THE 25 AUGUST 2003 ROCKFALL ON SLOPE NO. 7SW-C/C362 AT ROUTE TWISK NEAR TSUEN KAM INTERCHANGE TSUEN WAN

GEO REPORT No. 200

Maunsell Geotechnical Services Limited

GEOTECHNICAL ENGINEERING OFFICE
CIVIL ENGINEERING AND DEVELOPMENT 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. The GEO Reports can be downloaded from the website of the Civil Engineering and Development Department (http://www.cedd.gov.hk) on the Internet. Printed copies are also available for some GEO Reports. For printed copies, a charge is made to cover the cost of printing.

The Geotechnical Engineering Office also produces documents specifically for publication. These include guidance documents and results of comprehensive reviews. These publications and the printed GEO Reports may be obtained from the Government's Information Services Department. Information on how to purchase these documents is given on the second last page of this report.

R.K.S. Chan
Head, Geotechnical Engineering Office
January 2007

Table of Contents

Table of Contents

Table of Contents

FOREWORD

This report presents the findings of a review of a rockfall incident (Incident No. 2003/08/0170), which occurred on a soil/rock cut slope (No. 7SW-C/C362) at Route Twisk near Tsuen Kam Interchange, Tsuen Wan. The incident involved the detachment of about 8 m^3 of rock blocks and the displacement of a further 8 m^3 of rock fragments. Most of the detached rock blocks landed on an intermediate berm and about 0.5 m^3 of rock debris was deposited on the pedestrian pavement at the slope toe. The pedestrian pavement was temporarily closed as a result of the incident. No casualties were reported.

The key objectives of the review were to document the facts about the incident including past geotechnical input provided to the slope and pertinent site observations made under this review. The scope of the review does not include any ground investigation or detailed diagnosis of the causes of the incident. Recommendations for follow-up actions are reported separately.

This report was prepared as part of the 2003/2004 Landslide Investigation Consultancy for landslides occurring in Kowloon and the New Territories in 2003 and 2004, for the Geotechnical Engineering Office, Civil Engineering and Development Department (CEDD), under Agreement No. CE 94/2002 (GE). This is one of a series of reports produced during the consultancy by Maunsell Geotechnical Services Limited.

L. J. Endicott.

Dr. L.J. Endicott
Project Director
Maunsell Geotechnical Services Ltd.

Agreement No. CE 94/2002 (GE)
Study of Landslides Occurring in Kowloon and the New Territories in 2003 and 2004 – Feasibility Study

CONTENTS

1. INTRODUCTION

On the morning of 25 August 2003, a rockfall (Incident No. 2003/08/0170) occurred on a soil/rock cut slope (No. 7SW-C/C362) at Route Twisk near Tsuen Kam Interchange, Tsuen Wan (Figure 1). The incident involved the detachment of about 8 m³ of rock blocks and the displacement of a further 8 m³ of rock fragments (Figure 2 and Plate 1). Most of the detached rock blocks landed on an intermediate berm about 7 m above the slope toe and about 0.5 m³ of rock debris was deposited on the pedestrian pavement along Route Twisk (Plate 2). As a result of the incident, the pedestrian pavement was temporarily closed. No casualties were reported.

Following the rockfall incident, Maunsell Geotechnical Services Limited (MGSL), the 2003/2004 Landslide Investigation Consultant for Kowloon and the New Territories, carried out a review of the rockfall incident for the Geotechnical Engineering Office (GEO), under Agreement No. CE 94/2002 (GE).

This review report documents the facts about the incident and presents relevant background information and pertinent observations made by MGSL. The scope of the review does not include any ground investigation. Recommendations for follow-up action are presented separately.

2. THE SITE

Slope No. 7SW-C/C362 is a southeast to east facing soil/rock cut situated to the north of Tsuen Kam Interchange and to the west of Pa Tin Pa Tsuen, Tsuen Wan. A site location plan showing the boundary of the subject cut slope, together with the approximate location of the August 2003 rockfall, is shown in Figure 2. Route Twisk is located immediately below the rock cut portion of the subject slope.

The rock cut portion of slope No. 7SW-C/C362 is about 150 m long, up to 17 m high and inclined at an angle of about 56°. The soil cut portion is about 280 m long and about 11 m in height (Figure 2). The rock portion has two batters inclined generally at an angle of 56°, which are separated by an intermediate berm between 1.8 m and 2.5 m (Plate 4). A paved garden/sitting-out area is located about 5 m from the crest of the rock cut portion of the slope (Figure 2 and Plates 2 and 3). The rock portion is sparsely vegetated with some shrubs and trees in local areas. A ‘reserve zone’ of 1.5 m width has been provided between the pedestrian pavement and the slope toe (Plate 2). No wire mesh netting is provided on the rock cut portion prior to the 2003 rockfall (Plates 4 and 5).

A section of the rock cut at the central portion of the subject slope, which is about 20 m long (where the August 2003 rockfall is located), is inclined locally at an angle of about 60° at the second batter. The widths of the intermediate berm and the toe ‘reserve zone’ immediately below the source area of the August 2003 rockfall are about 1.8 m and 1.5 m respectively (Figure 3).

Surface drainage provisions on the rock cut portion mainly comprise a 200 mm wide crest U-channel running along the eastern part of the slope and a 300 mm U-channel running along the slope toe (Figure 2). A 200 mm wide half-round channel has also been provided on the intermediate berm (Figure 2 and Plate 5).

Based on information provided by the Water Supplies Department and the Drainage Services Department, the approximate alignments of water-carrying services in the vicinity of the site are shown in Figure 2. It is noted that no water-carrying services are located near the crest of the rock cut portion of slope No. 7SW-C/C362. No unrecorded water pipes were observed by MGSL during the post-failure inspections.

According to the Hong Kong Geological Survey 1:20,000 Solid and Superficial Geology Map Sheet 7 - Sha Tin (GCO, 1986), the site is underlain by granodiorite. The approximate interface between granodiorite and coarse ash crystal tuff is about 500 m to the north of the subject slope. A northeast-southwest trending quartzphyric rhyolite dyke intrusion of about 100 m width is located about 400 m to the northwest of the slope (Figure 4).

3. SITE HISTORY AND PAST INSTABILITY

The history of site development has been determined from an interpretation of the available aerial photographs, together with a review of relevant documentary information and site observations (see Figure A1). Detailed observations from the Aerial Photograph Interpretation (API) are summarised in Appendix A.

The earliest available aerial photographs (taken in 1963) show that, prior to the development, the rock cut portion of the slope was located on the southeast-facing natural hillside with a northeast-southwest trending minor spur. The natural hillside is inclined at an angle of about 30°. Cultivation terraces, isolated structures and some graves were present on the hillside at that time.

Based on GEO's file records, slope No. 7SW-C/C362 was formed between 1979 and 1982 by cutting into the natural hillside in connection with the project entitled "Tsuen Wan New Town - Tsuen Wan North Development, PWD 604/78, Formation in Areas 6, 7 & 39". The project comprised realignment of Route Twisk and site formation works for the Pa Tin Pa Tsuen development.

A flat area above the crest of the rock cut portion was formed by 1982, which was subsequently transformed into a garden/sitting-out area in 1985. Since 1993, vegetation has gradually become established on the rock cut portion of the slope. Based on API, no obvious signs of erosion or seepage were present on the slope surface after the completion of slope formation in 1982.

According to the GEO's landslide database, there are no records of landslides in the vicinity of slope No. 7SW-C/C362. The GEO Natural Terrain Landslide Inventory and Large Landslide Database also contain no records of landslide incidents in the vicinity of the subject slope.

4. MAINTENANCE RESPONSIBILITY AND LAND STATUS

According to the Slope Maintenance Responsibility Information System of the Lands Department, slope No. 7SW-C/C362 is of mixed maintenance responsibility (MR) (Figure 2). The western slope portion (where the August 2003 rockfall occurred) is under the MR of the Leisure and Cultural Services Department (LCSD), while the eastern slope portion is under the MR of the Architectural Services Department (Arch SD). Arch SD is the maintenance agent for the entire area of slope No. 7SW-C/C362.

5. PAST ASSESSMENTS AND SLOPE WORKS

5.1 Geotechnical Submission by Scott Wilson Kirkpatrick & Partners in 1980

In June 1980, Scott Wilson Kirkpatrick & Partners (SWKP), the geotechnical consultant to the Tsuen Wan New Town Development Office (TWNTDO) of the Public Works Department, submitted a geotechnical report (SWKP, 1980) for the project entitled "Tsuen Wan New Town, Tsuen Wan North Development, PWD 604/78, Formation in Areas 6, 7 & 39" to the Geotechnical Control Office (GCO, renamed GEO in 1991) for comments.

As indicated in the geotechnical report, the pre-existing natural hillside would be set back and slopes (including slope No. 7SW-C/C362) would be formed for the proposed road re-alignment and site formation works. The rock cut portion of slope No. 7SW-C/C362 was proposed to be "formed by pre-splitting" at 3 (V) on 1 (H) (i.e. about 70°) in one single batter and that the overall rock slope stability would be assessed "after the geological features have been determined on excavation". In August 1980, Binnie & Partners (B&P), acting on behalf of the GCO in checking the submission, commented that "Further details to be forwarded [to the GCO] in due course" which should include the "Design of rock slopes".

On 25 June 1981, B&P noted that formation of the subject rock slope by pre-splitting had commenced and that "the cut slope between approximate ch.350 and 450 on the realigned Route Twisk" (i.e. the rock cut portion of the subject slope) had been formed at 1.5 (V) on 1 (H) (about 56°) "to suit the actual site condition". B&P subsequently requested that "a design of the rock slope should be submitted as soon as possible". The request was conveyed to TWNTDO on 20 July 1981.

On 19 August 1981, SWKP submitted a geotechnical report entitled "Report on Rock Slope above Realigned Route Twisk and Village Access Road" (SWKP, 1981), which included the detailed design of the rock cut portion of slope No. 7SW-C/C362, to the GCO for comments. Based on the results of trial blasting and initial rock joint measurements, the report noted that "the critical structure feature was a 55° to 70° planar joint set dipping directly out of [dip direction of 140°] the slope face. It was therefore decided to eliminate these joints daylighting in the face and a 1.5 on 1 (56°) slope angle was instructed".

SWKP carried out a rock joint survey along the slope toe and the intermediate berm and about 100 rock joints were surveyed. The joints were found to be mostly spaced at 1 m to 10 m and occasionally greater than 10 m, with chlorite and iron oxide staining and apertures of less than 5 mm. The results of the survey are presented in Appendix B.

A contoured stereoplot of the rock joint data was generated by SWKP (reproduced as Figure 5). The joint friction angle with "an allowance for roughness is assessed from visual inspection as 35^{o}". The report noted from the stereoplot that "only a small section [of a major joint] is within 20^{o} of the slope face direction. There is therefore only a low probability of planar joints daylighting in the rock face". The report also noted that a toppling failure mode was not likely owing to the "blocky nature of the rock".

SWKP noted that minor rockfalls were possible and to deal with this scenario, a 2.5 m wide intermediate berm and a 1.5 m wide 'reserve zone' at the slope toe were proposed as "catchment zones".

The slope formation works were completed in September 1981 (Plates 7 and 8). No potential wedge instability was reported by SWKP on the rock cut portion. SWKP noted that "the constructed slopes are considered stable and no remedial works other than scaling of loose rock are anticipated".

Following a site inspection in September 1981, B&P "agreed that the overall stability of the rock slopes is acceptable". B&P noted the width of the intermediate berm was uneven and recommended remedial works comprising removal of loose blocks, provision of surface drainage, provision of a hard surface to the intermediate berm and sealing of a persistent weathered joint. B&P also recommended that SWKP should review the need for remedial works to potential toppling blocks. The comments and recommendations by B&P were conveyed to TWNTDO on 22 September 1981.

In March 1982, SWKP informed the GCO and B&P that the works order for the recommended remedial works had been issued. GCO further reminded SWKP to remove all loose rock blocks on slope surface.

In a memo dated 7 February 1983 to the Highways Office, the GCO accepted the geotechnical design of slope No. 7SW-C/C362.

5.2 SIFT and SIRST Studies

In July 1994, under the "Systematic Inspection of Features in the Territory" (SIFT) project, slope No. 7SW-C/C362 was designated SIFT Class 'C2', i.e. a slope that had "been formed or substantially modified after 30.6.78".

In February 1997, under the "Systematic Identification and Registration of Slopes in the Territory" (SIRST) project, slope No. 7SW-C/C362 was inspected by the SIRST Consultant. According to the SIRST inspection record, the overall maintenance condition of the slope was assessed as "good". The consequence-to-life category of the slope was assessed as "1".

5.3 Engineer Inspection and Routine Maintenance Inspection

In March 2002, Fugro (Hong Kong) Limited (FHK) carried out an Engineer Inspection (EI) of slope No. 7SW-C/C362 under Agreement No. CE 11/2001(GE) with Arch SD. As indicated in the EI report, no signs of distress (i.e. loose blocks or loose wedges on the slope,

badly fractured zones, open joints or seepage) were observed on the rock cut portion. The overall state of maintenance of the slope was assessed as "FAIR". The EI report noted that SIFT Class "C2" was assigned to the subject slope but "No available documents indicating studies have been carried out for the feature in the past". The EI recommended that stability assessment of the slope should be carried out.

Routine maintenance works for the rock cut portion comprising the removal of undesirable vegetation and clearance of blocked channels were recommended to the Arch SD. No preventive maintenance works were recommended.

In December 2002, a routine maintenance inspection (RMI) was carried out by the Arch SD. The RMI recommended clearance of blocked channels. According to the Arch SD, the maintenance works were completed in February 2003.

6. THE AUGUST 2003 ROCKFALL AND POST-FAILURE OBSERVATIONS

According to the GEO incident report, the rockfall incident occurred on the rock cut portion of slope No. 7SW-C/C362 at about 9 a.m. on 25 August 2003. The source of the rockfall was located within the second slope batter near the crest of the rock cut portion, just below a paved garden/sitting-out area (Figures 2 and 3).

The rockfall involved the detachment of about 8 m^3 of rock blocks and the displacement of a further 8 m^3 of rock fragments. The failure scar was approximately 5 m long by 8 m wide by 0.4 m deep (Figure 6 and Plate 1). The fallen rock blocks, with a maximum size of about 0.2 m^3, mostly landed on the intermediate berm (about 1.8 m wide at this point, see Figure 3) and some came to rest against a tree below the failure scar. Some rock debris (<0.5 m^3 in volume) was deposited on the 1.5 m wide 'reserve zone' and the 2.1 m wide pedestrian pavement at the slope toe (Plate 2). As a result of the rockfall, a section of the pedestrian pavement directly in front of the slope toe was temporarily closed. It is noted that no fence (e.g. chain link fence) has been provided to cordon off the 'reserve zone' and that it can be accessible by general public.

The back-release surface of the rockfall source is inclined at an angle of about 50° (see Figure 6). The materials exposed at the source comprised moderately strong, light greenish grey, moderately decomposed coarse-grained granodiorite with iron and manganese oxide stained joints that were occasionally infilled with non-cohesive soil. The August 2003 rockfall appears to have involved a planar failure of rock blocks along a steep release surface (50^o). It is noted that the rock section (about 20 m long) in the vicinity of the source of the rockfall is inclined locally at an angle of about 60^o, whilst the other slope sections are dipping at about 56°.

Based on the post-failure site observations and joint orientation measurements by MGSL, an assessment of the rock mass characteristics of the rock cut portion of slope No. 7SW-C/C362 was undertaken. Three joint sets (viz. 50°/160°, 62°/090° and 56°/191°) were identified. The joint set 50°/160° that was involved in the August 2003 rockfall was only observed locally at the source of the rockfall and not at the other rock exposures along the slope.

The rock cut portion of the slope is sparsely vegetated with some local shrubs (Plates 4 and 5). There are a number of trees in the vegetated area above the landslide scar and isolated trees on the rock cut portion of the slope (Plate 1). Tree roots of 10 mm to 20 mm diameter were exposed within the upper part of the basal sliding plane and adjacent to the source of the rockfall (Plates 5 and 9).

Both the crest channel and half-round berm channel in the vicinity of the August 2003 rockfall were almost completely blocked with vegetation (Plates 5 and 6). Also, a section of the crest channel (about 8 m long) was completely buried by soil of up to about 0.3 m thick and covered extensively with tree roots (Figure 2 and Plate 10). No signs of seepage were observed on slope No. 7SW-C/C362 during MGSL's inspections.

Site inspection by MGSL in March 2005 revealed that the slope remedial works as recommended by the GEO and Arch SD for the August 2003 rockfall, which comprised removal of loose rock blocks, vegetation clearance, installation of pattern rock dowels (Plate 11) and provision of wire mesh netting at selected areas (with the potential for minor ravelling failures), were completed (Plate 12).

Based on site inspections carried out by MGSL, no obvious signs of potential incipient large-scale instability or major adverse geological features were identified on the subject slope.

7. ANALYSIS OF RAINFALL RECORDS

Rainfall data were obtained from GEO automatic raingauge No. N03, which is the nearest raingauge to the landslide site and is located at the Tsuen Wan Treatment Works, Shing Mun Road, Tsuen Wan, approximately 1 km to the east of the rockfall site (Figure 1).

The raingauge records and transmits rainfall data at 5-minute intervals via a telephone line to the Hong Kong Observatory and the GEO. According to the GEO's incident report, the rockfall occurred at about 9 a.m. on 25 August 2003. The daily and hourly rainfall recorded by raingauge No. N03 prior to the August 2003 rockfall are presented in Figure 7. The daily rainfall records show that relatively light rainfall (i.e. about 8 mm) occurred within one hour preceding the rockfall. The maximum 24-hour rolling rainfall preceding the rockfall was about 80 mm. Table 1 presents the estimated return periods for the maximum rolling rainfall for various durations recorded by raingauge No. N03 with reference to the historical rainfall data at the Hong Kong Observatory in Tsim Sha Tsui (Lam & Leung, 1994). The results show that the return period of the 25 August 2003 rainstorm preceding the rockfall was about 2 years.

8. DISCUSSION

The 25 August 2003 rockfall involved the detachment and displacement of a total of 16 m^3 of rock blocks along a steep rock joint (50^o) on an engineered soil/rock cut. The rockfall was probably triggered by light rainfall, with the maximum hourly and 24-hour rolling rainfall of 8 mm and 80 mm respectively preceding the rockfall (Figure 7).

Tree roots of 10 mm to 20 mm diameter were exposed within the upper part of the source of rockfall (Plates 5 and 9), suggesting that the rock joint of concern had been subjected to root jacking action prior to the failure. The rockfall was probably caused by water ingress into a possibly dilated steep rock joint, resulting in the build-up of transient cleft water pressure behind rock blocks. According to the post-failure observations, both the crest and berm channels on the subject slope were probably completely blocked with vegetation at the time of the rockfall (Plates 5 and 6). Overflow of surface water probably resulted in concentrated water ingress into the dilated rock joints that involved in the August 2003 rockfall.

The subject cut slope was previously assessed by a geotechnical consultant and the geotechnical submission was checked and accepted by the GCO in 1983. Based on the results of a contoured stereoplot, the rock cut portion of the slope was proposed to be formed at about 56°. A 2.5 m wide intermediate berm and a 1.5 m wide 'reserve zone' at the slope toe were proposed by the geotechnical consultant to intercept possible minor rockfalls. At the location of the 2003 rockfall, however, the section of the slope was locally steeper (at about 60°). Also, one of the joint sets (50°/160°) that contributed to the kinematic feasibility of the rockfall was a local joint set exposed at the source of the rockfall and it could not be identified from surface mapping of the remaining rock exposures of the slope. This highlighted the uncertainty of the possible presence of local adverse joint sets in giving rise to potential rock slope instabilities. The incident also serves as a reminder of the possible presence of kinematically unstable rock joints that are not identified on a contoured stereoplot.

9. CONCLUSIONS

The 25 August 2003 rockfall was probably caused by water ingress into dilated steep rock joints, resulting in the build-up of transient cleft water pressure behind the rock blocks. One of the major sources of water was probably overspilling of surface water from the blocked crest drain directly above the source of the rockfall. Jacking action of the roots of unplanned mature trees on the slope was probably a key contributory factor to the August 2003 rockfall.

Based on the field inspections, no obvious signs of incipient large-scale instability or major adverse geological features were observed on slope No. 7SW-C/C362 during the course of this study.

10. REFERENCES

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Fugro (Hong Kong) Limited (2002b). Record of Engineering Inspection - 7SW-C/C362 at GL & GLA-TW310 (NT476) South of Pak Tin Pa Tsuen. Architectural Services Department, Hong Kong, 22 p.

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Scott Wilson Kirkpatrick and Partners (1981). Tsuen Wan New Town, Tsuen Wan North Development, PWD 604/78, Formation in Areas 6, 7 & 39 - Report on Rock slopes above Realigned Route Twisk and Village Access Road. Public Works Department, 5 p. and 6 appendices.

LIST OF TABLES

Table 1 - Maximum Rolling Rainfall at GEO Raingauge No. N03 for Selected Durations Preceding the Rockfall on 25 August 2003 and the Estimated Return Periods

Duration	Maximum Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years) (See Note 2)
5 Minutes	2.0	8:00 a.m. on 25 August 2003	< 2
15 Minutes	5.0	8:10 a.m. on 25 August 2003	< 2
1 Hour	8.0	8:20 a.m. on 25 August 2003	< 2
2 Hours	18.5	12:00 a.m. on 24 August 2003	< 2
4 Hours	26.0	12:00 a.m. on 24 August 2003	< 2
12 Hours	64.5	12:00 a.m. on 24 August 2003	< 2
24 Hours	79.5	9:10 a.m. on 25 August 2003	< 2
48 Hours	92.5	9:10 a.m. on 25 August 2003	< 2
4 Days	175.5	9:10 a.m. on 25 August 2003	< 2
7 Days	183.0	9:10 a.m. on 25 August 2003	< 2
15 Days	283.0	9:10 a.m. on 25 August 2003	< 2
31 Days	319.0	8:20 a.m. on 25 August 2003	< 2

Notes:
(1) Maximum rolling rainfall was calculated from 5-minute rainfall data.
(2) Return periods were derived from Table 3 of Lam & Leung (1994) and using data from Evans & Yu (2001). The return periods obtained by the two methods do not show a significant difference.
(3) The use of 5-minute data for return period of rainfall durations between 2 hours and 31 days results in better data resolution, but may slightly over-estimate the return periods using data by Lam & Leung (1994), which are based on hourly rainfall for these durations.
(4) According to the GEO Incident Report, the landslide occurred at 9:15 a.m. on 25 August 2003.
(5) The nearest GEO raingauge to the landslide site is raingauge No. N03 situated at about 1 km to the east of the site.

LIST OF FIGURES

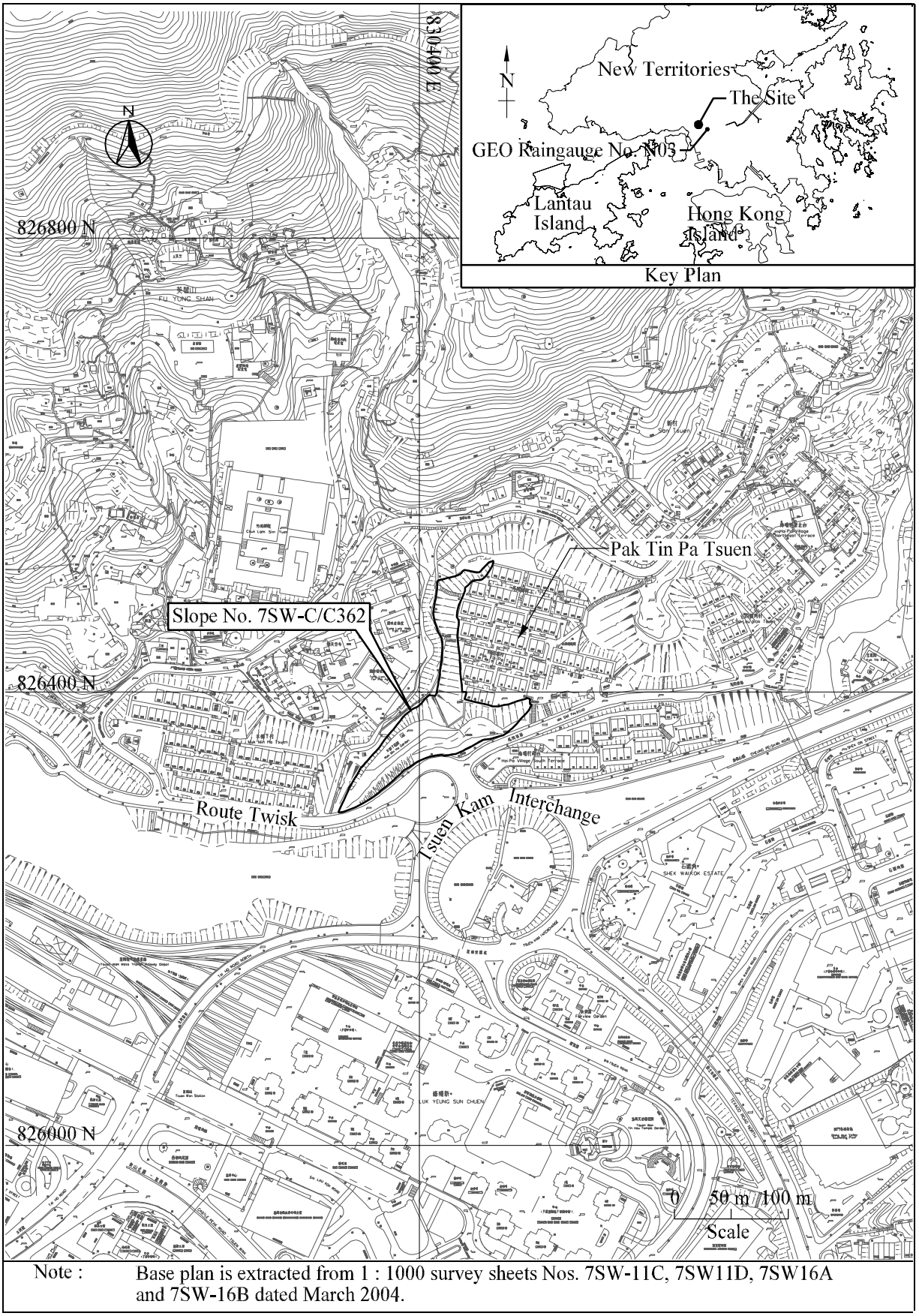


Figure 1 - Location Plan

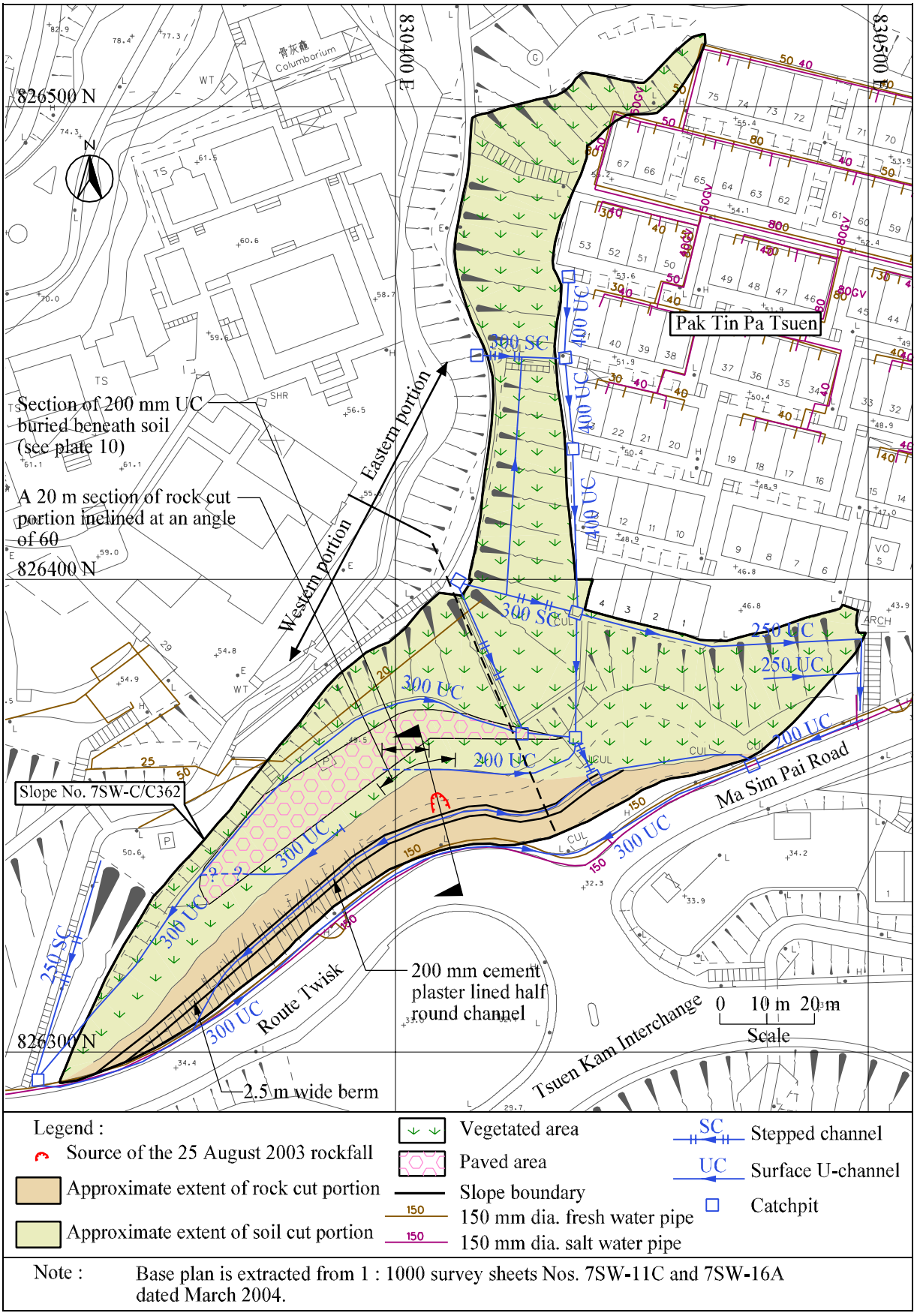
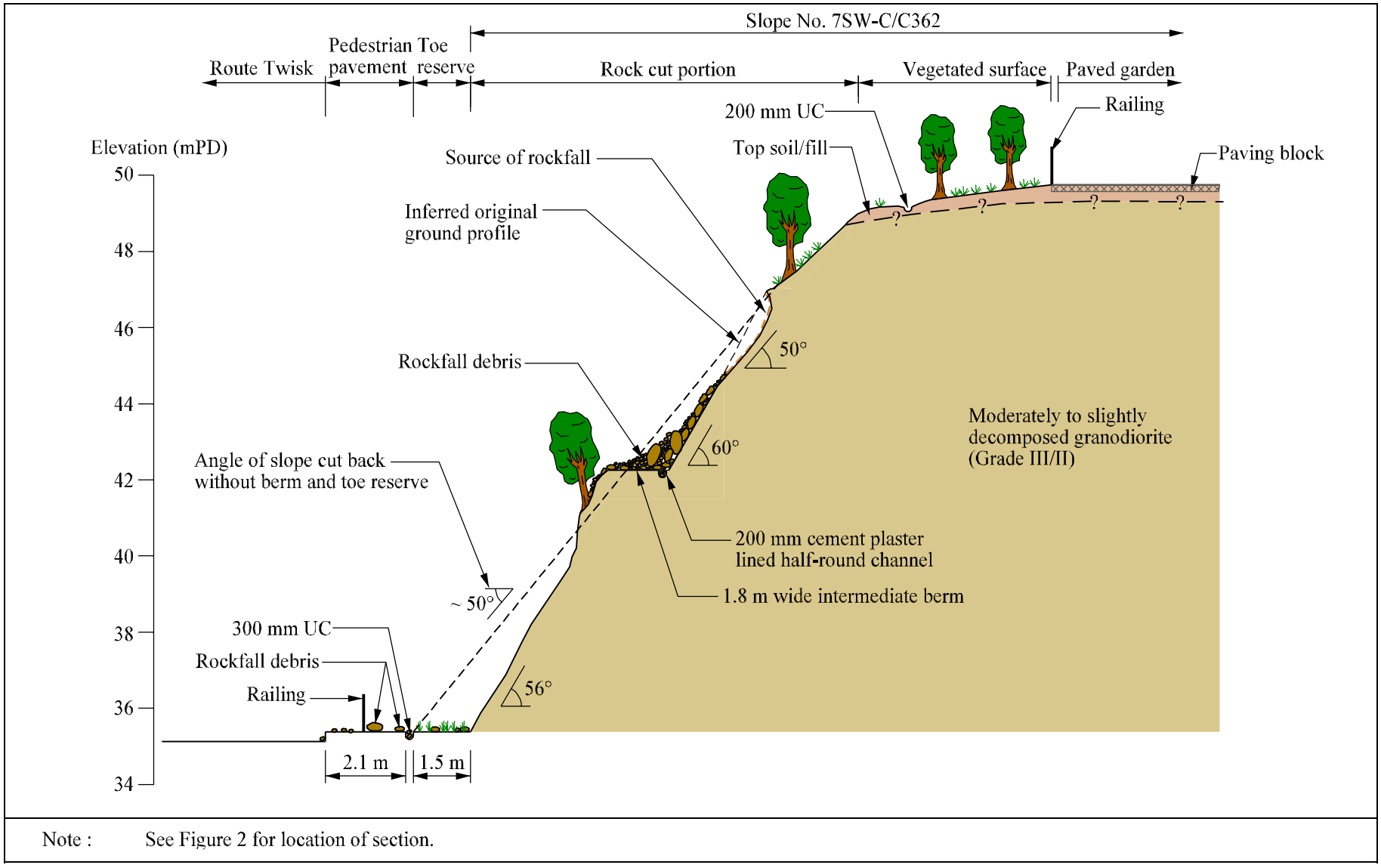
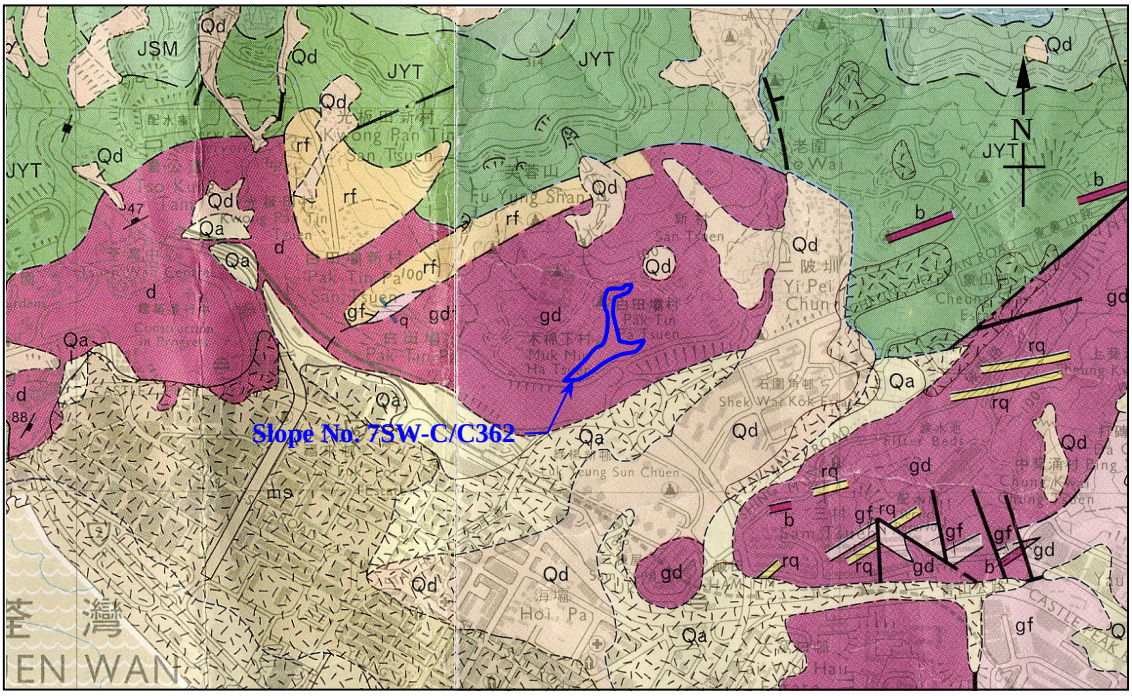


Figure 2 - Site Layout Plan



Note : See Figure 2 for location of section.

Figure 3 - Section through the August 2003 Rockfall Source



LEGEND:

0m — 1000 m

Scale

SUPERFICIAL DEPOSITS

Qa — Pleistocene and Holocene
Clay/silt, sand and gravel (Alluvium)

Qd — Sand, gravel, cobbles and boulders in silt matrix (Slope debris)

Fill

SOLID GEOLOGY

b — Basalt

JYT — Coarse ash crystal tuff (Tsuen Wan Volcanic Group)

rq — Quartzphyric rhyolite

gd — Granodiorite

rf — Feldsparphyric rhyolite

GEOLOGICAL LINES

Geological boundary, superficial deposits

Geological boundary, solid rock
(* Broken lines denote uncertainty)

Fault (crossmark indicates downthrow side)

Mineral vein

Photogeological lineament

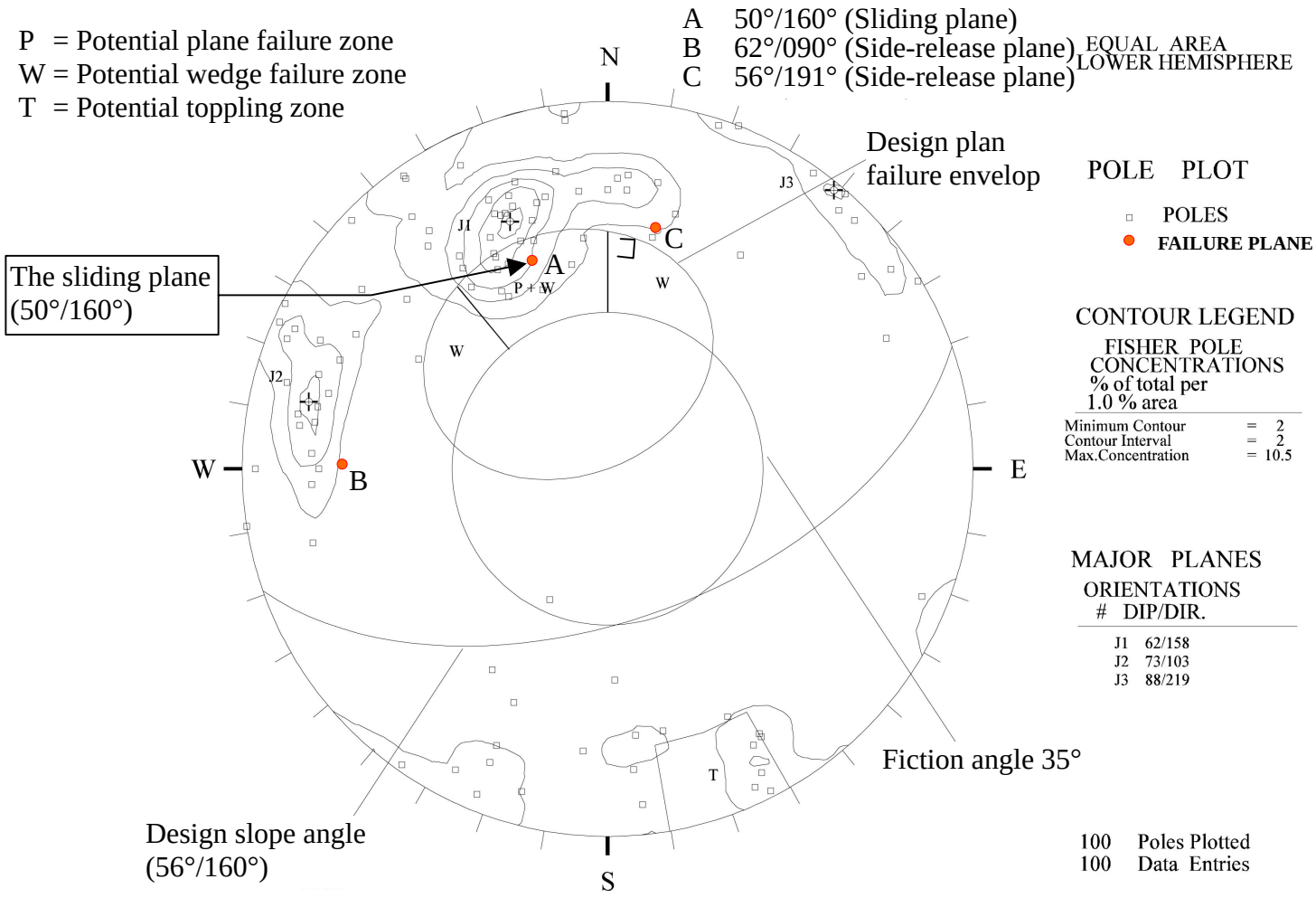
STRUCTURAL SYMBOLS

22 — Intrusive contact

Jointing for vertical

Note: Extracted from Hong Kong Geological Survey, Map Series HGM20, Sheets Nos. 6 and 7, 1:20 000 scale (GCO, 1986).

Figure 4 - Regional Geology



Notes: (1) Joint data extracted from "Report on Rock Slopes above Realigned Route Twisk and Village Access Road" (SWKP, 1981).
(2) Joint data A, B and C are measured by MGSL from the August 2003 rockfall source area.

Figure 5 - Kinematic Analysis by Scott Wilson Kirkpatrick & Partners in 1981

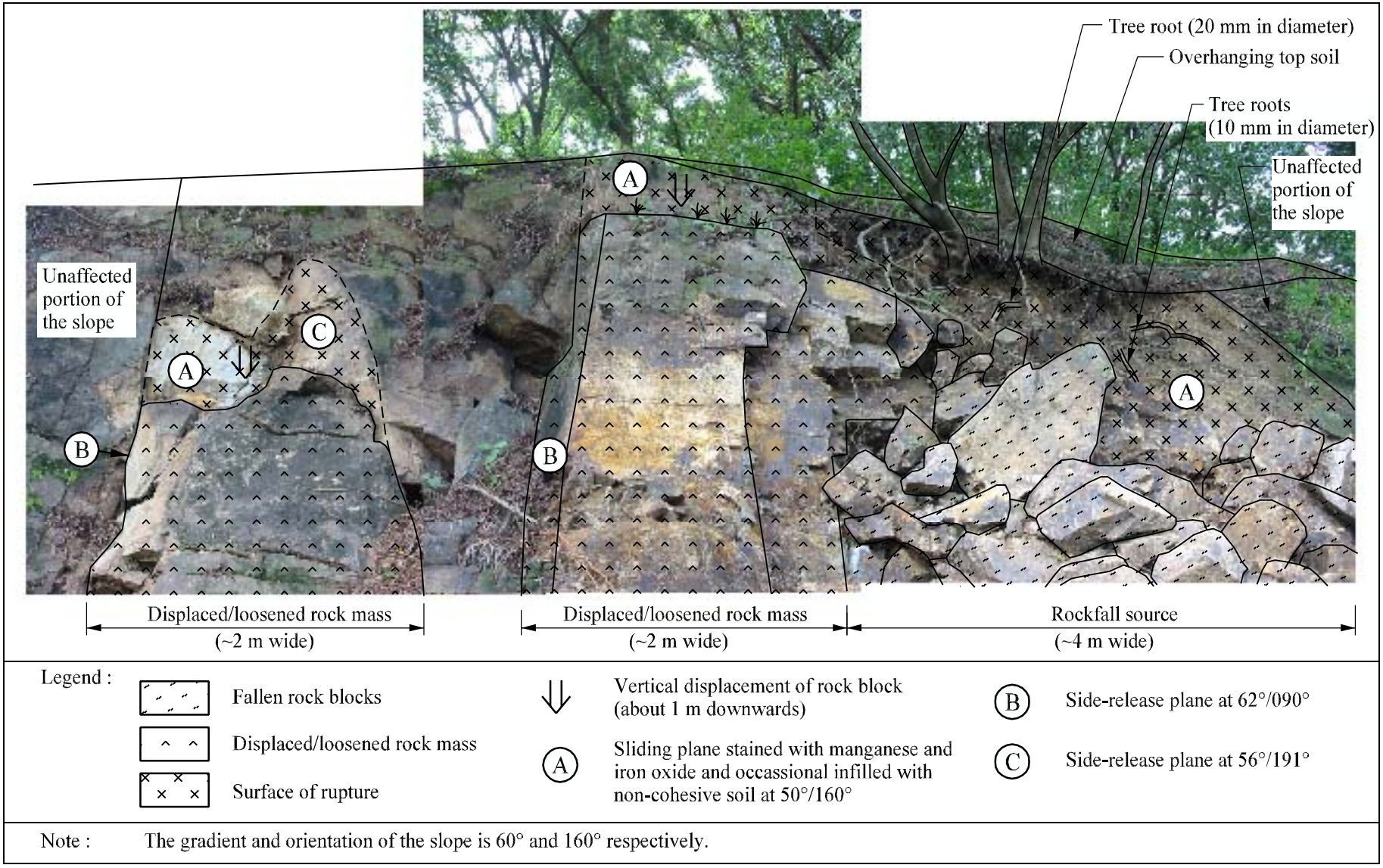
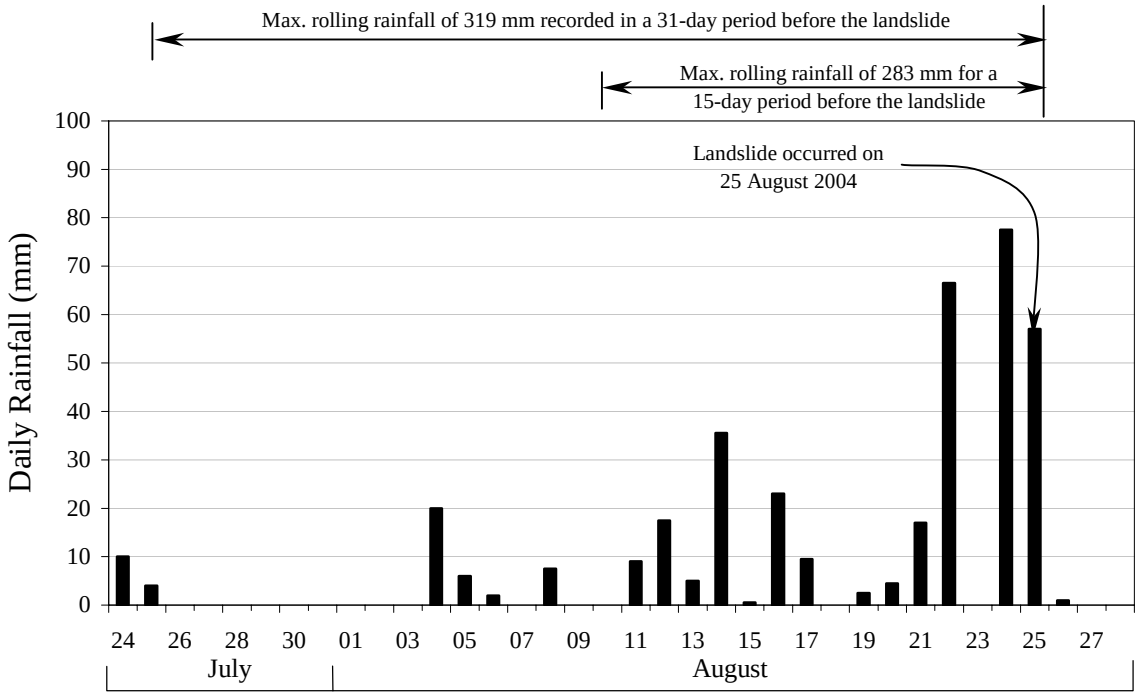
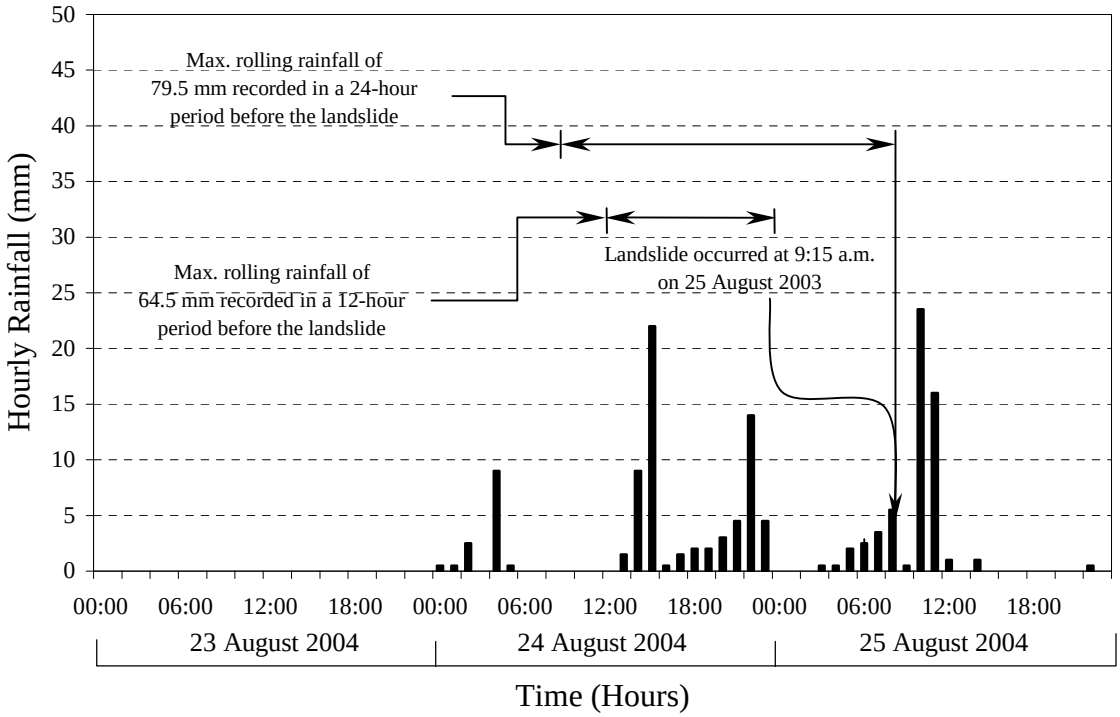


Figure 6 - The Source Area of the August 2003 Rockfall



(a) Daily Rainfall Recorded at GEO Raingauge No. N03 between 24 July 2003 and 28 August 2003



(b) Hourly Rainfall Recorded at GEO Raingauge No. N03 between 23 August 2003 and 25 August 2004

Figure 7 - Daily and Hourly Rainfall Recorded at GEO Raingauge No. N03

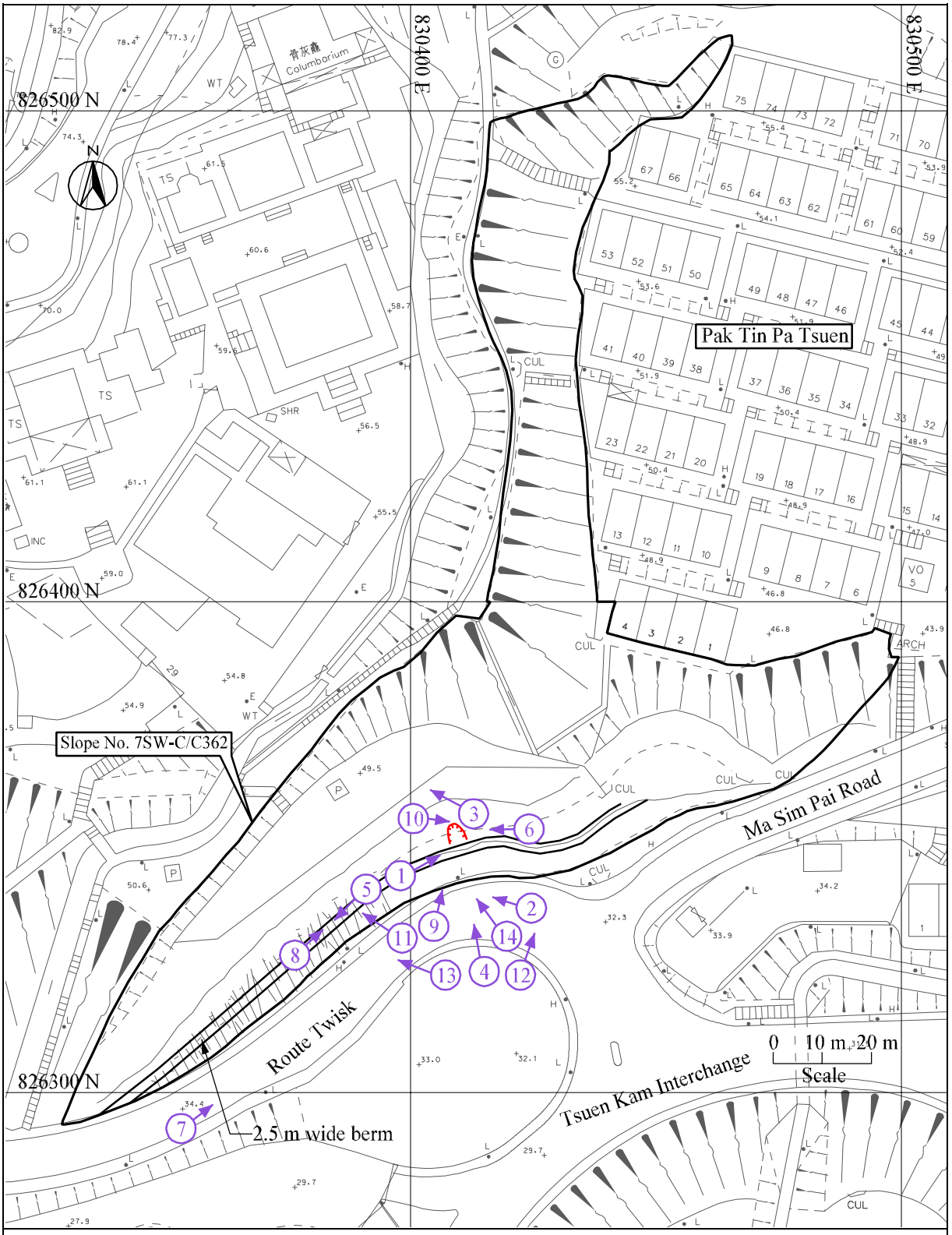


Figure 8 - Locations and Directions of Photographs

Table of Contents
Table of Contents
Table of Contents
Table of Contents

LIST OF PLATES

Plate 1 - The 25 August 2003 Rockfall at Slope No. 7SW-C/C362
(Photograph taken on 26 August 2003)

Plate 2 - View of the Rock Blocks Deposited on the
Pedestrian Pavement along Route Twisk
(Photograph taken on 25 August 2003)

Note: See Figure 8 for locations and directions of photographs.

Plate 3 - The Garden/Sitting-out Area at the Crest of the Rock Portion of the Slope No. 7SW-C/C362
(Photograph taken on 26 August 2003)

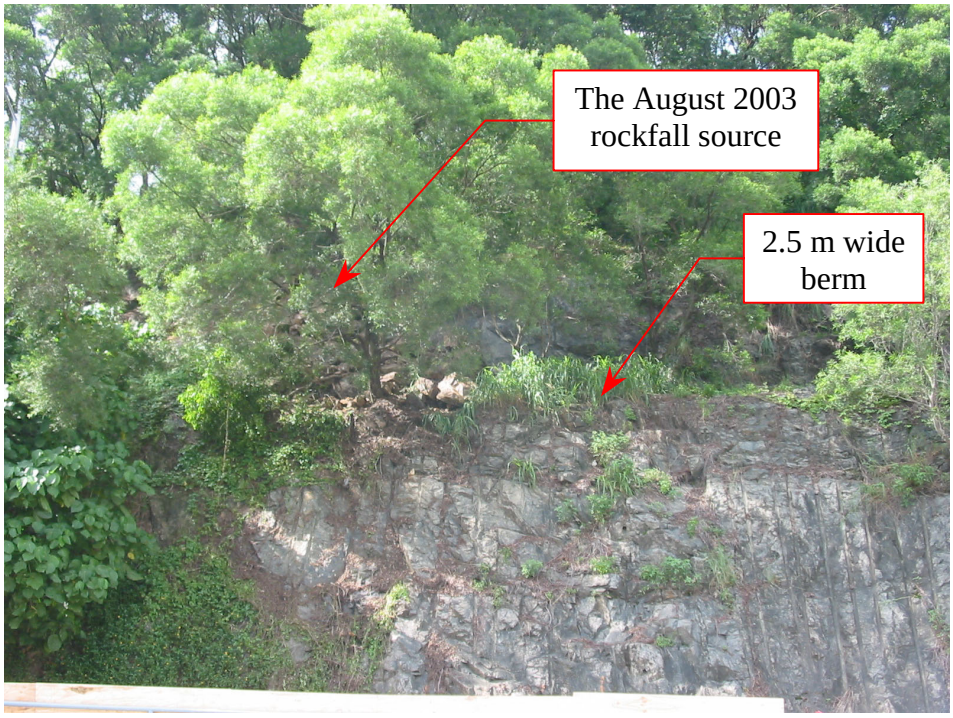


Plate 4 - General View of the Rock Portion of Slope No. 7SW-C/C362
(Photograph taken on 26 August 2003)

Note: See Figure 8 for locations and directions of photographs.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

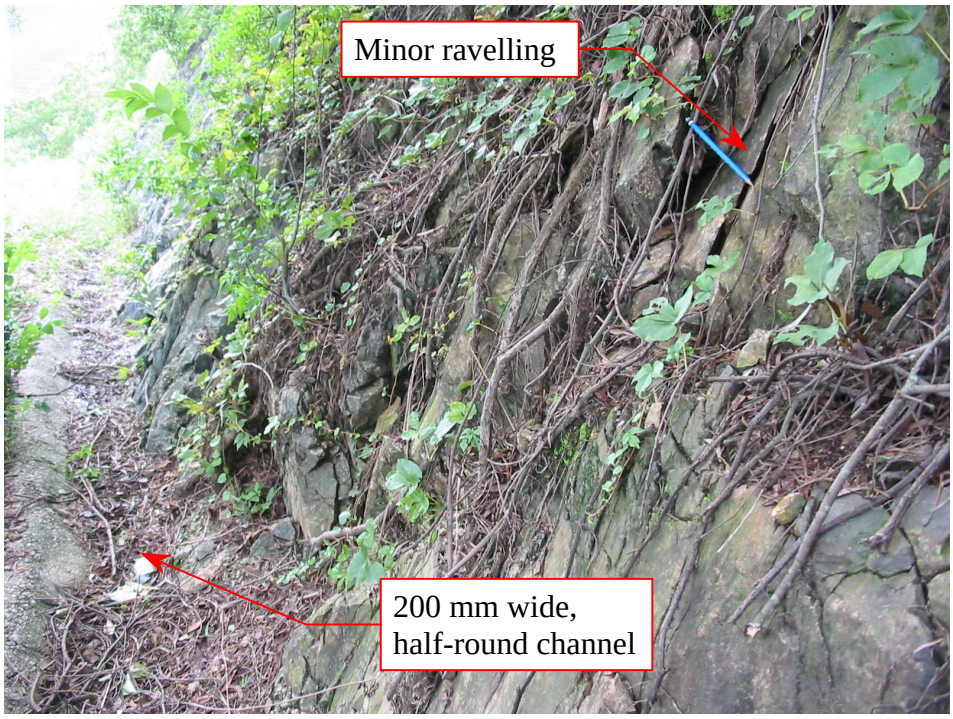


Plate 5 - View of the Half-round Channel along the Berm of the Rock Portion
(Photograph taken on 26 August 2003)

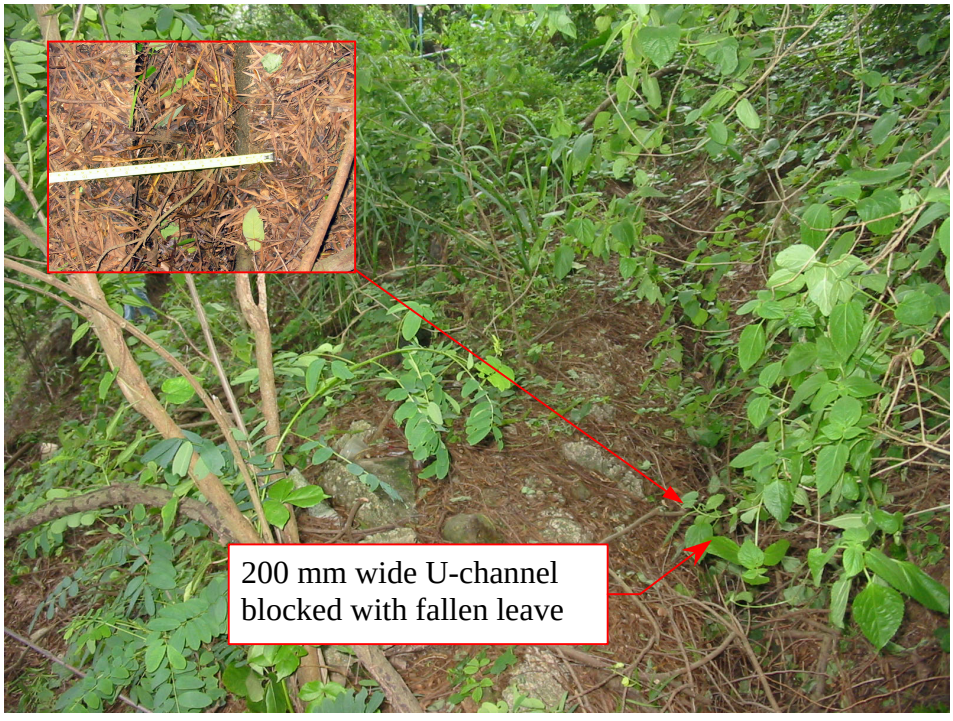


Plate 6 - View of the U-channel at the Crest of the Rock Portion
(Photograph taken on 26 August 2003)

Note: See Figure 8 for locations and directions of photographs.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

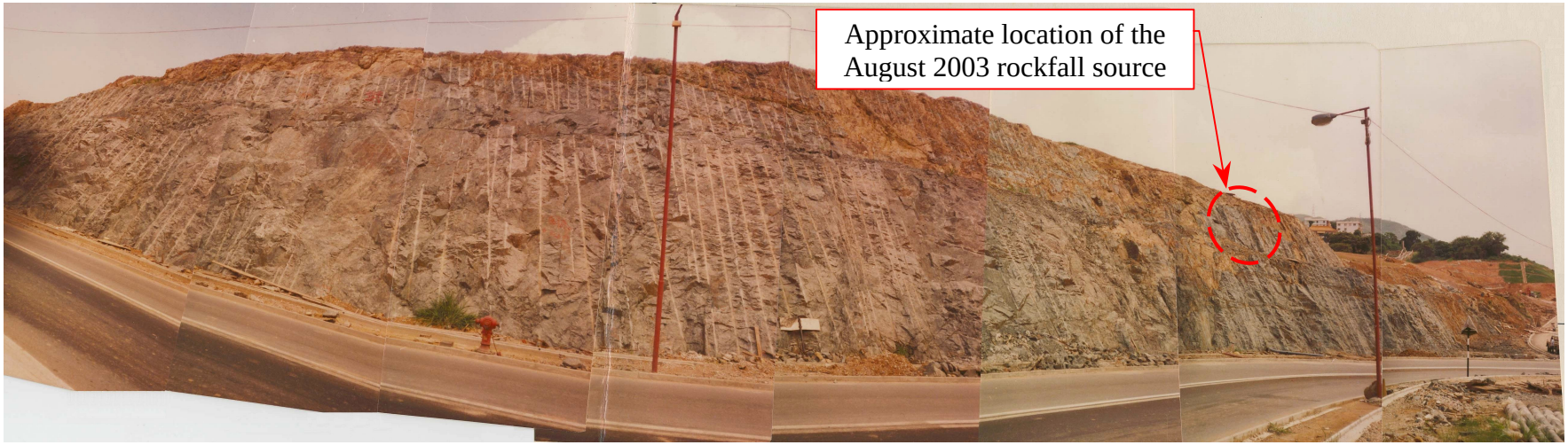


Plate 7 - General View of the Excavated Slope Face in 1981
(Photograph taken by GCO on 10 September 1981)

Note: See Figure 8 for locations and directions of photograph.

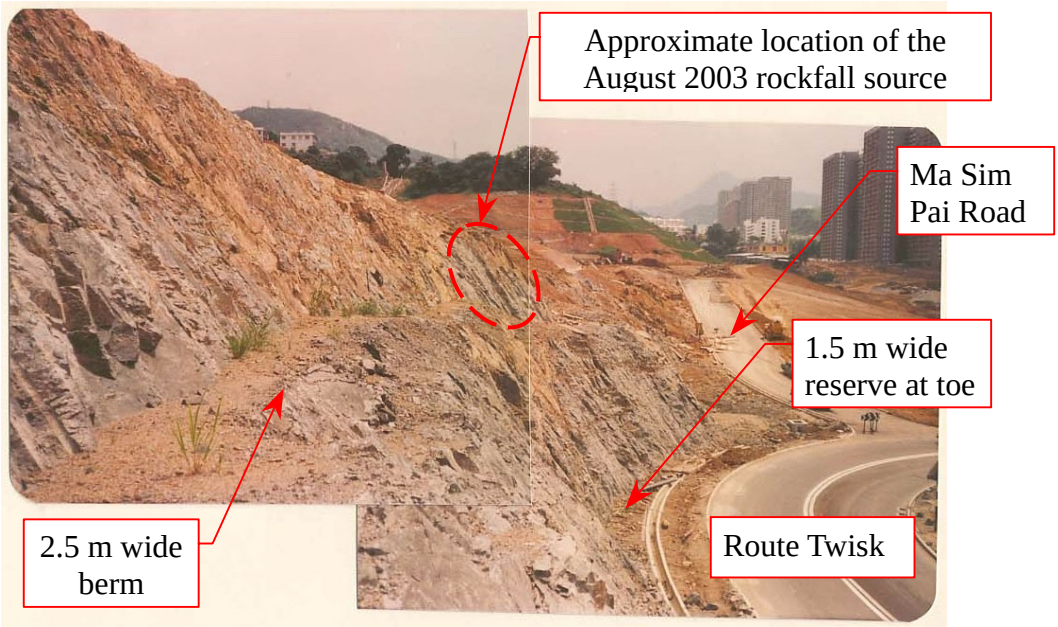


Plate 8 - View of the Rock Slope Batters in 1981 in the Vicinity of the August 2003 Rockfall Source (Photograph taken by GCO on 10 September 1981)

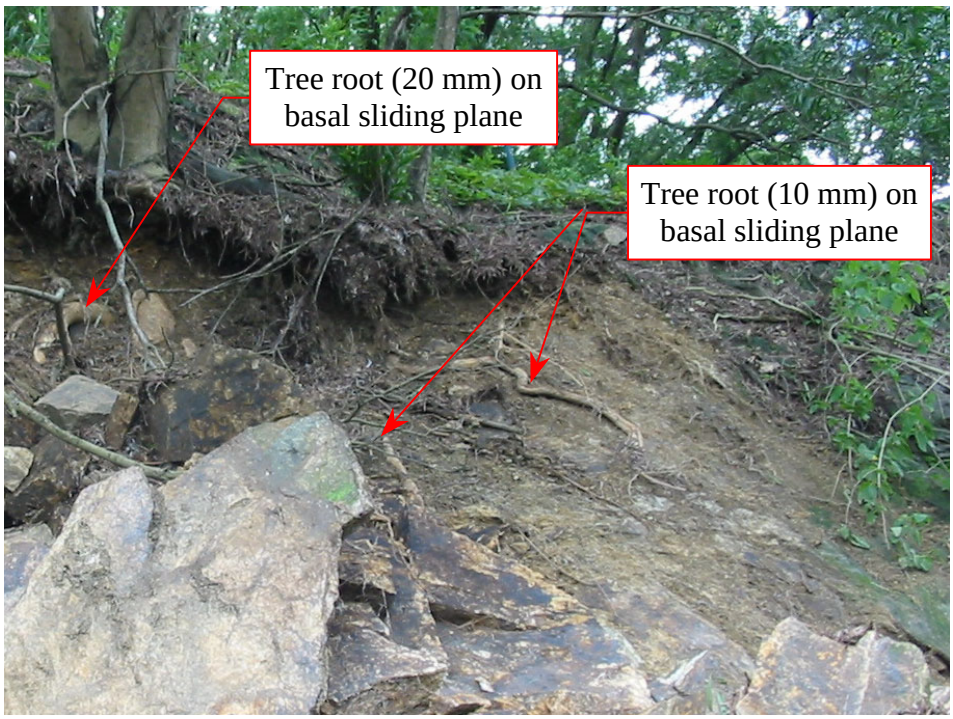


Plate 9 - Tree Roots Exposed within the Source of Rockfall (Photograph taken on 26 August 2003)

Note: See Figure 8 for locations and directions of photographs.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

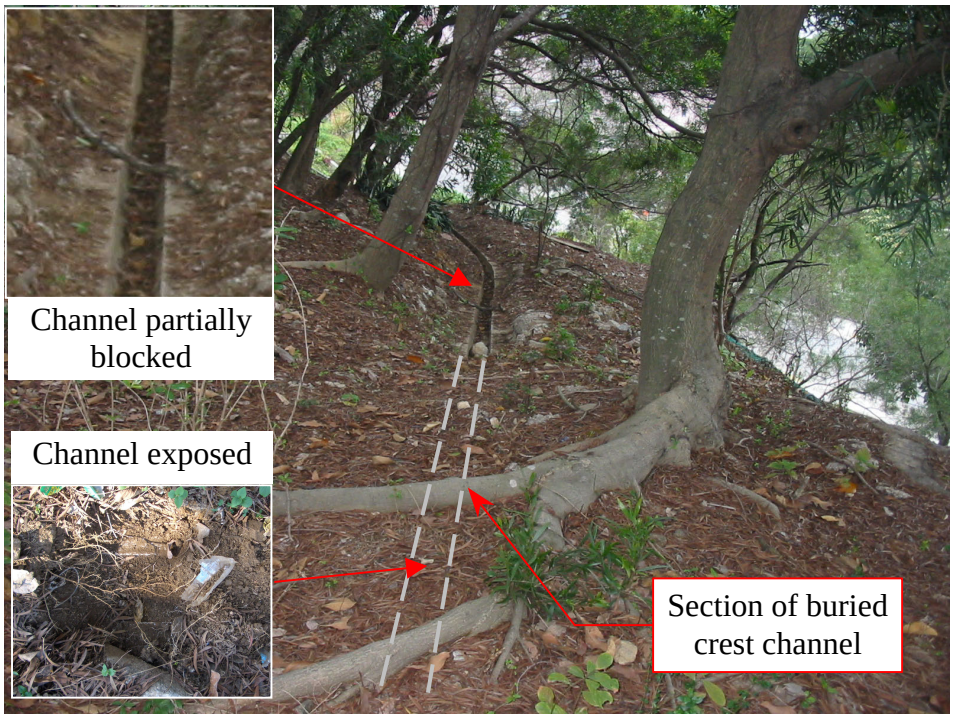


Plate 10 - View of the Buried Crest Channel above the Rockfall Source (Photograph taken on 17 March 2005)

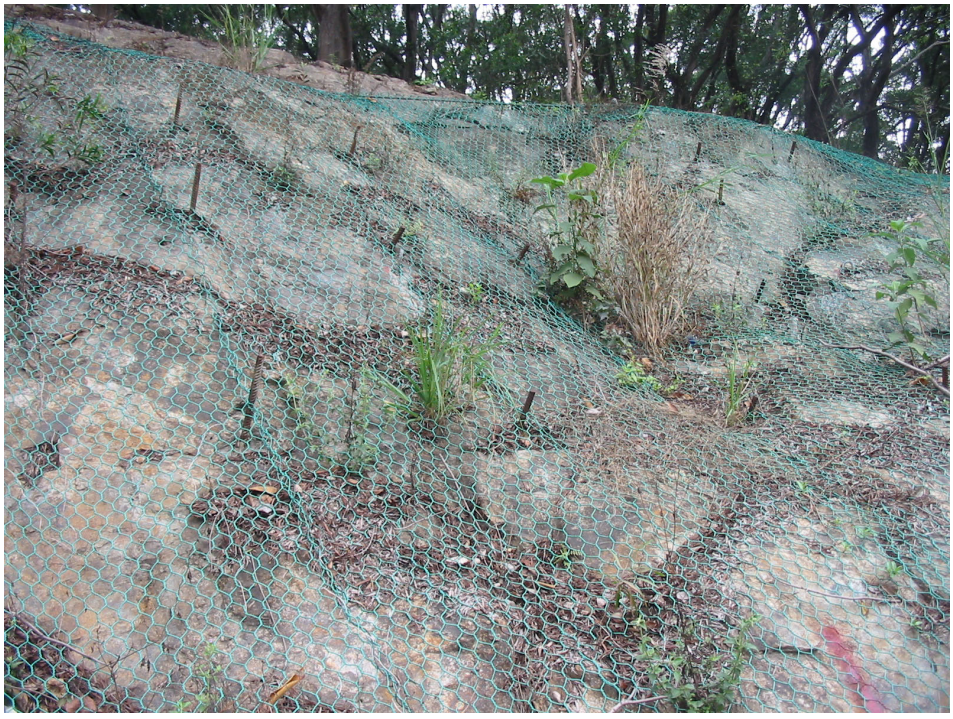


Plate 11 - View of the Pattern Rock Dowels Installed in the Vicinity of the August 2003 Rockfall Source (Photograph taken on 17 March 2005)

Note: See Figure 8 for locations and directions of photographs.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

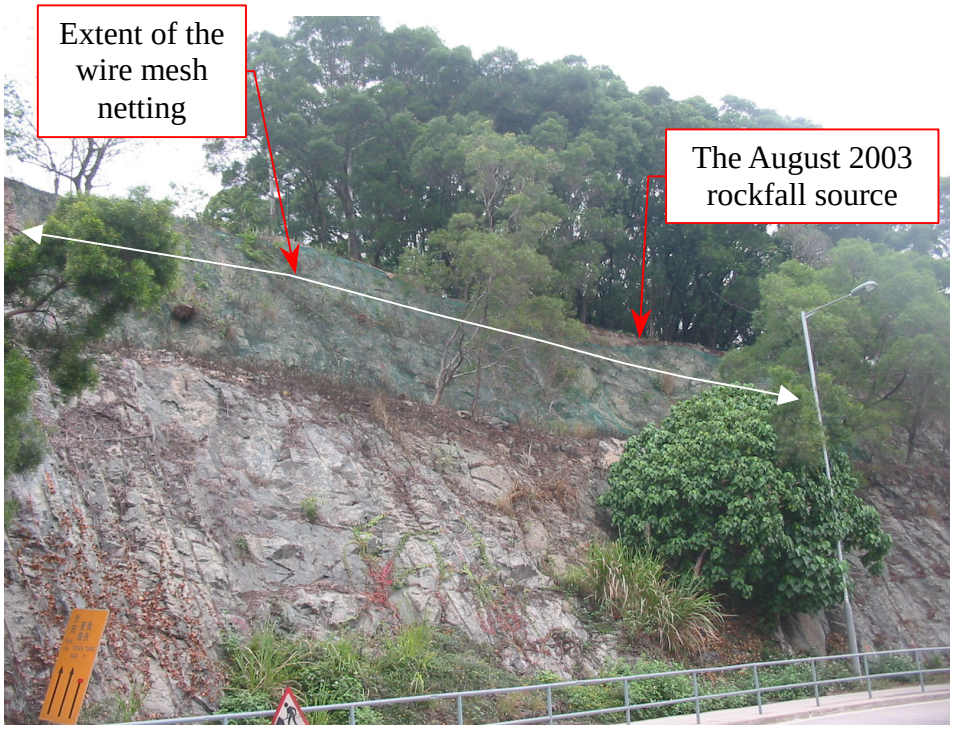


Plate 12 - View of the Area of the August 2003 Rockfall after the Slope Remedial Works (Photograph taken on 17 March 2005)

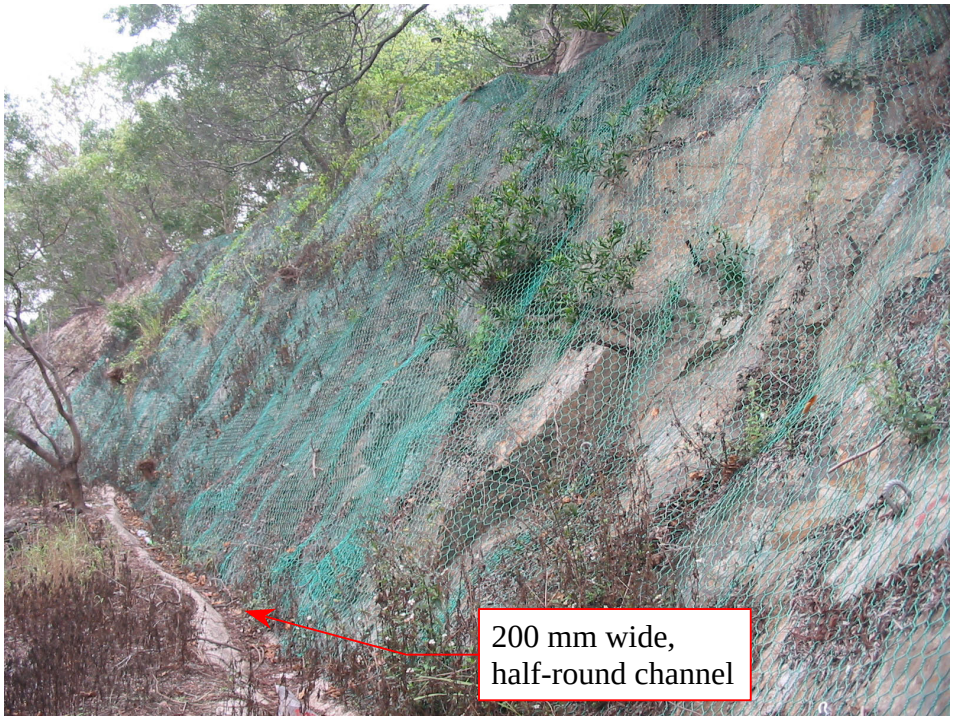


Plate 13 - View of the Rock Mesh Netting and the Berm Channel after the Slope Remedial Works (Photograph taken on 17 March 2005)

Note: See Figure 8 for locations and directions of photographs.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents

APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

CONTENTS

A.1 DETAILED OBSERVATIONS

The following comprises the detailed observations made from a review of aerial photographs taken between 1963 and 2003. A list of the aerial photographs studied is presented in Table A1 and the main observations of the API are shown in Figure A1.

YEAR OBSERVATIONS

1963 The study area is located along the toe of a southeast-facing hillside between two rounded spurs trending southwest and east. The rock portion of slope No. 7SW-C/C362 was located on the southeast flank, which is inclined at an angle of about 30°. A drainage line can be seen trending southwest below the steeper northwest flank and ribbons of bouldery colluvium were present along the drainage line.

Extensive cultivation terraces are visible from the mid-slope to the crest of the hillside. Isolated village structures were present at the foot of the hillside. A grave area is visible at the foot of the hillside near the southern end of the spur.

The original alignment of the Route Twisk is to the southwest of the study area. Tung Lum Hien Fah Tong has been built to the northwest of the study area.

1964 A high reflective area indicates recent activities on cultivation terraces.

1973 Some cultivation terraces were abandoned and covered with vegetation.

The site formation works of the Cheung Pei Shan Road is in progress.

1977 The photographs only cover the southern portion of the study area with no observable changes.

Extensive site formation works of the Cheung Pei Shan Road are in progress and excavation works extended to the southeast of the study area.

1978 A very good resolution low level photograph covers only the southern portion of the study area.

Site formation work is in progress and a haul road was formed to the south of the study area. The cultivation terraces observed in the 1964 photographs and to the southeast of this area have now been abandoned. The village structures in this area have been demolished.

1980 The formation of slope No. 7SW-C/C362 and the village platforms is in progress. Excavation for the realignment of Route Twisk, the platforms for Pa Tin Pa Tsuen is in progress on the southeast-facing hillside just below the spur line of the southwest trending spur. The east trending spur has been removed.

The upper section of the Cheung Pei Shan Road has been completed.

YEAR	OBSERVATIONS
1982	Slope No. 7SW-C/C362 has been formed except for the present-day garden/sitting-out area. The rock cut portion is bare and the soil cut portion near the Pa Tin Pa Tsuen is vegetated while the southwest portion of the soil cut slope is mostly bare, with sparse vegetation. A culvert has been constructed along the drainage line near the western portion of the rock cut slope. The realigned Route Twisk and Tsuen Kam Interchange were open to traffic. The low-rise houses in Pa Tin Pa Tsuen and Muk Min Ha Tsuen had been constructed.
1984	Vegetation has become established at the southwest portion of the soil cut slope and near the toe of the rock portion.
1985	The garden/sitting-out area above the rock cut portion can be seen. Trees have been planted along the crest of the rock cut portion.
1986	The soil cut portion was generally covered with dense vegetation. The rock cut portion remains bare except for some shrubs, which can be seen at the intermediate berm near the rockfall source.
1987	No observable changes.
1988	No observable changes.
1991	Trees are visible at the intermediate berm near the rockfall source.
1992	No observable changes.
1993	Vegetation has gradually become established on the rock portion.
1994	No observable changes.
1995	The crest of the rock slope is now covered with dense vegetation.
1996	The rock cut portion is now covered with vegetation.
1997	No observable changes.
1998	No observable changes.
1999	No observable changes.
2001	No observable changes.
2002	The rock cut portion is now covered with dense vegetation.
2003	No observable changes on the subject slope. A rock trap fence (probably temporary) is visible along Route Twisk in front of the August 2003 rockfall area. Site formation works have been carried out at the Tsuen Kam Interchange and the hillside below Route Twisk.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

LIST OF TABLES

Table A1 - List of Aerial Photographs

Date Taken	Altitude (ft)	Photograph Number
11 December 1964	2700	Y11276-77
31 December 1964	2300	Y11323-24
20 February 1973	5000	3260-63
14 July 1973	1700	4519-20
12 December 1977	4000	20055-56
16 November.1978	1000	23308-09
11 September 1980	6000	31603-04
13 November 1980	4000	32965-66
20 September1982	2500	43855-58
20 October 1984	4000	56514-15, 46-47
1 October 1985	10000	67244-45
17 September 1986	4000	A5700-01
4 October 1987	4000	A10504-05
4 June 1988	10000	A13752-53
10 October 1988	4000	70322-23
1 October 1991	4000	A27540-41
29 October 1991	10000	A28810-12
13 May 1992	4000	A31186-87
2 November 1993	4000	A35974-75, 87-88
21 October 1994	10000	A39480-81
8 November 1994	4000	A39943-45
23 November 1995	10000	CN12319-20
12 June 1996	4000	CN14216-17
21 November 1996	10000	CN16196-97
21 November 1997	10000	CN19028-29
10 November 1998	8000	CN21881-82
9 December 1999	8000	CN25100-01
14 September 2000	6000	CN28056-57
14 January 2001	8000	CN29355-56
25 October 2002	4000	RW1467-68
11 May 2003	4000	CW47196-97
30 October 2003	4000	CW51462-63
26 November 2003	4000	CW53672-73

Note: All aerial photographs are in black and white except for those prefixed with CN, CW or RW.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

LIST OF FIGURES

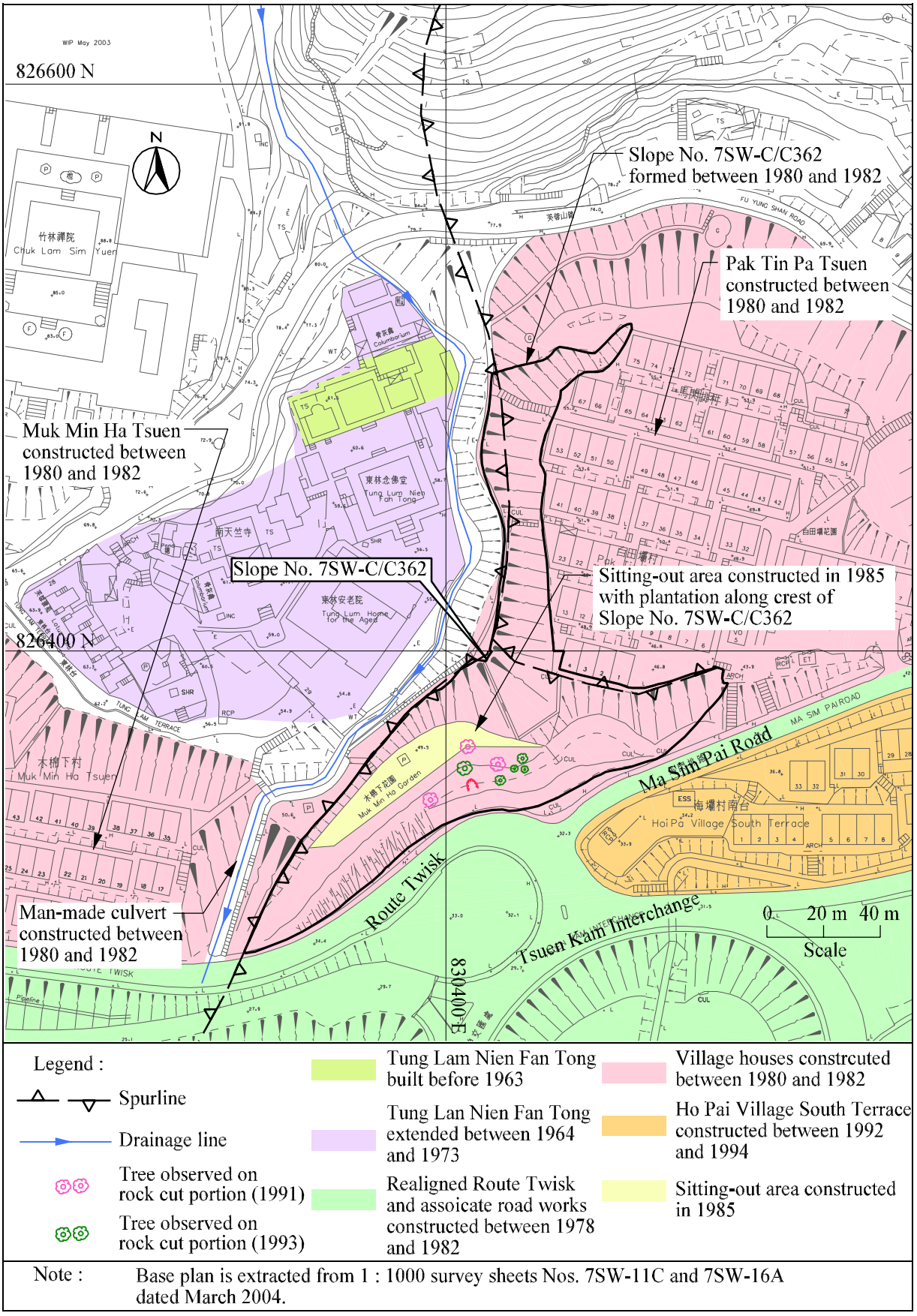


Figure A1 - Aerial Photograph Interpretation

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents

APPENDIX B

ROCK JOINT MAPPING RECORD BY SCOTT WILSON KIRKPATRICK & PARTNERS IN 1981

Table B1 - Discountinunity Survey Data by SWKP in 1981 (Sheet 1 of 4)

Chainage	Dip (Degree)	Dip Direction (Degree)	Persistence	Frequency	Opening	Nature of Infilling	Roughness	Remarks
Intermediate Berm at Ch.390	71	355	Fair	Mod.regular	Tight	Clean	Rough	
	86	145	"	"	"	"	"	
	81	354	"	"	"	"	"	
	86	090	Poor	Regular	"	Clean with chlorite	"	
	70	102	Fair	Mod. regular	"	Clean	"	
	81	027	Poor	"	"	"	"	
	47	149	Good	-	Narrow	Clean with oxide	Small steps	Sheet Joint
	90	081	Fair	Mod.regular	Tight	Chlorite	Rough	
	61	195	"	"	-	Clean	"	
	60	153	"	"	Tight	"	"	
	57	144	"	"	"	"	"	
	65	180	Poor	"	"	"	"	
	64	158	Fair	Regular	-	"	"	
	88	035	Fair	Mod.regular	Tight	Clean with oxide	Rough	
	60	145	"	Regular	-	Clean	"	
	72	126	"	Mod.regular	Very narrow	"	"	
	89	221	"	"	Tight	"	"	
	62	348	"	"	"	"	"	
	87	173	"	"	Very narrow	Oxide	"	
	67	118	Poor	"	-	Clean	"	
	56	152	Fair	"	-	Oxide	"	
	72	108	"	"	Tight	"	"	
	74	098	"	"	Very narrow	"	"	
	64	157	"	Regular	"	"	"	
	89	117	Fair	"	"	Oxide , chlorite	"	
	65	156	"	Mod.regular	-	Oxide	"	

Notes: (1) Joint spacing - Good (10-50 m), Fair (1-10 m) and Poor (<1 m).
(2) Opening size - Tight (<1 mm), Very Narrow (1-5 mm), Narrow (5-10 mm), Moderate Narrow (10-50 mm) and Moderate Narrow (10-50 mm).

Table B1 - Discountinunity Survey Data by SWKP in 1981 (Sheet 2 of 4)

Chainage	Dip (Degree)	Dip Direction (Degree)	Persistence	Frequency	Opening	Nature of Infilling	Roughness	Remarks
	65	160	"	"	Mod. Narrow	Chlorite	"	Firm consistency of infilling (50-150 kN/m²)
	68	112	Poor	Mod.regular	Tight	Oxide	Rough	
	88	333	"	"	Very narrow	"	"	
430	69	184	"	"	-	Clean	"	
↓	64	165	Fair	"	-	Oxide	"	
	87	134	"	"	Very narrow	"	"	
	81	154	Poor	"	"	Chlorite	"	Soft consistency of infilling (<50 kN/m²)
	71	170	Fair	"	"	Oxide	"	
	32	024	Good	"	"	"	"	
	55	162	Fair	Regular	"	"	Very rough	
	89	239	"	Mod.regular	"	Oxide	Rough	
	54	191	"	"	"	Chlorite	Very rough	
	85	173	Poor	"	Tight	"	"	
	65	184	Fair	"	Very narrow	"	Rough	
	70	087	Fair	Mod.regular	Tight	Chlorite	Rough	
	84	235	"	"	"	"	Smooth	
	65	174	"	"	-	Oxide	Rough	
	76	233	Poor	"	Very narrow	"	"	
	65	167	Fair	Regular	narrow	Chlorite	Defined ridges	Rock moderately decomposed
	75	114	"	Mod.regular	"	"	Rough	Soft consistency of infilling
	68	190	"	"	"	"	"	"
450	64	334	Poor	"	"	"	"	"
↓	56	159	Fair	"	Very narrow	"	"	
	74	322	Fair	"	"	"	"	
	82	292	"	"	"	"	"	
	55	152	"	Regular	"	"	"	

Notes: (1) Joint spacing - Good (10-50 m), Fair (1-10 m) and Poor (<1 m).
(2) Opening size - Tight (<1 mm), Very Narrow (1-5 mm), Narrow (5-10 mm), Moderate Narrow (10-50 mm) and Moderate Narrow (10-50 mm).

Table B1 - Discountinunity Survey Data by SWKP in 1981 (Sheet 3 of 4)

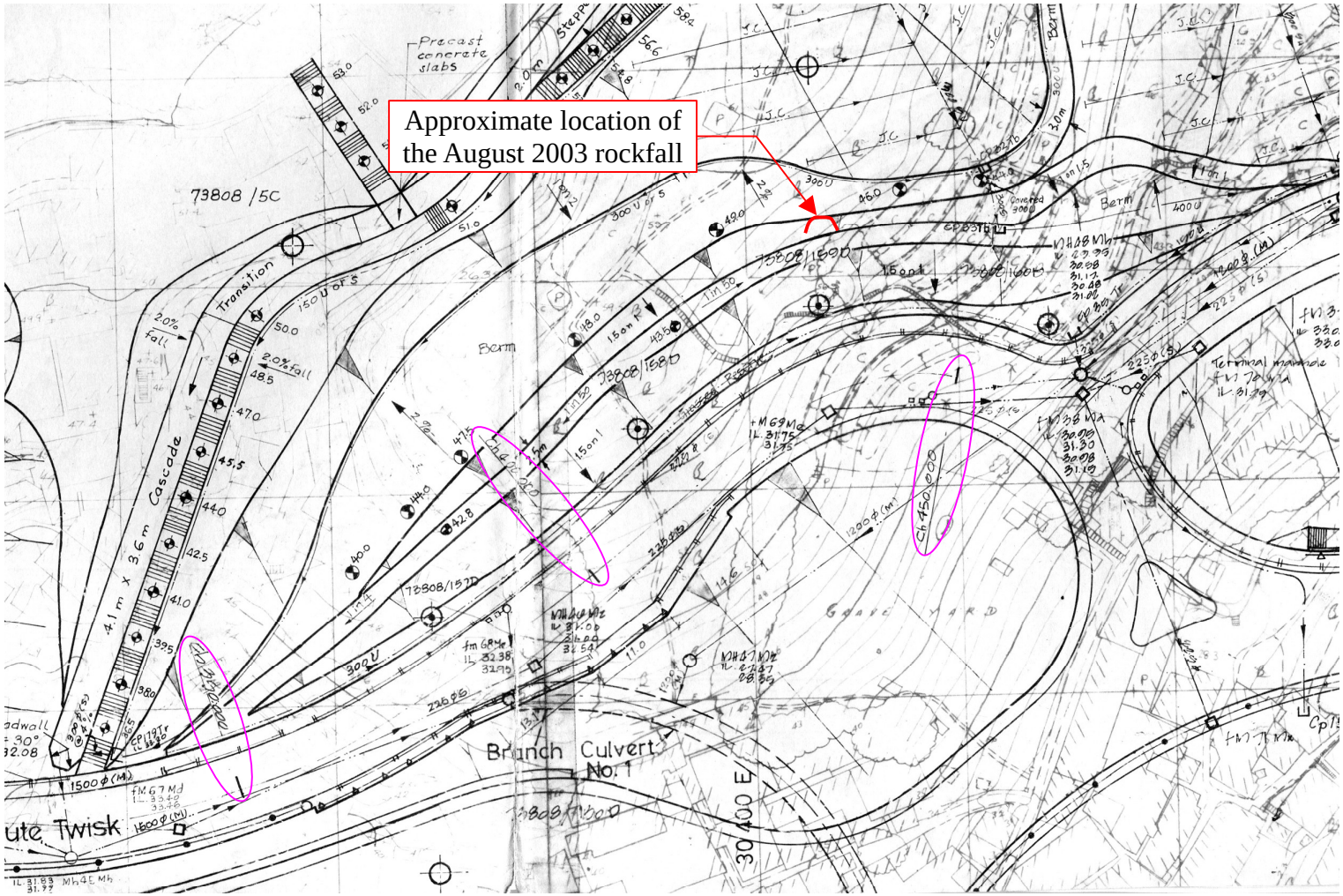
Chainage	Dip (Degree)	Dip Direction (Degree)	Persistence	Frequency	Opening	Nature of Infilling	Roughness	Remarks
Toe of Slope Ch. 380	52	143	Fair	Regular	-	Clean with chlorite	Rough	
↓	68	090	"	Mod.regular	Very narrow	"	"	
	70	099	"	"	"	"	"	
	71	162	"	"	"	"	"	
	75	100	"	"	-	"	"	
	66	005	"	"	Very narrow	"	"	
	80	105	"	"	"	"	"	
	53	030	"	Regular	"	Oxide	"	
	69	156	"	Mod.regular	-	Clean	"	
	73	330	Poor	"	Very narrow	Chlorite	Smooth/ rough	
	47	170	Fair	"	-	Clean	Rough	
	68	105	Poor	"	-	"	"	
	61	130	Fair	"	-	"	"	
	88	114	Poor	"	Tight	"	"	
	90	201	Poor	"	narrow	Chlorite	"	
	45	150	Fair	Mod.regular	Very narrow	Chlorite	Very rough	
	85	335	"	"	"	"	Rough	
	70	093	"	"	"	"	"	
	82	333	Poor	"	-	"	"	
	50	120	Good/Fair	"	Very narrow	"	Very rough	
	72	076	Fair	"	Tight	Clean with chlorite	Rough	
	58	212	"	"	"	"	"	
	72	330	Poor	"	"	Chlorite	"	
	87	145	"	"	-	Clean with chlorite	"	
	43	160	"	Irregular	-	"	"	
	53	174	Fair	Mod.regular	Very narrow	"	"	
	88	198	"	"	Tight	Chlorite	"	
	52	154	"	"	"	Clean with chlorite	"	

Notes: (1) Joint spacing - Good (10-50 m), Fair (1-10 m) and Poor (<1 m).
(2) Opening size - Tight (<1 mm), Very Narrow (1-5 mm), Narrow (5-10 mm), Moderate Narrow (10-50 mm) and Moderate Narrow (10-50 mm).

Table B1 - Discountinunity Survey Data by SWKP in 1981 (Sheet 4 of 4)

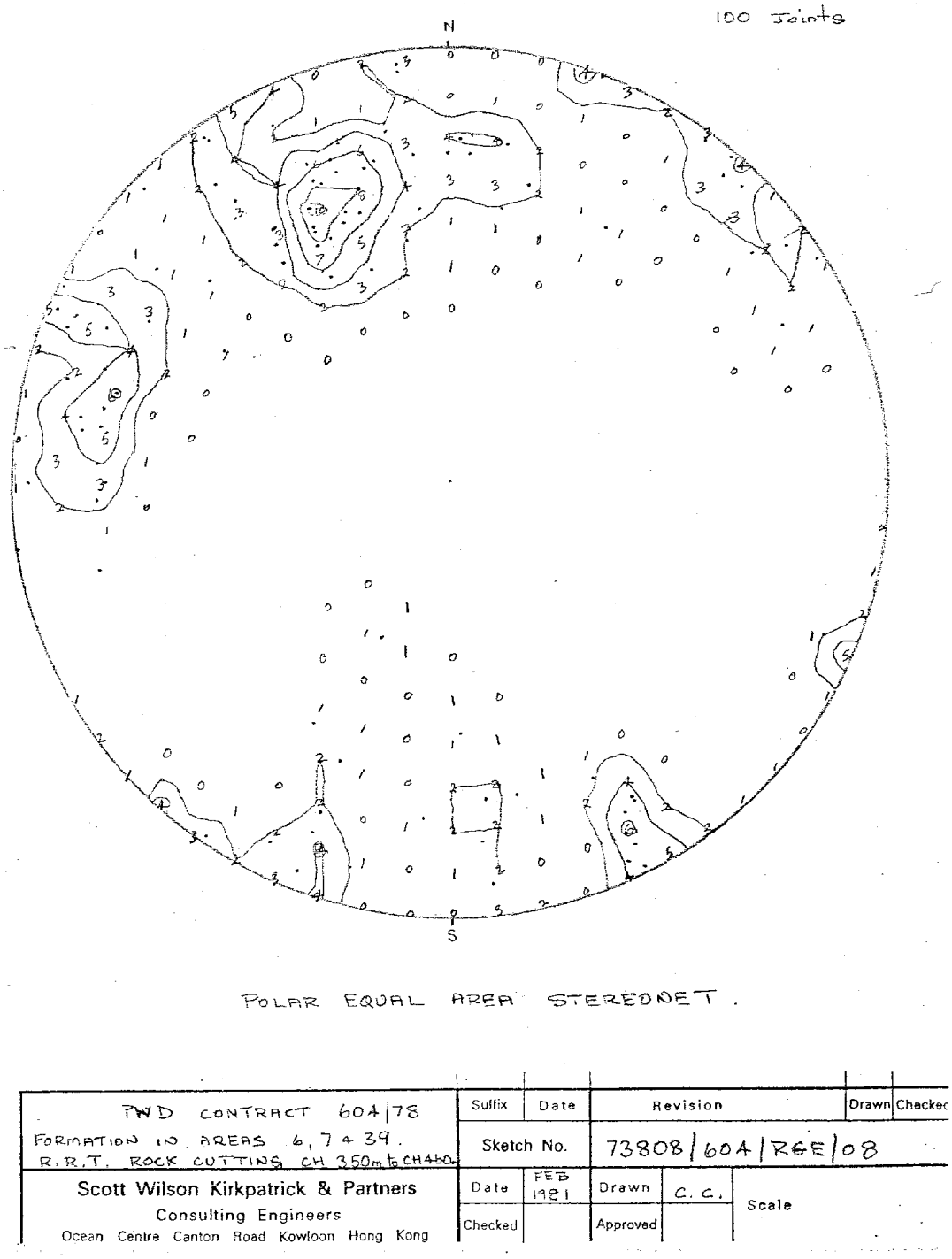
Chainage	Dip (Degree)	Dip Direction (Degree)	Persistence	Frequency	Opening	Nature of Infilling	Roughness	Remarks
	84	222	Fair	Mod.regular	Very narrow	Clean with chlorite	Rough	
	52	151	Poor	"	-	"	"	
	80	015	"	"	Tight	Chlorite	"	
	67	141	Fair	"	Very narrow	"	"	
	60	163	"	"	-	Clean	Very rough	
	84	112	"	"	-	"	Rough	
426	62	354	"	"	Tight	Oxide	"	
	70	143	"	"	Very narrow	Oxide, chlorite	"	
	85	022	"	"	Mod. Narrow	Cohesive	Very rough	
	76	142	"	"	Very narrow	-	"	
440	70	022	Poor	"	"	Oxide, chlorite	Rough	
460	83	114	Fair	"	"	Clean with chlorite	"	
	73	245	Poor	"	"	Oxide	"	
	75	022	Poor	Mod.regular	Very narrow	Oxide	Rough	
	88	215	Fair	"	"	Chlorite	"	
	58	022	"	Mod.regular/ Irregular	Mod.narrow/ narrow	Cohesive	"	Moderately decomposed rock
	68	160	"	Mod.regular	Narrow	"	"	
	85	225	Fair/Poor	"	Very narrow	Chlorite	"	
	48	358	Poor	"	Tight	"	"	
	68	182	Fair	"	-	"	"	
	*All the joint are dry.							

Notes: (1) Joint spacing - Good (10-50 m), Fair (1-10 m) and Poor (<1 m).
(2) Opening size - Tight (<1 mm), Very Narrow (1-5 mm), Narrow (5-10 mm), Moderate Narrow (10-50 mm) and Moderate Narrow (10-50 mm).



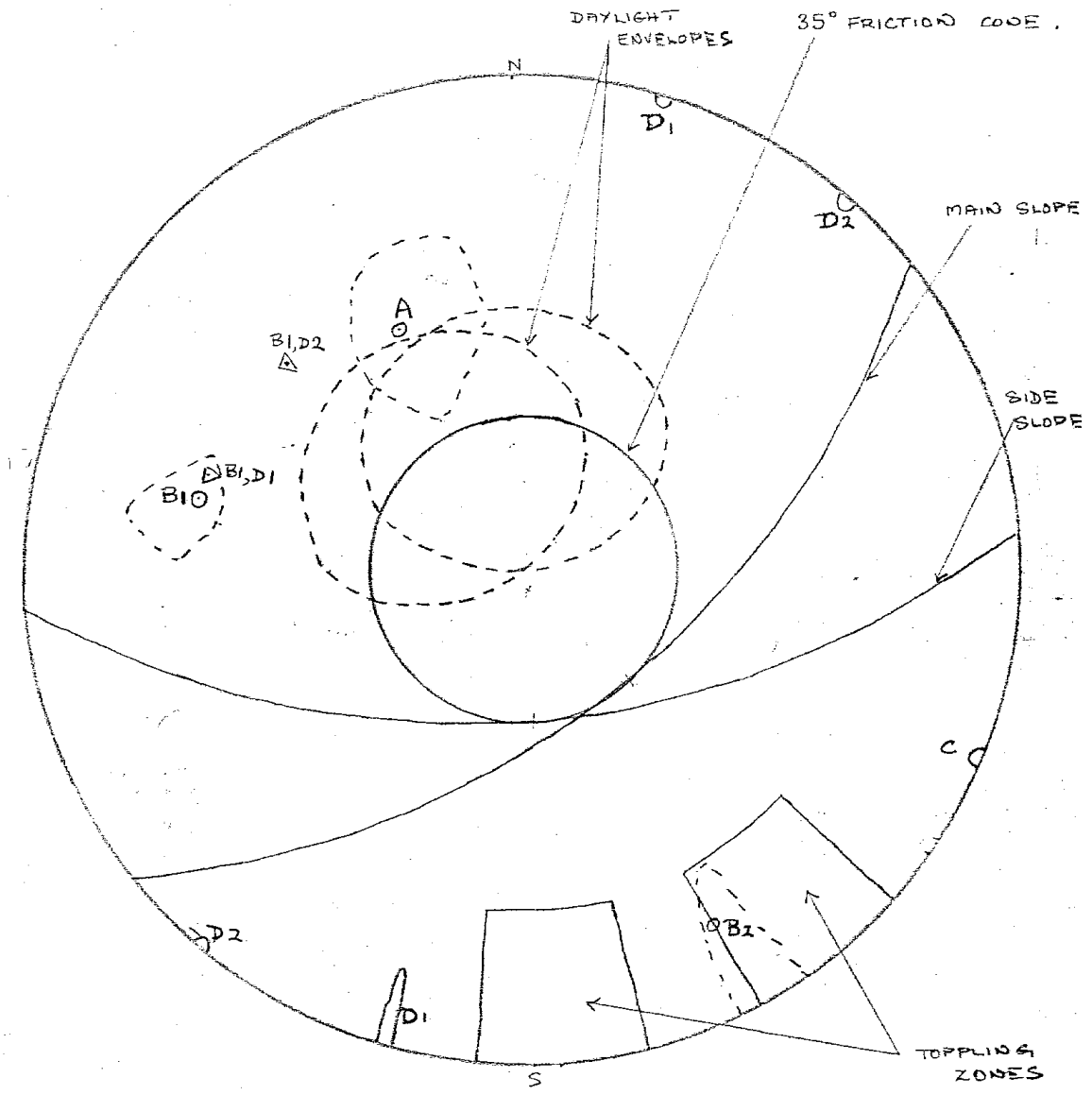
Note: Plan extracted from Drawing No. 73808/604/044L in PWD Contract 604/78 - Tsuen Wan New Town, Tsuen Wan North Development, Formation in Areas 6, 7 & 39.

Figure B1 - Layout of the Slope Works Design by SWKP



Note: Extracted from "Report on Rock Slopes Above Realigned Route Twisk and Village Access Road" prepared by SWKP in August 1981.

Figure B2 - Polar Plot of the Joint Data



Note: Extracted from "Report on Rock Slopes Above Realigned Route Twisk and Village Access Road" prepared by SWKP in August 1981.

Figure B3 - Equal Angle Stereoplot

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土力工程處刊物及訂購資料

A selected list of major GEO publications is given in the next page. An up-to-date full list of GEO publications can be found at the CEDD Website http://www.cedd.gov.hk on the Internet under "Publications". Abstracts for the documents can also be found at the same website. Technical Guidance Notes are published on the CEDD Website from time to time to provide updates to GEO publications prior to their next revision.

部份土力工程處的主要刊物目錄刊載於下頁。而詳盡及最新的土力工程處刊物目錄，則登載於土木工程拓展署的互聯網網頁 http://www.cedd.gov.hk 的"刊物"版面之內。刊物的摘要及更新刊物內容的工程技術指引，亦可在這個網址找到。

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Table of Contents
Table of Contents
Table of Contents

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GEOTECHNICAL MANUALS

Geotechnical Manual for Slopes, 2nd Edition (1984), 300 p. (English Version), (Reprinted, 2000).

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The Pre-Quaternary Geology of Hong Kong, by R.J. Sewell, S.D.G. Campbell, C.J.N. Fletcher, K.W. Lai & P.A. Kirk (2000), 181 p. plus 4 maps.

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TGN 1	Technical Guidance Documents

Table of Contents
Table of Contents
Table of Contents