REVIEW OF THE 7 JUNE 2008 ROCK SLOPE FAILURE ON SLOPE NO. 10NE-B/C56 BELOW TSING YI ROAD

GEO REPORT No. 288

C.L.H. Lam & H.W.K. Lam

GEOTECHNICAL ENGINEERING OFFICE

CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT

THE GOVERNMENT OF THE HONG KONG SPECIAL ADMINISTRATIVE REGION

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This report is largely based on GEO Landslide Study Report No. LSR 5/2010 produced in December 2010

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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.

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H.N. Wong
Head, Geotechnical Engineering Office
October 2013

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FOREWORD

This report presents the findings of a review study of a rock slope failure (Incident No. 2008/06/01888) that occurred on slope No. 10NE-B/C56 below Tsing Yi Road on 7 June 2008. The incident involved a debris volume of about 250 m^3. Part of an access road leading to a storage yard was temporarily closed. No casualties were report as a result of the incident.

The key objectives of the review study were to document the facts about the incident, past geotechnical input provided to the slope and pertinent site observations made after the failure. Recommendations for follow-up actions are reported separately.

Ms C.L.H. Lam and Mr H.W.K. Lam of the Landslip Preventive Measures Division 1 prepared this report. Survey Division of Civil Engineering and Development Department provided support on rock joint mapping using remote laser scanning. AECOM Asia Company Limited, the 2008 and 2009 Landslide Investigation Consultants, provided support on geological mapping and aerial photograph interpretation. All contributions are gratefully acknowledged.

W.K. Pun
Chief Geotechnical Engineer/LPM Division 1

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CONTENTS

1. INTRODUCTION

On 7 June 2008, a rock slope failure (Incident No. 2008/06/0188) occurred on the eastern part of Slope No. 10NE-B/C56 below Tsing Yi Road (Figure 1 and Plates 1 to 3) when the Black Rainstorm Warning and Landslip Warning were in force. The estimated debris volume was about 250 m^3. Part of an access road leading to a storage yard at the toe of the slope was temporarily closed. No casualties were reported in the incident.

This report documents the facts about the landslide incident, findings from relevant documentary records, and pertinent site observations. The use of remote laser scanning method for rock joint survey is also discussed.

2. THE SITE AND MAINTENANCE RESPONSIBILITY

Slope No. 10NE-B/C56 comprises mainly a rock cut with local soil portion at its upper western part. It is approximately 255 m long, with a maximum height of about 35 m. The slope angle of the rock and soil portions are about 60^o and 40^o respectively. The slope is partly covered with hard surface. Sparse vegetation was also observed on the slope face.

The failed portion of the slope is a 30 m high, southeast facing rock cut below Tsing Yi Road. The crest of the slope is a paved car park adjoining to Tsing Yi Road. At the slope toe is a 5 m wide drainage nullah with an adjoining access road leading to a storage yard (Figure 2).

The existing drainage system on the slope is shown in Figure 2. A 300 mm crest channel is located above the 7 June 2008 failure scar. To the east of the scar is a 1,000 mm wide stepped channel connecting to the nullah along the slope toe.

The slope had been maintained by the owner of Lot No. TYTL 46 R.P. before it was returned to the Government in June 2001. The slope was then maintained by the Highways Department (HyD). According to Lands Department, the maintenance responsibility (MR) of the slope was updated in the Slope Maintenance Responsibility Information System in early September 2008. Since then, the Lands Department and the tenant of the car park area above the slope (STT 3622K&T) were jointly responsible for the maintenance of the slope.

3. THE 7 JUNE 2008 ROCK SLOPE FAILURE

The incident was reported by HyD at 15:10 on 7 June 2008, and the exact time of the failure was unknown. The failure occurred at the eastern rock cut portion of slope No. 10NE-B/C56, with a failure volume of about 250 m^3 (Plates 1 to 4). Most of the debris was deposited within the drainage nullah at the toe of the slope and some was scattered further away on the access road adjoining to the nullah. The debris also severed part of the road-side fencing below the slope toe (Plate 2).

Subsequent to the incident, HyD carried out urgent repair works (Plate 5) which comprised removal of landslide debris and overhanging rock blocks, and provision of shotcrete to the rock mass near the scar. The works were completed on 9 September 2008.

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A sizeable rock block of about 2 to 3 m in diameter was deposited at the distal end further to the front of the main debris mound (Plate 2), about 10 m away from the slope toe.

4. SITE GEOLOGY

4.1 Regional Geology

According to the Hong Kong Geological Survey Sheet Report No. 3 – Geology of Tsing Yi (GEO, 1995), the region is located at a major plutonic body of granite with dominant eastnortheast-trending feldsparphyric rhyolite dyke intrusions in the southern part of the island. The Hong Kong Geological Survey (HKGS) 1:20,000 scale map series HGM (GCO, 1991) indicates that the site is underlain by fine-grained granite (to the north) and medium-grained granite (to the south) both of Jurassic-Cretaceous age. Two sub-parallel northwest-trending faults were noted bounding the slope (Figure 3).

4.2 Ground Investigation

No existing ground investigation (GI) data is available near slope No. 10NE-B/C56. No GI was carried out for the present study as the condition of the slope could be readily examined from the exposed rock face.

5. SITE HISTORY AND PAST INSTABILITY

The history of site development has been determined from an interpretation of the available aerial photographs since 1924, together with a review of relevant documentary information and site observations. Detailed observations from the Aerial Photograph Interpretation (API) are summarized in Appendix A and the salient features are given below (Figure 4).

Slope No. 10NE-B/C56 was probably formed to its present profile before 1969 by cutting into the natural hillside. A perennial drainage line is found running towards the eastern end of the feature. Signs of shotcreting works were evident in 1981 and 2002 and were probably associated with previous geotechnical studies of the feature (see Section 6.2).

Apart from a rock wedge failure recorded at feature No. 10NE-B/C80 (about 40 m away from the crest of the subject feature) during its formation in 1982 (GEO, 1993), there are no other recorded landslide at or near the subject slope (Figure 4).

6. PREVIOUS SLOPE INSPECTIONS AND STUDIES

6.1 General

Slope No. 10NE-B/C56 had been subjected to previous geotechnical assessments and stabilization works with details given below.

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6.2 Geotechnical Submissions

In 1980, the Buildings Department (BD) issued an advisory letter to the tenant of Lot No. TYTL 46 R.P. to remove loose blocks from the rock faces and clear vegetation at rock joints of slope No. 10NE-B/C56. In response to that, stability assessment and slope stabilization works on the slope were carried out. According to the Stability Report (kept in BD's file No. DH172/80/K) prepared by Maunsell Geotechnical Services Limited (MGSL) in September 1980, numerous loose blocks and blocky zones were identified. Six major blocks were found potentially unstable on the slope, one of which (Figure 5a) was located just above the 7 June 2008 failure location. The stabilization works comprised 21 rock 'bolts', 6 drains and shotcreting according to the as-built record plan. The extent of shotcrete appeared to cover the upper portion of the 7 June 2008 failure location, but no structural support or drainage provision were indicated at or near to the failed portion. The record plan also indicates seepage points near the 7 June 2008 failure location.

In 1997/1998, the Geotechnical Engineering Office (GEO) carried out a Stage 2 study on the slope. This study focused on the stability analysis for the soil portion and concluded that the service of a DH order is warranted. No detailed assessment of the rock slope was given in the study. A site inspection record dated 13 May 1997 was found in the slope files indicating seepage points near the 7 June 2008 failure location.

In 1999, the tenant initiated a study on the rock portion of the slope as required under the lease before the lot was returned to the Government. MGSL was appointed to carry out a rock slope stability assessment. According to the assessment report prepared by MGSL, rock joint mapping was carried out by means of the scan-line method along the slope toe, with the assistance of a lifting-cage for collecting rock joint data near the slope crest. Three major joint sets (79/096, 65/043 and 66/161) were identified, but no seepage at the 7 June 2008 failure location was recorded. The basal slip surface leading to the 7 June 2008 failure was not indicated on the design drawing (Figure 5b and see Section 7). Apart from sprayed concrete, no other stabilisation measures were proposed at or near to the 7 June 2008 failure location according to the design drawing.

The design of the rock slope stabilizations works was approved by the BD in 2001 and the geotechnical aspects of the completed site works were accepted by the GEO. The as-built records for the works could not be located.

6.3 Engineer Inspections and Routine Maintenance Inspections

In August 2005, the HyD's consultants, MGSL carried out an Engineer Inspection (EI) for slope No. 10NE-B/C56. The EI indicated that no records of previous routine maintenance inspection and works could be found and no proper access was available for inspection at that time. Minor slope defects (including blocked and cracked drainage channels, undesirable vegetation, and open rock joints) were recorded, mainly in the western and central parts of the slope. Signs of seepage were also noted at the central portion of the slope. No slope defects, sign of distress or sign of seepage was recorded at the 7 June 2008 failed portion.

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Routine maintenance inspection was carried out by the HyD in September 2007. Recommended maintenance works including removal of loose blocks and vegetation were completed in October 2007. There is no indication in the maintenance records that the routine maintenance inspection and maintenance works covered the crest channel above the 7 June 2008 failure.

7. POST-LANDSLIDE OBSERVATIONS

The site was first inspected by the GEO in the afternoon of 7 June 2008, following the landslide. A number of inspections were subsequently carried out between 12 June 2008 and 20 October 2009. The site observations are summarized below.

The landslide was up to about 20 m wide, 13 m high and 4 m deep. The landslide scar exposed slightly to moderately decomposed fine-grained to medium-grained granite. The main body of debris comprised rock blocks up to about 3 m in size, mixed with remnant of vegetation. Brown and black staining was observed at the scar and rock blocks in the debris. The staining may have been associated with seepage flow through discontinuities in the rock mass over a long period of time (Plates 6 and 10). Continuous seepage emerging from the basal slip surface of the scar was also observed during the inspection in October 2009 (Plate 9 and Figure 7).

The landslide comprised a main scar, and a minor scar at the crest of the northwest corner of the main scar (Figure 6). The main scar was defined by 3 major joint sets (Figure 6), viz the two side-release planes (namely J2 (82/079) and J3 (66/180)) and backscarp (namely J4 (80/143)). The three joint sets are in general subvertical. Brown staining was also observed along these joint sets. The basal slip surface which was defined by a distinct joint (namely J1 (32/124)) was planar and laterally-persistent (> 10 m wide) with black staining; and it undulates, having a southerly dip of about 32^{o}. No infill was observed on the basal slip surface.

The minor scar measured about 4 m wide, 4 m high and 2 m deep, in the form of a wedge. The failure volume was about 15 m^3 (Figure 6). This scar is defined by two joint sets (namely J5 (79/072) and J6 (72/179)), with the line of intersection plunging out of J4 (Figure 8). Above this scar, the overhanging rock blocks were removed as part of the emergency remedial works following the landslide (Figure 6).

A 300 mm surface channel was present along the crest of the cut slope, 15 m above the 7 June 2008 failure. The channel was fenced-off by a chain link fence and might not be readily accessible for maintenance (Plate 15). The channel collects runoff from a 4,500 m^2 paved carpark on the crest platform, and discharges the water, via some stepped channels, to the nullah at the slope toe. The crest channel was relatively shallow, and was found partly blocked by vegetation and debris during the inspection on 23 April 2009 (Plate 15). The channel runs in northeast direction and bends at a location immediately above the 7 June 2008 failure (Figure 2). At this location, a slight depression was observed on the ground profile downslope of the channel. The ground depression was probably associated with surface erosion due to overspilling from the channel, and the area had been covered by cement (Plate 15). The API indicated that the cement was probably placed in 2002.

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On the unfailed parts of the slope, the rock mass is characterised by closely to medium-spaced open joints with a width in the order of centimetres (Plate 12). The sprayed shotcrete proposed in the design drawing in 1999 could not be found (Section 6.2). Displaced rock blocks probably due to root-wedging effect were observed (Plates 11 and 13). Minor rock fall (< 0.1 m^3) (Plate 14) was also noted depositing on the nullah at the slope toe.

8. ANALYSIS OF RAINFALL RECORDS

Rainfall data were obtained from the nearest GEO automatic raingauge No. N11, which is located at about 800 m northwest of the 7 June 2008 landslide location (Figure 1). The raingauge records and transmits rainfall data at 5 minute intervals to the Hong Kong Observatory and the GEO. Severe rainfall was recorded between 7:00 a.m. and 11:00 a.m on 7 June 2008. The incident was reported by the HyD at 3:10 p.m. on 7 June 2008, but the exact timing of the landslide was unknown. For the purposes of rainfall analysis, it is assumed that the incident occurred between 7:00 a.m. and 11:00 a.m. on 7 June 2008.

The daily rainfall over the preceding month and three days following the incident, together with the hourly rainfall data for the period between 5 and 7 June 2008, is presented in Figure 9. Table 1 presents the estimated return periods for the maximum rolling rainfall for various durations recorded by raingauge No. N11 with reference to historical rainfall data at the Hong Kong Observatory in Tsim Sha Tsui (Lam & Leung, 1994) and local rainfall data of raingauge No. N11 (Evans & Yu, 2001). The results show that rainfall durations of both 4 hours and 24 hours of the 7 June 2008 rainstorm were most severe with return periods over 100 years.

The 7 June 2008 rainstorm is the most severe in comparison with the previous major rainstorms for rainfall durations between 2 hours and about 24 hours since the raingauge came into operation in August 1984 (Figure 10).

9. DISCUSSION

The 7 June 2008 rock slope failure probably took place in two stages. The main failure might have involved a translational slide with a large rock mass sliding outward along the basal slip surface. The slide mass could have resulted in loss of support to the overhanging rock wedge, and triggered a secondary, minor wedge failure. Debris of the wedge failure came from an elevated height with a higher energy level, and hence travelled further. This could explain why some sizeable rock blocks were deposited further away from the main body of the debris (Plate 2 and Section 7).

The 7 June 2008 landslide was probably rain-induced following a day of severe rainfall preceding the failure. Water could have flowed through discontinuities in the rock mass via. subsurface seepage flow from a major drainage line at its immediate east. This is evident by seepage came out from the failed portion even in the dry season. The backscarp of the main failure, which is defined by a subvertical joint set (080/143), might have also become rapidly filled with water and developed cleft pressures in conditions of heavy rain.

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The slope crest channel above the 7 June 2008 failure location was blocked by vegetation and debris, probably due to lack of maintenance. This would have resulted in overspillage and additional water ingress into the slope. Signs of deterioration including minor rock falls, displaced rock blocks and opening of rock joints were also observed on the unfailed portions of the slope.

The slope was subject to stabilisation in 1981 and stability assessment in 1999. The rock 'bolts' installed in 1981 were proved to be effective in stabilising the portion of the rock slope above the failure location (Plate 1). However, the critical joint (i.e. the basal slip surface) leading to the 7 June 2008 failure was not identified in the previous assessments. Hence, no stabilization works were applied to the portion that failed.

No access was readily available for detailed mapping of the rock slope. The use of remote laser scanning method was tried out before scaffolding was erected. The results are promising and are discussed below. This technique may be applied where situation warrants.

10. APPLICATION OF LASER SCANNING FOR ROCK JOINT MAPPING

As part of the study, remote laser scanning method using High-Definition Surveying laser scanner (HDS3000) developed by the Lecia Geosystems, has been used by the Survey Division of Civil Engineering and Development Department to facilitate the rock joint mapping (Plates 16 and 17). Laser scanner is a LiDAR (Light Detection and Ranging) technology that measures properties of scattered light to find the distance and other information (e.g. color) of a point target. The distance of a point target can be determined based on the round-trip time of a pulse of light reflected by the target. The dip angle and dip direction of a target joint plane can be determined from (x,y,z) coordinates of a minimum of three points on the plane.

The laser scanner used in the current study, though is classified as short-range, allows measurement of objects up to 200 m away. It is potable (only 17 kg) and has a dual-window design allowing a maximum 360^{o} x 270^{o} field-of-view without re-orientation of the instrument. The scanner is also equipped with a digital camera for automatically calibrated photo overlays. A typical laser scanner can measure a distance of over 50,000 point targets simultaneously per second, and collect millions of points over a surface to form an image, similar to taking a photograph. The high-density data obtained using this technology distinguishes it from conventional surveying methods that are based on discrete points.

The data collected from the scanner have been compared with those obtained from manual measurement using engineering compass. Joint data collected for 12 pairs of rock joints by the two methods are plotted in Figure 11 for comparison. It shows that the two methods give similar results, in terms of dip angle and dip direction of the joint planes.

Comparing with the manual method, the use of remote laser scanning is more efficient in respect of data acquisition. The effort required for data analysis was comparable. For the rock slope under investigation, it took only a couple of days to complete the site survey and analysis of results. Also, the laser scanning technique does not require the erection of inspection scaffolding and is particularly useful for slopes with access problem.

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However, the use of laser scanning is not applicable to densely vegetated slopes. Moreover, the method only gives spatial information. While this may be sufficient for kinematic analysis, other important information for rock slope assessment, such as degree of weathering, condition of fill materials, would need to be obtained by other means.

11. CONCLUSIONS

The 7 June 2008 landslide involved a 250 m^3 rock slope failure on slope No. 10NE-B/C56 below Tsing Yi Road. The landslide was probably rain-induced and involved a two-stage failure process. Possible overspillage from the crest channel, lack of maintenance and slope deterioration were contributory to the incident.

The slope was stabilised in 1981 and was also subject to stability assessment in 1999. However, the critical joint which formed the basal slip surface of the 7 June 2008 failure was not identified in the past assessments.

The use of remote laser scanning method has been explored. Based on limited field data, the interpreted dip angles and directions obtained from the laser scanning method are comparable to those from manual measurement using engineering compass.

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Table 1 - Maximum Rolling Rainfall at GEO Raingauge No. N11 for Selected Durations Preceding the 7 June 2008 Landslide and the Estimated Return Periods

Duration	Maximum (1) Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years)	
			Lam & Leung (2) (1994)	Data of N11 (3) from Evans & Yu (2001)
5 Minutes	12.5	10:00 a.m. on 7 June 2008	< 2	2
15 Minutes	34.5	10:10 a.m. on 7 June 2008	5	9
1 Hour	94.5	10:25 a.m. on 7 June 2008	6	9
2 Hours	162.5	10:25 a.m. on 7 June 2008	17	24
4 Hours	283.5	10:30 a.m. on 7 June 2008	91	> 100
12 Hours	355.0	11:00 a.m. on 7 June 2008	28	64
24 Hours	464.5	11:00 a.m. on 7 June 2008	30	> 100
48 Hours	487.0	11:00 a.m. on 7 June 2008	17	33
4 Days	559.5	11:00 a.m. on 7 June 2008	14	17
7 Days	659.0	11:00 a.m. on 7 June 2008	19	30
15 Days	822.5	11:00 a.m. on 7 June 2008	18	18
31 Days	889.0	11:00 a.m. on 7 June 2008	7	4

Notes : (1) Maximum rolling rainfall was calculated from 5-minute rainfall data.

(2) Return periods were derived from the statistical parameters extracted from Table 3 of Lam & Leung (1994).

(3) Return periods were also derived from the statistical parameters of raingauge No. N11 extracted from Appendix B of Evans & Yu (2001) to assess the spatial variability of rainfall.

(4) According to the incident record, the exact time of the incident is not known but reported on 3:10 p.m. on 7 June 2008. The major rainfall was recorded between 7:00 a.m. and 11:00 a.m. For the purpose of rainfall analysis, the rockfall was assumed to have occurred between 7:00 a.m. and 11:00 a.m. on 7 June 2008.

(5) The nearest GEO raingauge to slope No. 10NE-B/C56 is raingauge No. N11, about 800 m to the northwest of the slope.

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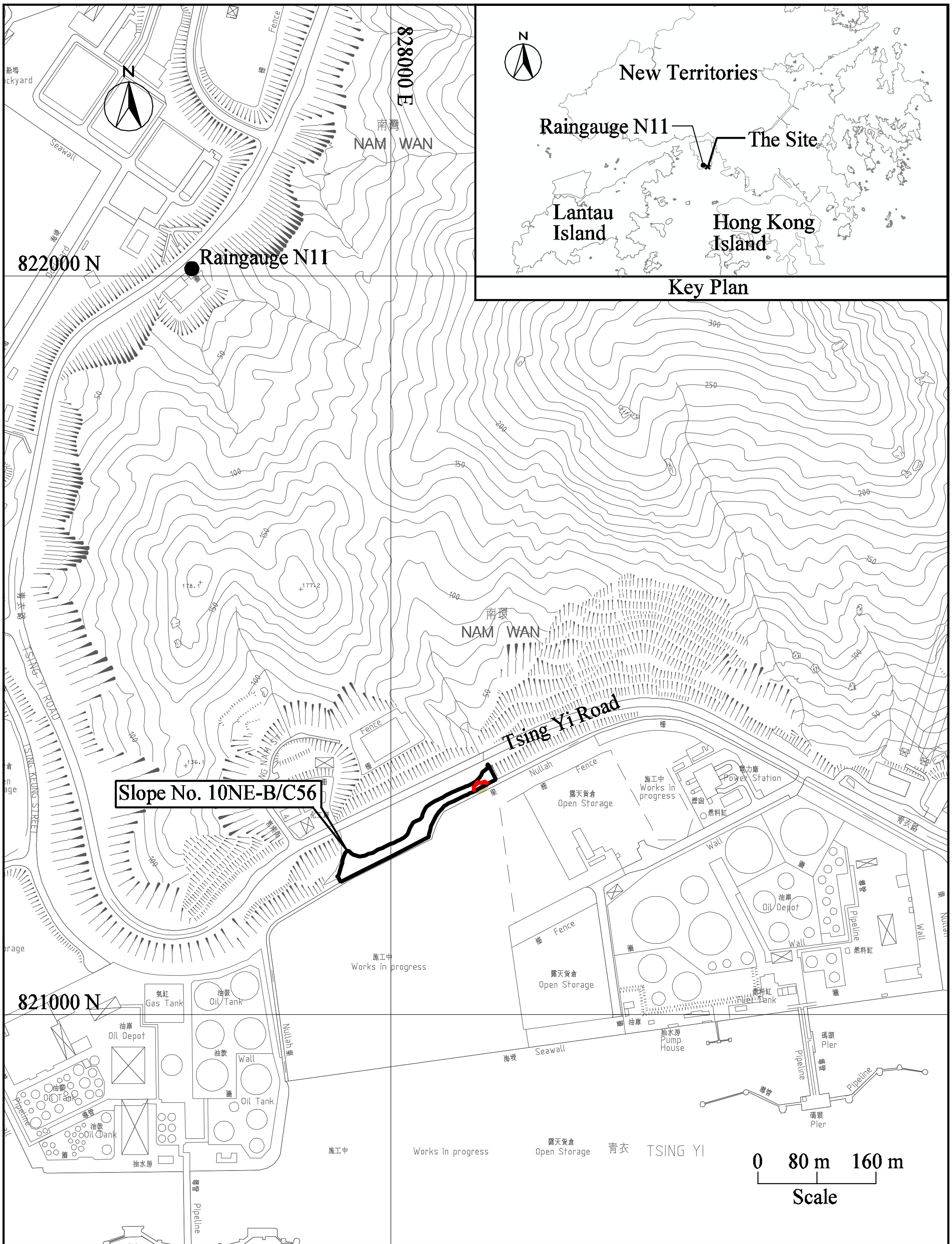

Legend : 7 June 2008 failure scar

Note : Base plan is extracted from 1 : 5000 survey sheets Nos. 10NE-D and 10NE-D dated March 2009.

Figure 1 - Location Plan

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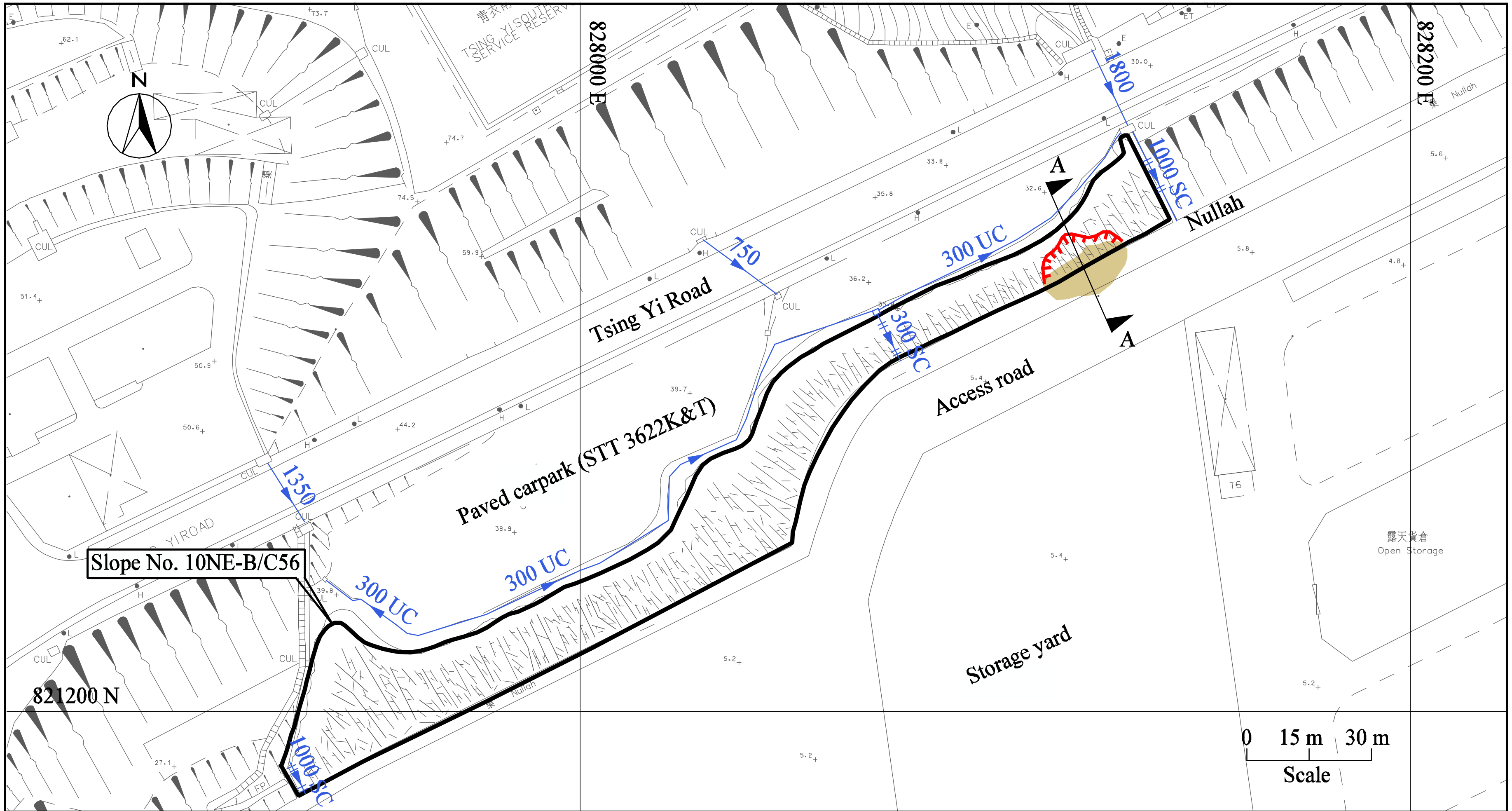

Legend :							
	7 June 2008 failure scar		Rockfall debris	1350	1350 mm diameter cross-road drain	300 SC	300 mm stepped channel
				300 UC	300 mm U-channel		

Note : Base plan is extracted from 1 : 1000 survey sheet No. 10NE-14B dated March 2008.

Figure 2 - Layout Plan

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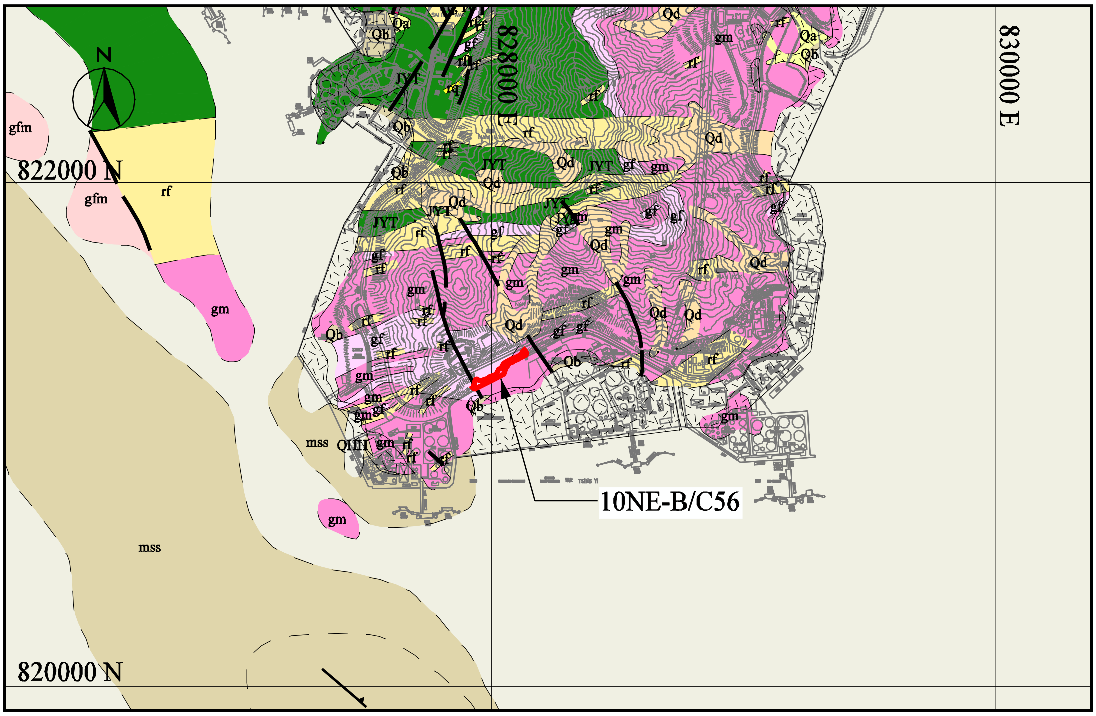

Legend :

0 300 m 600 m
Scale

Superficial deposits

Qa	Alluvium	Clay/silt, sand and gravel; well-sorted to semi-sorted
Qd	Debris flow deposits	Unsorted sand, gravel, cobbles and boulders; clay/silt matrix
Qb	Terraced alluvium	Clay/silt, gravelly sandy, well-sorted to semi-sorted
mss	Marine sand	Sand, part silty

Solid geology

rf	Feldsparphyric rhyolite
JYT	Coarse ash crystal tuff

Major intrusive igneous rocks

gm	Medium-grained granite, 2 - 6 mm
gf	Fine-grained granite, < 2 mm
gfm	Fine to medium-grained granite

Geological lines

- Photogeological lineament
- Fault
- Geological boundary, superficial deposits
- Dyke to dyke contact

Note : Extracted from Hong Kong Geological Survey, Map Series HGM 20, Sheet 10. 1:20 000 scale (GCO, 1991).

Figure 3 - Regional Geology

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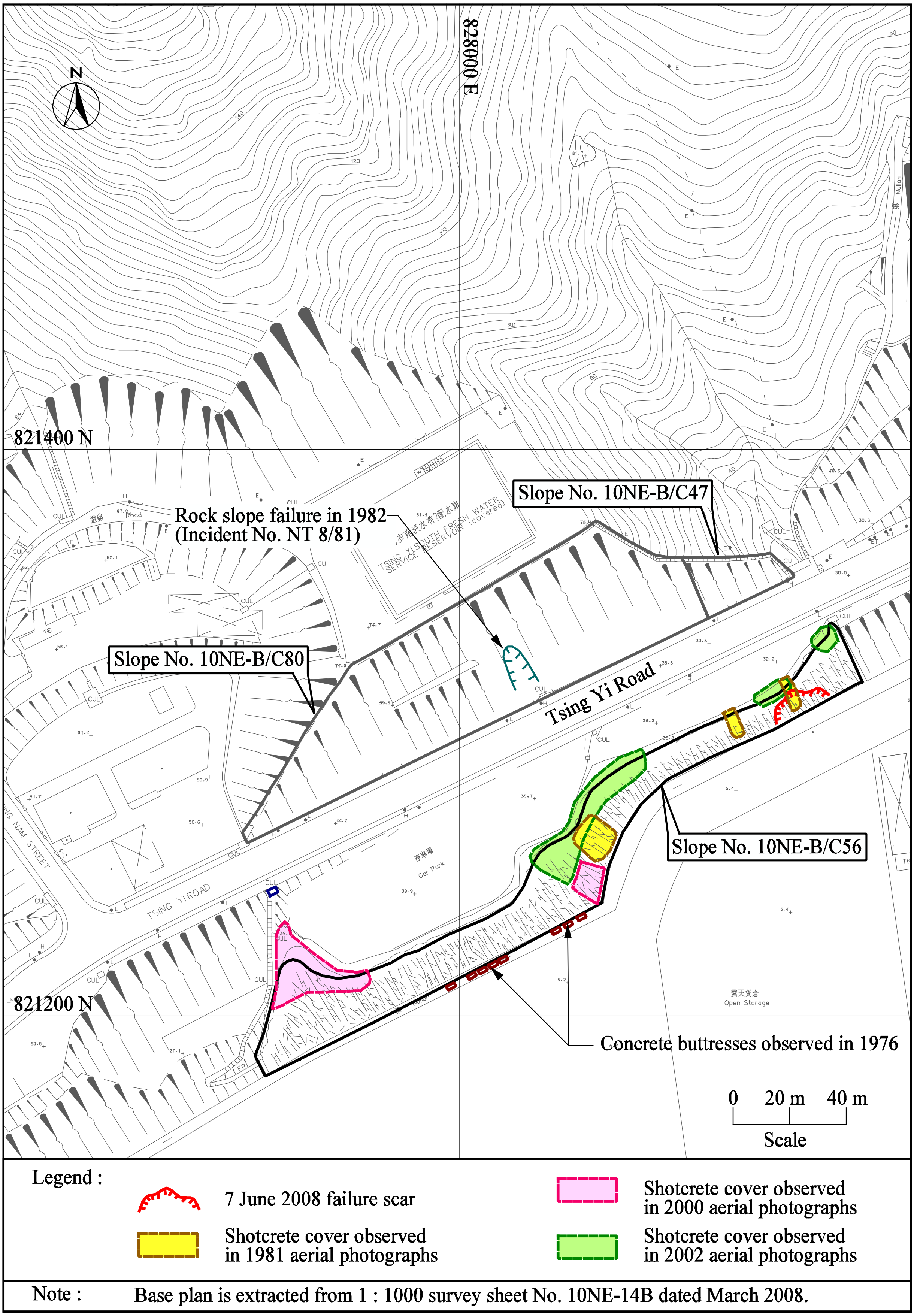

Figure 4 - Site History

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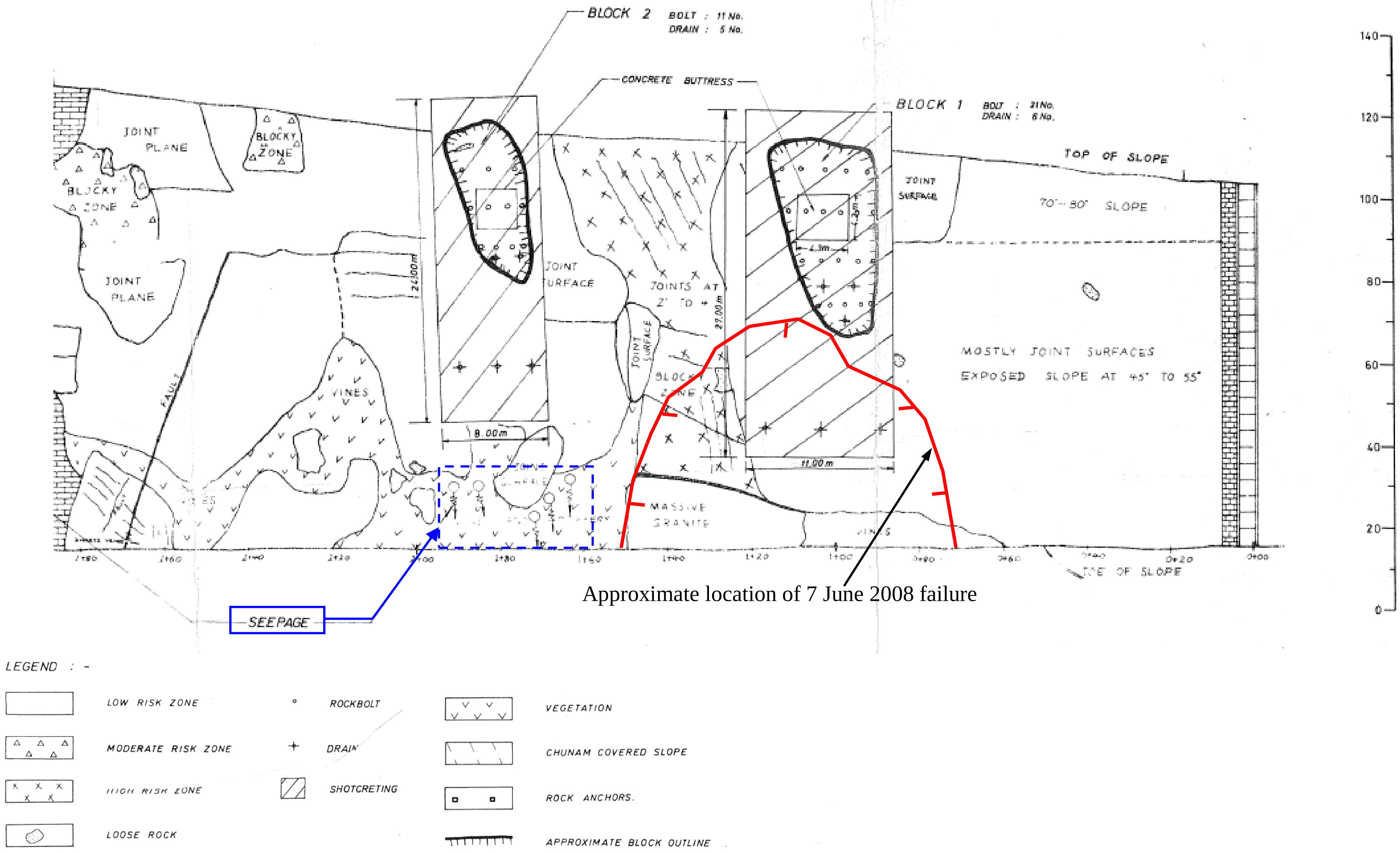

Extracted from As-built Record Drawing No. 5118/1001A prepared by Maunsell Geotechnical Services Ltd. in 1981

Figure 5a – Stabilization Works (Sheet 1 of 2)

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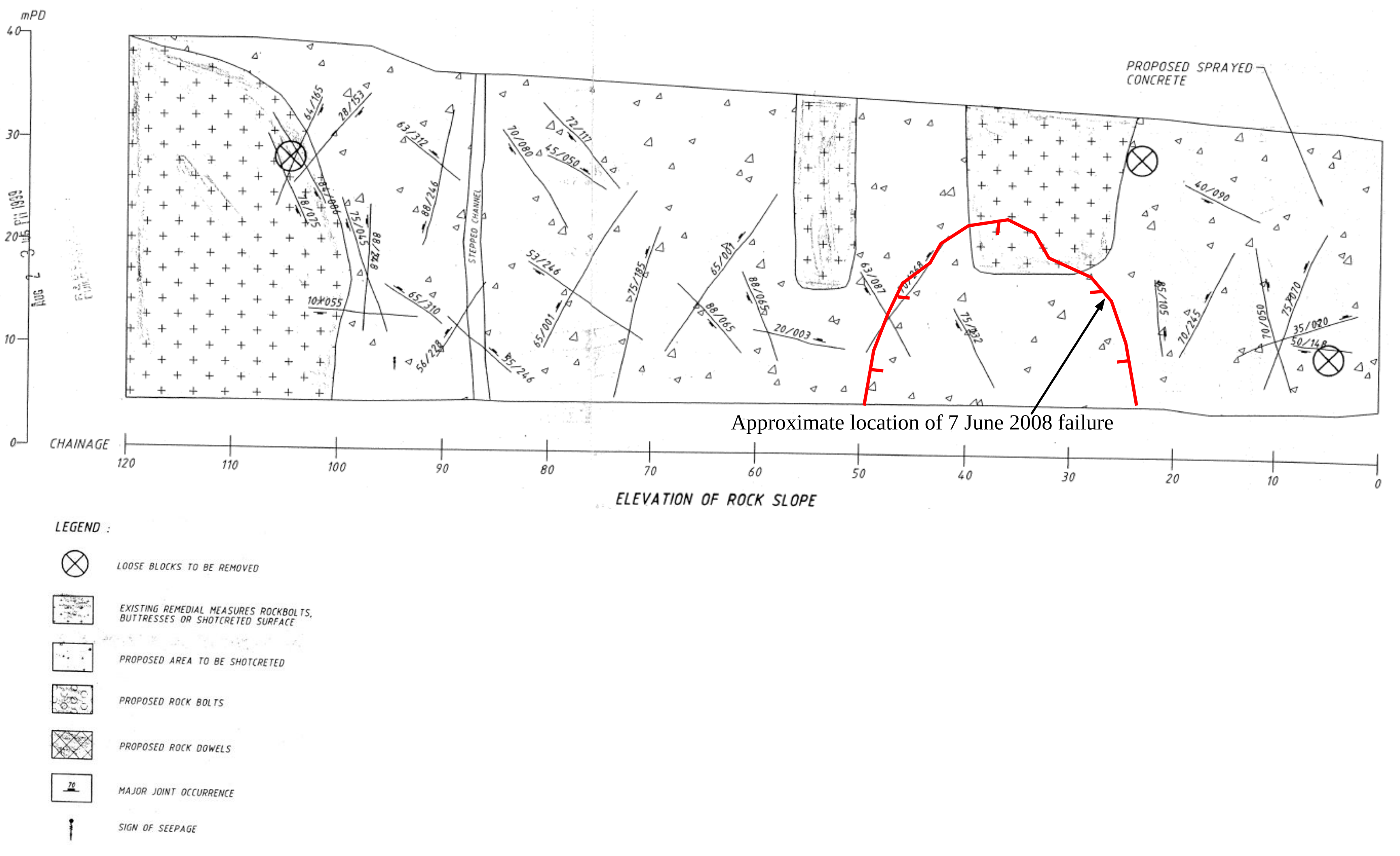

Extracted from Submission Drawing No. 50199/C56/103 prepared by Maunsell Geotechnical Services Ltd. in 1999

Figure 5b – Stabilization Works (Sheet 2 of 2)

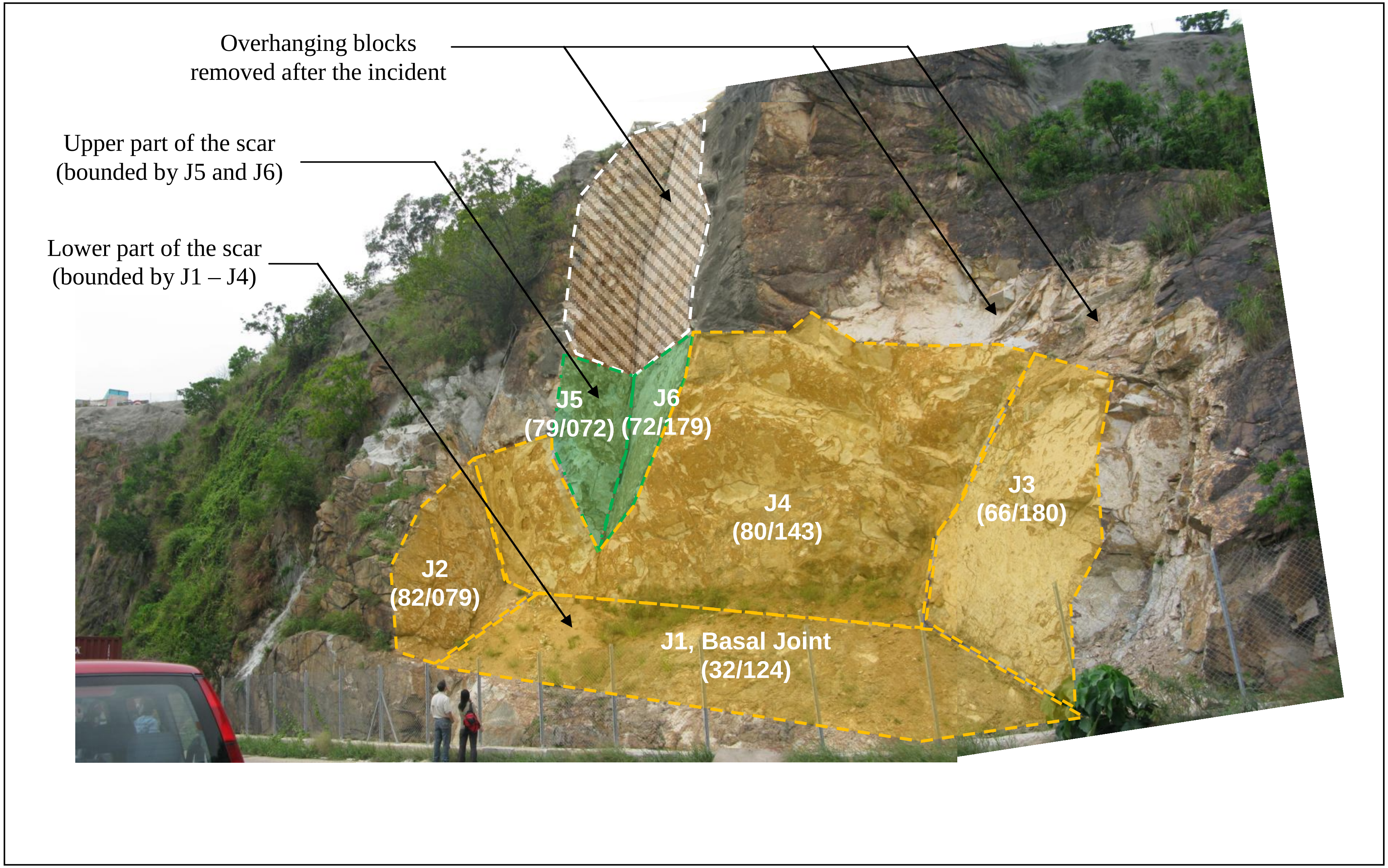

Figure 6 - Post-Incident Site Observations

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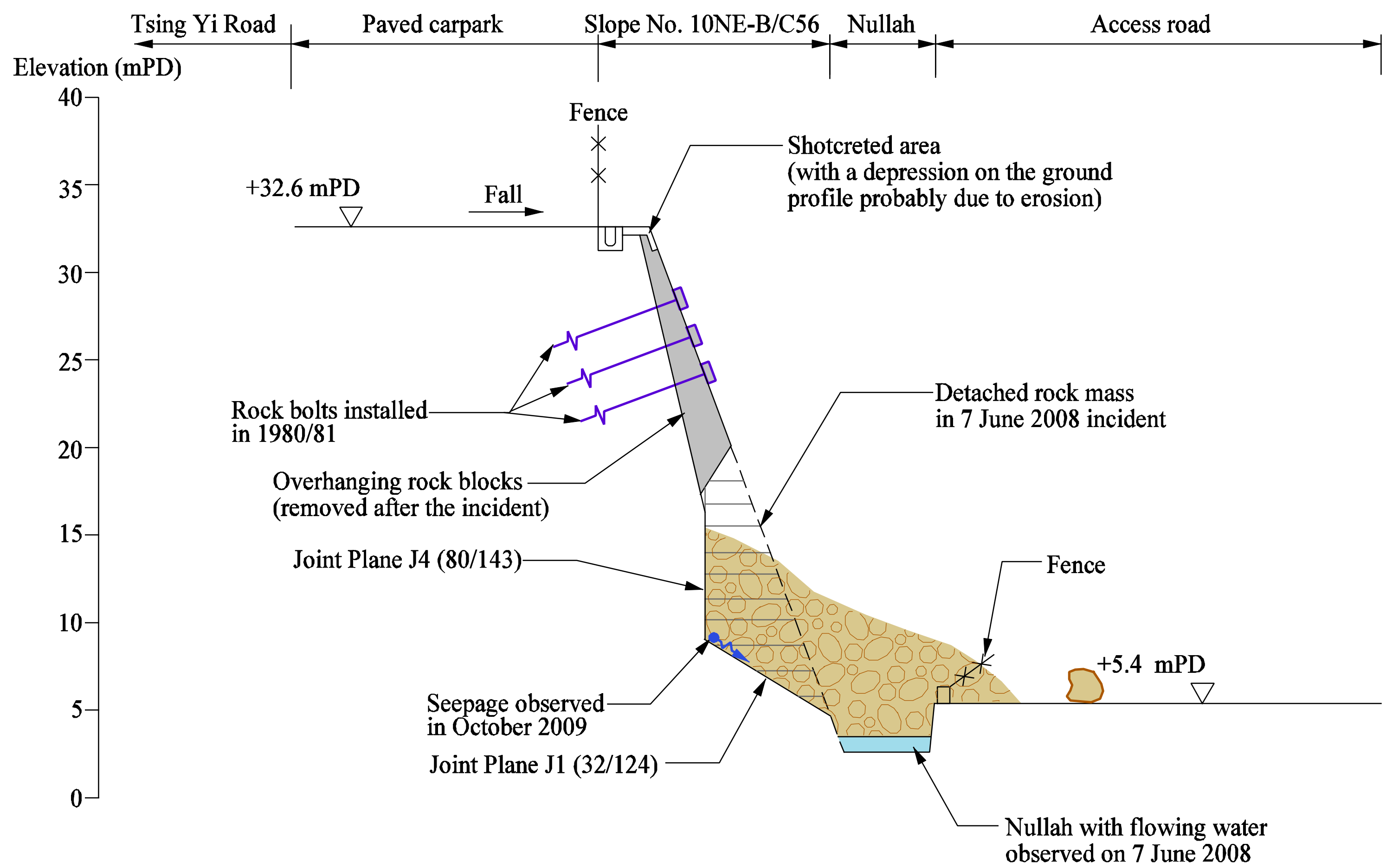
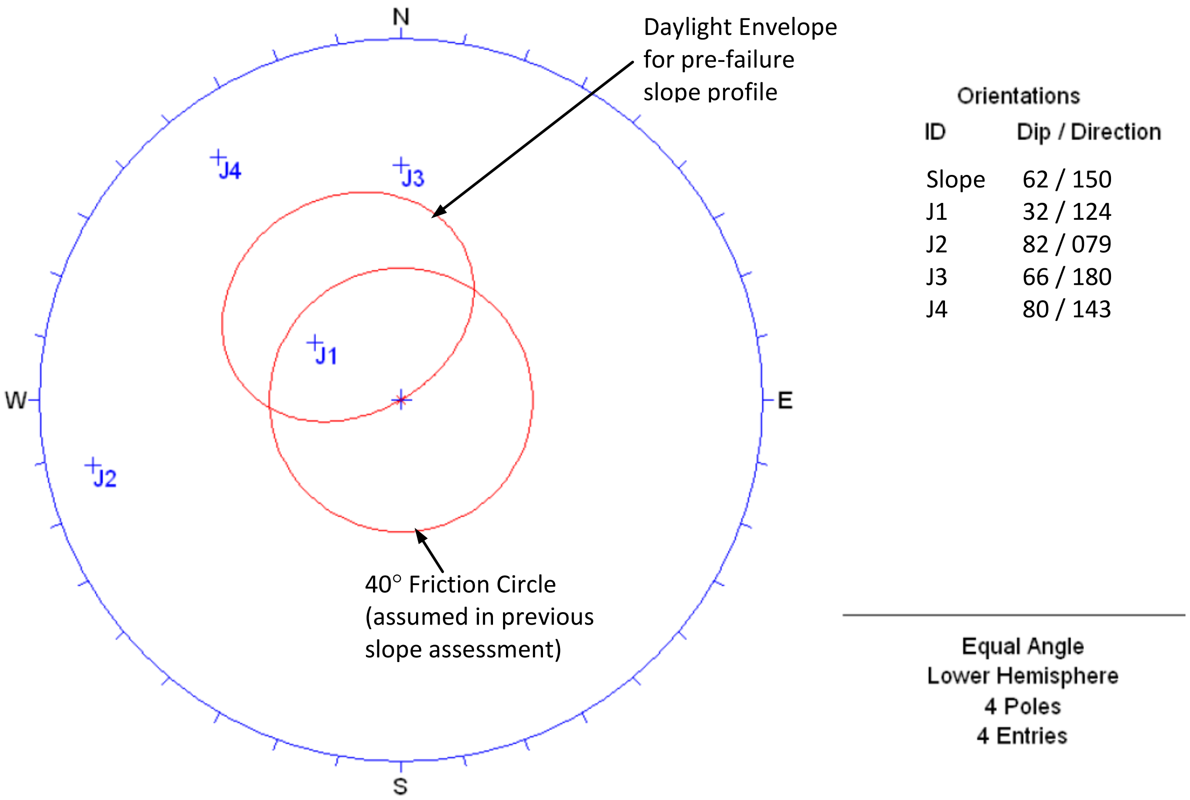
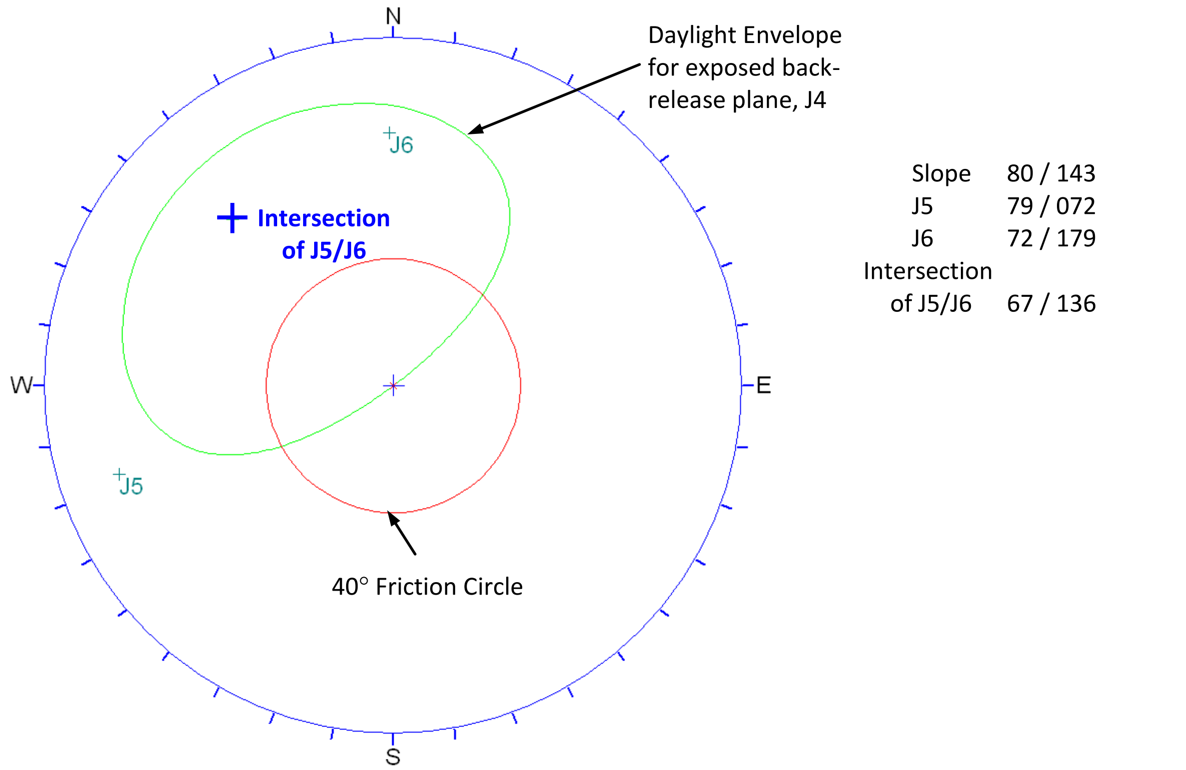


Note : See Figure 2 for location of Section A-A.

Figure 7 - Section A-A



Stereograph Showing J1 Falling within Daylight Envelope for Pre-Failure Slope Profile



Stereograph Showing the Intersection of J5 and J6 Falling within Daylight Envelope for Exposed Back-release Plane, J4

Figure 8 – Stereograph of Rock Joints Bounding the Scar

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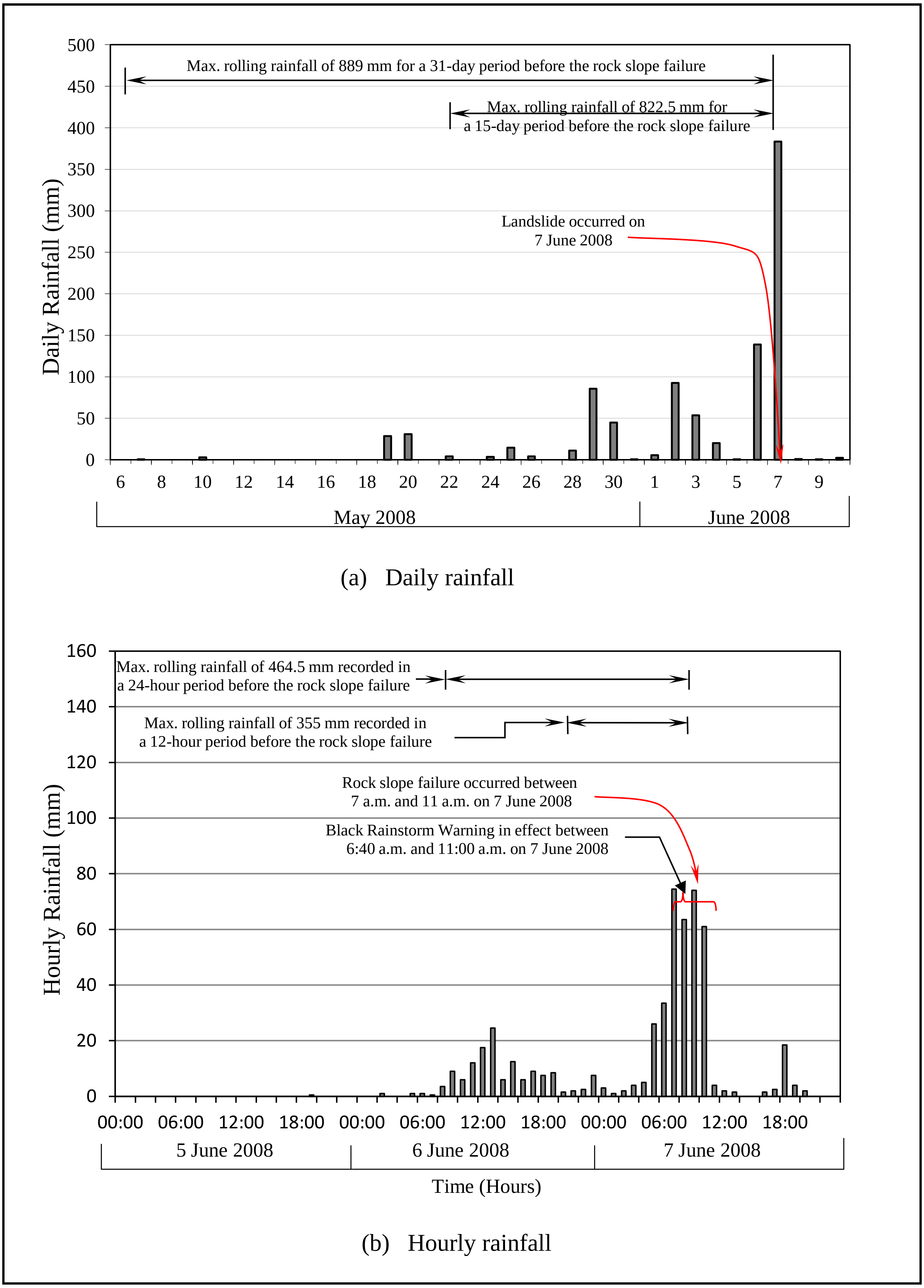

Figure 9 - Daily and Hourly Rainfall Recorded at GEO Raingauge No. N11

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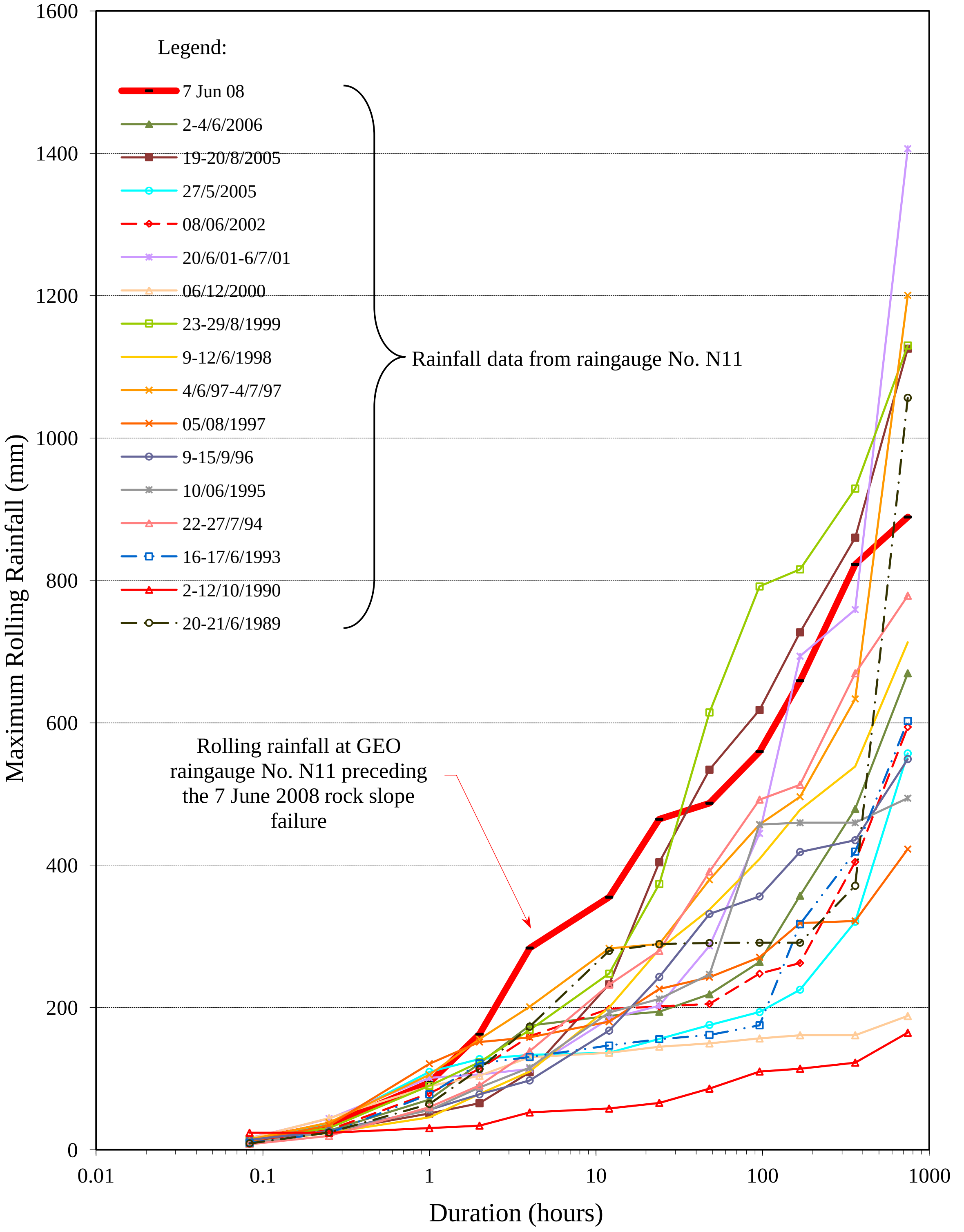

Notes: (1) Rainfall data evaluated from 5-minute readings from GEO raingauge No. N11 (about 800 m to the northwest of the site).
(2) Rolling rainfall of previous rainstorms calculated at GEO raingauge No. N11 since August 1984 when the raingauges became operational.

Figure 10 - Maximum Rolling Rainfall for Previous Major Rainstorms at GEO Raingauge No. N11

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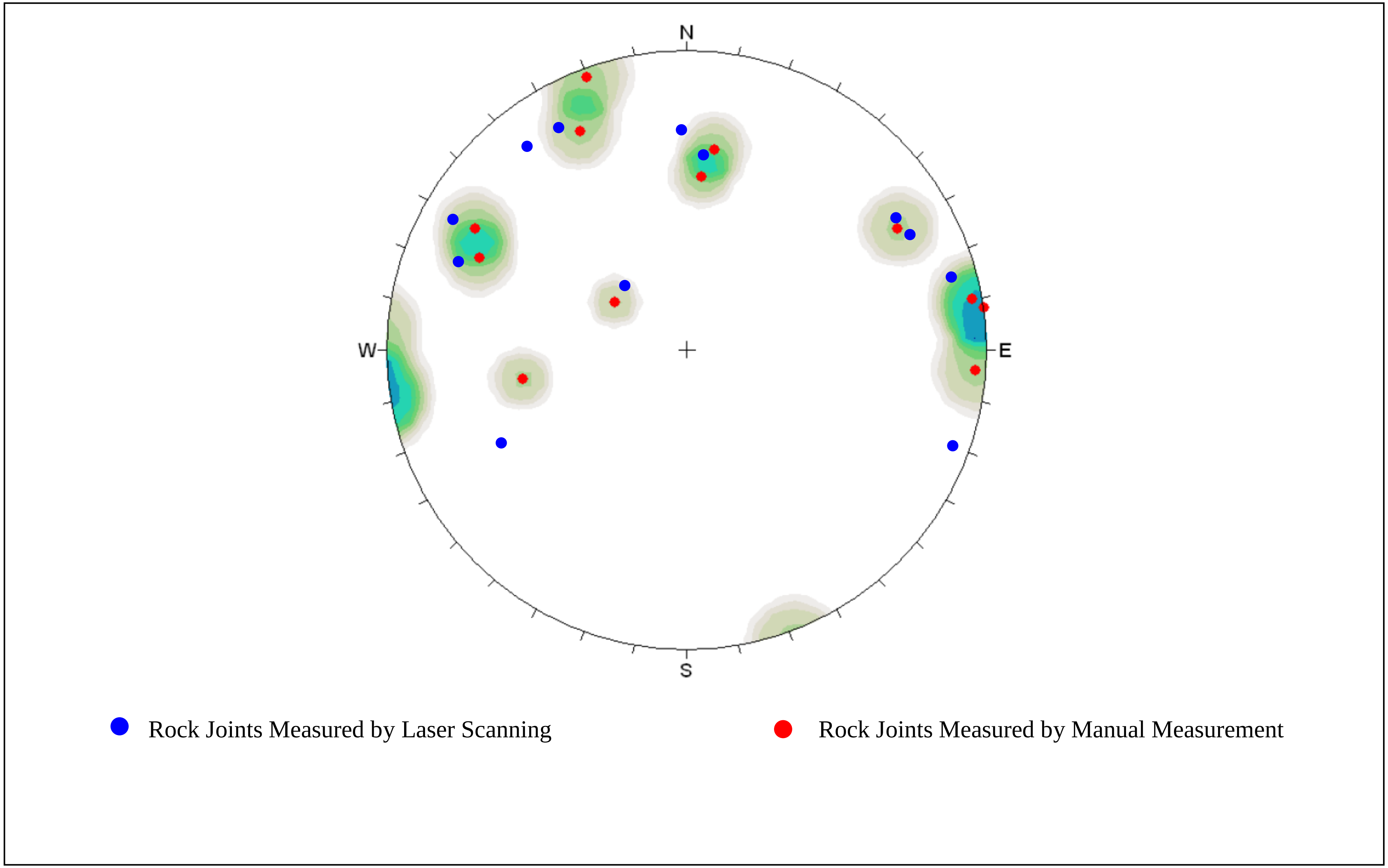
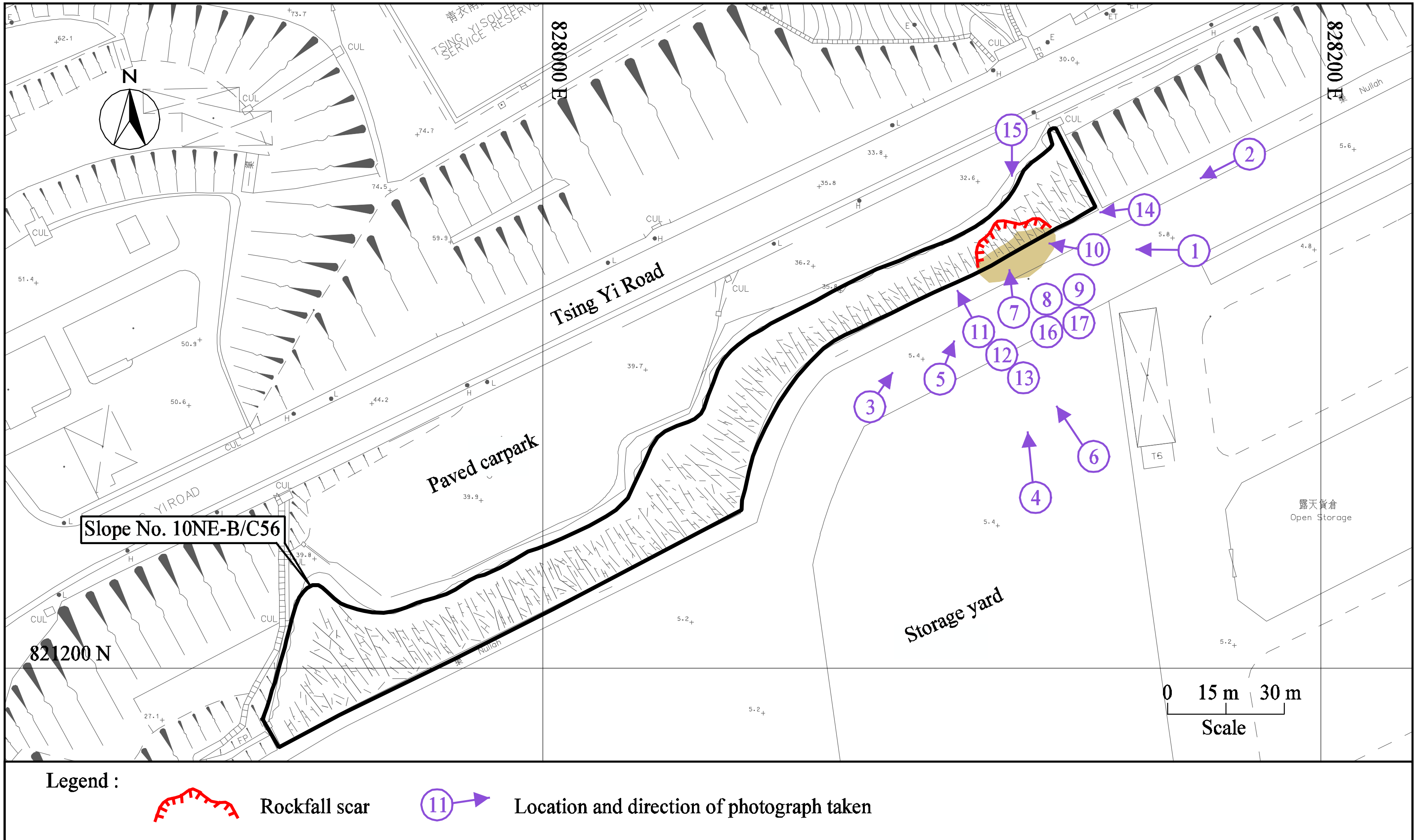


Figure 11 – Comparsion of Stereographs of Rock Joints by Laser Scanning Method and by Direct Manual Measurement



Note : Base plan is extracted from 1 : 1000 survey sheet No. 10NE-14B dated March 2008.

Figure 12 – Locations and Directions of Photographs Taken

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Plate 1 - General View of the 7 June 2008 Failure on Slope No. 10NE-B/C56 (Photograph taken on 12 June 2008)

Plate 2 - Side View of the Rock Slope Failure towards the West and the Drainage Channel of Slope No. 10NE-B/C56 (Photograph taken on 12 June 2008)

Note: See Figure 12 for location and direction of photograph.

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Plate 3 - Side View of the Rock Slope Failure towards the East (Photograph taken on 12 June 2008)

Plate 4 - Close View of Overhanging Blocks and the Rock Stabilisation Measures Installed in the 1980s above the Scar (Photograph taken on 12 June 2008)

Note: See Figure 12 for location and direction of photograph.

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Plate 5 - Urgent Repair Works by the Highways Department after the 7 June 2008 Landslide

Note: See Figure 12 for location and direction of photograph.

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Plate 6 - General View of the Scar after Removal of Debris and Overhanging Rock Blocks
(Photograph taken on 23 April 2009)

Note: See Figure 12 for location and direction of photograph.

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Plate 7 - General View of the Basal Slip Surface (Photograph taken on 20 October 2009)

Plate 8 - Close View of the Basal Slip Surface (Photograph taken on 20 October 2009)

Note: See Figure 12 for location and direction of photograph.

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Plate 9 - Seepage with Growth of Algae Observed at the Basal Slip Surface (Photograph taken on 20 October 2009)

Note: See Figure 12 for location and direction of photograph.

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Plate 10 - Signs of Degradations and Heavy Staining at Release Joints (Photograph taken on 25 June 2009)

Plate 11 - Unplanned Vegetation on Rock Mass Adjoining the Scar (Photograph taken on 23 April 2009)

Note: See Figure 12 for location and direction of photograph.

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Plate 12 - Opening-up of Rock Joint Observed Close to the Scar (Photograph taken by 20 October 2009)

Plate 13 - Signs of Root-wedging and Dislodged Rock Blocks Near the Scar (Photograph taken by 23 April 2009)

Note: See Figure 12 for location and direction of photograph.

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Plate 14 - Fallen Rock Fragments Noted after the 7 June 2008 Failure (Photograph taken on 20 October 2009)

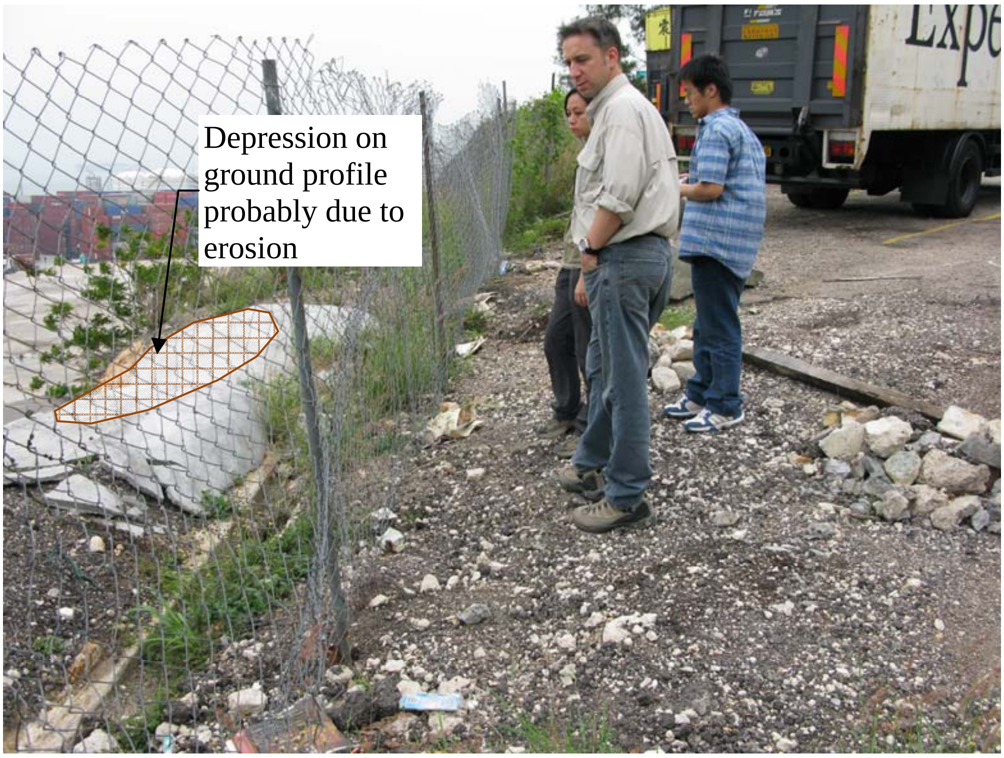

Plate 15 - Conditions of the Crest Channel above the Incident and Signs of Surface Repair (Photograph taken on 23 April 2009)

Note: See Figure 12 for location and direction of photograph.

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Plate 16 - Remote Laser Scanning Method for Rock Joint Mapping
(Photograph taken on 6 July 2009)

Plate 17 - High-Definition Surveying Laser Scanner Developed by Lecia Geosystems (Photograph taken on 6 July 2009)

Note: See Figure 12 for location and direction of photograph.

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APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

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A1. SUMMARY OF OBSERVATIONS

This appendix sets out the detailed observations made from an interpretation of aerial photographs taken between 1924 and 2006. A list of the aerial photographs studied is presented in Table A1 and the main observations of API are shown in Figure A1.

Formation History of Slope

As revealed from the earliest set of available aerial photographs (1924), the subject feature has not been formed. The registered slope No. 10NE-B/C56, a large cut slope, was formed to its present profile in association with the reclamation development of the study area commenced between 1964 and 1969. In the 1969 aerial photographs, three vertical surface drainages are visible on mid-portal, eastern and western end of the subject feature. The surface of the subject feature is a rock outcrop without concrete cover except the upper part of the western end of the subject area is covered by concrete and a U-channel is visible on that area. A nullah is evident at the toe of the subject feature.

Past Instability

No past instability can be identified in the vicinity of the subject feature.

Natural Terrain

The hillside above the subject feature is delineated by a north-south trending undeveloped ridgeline. The ridgeline has a high reflectivity that suggests the area is under erosion with insufficient vegetation cover. Two southeast-draining ephemeral streamcourses can be observed running towards the eastern end of the subject feature.

A2. DETAILED OBSERVATIONS

YEAR	OBSERVATIONS
1924	Single high-flight, poor resolution aerial photograph. The subject feature has not been formed. The hillside above the subject feature is delineated by a north-south trending undeveloped ridgeline. The ridgeline has a high reflectivity that suggests the area is under erosion with insufficient vegetation cover. The approximate location of the ridgeline is shown on Figure No. A1.
1963	Low-flight, excellent resolution aerial photographs. The study area remains undeveloped and deep incised erosional gullies are clearly evident on the ridgeline suggesting an area of deep weathering.

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YEAR	OBSERVATIONS
1964	High-flight, good resolution aerial photographs. The study area remains undeveloped.
1969	Low-flight, low resolution aerial photographs. Large scale reclamation development of the study area is in progress and the former deeply weathered ridgeline has been removed by substantial earth excavation to form development platforms. Vehicular Road M1 is visible on the crest of the subject feature. The subject feature No. 10NE-B/C56, a large cut slope, is formed in association with the reclamation development of the study area. Three vertical surface drainages are visible on mid-portal, eastern and western end of the subject feature. A streamcourse runs toward to the eastern end of subject feature. The surface of the surface feature is a rock outcrop without concrete cover except the upper part of the western end of the subject area is covered by concrete and a U-channel is visible on that area. A nullah is evident at the toe of the subject feature. A building M2 is constructed at the toe of the western end of the subject feature while a large tank structure M3 is constructed on the crest of the subject feature. A stairway M4 is evident at the western end of the subject feature. Neighbouring feature Nos. 10NE-B/C55, 10NE-B/C57, 10NE-B/FR11, 10NE-B/C270, 10NE-B/C80 and 10NE-B/C47 have been formed.
1973	Low-flight, good resolution aerial photographs. No significant changes to the subject feature are apparent. Two more large tank structures M5 and M6 are constructed on the crest of the subject feature. Five buildings (M7, M8, M9, M10 and M11) are constructed below the subject feature. The toe of the western end of the subject feature appears to be covered by vegetation.
1974	Low-flight, excellent resolution aerial photographs only cover the eastern half of the subject feature. No significant changes to the eastern half of the subject feature are apparent except a pipeline structure (M12) is being constructed at the middle area of the subject feature connecting the platform on the crest to the toe of the subject feature.
1975	Single high-flight, poor resolution aerial photograph precludes detailed interpretation.

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YEAR	OBSERVATIONS
	No significant changes to the study area are apparent.
1976	Low-flight, excellent resolution aerial photographs.
	No significant changes to the subject feature are apparent except a pipeline structure (M13) is constructed at the western part of the subject feature connecting the tanks (M3, M5 and M6) and building M2.
	Eight possibly concrete buttress structures are visible at the toe of the western half of the subject feature.
1977	Low-flight, good resolution aerial photographs.
	No significant changes to the subject feature are apparent except many containers are visible on the crest of the eastern half of the subject feature.
1978	Low-flight, good resolution aerial photographs.
	No significant changes to the subject feature are apparent except the containers that visible in 1977 are no longer visible.
1979	No significant changes to the subject feature are apparent.
1980	No significant changes to the subject feature are apparent.
1981	High-flight, good resolution aerial photographs.
	No significant changes to the subject feature are apparent except there are three surface areas (M14, M15 and M16) of the subject feature shows high reflectivity suggesting possibly slope improvement works or vegetation clearance.
	The water tank M5 is demolished. A dwelling M17 is built at the toe of the subject feature.
1982	No significant changes to the subject feature are apparent.
1983	No significant changes to the subject feature are apparent.
1984	No significant changes to the subject feature are apparent.
1985	No significant changes to the subject feature are apparent.
1986	No significant changes to the subject feature are apparent.
1987	No significant changes to the subject feature are apparent.

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YEAR	**OBSERVATIONS**
1988	No significant changes to the subject feature are apparent.
1989	No significant changes to the subject feature are apparent.
1990	No significant changes to the subject feature are apparent.
1991	No significant changes to the subject feature are apparent.
1992	No significant changes to the subject feature are apparent except the dwelling M17 is no longer visible.
1993	No significant changes to the subject feature are apparent.
1994	No significant changes to the subject feature are apparent.
1995	No significant changes to the subject feature are apparent.
1996	No significant changes to the subject feature are apparent.
1997	No significant changes to the subject feature are apparent.
1998	No significant changes to the subject feature are apparent except the buildings M2, M7, M8, M9, M10 and M11 are demolished.
1999	No significant changes to the subject feature are apparent except the two pipelines M12 and M13 are no longer visible.
2000	The western end and the middle part of the subject feature together with feature Nos. 10NE-B/FR11 and 10NE-B/C57 show high reflectivity suggesting slope improvement works and covered by concrete.
2001	No significant changes to the subject feature are apparent.
2002	No significant changes to the subject feature are apparent except three more surface areas show high reflectivity suggesting concrete cover emplaced.
2003	No significant changes to the subject feature are apparent.
2004	No significant changes to the subject feature are apparent.
2005	No significant changes to the subject feature are apparent.
2006	No significant changes to the subject feature are apparent.

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Table A1 - List of Aerial Photographs (Sheet 1 of 2)

Date Taken	Altitude (ft)	Photograph Number
1924	-	Y146
6 February 1963	3,900	Y8262-24
13 December 1964	12,500	Y12923-25
1969	-	Y14823-26
12 October 1973	2,000	6901-02
4 April 1973	6,000	3963-65
8 September 1974	2,000	9213-16
24 December 1975	12,500	11997
16 August 1976	1,900	14663-64
21 December 1977	4,000	20323-25
12 July 1978	4,000	23971-72
10 February 1979	4,000	27424
18 January 1980	4,000	28806-07
26 October 1981	10,000	39066-68
15 July 1982	2,500	42581-82
10 November 1982	4,000	44831-33
25 January 1983	4,000	47377-78
20 June 1983	1,000	49083-84
10 March 1984	4,000	56188-89
1985	4,000	66691-92
17 September 1986	4,000	A5768-69
10 April 1987	4,000	A10593-94
10 June 1988	4,000	A14747-48
20 November 1989	10,000	A19373-74
13 November 1990	4,000	A23591-92
13 May 1992	4,000	A31275-76
2 November 1993	4,000	A36128
6 May 1994	5,000	A38088-89
21 January 1994	10,000	CN5996-97
26 April 1995	3,500	CN13312-13
18 November 1996	5,000	CN15574-75
26 May 1997	4,000	CN17226
14 August 1998	3,500	CN20715
11 June 1999	2,600	CN22998-3000
16 September 2000	4,000	CN28220
15 March 2001	4,000	CN30180-81
9 October 2002	8,000	CW45170-71
11 May 2003	4,000	CW47085-86
20 April 2004	4,000	CW56851-52
8 March 2005	4,000	CW63872-74

Table A1 - List of Aerial Photographs (Sheet 2 of 2)

Date Taken	Altitude (ft)	Photograph Number
5 March 2005	6,000	RW4940-41
19 May 2006	4,000	CW71566-68
Note: All aerial photographs are in black and white except for those prefixed with CN, CW or RW.		

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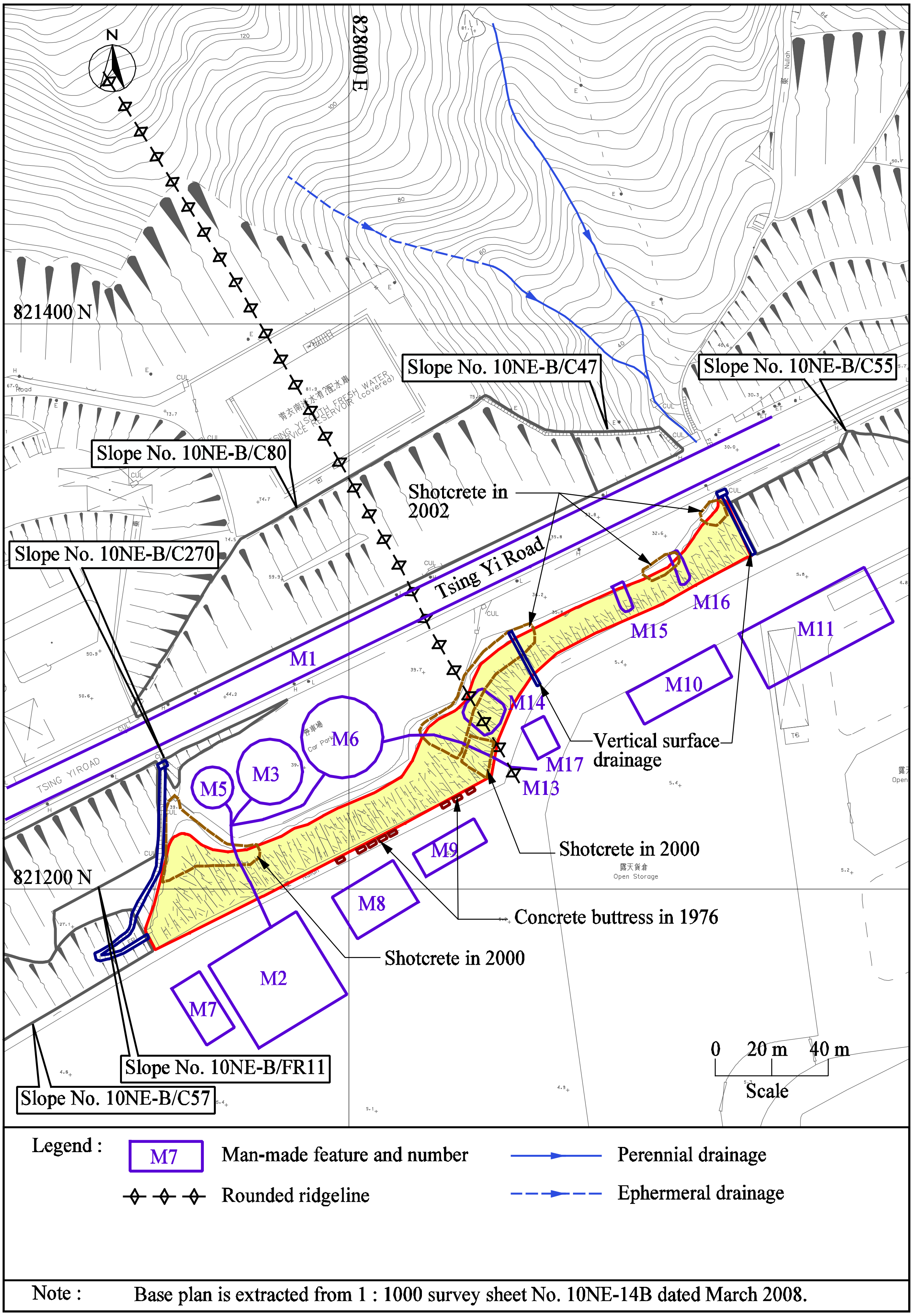

Figure A1 - Site History

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GEO PUBLICATIONS AND ORDERING INFORMATION
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。

Copies of GEO publications (except geological maps and other publications which are free of charge) can be purchased either by:

Writing to
Publications Sales Unit,
Information Services Department,
Room 626, 6th Floor,
North Point Government Offices,
333 Java Road, North Point, Hong Kong.

or

- Calling the Publications Sales Section of Information Services Department (ISD) at (852) 2537 1910
- Visiting the online Government Bookstore at http:// www.bookstore.gov.hk
- Downloading the order form from the ISD website at http://www.isd.gov.hk and submitting the order online or by fax to (852) 2523 7195
- Placing order with ISD by e-mail at puborder@isd.gov.hk

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香港北角渣華道333號
北角政府合署6樓626室
政府新聞處
刊物銷售組

或

- 致電政府新聞處刊物銷售小組訂購 (電話：(852) 2537 1910)
- 進入網上「政府書店」選購，網址為 http://www.bookstore.gov.hk
- 透過政府新聞處的網站 (http://www.isd.gov.hk) 於網上遞交訂購表格，或將表格傳真至刊物銷售小組 (傳真：(852) 2523 7195)
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Map Publications Centre/HK,
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333 Java Road, North Point, Hong Kong.
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電話: (852) 2231 3187
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Chief Geotechnical Engineer/Planning,
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Civil Engineering and Development Department,
Civil Engineering and Development Building,
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Civil Engineering and Development Department,
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Homantin, Kowloon, Hong Kong.
Tel: (852) 2762 5346
Fax: (852) 2714 0275
E-mail: florenceko @cedd.gov.hk

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香港九龍何文田公主道101號
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土木工程拓展署
土力工程處
規劃部總土力工程師
(請交:香港地質調查組)
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傳真: (852) 2714 0247
電子郵件: jsewell@cedd.gov.hk

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標準及測試部總土力工程師
電話: (852) 2762 5346
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電子郵件: florenceko@cedd.gov.hk

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MAJOR GEOTECHNICAL ENGINEERING OFFICE PUBLICATIONS
土力工程處之主要刊物

GEOTECHNICAL MANUALS

Geotechnical Manual for Slopes, 2nd Edition (1984), 300 p. (English Version), (Reprinted, 2011).

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

GEOGUIDES

Geoguide 1	Guide to Retaining Wall Design, 2nd Edition (1993), 258 p. (Reprinted, 2007).
Geoguide 2	Guide to Site Investigation (1987), 359 p. (Reprinted, 2000).
Geoguide 3	Guide to Rock and Soil Descriptions (1988), 186 p. (Reprinted, 2000).
Geoguide 4	Guide to Cavern Engineering (1992), 148 p. (Reprinted, 1998).
Geoguide 5	Guide to Slope Maintenance, 3rd Edition (2003), 132 p. (English Version).
岩土指南第五冊	斜坡維修指南，第三版(2003)，120頁(中文版)。
Geoguide 6	Guide to Reinforced Fill Structure and Slope Design (2002), 236 p.
Geoguide 7	Guide to Soil Nail Design and Construction (2008), 97 p.

GEOSPECS

Geospec 1	Model Specification for Prestressed Ground Anchors, 2nd Edition (1989), 164 p. (Reprinted, 1997).
Geospec 3	Model Specification for Soil Testing (2001), 340 p.

GEO PUBLICATIONS

GCO Publication No. 1/90	Review of Design Methods for Excavations (1990), 187 p. (Reprinted, 2002).
GEO Publication No. 1/93	Review of Granular and Geotextile Filters (1993), 141 p.
GEO Publication No. 1/2006	Foundation Design and Construction (2006), 376 p.
GEO Publication No. 1/2007	Engineering Geological Practice in Hong Kong (2007), 278 p.
GEO Publication No. 1/2009	Prescriptive Measures for Man-Made Slopes and Retaining Walls (2009), 76 p.
GEO Publication No. 1/2011	Technical Guidelines on Landscape Treatment for Slopes (2011), 217 p.

GEOLOGICAL PUBLICATIONS

The Quaternary Geology of Hong Kong, by J.A. Fyfe, R. Shaw, S.D.G. Campbell, K.W. Lai & P.A. Kirk (2000), 210 p. plus 6 maps.

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.

TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents

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