary of Site Development from Aerial Photograph Interpretation  
(Sheet 3 of 4)

Year	Photographic Reference No.	Altitude	Observations
1978	24039/40	4000 ft	There was evidence of minor gully erosion on Slope No. 6SE-C/F10 from the crest, possibly due to the absence of a drainage channel at this time. Construction offices were present at the crest of Slope No. 6SE-C/F10. There was also evidence of minor gully erosion on the eastern side of Slope No. 6SE-C/F9. Works were being undertaken on Telford Bridge at this time.
1980	31596	6000 ft	Vegetation cover was dense on Slope Nos. 6SE-C/F9 and 6SE-C/F10 and there was no evidence of the previous gully erosion. Works were on-going on Tuen Mun Road Stage II and Telford Bridge.
1982	4310/11	3000 ft	Stage II works had been completed and Tuen Mun Road was open to traffic on both east- and west-bound carriageways. There was evidence of washout of the natural terrain above the unregistered cut slope adjacent to the Telford Bridge abutment. Slope No. 6SE-C/F10 was densely vegetated and the herringbone slope drainage channels were not visible. There had been a minor shallow landslide affecting the western edge of Slope No. 6SE-C/F9.
1984	56521	4000 ft	The area of washout had been repaired and re-surfaced. There was evidence of shallow landslides on the slopes below Slope No. 6SE-C/F9.
1985	67628/29	4000 ft	Two stepped channels had been added to the unregistered cut slope adjacent to the Telford Bridge abutment. Slope No. 6SE-C/F10 had a dense vegetation cover.

Table 1 – Summary of Site Development from Aerial Photograph Interpretation  
(Sheet 4 of 4)

Year	Photographic Reference No.	Altitude	Observations
1987	A10525/26	4000 ft	No changes were apparent.
1988	A70304/5	4000 ft	No changes were apparent to Slope No. 6SE-C/F10. Clearance work was in progress on Slope No. 6SE-C/F9 in the area of Incident No. MW86/6/1.
1989	A18351/52	4000 ft	The area above the unregistered cut slope adjacent to the Telford Bridge abutment and the cut slope itself had been re-surfaced. Repair works were complete on Slope No. 6SE-C/F9 and the slope appeared to be grassed and had a herringbone slope drainage system.
1990	A20985/6	4000 ft	Drainage U-channels and catchpits had been added to the re-surfaced, unregistered cut slope around the Telford Bridge abutment.
1991	A27578/79	4000 ft	Vegetation had been cleared on Slope Nos. 6SE-C/F9 and 6SE-C/F10. U-channels were clearly visible.
1994	A38173/74	5000 ft	No changes were apparent.
1996	A44142/43	4000 ft	The toe area of Slope No. 6SE-C/F10 had been cut back to allow construction plant access for the Route 3 works. Bridge pier D2/2 was under construction and foundation excavation for bridge pier D2/3 was underway.

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

Source	Information Obtained
Geotechnical Information Unit (GIU) at the Civil Engineering Department (CED) Library.	<ul style="list-style-type: none"> <li>(a) Improvements to Tuen Mun Road Ground Investigation. Vol. 1, Intrusion Prepaht (Far East) Ltd., 1993.</li> <li>(b) CED Contract No. GE/93/08 Ground Investigation New Territories West Term Contract. Works Order No. GE/93 08.73 Slope No. 6SE-C/F9 and F10. Tuen Mun Road Ting Kau Ground Investigation. Fieldwork Report by Lam Geotechnics, 1995.</li> <li>(c) Tuen Mun Road Second Carriageway Tsuen Wan to Sham Tseng, PWD Contract 651/77. Report on Stability Assessment of Fill Slopes by GCO Probe Tests June 1981, Scott Wilson Kirkpatrick and Partners, 1981.</li> </ul>
Slope Files and District Files from Mainland West Division and Files from Design Division of the GEO.	<ul style="list-style-type: none"> <li>(a) Field sheet for Slope No. 6SE-C/F10, Binnie &amp; Partners (HK) 1978.</li> <li>(b) Stage 1 Study Report for Slope Nos. 6SE-C/F9 and 6SE-C/F10.</li> <li>(c) LPM Selection Nominated Features Study Report for Slope Nos. 6SE-C/F9 and 6SE-C/F10.</li> <li>(d) Correspondence from Chief Geotechnical Engineer of Works Division to Chief Highway Engineer / New Territories reference GCW 2/A2/207(D) deleting Slope Nos. 6SE-C/F9 and 6SE-C/F10 from the LPM Programme, and giving reasons for the deletion.</li> <li>(e) Route 3 Country Park Section design drawings.</li> </ul>
GEO Publications, Reports, Maps and Memoirs.	<ul style="list-style-type: none"> <li>(a) Yuen Long: Solid and superficial geology, Hong Kong Geological Survey, Map Series HGM 20, Sheet 6, 1:20 000 scale.</li> <li>(b) Geology of the Western New Territories, Hong Kong Geological Survey Memoir No. 3.</li> </ul>
GEO Landslide Incident Report database.	Details of past landslides reported to GEO.

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

Source	Information Obtained
GEO Planning Division.	(a) Aerial photographs 1924, 1963, 1964, 1972, 1975, 1976, 1977, 1978, 1980, 1982, 1984, 1985, 1986, 1988, 1989, 1990, 1991, 1992, 1993, 1994 and 1996. (b) API report on Incident No. MW86/6/1.
GEO Slope Safety Division.	Slope Record and Engineers Inspection Record for Slope No. 6SE-C/F10.
Lands Department, District Lands Office (DLO).	(a) Land status. (b) Maintenance Responsibility.
Water Supplies Department (WSD).	Existing Utility Information.
Drainage Services Department (DSD).	Existing Utility Information.
LPM / SIRST / SIFT Databases.	Registration status of Slope Nos. 6SE-C/F10 and 6SE-C/F9.
Gammon Construction Ltd (GCL).	(a) Photographs taken on the day of the landslide. (b) Report on the landslip at the Tuen Mun Road embankment near pier D2/3 on 2 July 1997.
Route 3 Contractors Consortium (R3CC).	A brief report on 2 July 1997 landslide.
Hong Kong Police Force (HKPF).	Written accounts of observations made by two police officers who attended the scene of 2 July 1997 landslide.
Hong Kong Observatory (HKO).	(a) Hourly rainfall data between January 1984 and July 1997 for GEO Raingauge No. N10. (b) Isohyets of rainfall between 02:00 hours and 09:30 hours on 2 July 1997.
Highways Department (HyD).	(a) Tuen Mun Road Stage I as-constructed drawings. (b) Tuen Mun Road Stage II as-constructed drawings.

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 hours	120	09:00 hours on 2 July 1997	4
4 hours	129.5	09:00 hours on 2 July 1997	3
12 hours	178	10:00 hours on 2 July 1997	2
24 hours	186	10:00 hours on 2 July 1997	2
2 days	260	10:00 hours on 2 July 1997	2
4 days	273	10:00 hours on 2 July 1997	2
7 days	281.5	10:00 hours on 2 July 1997	1
15 days	365.5	10:00 hours on 2 July 1997	1
31 days	666	10:00 hours on 2 July 1997	2
Notes:	<p>(1) Return periods were derived from the Gumbel equation and data published in Table 3 of Lam &amp; Leung (1994).</p> <p>(2) Maximum rolling rainfall was calculated from 5-minute data for durations up to one hour and from hourly data for longer rainfall durations.</p>		

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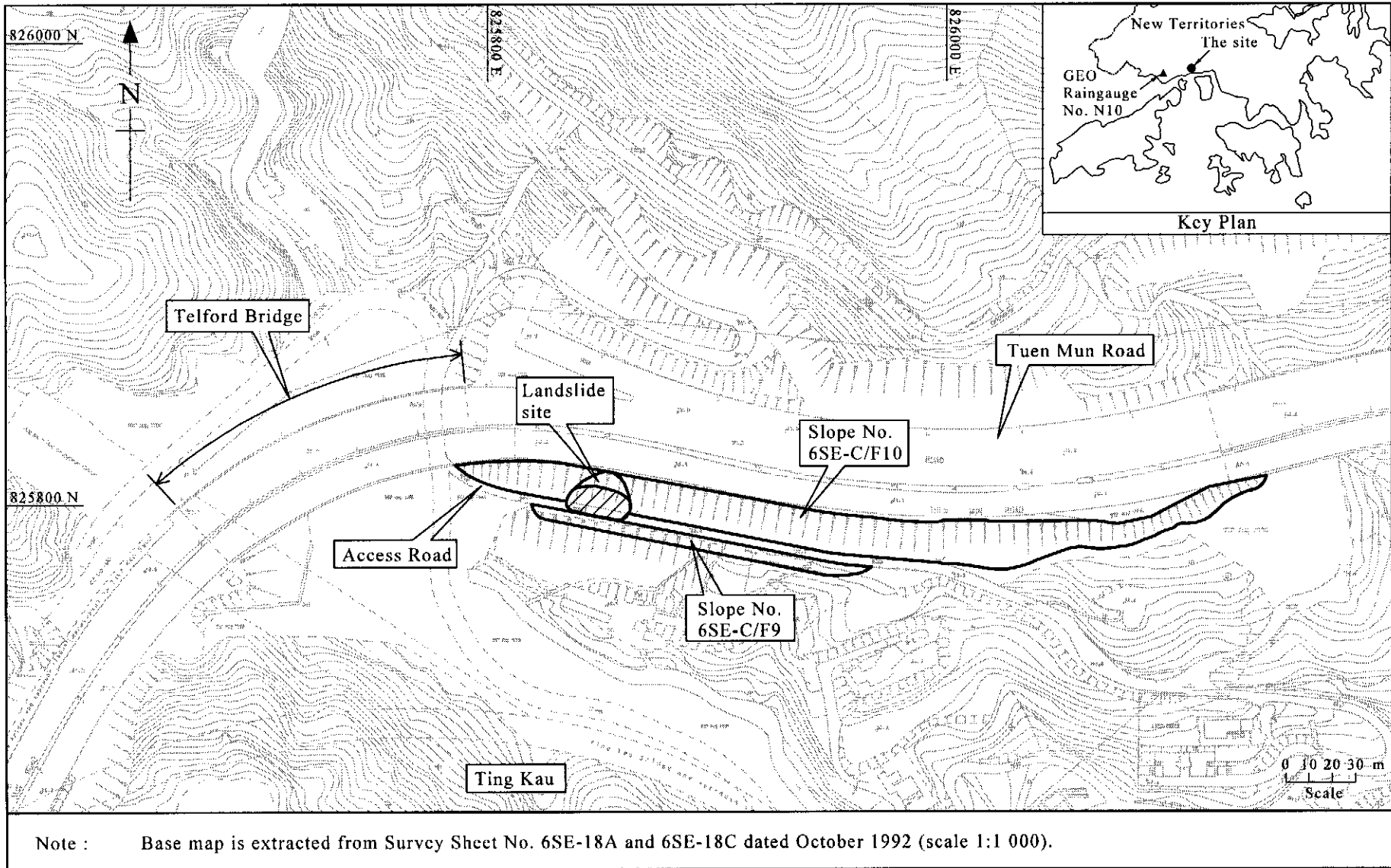


Figure 1 - Site Location Plan



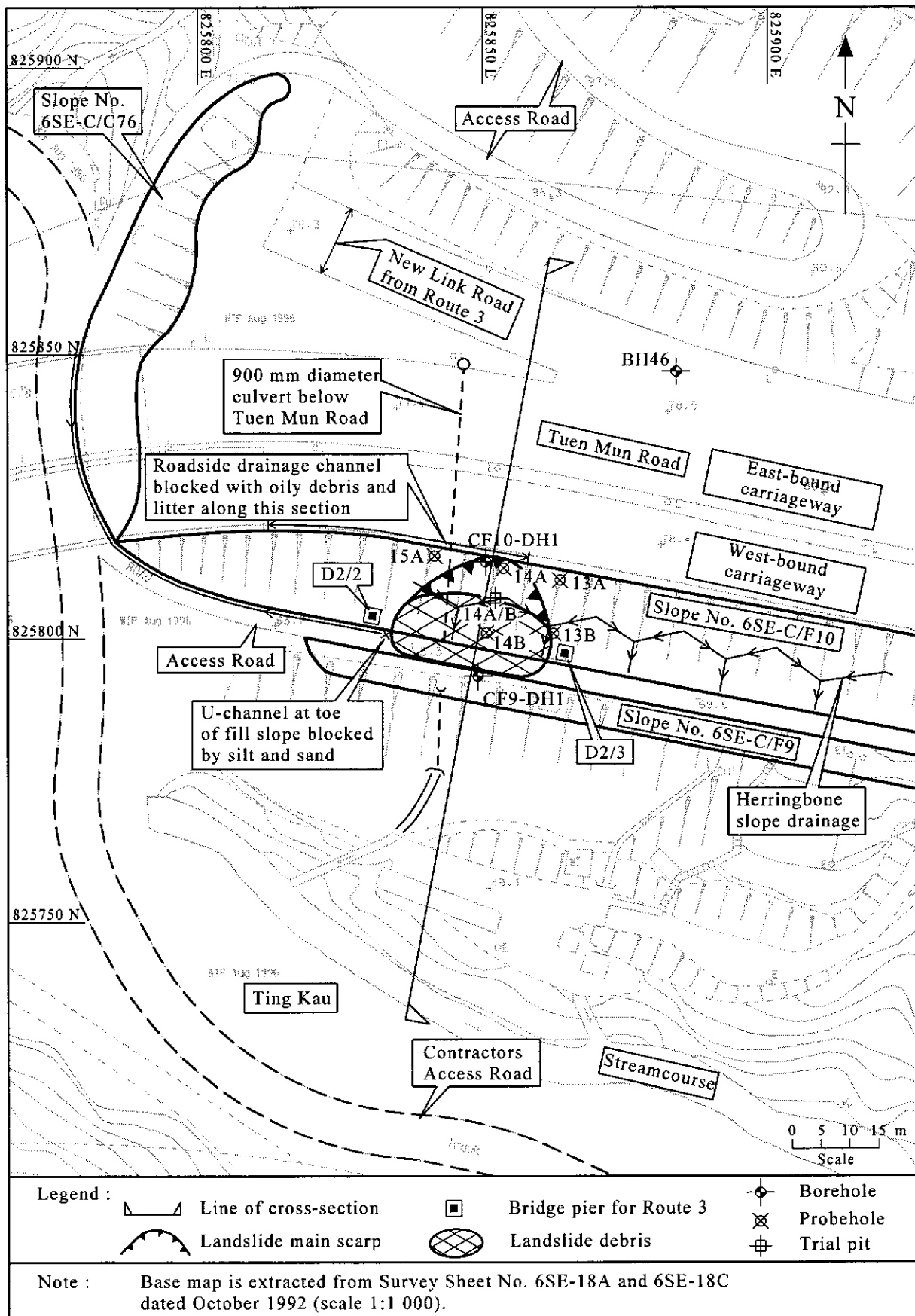


Figure 2 - Plan of the Landslide Site

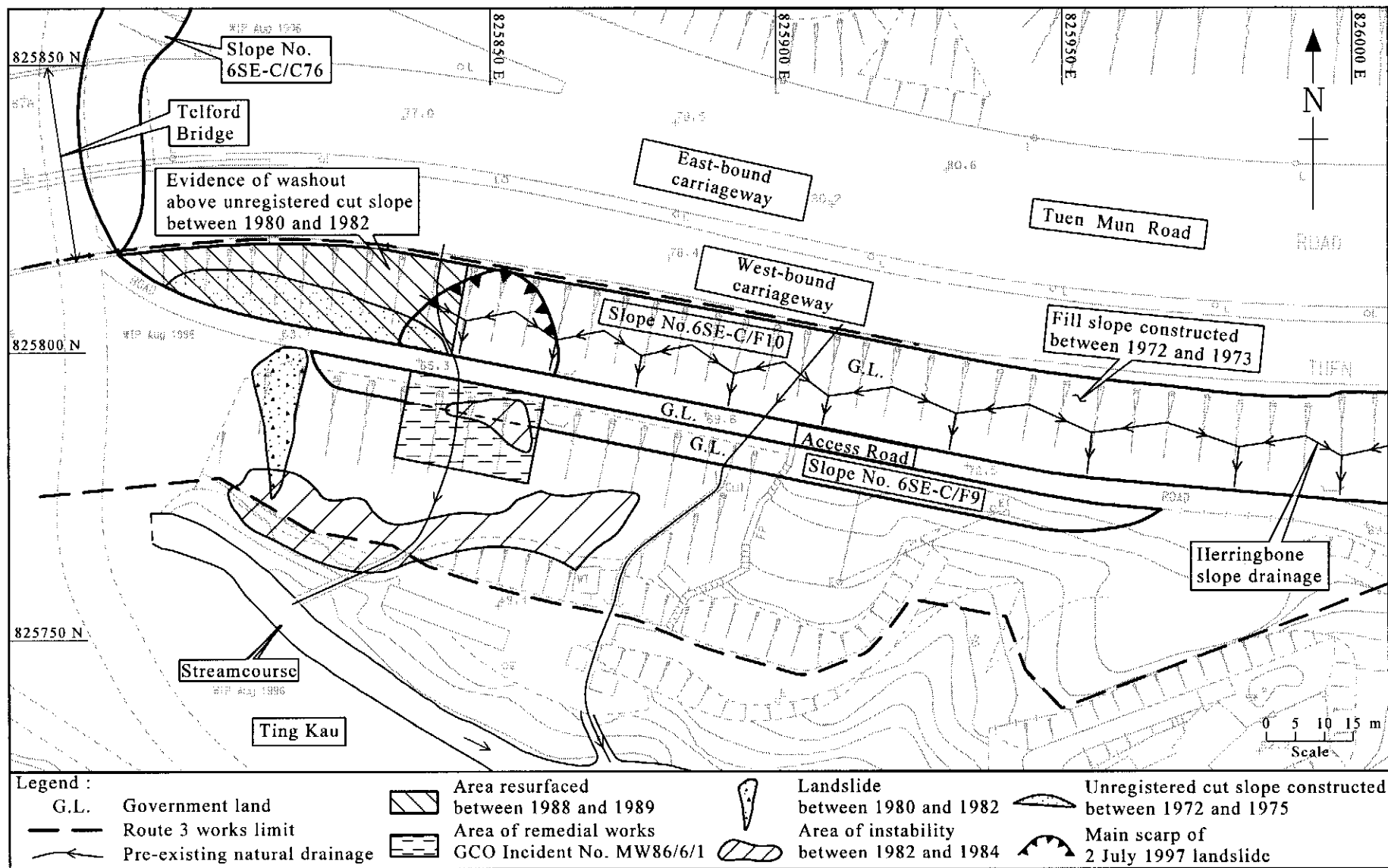


Figure 3 - Site History and Land Status

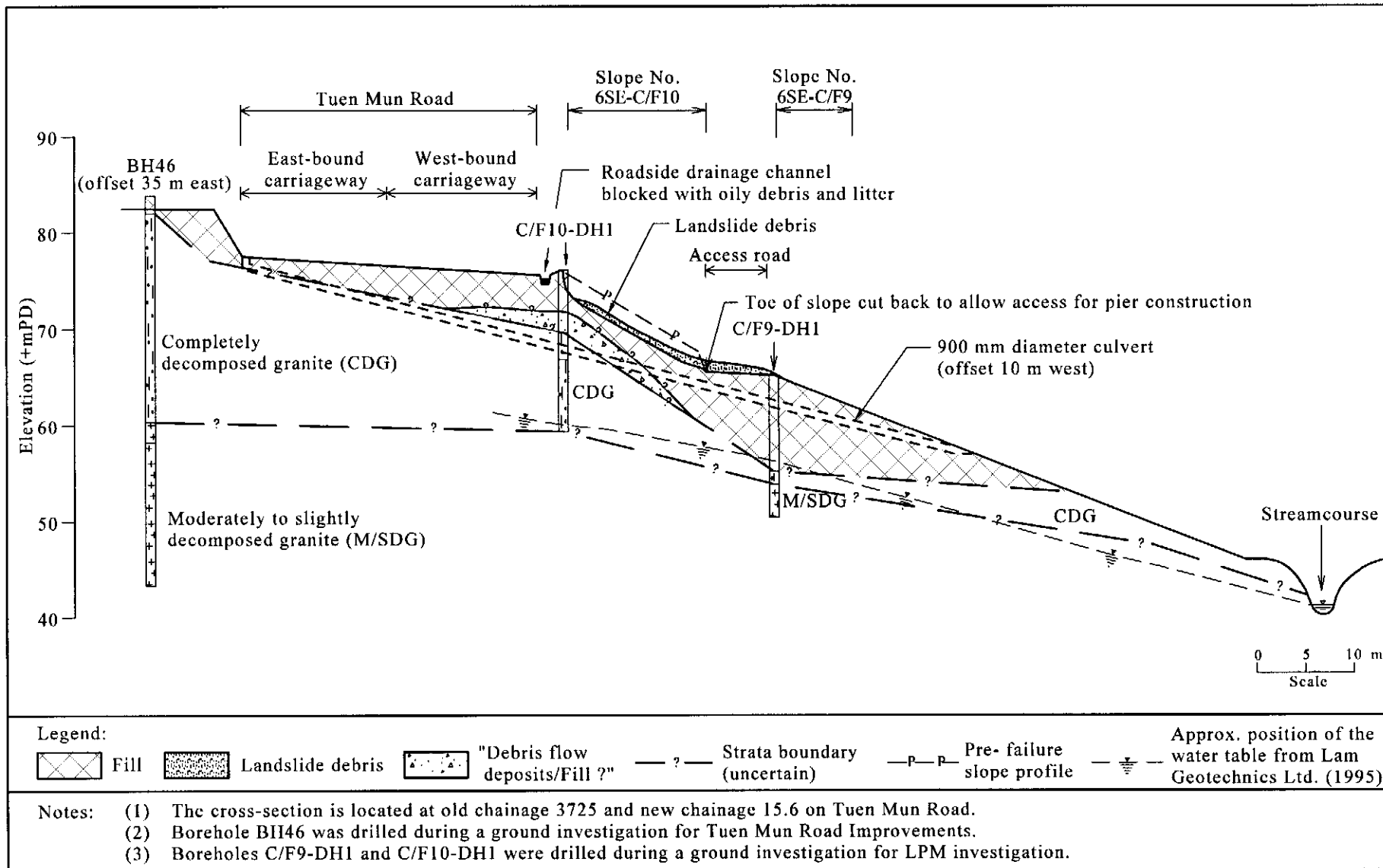


Figure 4 - Cross-section Through the Landslide

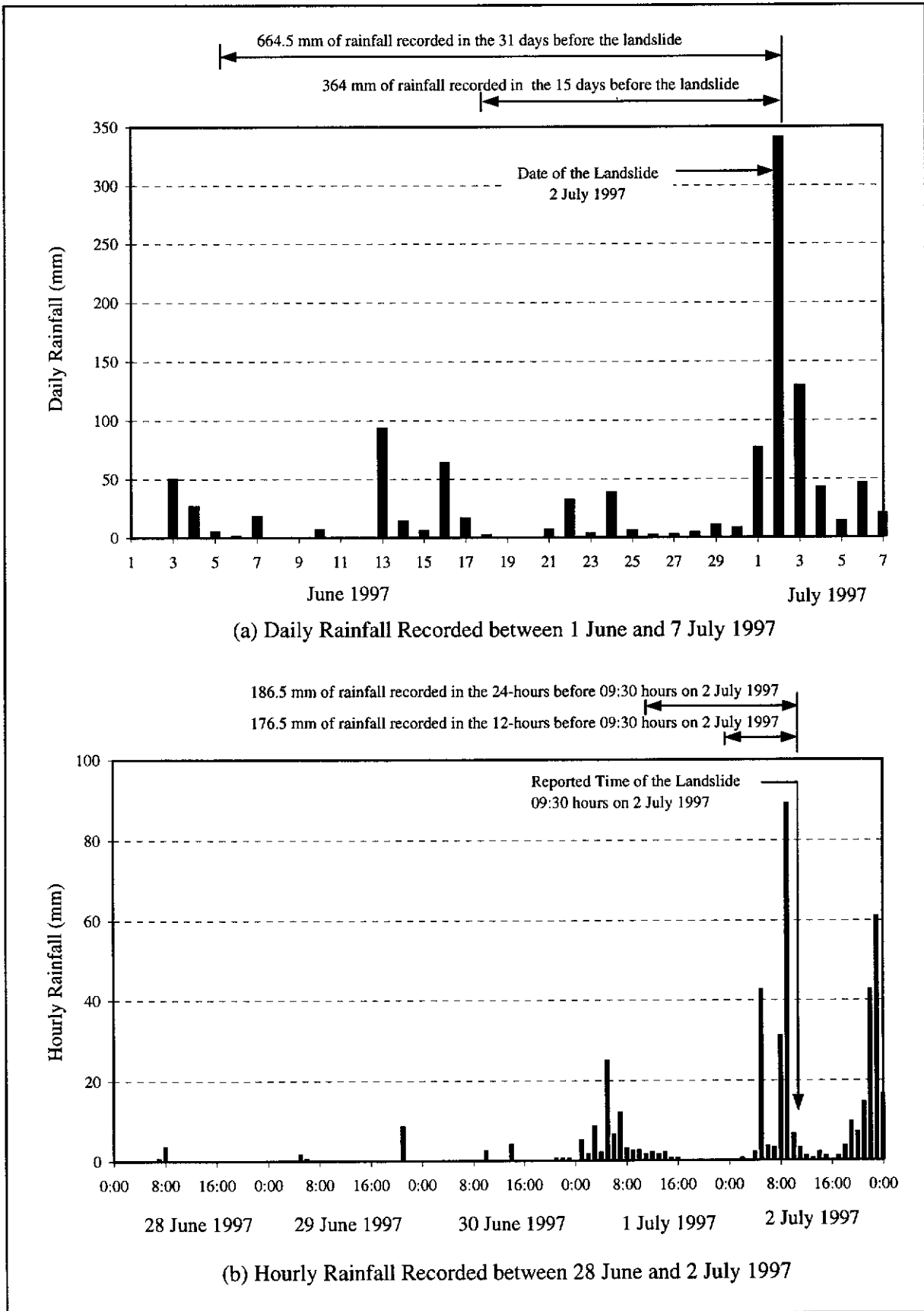


Figure 5 - Rainfall Recorded at GEO Raingauge No. N10

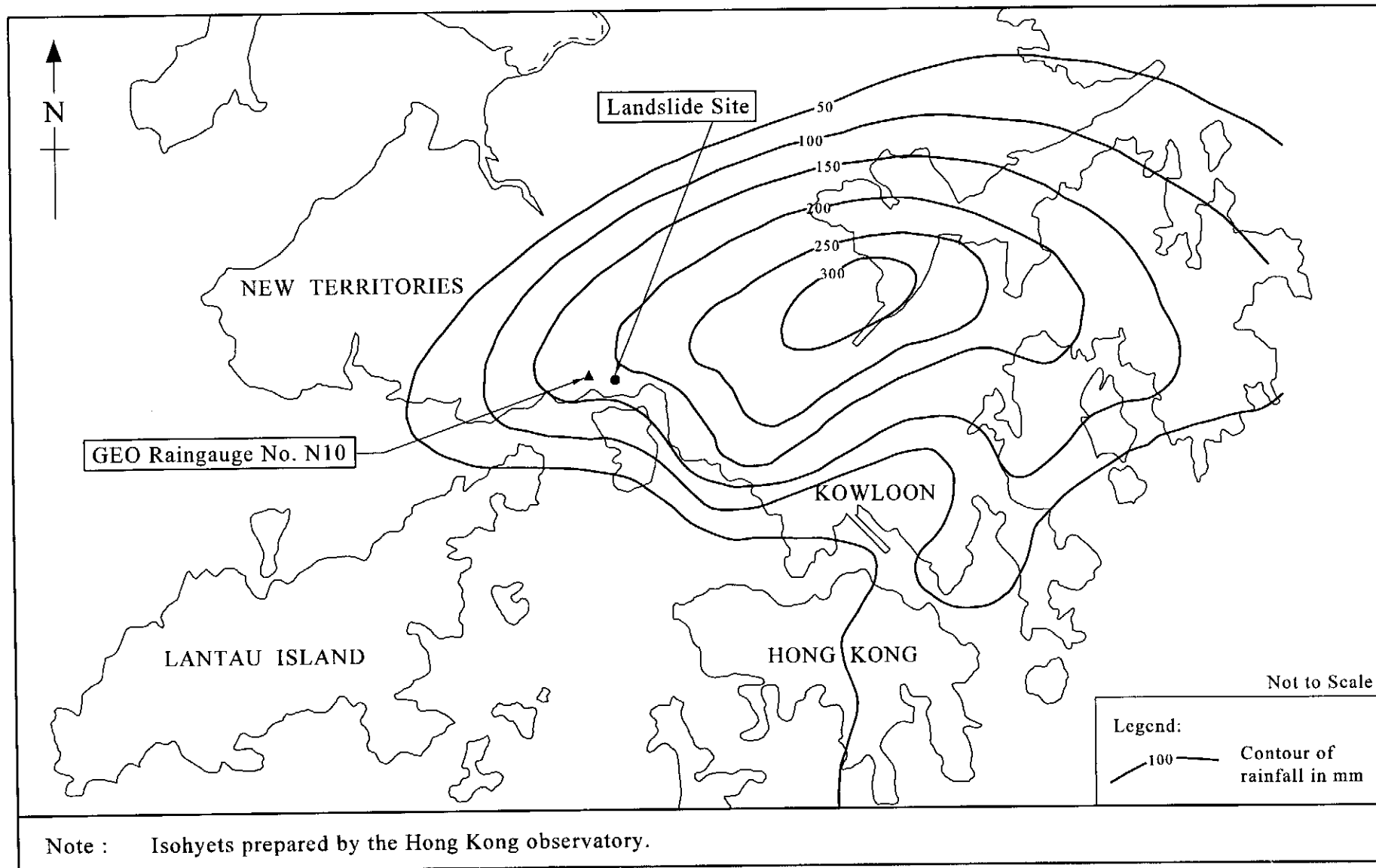


Figure 6 - Isohyets of Rainfall Between 02:00 Hours and 09:30 Hours on 2 July 1997

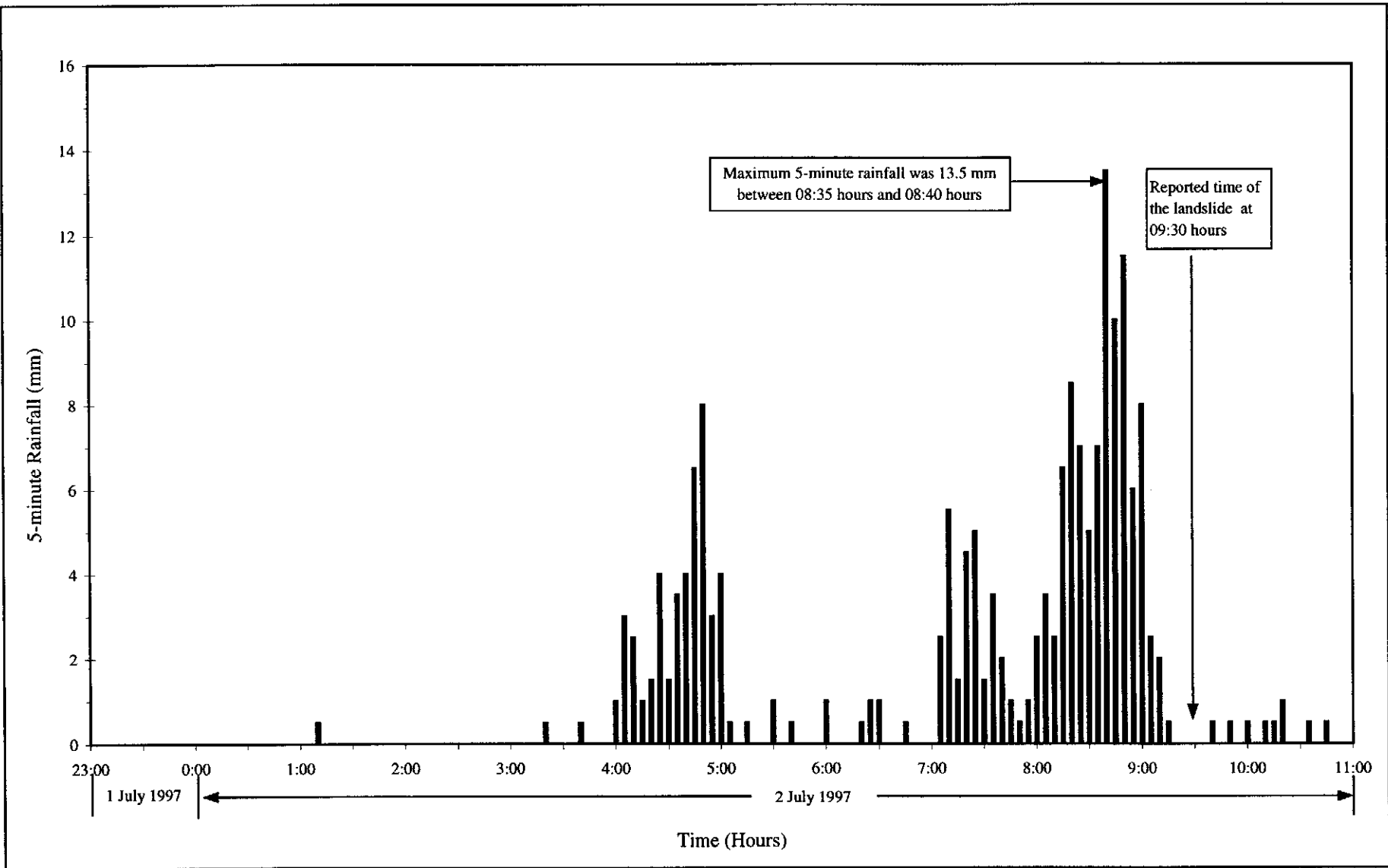


Figure 7 - Rainfall Recorded at GEO Raingauge No. N10 at 5-minute Intervals on 1 and 2 July 1997

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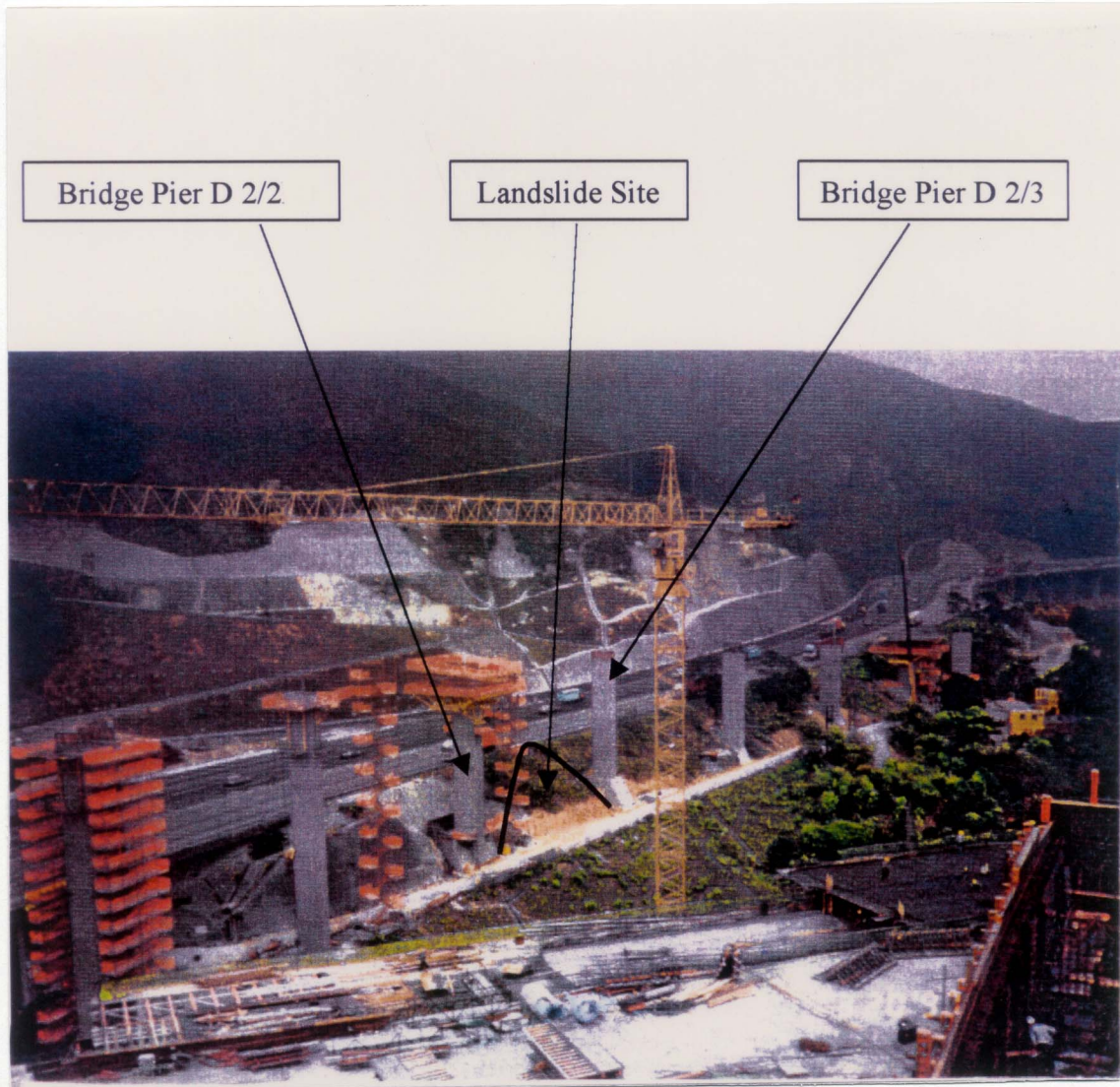


Plate 1 - View showing the Construction of Bridge Piers D2/3 and D2/2 for Route 3 Adjacent to Tuen Mun Road (Photograph Taken in January 1997)





Plate 2 - View to the West Along the Access Road Which was Blocked with Landslide Debris (Photograph Taken on 2 July 1997. Note Bridge Pier D2/3 in the Foreground and Bridge Pier D2/2 in the Centre of the Photograph)



Plate 3 - View of the Eastern Flank of the Landslide (Photograph Taken on 2 July 1997. Note the Sections of Broken U-channel in the Debris)



Plate 4 - View to the Western Flank of the Landslide (Photograph Taken on 2 July 1997. Note the Broken Chunam Surfacing in the Debris)



Plate 5 - View from the Crest of the Landslide (Photograph Taken on 2 July 1997. Note the Small Water Pipe and the Two Cable Conduits Exposed by the Landslide)



Plate 6 - View to the West Along Tuen Mun Road During the Inspection of the Roadside Drainage System and the Road Pavement (Photograph Taken on 2 July 1997)



Plate 7 - Roadside Drainage Channel to the West of the Landslide Site (Photograph Taken on 2 July 1997. Note the Blockage of the Channel with Oily Debris and Litter)



Plate 8 - View Showing the Urgent Repair Works (Photograph Taken on 3 July 1997. Note the Vegetation Covering the Slope to the East of the Landslide and Chunam Covering the Slope to the West of the Landslide)



Plate 9 - Close-up of the Urgent Repair Works Showing the Main Scarp Infilled with Rockfill (Photograph Taken on 3 July 1997)