INVESTIGATION OF SOME SELECTED LANDSLIDE INCIDENTS IN 1997 (VOLUME 3)

GEO REPORT No. 89

Halcrow Asia Partnership Ltd.

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

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PREFACE

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

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

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

EXPLANATORY NOTE

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

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

(a) establishment of an improved slope assessment methodology,

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

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

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

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

SECTION 1: DETAILED STUDY OF THE LANDSLIDES AT TAO FUNG SHAN CHRISTIAN CEMETERY ON 2 JULY 1997

Halcrow Asia Partnership Ltd

This report was originally produced in March 1998 as GEO Landslide Study Report No. LSR 2/98

FOREWORD

This report presents the findings of a detailed study of two landslides (GEO Incident Nos. ME97/7/69 and ME97/7/5) which occurred at Tao Fung Shan Christian Cemetery on 2 July 1997. Landslide debris affected residential property below the northern and eastern sides of the cemetery, but no fatalities or injuries were reported.

The key objectives of the detailed study were to document the facts about the landslides, to present relevant background information and to determine the probable cause of the failures. The scope of the study is 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 Landslip Investigation Consultancy (LIC), 1997, for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 68/96. It is one of a series of reports produced during the consultancy by Halcrow Asia Partnership Limited (HAP).

G. Daughton
Project Director/Halcrow Asia Partnership Ltd

CONTENTS

1. INTRODUCTION

On the morning of 2 July 1997, two landslides occurred on separate slopes along the northern (Landslide A) and eastern (Landslide B) slope boundaries of Tao Fung Shan Christian Cemetery (Figure 1 and Plates 1-3). Landslide A involved the failure of a fill slope, while landslide B involved failure of two retaining walls. No injuries resulted from either of the landslides, although a squatter house was partially destroyed by Landslide B.

The key objectives of the detailed study were to document the facts about the landslides, to present relevant background information and to determine the probable cause of the failures. The scope of the study is 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 Landslip Investigation Consultancy (LIC), 1997, for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE68/96. It is one of a series of reports produced during the consultancy by Halcrow Asia Partnership Limited (HAP).

This report presents the findings of the detailed study, carried out between July 1997 and February 1998, which comprised the following key tasks:

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

(b) analyses of rainfall records,

(c) interviews with persons who witnessed or were involved in the incident,

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

(e) diagnosis of the probable cause of the failures.

The GEO produced a preliminary assessment report concerning the landslides (GEO, 1997), and their relevant findings are incorporated into this report.

2. THE SITE

2.1 Site Description

The Tao Fung Shan Christian Cemetery, operated by the Christian Mission to Buddhists (CMB), is located about 1 km west of Kek Yuen Estate, Sha Tin on a slightly domed and elongated hilltop. Figure 2 presents a plan of the two landslides which occurred on the north-facing (Landslide A) and east-facing (Landslide B) partly modified natural slopes.

The elevation of the cemetery hilltop is 117 mPD, while the base of the north- and east-facing slopes in the Pai Tau valley is around 50 mPD. Prior to the landslides, the north-facing slope was inclined at a uniform angle of about 40° and the east-facing side slope was inclined at about 36°. Both slopes had been steepened near the crest by the placement of fill and, in the case of the east-facing slope, also by the construction of retaining walls.

Much of the hilltop is covered by concrete pathways and graves. The graves generally consist of concrete tombs, measuring about 2 m long, 1.5 m wide and 1 m high, founded on cemented brick walls infilled with fill. No purpose-built surface drains were observed in the cemetery. Surface water run-off to the sections of the north- and east-facing slopes that failed would have been derived from gently sloping parts of the cemetery with estimated surface areas of about 500 m^2 and 750 m^2, respectively.

Prior to the landslide, a fill body was present at the northern boundary of the cemetery. The fill had been tipped in an irregular manner, at the crest of the north-facing slope, to form a narrow platform on which a concrete footpath had been constructed (Figure 2). The fill body had a maximum depth of about 2 m and the lower part formed a slope inclined at about 50°. The fill body and the north-facing slope below were densely vegetated, with the exception of the eastern end, where the fill platform was covered in short grass. On the lower part of the slope there was a series of agricultural terraces and several drainage channels extended laterally across the slope. At the toe of the slope, there were several low-rise, privately owned residential buildings and a series of low terraces and retaining walls. An electricity cable and an access path crossed the slope at about 95 mPD.

The eastern end of the cemetery comprised five terraces of graves, each terrace being primarily composed of fill that was retained by a concrete wall. Retaining wall Nos. 1 and 2 (Figure 2), located closest to the boundary of the cemetery, were about 2.5 m to 3.0 m high. The fill terrace behind retaining wall No. 1 was inclined at about 28° and covered by deteriorated chunam, while the fill terrace behind retaining wall No. 2 was partly occupied by graves with the remainder being grassed. The drainage provision for the walls was limited to weepholes of 20 mm diameter spaced at centres of about 2 m. No drainage filter layers were observed behind the parts of the walls remaining after the landslide.

Squatter huts were located mid-way down the eastern slope. One of these was house No. 163, measuring 6 m wide by 27 m long and located on a cut and fill platform, which was partly demolished by Landslide B (Figure 2). The masonry-clad and chunam cut slope at the back of the platform was about 5 m high.

The design and construction of the fill slope and retaining walls were not submitted to Government for checking or approval and in this regard the fill slopes and retaining walls were unauthorised (Appendix A).

Debris from the landslide on the north-facing slope affected residential buildings and an area of land containing sections of several low retaining walls and cut slopes. Debris from the landslide at the eastern end of the cemetery affected squatter huts and part of the natural slope.

The Government and CMB are currently considering the land status (Figure 3) and maintenance responsibility of the site. According to the District Lands Office (DLO),

Sha Tin, "the CMB claimed that they entered the site more than 50 years (ago) with the permission of then New Territories Administration but documents were lost during the Occupation" (DLO, 1998). The DLO has also confirmed that "Although a lot number (Lot 618 in D.D. 185) was allocated to the cemetery, there was no trace of a land grant from government offices". Prior to the landslides, it is estimated that a 15 m long section of the cemetery boundary and the postulated northern extent of the fill body, both located along the crest of the north-facing slope, encroached on to Government land by up to 2 m and 3 m, respectively. On the east-facing slope, retaining wall Nos. 1 and 2 were located entirely within the lot boundary. According to the DLO, in December 1997, the District Lands Commission (DLC) confirmed that "the CMB should be responsible for the maintenance liability of Landslide B." The maintenance responsibilities arising from Landslide A are currently being considered by the Government and the CMB.

2.2 Site History

The historical development of the site has been determined from review of a sequential series of aerial photographs, and available relevant documentation including files held at GEO. Key events in the history of the site are summarised below with reference to Figures 4 and 5.

In 1924, the site of the cemetery was undeveloped, comprising a grass-covered hill with fields present in the valley to the north. By 1949, a fill platform had been formed in the Pai Tau valley to the south of the hill, terraces had been cut into the toe of the northern slope and several buildings had been constructed in the fields. The first development on the eastern slope was observed in aerial photographs taken in 1949 and most of the houses in the vicinity, including house No. 163, were present by 1963. By this time, small agricultural terraces had been formed on the eastern slope above house No. 163 and near the toe of the northern slope.

Interpretation of aerial photographs indicates that two areas of fill were first formed at the crest of the northern slope during 1988. Fill was regularly tipped, during subsequent years, at four further locations along the crest (Figure 4). After the landslide, inspections confirmed that the fill probably formed a continuous platform. Therefore, the full extent of fill is likely to have been greater than identified from interpretation of aerial photographs. In 1996, a concrete path was formed on the platform and along the boundary of the cemetery.

At the eastern end of the cemetery, retaining wall No. 4 and its associated terrace had been constructed by 1973 (Figure 4). A single large grave had also been constructed by this time, with a concrete footpath leading to it across the eastern slope. In 1987, the terrace for retaining wall No. 5 was under construction and in 1989, a leveled fill platform was in place as the foundation for a terrace which would later be formed behind retaining wall No. 3. Most development at the eastern end of the cemetery occurred in 1989. During this year, retaining wall Nos. 1, 3 and 5 were completed and retaining wall No. 2 was under construction. The backfilling of the retaining walls to form terraces continued through 1989 and into 1990, when the pre-landslide layout of the eastern end of the cemetery was attained. The terraces behind retaining wall Nos. 1 and 2 were covered with chunam and grass vegetation, respectively, whilst the three other terraces were covered by concrete paving and graves.

The history of vegetation cover and clearance of the eastern slope is shown in Figure 5.

Prior to 1945, the slope was undeveloped and unvegetated, but by 1963 sparse vegetation was established on the hilltop. Vegetation spread unchecked and encroached further down slope until around 1980. Over the next ten years, the vegetation was progressively cleared at the same time as the five retained terraces were formed.

Since 1989, the GEO, DLO, DO and CMB have carried out various inspections of the slopes and retaining walls at the site (Appendix A; Tables A1 and A2). Drainage and slope instability problems to both the northern and eastern slopes were identified (Figure 4).

GEO's landslide records indicate a failure occurred in the vicinity of the cemetery on 21 May 1989 (Figure 4). The landslide was about 20 m^3 in volume and occurred below squatter house No. 152 on the northern slope.

A large landslide and erosion event is documented as having occurred shortly before 21 June 1993 (Appendix A), although there is no record of this in GEO's landslide database. The landslide was over 30 m high and was located on the east side of the northern slope, below a man-made drainage channel at the north end of retaining wall No. 1 (Figure 4). A retaining wall failure also occurred, at the same time as the landslide, at the toe of the northern slope, adjacent to house No. 182. Observations of aerial photographs indicated that the landslide and erosion scar of the 1993 landslide, at the east side of the northern slope, was enlarged during two further shallow erosion events in 1994 and 1995.

Two shallow erosion events previously occurred on the eastern slope. Prior to 1989, staff of the CMB had noted quite extensive erosion at the eastern boundary of the cemetery, which they assumed was due to the lack of a surface water drainage system (Appendix A). This was not reported to the GEO. Aerial photographs taken in 1992 also show an erosion scar on the eastern slope above squatter house No. 163.

In July 1997, after the landslides, the Buildings Department (BD) issued the cemetery with a closure order. Emergency stabilisation measures, carried out by the CMB, commenced in October 1997 at the eastern slope (Landslide B) and in December 1997 at the upper part of the northern slope (Landslide A). The closure order was lifted in November 1997.

The DLO is currently "considering proposal to grant the cemetery site and the ground affected by the landslides as green-hatched-black area to CMB by private treaty" (DLO, 1998). The site is to be known as Sha Tin Town Lot No. 349.

2.3 Previous Studies

The fill body at the crest of the northern slope and retaining wall Nos. 1 and 2 at the crest of the eastern slope, were not present when the 1977/78 Catalogue of Slopes was prepared.

In mid-1992, the GEO initiated a project entitled "Systematic Inspection of Features in the Territory" (SIFT) to search systematically for slopes not included in the 1977/78 Catalogue of Slopes, by studying aerial photographs. The retaining wall Nos. 1 and 2, involved in Landslide B, were identified by the SIFT project in August 1996 to be over 3 m high and therefore registerable. They were categorised as Class B2 features, having "been formed or

substantially modified after 30.6.1978" and were allocated the Feature Nos. 7SW-B/R50 (retaining wall No. 1) and 7SW-B/R51 (retaining wall No. 2). The fill body involved in Landslide A was not of sufficient height to be registered by SIFT. Prior to the landslides, neither the fill body nor the slope at the northern boundary of the cemetery had been inspected by either the GEO or any other Government Department.

In 1994, the GEO commenced a project entitled "Systematic Identification and Registration of Slopes in the Territory" (SIRST) to systematically update the 1977/78 Catalogue of Slopes. The GEO's consultants for the SIRST project inspected retaining walls A and B in February 1997 and found them to be less than 3 m high and therefore non-registerable. At the time of the landslides, the retaining walls were awaiting de-registration.

In December 1996, the CMB commissioned a consultant to review the stability of retaining wall Nos. 1 and 2. They observed and concluded that the walls were below acceptable standards and they advised that the walls were unstable as vertical cracking was evident in the structures (personal communication with the consultant involved). Photographs taken by the consultants on 30 December 1996 confirm this to be the case.

2.4 Subsurface Conditions

The Hong Kong Geological map sheet 7 (GCO, 1986a) indicates that the site is underlain by coarse-grained granite. Minor intrusions into the granite include fine-grained granite about 200 m to the west of the site and feldsparphyric rhyolite near the toe of the slope below the cemetery (Addison, 1986). Debris flow deposits of Pleistocene and Holocene age have been mapped at the toe of the slopes (GCO, 1987).

Three ground investigations have previously been conducted within 300 m of the site (Figure 6). These investigations, which in terms of terrain and elevations were located in similar settings to the site of the cemetery, indicate the presence of a thin layer of residual soil overlaying completely decomposed granite, which increases in density with depth (Table 1). Moderately to slightly decomposed granite (i.e., rockhead) was typically encountered at depths greater than 30 m below ground level, at an elevation of about 100 mPD. The drillholes did not encounter groundwater at this elevation. Observations at the landslide sites generally concur with this geology and hydrogeology. In particular, the observations of a natural spring line at about 80 mPD to 65 mPD on the northern slope below the cemetery (see Section 3.2.1 and Figures 7 and 8), confirm the existence of a deep groundwater table.

The materials exposed in the main scarp of Landslide A comprised fill material over a thin layer of natural topsoil and charcoal which was underlain by residual soil. The layer of fill was typically about 1 m to 2 m thick, and comprised loose to very loose, moist, yellowish brown, gravelly, silty, clayey, medium to coarse sand with fragments of concrete, bricks and plastic. The topsoil was a non-continuous layer up to 0.2 m thick, of soft, moist, dark brown, slightly clayey, sandy silt. Charcoal often formed a thin layer at the base of the fill. The residual soil was loose to medium dense, orange brown, slightly gravelly, slightly clayey, silty coarse sand. The landslide debris ranged from wet, soft to very soft, clayey silt and sand to moist, firm, slightly clayey, silty coarse sand and gravel with mixed vegetation.

3. THE LANDSLIDES

3.1 Time of the Failures

The times at which the two landslides occurred were established from accounts given to GEO and HAP by four eye-witnesses who lived in residential buildings below the northern and eastern slopes. Landslide A was reported to have occurred at 06:30 hours on 2 July 1997 in a single event that led to landslide debris reaching to within 2 m of house No. 182.

Two times were given for Landslide B, being 06:30 hours or 09:00 hours on 2 July 1997. The most reliable account was given by a resident living below the landslide on the eastern slope, who recalled the time of failure at about 06:30 hours. Shortly after the landslides, officials of the Tao Fung Shan Christian Cemetery conducted their own investigation into the time of failure. They concluded that both of the failures occurred almost at the same time, at 06:30 hours on 2 July 1997.

3.2 Description of the Landslides

3.2.1 Landslide A

A plan of the failure is given in Figure 7 and a representative cross-section through the landslide is given in Figure 8. Photographs of the landslide are shown in Plates 4 and 5.

The landslide involved failure of an unregistered fill slope on the northern perimeter of the cemetery, the debris from which travelled down the natural terrain and over a low retaining wall at the toe of the slope. The landslide caused damage to several abandoned and derelict buildings at the toe of the slope. The masonry wall that had previously failed in 1993, adjacent to abandoned house No. 183, collapsed in the central portion and a surface electricity line was cut.

The main scarp of the landslide measured 52 m wide and comprised two back scarps separated by an area of densely vegetated loose fill, which had not collapsed during the landslide. The larger back scarp to the east was about 32 m wide, 15 m long, 3 m high and inclined at about 50° to 60° (Plate 4). The smaller back scarp to the west was about 10 m wide, 10 m long, 2 m high and inclined at about 50°.

The volume of debris derived from the main scarp was estimated to be about 600 m^3 and an estimated volume of about 300 m^3 of soil and debris was entrained as the landslide travelled down the natural hillside. Although an area of 3 500 m^2 was affected by the landslide, only a thin layer of material was removed from the natural slope. Extensive rills formed by subsequent surface water erosion were observed, cutting through the residual soil to expose the underlying granitic rock.

The landslide debris trail on the natural hillside diverged into two separate trails from about 80 mPD, on either side of a small densely vegetated spur. The debris below the smaller scarp was deposited in a densely vegetated part of the natural hillside at a repose angle of about 15°. Most of the debris from the larger scarp was deposited at the toe of the slope on relatively

level ground. The debris spread to within 5 m of house No. 182, coming to rest at a repose angle of about 10°. Residents also reported silty, outwash deposits entering the house. Only a small amount of debris and occasional slabs of concrete remained on the slope after the landslide. The overall travel angle of the landslide was about 30°, which corresponds to the lower end of the 30° to 40° range for typical rain-induced landslides in Hong Kong described by Wong & Ho (1996).

Natural erosion pipe holes up to 100 mm in width were observed at depths of 2 m below ground level in the fill, and in the main scarp, appeared to be most numerous where the fill was adjacent to the brickwork of the graves. Further down the natural slope, seepage was observed issuing from the base of the landslide scar at about 65 mPD to 80 mPD. During an inspection on 27 August 1997, stream water was flowing from a natural springline at an elevation of 65 mPD in the centre of the debris trail below the larger back scarp.

3.2.2 Landslide B

Details of the failure are presented in Figure 9 and a representative cross-section through the landslide is given in Figure 10.

The landslide primarily involved the failure of two retaining walls at the eastern end of the cemetery. The central sections of the walls failed, both measuring about 25 m in length. Cracking and limited amounts of rotation of adjacent unfailed sections of the walls also occurred. Most of the landslide debris originated from behind the retaining walls and travelled downslope, stripping about 150 m^3 of additional material from the natural hillside and coming to rest on the cut and fill platform below the cemetery. The total volume of the debris was estimated to be about 400 m^3. The landslide demolished part of house No. 163.

The main scarp extended about 2 m upslope from the original position of retaining wall No. 2 and was about 28 m wide, 2 m high and inclined at about 80°. The exposed material comprised wet, firm to soft, slightly gravelly, slightly clayey sandy silt (fill) up to 2 m thick overlying moist to firm, slightly gravelly, slightly clayey sandy silt (residual soil). Part of the main scarp coincided with smooth sub-vertical surfaces in the fill and residual soil, that clearly existed before the landslide (Plates 6). It is likely that these surfaces represent old chunam covered faces of the fill slope prior to the construction of retaining wall Nos. 1 and 2. Extensive gully erosion of the landslide scarp, up to 1 m deep, cut through the residual soil to expose completely to highly decomposed granite.

The landslide exposed a section through the retaining wall No. 1 and the fill terrace behind (Plate 7). The drainage provision did not conform to generally accepted standards (GEO, 1993). There was no drainage material and the weepholes were only 20 mm in diameter.

Although some debris, up to 1 m thick, was evident at the southern side of the landslide scarp, the bulk of the debris came to rest on the platform where house No. 163 was located. It comprised wet, soft to very soft, remoulded fill and residual soil, and included steel railings, the remains of two graves and several intact lengths of the retaining walls, one of which was about 16 m long (Plate 8). The travel angle of the landslide was about 35° which, according to Wong & Ho (1996), is typical for rain-induced landslides. The GEO observed further debris,

consisting of channelised secondary washout deposits of fine material, reaching to a point about 30 m downslope from the platform.

During an inspection of the landslide on 2 July 1997, the GEO observed substantial flow of surface water over the terraces behind the main scarp of the landslide. Drainage of this surface water would have been limited to a single discharge point at the northern end of retaining wall No. 1. However, since the centre of the wall and its associated terrace were up to 1 m lower than the eastern and northern ends of the wall, surface water would have concentrated (i.e., ponded) in the middle of the terrace behind the retaining wall. Severe cracking of the chunam on the terrace behind retaining wall No. 1, along with the uncovered nature of the terrace behind retaining wall No. 2, and the general cracking of paved areas within the cemetery, would have allowed water to infiltrate the retained fill.

4. RAINFALL

The nearest GEO automatic raingauge No. N02 is located at Shun Wo House on Wo Che Estate, approximately 950 m to the southeast of the landslide. The daily rainfall recorded in June and July 1997, together with the hourly rainfall from 29 June to 2 July 1997, are shown in Figure 11.

A total of 970 mm of rain was recorded by raingauge No. N02 in the 31 days before the landslide. Rain was heavy in the morning of 2 July 1997 to the time of the failure at 06:30 hours. The 12-hour and 24-hour rainfalls before the landslide were 209 mm and 237 mm, respectively. The peak 1-hour rainfall of 124 mm was recorded in the hour prior to the landslides on 2 July 1997. Isohyets of rainfall prior to the landslide are shown in Figure 12.

The estimated return periods for the maximum rolling rainfall for various durations based on historical rainfall data at the Hong Kong Observatory (Lam & Leung, 1994) are given in Table 2. For durations between 7 days and 12 hours, the return periods were about 2 to 3 years. For durations of 4 hours to 1 hour, the return periods were more exceptional, with the return period for the one hour rainfall total being around 32 years.

The maximum rolling rainfalls for the rainstorm on 2 July 1997 have been compared with the previous most severe rainstorms since February 1980 (Figure 13). The maximum rolling rainfall for durations of between 20 minutes and 5 hours exceeds that from previous rainstorms at the raingauge.

5. PROBABLE CAUSES OF FAILURE

The close correlation between the peak rainfall intensities and the time of failure indicates that both of the landslides were probably triggered by intense rainfall. A number of contributory factors combined to cause the landslides.

The following factors that may have contributed to Landslide A have been considered :

(a) surcharge loading of the upper part of the hillside by the fill

body,

(b) the susceptibility of the fill to infiltration by water due to the absence a surface seal,

(c) the lack of a formal drainage scheme to collect and discharge surface water run-off from the fill platforms and terraces in the cemetery in a controlled manner, and

(d) the steep natural terrain below the cemetery.

The presence of the fill body, particularly when in a saturated condition, would have increased the shear stresses within the upper part of the hillside, thereby reducing its stability.

The fill body was formed by tipping excavated soil materials along the cemetery boundary. The provision of a surface protection covering was largely absent, allowing water to readily infiltrate the loose fill material. Erosion pipe holes in the fill exposed in the main scarp of the landslide, formed preferential seepage flowpaths and would also have contributed to the saturation of the fill body.

Surface water drainage provision in the area of the cemetery above the fill body was absent. The replacement of the natural terrain by paved areas will have altered the surface water drainage paths, increasing run-off and concentrated flows. Water falling onto the paving and masonry slabs covering the site would have accumulated and eventually flowed over the edges of the cemetery. The stability of the fill body, being located in the path of the flowing water, would have been significantly reduced. The poorly maintained paving may also have allowed infiltration into the fill to be concentrated in areas of settlement and cracking.

The north-facing slope below the cemetery was inclined at a relatively steep angle of about 40°, with a thin layer of residual soil overlying rock. Therefore, the slope may be susceptible to landsliding in response to rainstorms and other destabilising influences. There are no records of past landslides on the hillside apart from the landslide and erosion event in 1993, which was probably caused by water discharging from a surface drain at the north end retaining wall No. 1 onto the hillside. There is also no evidence to suggest that water from the surface drain affected the ground involved in the recent landslide.

Given the factors considered above, it is probable that the development of the cemetery, in particular the placement of a fill body on the hillside, would have significantly contributed to Landslide A. However, the possibility that the natural hillside could have failed without the influence of the development of the cemetery, cannot be ruled out for such severe rainfall conditions.

The following factors that may have contributed to Landslide B have been considered :

(a) sub-standard construction of retaining walls and fill terraces,

(b) inadequate maintenance of retaining walls and fill terraces, and

(c) inadequate control of surface water run-off from the terraces in the cemetery.

The two retaining walls at the eastern end of the cemetery were not designed and constructed to current standards. Empirical design methods were used which resulted in structures that were inadequately founded and drained.

The ingress of water into the fill behind the retaining walls almost certainly occurred due to a lack of maintenance that resulted in cracking of paved, masonry and chunam covered areas.

Proper control of surface water drainage was lacking on the eastern side at the cemetery. Consequently, water would have pooled and eventually flowed over the terraces in the cemetery, with much of it collecting behind the inadequately drained retaining wall No. 1.

Theoretical stability analyses were carried out for the slope using the cross-section profile and assumed shear strength parameters shown in Figure 14 to replicate the interpreted failure mechanism. The results are presented in Figure 15. The analyses indicate that water pressure would have been critical for triggering the landslide given a typical range of soil strength parameters. The absence of effective drainage within the walls would have permitted a water table to develop within the fill, leading to a reduction in stability and ultimately to failure.

6. CONCLUSIONS

Landslide A involved a translational slide of both natural residual soil and overlying fill, but the location and extent of the initial failure is not clear. During its travel downslope, the landslide debris effectively stripped the thin residual soil and shallow rooted vegetation from the natural terrain over a large area. Surcharge by the body of fill at the crest of the slope and the large quantity of surface water run-off from the cemetery were probably both significant factors contributing to the failure. However, the possibility that the steep hillside might itself have failed as a consequence of such a severe rainstorm cannot be discounted.

Landslide B was almost certainly initiated by failure of retaining wall Nos. 1 and 2. Excessive surface water run-off, which has also been observed by the CMB in the past, would have led to concentration of surface water behind the retaining walls and, owing to the lack of maintenance of chunam coverings, a high rate of infiltration is likely to have occurred. Surcharge loading due to the retaining walls and the saturated fill behind them, along with the inevitable reduction in shear strength, most likely led to a rapid, fast-moving failure involving both walls.

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LIST OF TABLES

Table 1 - Typical Stratigraphy from Previous Ground Investigations

			Thickness of Stratigraphy (m)					
Drillhole No.	Drillhole Location (Easting/ Northing)	Drilhole Ground Level (mPD)	Residual Soil	CDG (loose)	CDG (loose to medium dense)	CDG (dense to very dense)	CDG/ HDG	Depth of Rockhead (m, below ground level)
DH1	836787.8E 827169.4N	127.5	3.5	0.0	13.0	6.3	7.2	30.0
DH2	836803.4E 827158.5N	127.6	0.0	2.0	18.5	11.0	16.4	47.9
DH3	836795.4E 827148.6N	127.3	1.5	0.0	20.1	11.1	0.0	32.7
DH4	836781.6E 827159.0N	127.4	1.5	1.8	12.4	0.0	>15.8	>31.5
F2	836561.6E 827314.7N	131.0	5.5	0.0	0.0	20.8	0.0	26.3
F7	836633.4E 827340.7N	130.0	7.5	0.0	7.5	3.5	1.3	19.8
BH2	836524.9E 827359.9N	132.3	6.0	18.0	6.5	0.0	0.0	30.5
BH11	836619.3E 827288.9N	127.1	6.0	26.1	0.0	0.0	0.0	>32.1
BH12	836623.6E 827276.6N	120.6	4.0	19.8	2.0	0.0	2.3	>28.1
BH14	836531.2E 827252.4N	125.6	8.0	6.0	10.2	0.0	0.0	24.2
BH15	836583.4E 827261.8N	127.8	10.0	17.1	0.5	0.0	0.0	27.6
BH16	836720.7E 827230.2N	127.7	3.0	25.6	5.6	0.0	0.0	34.2

Note : (1) Data extracted from Geotechnical Assessment Report (1988) produced by Maunsell Geotechnical Services Ltd. (GIU Report No. 11972) and Geotechnical Assessment Report (1989) produced by Ho Tin & Associates Architects Engineers Limited (GIU Report No. 11977).

(2) Rockhead refers to moderately to slightly decomposed granite.

Table 2 – Maximum Rolling Rainfall at GEO Raingauge No. N02 for Selected Durations Preceding the Landslide on 2 July 1997 and Their Corresponding Estimated Return Periods

Duration	Maximum Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years)
5 minutes	12.5	06:15 on 2 July 1997	2
15 minutes	34.5	06:15 on 2 July 1997	6
1 hour	124	06:25 on 2 July 1997	32
2 hours	172.5	06:30 on 2 July 1997	25
4 hours	203.5	06:30 on 2 July 1997	13
12 hours	209	06:30 on 2 July 1997	3
24 hours	237	06:30 on 2 July 1997	2
2 days	286	06:30 on 2 July 1997	3
4 days	292	06:30 on 2 July 1997	2
7 days	339	06:30 on 2 July 1997	2
31 days	970	06:30 on 2 July 1997	11

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 all durations.

(3) The rainfall totals quoted are for durations ending at 06:30 hours on 2 July 1997.

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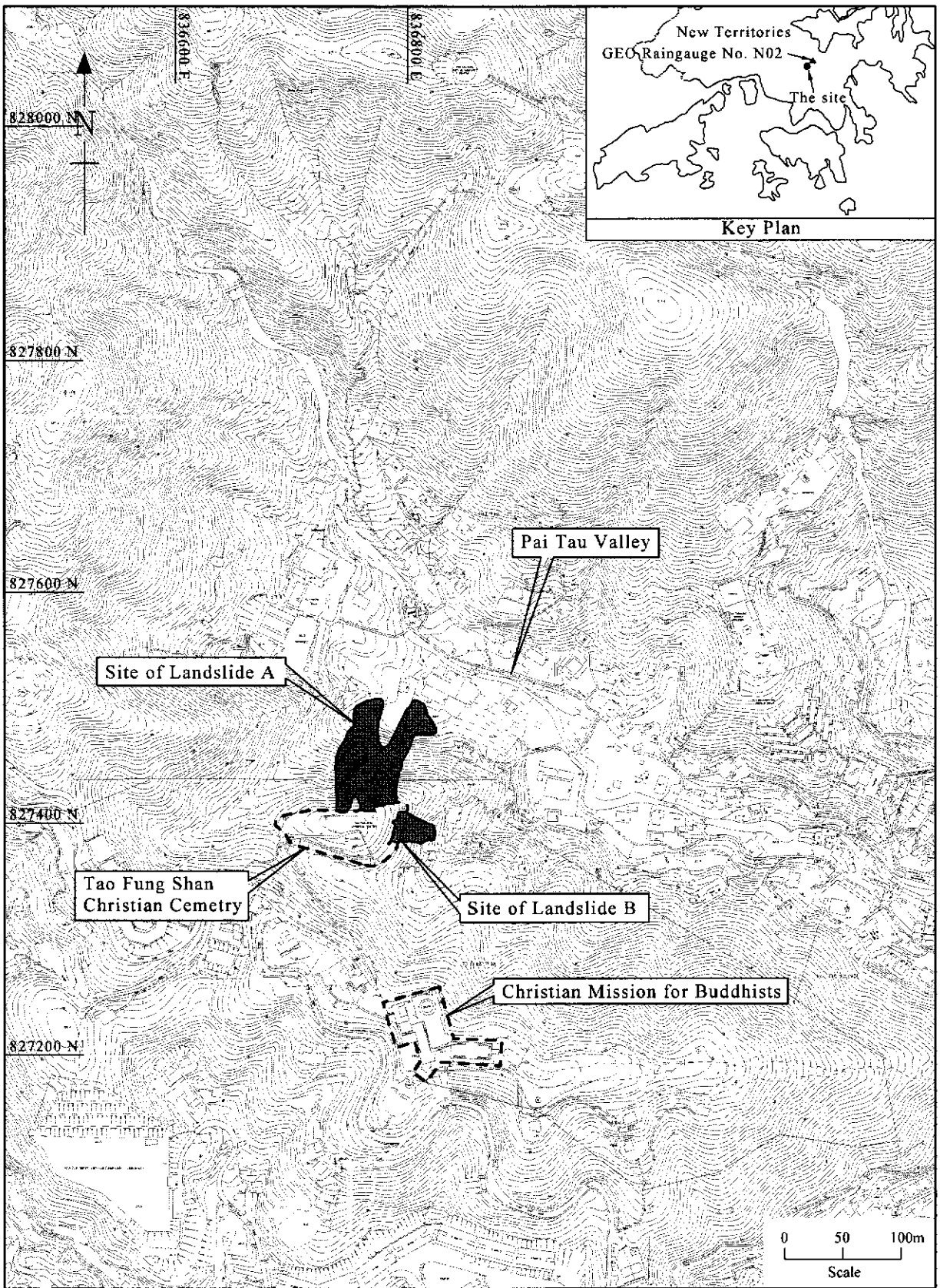


Note : Base map is extracted from Survey Sheet Nos. 7-SW-15A and 7-SW-15B dated October 1992 (scale 1:1000).

Figure 1 - Site Location Map

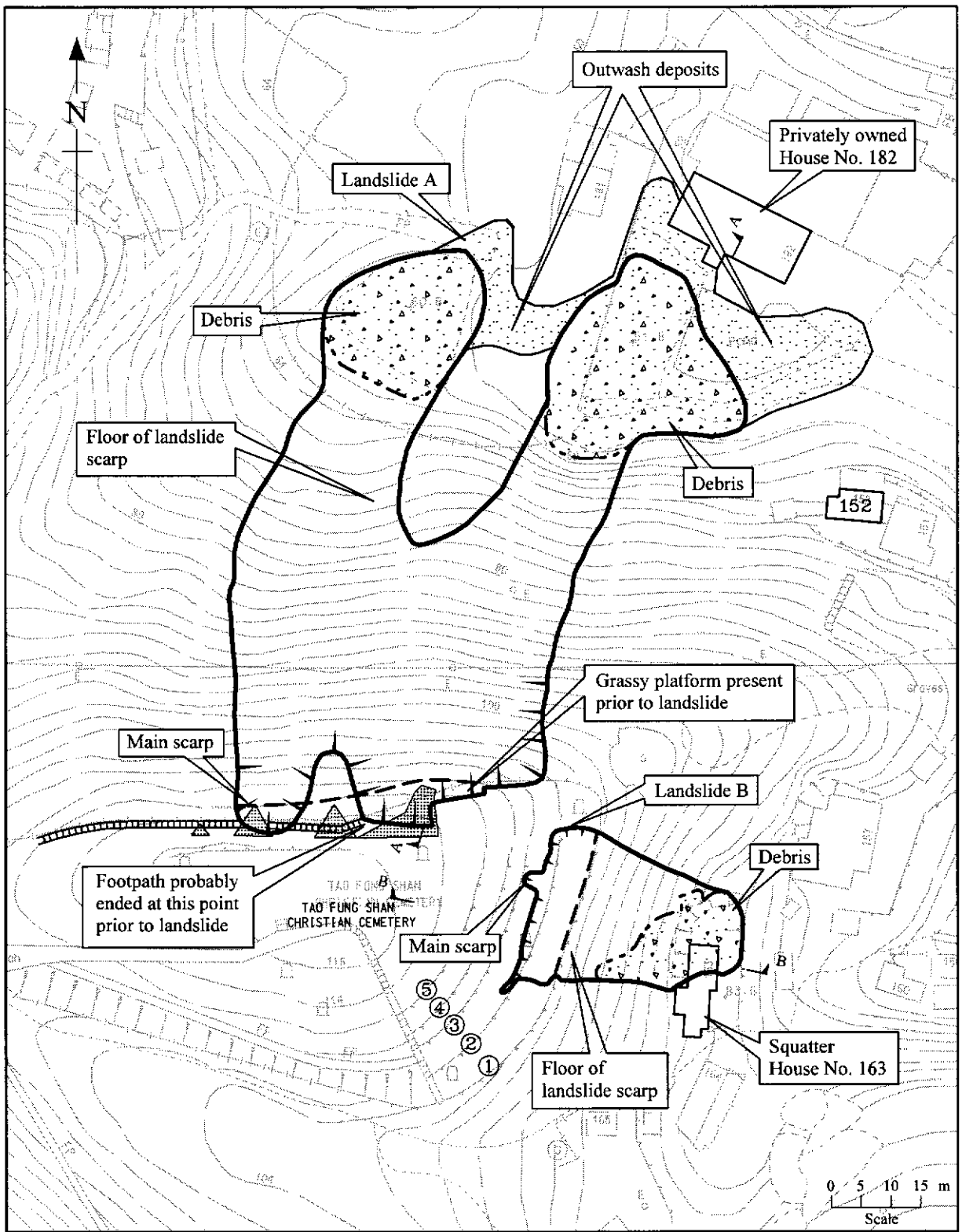


Figure 2 - Plan of the Landslides

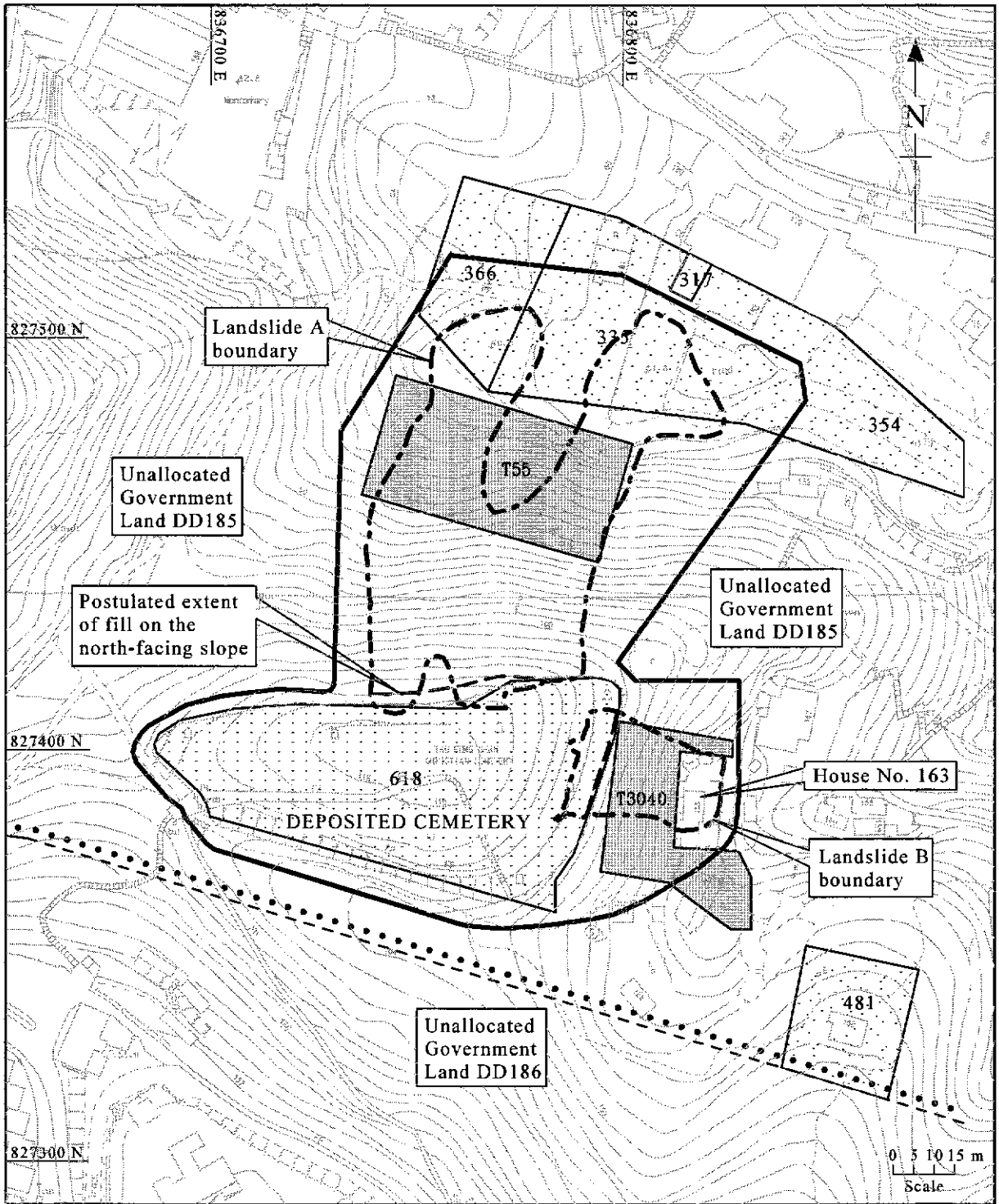
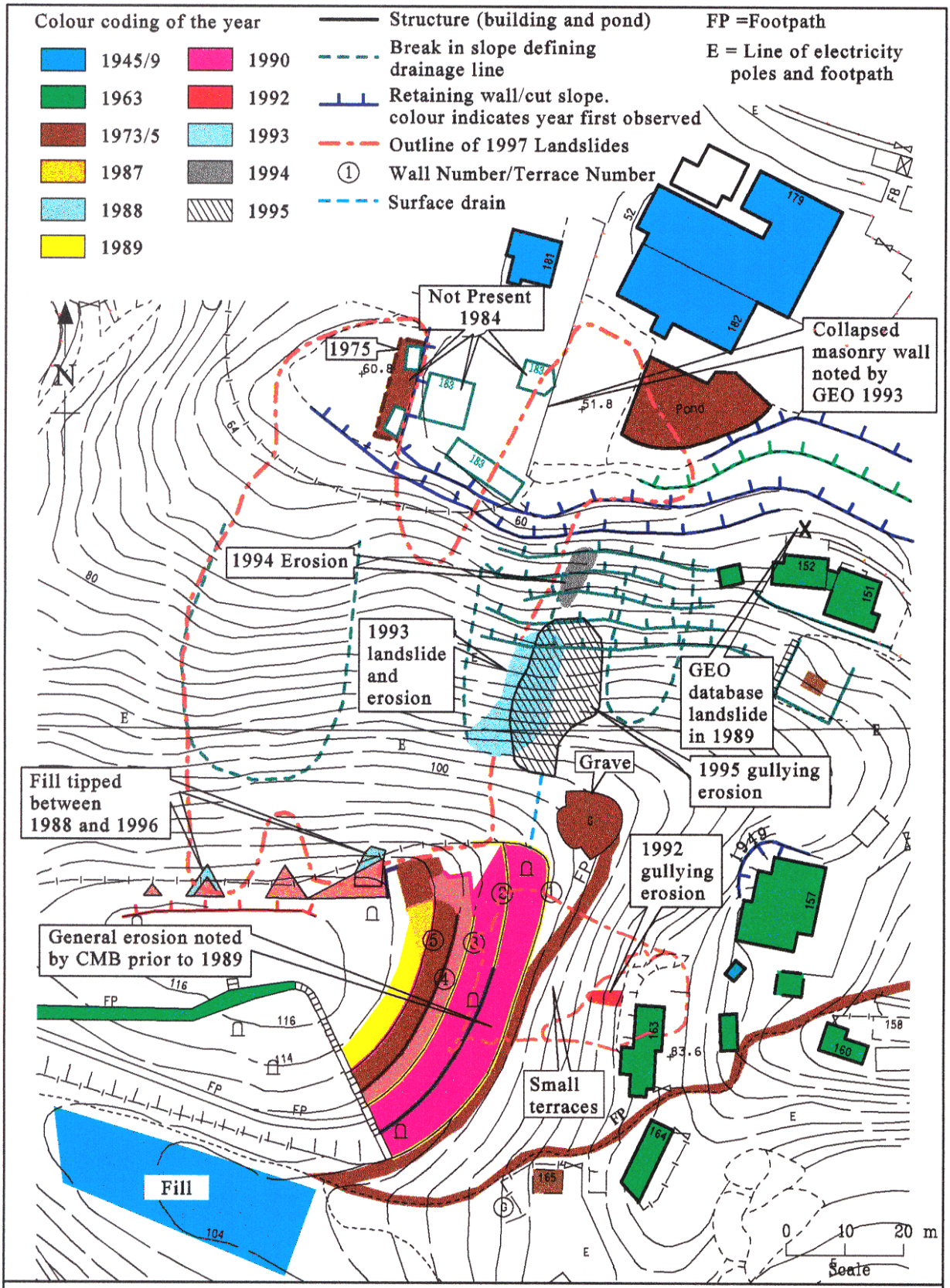


Figure 3 - Land Status



Note : Modified Provisional API study of Tao Fung Shan Cemetery based on the draft report produced by Planning Division of GEO (1997).

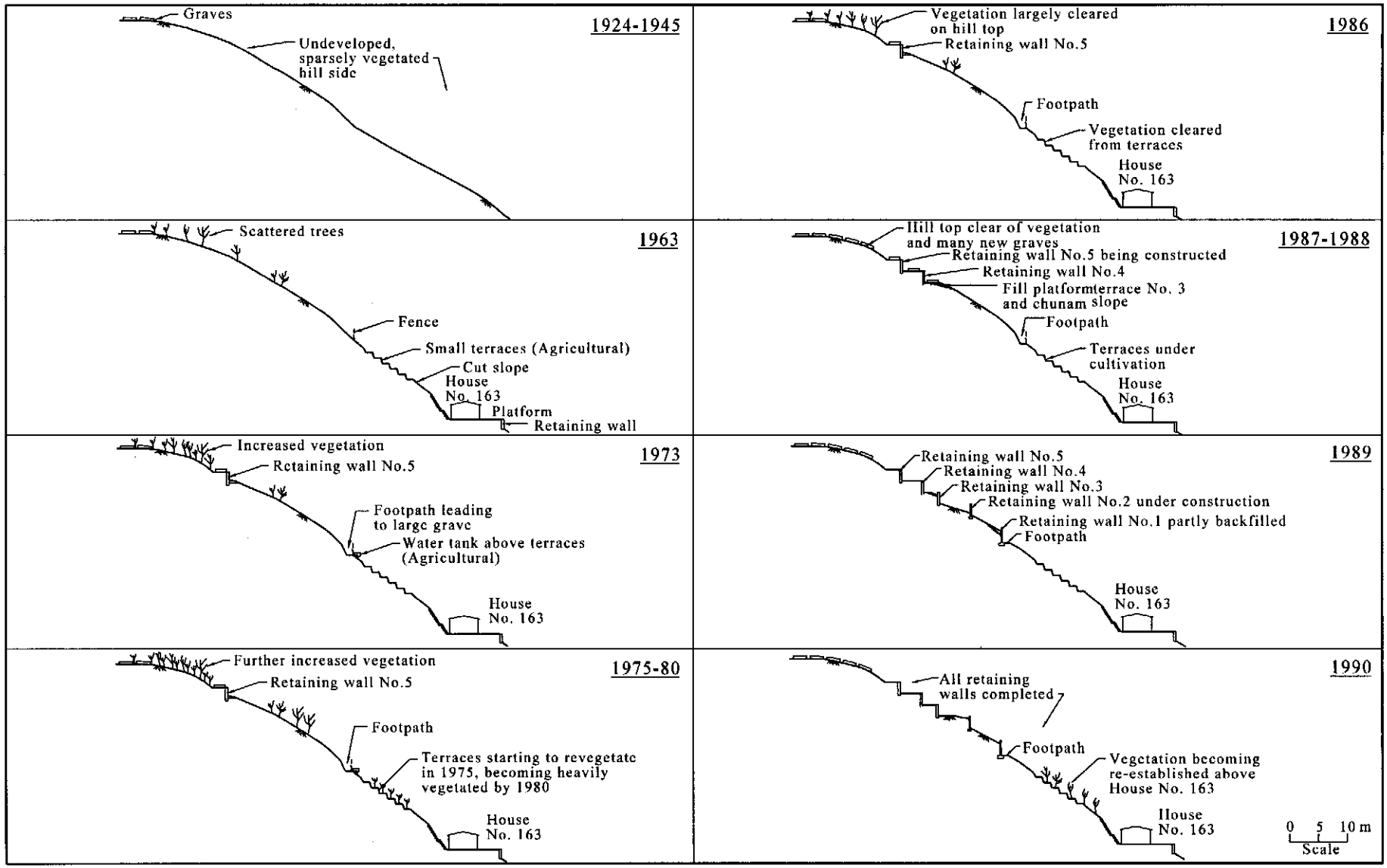
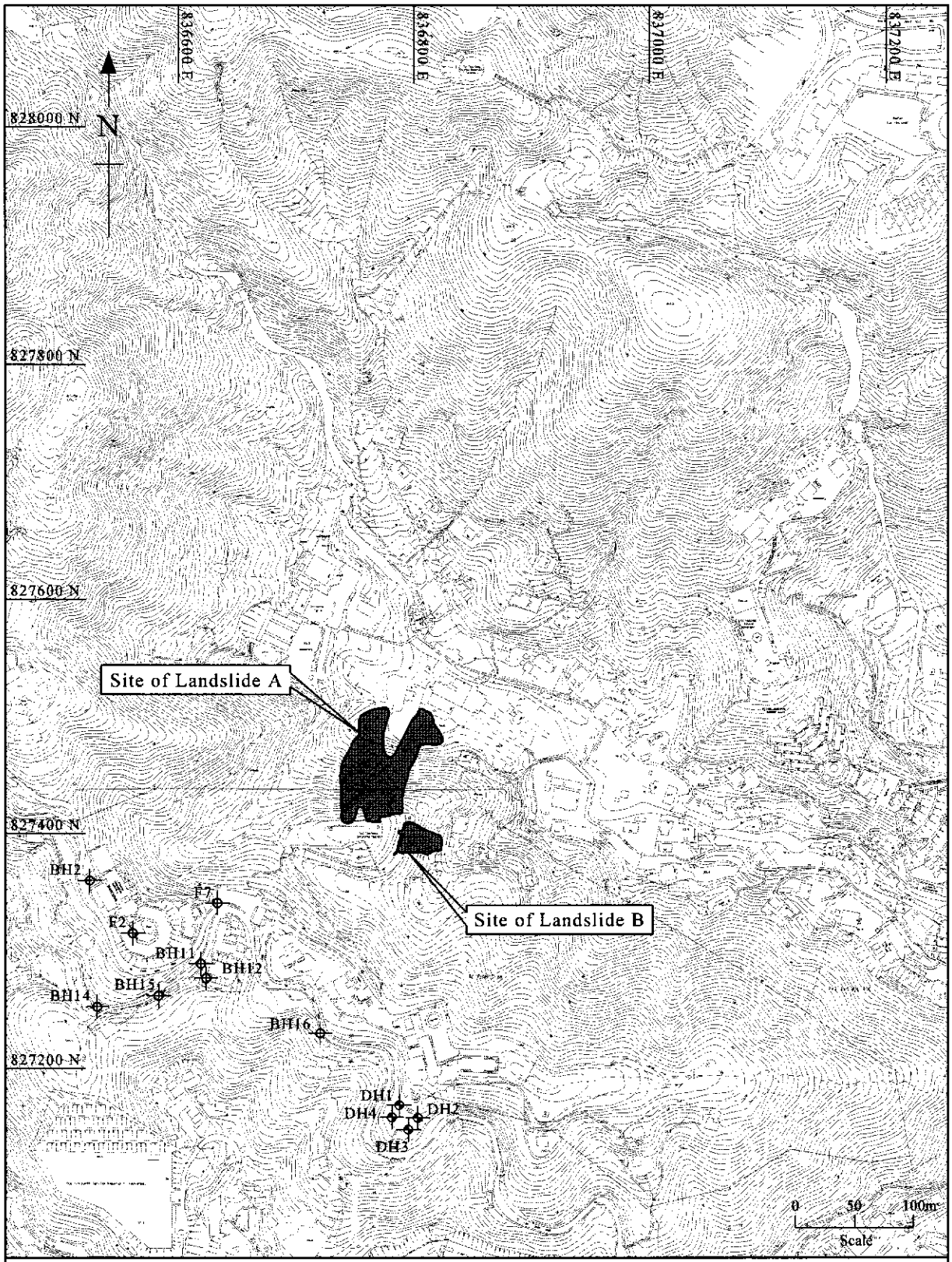


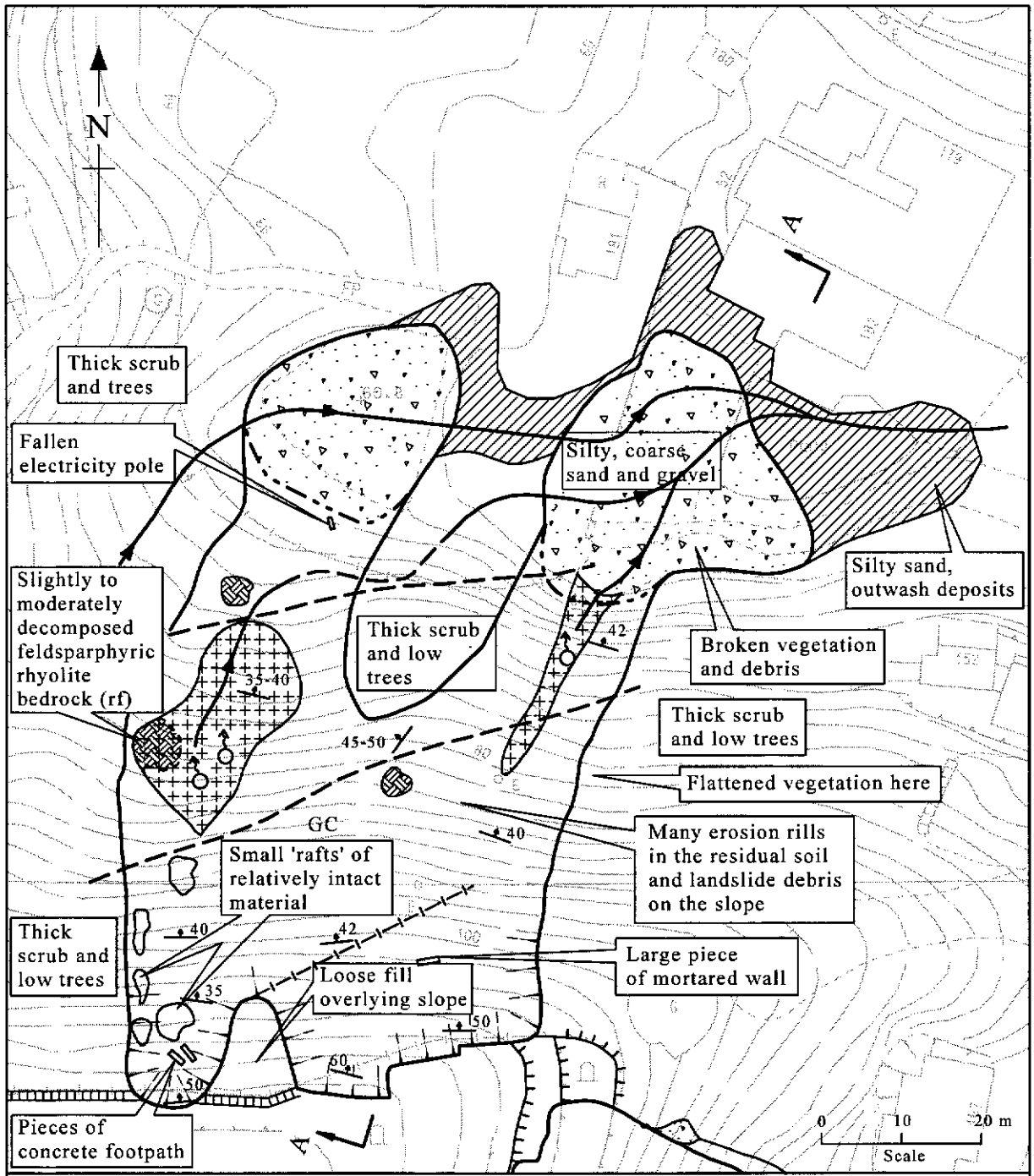
Figure 5 - Schematic Representation of Slope Development at Site of Landslide B



Legend : Borehole (GIU Report No. 11972) Borehole (GIU Report No. 11977)

Note : Base map is extracted from Survey Sheet Nos. 7-SW-15A and 7-SW-15B dated October 1992 (Scale 1:1000).

Figure 6 - Location Plan of Previous Ground Investigation Works



Legend :

- Feldsparphyric rhyolite
- gc Coarse grained granite
- Outwash deposits
- Debris
- Geological boundary
- Displaced wire fence
- Retaining wall
- 40 Slope angle
- Footpath
- Main scarp
- Boulder
- Seepage(observed on 7 July 1997)
- Surface water flow

Notes : (1) Modified from "Sketch Map of July 2 1997 landslide at Tao Fung Shan Cemetery" produced by Planinng Division of GEO.
(2) See Figure 8 for Section A-A.

Figure 7 - Site Plan and Details of Landslide A

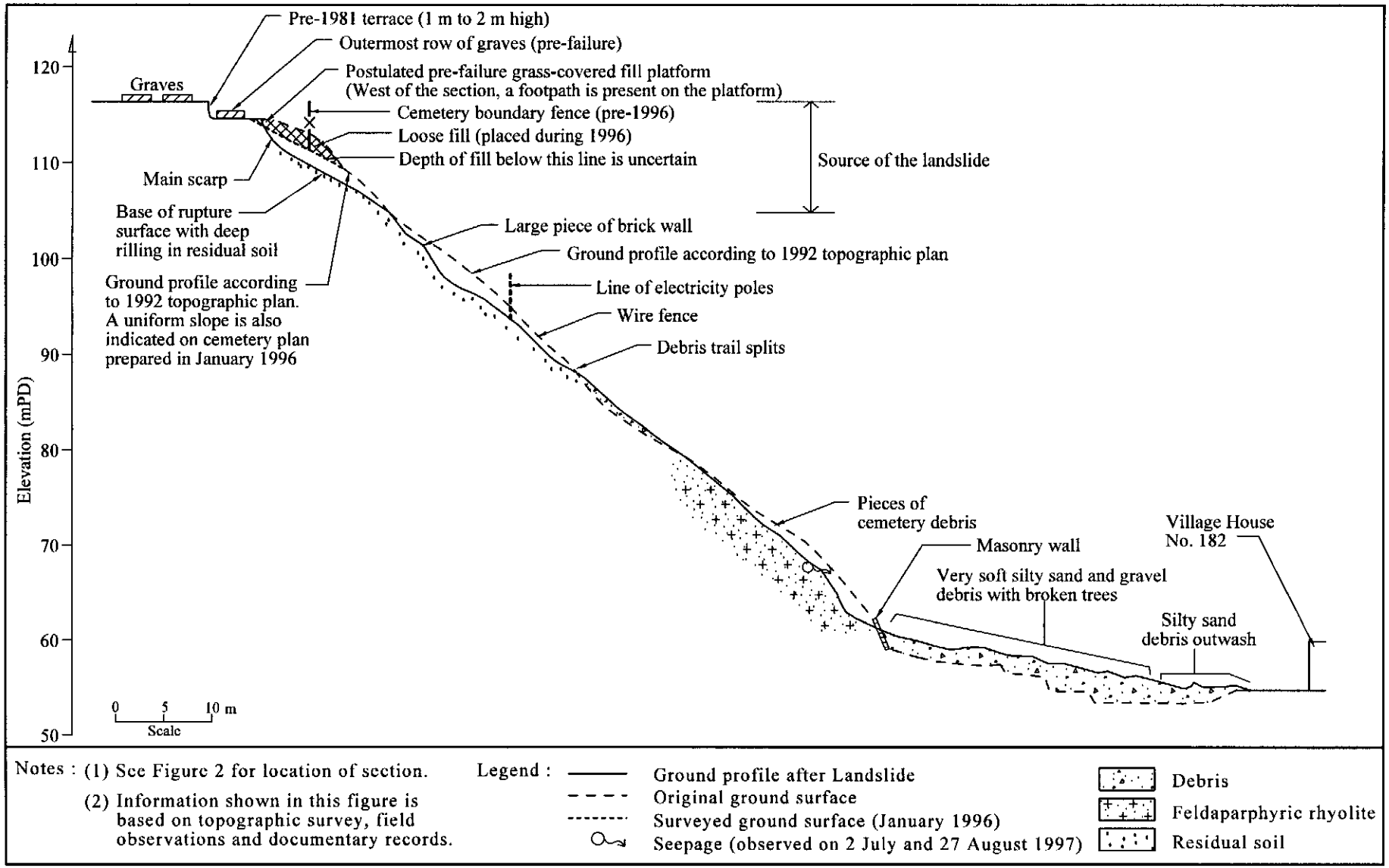


Figure 8 - Cross-section A-A of Landslide A

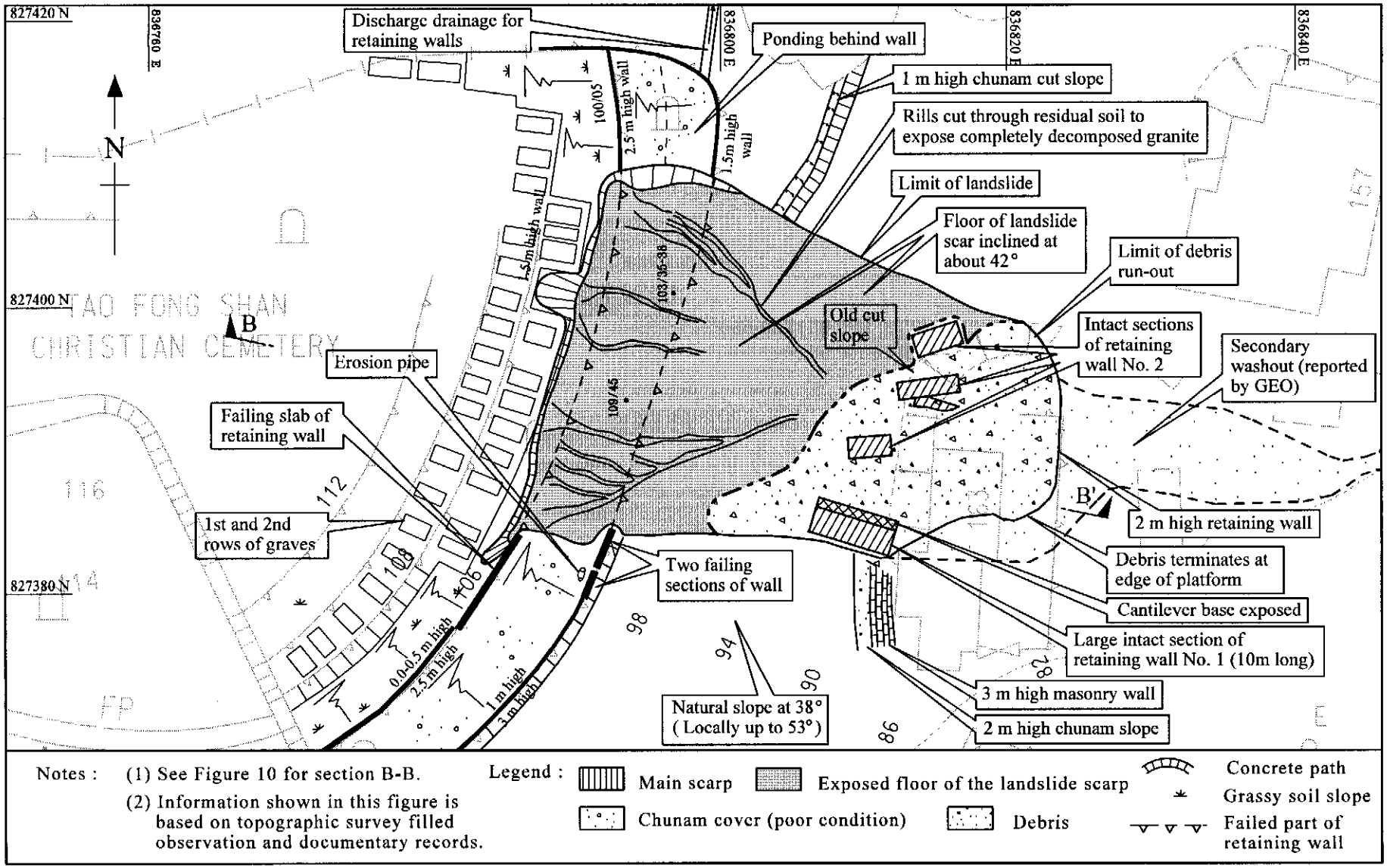


Figure 9 - Site Plan and Details of Landslide B

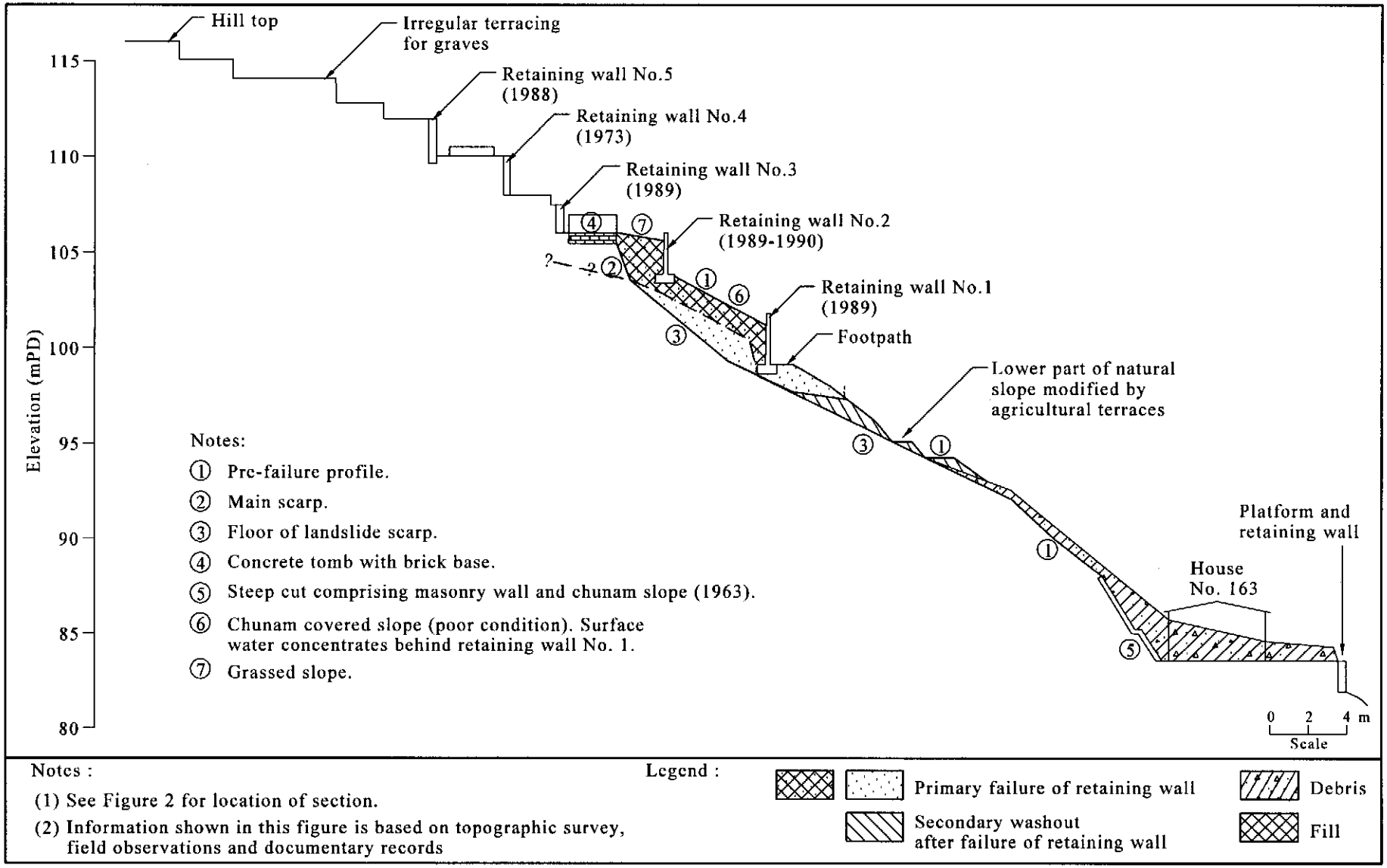
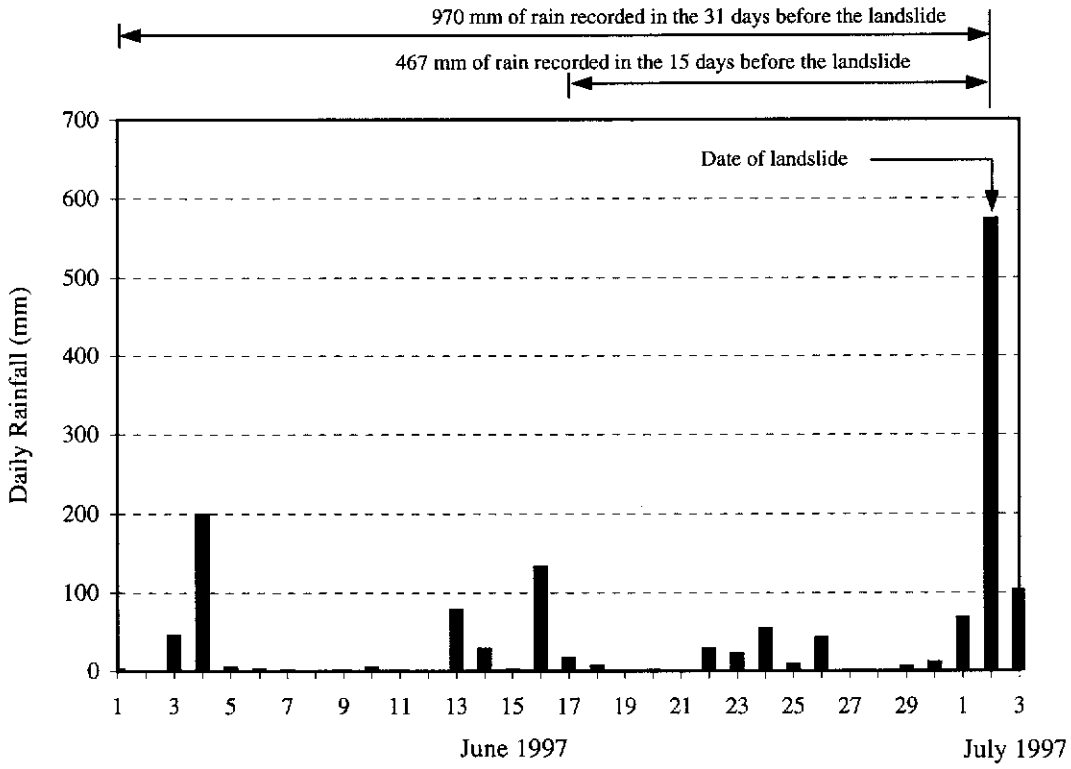
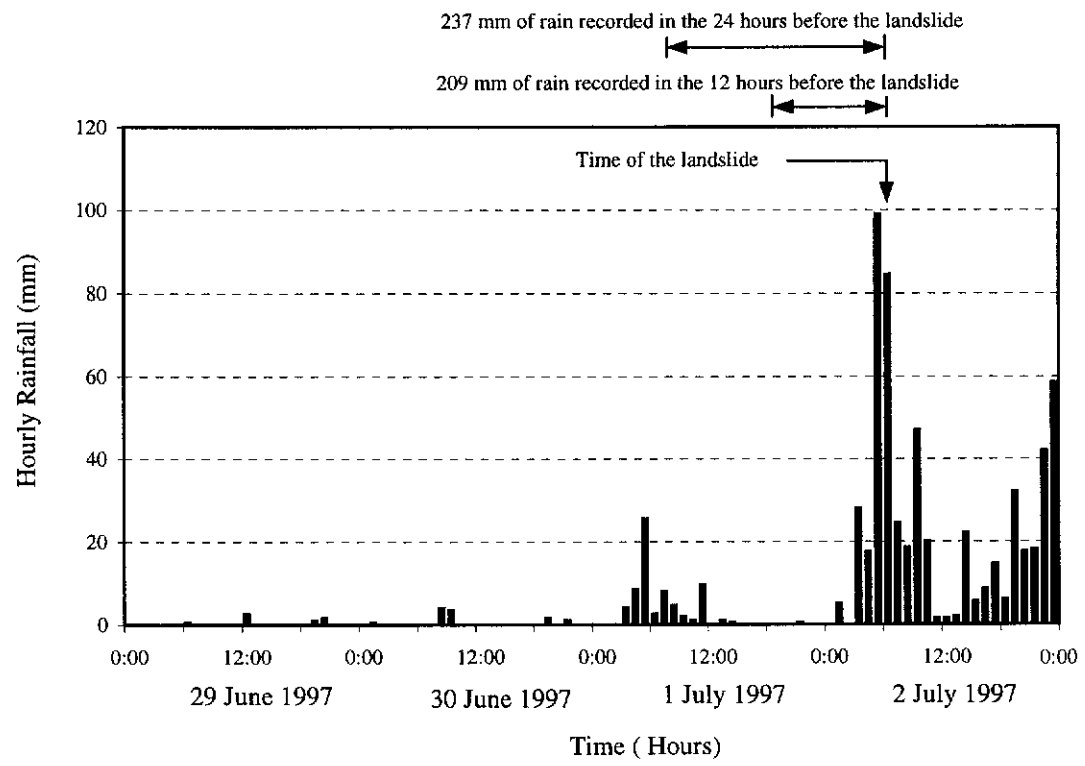


Figure 10 - Cross-section B-B of Landslide B



(a) Daily Rainfall Recorded between 1 June and 3 July 1997



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

Figure 11 - Rainfall Records of GEO Raingauge No. N02

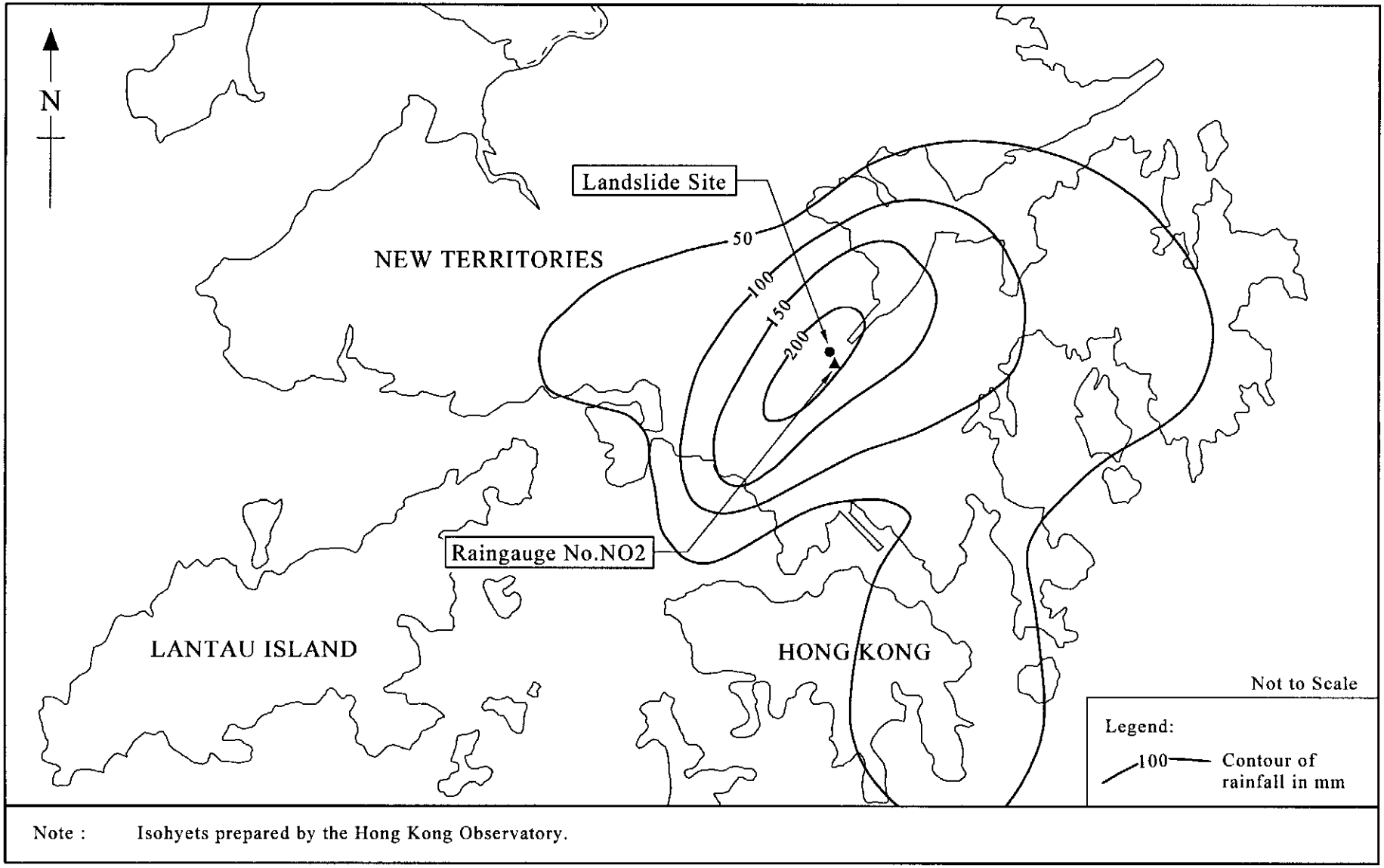


Figure 12 - Isohyets of Rainfall from 03:05 Hours to 06:30 Hours on 2 July 1997

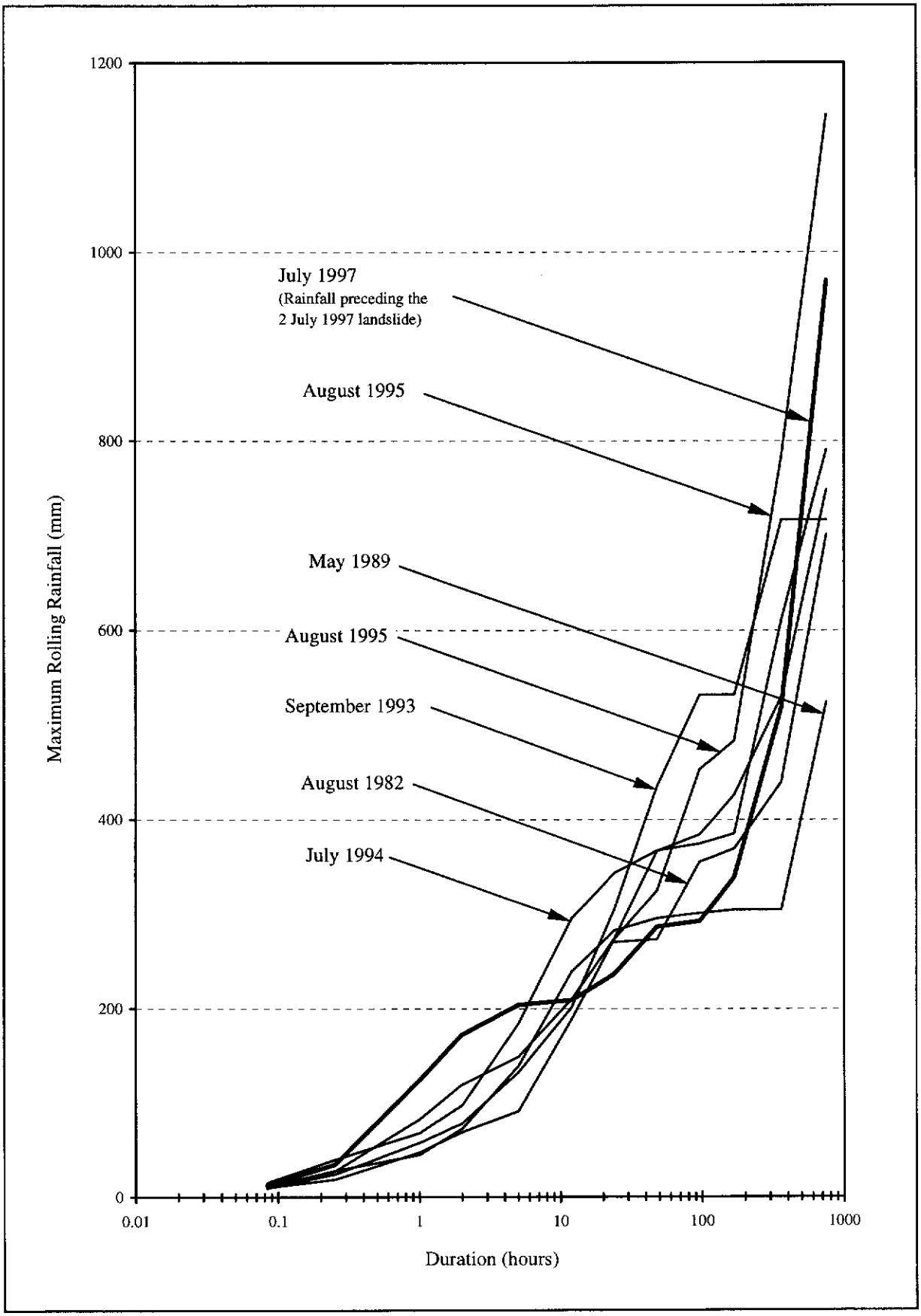


Figure 13 - Maximum Rolling Rainfall at GEO Raingauge No. N02 for Major Rainstorms

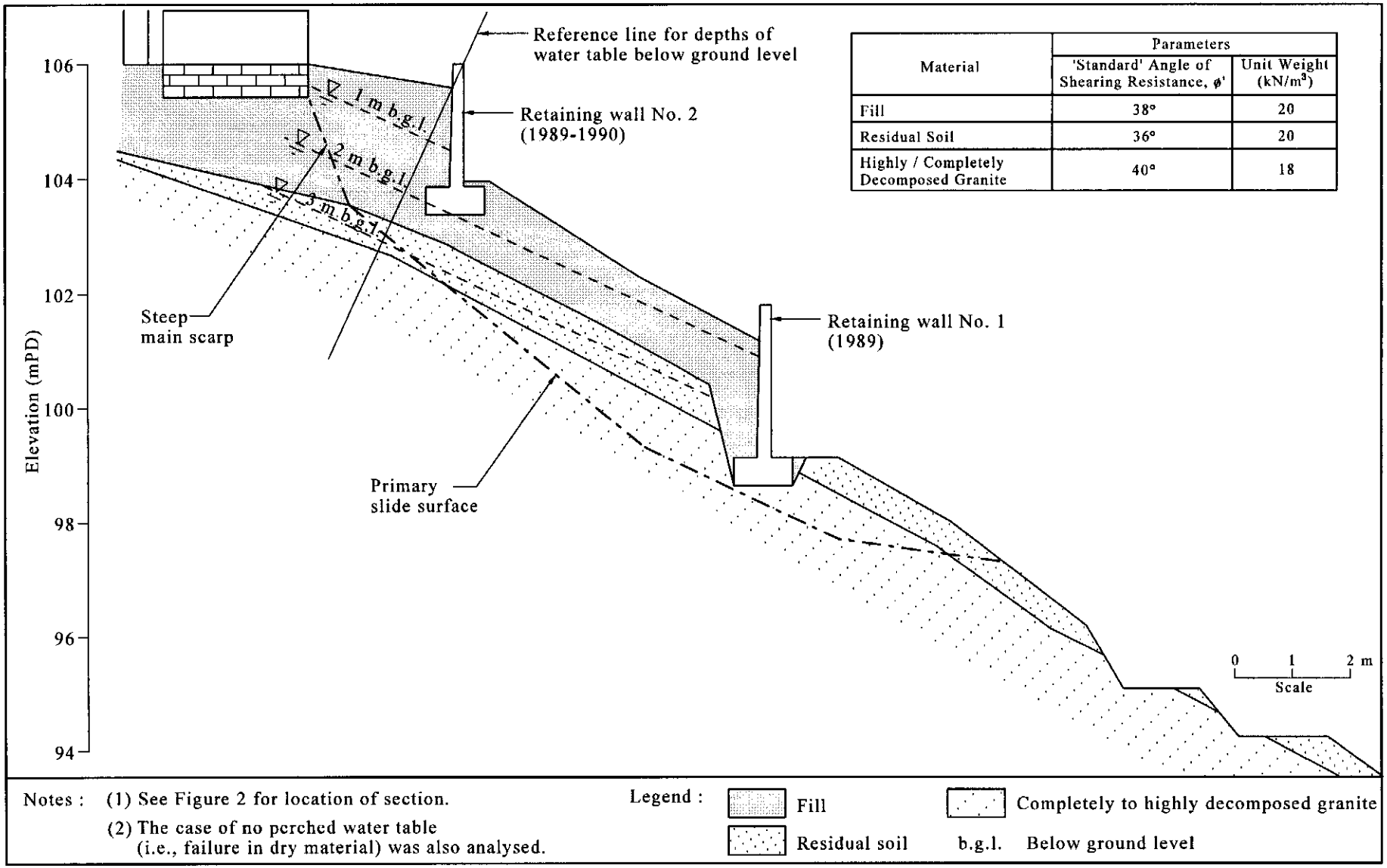
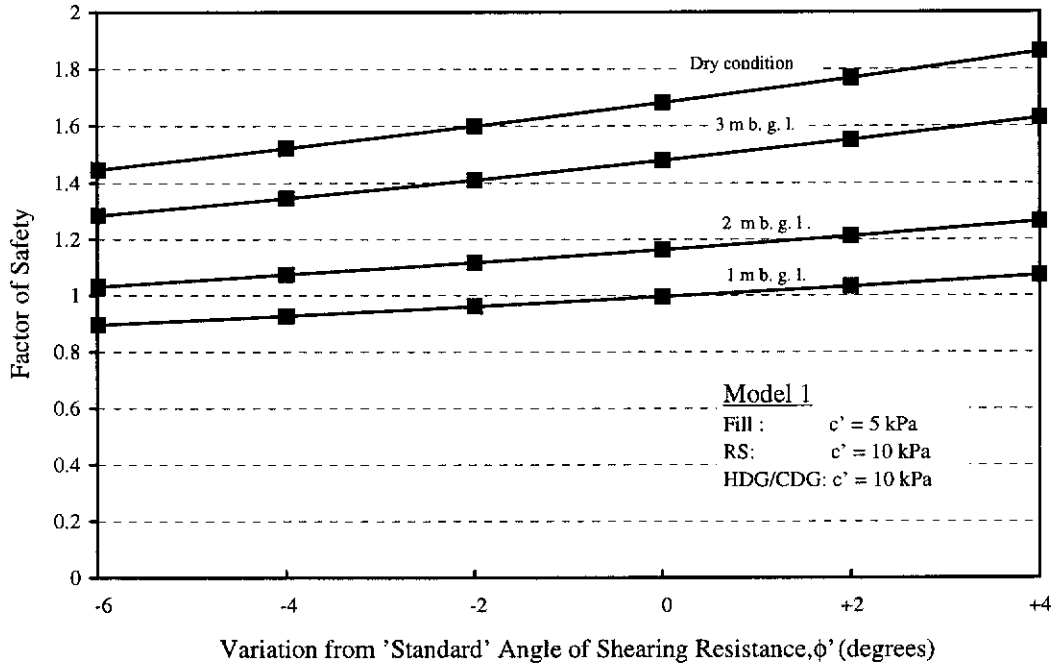
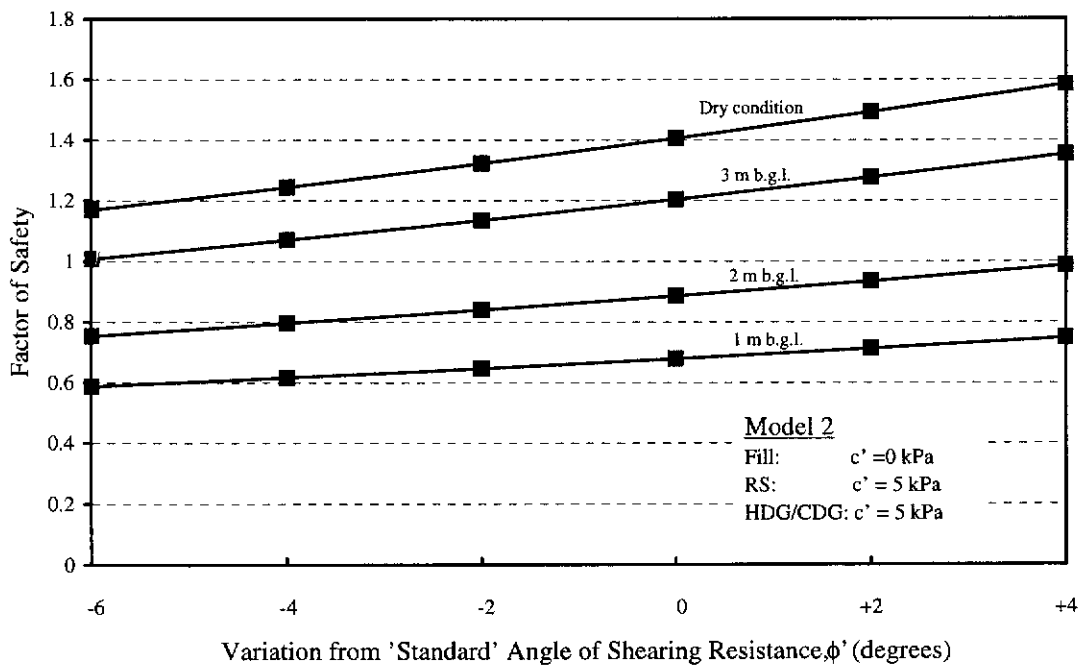


Figure 14 - Representative Cross-section of Landslide B used for Theoretical Stability Analyses



(a) Results with High Cohesion



(b) Results with Low Cohesion

Note: b.g.l. means below ground level at reference line (see Figure 14).

Figure 15 - Results of Theoretical Stability Analyses

LIST OF PLATES

Plate 1 - Aerial View of the Site, Showing Landslides A and B

Plate 2 - Aerial View of Landslide A on the Northern Slope
(Photograph Taken on 2 July 1997)

Plate 3 - General View of Landslide B on the Eastern Slope
(Photograph Taken by GEO on 15 July 1997)

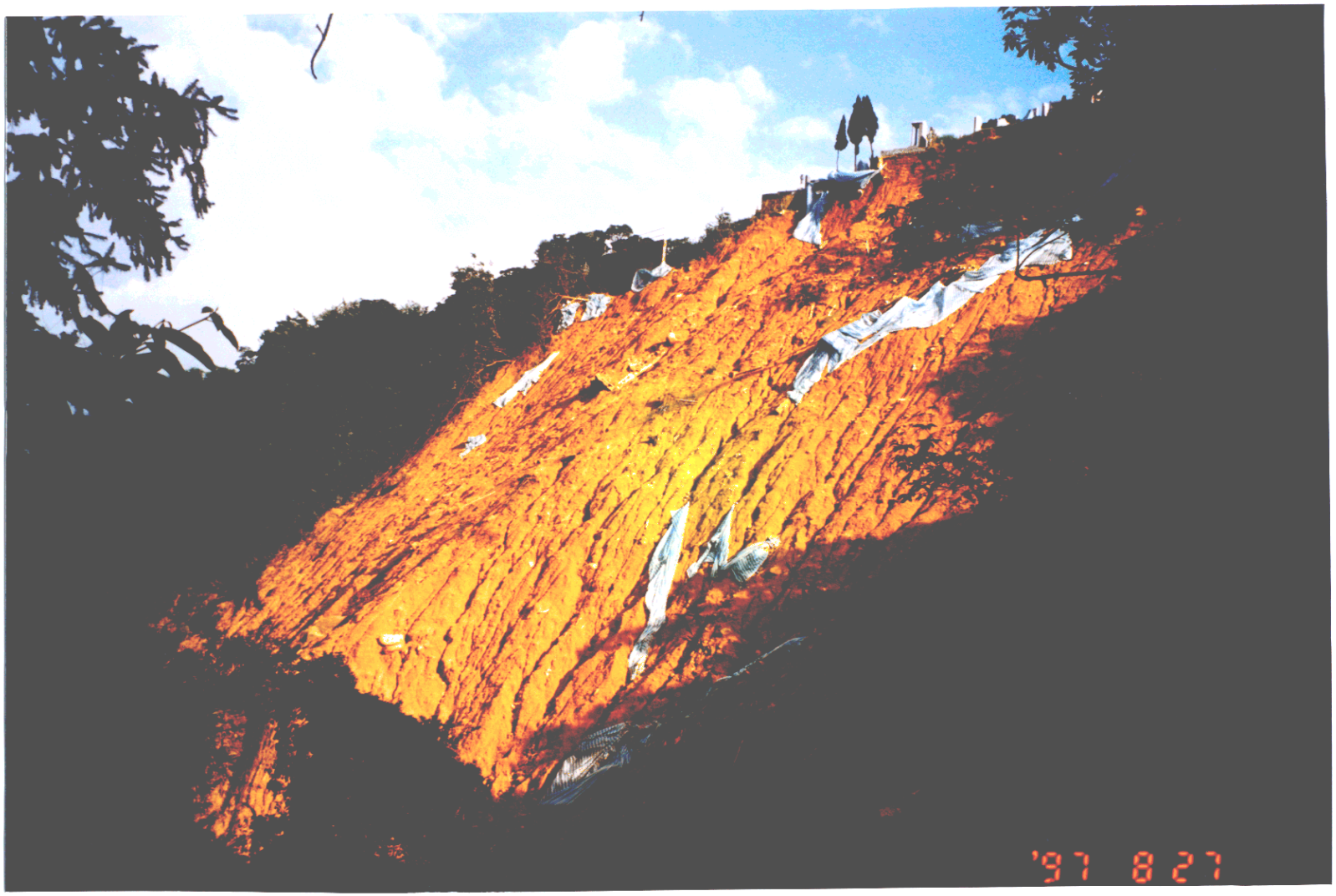


Plate 4 - View of Landslide A (Photograph Taken on 27 August 1997)

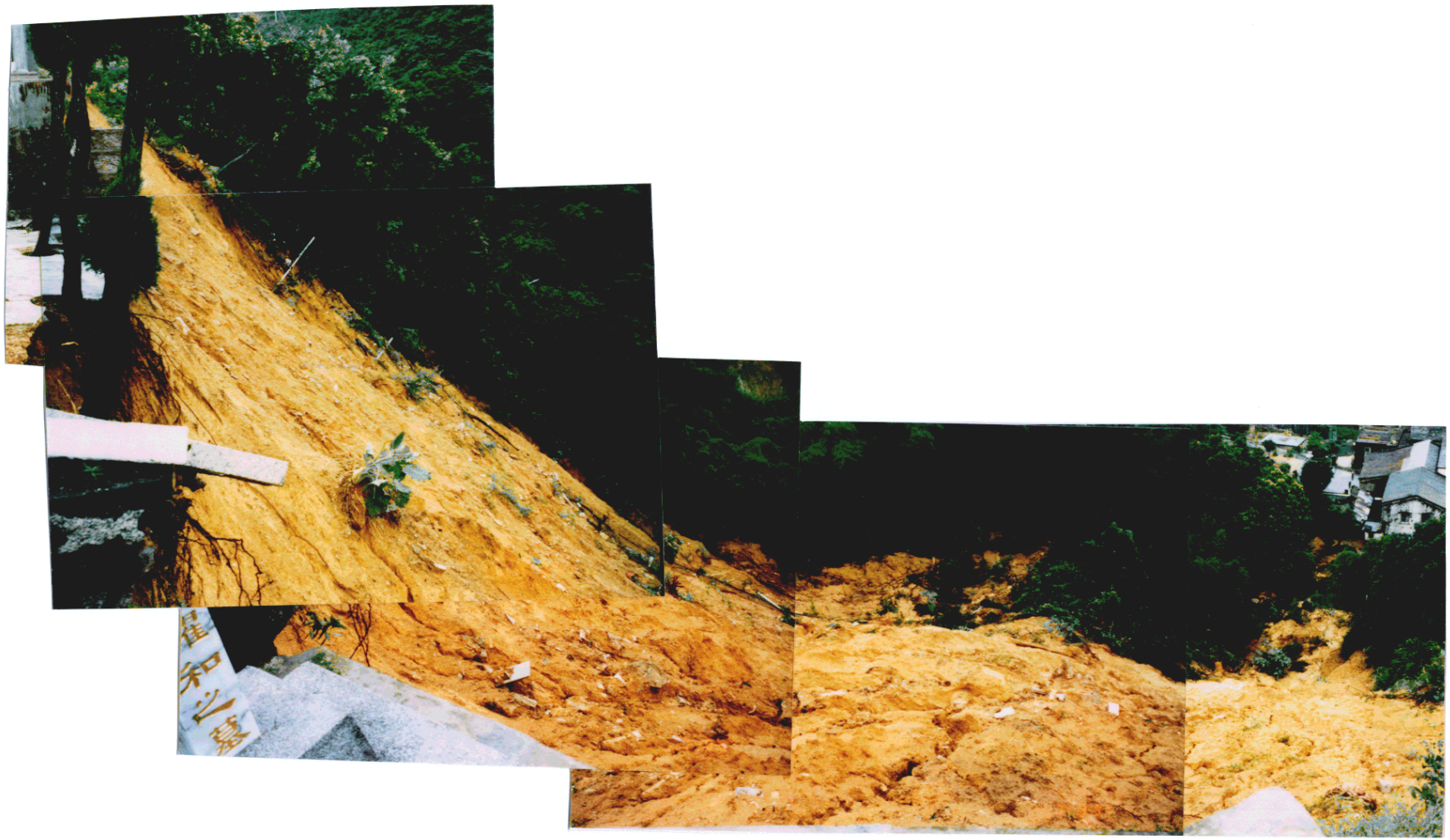


Plate 5 -The Main Scarp of Landslide A (Photograph Taken on 3 July 1997)
(Note Photograph Taken from the Crest of the Northern Slope, Showing the Debris Trails and Steep Upper Part of the Main Scarp)

Plate 6 - The Main Scarp of Landslide B (Photograph Taken on 26 August 1997)
(Note the Smooth Surface of the Pre-existing Slope)

Plate 7 - Retaining Wall No. 2 of Landslide B (Photograph Taken on 8 August 1997)

Plate 8 - The Debris from Landslide B and the Partly Demolished House No. 163 (Photograph Taken on 8 August 1997)

APPENDIX A

BACKGROUND INFORMATION

Table A1 –Background Information for the Northern Slope (Landslide A)

Date of Correspondence	Content
21-5-1989	Landslide (20 m^3) below house no. 152 (GEO database of previous landslides).
08-12-1992	In response to a complaint about blocked drainage channels in the toe area of the northern slope, a joint inspection by GEO, DLO and DO was held on 7 December 1992. Poor drainage conditions were found and the GEO warned that severe overflow of the blocked drainage channels was expected during the ensuing rainy season. GEO recommended that DO carry out improvement works to ensure the long-term stability of the area concerned (Memo Ref. GCMd 2/E1/7SW-B, dated 8/12/92).
08-11-1993	Arrangements for the clearance of squatter hut No. 152 (see Figure 2) was being arranged in December 1992 to be carried out by HM/SC/ST of the Housing Department (Memo Ref. GCMd 2/E1/7SW-B, dated 8/12/92).
08-11-1993	The GEO responded to a complaint by a resident of house No. 182 regarding drainage problems on the northern slope. GEO inspected the site on 21 June 1993 and found a landslide at about mid-height on the natural slope and a collapsed masonry wall on the level area below the toe of the slope. The failures were attributed to blocked drains traversing the slope in the lower half of the natural slope (Letter from SGE/ENT & Squatters - Memo Ref. GCMd 4/13/RA11, dated 8/11/93).
20-11-1993	The DO also visited the site, on 23 June 1993, and inspected the whole slope, including the cemetery at the crest of the natural slope. They found that there was no drainage provision in the cemetery and that the water collected within the cemetery discharged directly onto the slopes below. It was concluded that this improper drainage led to the failure and could adversely affect the long-term stability of the slopes (Memo Ref. GCMd 2/E1/7SW-B, dated 20/11/93).
20-11-1993	The GEO, the DO and the HyD jointly inspected the site of the northern slope on 19 November 1993 to solve the drainage problems. They concluded that the slope did not pose an immediate and direct risk to the adjacent occupied houses. The GEO requested that the DO and DSD arrange a joint inspection to resolve the drainage problems (Memo Ref. GCMd 2/E1/7SW-B, dated 20/11/93).
Notes on Abbreviations	See Table A2.

Table A2 –Background Information for the Eastern Slope (Landslide B)

Date of Correspondence	Content
20-2-1989	DLO wrote to CMB with regard to the unauthorized retaining wall (No.1), which was due be completed by 27/2/1989 (DO" letter ref. (36) in LNT 313/2MS/74 dated 20/2/1989). The memo noted that the cemetery was on Government Land and that regularisation by a land grant was being considered.
4-3-1989	In response, CMB replied to DLO in a letter of 4/3/1989, admitting fault for constructing a retaining wall at boundary without approval. Previous extensive erosion led CMB to believe there was a real danger of a major landslide during the rainy season that would endanger the 7 or 8 families living below. To prevent landslip, they built the wall.
19-4-1989	DLO asked GEO for preliminary design checks (Memo Ref. (38) in LNT 313/2MS/74 dated 19/4/1989).
27-5-1989	GEO advised of the retaining walls existing and that there were no signs of distress with condition generally good and no apparent threat to squatter dwellers on slope below the wall (Memo. Ref. GCMd 2/E1/7SW-B dated 27/5/1989). GEO advised DLO to request design details.
17-7-1989	CMB submitted drawings and design details to DLO who passed them to GEO (17/7/1989).
21-8-1989	Although no design calculations were submitted, GEO checked stability, and concluded in letter to DLO that the walls did no possess an adequate Factor of Safety. GEO recommended that remedial/preventive measures must be carried out to improve stability of walls to the required standard. GEO requested design calculations showing adequate Factor of Safety or details of remedial/preventive measures (Memo Ref. GCMd 2/E1/7SW-B dated 21/8/1989).
11-4-1990	DLO requested CMB to submit design calculations or details of remedial measures (Letter Ref. (45) in LNT 313/2MS/74 dated 4/9/1989 and Letter Ref. (46) in LNT 313/2MS/74 dated 11/4/1990).
2-5-1990	CMB responded to DLO. The CMB's contractor was not in position to submit the required design calculations. CMB asked for advice (Letter from CMB to DLO, dated 2/5/1990). CMB explained that the walls were constructed using the Contractors practical experience.
11-5-1990	DLO wrote to CMB indicating that they had no objection to the walls, since there was no evidence of distress. However, due to a lack of design calculations, DLO required CMB to confirm responsibility, of whatever nature, for any failure in the future (Letter Ref. (48) in LNT 313/2MS/74 dated 11/5/1990). CMB did not respond to this request.
28-2-1991	DLO wrote to GEO stating that further submission of designs from CMB was unlikely (Memo Ref. LNT 313/2MS/74 dated 28/2/1991).

Table A2 –Background Information for the Eastern Slope (Landslide B)

Date of Correspondence	Content
28-2-1991	GEO visited the site on 1/5/1991 and found the ground condition to be similar to their previous inspection (i.e. inspection of 27/5/1989 conducted by GEO). (Note in Memo Ref. (55) in LNT 313/2MS/74 dated 28/2/1991).
4-9-1991	GEO/DLO joint inspection on 4/9/1991 found no signs of distress and the condition of the slope was similar to the inspection of 1/5/1991. GEO stated "No further action is considered required at this stage." (HAP are missing this correspondence, information is from an internal review of document of site history by GEO Planning).
January 1997	CMB commissioned a consultant to investigate the walls. The consultant concluded the walls were sub-standard and showed signs of distress, and made recommendations to upgrade the walls.
1997 (post-failure) In File: GCME DH578/97NT	There was joint inspection on 4/7/97 (after the failure). GEO recommended BD to issue a DHO on 25 July. Owing to doubts over the land status raised by BD, the DHO was not issued. CMB commissioned a consultant to carry out emergency slope stabilization works. Proposal was issued on 18/7/97. There was no geotechnical objection by CGE/ME on 23/7/97. Commencing in October 1997, the works were carried out by owner of the cemetery. Memo sent from CBS/BD to CGE/ME on 20/10/97 states that "cemetery is on G.L. (Government Land) is beyond doubt." In a memo sent from DLO to CBS/SS on 16/10/97, BD states that "Tao Fung Shan Christian Cemetery is active in use for more than 50 years but without proper land grant. DLC on 3/10/97 approved a private treaty grant to the Christian Mission to Buddhists for the said cemetery subject to the policy support from the Secretary for Recreation and Culture."

Table A2 –Background Information for the Eastern Slope (Landslide B)

Date of Correspondence	Content
Notes on Abbreviations	BD = Buildings Department CBS = Chief Buildings Surveyor CGE = Chief Geotechnical Engineer CMB = Christian Mission for Buddhists DHO = Dangerous Hillside Order DLC = District Lands Commission DLO = District Lands Office, Shatin DO = District Office, Shatin DSD = Drainage Services Department GEO = Geotechnical Engineering Office HyD = Highways Department ME = Mainland East SC/ST = Squatter Control Office, Shatin SGE = Senior Geotechnical Engineer