SECTION 4: DETAILED STUDY OF TWO LANDSLIDES AT KWAI CHUNG ROAD LAI KING ON 8 MAY 1997 AND 4 JUNE 1997

Halcrow Asia Partnership Ltd

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FOREWORD

This report presents the findings of a detailed study of two landslides (GEO Incident Nos. MW97/5/6 and MW97/6/21) which occurred on 8 May 1997 and 4 June 1997. The incidents were located on rock cut slopes adjacent to Kwai Chung Road, Lai King. Landslide debris from Incident No. MW97/5/6 blocked one lane of the Kowloon-bound carriageway causing disruption to traffic flow, whilst debris from Incident No. MW 97/6/21 accumulated at the toe of the slope. No fatalities or injuries were reported.

The key objectives of the detailed study were to document the facts about the landslides, present relevant background information and establish the probable causes of the landslides. The scope of the study was generally limited to site reconnaissance, desk study and analysis. Recommendations for follow-up actions are reported separately.

The report was prepared as part of the 1997 Landslip Investigation Consultancy (LIC) for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 68/96. This is one of a series of reports produced during the consultancy by Halcrow Asia Partnership Ltd (HAP). The report was written by Mr P Smith and reviewed by Dr R Moore and 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 8 May 1997, a landslide (GEO Incident No. MW97/5/6) occurred on a registered cut slope (No. 11NW-A/C79) adjacent to Kwai Chung Road, Lai King (Figure 1 and Plate 1). Debris from the landslide blocked the inside lane of the Kowloon-bound carriageway. The inside lane was closed to allow clearance of debris which caused disruption to traffic flow, and remained closed until February 1998 to allow remedial works to be carried out. A second landslide (GEO Incident No. MW97/6/21) occurred on an nearby registered cut slope (No. 11NW-A/C78) on the morning of 4 June 1997. Debris from this landslide accumulated at the toe of the slope with no significant consequence. No fatalities or injuries were reported for either incident.

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

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

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

2. THE SITES

2.1 Site Description

The locations of the landslides are shown in Figure 1. GEO Incident No. MW97/5/6 (Figure 2) occurred in the central part of a 170 m long soil/rock cut slope (No. 11NW-A/C79). The slope has a maximum height of about 28 m. The lower 16 m of the slope comprise predominantly bare rock, inclined at between 75° and 90° to the horizontal. The upper part of the slope is formed in soil and is inclined at about 40° to the horizontal. Its surface is partly shotcreted and partly vegetated. The cut slope is located on the eastern side of Kwai Chung Viaduct on Route 3 (Figure 1).

GEO Incident No. MW97/6/21 (Figure 3) occurred at the southern end of a 168 m-long rock cut slope (No. 11NW-A/C78) with some areas of chunam cover. The slope is up to 25 m in height with a slope angle of typically 65° to 85° to the horizontal in the lower 10 m that reduces to around 40° to the horizontal in the upper part. A 300 mm stepped-channel carries surface water from above the failed rock cut slope to the toe of the slope where it connects with a 300 mm U-channel. An area of open space, which was occupied by construction site offices at the time of the failure, separates the toe of the cut slope from Kwai Chung Road.

The failed sections of Slope Nos. 11NW-A/C79 and 11NW-A/C78 were located on Government land. As confirmed by the "Systematic Identification of Maintenance Responsibility of Slopes in the Territory" (SIMAR) consultancy, the Highways Department (HyD) is responsible for the maintenance of Slope No. 11NW-A/C79 and the southern 25 m of Slope No. 11NW-A/C78. The Mass Transit Railway Corporation (MTRC) is responsible for the maintenance of the remainder of Slope No. 11NW-A/C78.

2.2 Site History

The history of development of the landslide sites was determined from a review of aerial photographs taken between 1949 and 1997 and other documentary information listed in Table 1.

In 1964, construction of Slope No. 11NW-A/C79 commenced within an area of natural hillside. The construction of the slope was part of the works for Kwai Chung Road, which together with Lai King Hill Road above the cut slope, formed part of the Kwai Chung Development Scheme II, Public Works Department Contract No. 35 of 1962. Kwai Chung Road was completed in 1967.

In 1969, cutting of the natural hillside to form Slope No. 11NW-A/C78 commenced as part of the construction of a slip road from the Container Port Road flyover to Kwai Chung Road. These works were completed in 1973. Over the same period, site formation works and construction of housing blocks and factories uphill of the features were ongoing. Construction of the Lai King MTR Station to the north of Slope No. 11NW-A/C78 had commenced by 1978 and was completed by 1984.

Construction of the elevated Route 3 highway started in the early 1990s. The slip road from the Container Port Road, which was constructed along with Slope No. 11NW-A/C78, was demolished in 1992 and the southern end of Slope No. 11NW-A/C78 was reprofiled to accommodate a slip road connecting Kwai Chung Road to Route 3. It is understood that blasting was not used in connection with the widening of Kwai Chung Road at this location.

2.3 Previous Studies

2.3.1 Cut Slope No. 11NW-A/C79

The slope was inspected by Binnie & Partners (B & P) in June 1977 and registered in the 1977/78 Catalogue of Slopes. At the time of that inspection, steady seepage was noted from rock joints at a height of 6 m above the toe of the slope. The precise location of this seepage was not recorded. Signs of distress, described as "loose blocks, erosion along joints", were noted and B & P recommended that the loose blocks should be removed. No further action was recommended as the slope was to be included in the proposed Lai Chi Kok Phase II Study Area.

The Phase IID Landslide Study by Binnie & Partners (B & P, 1981a) of Slope No. 11NW-A/C79 summarised the findings of a desk study, site inspection, ground investigation and stability analysis. Steady seepage was observed from rock joints and some loose blocks were also noted. On the basis of stability analysis, B & P concluded that the upper part of the slope, comprising soil and rock, had "a satisfactory factor of safety against circular slip failure". B & P examined the face of the rock slope "as well as access would permit" and carried out a discontinuity survey of the "north western 72 metres" of the slope, which would have included the area affected by the 1997 landslide. Stereographic analysis of the discontinuity data, assuming a friction angle of 39°, indicated potential for either plane or toppling failure (Figure 4). B & P's inspection of this part of the slope, however, did not identify "evidence of plane or toppling failure" and it was considered that the slope was in a "safe situation except where some overhangs need to be supported and some loose blocks removed". The report recommended various slope maintenance, protection and drainage measures, including the installation of rock bolts and construction of a concrete buttress.

Monitoring of piezometers installed in a borehole formed on the slope as part of the investigation (Section 2.4.1 and Figure 6) indicated that the "groundwater level (was) well below bedrock". However, "rapid response of the lower piezometer reading to rainfall and seepage observed from rock joints" was considered to "indicate an open rock mass". Clay infill was not recorded in the description of discontinuities in B & P's report.

The entire slope was included in the 1984/85 Landslip Preventive Measures (LPM) Programme. Upgrading works were completed by the Geotechnical Control Office (GCO) in 1987 under Contract No. GC/84/03. No records of the stability assessment of the slope carried out as part of the LPM works were located by HAP. Figure 2, which is based on as-constructed drawings, shows the areas of slope protection and drainage installed during the works, together with areas where loose blocks were removed and rock bolts and dowel bars installed.

A Stage 1 Study was completed in August 1991 by the GEO Design Division. It was reported that the rock slope was unprotected with loose boulders and overhangs in places and further study was recommended. The scope of the study did not include review of the site history and previous slope assessments.

The slope was nominated by HyD for the LPM Programme in 1992/93 but was not included in the programme as LPM works had previously been completed in 1987.

In 1992, the GEO initiated the consultancy agreement entitled "Systematic Inspection of

Features in the Territory" (SIFT), which, inter alia, aimed to search for features not registered in the New Catalogue of Slopes and to update information on previously registered features, based on studies of aerial photographs and limited site inspection. In September 1994, the slope was assigned to SIFT Class "C1" which is for features that are "assumed (to be) formed pre-1978".

In June 1995 the slope was inspected by Fugro Mouchel Rendel (FMR) consultants who were appointed by HyD to undertake the "Roadside Slope Inventory and Inspections" project. The overall state of maintenance of the slope was rated as "fair" in accordance with Geoguide 5 (GEO, 1995). It was noted that drainage channels, catchpits and sand traps were blocked and that drainage channels were cracked and damaged. Minor ravelling of the slope was noted, and seepage was observed from the toe of the slope and from the slope face (Figure 2), with erosion of fines observed from rock joints. Routine maintenance works and preventive maintenance, comprising the removal of loose rocks, were recommended. A stability assessment, specialist investigation and annual Engineer Inspections were also recommended.

In 1994, the GEO began the "Systematic Identification and Registration of Slopes in the Territory" (SIRST) to update the 1977/78 Catalogue of Slopes and prepare the New Catalogue of Slopes. A SIRST report was not prepared for Slope No. 11NW-A/C79, as the information required for the New Catalogue of Slopes had been obtained during the earlier Engineer Inspection of the slope by FMR.

The cut slope was assessed in 1996 by consultants to HyD in association with construction of the Route 3 Kwai Chung Viaduct (Scott Wilson, 1996). As part of the investigation vegetation was cleared and an access scaffold erected to "more thoroughly investigate the condition of the rock slope and to carry out joint mapping". Subsequently, "selective mapping of the rock joints was carried out" to identify "only (the) major (discontinuity) sets". Stereographic analysis of the discontinuity data, assuming a friction angle of 39°, identified potential for "sliding and toppling failure" and concluded that remedial measures were necessary. Clay infill to discontinuities was not identified during the assessment by Scott Wilson. Proposed remedial works, which included construction of a buttress at the toe where the 1997 landslide occurred, were submitted in November 1996 and subsequently checked and approved by the GEO in February 1997. The remedial works were under construction at the time of the 1997 landslide, but the intended works had not been carried out at the actual location of the failure. Construction of the buttress, which would have supported the part of the slope that failed, was subsequently completed in February 1998 (Figure 2).

2.3.2 Cut Slope No. 11NW-A/C78

The slope was inspected by B & P in June 1977 and registered in the 1977/78 Catalogue of Slopes. At the time of that inspection, seepage from rock joints was noted at a height of 10 m above the slope toe and signs of distress, described as "erosion and loose blocks", were observed. No further action was recommended as the feature was to be included in the proposed Lai Chi Kok Phase II Study Area.

The Phase IID Landslide Study (B & P, 1981b) summarised the results of a desk study, site inspection, ground investigation and stability analysis of the slope. Stability analysis of the soil face in the upper part of the slope, which included the slope within the boundary of

11NW-A/F12 (Figure 3), indicated a "satisfactory factor of safety against circular slip failure". In assessing the stability of the rock slope, B & P examined "the cut face as well as access would permit" and carried out a "survey of the discontinuities along the toe of the slope". A stereographic analysis of the discontinuity data, assuming a friction angle of 39°, concluded that "the joint system will not give rise to serious rock failure". A discontinuity set (P3 in Figure 5) was, however, identified that "could give rise to toppling failure" but on the basis of an assessment of the spacing of the discontinuities it was considered that "toppling failure was most unlikely", that the slope was in a "safe condition and only some loose blocks and overhangs need to be removed or secured." Clay infill was not recorded in the discontinuity descriptions given in B & P's report. In general, the "overall stability of the (rock) slope" was considered "to be satisfactory". Preventive works, including scaling of loose blocks, installation of rock bolts, trimming of locally unstable areas and construction of two concrete buttresses, were recommended to "maintain the stability of the slope". The two concrete buttresses proposed were about 50 m and 100 m northeast of the 1997 landslide location.

The effect of groundwater on the shear strength of the discontinuities appears not to have been considered in the assessment.

The entire slope was included in the 1984/85 LPM Programme. Upgrading works, including installation of rock bolts and dowels, localised re-surfacing of the slope and sealing of vertical joints with cement mortar, were completed in 1987 by the GCO under Contract No. GC/84/03 (Figure 3). No records of the stability assessment of the slope carried out as part of the LPM works were located by HAP.

In September 1994, the slope was assigned to SIFT Class "C1" as it was "assumed (to have been) formed pre-1978".

In June 1995 the slope was inspected by FMR consultants as part of the "Roadside Slope Inventory and Inspections" project. The overall state of maintenance of the slope was rated as "fair" in accordance with Geoguide 5 (GEO, 1995). It was noted that drainage channels, catchpits and sand traps were blocked. Minor ravelling of the slope was noted and moderate seepage was observed at the slope crest. Routine maintenance and preventive maintenance works were recommended to improve the surface drainage, together with a stability assessment of the slope.

A SIRST report was not prepared for Slope No. 11NW-A/C78 as the information required for the New Catalogue of Slopes had been obtained during the Engineer Inspection of the slope by FMR.

The cut slope was not assessed by the consultants to HyD as part of the Route 3 Kwai Chung Viaduct Project or by MTRC in association with the 1997/98 construction works at Lai King MTR Station.

No records have been located in respect of the blasting work carried out as part of the Airport Expressway Rail Link extension works undertaken in the vicinity of Lai King Station, about 150 m to the northeast of the site (Figure 3).

2.4 Subsurface Conditions

According to the Hong Kong Geological Survey Map Sheet No. 11 (GCO, 1986) a 60 m-wide zone of fine-grained granite extends northeast to southwest between the sites. Coarse-grained granite occurs both to the north and south of the fine-grained granite zone. Most of Slope No. 11NW-A/C78 is formed in coarse-grained granite with the southern part of the slope shown lying on the boundary between fine- and coarse-grained granite. Slope No. 11NW-A/C79 is formed predominantly in coarse-grained granite. Cross-sections of Slope Nos. 11NW-A/C79 and 11NW-A/C78 are shown in Figures 6 and 7 respectively.

2.4.1 Cut Slope No. 11NW-A/C79

A borehole (LK20) was drilled from the playground of Mu Kuang Lai King Primary School above the slope (Figure 2) as part of the Phase IID Study of Slope No. 11NW-A/C79 in December 1978 (Binnie & Partners, 1981a). The borehole encountered 1 m of fill overlying 3 m of highly to completely decomposed granite, above 5 m of moderately to highly decomposed granite with corestones of slightly to moderately decomposed granite. Slightly to moderately decomposed coarse-grained granite was encountered at 11.2 mPD.

Two piezometers were installed in the borehole and monitored monthly between February and October 1979. The upper piezometer remained dry throughout the monitoring period with the lower piezometer recording water levels varying between 10.8 mPD and 11.8 mPD (Figure 6).

In May 1997 and February 1998, HAP inspected the slope and observed seepage from most of the weepholes in the buttress which was constructed following the landslide incident (see Section 2.3.1). Seepage stains and damp patches were noted on the buttress, up to 0.2 m above the toe of the slope. At the location of a 300 mm stepped-channel, 50 m south of the landslide scar (Figure 2), moderate seepage was also observed from the rock face, up to 3 m above the slope toe. An assumed groundwater table within the slope, based on piezometer data and recent seepage observations, is shown in Figure 6.

HAP observed three planar, clay-coated discontinuities at the location of the failure with dips and dip directions of 37°/240°, 85°/300° and 68°/168° (Plate 2). Loose blocks were evident on either side of the failure, with joint apertures of up to 50 mm. The lower slope face has an irregular and blocky appearance.

2.4.2 Cut Slope No. 11NW-A/C78

A borehole (EF 30/1027) was drilled by Gammon (Hong Kong) Limited (1977) at the crest of the cut slope upslope of the landslide site (Figure 3). This borehole proved fill to a depth of 2.6 m overlying bedrock. No water strikes were recorded during drilling.

The dominant discontinuities in the rock slope have dips and dip directions of 25°/276°, 60°/042° and 70°/104°. The shallow-angle discontinuity at 25°/276° is smooth, undulating and laterally persistent for several metres, whereas the two higher-angle discontinuities are closely-spaced, planar, smooth and persistent for less than a metre. Light brown clay-rich infill was locally observed on the dominant discontinuities. Slope morphology is controlled by the shallow discontinuities where the overall slope angle is less than 50°, and the rock surface is stepped where the overall slope angle is greater than 50°.

There was no evidence of seepage at the rock face or the toe of the slope when HAP made inspections in June 1997 and January 1998.

2.5 Previous Landslides

A landslide (GCO Incident No. NT82/8/26) occurred on 17 August 1982 on Slope No. 11NW-A/C79 (Figure 2). The incident involved failure of two blocks of rock which affected two lanes of the Kowloon-bound carriageway of Kwai Chung Road. The blocks were each reported to be about 3 m^3 to 4 m^3 in volume. One car was damaged, but no fatalities or injuries were reported. According to the landslide incident report prepared by the GEO, the failure was joint-controlled and groundwater was the cause of failure.

3. THE LANDSLIDES

3.1 Time of Failure

3.1.1 GEO Incident No. MW97/5/6

The landslide was reported to the GEO at 13:07 hours on 8 May 1997. The time of occurrence was given in the GEO Incident Report as 11:00 hours on 8 May 1997. A Landslip Warning was issued by the GEO at 11:05 hours on 8 May 1997.

3.1.2 GEO Incident No. MW97/6/21

The landslide was reported to the GEO by Highways Department on 4 June 1997. Staff at the construction site offices, located near to the landslide site, first noticed the landslide at 08:00 hours on 4 June 1997. The landslide probably occurred shortly before 08:00 hours on 4 June 1997. A Landslip Warning had been issued at 07:45 hours on 4 June 1997.

3.2 Description of the Landslides

3.2.1 GEO Incident No. MW97/5/6

The landslide affected the lower rock slope portion of Slope No. 11NW-A/C79 adjacent to Kwai Chung Road. The base of the failure was about 1 m above the road level. The failure was 3 m wide, 5 m long and 1.5 m deep with an estimated volume of about 23 m^3. The debris was deposited on the verge and partially blocked the inside lane of the Kowloon-bound carriageway of Kwai Chung Road (Figure 6 and Plate 1).

The landslide debris and scar consisted of moderately strong to strong, medium-grained moderately to slightly decomposed granite. The debris comprised several large angular blocks in excess of 3 m^3 and numerous smaller-sized angular blocks (Plate 1).

The location and shape of the basal failure surface was controlled by an adversely orientated discontinuity dipping at 37° with a dip direction of 240° (Plate 2). The discontinuity surface was coated with about 50 mm of soft white-grey clay. During the inspection by HAP on 8 May 1997, no seepage was observed on the failure surface, although in the vicinity of the failure there was seepage from similarly orientated discontinuities daylighting at about 0.5 m above the toe of the slope. The landslide probably occurred rapidly and involved sliding of the rock mass along the adversely orientated, clay-coated discontinuity.

High-angle discontinuities along the flanks and main scarp of the failure provided release surfaces and facilitated the detachment of the rock blocks. These high-angle discontinuities were medium-spaced and persistent for several metres. Their surfaces were smooth, undulating and locally stained. Some of the discontinuities were infilled with up to about 50 mm of clay.

Following the landslide, GEO recommended that the inside lane of the Kowloon-bound carriageway should be closed until the remedial works on the rock slope, that were in progress by HyD at the time of failure (Section 2.3.1), were completed. In addition, the GEO recommended that placement of a rock fence along the affected section of the road.

The inside lane of the Kowloon-bound carriageway remained closed until February 1998 to allow completion of the repair works.

3.2.2 GEO Incident No. MW97/6/21

The landslide was located at the southern end of Slope No. 11NW-A/C78 (Figure 3). The failure occurred about 4 m above the toe of the slope and was 6 m wide, 5 m long and 1 m deep, with an estimated volume of about 15 m^3 (Plates 3 and 4). The debris accumulated on the open space at the toe of the slope adjacent to an access path (Plate 3).

Shortly after the landslide, HAP observed that drainage channels and two sand traps at the toe of the slope near the failure were partly blocked with rubbish and construction debris.

The landslide debris consisted of blocky moderately strong, medium-grained, moderately decomposed granite, with individual block sizes of less than 1 m^3 (Plate 5).

Clay infill was observed on the surfaces of the release discontinuities. The main scarp was formed of high-angled discontinuities with a height of about 1m. Persistent orthogonal discontinuities were evident throughout the slope. No seepage was observed at the time of the initial or subsequent site inspections.

The landslide probably occurred rapidly and involved sliding of detached rock blocks over a basal discontinuity dipping at 25°, which had a coating of clay-rich material up to about 20 mm thick. Other discontinuities along the southern flank and main scarp of the failure facilitated the detachment of further material. Following sliding, the outermost detached blocks fell over the 2 m high near-vertical face at the toe of the slope and onto the open space below (Figure 7 and Plate 5). Evidence of failure by minor toppling, controlled by the closely-spaced high-angled discontinuities, was apparent from the main scarp.

Urgent repair works recommended by the GEO comprised construction of a mass concrete buttress secured by two rows of dowel bars at 1.5 m centres, penetrating 1.5 m into rock. During subsequent visits in January 1998, HAP noted that overhanging rock had been trimmed and that the failure scar was covered with shotcrete. Weepholes, which were observed to be dry, had been installed at approximately 1.5 m centres at the base of the shotcrete.

4. RAINFALL

The nearest GEO automatic raingauge to the site is No. N04 which is located at Kai Kwang Lau, Cho Yin Estate, Lai King, about 450 m east of the landslides (Figure 1).

4.1 GEO Incident No. MW97/5/6

The daily rainfall recorded between 4 April and 9 May 1997, and hourly rainfall recorded between 4 May and 8 May 1997 are shown in Figure 8. An isohyet plot of rainfall distribution between 00:00 hours and 11:00 hours on 8 May 1997 is shown in Figure 9.

Rainfall on the 8 May 1997 was continuous between about 04:00 hours and 11:00 hours, the time that the failure was reported to have occurred. The maximum rolling hourly rainfall prior to the landslide (128.5 mm) was recorded between 09:45 hours and 10:45 hours on 8 May 1997, shortly before the reported time of failure.

The estimated return periods for maximum rolling rainfall for selected durations before the landslide, based on historical rainfall data at the Hong Kong Observatory (Lam & Leung, 1994), are presented in Table 2. The 1-hour rolling rainfall was the most severe, with an estimated return period of about 40 years.

A comparison of the rainfall prior to the landslide with previous major rainstorms recorded at raingauge No. N04 is shown in Figure 10. The rainfall preceding the landslide was the highest recorded by the raingauge since its installation in 1978 for durations of less than 8 hours.

4.2 GEO Incident No. MW97/6/21

The daily rainfall recorded between 4 May and 8 June 1997, and hourly rainfall recorded between 1 June and 5 June 1997 are shown in Figure 11. An isohyet plot of rainfall distribution between 00:00 hours and 08:00 hours on 4 June 1997 is shown in Figure 12.

Rainfall on 4 June 1997 was continuous between about 01:00 hours and 08:00, the time when the landslide was first noticed. The maximum rolling hourly rainfall prior to the landslide (128.5 mm) was recorded between 06:00 hours and 07:00 hours on 4 June 1997.

The estimated return periods for maximum rolling rainfall for selected durations before the landslide, based on historical rainfall data at the Hong Kong Observatory, are presented in Table 3. The 1-hour rolling rainfall was the most severe, with a corresponding estimated return period of about 40 years.

A comparison of the rainfall prior to the landslide with previous major rainstorms recorded by raingauge No. N04 is shown in Figure 10. The rainfall preceding the landslide was the highest recorded by the raingauge since its installation in 1978 for durations of between 2 hours and 4 days.

5. PROBABLE CAUSES OF FAILURE

The close correlation between severe rainstorms and the occurrence of the landslides indicates that they were probably triggered by intense rainfall.

Both failures involved planar rock slides, controlled principally by a basal shear surface on a daylighting, clay-infilled discontinuity, with high-angle planar discontinuities providing the lateral release surfaces. The clay infill observed on the basal discontinuities probably had a shear strength lower than the 39° used in the B & P stability assessment. It is likely that water pressure developed along the discontinuities, lowering the shearing resistance and resulting in failure.

There is no evidence of overtopping of surface water from the drainage channels above the landslides.

Slope No. 11NW-A/C79, however, has a history of seepage from discontinuities on the rock face and near the toe of the slope, which is likely to have originated from base groundwater flows. The development of water pressure in the slope was most likely, therefore, the result of a rise in the base groundwater table and water ingress into open discontinuities in response to direct infiltration of rainfall during the intense rainstorm on 8 May 1997. High-angle discontinuities within the exposed rock face above the failure would have facilitated the ingress of water into the slope.

The landslide on Slope No. 11NW-A/C78 was located close to the crest of the rock slope (Figure 7). The absence of observed seepage on this part of the slope suggests that the base groundwater does not repeatedly rise to such elevations. It is more probable, therefore, that the landslide was caused by local development of transient water pressure on the clay-infilled basal discontinuity in response to infiltration of rainfall into the unprotected area upslope of the landslide site. The closely-spaced, high-angle discontinuities present behind the main scarp may have assisted the infiltration process. Water pressure in the discontinuities would have destabilised the rock mass, initiating detachment and sliding. Not all the blocks had sufficient momentum to reach the toe of the slope, possibly due to dissipation of water pressure during movement of the rock mass on a moderately steep (25°) sliding surface.

6. DISCUSSION

The failures were principally the result of increase in water pressures at adversely orientated, clay-infilled discontinuities due to severe rainfall.

The landslides occurred on slopes that had previously been included in the 1984/5 LPM Programme and upgrading works were carried out, although no works were undertaken at the actual locations of the 1997 failures. Further study of Slope No. 11NW-A/C79, recommended following a Stage 1 Study in 1991 which noted loose boulders and overhangs, was not carried out because the slope had already been upgraded under the LPM Programme. Consultants further assessed Slope No. 11NW-C/79 in 1996 as part of the development project for Route 3 Kwai Chung Viaduct and upgrading works, including a buttress at the location of the subsequent 1997 landslide, were considered necessary.

Sliding instability of the rock slope along daylighting joint sets, with an assumed friction angle of 39°, was considered during the stability assessment of both slopes in 1981. It appears that the presence of clay infill along the discontinuities was not referred to and considered in that assessment. Stereographic analysis was carried out but the effect of groundwater did not appear to have been taken into account explicitly in the stability assessment.

7. CONCLUSIONS

The principal cause of both landslides was the presence of local adversely orientated clay-infilled discontinuities, which daylighted in both the concerned rock cut slopes, with high-angle discontinuities providing release surfaces for the failures.

Increase in water pressures at the discontinuities during severe rainstorms, which had estimated return periods of about 40 years or more, most probably destabilised the rock masses and triggered the failures.

Both slopes were previously upgraded under the LPM Programme. The failures occurred in areas where no works had been undertaken.

8. REFERENCES

Binnie & Partners (1978). Re-Appraisal of Cut Slopes and Natural Slopes and Retaining Walls, Landslide Studies Phase 1. Technical Report, Binnie and Partners (Hong Kong) Ltd, Consulting Engineers for Government of Hong Kong.

Binnie & Partners (1981a). Slope Reference No. 11NW-A/C79, Landslide Study Phase IID, Lai King Area. Technical Report, Binnie and Partners (Hong Kong) Ltd, Consulting Engineers for Government of Hong Kong, 39 p.

Binnie & Partners (1981b). Slope Reference No. 11NW-A/C78, Landslide Study Phase IID, Lai King Area. Technical Report, Binnie and Partners (Hong Kong) Ltd., 35 p.

Gammon (Hong Kong) Limited (1977). Prince Edward to Kwai Fong - Borehole Records and Summary of Test Results. Ground Investigation Factual Report, Gammon (Hong Kong) Ltd, Contractors for Mass Transit Railway Corporation, Hong Kong.

Geotechnical Control Office (1986). Hong Kong and Kowloon : Solid and superficial geology. Hong Kong Geological Survey, Map Series HGM 20, Sheet 11, 1:20 000 scale. Geotechnical Control Office, Hong Kong.

Geotechnical Control Office (1987). Geotechnical Area Studies Programme - Central New Territories. Geotechnical Control Office, Hong Kong. GASP Report no. II, 165 p., plus 4 maps.

Geotechnical Engineering Office (1995). Guide to Slope Maintenance (Geoguide 5). Geotechnical Engineering Office, Hong Kong, 91 p.

Lam, C.C. & Leung, Y.K. (1994). Extreme Rainfall Statistics and Design Rainstorm Profiles at Selected Locations in Hong Kong. Royal Observatory, Hong Kong, Technical Note no. 86, 89 p.

Scott Wilson (1996). Rock slope adjacent to Gridline 39 – 44 (Mainline), Contract No. HY/92/04 Route 3 – Kwai Chung Viaduct. Technical Report, Scott Wilson (Hong Kong) Ltd, March 1996, Consulting Engineers to Highways Department, Hong Kong.

LIST OF TABLES

Table 1 – Summary of Information Sources

Source	Documents
Water Supplies Department (WSD).	Utility Records
Drainage Services Department (DSD).	Utility Records
Mainland West Division of GEO.	Slope File 11NW-A/C79
Design Division of GEO.	Slope File GCE 11NW-A/C78 Slope File GCD 2/A1/11NW-A/C79 Cut Slope Master List
Highways Department/New Territories Region.	Utility Records Site Formation Plans Confirmation of Maintenance Responsibility
Geotechnical Information Unit (GIU) at the Civil Engineering Department (CED) Library.	GIU Ref 06804 (11NW-A/F23) GIU Ref 04935 (MTRC boreholes)
Civil Engineering Library.	Landslip Card NT 82/8/26 1977/78 Slope Catalogue SIFT Records 11NW-1DS/3 and 11NW-1DS/5 Piezometer Records (11NW-A/F23)
Scott Wilson Kirkpatrick & Partners.	Kwai Chung Development Scheme II, PWD Contract No. 35. As constructed Drawing 6080/696A.
GEO Planning Division.	Aerial photographs dated 1949, 1963, 1964, 1968, 1969, 1970, 1972, 1973, 1978, 1980, 1984, 1986, 1988, 1990, 1991, 1992, 1993, 1994, 1995, 1996 and 1997.

Table 2 – Maximum Rolling Rainfall at GEO Raingauge No. N04 for Selected Durations Preceding the 8 May 1997 Landslide and The Corresponding Estimated Return Periods

Duration	Maximum Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years)
5 minutes	16	10:35 hours on 8 May 1997	6
15 minutes	43	10:40 hours on 8 May 1997	26
1 hour	128.5	10:45 hours on 8 May 1997	41
2 hours	170	11:00 hours on 8 May 1997	23
4 hours	180.5	11:00 hours on 8 May 1997	8
12 hours	204.5	11:00 hours on 8 May 1997	3
24 hours	210	11:00 hours on 8 May 1997	2
2 days	230	11:00 hours on 8 May 1997	2
4 days	284	11:00 hours on 8 May 1997	2
7 days	302	11:00 hours on 8 May 1997	2
15 days	305.5	11:00 hours on 8 May 1997	1
31 days	417.5	11:00 hours on 8 May 1997	1

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.

Table 3 – Maximum Rolling Rainfall at GEO Raingauge No. N04 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	14	07:00 hours on 4 June 1997	3
15 minutes	38	07:00 hours on 4 June 1997	10
1 hour	128.5	07:00 hours on 4 June 1997	41
2 hours	180	08:00 hours on 4 June 1997	33
4 hours	224	08:00 hours on 4 June 1997	21
12 hours	304	08:00 hours on 4 June 1997	13
24 hours	314.5	08:00 hours on 4 June 1997	5
2 days	345.5	08:00 hours on 4 June 1997	4
4 days	345.5	08:00 hours on 4 June 1997	3
7 days	346.5	08:00 hours on 4 June 1997	2
15 days	348	08:00 hours on 4 June 1997	2
31 days	837	08:00 hours on 4 June 1997	5

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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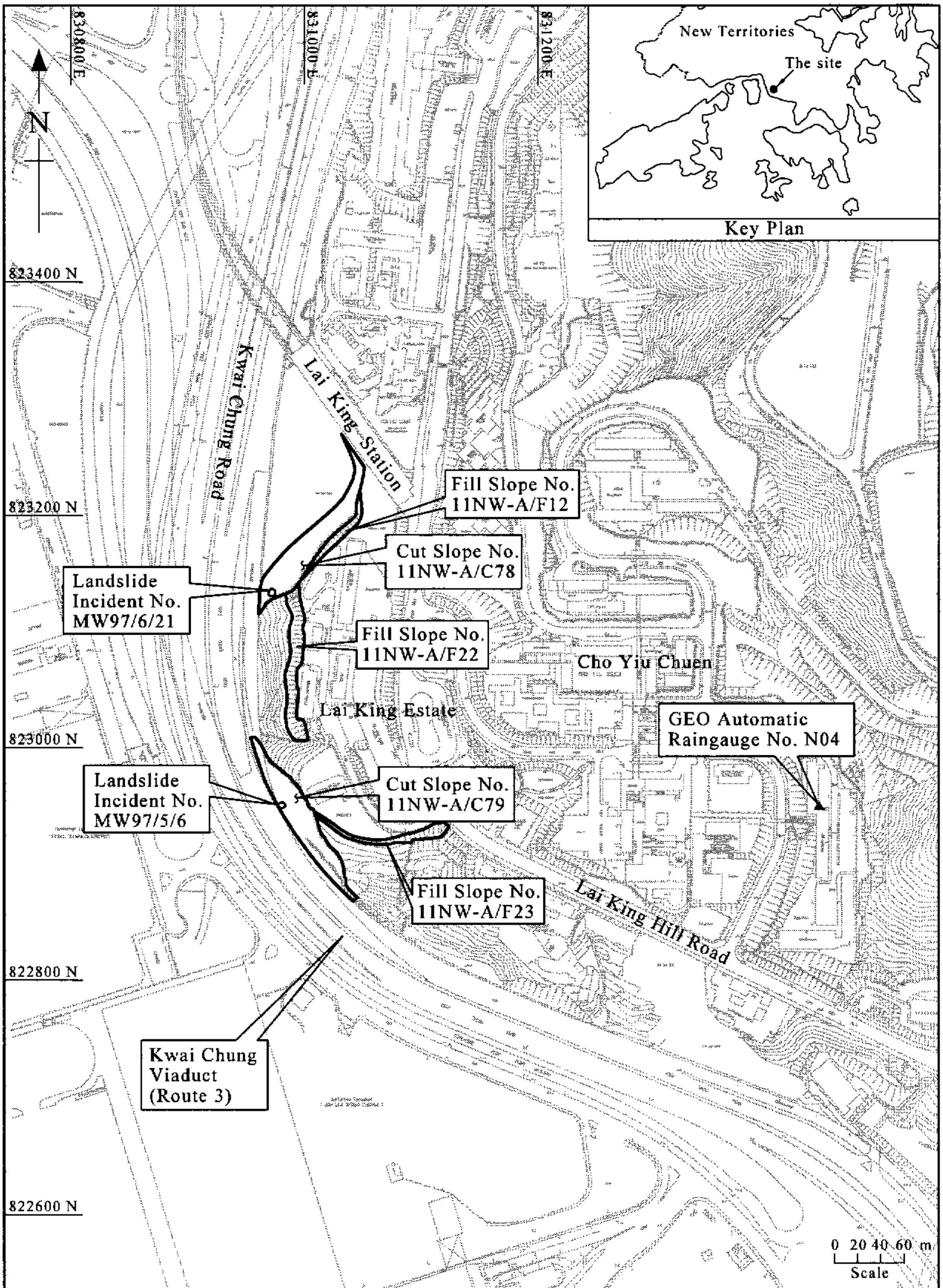


Note : Base map is extracted from Survey Sheet Nos. 11NW-1B, 11NW-1D and 11NW-6B dated October 1992 (Original scale 1:1 000).

Figure 1 - Location Plan

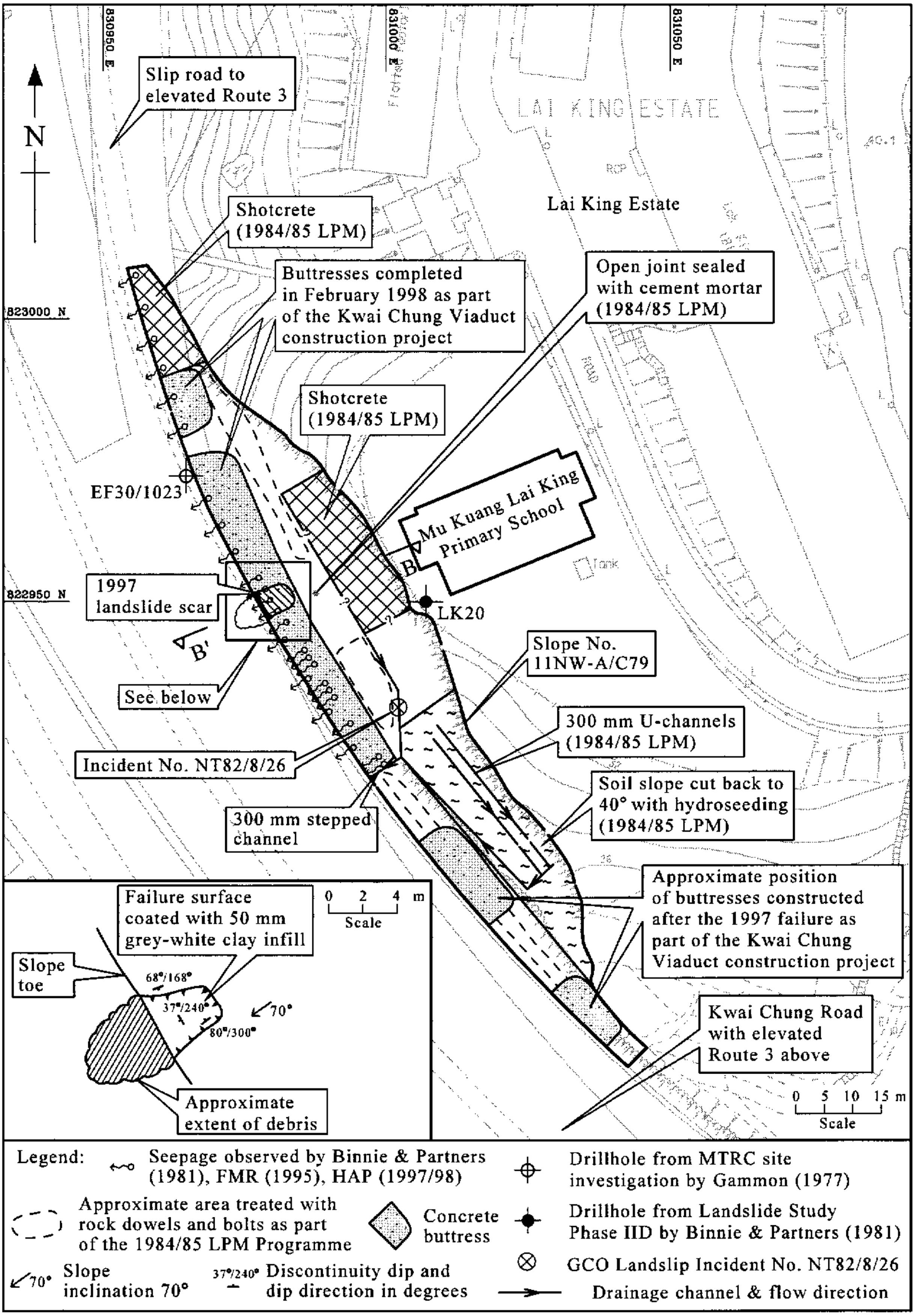


Figure 2 - Site Plan (GEO Incident No. MW97/5/6)

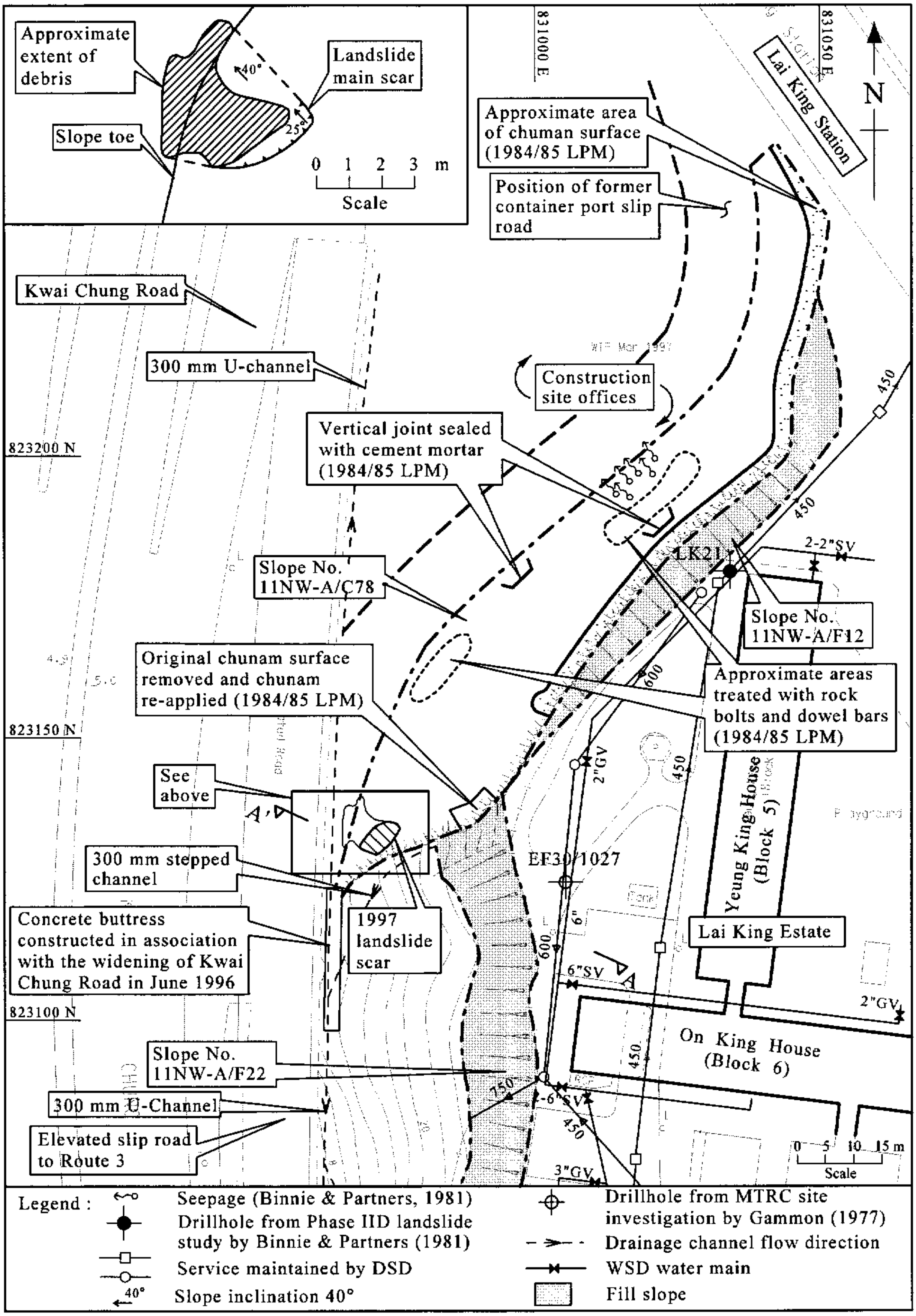
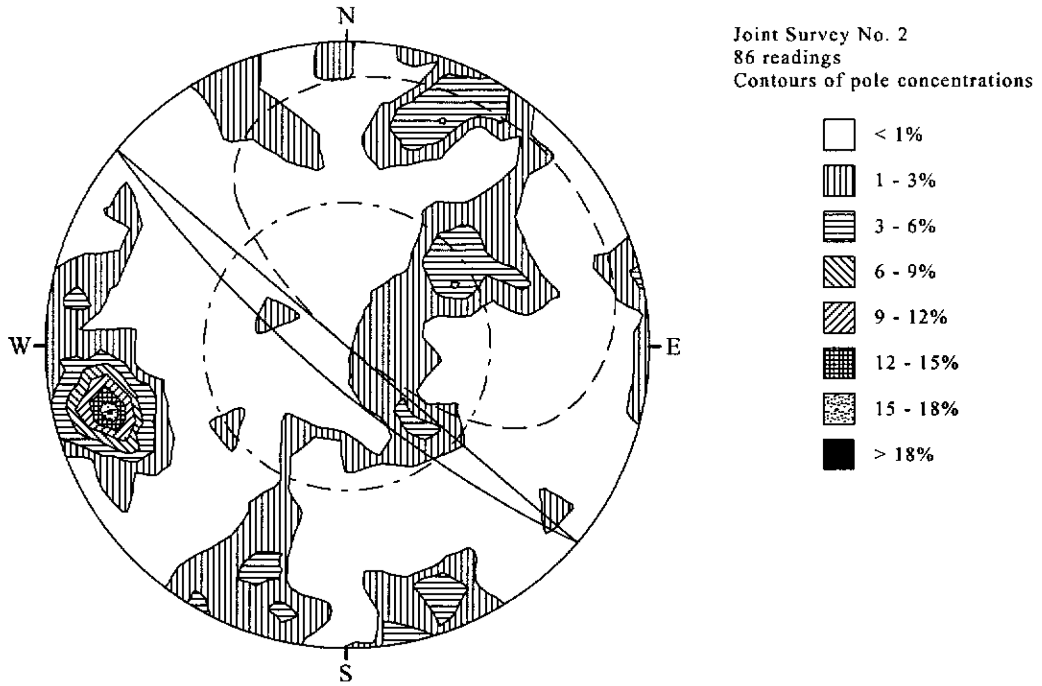
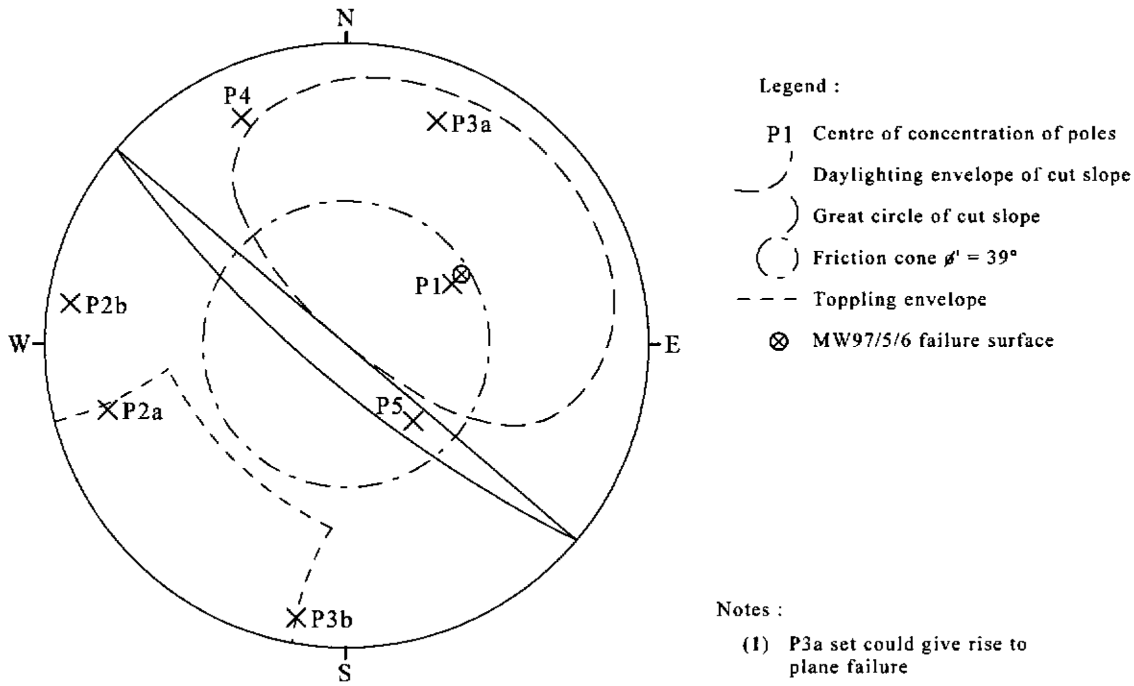


Figure 3 - Site Plan (GEO Incident No. MW97/6/21)



Equal Area Polar Net



Equal Area Equatorial Net

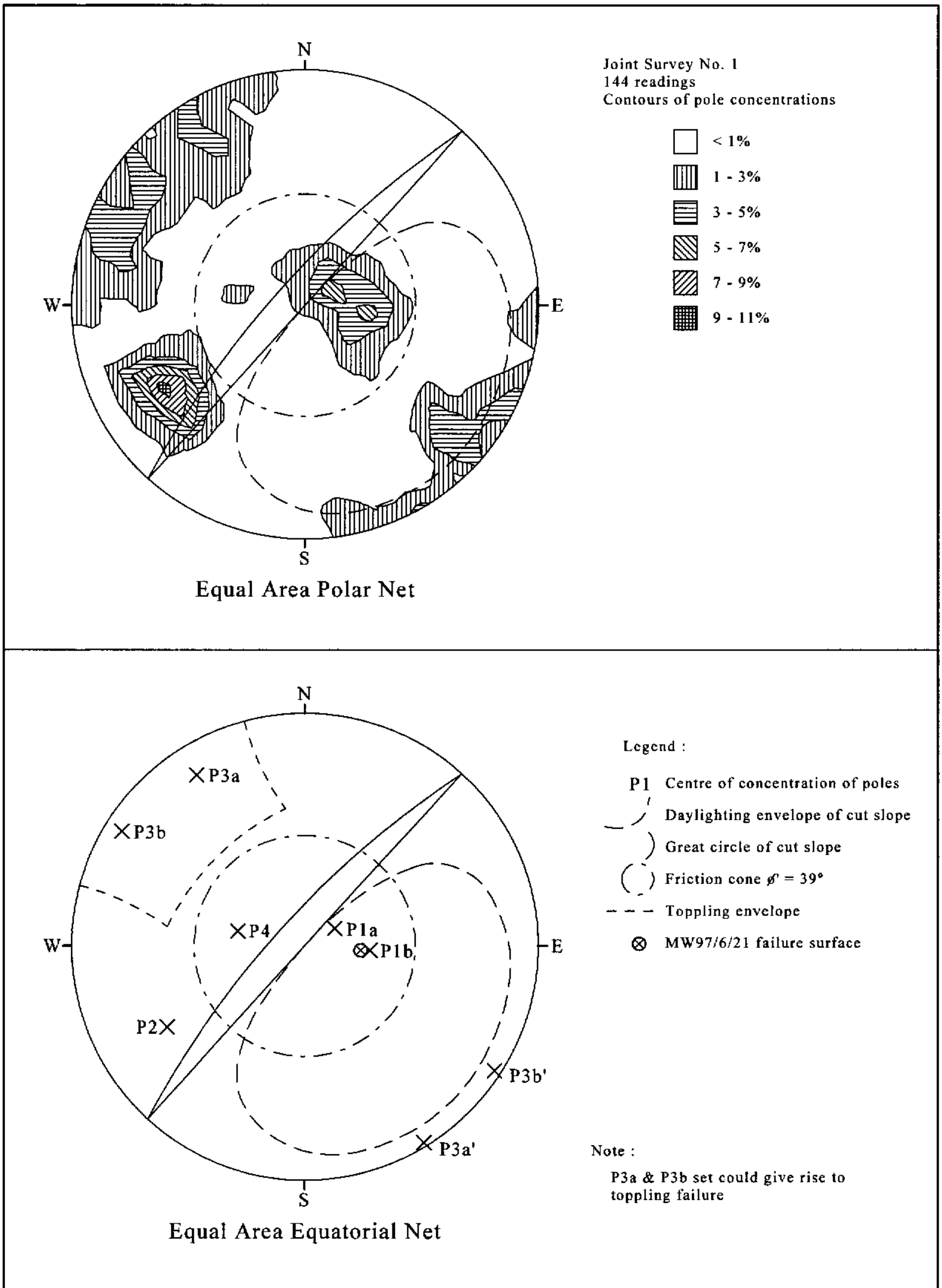
Notes :

(1) P3a set could give rise to plane failure

(2) P2a set and P3b set could give rise to toppling failure

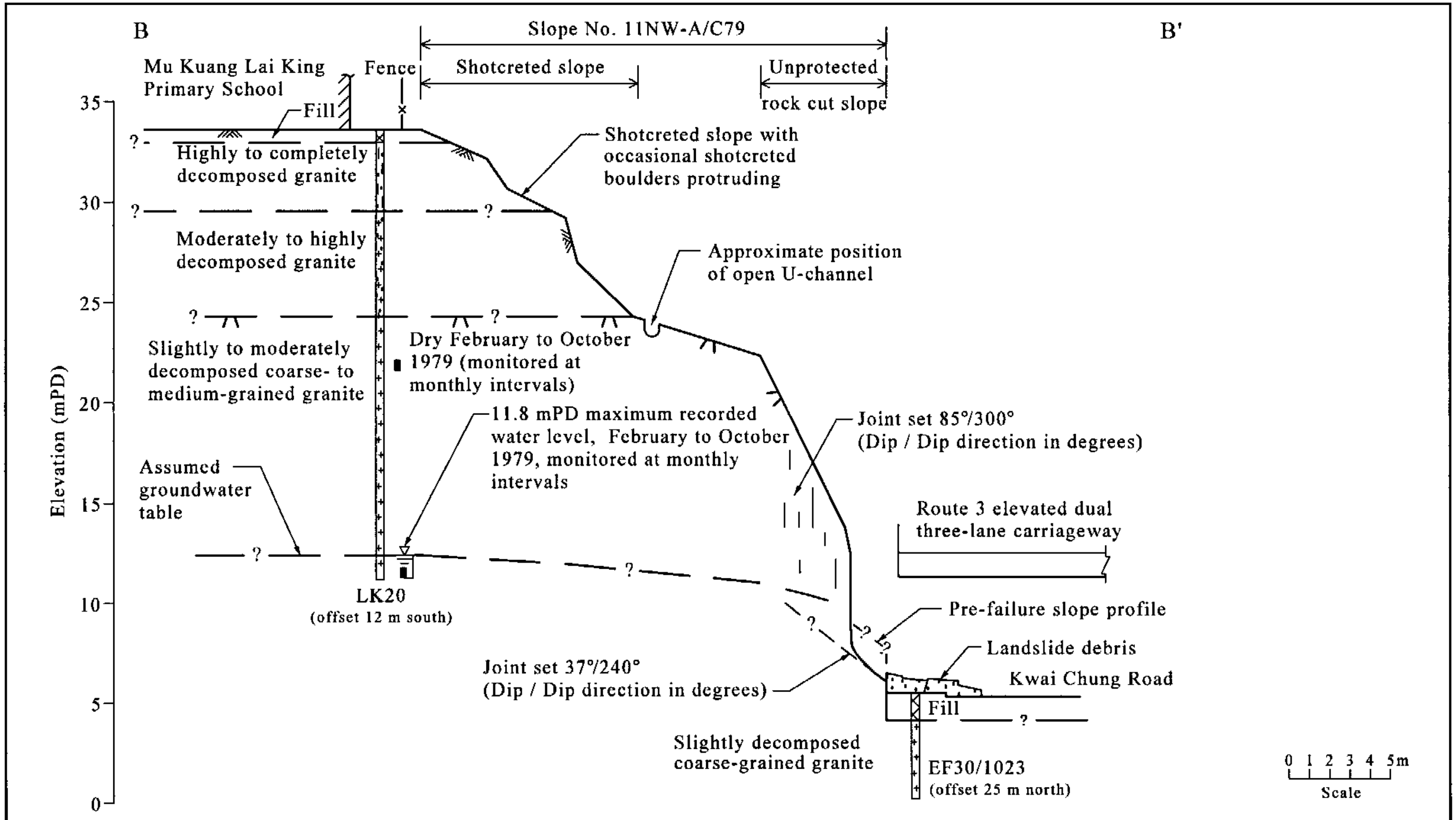
Note : Stereonet contouring and pole concentration data extracted from Landslide Study Phase IID by Binnie & Partners (1981).

Figure 4 - Rock Discontinuity Stereonet for Slope No. 11NW-A/C79



Note : Stereonet contouring and pole concentration data extracted from Landslide Study Phase IID by Binnie & Partners (1981).

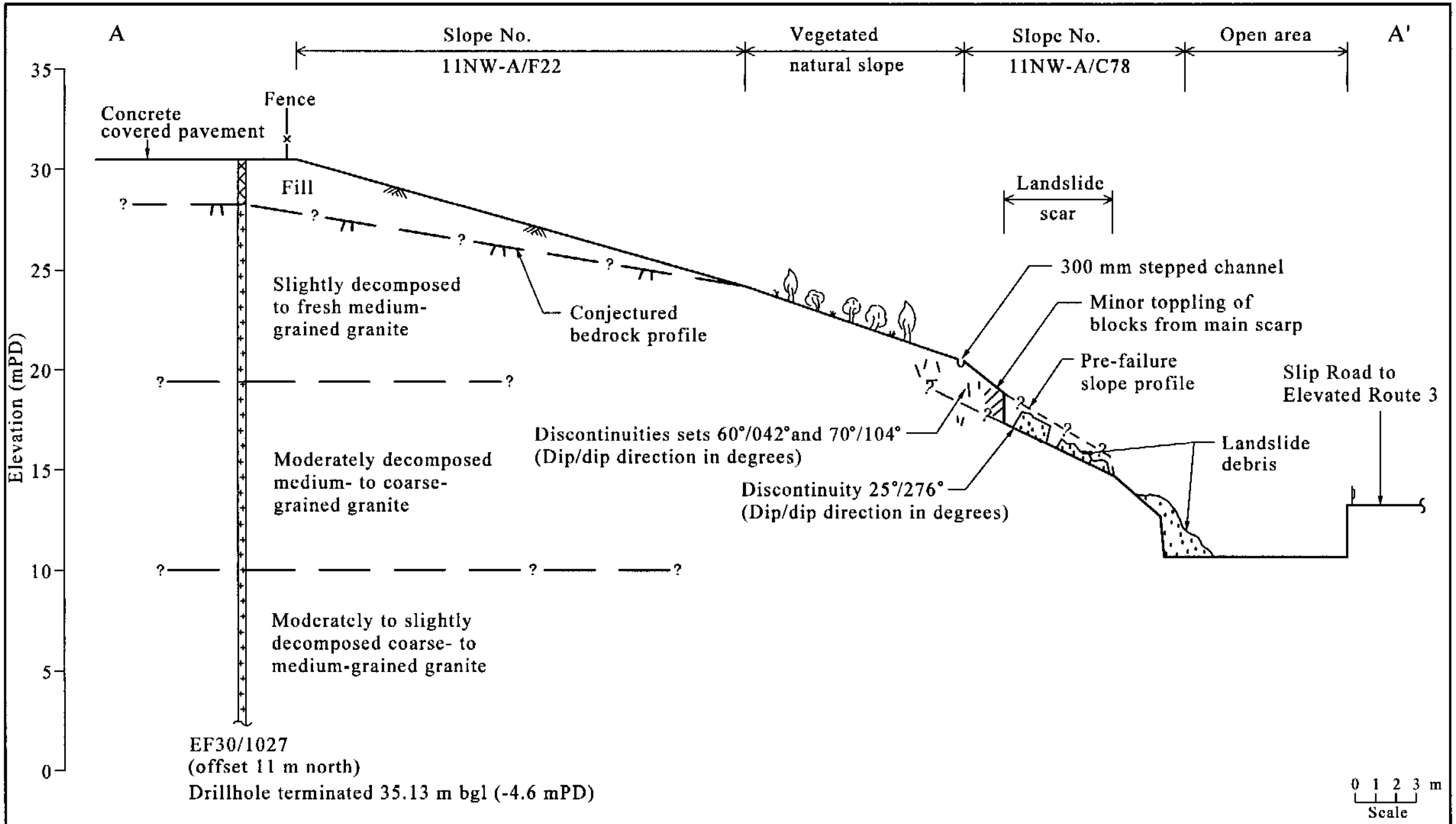
Figure 5 - Rock Discontinuity Stereonet for Slope No. 11NW-A/C78



Notes : (1) See Figure 2 for location of section.
(2) Information shown in this figure is based on slope profile extracted from Binnie & Partners (1981), geological mapping, field observations and documentary records.

Legend : Piezometer tip and observed water level

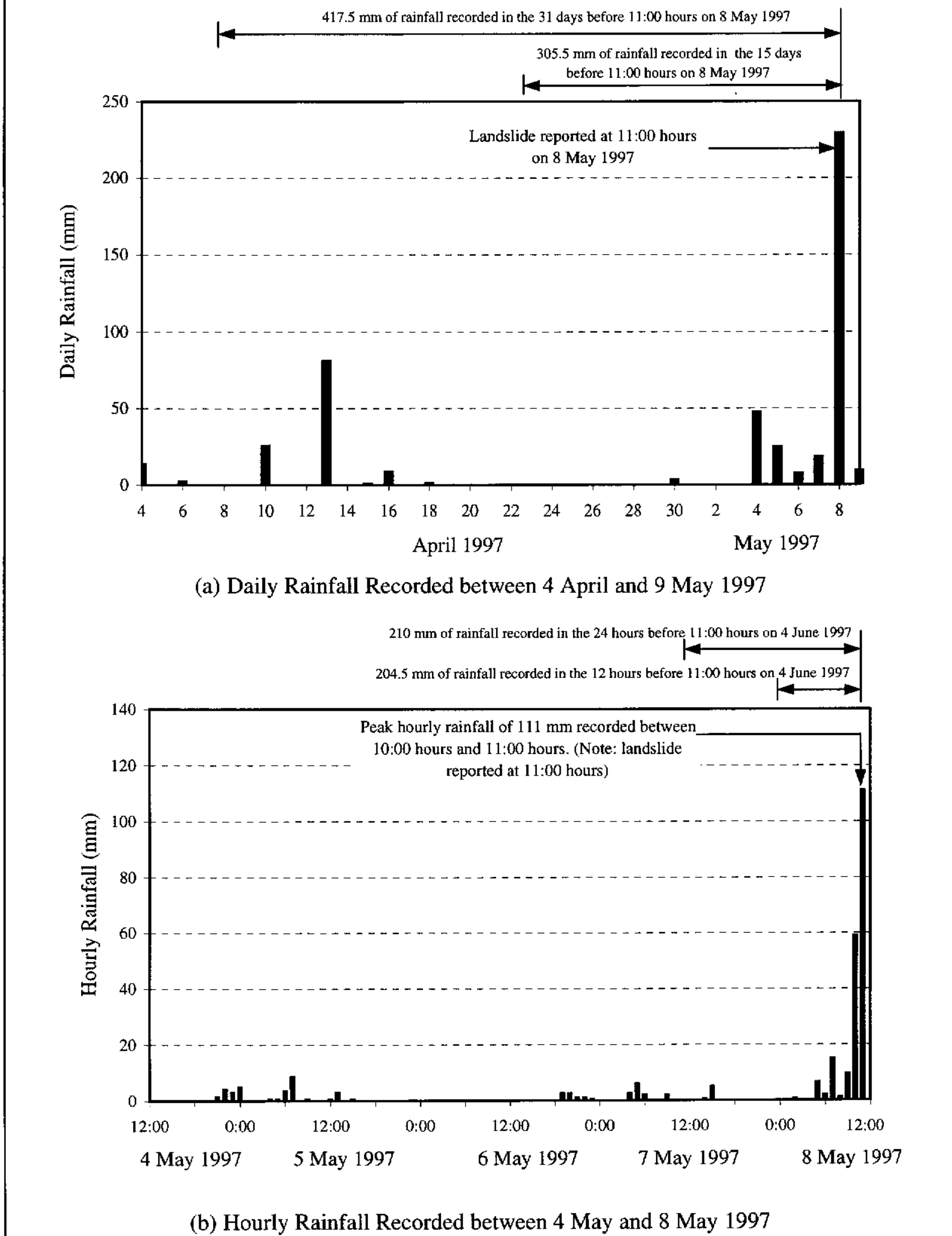
Figure 6 - Cross-section through the Landslide (GEO Incident No. MW97/5/6)



Notes : (1) See Figure 3 for location of section.

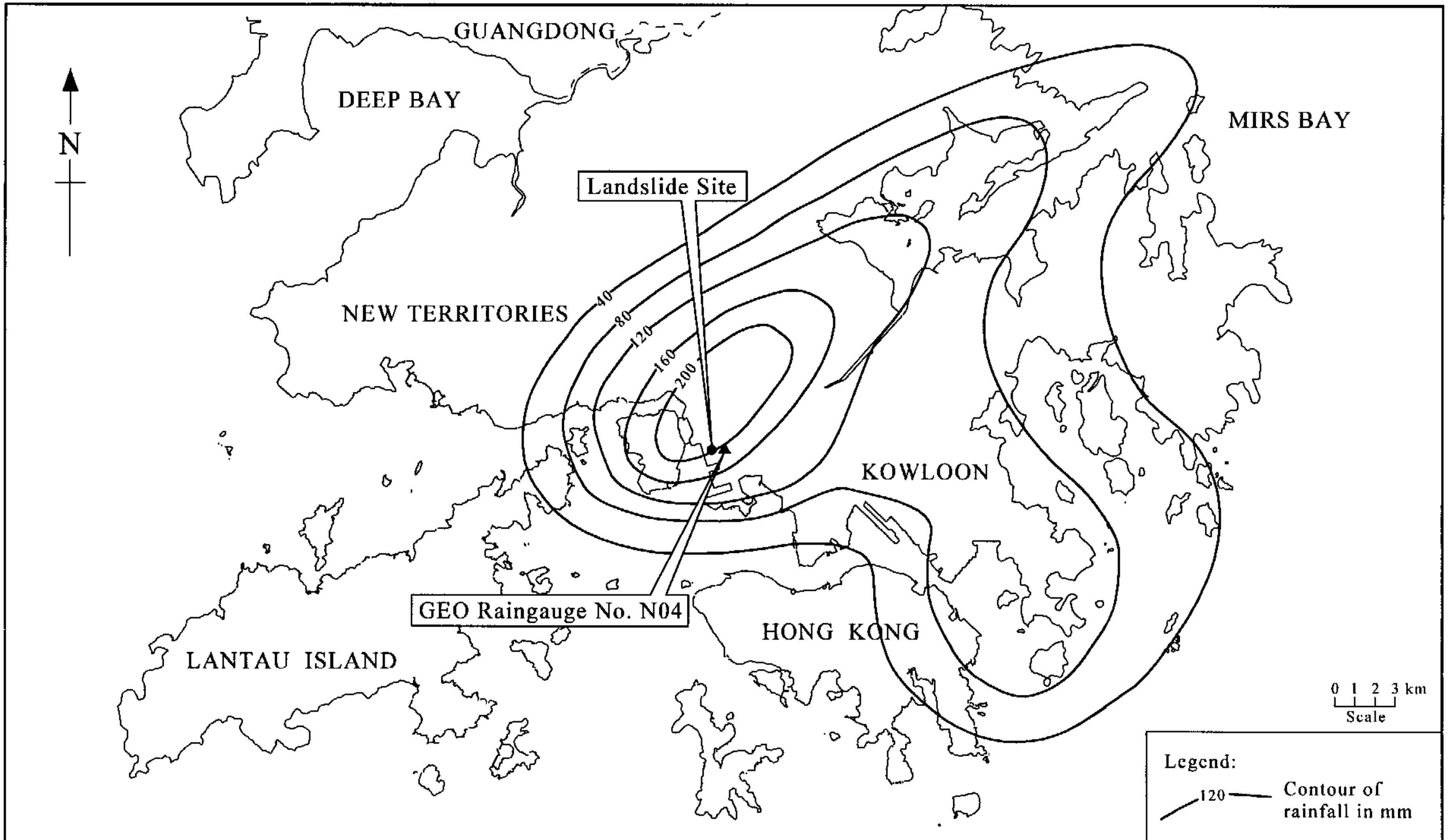
(2) Information shown in this figure is based on topographic survey, 1:1 000 survey map, geological mapping, field observations and documentary records.

Figure 7 - Cross-section through the Landslide (GEO Incident No. MW97/6/21)



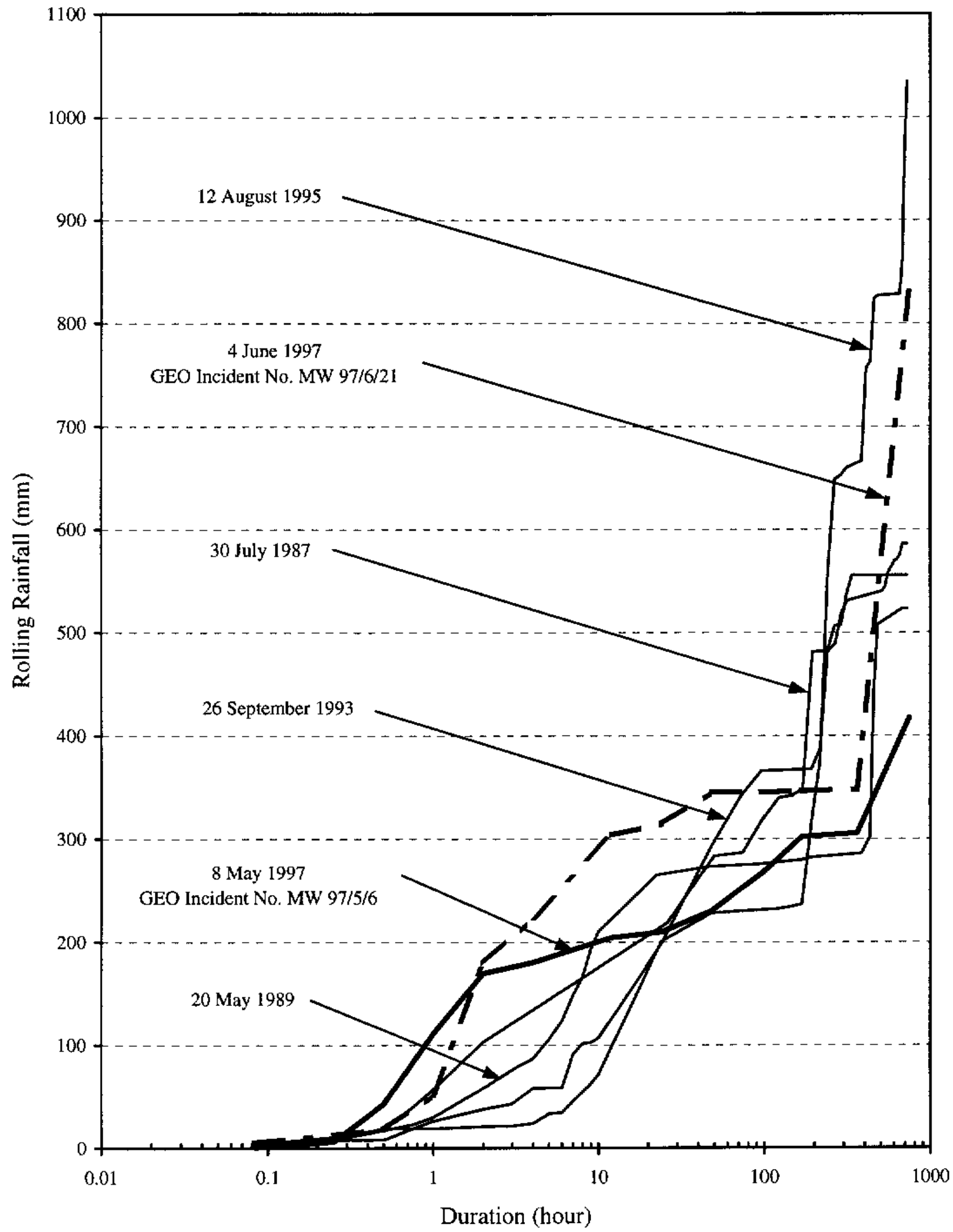
Note : GEO Incident Report recorded time of failure at 11:00 hours on 8 May 1997 though the precise time of failure is not known.

Figure 8 - Rainfall Records at GEO Raingauge No. N04 between 4 April and 9 May 1997



Note : Isohyets prepared by the Hong Kong Observatory.

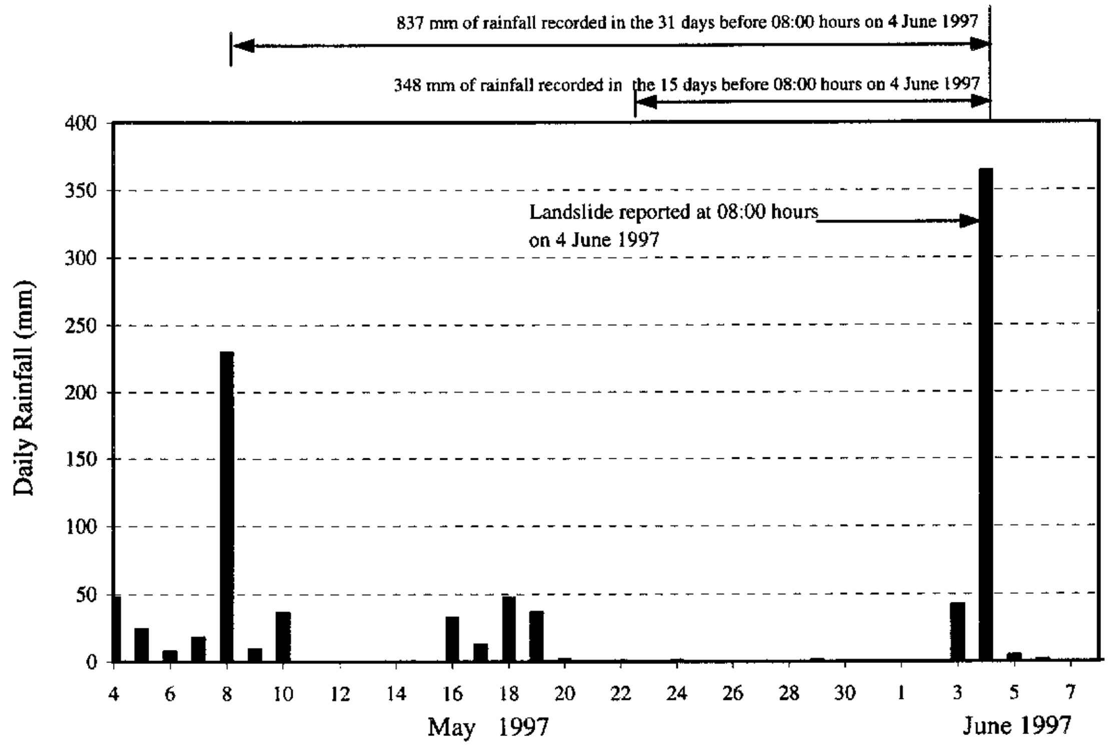
Figure 9 - Isohyets of Rainfall between 00:00 Hours and 11:00 Hours on 8 May 1997



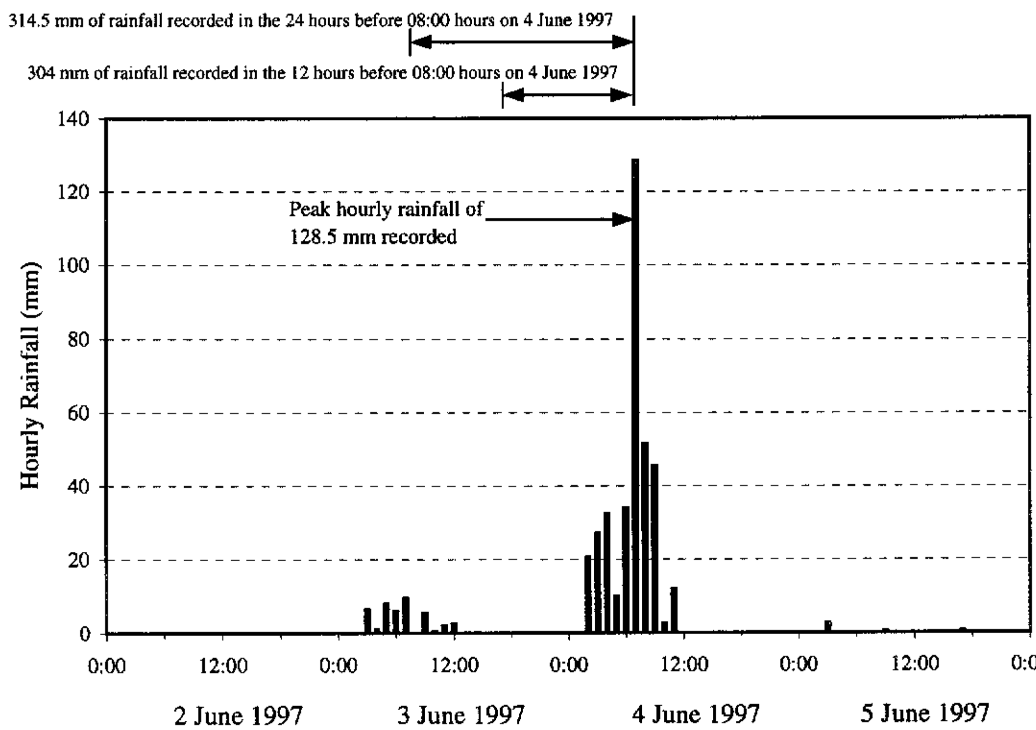
Notes : (1) GEO Incident Report recorded time of failure at 11:00 hours on 8 May 1997 though the precise time of failure is not known.

(2) Landslide incident first noted at 08:00 hours on 4 June 1997 by staff at the construction site offices though the precise time of failure is not known.

Figure 10 - Maximum Rolling Rainfall at GEO Raingauge No. N04 for Major Rainstorms



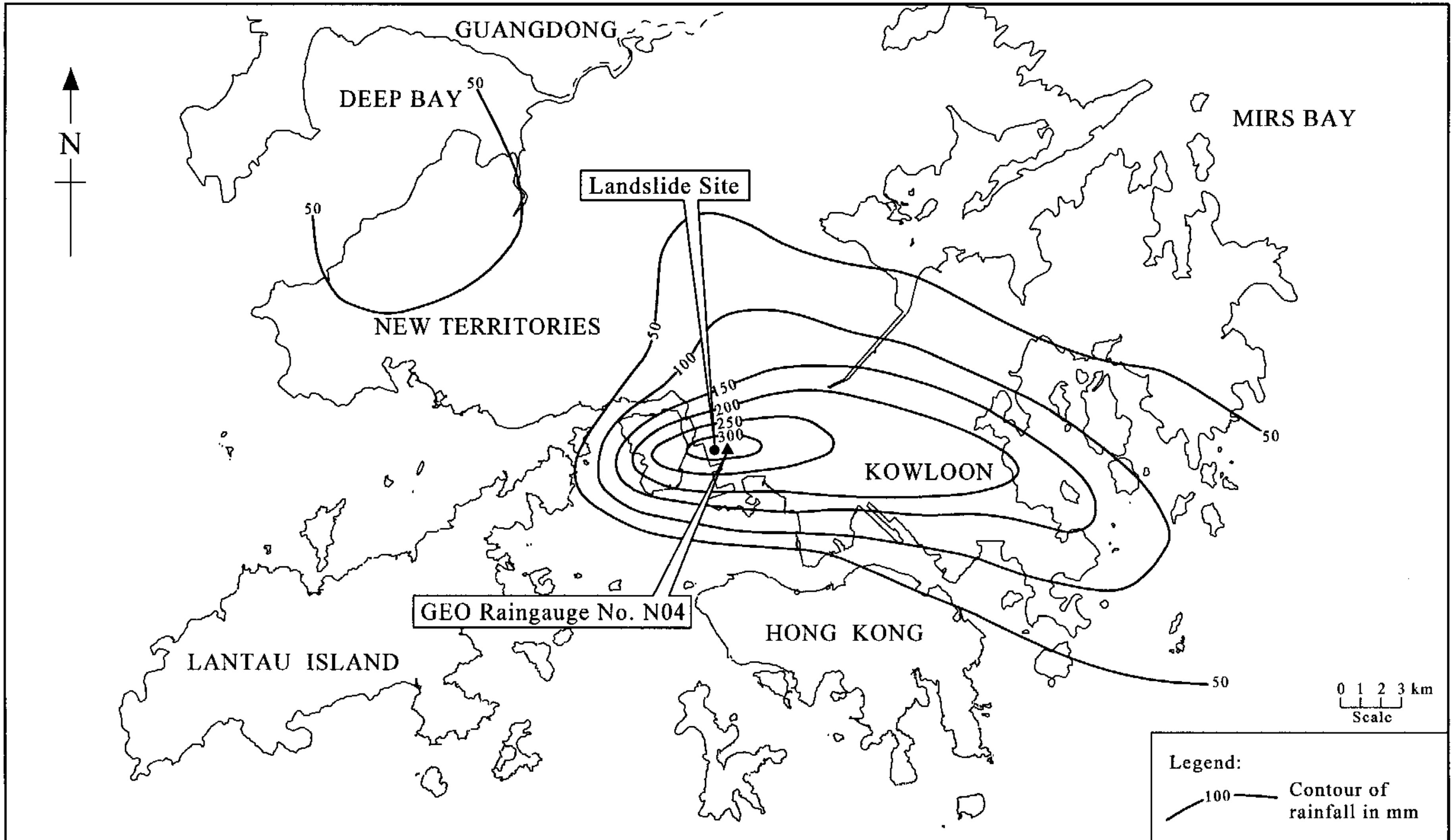
(a) Daily Rainfall Recorded between 4 May and 8 June 1997



(b) Hourly Rainfall Recorded between 2 June and 5 June 1997

Note : Landslide incident first noted at 08:00 hours on 4 June 1997 by staff at the construction site offices though the precise time of failure is not known.

Figure 11 - Rainfall Records at GEO Raingauge No. N04



Note : Isohyets prepared by the Hong Kong Observatory.

Figure 12 - Isohyets of Rainfall between 00:00 Hours and 08:00 Hours on 4 June 1997

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Plate 1 - View to Southeast of Landslide Debris on the Kowloon-bound Carriageway of Kwai Chung Road, Incident No. MW97/5/6 (Photograph Taken on 8 May 1997)

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Plate 3 - View of Debris at Slope Toe from Incident No. MW97/6/21
(Photograph Taken on 18 June 1997)

Plate 4 - General View to South Showing Incident No. MW97/6/21
(Photograph Taken on 18 June 1997)

Plate 5 - Detailed View of Incident No. MW97/6/21 (Photograph Taken on 18 June 1997)