SECTION 2: DETAILED STUDY OF THE 23 AUGUST 1999 LANDSLIDE AT ROUTE TWISK OPPOSITE THE LOOKOUT POINT NEAR SHEK KONG

Fugro Maunsell Scott Wilson Joint Venture

This report was originally produced in August 2000 as GEO Landslide Study Report No. LSR 5/2000

FOREWORD

This report presents the findings of a detailed study of the 1000 m^3 landslide (GEO Incident No. MW 1999/8/14) that occurred on cut slope No. 6NE-D/C57 opposite the Lookout Point at Route Twisk near Shek Kong on 23 August 1999. Debris from the landslide completely blocked Route Twisk for several weeks. No casualties were reported following the landslide. A second failure occurred near the crest of the scar, 5 days after the initial landslide during urgent repair works. Two labourers working on the slope suffered minor injuries as a result of the second failure.

The objectives of the detailed study were to document the facts about the landslide, present relevant background information and establish the probable causes of the failure. The scope of the study comprised site inspection, limited ground investigation, desk study and engineering analysis. Recommendations for follow-up actions are reported separately.

The report was prepared as part of the 1999 Landslide Investigation Consultancy (LIC), for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 101/98. This is one of a series of reports produced during the consultancy by Fugro Maunsell Scott Wilson Joint Venture (FMSW).

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1. INTRODUCTION

Some time before 10:00 a.m. during the severe rainstorm of 23 August 1999, a landslide (GEO Incident No. MW 1999/8/14) occurred at slope No. 6NE-D/C57 opposite the Lookout Point at Route Twisk near Shek Kong (Figure 1 and Plate 1). The landslide involved the failure of an approximately 50 m wide section of the slope and resulted in the release of about 1000 m^3 of debris. Landsliding extended into the ground above the cut slope. The landslide debris completely blocked Route Twisk for several weeks. No casualties were reported as a result of the landslide. A second failure occurred near the crest of the scar, 5 days after the initial landslide during urgent repair works. Two labourers working on the slope suffered minor injuries as a result of the second failure.

Following the first incident, Fugro Maunsell Scott Wilson Joint Venture (FMSW), the 1999 Landslide Investigation Consultants, carried out a detailed study of the failure for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 101/98. This is one of a series of reports produced during the consultancy by FMSW.

The objectives of the study were to document the facts about the landslide, present relevant background information and establish the probable causes of the failure. Recommendations for follow-up actions are reported separately. This report presents the findings of the detailed study, which comprised the following key tasks:

(a) review of relevant documentary records,

(b) aerial photograph interpretation (API),

(c) field mapping,

(d) limited ground investigation,

(e) analysis of rainfall data,

(f) engineering analysis of the slope, and

(g) diagnosis of the probable causes of the failure.

2. THE SITE

2.1 Site Description

The landslide occurred at the northern part of slope No. 6NE-D/C57 opposite the Lookout Point on Route Twisk near Shek Kong (Figure 1 and Plate 1). A plan of the landslide site is shown in Figure 2.

The slope was cut into one of the many northwest trending spurs below Tai Mo Shan (Figure 3), in connection with the construction of Route Twisk. The feature is a soil/rock cut slope, which is about 160 m long, up to 25 m high and has an average gradient of about 45° at the landslide site.

The failed part of the slope can be divided into eastern and western portions. Based on aerial photographs and site observations of the surrounding area, the eastern portion comprised a single batter (up to about 6 m high) with lined surface channels at the toe and crest, prior to the 1999 landslide. The western portion was about 25 m high and comprised two batters separated by a narrow berm. Lined surface channels were located along the berm and at the toe and crest of this portion. It is possible that the mid-slope berm of the western portion connected into the crest channel of the eastern portion. A trapezoidal channel (about 1 m wide by 0.5 m deep) was located above the crest of the slope, prior to the landslide, which discharged into an ephemeral drainage line at its eastern boundary (Figures 2 and 3).

At the time of the landslide, the cut slope had no surface protection (except for a localised area, see Section 3.3) and was densely vegetated with trees, shrubs and grass.

The remains of stone-faced agricultural terraces (0.5 m to 1 m high) are located on the hillside above the 1999 landslide scar (Figure 3). The terraces are orientated in a west southwest-east northeast direction and are overgrown with trees and bushes.

2.2 Maintenance Responsibility

According to the "Systematic Identification of Maintenance Responsibility of Registered Slopes in the Territory" (SIMAR) project undertaken by the Lands Department, the maintenance responsibility for slope No. 6NE-D/C57 rests with the Highways Department (HyD).

3. SITE HISTORY

3.1 General

The history of development at the site has been determined from an interpretation of aerial photographs as well as a review of the relevant documentary information. Detailed observations from aerial photograph interpretation (API) are given in Table 1.

3.2 History of Development

The 1924 aerial photographs indicate that the hillsides in the vicinity of the 1999 landslide were extensively terraced for agricultural purposes (Figure 3). Route Twisk and slope No. 6NE-D/C57 were constructed between 1949 and 1963. There were no significant changes to the road alignment or cut slope configuration following their formation.

3.3 Past Instability

Slope No. 6NE-D/C57 has a history of instability.

The GEO's landslide database has a record of two past landslide incidents within slope No. 6NE-D/C57. Incident No. MW 97/8/13 was located about 35 m to the southwest of the 1999 landslide (Figure 3), and comprised the failure of a moderately vegetated portion of the soil/rock cut slope, involving between 5 m^3 and 10 m^3 of partially weathered rock with rock mass weathering grade, PW 0/30. The possible cause of failure was considered to be "wash-out" as noted in the GEO Incident Report. One lane of Route Twisk was closed as a result of the landslide. The lower batter of the north portion of the southern part of slope No. 6NE-D/C57, including the 1997 failed area, was covered with shotcrete by 1998 (Figure 3).

Incident No. MW 99/6/1 was located about 50 m to the southwest of the 1999 landslide (Figure 3) within a moderately vegetated portion of the slope and comprised a minor rock fall, about 0.2 m^3 in volume and involving "about 10 pieces" of "maximum size about 0.25 m". Possible contributory factors to the failure included "weathering and unfavourable rock joints" as noted in the GEO Incident report.

Two landslide scars were also observed during an inspection of the slope by Fugro Mouchel Rendell Joint Venture (FMR) on 31 October 1995 under the HyD's Roadside Slope Inventory and Inspections consultancy (FMR, 1996) (see Section 3.4). The first scar was located close to the eastern flank of the 1999 landslide and was described as a shallow, soil slope failure about 0.5 m deep and 3 m wide (Figure 3). The second scar was located above the berm within the southern part of the slope (Figure 3). The dimensions of the second scar are not known.

In the 1924 and 1949 aerial photographs, several relic landslide scars are noted in the vicinity of the 1999 landslide site (Figure 3). In particular, a large scar is noted about 5 m to the east of the 1999 landslide above the boundary of slopes Nos. 6NE-D/C57 and 6NE-D/C131 (Figure 3). In 1963, following the formation of Route Twisk, two possible landslide scars are noted within the area affected by the 1999 landslide (Figure 3). The first scar appeared to be relatively shallow and its crest was located between the trapezoidal channel and the crest channel. The second scar was noted about 8 m above the first scar.

In the 1973 aerial photograph, several areas characterised by a light tone are located slightly to the south of the 1999 failed portion of the slope. These areas may represent minor landslide and/or erosion scars. The location of one of these areas coincides approximately with a small landslide scar observed within the upper batter of slope No. 6NE-D/C57 during post-failure mapping by FMSW. The scar was about 3 m wide, 4 m long and up to about 0.5 m deep.

A small arcuate landslide scar was noted on the 1993 aerial photographs, close to the scars observed on the 1963 photographs (Figure 3).

There are no records of past landslides on the hillsides above and below slope No. 6NE-D/C57 in the GEO's Natural Terrain Landslide Inventory (NTLI).

3.4 Previous Studies and Assessments

Slope No. 6NE-D/C57 was not registered in the 1977/78 Catalogue of Slopes.

In 1992, the GEO commenced a consultancy agreement entitled "Systematic Inspection of Features in the Territory" (SIFT), to search systematically for slope features not included in the 1977/78 Catalogue of Slopes and to update information on previously registered features, by studying aerial photographs together with limited site inspections. Slope No. 6NE-D/C57 was considered as part of this study in February 1994. The SIFT study assigned the slope to category "C1", i.e. a slope "assumed formed pre-1978 or illegally formed". In addition, it was noted that the feature was constructed pre-1964 and that there was "early evidence of erosion and slope failure".

In October 1995, the cut slope was inspected by consultants under HyD's project entitled "Roadside Slope Inventory and Inspections". The record of the Engineer Inspection stated that there were past failures on the slope (see Section 3.3) and noted that "routine maintenance not carried out satisfactorily because surface drainage systems not clear, drainage channels cracked/damaged, and detrimental vegetation not cleared". The Engineer Inspection recommended to carry out the necessary routine maintenance works and "regrade oversteepend portion of slope" as part of preventive maintenance works. No signs of seepage or slope distress were noted during the inspection.

In July 1994, the GEO commenced a consultancy agreement entitled "Systematic Identification and Registration of Slopes in the Territory" (SIRST), to update the 1977/78 Catalogue of Slopes and to prepare the New Catalogue of Slopes. Slope No. 6NE-D/C57 was considered as part of this consultancy in October 1997. The SIRST information sheet indicates that the slope was inspected by the HyD.

Routine inspection and maintenance works were undertaken by HyD at slope No. 6NE-D/C57 during April and May 1999. The works comprised clearing the catchpit "of accumulated debris" at the northern part of the slope

There is no record in the GEO of any stability assessments for slope No. 6NE-D/C57.

4. THE LANDSLIDE

4.1 Time of Failure

The landslide was reported to the Hong Kong Police Force by a member of the public at 9:58 a.m. on 23 August 1999. Police arrived at the landslide site at 10:05 a.m. and the landslide was reported to the GEO at 1:30 p.m. on the same day.

At about 2:30 p.m. on 28 August 1999, following a rainstorm, a further minor landslide occurred within the upper part of the western flank of the 23 August 1999 landslide scar during urgent repair works.

4.2 Description of the Landslide

A plan of the landslide site and cross-section are shown in Figures 2 and 4, respectively.

FMSW first inspected the site in the afternoon of 23 August 1999 during heavy rain. The landslide scar was about 40 m long by 50 m wide, with a maximum depth of about 5 m and a volume of about 1000 m^3 of landslide debris was released.

The landslide main scarp was about 6 m high and was principally located in the hillside above slope No. 6NE-D/C57, with the lower western end affecting the upper batter of slope No. 6NE-D/C57. The lower batter below the western flank of the landslide remained largely intact (Figure 2 and Plates 1 and 2). The overall direction of movement along the surface of rupture was in a north-northeasterly direction, slightly oblique to the direction of the slope.

Field mapping identified that both flanks of the landslide comprised partially weathered tuff (with rock mass weathering grade PW0/30 to PW50/90) with open and infilled joints, overlain by residual soil (see also Section 5.2). Joints dipping at about 80° to the northeast, and at about 50° to the north and northwest were recorded in the western and eastern flanks of the landslide respectively. These joint sets formed the dominant release surfaces on either flank of the landslide. The jointing, in conjunction with the direction of movement of the detached mass, suggest a strong structural control to the failure.

The majority of the landslide debris was deposited on Route Twisk at the toe of the slope (with debris thickness up to about 4 m), but an isolated raft of soil bound by vegetation remained in the upper western portion of the main scarp (Plate 2). A thin veneer of debris (maximum thickness about 0.5 m) covered the intact lower batter below the western flank of the landslide, flattening vegetation in the process (Figure 2 and Plate 2). Broken sections of trapezoidal drainage channel were noted within the debris on this portion of the slope.

The landslide debris at the slope toe was saturated and water was flowing from the blocked toe channel towards the eastern flank of the scar (Plate 2). The debris comprised a large number of subangular to subrounded cobbles and boulders (up to 3 m x 3 m x 3 m in size), within a saturated structureless matrix of very soft reddish brown clayey very sandy silt (Plate 3). A large number of trees and bushes were also observed within the debris. The nature and extent of the debris suggests a fast-moving landslide.

The travel distance of the landslide debris was about 12 m (in plan) beyond the slope toe. The travel angle of the landslide debris, determined after Wong & Ho (1996a), was approximately 35°. This value is within the range of values usually encountered in Hong Kong for typical rainfall-induced landslides.

A section (about 20 m long) of corrugated crash barrier on the outside lane of Route Twisk, together with a street lamp and the roadside catchpit/culvert at the toe of the eastern flank of the scar, were destroyed by the landslide.

At the time of FMSW's first inspection, several hours after the failure, surface water was discharging from the trapezoidal surface channel above the slope crest, which had been severed by the landslide, across the eastern flank and onto the debris. The trapezoidal channel on both the eastern (Plate 5) and western flanks was cracked and partially displaced in several locations. Some of these cracks appeared to have been repaired (with bitumen) and then reactivated, indicating past and more recent slope movement (Plate 6). Many of the cracks were covered with moss and contained roots indicating that they had been exposed for some time. It was also noted that the channel located above the main scarp along the western flank was blocked with vegetation.

A scar, formed by post-landslide erosion, was located on the lower eastern flank of the landslide adjacent to the roadside culvert (Figure 2). Seepage flows were observed by FMSW along joints in the rock mass (PW50/90) exposed within the erosion gully up to 4 m above the slope toe (Figure 2 and Plate 7). In addition, seepage flow was noted at the slope toe to the east of the gully (Figure 2). These seepages were observed over one week after the incident took place.

Two pre-existing tension cracks were observed above the eastern flank of the landslide scar (Figure 2 and Plate 8). The largest tension crack was about 16 m long, up to 200 mm wide and open, with vertical down-slope displacement of up to 400 mm (see also Section 5.2). The smaller tension crack was about 7 m long and up to about 20 mm wide. The depth of the tension crack and nature of infilling is not known. Both tension cracks were trending in a west northwest-east southeast direction, which indicates ground movement towards the north northeast. It is not certain whether these pre-existing tension cracks were associated with the relic landslide scar to the east of the 1999 landslide scar.

About 50 m^3 of debris was released during a later incident on 28 August 1999, which partially buried an excavator that was trimming back the slope as part of the urgent repair works at that time (Plate 9). Eye-witnesses reported that the trees at the crown of the landslide scar "slid down" undergoing a slow downward movement for about one metre before rapidly falling onto the mid-slope berm and excavator below. Following the failure, eye-witnesses observed a significant amount of water issuing from the toe of the failed slope, describing it as a "mud flow" with the "release of trapped water" from within the debris.

4.3 Consequences of the Landslide

Following the 23 August 1999 landslide, Route Twisk was completely blocked by landslide debris and was closed for several weeks as urgent repair works were being carried out. The northbound lane of Route Twisk was re-opened to traffic on 4 October 1999, with both lanes being re-opened on 11 November 1999.

During the second landslide on 28 August 1999, two labourers working on the slope suffered minor injuries.

5. SUBSURFACE CONDITIONS OF THE SITE

5.1 General

The subsurface conditions at the site were inferred using information from desk and field studies. The desk study included a review of existing information supplemented by API, whilst the field study included geological mapping and limited ground investigation undertaken by HyD after the landslide.

Geological mapping of the site was carried out by FMSW between August and November 1999. Ground investigation comprised four trial pits and commenced on 9 September 1999.

5.2 Geology and Ground Investigation

The geological features mapped at the site by FMSW, together with the trial pit locations, are shown in Figure 5. A geological section through the landslide is shown in Figure 4.

The Hong Kong Geological Survey's 1:20 000 scale map, Sheet 6 Yuen Long Solid and Superficial Geology (GCO, 1988a), indicates that the site is underlain by fine to coarse ash tuff, tuff breccia and tuffite of the Shing Mun Formation of the Repulse Bay Volcanic Group, which is Upper Jurassic in age (Figure 6). A geological boundary is indicated about 50 m to the southeast of the 1999 landslide scar, separating this unit from coarse ash crystal tuff of the Tai Mo Shan Formation, also of the Repulse Bay Volcanic Group.

The geology at the landslide site, shown in Figure 5, comprises partially weathered, jointed, predominantly coarse ash, and occasionally lapilli-bearing, tuff overlain by residual soil up to about 1.5 m thick. The partially weathered rock (PW 0/30 to PW 50/90) consists of completely to highly decomposed tuff (C-HDT) with occasional corestones, overlying moderately to slightly decomposed tuff (M-SDT). The C-HDT was generally medium dense very silty fine sand with occasional fine quartz gravel.

On the western flank of the landslide scar, the slope comprised C-HDT, which was slightly moist to dry, medium dense to dense, very silty fine-grained sand with occasional fine gravel. The C-HDT contained many closely spaced joints of low persistence (generally < 3 m) dipping into the slope at about 70° towards the southwest (240°), which were generally infilled with slickensided (plunging parallel to dip) kaolin and manganese oxide deposits (about 1 mm thick). A medium to widely spaced, smooth to rough joint set, infilled with slickensided (plunging parallel to dip) kaolin and manganese oxide deposits (about 2 mm thick) and dipping at about 65° to 80° towards the northeast (061°), formed release planes along the western flank.

In the central portion of the main scarp, the slope comprised essentially open-jointed MDT (possibly corestone) overlain by about 0.5 m of residual soil with cobble and boulder size corestones of MDT. The material exposed in this part of the scar could be easily excavated with a pick due to the closely-spaced and open-jointed nature of the MDT

(Figure 5). A soil pipe up to 0.5 m wide was observed within the residual soil (and some CDT) following trimming of the main scarp (Plate 10).

At the mid-section of the eastern flank of the scar, the slope comprised corestones of MDT within CDT (Plates 11 and 12). The CDT was typically moist soft reddish brown, slightly sandy clay/silt. The main release planes on the eastern flank were dominated by joints dipping at about 50° to the northwest and north (305° to 360°), respectively (Plates 11 and 12). The joints were typically closely to medium spaced, smooth, slightly undulating to planar, and infilled with slickensided (plunging at about 20° to southwest) kaolin (1 mm to 2 mm) and manganese oxide (< 1 mm thick) deposits. Some of the surfaces exposed on the eastern flank were covered with moist to wet, soft, yellowish brown, mottled reddish brown, fine sandy clay/silt up to 200 mm thick with rootlets (Plate 13). Many joints were infilled with similar material, which extended into the rock mass behind the scar (Plates 11 and 12). These relatively thick deposits were probably washed into persistent open discontinuities and possible deep (> 5 m) tension cracks exposed within the scar prior to the 1999 landslide.

Discontinuity data from the landslide site, together with the results of kinematic stability analyses, are presented on a stereoplot in Figure 7. Considering the four main joint sets (Joint Sets “Ja” to “Jd”), which were mapped at the site, a wedge failure along the intersection of joint sets “Jb” and “Jc” appears to be kinematically permissible given the steep slope angle prior to failure (about 50° at the eastern flank of the scar). This, plus the exposure of joint sets “Jb” and “Jc” on the flanks of the scar and the general north northeasterly trend of the scar and debris trail, which was slightly oblique to the slope direction, suggests a strong structural control to the failure. Localised planar sliding may also have occurred along joint set Jb (Figure 7).

Two zones of CDT (each up to 1.5 m thick) comprising persistent (> 10 m), very closely-spaced discontinuities infilled with slickensided (plunging parallel to dip) kaolin and manganese oxide deposits (up to 60 mm thick), and dipping at about 52° to 70° in a south southeast direction (i.e. joint set Ja in Figure 7), were mapped across the landslide scar (Figure 5 and Plate 14). Joints from set Ja were also mapped on the flanks of the scar, some of which were open and infilled with clayey silt deposits. The open and infilled nature of joint set Ja suggests past dilation and an element of toppling (Figure 7) along these discontinuities. Similar toppling movement may have been involved in the 1999 landslide.

Four trial pits were sunk in the ground above the landslide scar (TP1 to TP4). The location of the trial pits are shown in Figure 5 and the logs prepared by FMSW are given in Appendix A.

Trial pit No. TP1 encountered about 1 m to 1.5 m of soft to firm reddish brown sandy clayey silt (residual soil) above CDT and occasionally MDT. Soil pipes up to 200 mm in diameter were observed within the residual soil (Plate 15). They may have been formed by root action, bioturbation or erosion, or a combination of these processes. A pre-existing tension crack (up to 200 mm wide and over 2.8 m deep), which was infilled with loose, structureless, reddish brown, clayey sandy silt, was also noted within the residual soil (see Section 4.2). Trial pits Nos. TP2, TP3 and TP4 encountered up to 0.5 m of fill/reworked residual soil and CDT, above CDT.

5.3 Groundwater Conditions

No groundwater monitoring records are available for the area. The groundwater conditions at the landslide site have been assessed from observations made during post-landslide field mapping.

The mass permeability of the decomposed tuff is likely to be influenced by the soil pipes observed above the landslide scar and within the trimmed main scarp. They were dry at the time of inspection. In addition, the partially weathered tuff within the landslide scar comprised open and infilled joints which would have significantly affected and complicated the groundwater regime.

Seepages were noted up to 4 m above the toe of the slope, and along joints in the exposed rock mass on the eastern flank of the scar (Figure 2 and Plate 8). In addition, eye-witnesses observed a significant amount of water issuing from the slope shortly following further landsliding on 28 August 1999.

The available groundwater information suggests that the landslide site may have been subject to a seasonally high groundwater regime with a quick storm response. Additionally, the presence of open and infilled discontinuities and pre-existing tension cracks is conducive to the possible build-up of localised cleft water pressures.

6. ANALYSIS OF RAINFALL RECORDS

The nearest GEO automatic raingauge is No. N14, located at the Wireless Station on Tai Mo Shan about 1.5 km to the southeast of the landslide site (Figure 1). This raingauge records and transmits rainfall data at 5-minute intervals via a telephone line to the GEO.

Based on eye-witnesses' accounts, the landslide was assumed to have occurred at 9:55 a.m. on 23 August 1999 for the purposes of rainfall analysis.

The daily rainfall recorded by this raingauge over the month preceding, and seven days following, the incident is presented in Figure 8. The rainstorm was concentrated on 23 August 1999. The hourly data for the period from 9:55 a.m. on 21 August 1999 until 3:55 p.m. on 23 August 1999 is also shown on Figure 8. Peaks in rainfall intensity between 2:00 p.m. and 4:00 p.m. on 22 August 1999, and between 5:00 a.m. and 8:00 a.m. on 23 August 1999, were generally in the range of 50 mm/hr to 80 mm/hr.

Analysis of the return periods of the rainfall intensities of the rainstorm before the landslide for different durations based on historical rainfall data at the Hong Kong Observatory (Lam & Leung, 1994), shows that the 24-hour rainfall was the most severe, with a corresponding return period of about 85 years (Table 2). The 12-hour and 48-hour rainfalls were also severe, with corresponding return periods of about 37 and 39 years, respectively (Table 2).

A comparison between the patterns of past major rainstorms recorded at raingauge No. N14 between 1994 and 1999, is given in Figure 9. The rolling rainfall indicates that the rainstorm preceeding the 1999 landslide was not as severe as some of the previous rainstorms recorded at raingauge No. N14 since its installation in June 1983.

7. THEORETICAL STABILITY ANALYSES

Theoretical stability analyses using the rigorous solution of Morgenstern & Price (1965) were carried out to assist in the diagnosis of the probable causes of the landslide. The analyses examined the likely operative range of shear strength parameters along the surface of rupture for different groundwater conditions at the time of failure. A representative cross-section of the landslide site is shown in Figure 10.

The pre-failure slope profile was based on topographic survey plans, photographic records and engineering judgement. The geometry of the surface of rupture and ground profile is based on site measurements by FMSW and post-failure topographic survey.

The stability analyses were carried out using a range of shear strengths which covers the generalised range of parameters given for decomposed volcanics in Table 8 of Geoguide 1 (GEO, 1993). Various levels of elevated groundwater pressures above the surface of rupture were assumed for the purposes of the stability analyses.

The results of the analyses are presented in Figure 10. These indicate that the development of an elevated groundwater pressure of about 0.25 m above the surface of rupture would be required to initiate failure in the slope.

8. DIAGNOSIS OF THE PROBABLE CAUSES OF THE LANDSLIDE

8.1 Mode of the Landslide

Based on the field mapping, the mode of the landslide involved principally a sliding, possibly wedge-type failure along adversely-orientated discontinuities observed along the surface of rupture. The central portion of the main scarp comprised decomposed tuff with open joints and some soil pipes, which probably formed preferential flow paths promoting rapid water ingress into the slope, and contributing to the failure. Evidence of seepage near the toe of the scar also indicates that the failure was associated, to a certain extent, with subsurface water. The nature and extent of the landslide debris suggests that the landslide movement was extremely rapid.

8.2 Factors Contributing to the Landslide

The close correlation between the rainfall recorded on 23 August 1999 and the time of failure suggests that the landslide was triggered by rainfall. The failure was probably caused by the development of transient elevated groundwater pressure in the ground mass together with cleft water pressure in the pre-existing open and infilled tension cracks following water ingress.

Slope No. 6NE-D/C57 was formed between 1949 and 1963, and has not been designed and checked to current geotechnical standards. The slope has a history of instability, including a relic scar in the ground above and to the southeast of the crest of the cut slope prior to slope formation. The numerous previous untreated slope failures and movement would likely have resulted in tension cracks and localised disturbed zones, and consequently highly variable near-surface hydrogeology. The presence of erosion pipes together with pre-existing tension cracks would have promoted rapid water ingress during periods of heavy rain.

The large-scale failure in 1999 had a strong element of structural control. The presence of adversely-orientated relic joints is exacerbated by the weak infill material comprising slickensided kaolin and manganese oxide deposits.

Theoretical stability analyses indicate that relatively small increases in groundwater pressures above the surface of rupture are required to initiate the significant failure.

The rainstorm that triggered the 1999 failure was not as severe as some of the previous rainstorms recorded by the nearest automatic raingauge since its installation in 1983. In this respect, the failure was a “surprise” from a rainfall loading point of view in that the slope had apparently survived more severe rainstorms in the past without major instability. However, post-failure field mapping suggests that the slope condition was probably deteriorating with time, involving local slope movement and formation or widening of tension cracks. As a result, the ground was progressively being opened up and becoming more conducive to direct water ingress. Subsurface seepage from the uphill area was also probable, given the presence of erosion pipes.

The presence of tension cracks in the ground and the cracked surface drainage channels were not referred to in the previous Engineer Inspection. It is not certain whether this was a result of the difficulty associated with the dense vegetation and constraints in the access arrangement. The blocked nature and poor condition of the surface drainage channels adjacent to the landslide scar suggests inadequate slope maintenance. This may have been a contributory factor to the failure.

9. CONCLUSIONS

It is concluded that the 23 August 1999 landslide was probably triggered by severe rainfall with an estimated return period of about 85 years. The 1,000 m^3 landslide affected the northern part of slope No. 6NE-D/C57 and the ground above. The affected area has a history of instability.

The slope has not previously been designed and checked to current geotechnical standards. The condition of the slope has probably been subject to progressive deterioration over time, as evidenced by the presence of major tension cracks, which were likely to have existed for some time prior to the 1999 landslide. The failure had a strong element of structural control given the adverse relic jointing in the insitu soil profile. Other factors that contributed to the failure include increased infiltration through pre-existing tension cracks and groundwater flow through erosion pipes. In addition, the cracked and blocked crest channel, due to lack of maintenance, probably resulted in increased infiltration into the slope.

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LIST OF TABLES

Table 1 – Summary of Site Development from Aerial Photograph Interpretation

Year	Photograph Reference No.	Altitude (feet)	Observations (Sheet 1 of 4)
1924	Y135, Y136, Y137	High Level (19,853)	The photographs are high level and of poor quality. Route Twisk has not been constructed. Several depressions interpreted as landslide scars are located in the vicinity of the 1999 landslide site. Terraces are located on the vegetated hillsides.
1949	Y01964, Y01965	High Level (>10,000)	The photographs are high level and of poor quality, with significant distortion around the margins. Route Twisk is not present, but there is a small path/track near to the current alignment. The roughly parallel southeast-northwest trending spur and valley profiles of the study area form a strong southeast-northwest topographic fabric that may be structurally controlled. The boundary of this terrain to the northwest is a prominent, southwest-northeast trending lineament (indicated as a fault on the corresponding Solid and Superficial Geology Map) defined by similarly aligned drainage lines. Agricultural terraces constructed in a herringbone pattern are evident on most ridge crests and side slopes, and vegetation is present in hillside depressions (swales) and along the larger drainage lines. Subtle, arcuate breaks in slope are present at the heads of some depressions and may be relic failure scars. One such break in slope coincides approximately with a landslide (6NE-D14) mapped in the Natural Terrain Landslide Inventory (King, 1997). No significant areas of surficial deposits are present in the study area. Alluvial/colluvial valley fill and fan deposits are present along drainage lines below Route Twisk, to the northeast of the landslide site. Within the study area Route Twisk is mapped as being underlain by fine to coarse ash tuff, tuff-breccia and tuffite of the Shing Mun Formation. The slopes above Route Twisk are mapped as being underlain by coarse ash crystal tuff of the Tai Mo Shan Formation. The contact between these two Formations is not evident from the photographs.
1963	Y09315, Y09316	3,900	The photographs are of excellent quality. Route Twisk is now present along the current alignment and was constructed by cutting the southeast-northwest trending spurs and filling the intervening valleys. The Shek Kong Lookout Point is under construction. Remnants of an older, more meandering road/track are present locally upslope of the existing road to the south of the 1999 landslide site. A track is evident traversing the slopes below Route Twisk.

Year	Photograph Reference No.	Altitude (feet)	Observations (Sheet 2 of 4)
			Slope No. 6NE-D/C57 can be divided into northern and southern parts. The southern part of slope No. 6NE-D/C57 can be divided into two portions. The southwestern portion consists of a section of pre-existing road (bench) located mid-slope, with steep, near-vertical cut slopes above and below, and lined drainage channels at the crest and toe of the slope. This portion is partially vegetated and appears to be uncovered. The northeastern portion appears to consist of a single cut slope, although a very narrow mid-slope berm may be present on the southwestern side, with lined drainage channels at the crest and toe of the slope. The slope, particularly the lower part, has a rough texture and appears to be uncovered. This portion may have recently experienced shallow rock failures as indicated by the rough surface and recent re-surfacing of the road below. The northern part of slope No. 6NE-D/C57 can also be divided into two portions. The western portion consists of two batters separated by a mid-slope drainage berm, with lined drainage channels at the crest and at the toe of the slope. A drainage channel is also located above the crest of the upper batter. The lined drainage channel at the crest of the slope may join with both the mid-slope drainage berm and the lined drainage channel at the crest of the adjacent eastern slope portion, at the junction between the portions, draining in a generally eastwards direction towards the ephemeral drainage line on the eastern flank of slope No. 6NE-D/C57. It is not clear whether these drainage features connect into the drainage channel above the crest of the western and eastern portions. The slope below the mid-slope berm on the western portion is rough and appears to be uncovered. A small berm is present along a portion of the toe of the slope. The slope above the mid-slope berm is smooth, but also appears to be uncovered. A portion of the road below this portion has been recently resurfaced. The western portion comprises a change in slope orientation from northwest to north-northwest as the slope and road curves around the spur opposite the Lookout Point. Agricultural terraces are present immediately above the upper lined drainage channel and appear to have been truncated by construction of the slope. A small white circle on the spur above the crest of the slope may be a grave. A path follows the ridgeline above the crest of the slope. The eastern portion is mostly in shadow but appears to consist of a single batter with lined drainage channels at the crest and toe of the slope. The crest of the slope is approximately coincident with the mid-slope berm on the western portion. The area above the slope is vegetated. It appears that the lined drainage channel above the crest of the slope outfalls to the adjacent drainage line between slope Nos. 6NE-D/C57 and 6NE-D/C131. A possible landslide scar is located above the eastern portion of the northern part of slope No. 6NE-D/C57. The drainage at the crest of the slope below may have been affected by the landslide. An arcuate convex break of slope is also noted above this scar which may also have been caused by instability. However, both areas are mostly obscured by shadow. Another possible landslide scar is located in a vegetated concave depression above Route Twisk between slopes, Nos. 6NE-D/C57 and 6NE-D/C131. The lower part of the depression has been modified by the construction of the drainage network on the eastern margin of slope No. 6NE-D/C57.

Year	Photograph Reference No.	Altitude (feet)	Observations (Sheet 3 of 4)
			Local areas of southeast-northwest and east-west trending lineaments are present to the southwest (above the road) and to the northeast (below the road) of slope No. 6NE-D/C57, respectively. The drainage line immediately above the culvert on the western flank of slope No. 6NE-D/C131 is linear and may be structurally controlled. Along Route Twisk, excluding slope No. 6NE-D/C57, five small and one larger "fresh" scars are present in cut slopes above the road.
1964	Y12056, Y12057	1,800	The photographs are of excellent quality. The Lookout Point is now complete. The possible landslide scar observed above the eastern portion of the northern part of slope No. 6NE-D/C57 on the 1963 photographs can now be more clearly defined. The crest of the scar is located between the uppermost drainage channel and the crest channel. The scar appears to be relatively shallow, and the crest channel appears to have been severed by the landslide.
1973	3191	5,000	The photograph is of good quality. Lighter-coloured areas are evident on the curved part of the cut slope opposite the Lookout Point. One of these areas coincides approximately with the location of a failure scar observed in the field during this detailed study. These areas may represent past failure scars, erosion scars or simply exposed soil surfaces. The drainage channels at the crest of the eastern portion of the northern part of slope No. 6NE-D/C57, possibly severed by the past landslide noted on the 1963 aerial photographs can be seen. It is not clear if any repair works were done.
1980	31557, 31558	6,000	The photographs are of good quality. Extensive slope works have been completed on several slopes along Route Twisk in the vicinity of the 1999 landslide but not slope No. 6NE-D/C57. A short trail is present on the ridgeline below the Lookout Point. No significant changes are apparent.

Year	Photograph Reference No.	Altitude (feet)	Observations (Sheet 4 of 4)
1993	A36596, A36597	4,000	The photographs are of poor quality, with significant haze and distortion, and cover only the immediate area of slope No. 6NE-D/C57.
			A small, arcuate landslide scar is present just above the junction between the eastern and western portions of the northern part of slope No. 6NE-D/C57. Recent additional work has been completed to two cut slopes along Route Twisk northeast of slope No. 6NE-D/C57. No other significant changes are apparent.
1998	CN21521, CN21522	8,000	The photographs are high level and of poor quality, with significant haze. The slopes and mid-slope berm within the western portion of the northern part of slope No. 6NE-D/C57 are heavily-vegetated. They do not appear to have had any recent work carried out on them. The landslide scar evident in 1993 is not apparent. The lower batter of the northeastern portion of the southern part of the slope is covered with shotcrete. No significant changes are apparent.
1999	CN22580, CN22581	4,000	The photographs are high level. The slopes in the vicinity of slope No. 6NE-D/C57 remain heavily-vegetated. No significant changes are apparent.

Table 2 - Maximum Rolling Rainfalls at GEO Raingauge No. N14 and Estimated Return Periods for Different Durations Preceding the Landslide on 23 August 1999

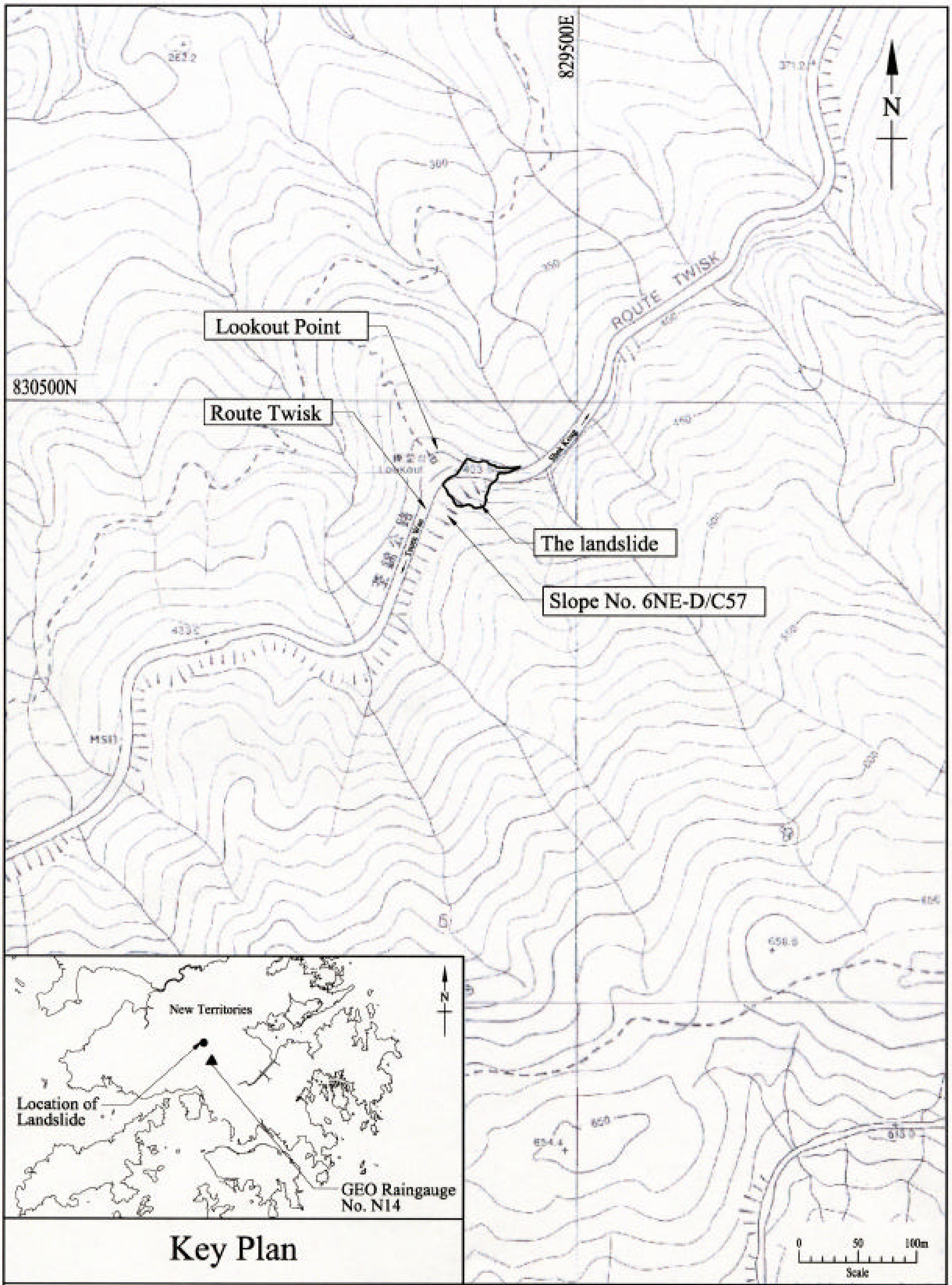
Duration	Maximum Rolling Rainfall (mm)	End of Period (Hours)	Estimated Return Period (Years)
5 Minutes	10.5	6:05 on 23 August 1999	< 2
15 Minutes	29.5	6:05 on 23 August 1999	3
1 Hour	99.5	6:20 on 23 August 1999	9
2 Hours	155.0	7:15 on 23 August 1999	15
4 Hours	227.5	9:05 on 23 August 1999	25
12 Hours	366.0	9:05 on 23 August 1999	37
24 Hours	548.0	9:55 on 23 August 1999	85
48 Hours	562.5	9:55 on 23 August 1999	39
4 Days	562.5	9:55 on 23 August 1999	15
7 Days	563.0	9:55 on 23 August 1999	9
15 Days	569.5	9:55 on 23 August 1999	4
31 Days	737.0	9:55 on 23 August 1999	3

Notes :
(1) Return periods were derived from Table 3 of Lam & Leung (1994).

(2) Maximum rolling rainfall was calculated from 5-minute data.

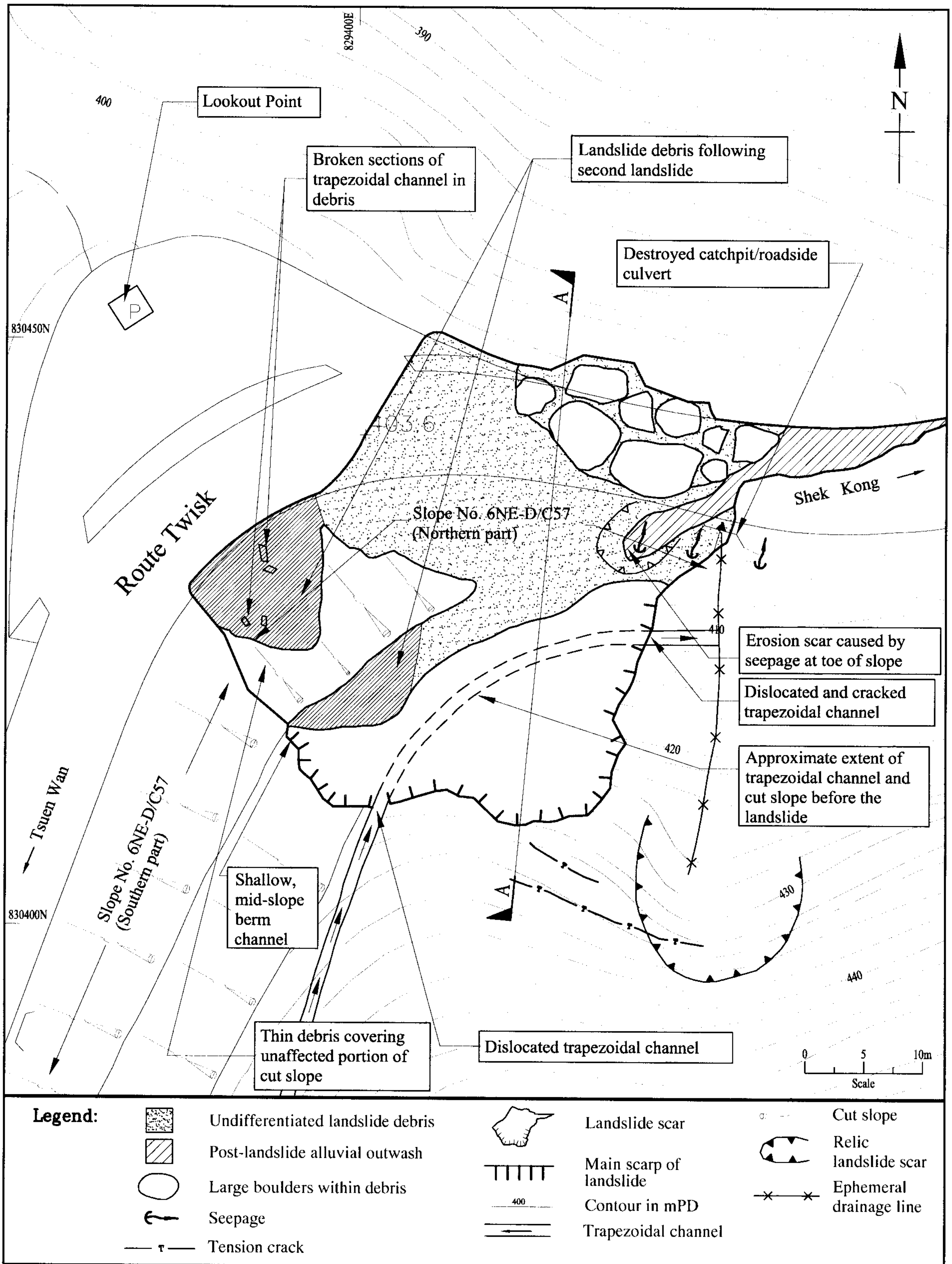
(3) The use of 5-minute data for durations between 4 hours and 31 days results in better data resolution, but may slightly over-estimate the return periods using Lam & Leung (1994)'s data, which are based on hourly rainfall for these durations.

LIST OF FIGURES



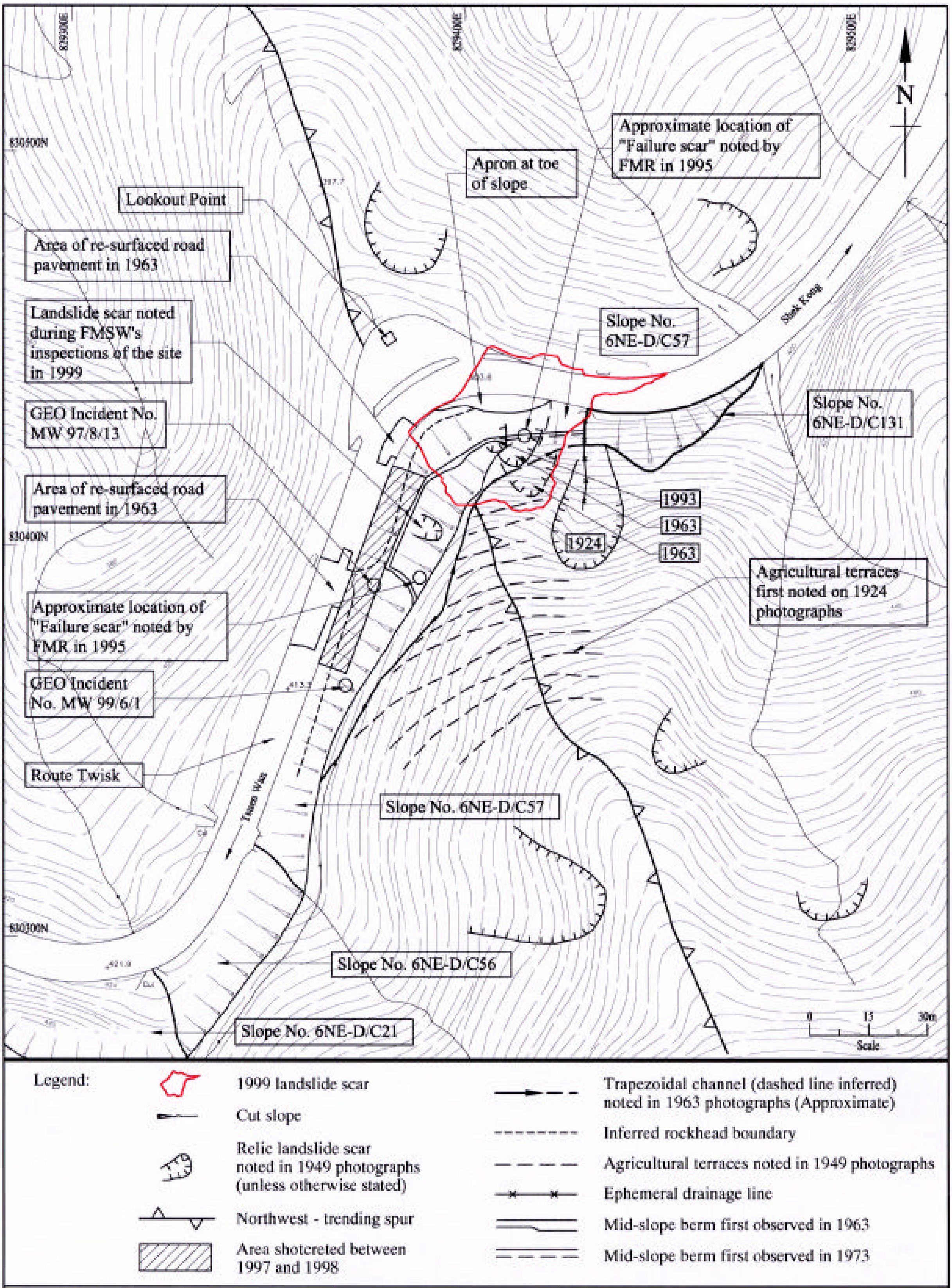
Notes: (1) Base Map is extracted from Survey Sheet No. 6NE-D & 6SE-B, scale 1:5000.
(2) Information shown on this figure is based on topographical survey and documentary records compiled during the detailed study.

Figure 1 - Site Location Plan



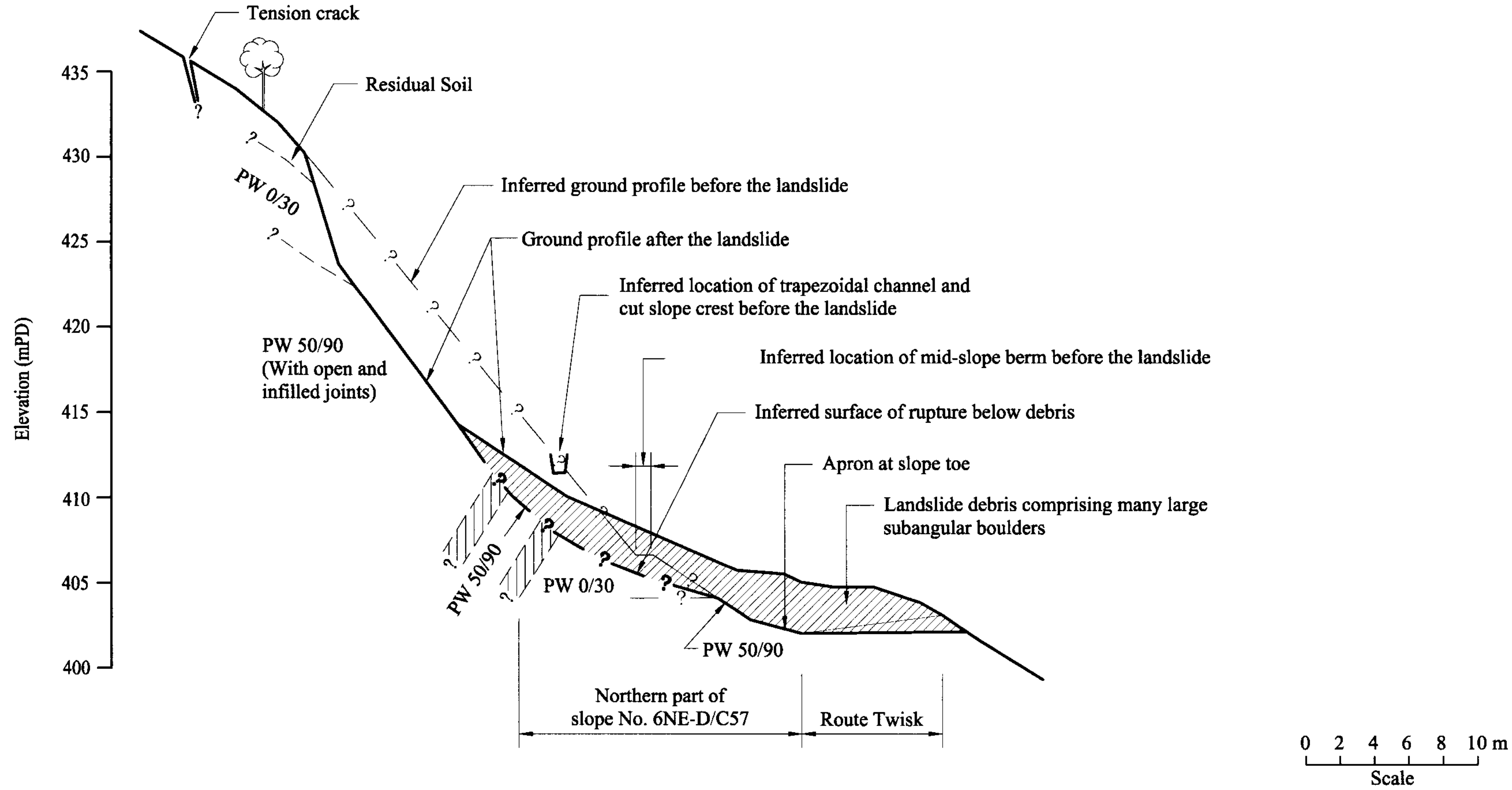
Notes:
(1) Base Map is extracted from Survey Sheet No. 6NE-25D, scale 1:1000.
(2) Information shown on this figure is based on topographical survey, field mapping and documentary records.
(3) For details of Section A-A, refer to Figure 4.

Figure 2 - Plan of the Landslide



Notes:
(1) Base Map is extracted from Survey Sheet No. 6NE-25D, scale 1:1000.
(2) Information shown on this figure is based on API, topographical survey, post-landslide field observations and documentary records.

Figure 3 - History of Site Development and Past Instability



Legend: Landslide debris

PW 30/50 Partially weathered tuff, 30% to 50% rock

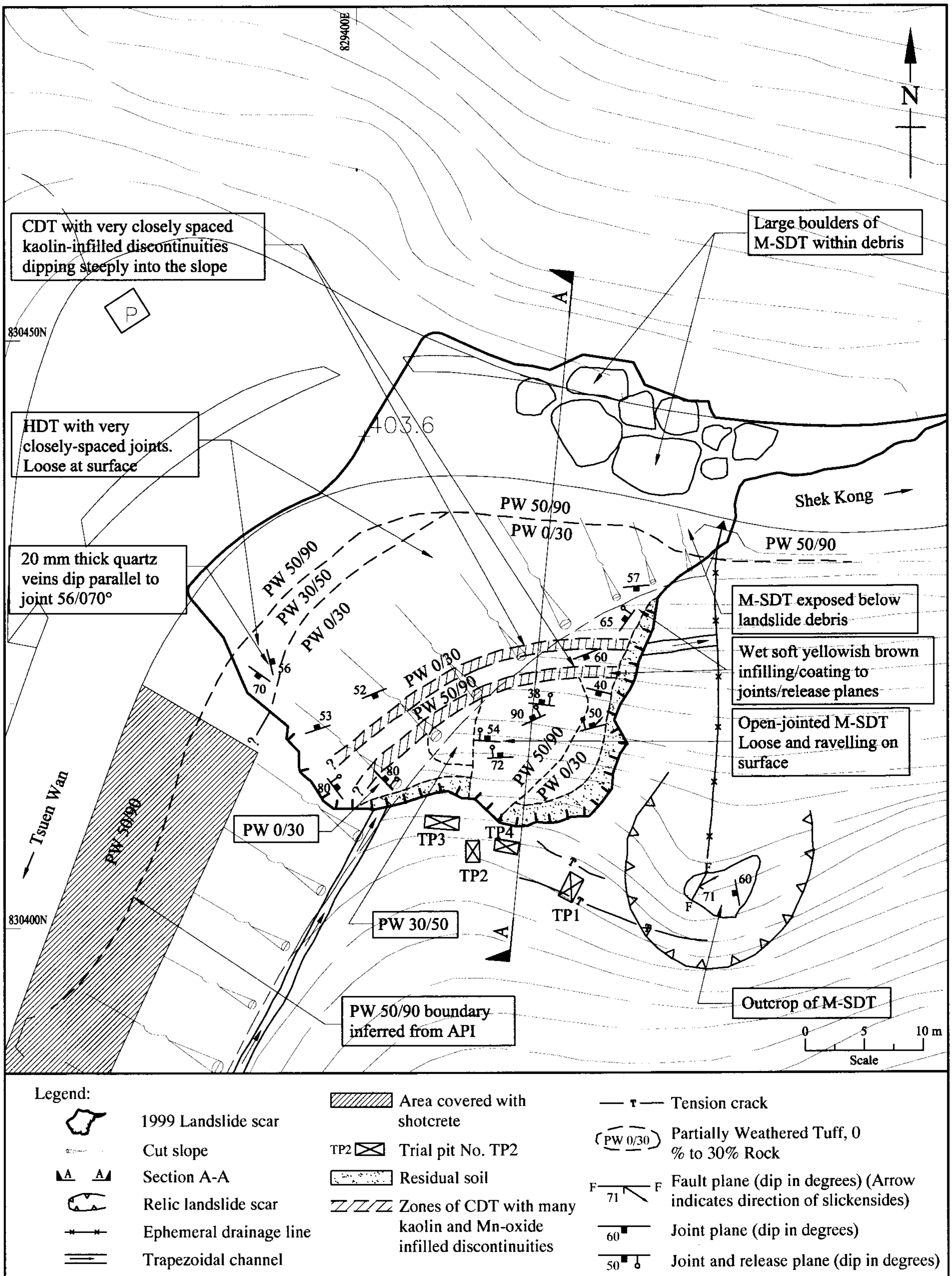
? ZZ ZZ ZZ Inferred zone of CDT with many kaolin and Mn-oxide infilled discontinuities

Notes:

(1) See Figures 2 and 5 for location of section.

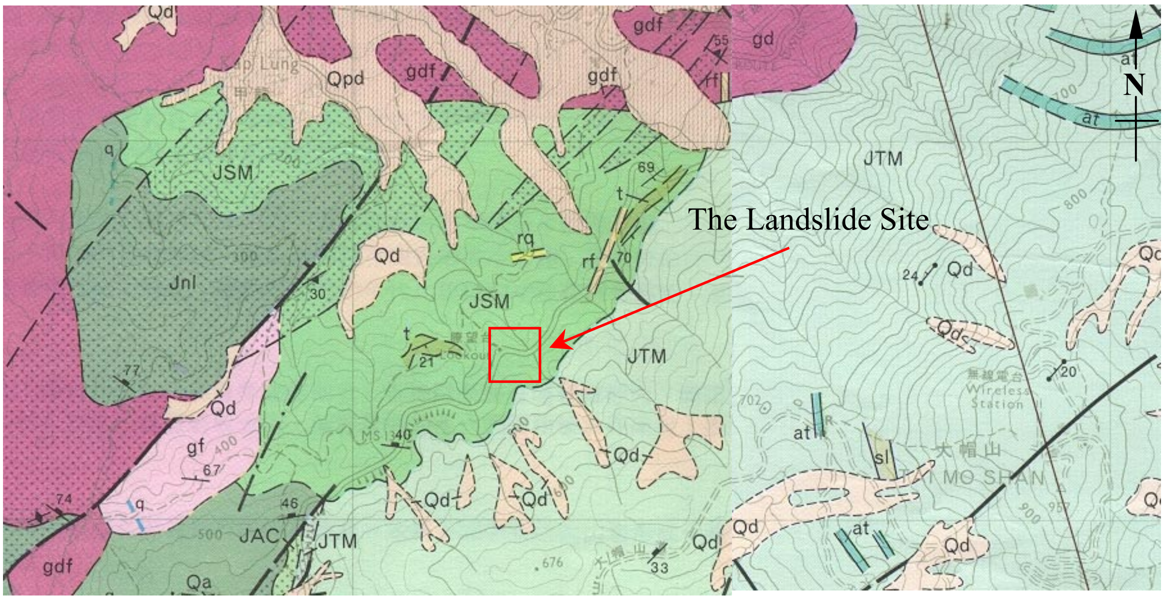
(2) Information shown in this figure is based on topographical survey, field mapping and documentary records.

Figure 4 - Section A-A through the Landslide



Notes:
(1) Base Map is extracted from Survey Sheet No. 6NE-25D, scale 1:1000.
(2) Information shown on this figure is based on topographical survey, API and field mapping.
(3) For details of Section A-A refer to Figure 4.

Figure 5 - Geological Plan of the Landslide Site



LEGEND:

SUPERFICIAL DEPOSITS

- Qd — Debris flow deposits
- Qpd — Debris flow deposits (Pleistocene)

SOLID GEOLOGY

- JTM — Coarse ash crystal tuff
- JAC — Fine ash vitric tuff
- JSM — **Crystal and lithic tuff, tuff-breccia and tuffite**
- Jnl — Crystal and vitric tuff
- t — Undiffrerntiated tuff and tuffite
- sl — Siltstone
- gf — Fine-grained granite; < 2 mm
- gdf — Fine-grained granodiorite, <2mm
- gd — Granodiorite
- rf — Feldsparphyric rhyolite
- rq — Quartzphyric rhyolite
- Metamorphosed

GEOLOGICAL LINES

- Geological boundary, superficial deposits
- Geological boundary, solid rock
- Fault (crossmark indicates downthrow side)
- Mineral vein
- Photogeological lineament

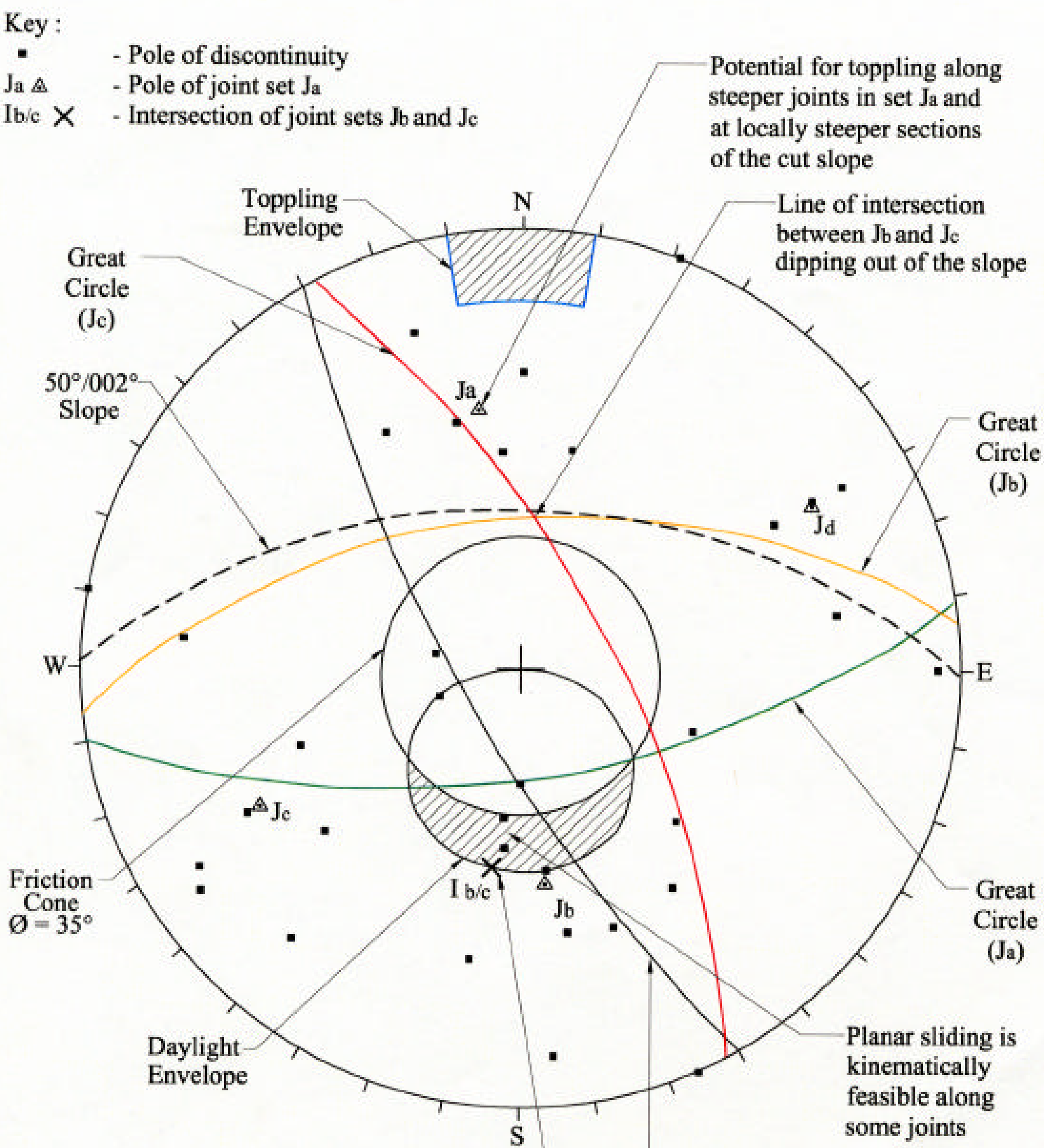
(* Broken lines on map denote uncertainty)

STRUCTURAL SYMBOLS

- 20 Inclined bedding
- 20 Inclined flow fabric
- 20 Inclined intrusive contact
- 20 Inclined jointing
- 20 Inclined metamorphic foliation

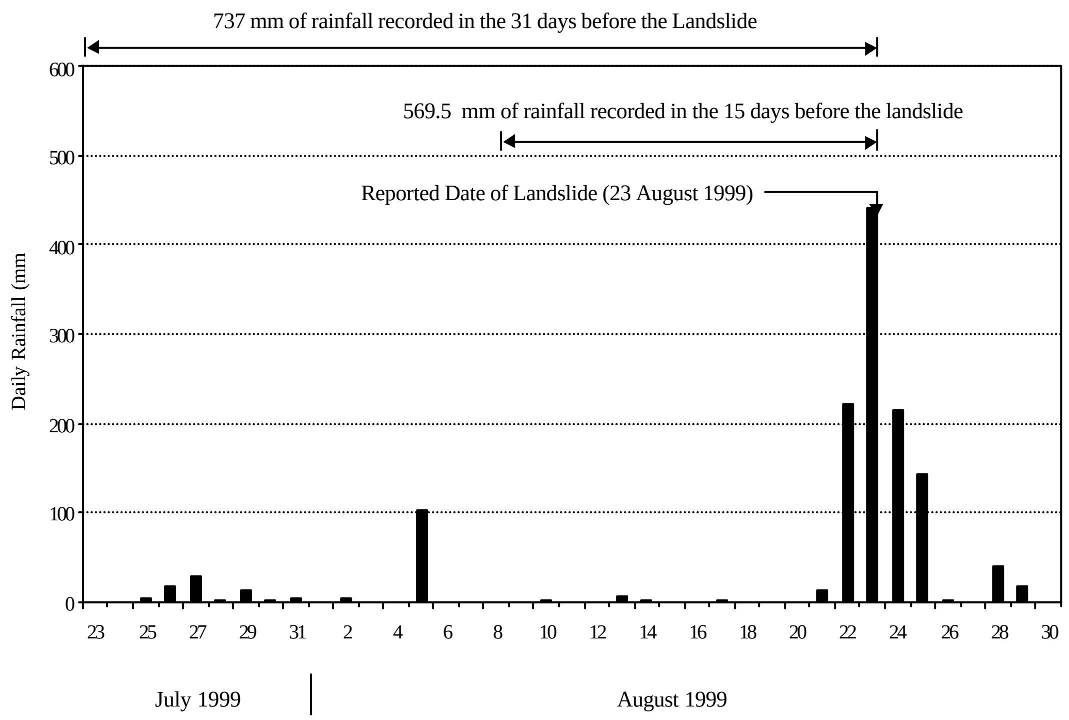
Notes: (1) Geology relevant to study area shown bold.
(2) Extracted from Sheets 6 and 7of the Hong Kong Geological Survey 1 : 20,000 Scale Map Series HGM20, (GCO, 1988a and 1986).

Figure 6 – Regional Geology

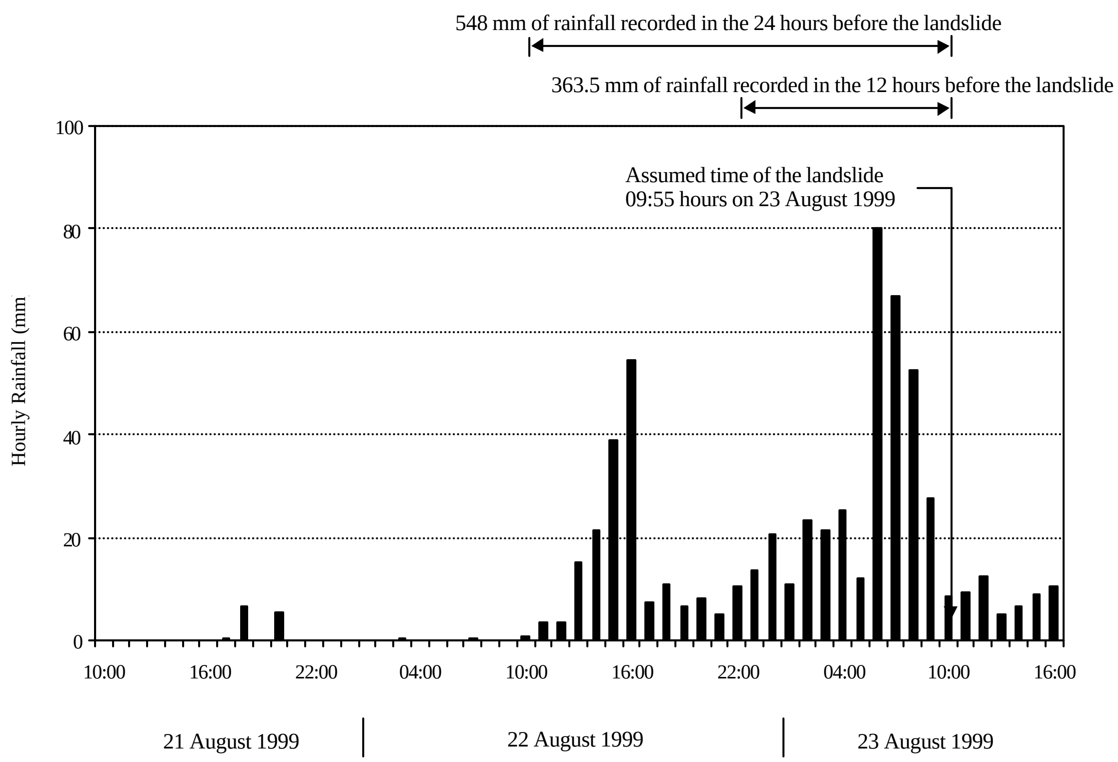


Joint set	Dip Direction(°)	Dip (°)
Ja	170	62
Jb	353	52
Jc	061	67
Jd	240	74

Figure 7 - Stereonet Plot of Discontinuity Data

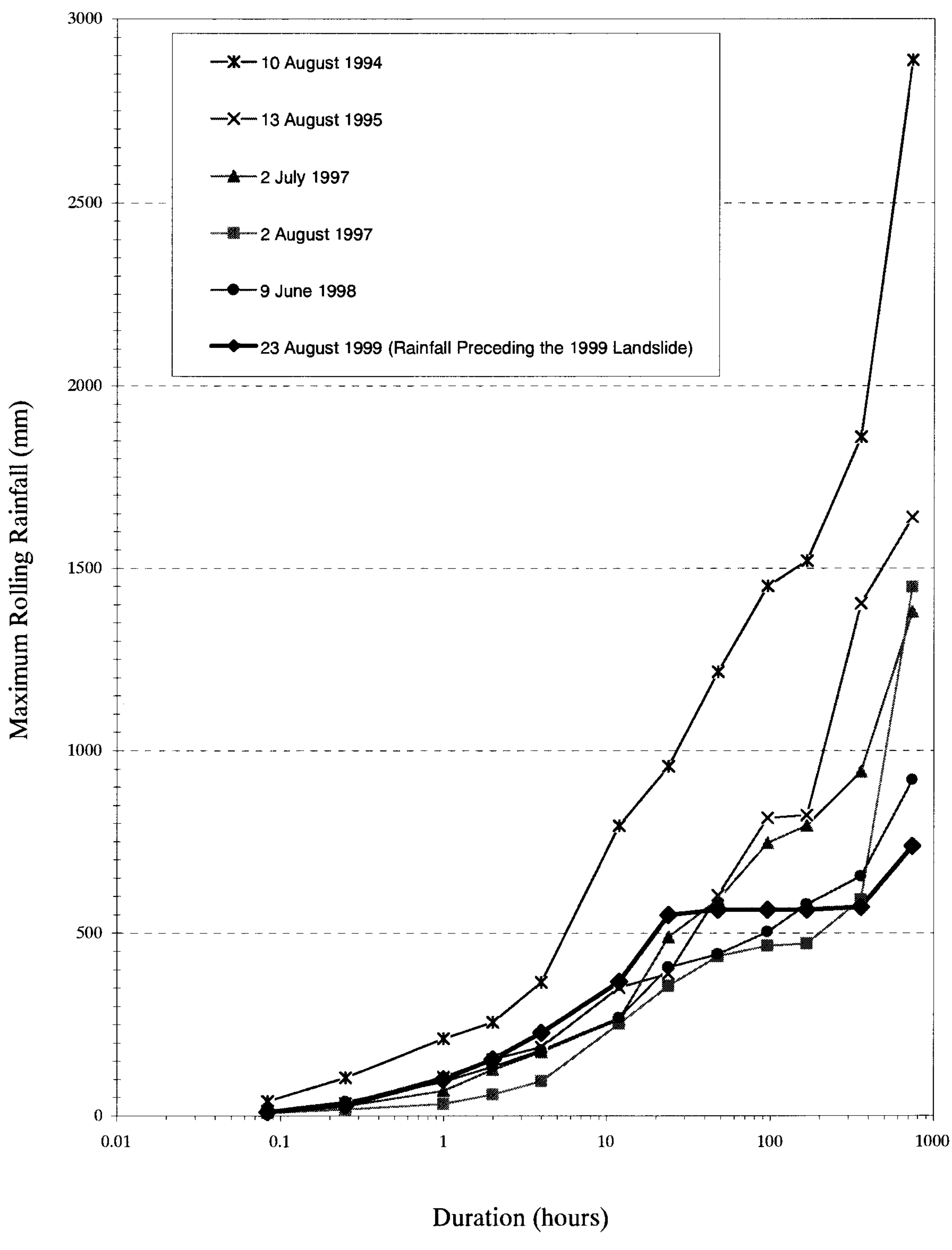


(a) Daily Rainfall Recorded between 23 July and 30 August 1999



(b) Hourly Rainfall Recorded between 10:00 hours on 21 August and 16:00 hours on 23 August 1999

Figure 8 - Rainfall Recorded at GEO Raingauge No. N14



Note: Rainfall data are 5-minute statistics from GEO raingauge No. N14

Figure 9 - Maximum Rolling Rainfalls Preceding the Landslide on 23 August 1999 and Selected Previous Major Rainstorms

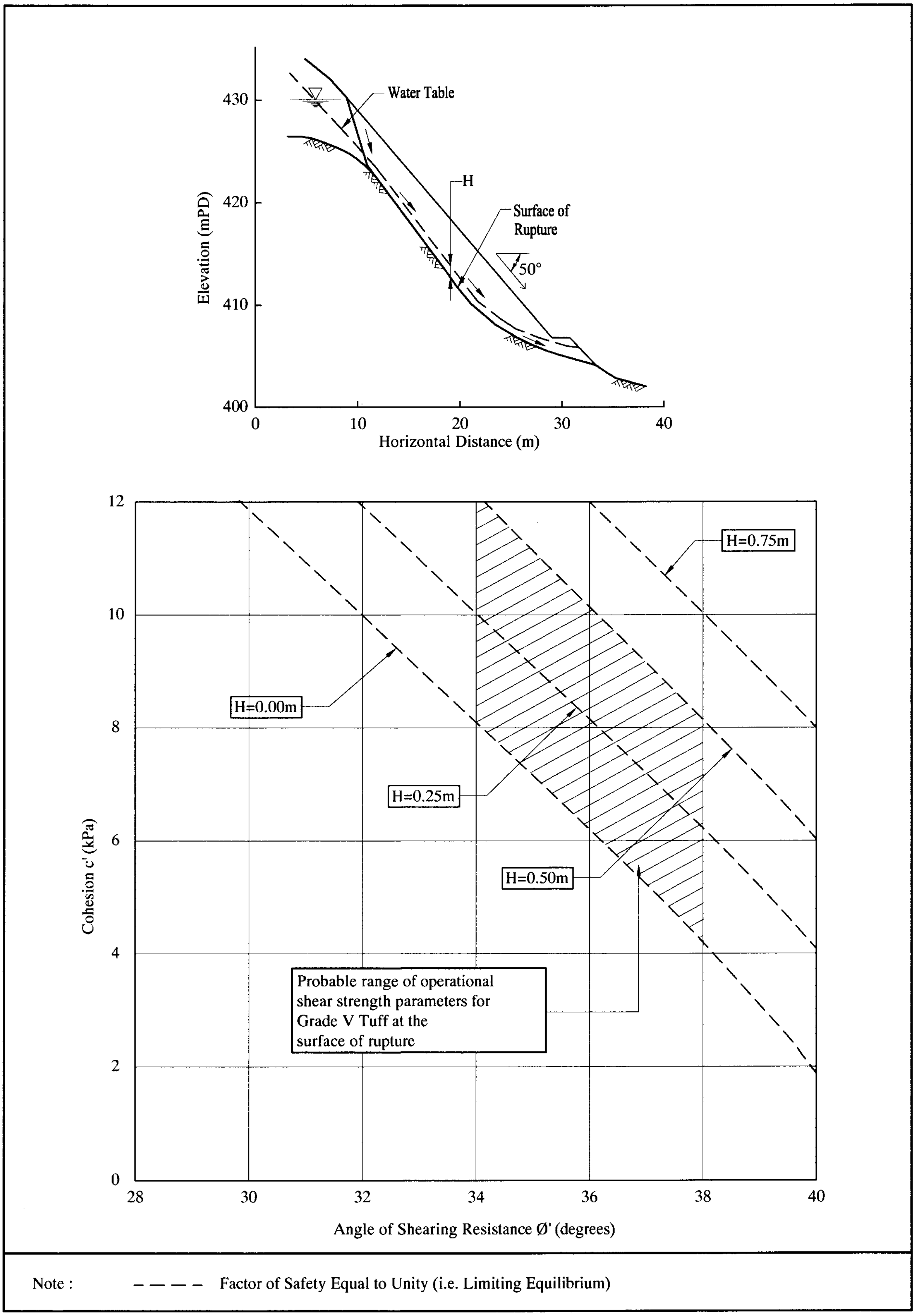
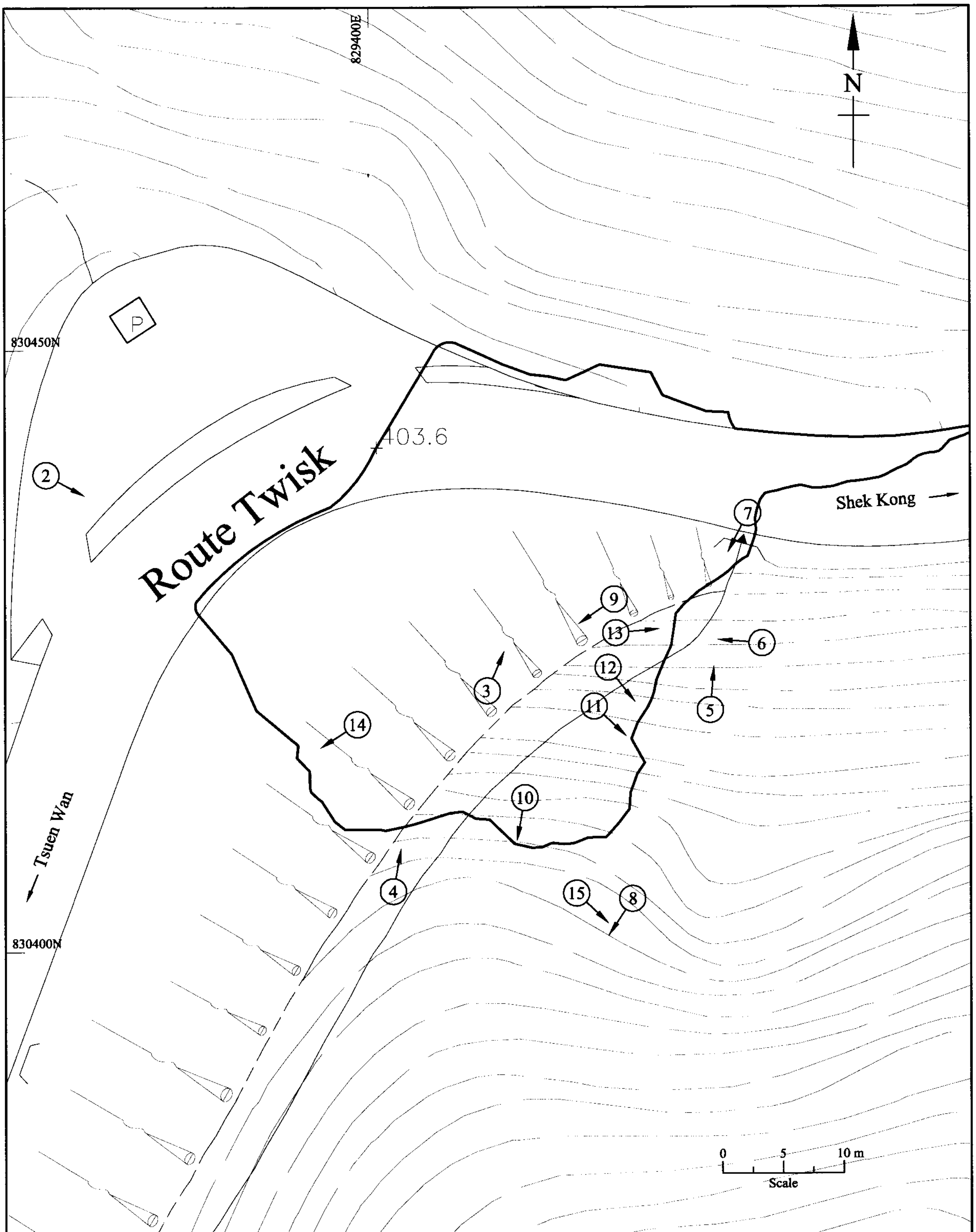


Figure 10 - Summary of Sensitivity Analyses



Legend: 1999 Landslide scar; (12) Approximate location from which Plate No. 12 was taken with general direction of view

Notes:
(1) Base Map is extracted from Survey Sheet No. 6NE-25D, scale 1:1000.
(2) Plate no. 1 was taken from a helicopter.
(3) Information shown on this figure is based on topographical survey and post-landslide field observations.

Figure 11 - Location Plan of Photographs Taken

LIST OF PLATES

Plate 1 – Oblique Aerial View of the Landslide Site
(Photograph Taken on 1 September 1999)

Plate 2 – General View of Landslide Scar Shortly after Failure. Note Water on Margin of Debris Toe (Photograph Taken on 23 August 1999. See Figure 11 for Location)

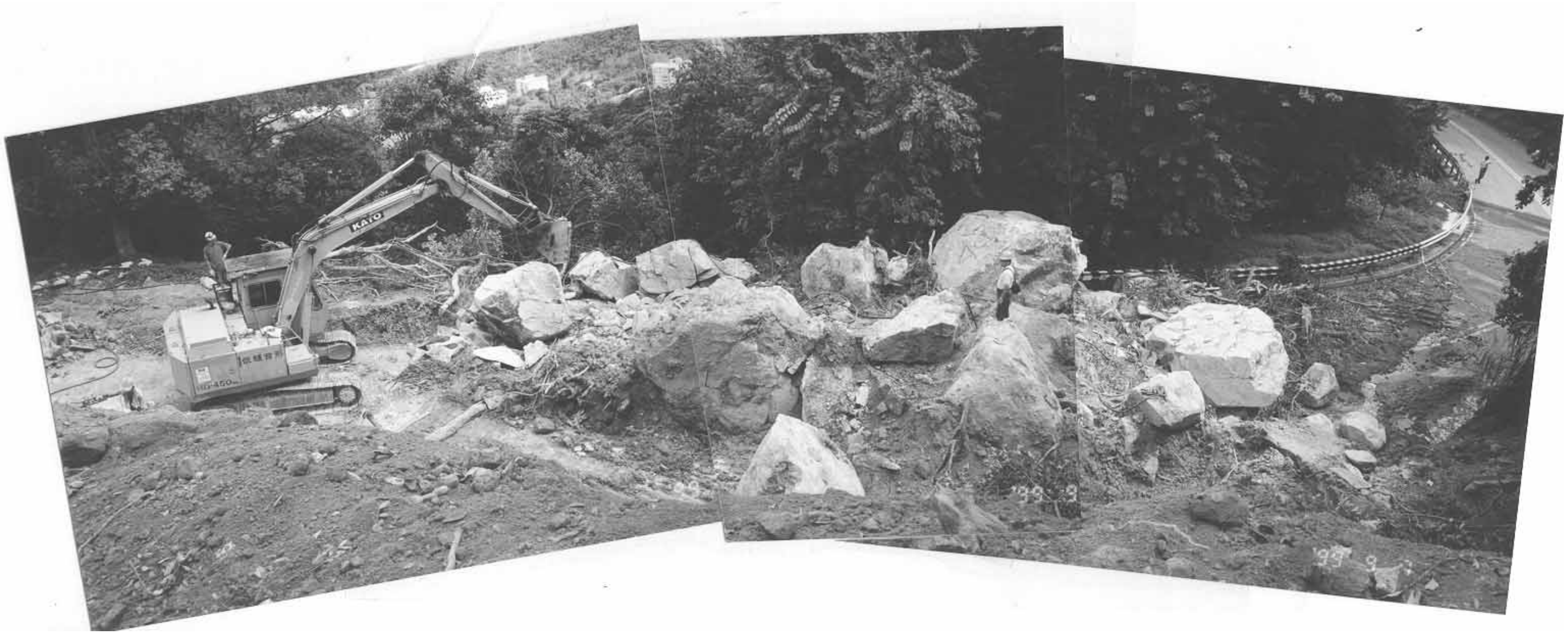


Plate 3 – Large Boulders within Debris Deposited on Route Twisk (Photograph Taken on 7 September 1999. See Figure 11 for Location)

Plate 4 – Dislocated Trapezoidal Drainage Channel above the Western Flank of the Main Scarp (Photograph Taken on 3 September 1999. See Figure 11 for Location)

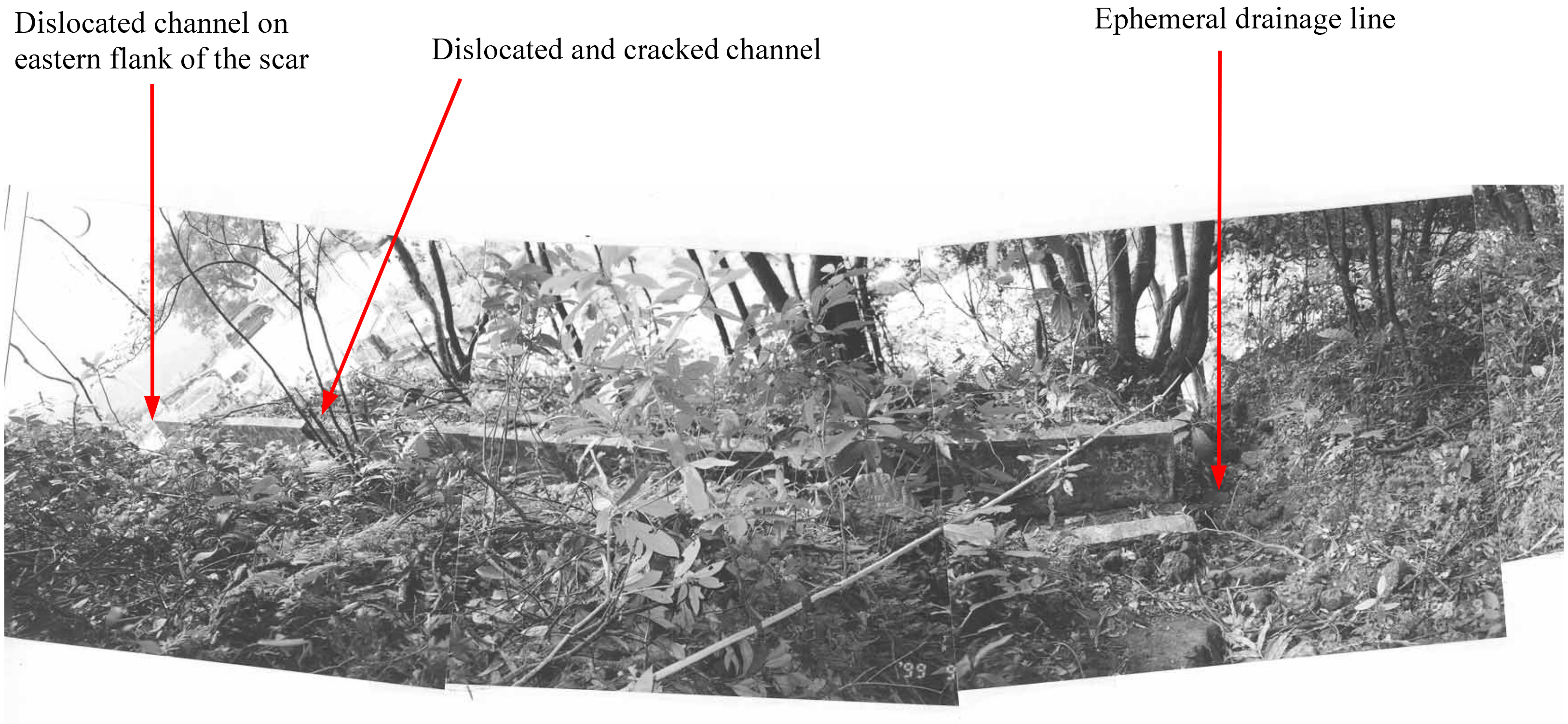


Plate 5 – Lower Part of Trapezoidal Drainage Channel between the Eastern Flank of the Landslide Scar and the Ephemeral Drainage Line (Photograph Taken on 3 September 1999. See Figure 11 for Location)

Plate 6 – Bitumen-coated, Reactivated Crack across the Trapezoidal Channel between the Eastern Flank and the Ephemeral Drainage Line (Photograph Taken on 3 September 1999. See Figure 11 for Location)

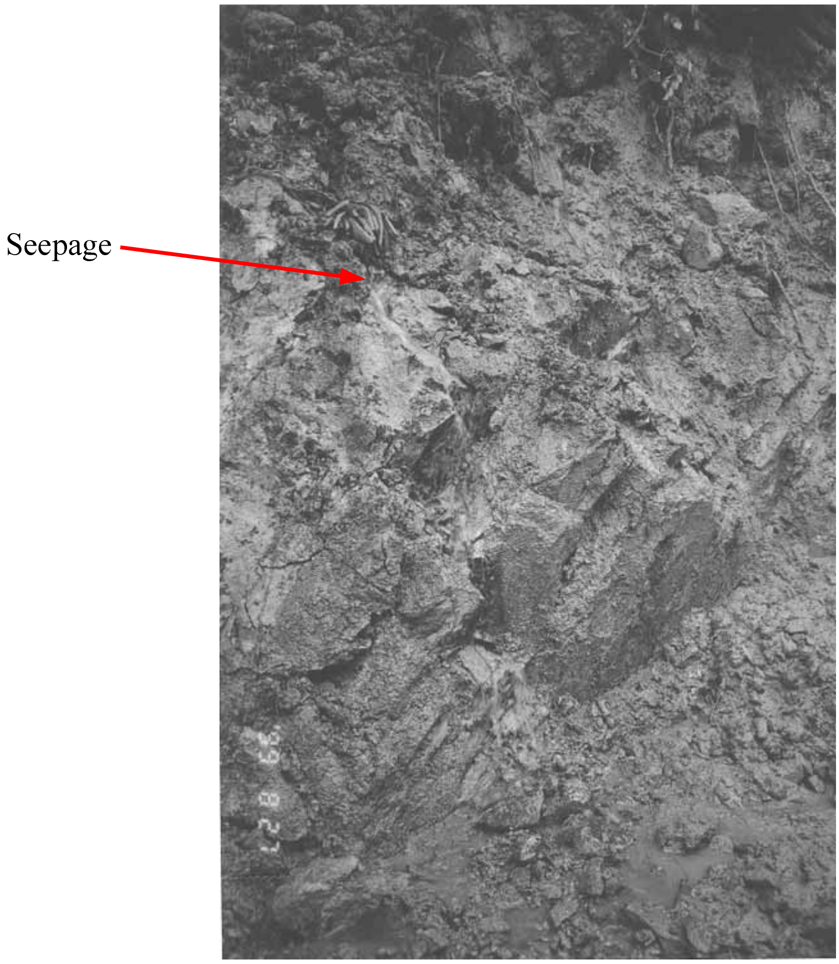


Plate 7 – Seepages Observed along Joints within MDT Close to Rockhead at the Toe of the Eastern Flank of the Scar (Photograph Taken on 27 August 1999. See Figure 11 for Location)

Plate 8 – Pre-existing Tension Crack Located on the Slope above the Crest of the Landslide Scar (Photograph Taken on 8 September 1999. See Figure 11 for Location)

Plate 9 – Main Scarp Following Further Landsliding on 28 August 1999. Note Debris Covering Excavator (Photograph Taken on 30 August 1999. See Figure 11 for Location)

Plate 10 – Soil Pipe Exposed behind the Main Scarp Following Trimming (Photograph Taken on 9 September 1999. See Figure 11 for Location)

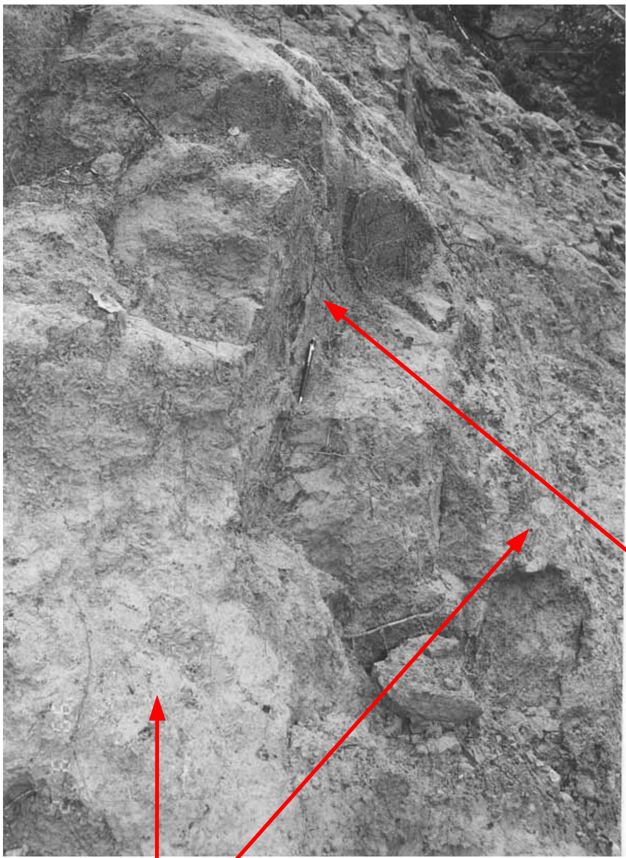


Plate 11a – Release Planes within MDT. Note Infilling and Roots along Joint Planes (Photograph Taken on 2 September 1999. See Figure 11 for Location)

Steeply-dipping release plane (joint)

Release plane coated with clay/silt (joint/tension crack infilling)

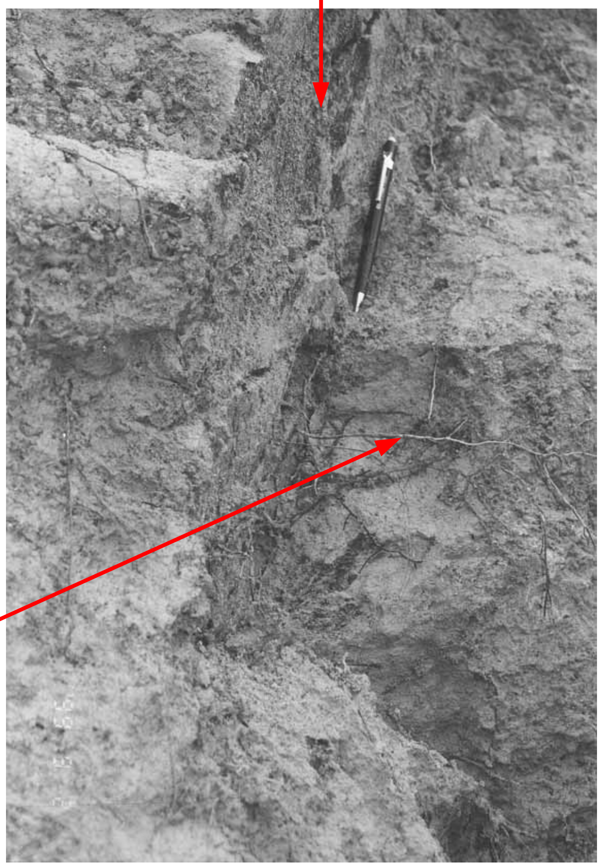


Plate 11b – Close-up View of Infilling with Roots along Release (Joint) Planes (Photograph Taken on 2 September 1999. See Figure 11 for Location)

Roots

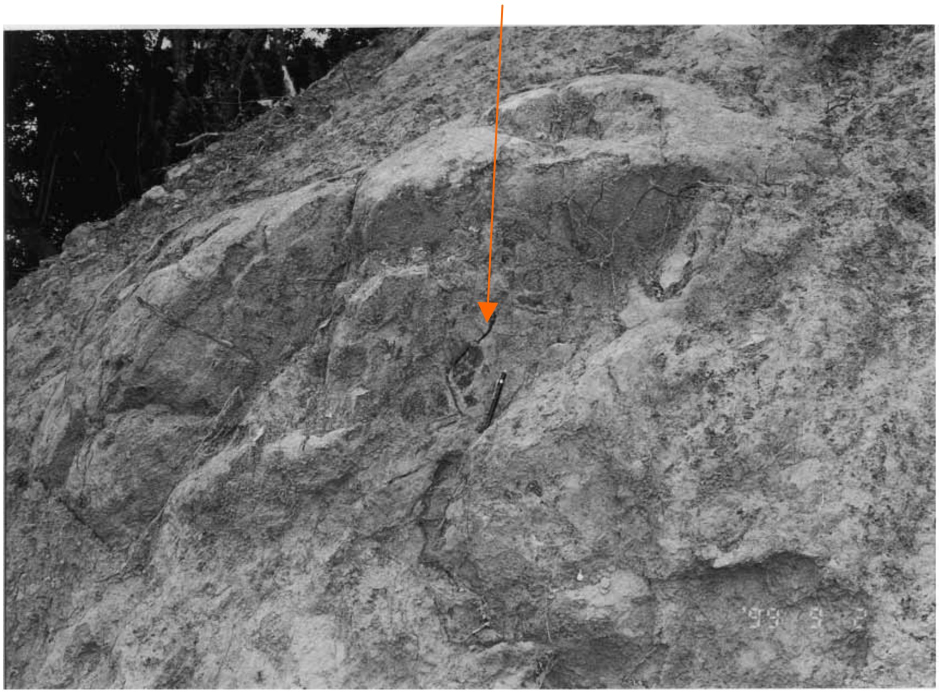


Plate 12a – MDT Corestone within CDT (Surface of CDT is Covered with Previous Tension Crack/Joint Infilling Material). Note Slickensided Manganese Oxide Stained Release Planes. (Photograph Taken on 2 September 1999. See Figure 11 for Location)

Plate 12b – Close-up View of Slickensided Manganese Oxide Stained Release Plane and Open Discontinuity (Photograph Taken on 2 September 1999. See Figure 11 for Location)

Plate 13 – Previous Tension Crack/Joint Infilling Exposed along Release Planes on Eastern Flank of the Scar (Photograph Taken on 2 September 1999. See Figure 11 for Location)

Plate 14a – CDT with Closely-Spaced Discontinuities along Western Flank of the Scar (Photograph Taken on 2 September 1999. See Figure 11 for Location)

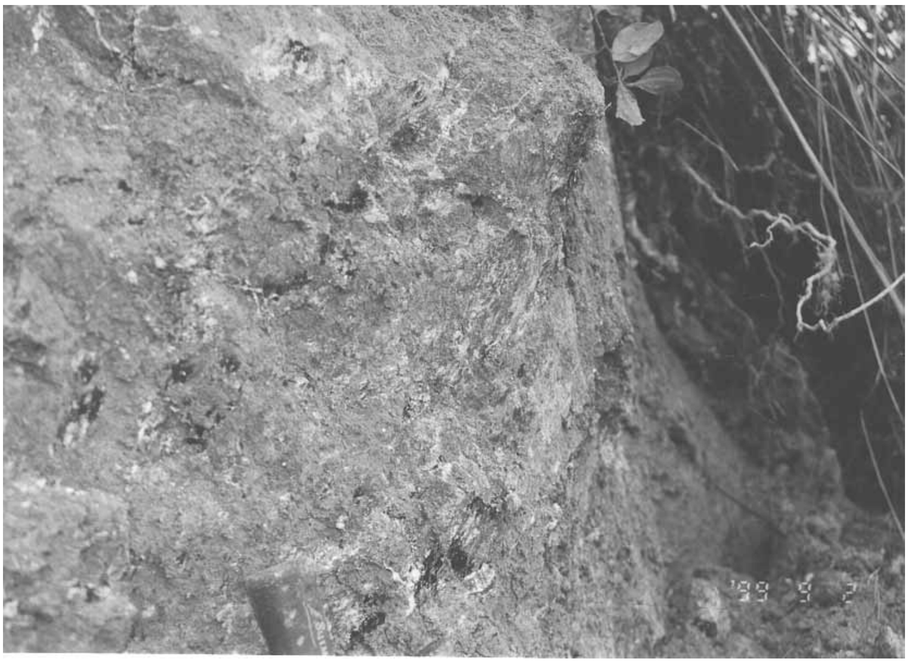


Plate 14b – Close-up View of Discontinuities Infilled with Kaolin and Manganese Oxide Deposits within CDT on Western Flank of the Scar (Photograph Taken on 2 September 1999. See Figure 11 for Location)

Plate 15a – Soil Pipe within Residual Soil in Trial Pit No. TP1 (Photograph Taken on 3 September 1999. See Figure 11 for Location)

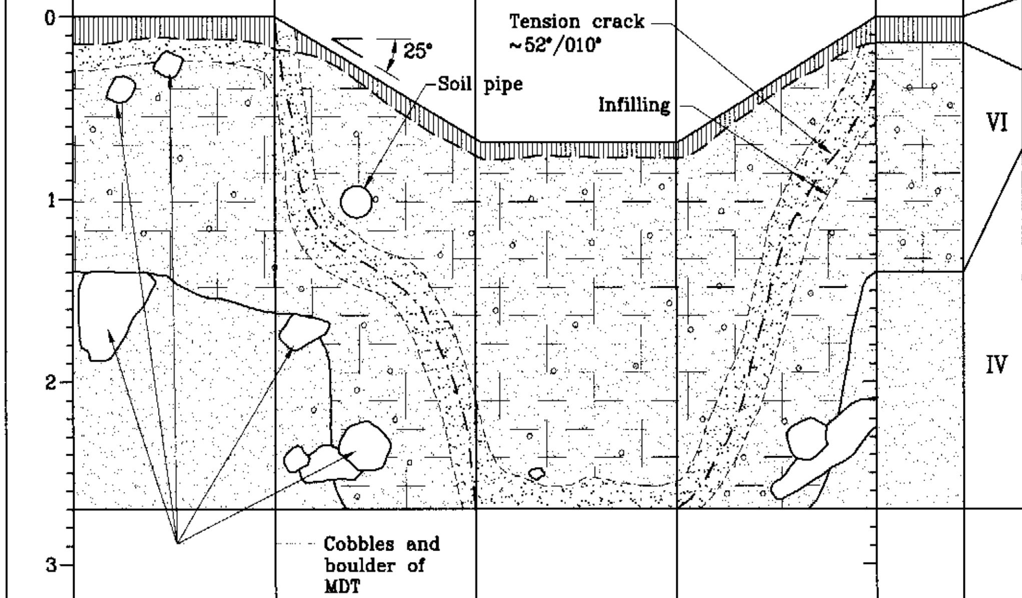
Plate 15b – Close-up View of Soil Pipe (Photograph Taken on 3 September 1999. See Figure 11 for Location)

APPENDIX A

TRIAL PIT RECORDS

Fugro Maunsell Scott Wilson Joint Venture **Agreement No. CE 101/98** **The 1999 Landslide Investigation Consultancy** **Detailed Study No. 8** **Route Twisk, Shek Kong**	TRIAL PIT RECORD		Sheet 1 of 1
	TRIAL PIT No. 1	EXCAVATION DATE: 9/1999 BACKFILL DATE:	
	CO-ORDINATES 829414 E , 830409 N GROUND LEVEL 429.8 mPD	LOGGED BY: KY DATE: 9/1999 CHECKED BY: GRT DATE: 9/1999	

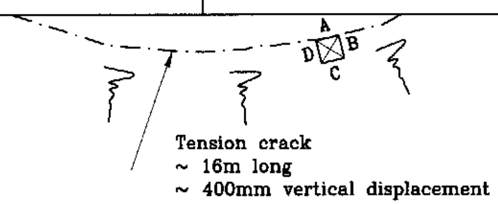
Samples & tests	Depth (m)	FACE A: 1.00 m	FACE B: 1.50 m	FACE C: 1.00 m	FACE D: 1.50 m	Legend	Grade	Description



Grade	Description
	Loose, greyish brown, sandy SILT, with occasional angular to sub-angular fine to coarse gravel, and roots (TOP SOIL)
VI	Loose, reddish brown, sandy, clayey SILT, with some angular to sub-angular fine to coarse gravel, occasional cobbles and boulders of MDT (Residual Soil)
IV	Dense, reddish brown and red, sandy SILT with fine to coarse gravel and many angular to sub-angular cobbles and boulders of MDT (Very weak highly decomposed coarse ash TUFF).

Note : Tension crack within residual soil infilled with loose reddish brown sandy, clayey silt.

PLAN (NOT TO SCALE)

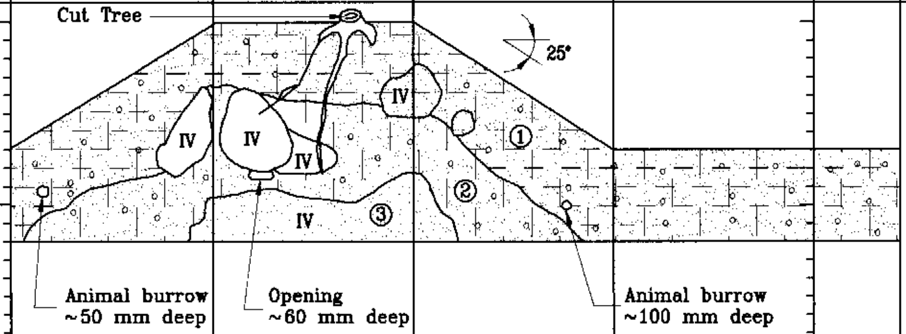


KEY

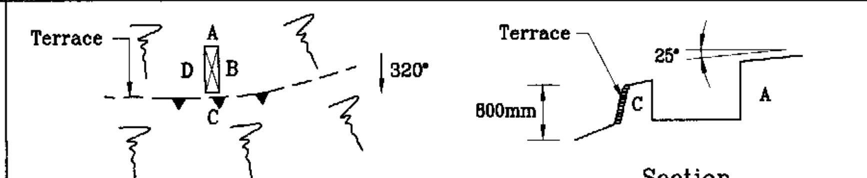
NORTH ARROW

REMARKS

Fugro Maunsell Scott Wilson Joint Venture Agreement No. CE 101/98 The 1999 Landslide Investigation Consultancy Detailed Study No. 8 Route Twisk, Shek Kong	TRIAL PIT RECORD		Sheet 1 of 1
	TRIAL PIT No. 2	EXCAVATION DATE: 9/1999 BACKFILL DATE:	
	CO-ORDINATES 829406.5 E , 830411.6 N GROUND LEVEL 427.6 mPD	LOGGED BY: KY DATE: 9/1999 CHECKED BY: GRT DATE: 9/1999	

Samples & tests	Depth (m)	FACE D: 1.80 m	FACE A: 0.50 m	FACE B: 1.80 m	FACE C: 0.50 m	Legend	Grade	Description
	0–3							① loose, greyish brown, sandy SILT with some angular fine to medium and occasional coarse gravel (FILL/REWORKED residual soil and CDT) ② loose, yellowish brown, sandy, clayey SILT with occasional sub-angular coarse gravel and cobbles of highly decomposed Tuff (Extremely weak completely decomposed coarse ash Tuff) ③ Dense reddish brown sandy SILT (Moderately weak highly decomposed coarse ash TUFF)

PLAN (NOT TO SCALE)



Section

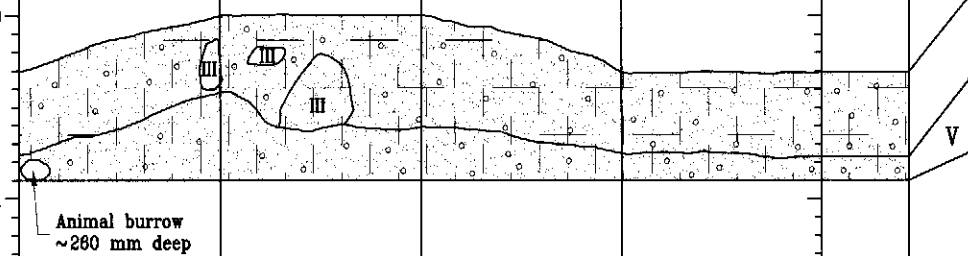
KEY

NORTH ARROW

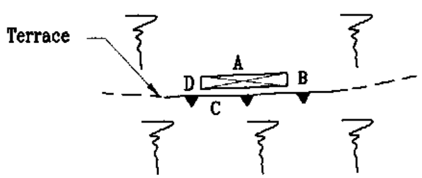
REMARKS

Fugro Maunsell Scott Wilson Joint Venture Agreement No. CE 101/98 The 1999 Landslide Investigation Consultancy Detailed Study No. 8 Route Twisk, Shek Kong	TRIAL PIT RECORD		Sheet 1 of 1
	TRIAL PIT No. 3	EXCAVATION DATE: BACKFILL DATE:	from 9/1999
	CO-ORDINATES 829404.5 E , 830412.5 N GROUND LEVEL 426.9 mPD	LOGGED BY: KY CHECKED BY: GRT	DATE: 9/1999 DATE: 9/1999

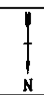
Samples & tests	Depth (m)	FACE D: 0.45 m	FACE A: 2.20 m	FACE B: 0.45 m	FACE C: 2.20 m	Legend	Grade	Description
	0							Loose, greyish brown, sandy clayey SILT, with some angular, fine to coarse gravel and cobbles of MDT (FILL/REWORKED residual soil and CDT)
							V	Loose, yellowish brown to reddish brown, sandy SILT with some sub-angular, medium to coarse gravel (Extremely weak completely decomposed coarse ash TUFF)
	1							
	2							
	3							



PLAN (NOT TO SCALE)



KEY



NORTH ARROW

REMARKS

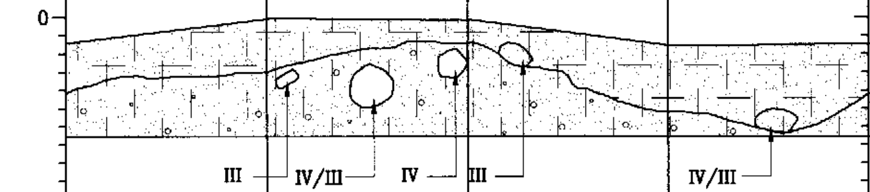
Fugro Maunsell Scott Wilson Joint Venture
Agreement No. CE 101/98
The 1999 Landslide Investigation Consultancy
Detailed Study No. 8
Route Twisk, Shek Kong

TRIAL PIT RECORD

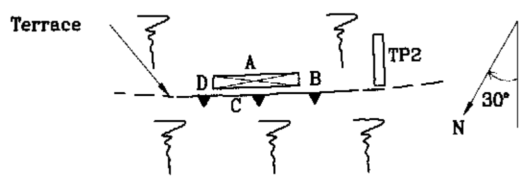
TRIAL PIT No. 4

EXCAVATION DATE:	from 9/1999
BACKFILL DATE:	
CO-ORDINATES	829408.7 E , 830412.8 N
GROUND LEVEL	426 mPD
LOGGED BY: KY	DATE: 9/1999
CHECKED BY: GRT	DATE: 9/1999

Samples & tests	Depth (m)	FACE A: 0.60 m	FACE B: 1.50 m	FACE C: 0.60 m	FACE D: 1.50 m	Legend	Grade	Description
	0							Loose, greyish brown, clayey sandy SILT with occasional cobbles of H-MDT (FILL/REWORKED residual soil and CDT)
							V	Loose, yellowish brown, sandy SILT with occasional cobbles of H-MDT (Extremely weak completely decomposed coarse ash TUFF)
	1							
	2							
	3							



PLAN (NOT TO SCALE)



KEY

NORTH ARROW

REMARKS