Review of the June 2008 Landslide on Soil-nailed Slope No. 7NE-A/C167 at Ting Kok Road Tai Po

GEO Report No. 295

C.L.H. Lam

Geotechnical Engineering Office
Civil Engineering and Development Department
The Government of the Hong Kong
Special Administrative Region

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Preface

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H.N. Wong
Head, Geotechnical Engineering Office
March 2014

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Foreword

This report presents the findings of a review of a landslide incident (Incident No. 2008/06/0320) on a soil-nailed cut slope No. 7NE-A/C167 at Ting Kok Road, Tai Po. The incident probably occurred on 7 June 2008, involving a shallow failure on the upper batter of the slope. The failure volume was about 20 m^3. No casualties were reported as a result of the incident.

The key objectives of the review were to document the facts about the landslide incident including past geotechnical input to the slope and site observations. Recommendations for follow-up actions are reported separately.

The review was carried out by Ms. C. L. H. Lam of Landslip Preventive Measures Division 1. Assistance and technical support provided by the landslide investigation consultants AECOM Asia Company Limited are gratefully acknowledged.

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Chief Geotechnical Engineer/LPM Division 1

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1 Introduction

A landslide incident (Incident No. 2008/06/0320) involving a soil-nailed cut slope No. 7NE-A/C167 located along Ting Kok Road, Tai Po (Figure 1.1) was reported on 12 June 2008. The landslide probably occurred on 7 June 2008 at the upper batter of the cut slope, with a failure volume of about 20 m^3. The debris was largely deposited on the berm immediately below the landslide scar, exposing four soil nail heads. The landslide did not result in any casualties or road closure.

Figure 1.1 General View of the June 2008 Landslide at Slope No. 7NE-A/C167 (Photograph taken on 11 June 2008)

This report documents the facts about the landslide incident including past geological input to the slope and site observations. Recommendations for follow-up actions are reported separately.

2 Description of the Site

Slope No. 7NE-A/C167 is located about 30 m to the north from the junction of Ting Kok Road and Sam Mun Tsai Road, Tai Po. Above the crest of the cut slope is a natural hillside with its ridge line located some 10 m to 20 m uphill. The slope adjoins slope No. 7NE-A/R33 to the east and slope no. 7NE-A/CR165 to the west (Figure 2.1).

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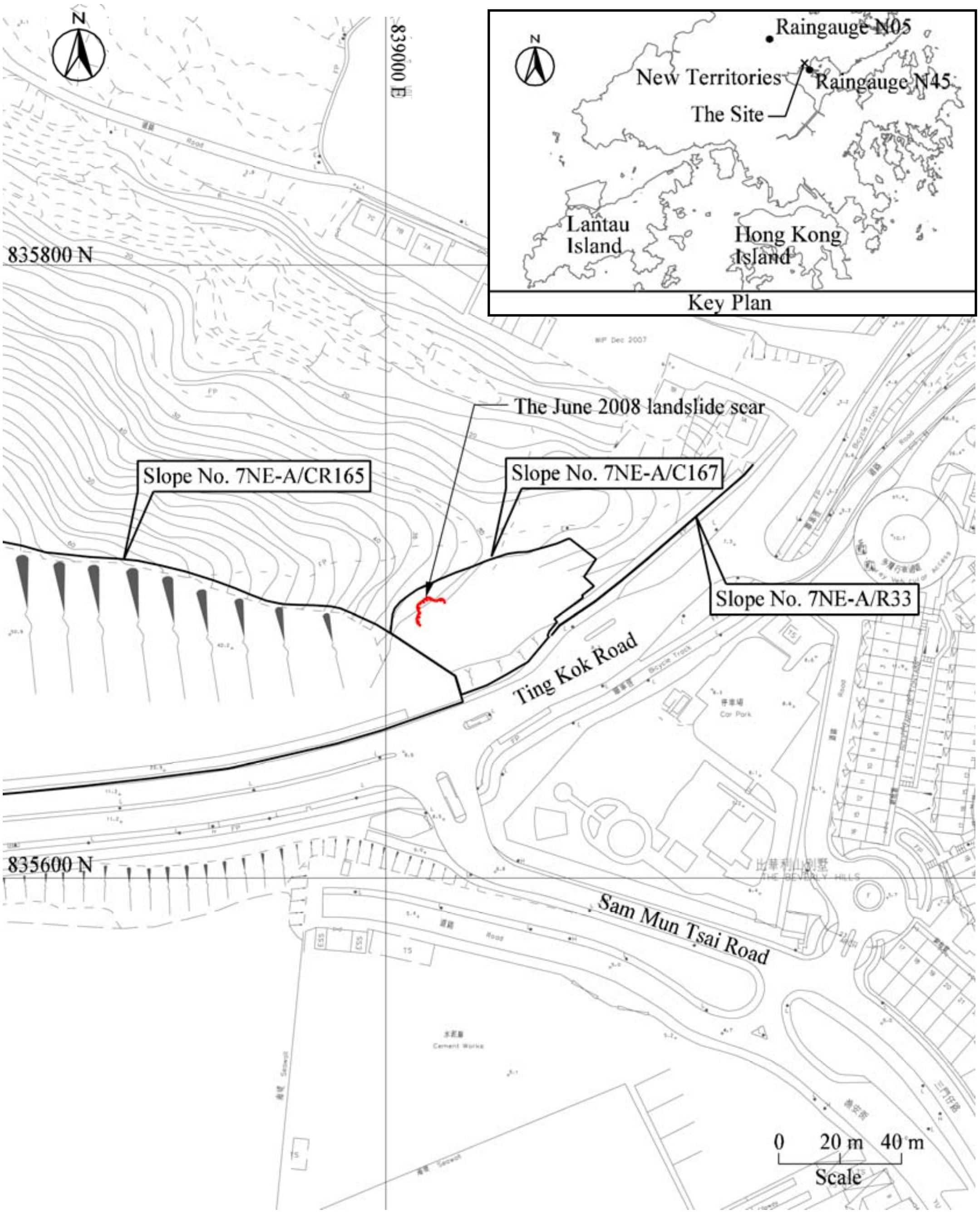

Note: Base plan is extracted from 1:1000 survey sheets Nos. 7NE-1B and 7NE-2A dated March 2008.

Figure 2.1 Location Plan

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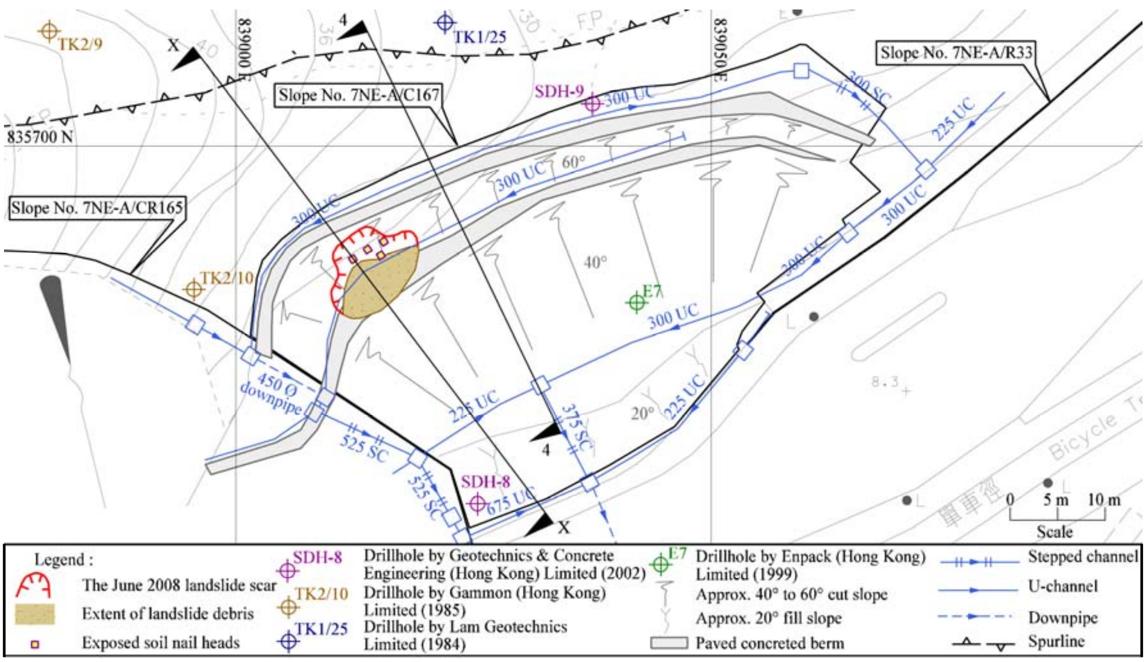
Slope No. 7NE-A/C167 is about 60 m long, up to 24 m high and has two batters. The lower batter is about 14 m high with a slope angle of about 40°. The upper batter is about 9 m high inclining at 60°. The two batters are separated by a 3 m wide concrete berm. A 1.5 m wide concrete berm is also present near the crest of the slope. Two rows of soil nails spaced at about 2 m centres, vertically and horizontally, were installed on the upper batter of the slope, where the June 2008 landslide occurred. Seven rows of soil nails at approximately 1.5 m centres vertically and 2 m centres horizontally were installed on the lower batter (Figures 2.2 and 2.3).

The slope has perimeter channels and U-channels along the slope berms and toe (Figure 2.2). The channels discharge to the public stormwater drainage system, and were constructed as part of the Ting Kok Road widening project (see Section 4). The slope surface was covered with erosion control mats (Figure 2.4), and was heavily vegetated (Figure 1.1) prior to the failure.

According to the SIMAR record, the maintenance agent of slope No. 7NE-A/C167 is the Highways Department (HyD).



Notes: **(1) Base plan is extracted from 1:1000 survey sheets Nos. 7NE-1B and 7NE-2A dated March 2008.**
(2) See Figure 2.3 for Section X-X and Figures 4.1 and 4.2 for design Section 4-4.
(3) The layout of slope and surface drainage system are based on as-constructed drawing No. 66493/18/1602.

Figure 2.2 Layout Plan with As-constructed Drainage System and Ground Investigation Stations

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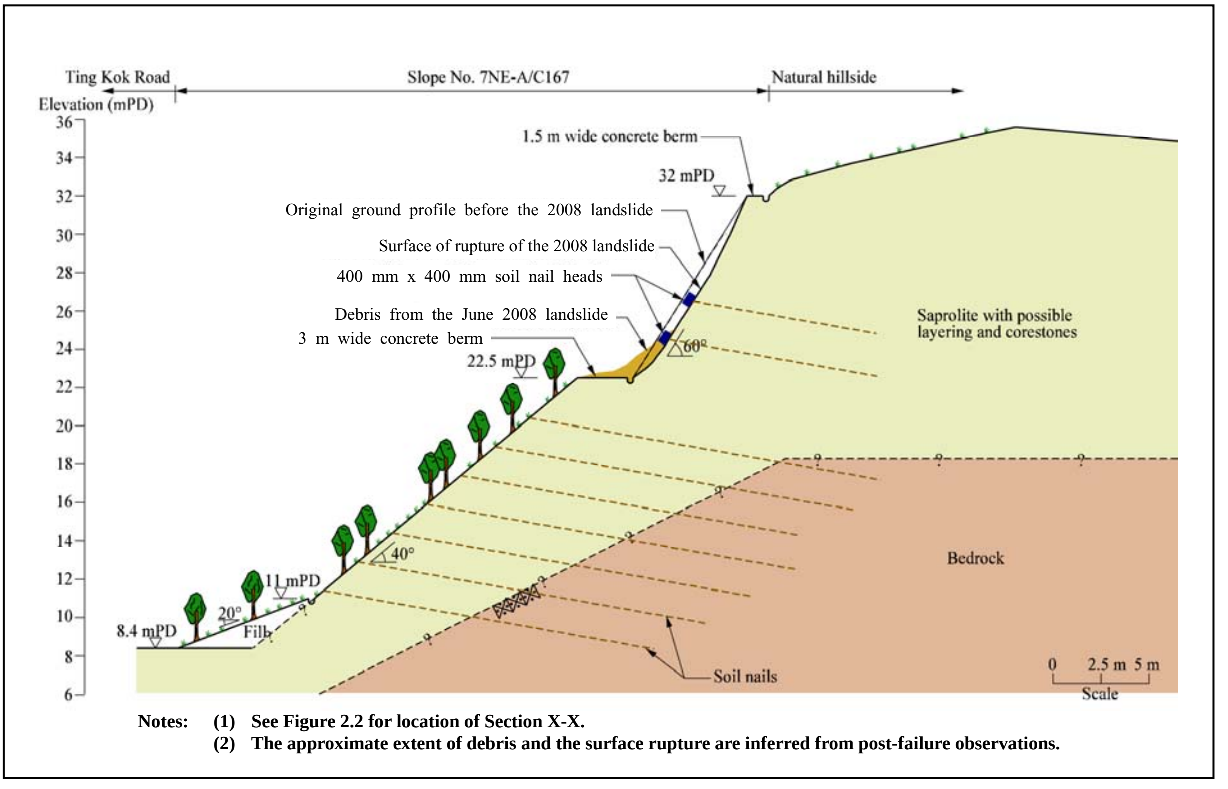

Figure 2.3 Geological Section X-X through the Landslide Scar

Figure 2.4 View of Slope No. 7NE-A/C167 before Failure (Photograph extracted from Slope Maintenance Manual taken on 30 April 2006)

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3 Site History and Past Instability

3.1 Site History

The history of the site has been determined from an interpretation of aerial photographs, together with a review of relevant documentary records. Detailed observations from Aerial Photograph Interpretation (API) are summarised in Figure 3.1 and Appendix A and the salient observations are noted below.

The earliest available aerial photographs taken in 1949 show that the subject slope had not been formed. The area under consideration is located on the south-eastern flank of an east to northeast trending spur near the coastal area of Tolo Harbour. The terrain is generally covered by moderately dense vegetation.

A cut slope No. M1c (Figure A1) covering the lower portion of the present-day slope (No. 7NE-A/C167) was formed in 1964 in conjunction with the realignment of Ting Kok Road. The lower part of slope No. M1c was subsequently cut back further and modified into slope No. M1d, during the road widening works in 1973 (Figures 3.1 and A1).

Slope No. M1d was modified into the present-day profile of slope No. 7NE-A/C167 during the Tai Po Development, Ting Kok Road Upgrading Project Stage I Phase II. The modification works included forming an upper slope batter by cutting into the natural hillside. The upper slope batter, where the June 2008 landslide occurred, was probably formed between June 2004 and April 2005 (Figures 3.1 and A4).

The slope (No. 7NE-A/C167) was handed back to the maintenance office, HyD, in December 2007. At the time of the handover, the slope was covered by vegetation (Figure 2.4).

3.2 Past Instability

The GEO's Landslide Database, Large Landslide Database, and Enhanced Natural Terrain Landslide Inventory (ENTLI) contain no record of landslides within or in the vicinity of cut slope No. 7NE-A/C167.

Based on API, a minor landslide was identified in the October 1993 aerial photographs (Figures 3.1 and A3). The failure occurred on a cut slope about 10 m to the east of the June 2008 landslide, prior to the formation of the present-day profile of slope No. 7NE-A/C167. The failure was shallow and linear in shape, measuring about 12 m wide by 8 m long. Extensive erosion was also observed to the west of the scar (Figure A3).

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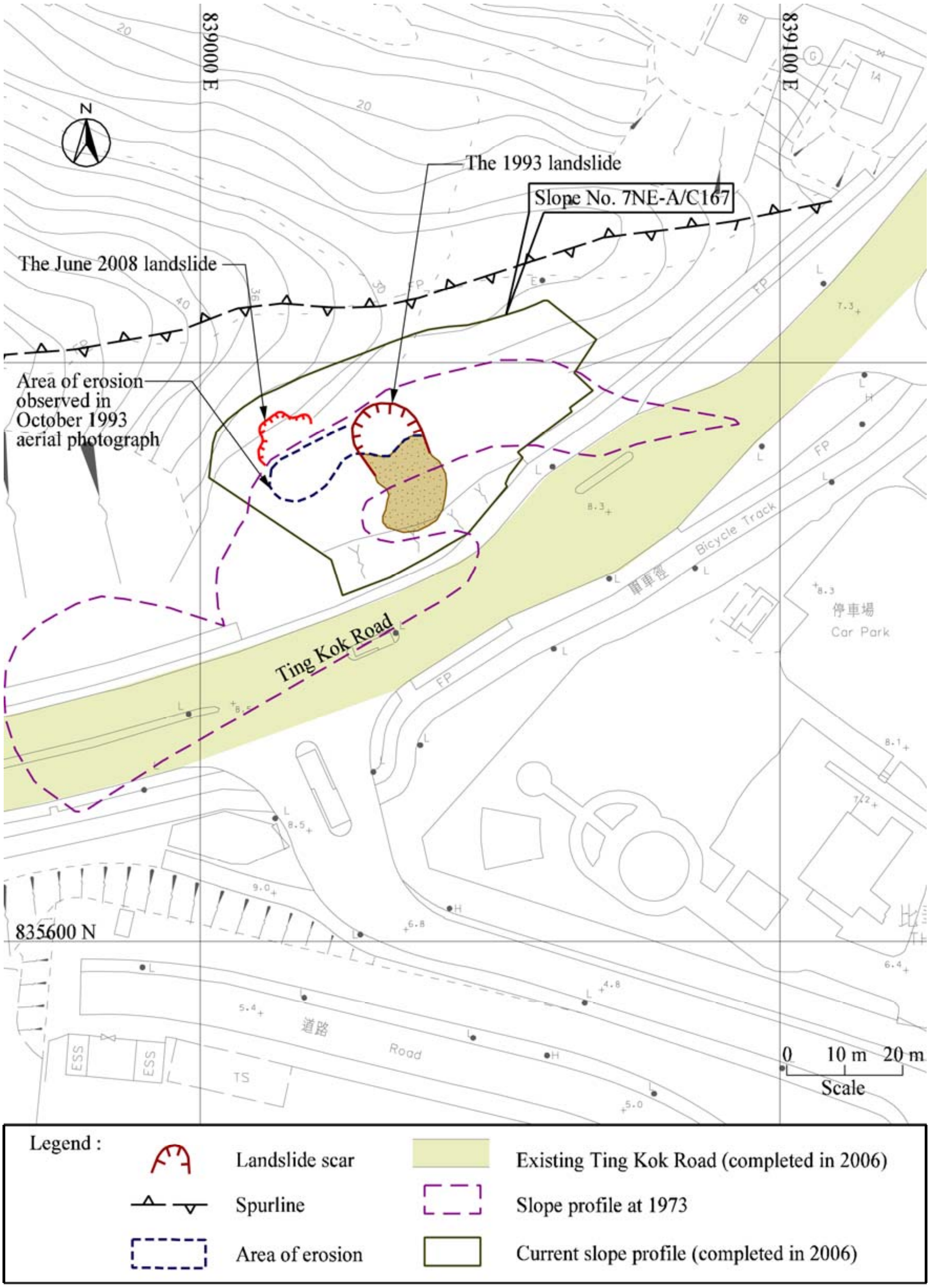

Note: Base plan is extracted from 1:1000 survey sheets Nos. 7NE-1B and 7NE-2A dated March 2008.

Figure 3.1 Site History and Past Instability

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4 Previous Assessments and Slope Works

4.1 General

Based on available records, the upgrading works of slope No. 7NE-A/C167 was designed by Maunsell Geotechnical Services Limited (MGSL) as part of the road widening project – Tai Po Development, Ting Kok Road Upgrading Project Stage I Phase II during 2003 to 2006 (Appendix B.1). A summary of the submissions is given in Table B1 and the salient observations are summarised below.

4.2 Original and Revised Geological Section Close to the June 2008 Landslide Site

The simplified geological section (Figure 4.1) adopted in 2002 for the design of the slope upgrading works is located about 10 m to the east of the June 2008 landslide (Figure 2.2). The lower and upper batter of the slope was assumed to be inclining at 56° and 52° respectively. Soil nails of 16 m to 20 m long, spaced at 1.5 m to 2 m centre-to-centre were proposed. The minimum factor of safety (FoS) was 1.42 (MGSL, 2002a).

In February 2003, during construction, discrepancy was found between the slope profile formed and that required in the design. A design review was subsequently conducted and a stability check was also carried out in March 2003, taking into account that the slope angle of the upper batter had increased from 52° to 60° (Figure 4.2). The groundwater table was assumed at 3 m above bedrock (i.e. about 10 m below ground level) for a 10-year return period rainfall. No perched water table was modelled in the analysis. The review confirmed that no changes to the details of soil nails were necessary, as the calculated minimum FoS was found adequate. It was considered that there was no major design change and hence the design amendment to the slope profile was not submitted to the GEO for vetting.

The slope works were completed in July 2006. Based on the as-built record, a 2.6 m high fill body was provided at the toe of the slope (Figure 2.3), probably as additional toe support. In December 2006, the GEO issued a checking certificate (Ref. No. GEO/ME042/2006) for the slope.

4.3 Routine Maintenance Inspections

Routine Maintenance Inspections (RMI) of slope No. 7NE-A/C167 had been carried out by the HyD in October 2007 and April 2008, before the June 2008 landslide. No signs of seepage or distress were noted in the inspections. No blockage was observed along the surface drainage channel above the June 2008 landslide location.

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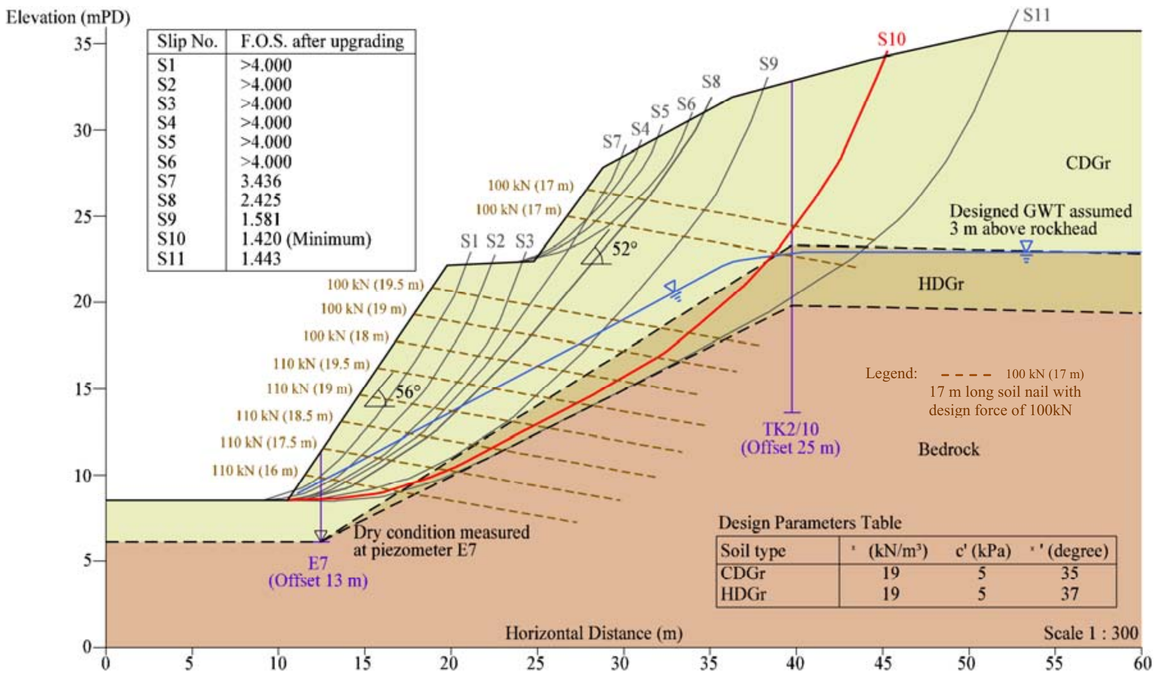
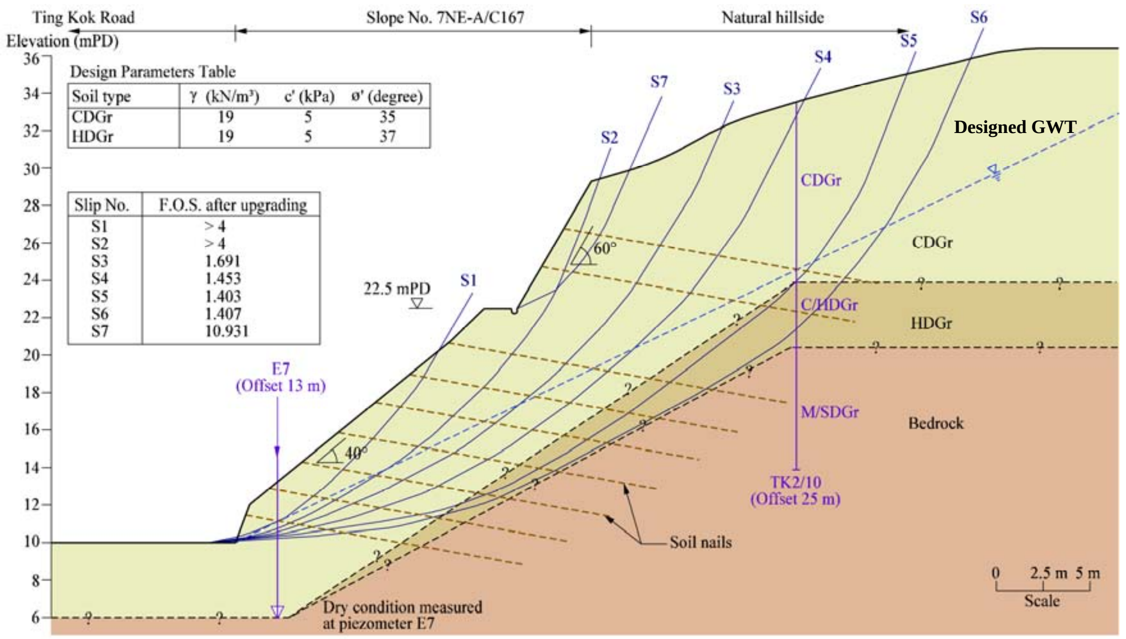


Notes: (1) Section 4-4 extracted from Tai Po Development, Ting Kok Road Upgrading Stage I Phase II, Geotechnical Submission Amendment No. 2 (31 May 2002).
(2) See Figure 2.2 for location of Section 4-4.

Figure 4.1 Original Design Geological Section 4-4



Notes: (1) Section 4-4 extracted from the design review carried out in March 2003.
(2) See Figure 2.2 for location of Section 4-4.

Figure 4.2 Revised Design Geological Section 4-4

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5 The June 2008 Landslide and Post-failure Observations

The June 2008 landslide occurred on the upper batter of a cut slope (No. 7NE-A/C167). No seepage was observed from the landslide scar or in the vicinity, during a post-landslide inspection on 19 June 2008. There was no field evidence indicating concentrated surface runoff toward the failure location.

The landslide was shallow, comprising a central portion and two "wings". The central portion of the landslide measured about 8 m wide by 7 m long, up to 0.5 m deep. The detached portions on both sides (i.e. the "wings") measured about 5 m wide by 4.5 m long (Figures 2.2 and 5.1). The total failure volume was about 20 m^3.

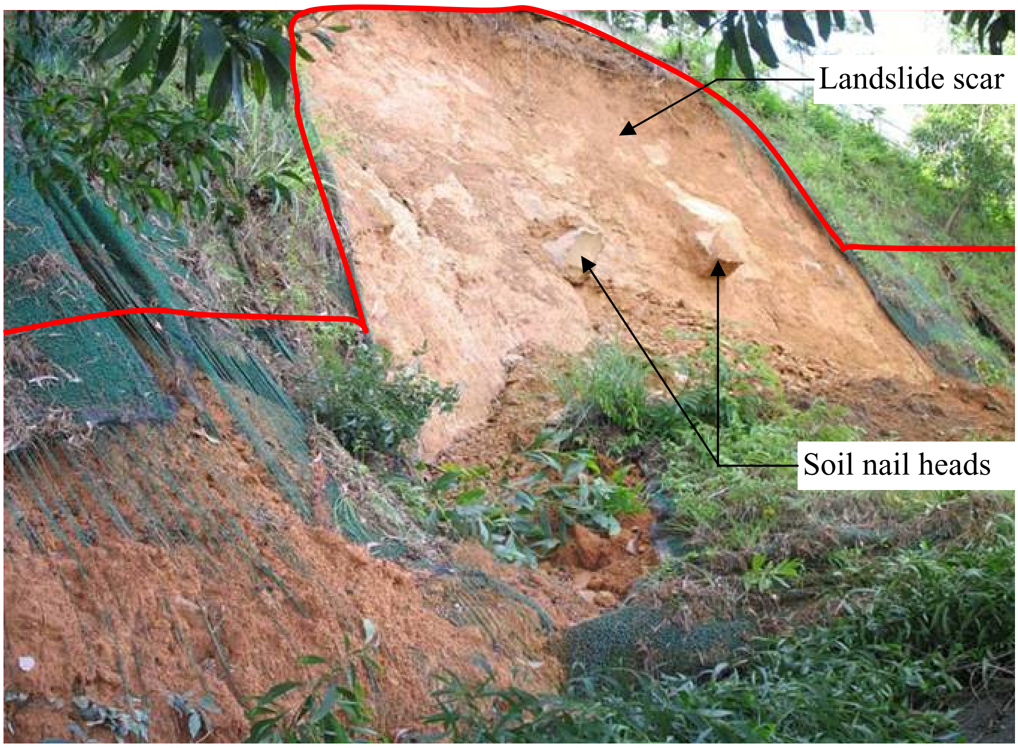

Figure 5.1 View of the Landslide Scar (Photograph taken on 11 June 2008)

Debris from the central portion of the landslide was largely deposited on the berm immediately below (Figure 5.2), while debris detached from the sides was mostly retained by the erosion control mat present (Figures 5.3 and 5.4). No wire mesh was provided on the top of the erosion control mat. The debris comprised yellowish brown, sandy clayey SILT of completely to highly decomposed granodiorite, with occasional cobble-sized fragments of moderately decomposed granodiorite (Figure 5.4).

Four soil-nail heads of 400 mm x 400 mm were exposed on the landslide scar (Figures 2.2 and 5.5). No damage to the exposed soil nail heads was observed during the post-failure inspection on 19 June 2008. Above the nail heads, the landslide scar involved a 4 m high unsupported portion of the cut slope, immediately below the crest channel (Figure 5.6).

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Figure 5.2 Side View of the Landslide and Slope Berm (Photograph taken on 19 June 2008)

Figure 5.3 View of the Minor Detachment on the West (Photograph taken on 19 June 2008)

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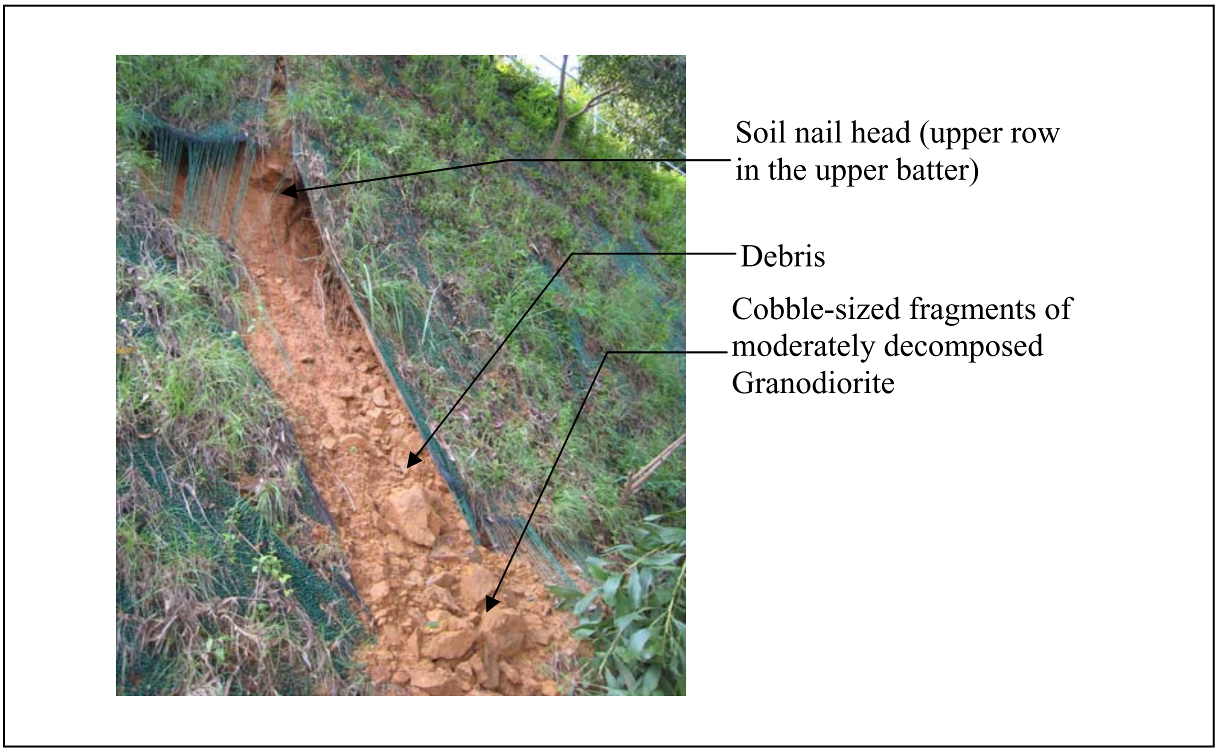

Figure 5.4 View of the Minor Detachment on the East (Photograph taken on 19 June 2008)

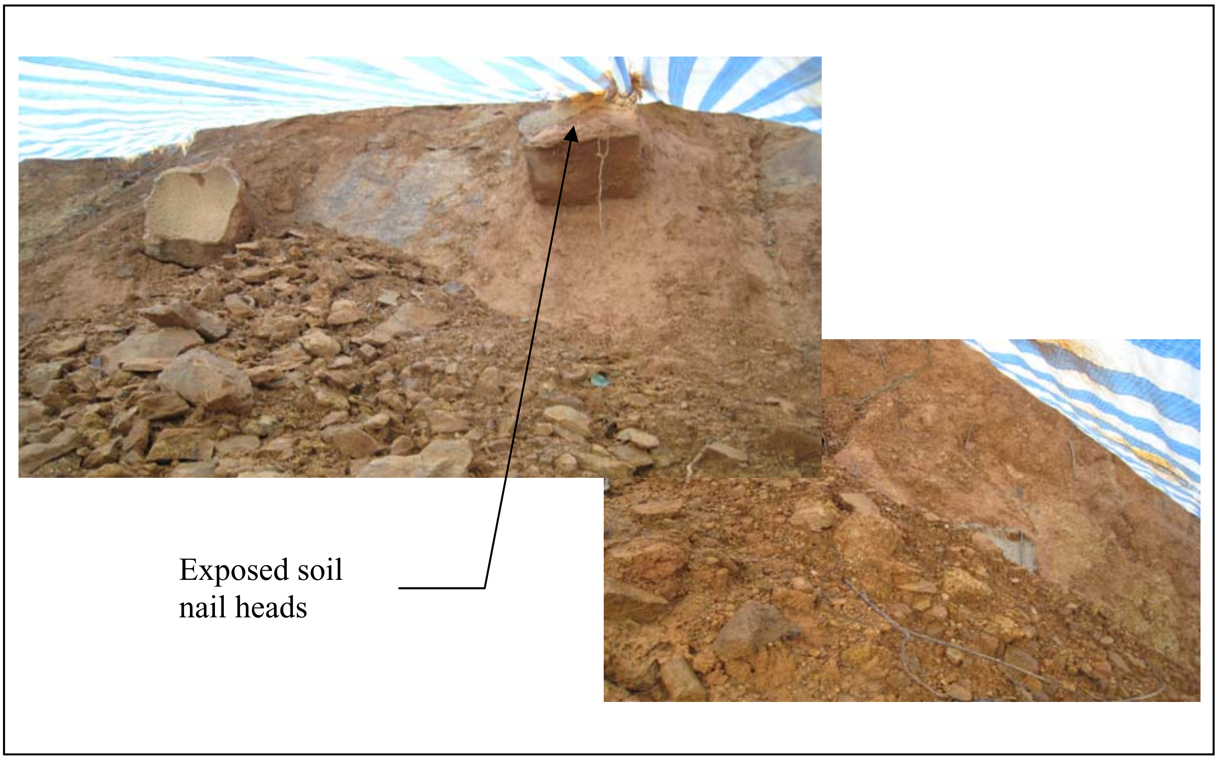

Figure 5.5 View of the Exposed 400 mm x 400 mm Soil Nail Heads (Photograph taken on 19 June 2008)

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The rupture surface mainly ran along the near surface CDGr. A relict joint plane measuring about 3 m wide and 1 m long was observed on the central portion of the landslide scar, in-between the exposed nail heads (Figures 5.5 to 5.7). The dip angle/orientation of the joint is 58/165, which is sub-parallel to the 60° slope. The joint could have daylighted on the slope surface prior to the failure. A portion of the joint plane exposed moderately decomposed granodiorite (MDGr), which could be part of a corestone (Figure 5.7). Some layering with similar dipping and orientation was observed at the landslide scarp (Figure 5.6), which could be an extension of the relict joint exposed at the central portion of the landslide. The lateral extent of the relict joint is uncertain as the debris detached from both sides was retained in place by the erosion control mat at the time of inspection.

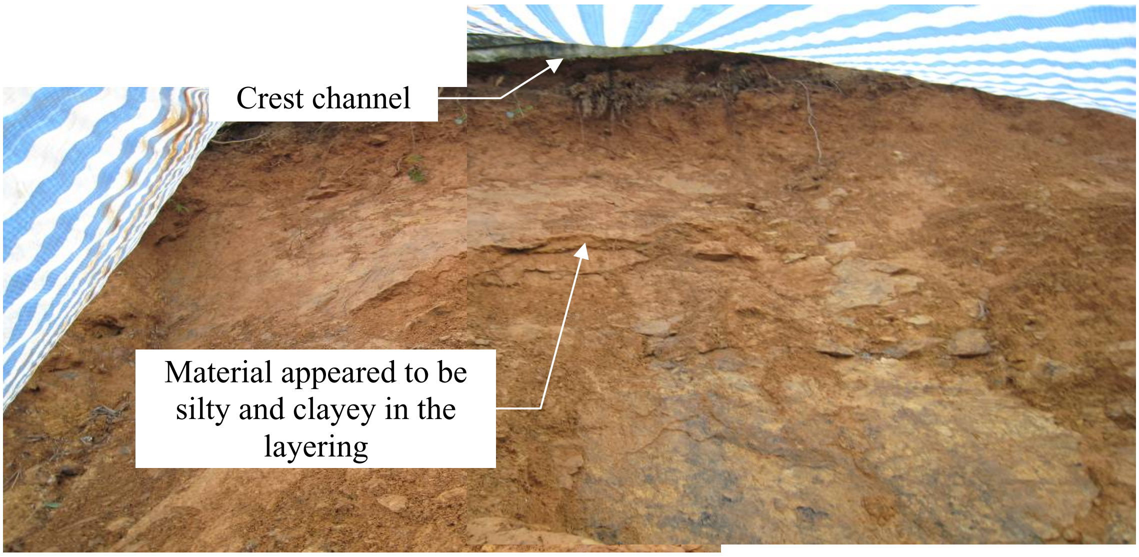

Figure 5.6 View of Layering at the Landslide Scarp (Photograph taken on 19 June 2008)

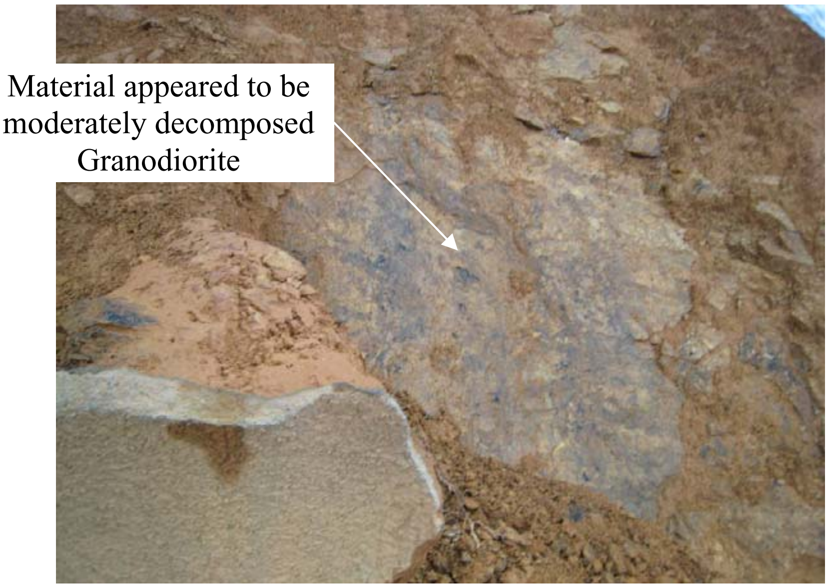

Figure 5.7 Close-up View of the Joint Plane Exposed between the Nail Heads (Photograph taken on 19 June 2008)

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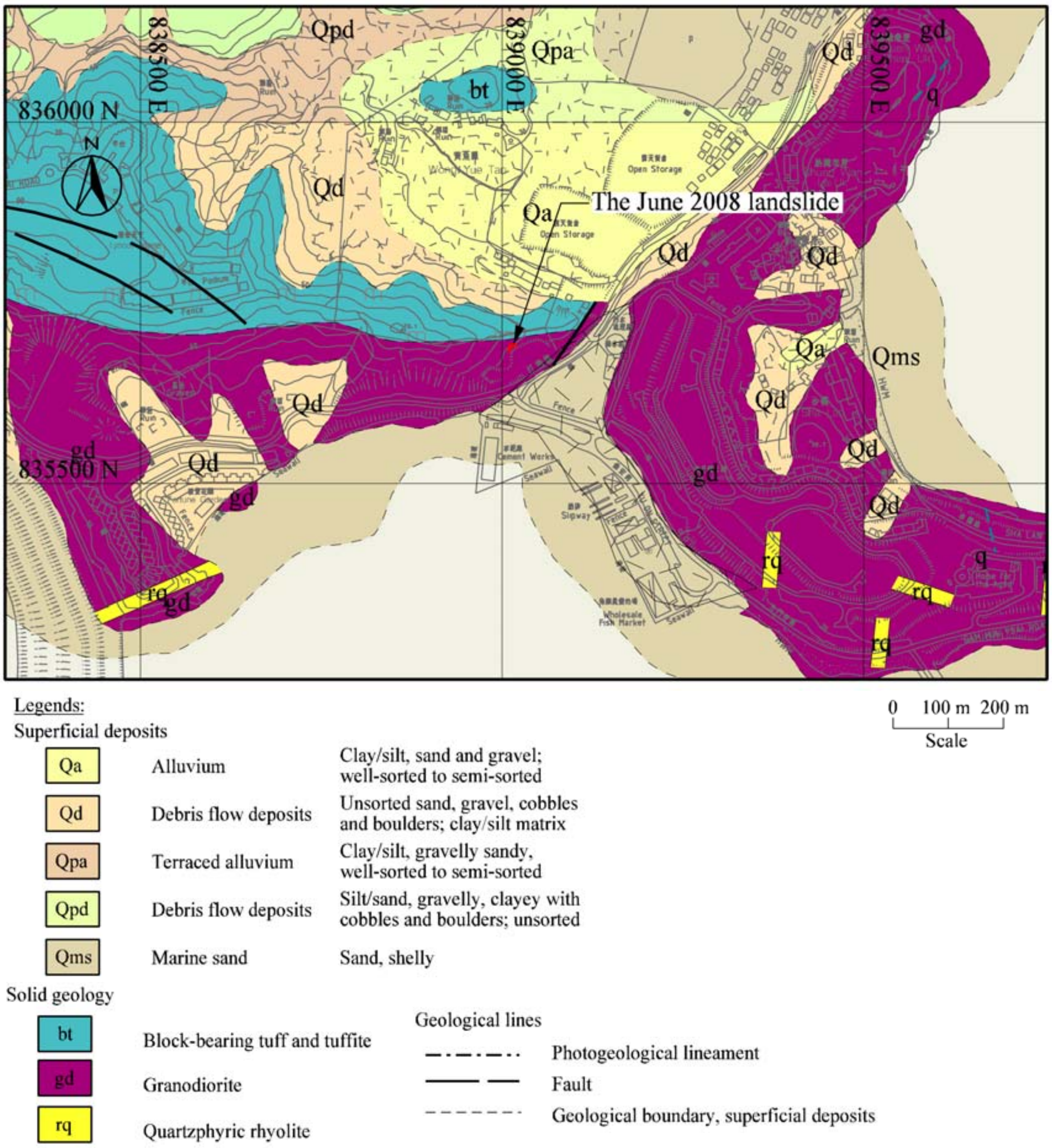
6 Geology and Geological Model

6.1 Regional Geology

According to the Hong Kong Geological Survey (HKGS) 1:20,000 Solid and Superficial Geology Map Sheet Nos. 3 and 7 (GCO, 1986), the site is underlain by Jurassic granodiorite (Figure 6.1). The geological map also shows a contact zone between block-bearing tuff/tuffite and granodiorite close to the crest of the failed slope No. 7NE-A/C167, and a northeast-southwest striking fault at approximately 60 m to the southeast of the slope (Figure 6.1). The presence of the fault in the vicinity may influence of the structural geology of the regional terrain.



Note: **Extracted from Hong Kong Geological Survey, Map Series HGM 20, Sheets Nos. 3 and 7, 1:20,000 scale (GCO, 1986).**

Figure 6.1 Regional Geology

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6.2 Geological Model

No ground investigation (GI) was carried out as part of the present study. Based on the GI carried out previously (Figure 2.2 and Appendix B.2), the slope site comprises a layer of completely decomposed granodiorite (CDGr) about 6 m to 10 m thick, overlying about 4 m of completely to highly decomposed granodiorite (C/HDGr) with the presence of corestones. Closely-spaced joints with various dip angles from 10° up to 75° are recorded in the C/HDGr and corestones. The joints were described as rough undulating and narrow, with iron and manganese oxide staining and some were infilled with kaolin. Altered granodiorite and fault breccias were also noted in a drillhole (No. SDH-8) between 2 mPD and -8 mPD (Figure 2.2), which may suggest possible alteration due to the presence of a nearby contact zone.

The catchment area of the natural terrain above the slope is relatively small, and there is no field evidence indicating concentrated surface runoff towards to the June 2008 landslide location. Monitoring data obtained from the piezometers show that the base groundwater table was close to the bedrock level, some 10 m below ground level.

7 Analysis of Rainfall Records

Rainfall data were obtained from the nearest GEO automatic raingauge (No. N45), which is located about 410 m to the southeast of the landslide site (Figure 2.1).

According to the incident record, the landslide was reported on 12 June 2008. As the exact date and time of the landslide is not known, an analysis (Appendix C) was carried out to deduce the maximum rolling 1-hour, 2-hour and 4-hour rainfall, of five rainstorms that occurred between 6 and 12 June 2008 (Figure 7.1). Results of the analysis indicate that the 2-hour rolling rainfall in the evening of 7 June 2008 was the most severe.

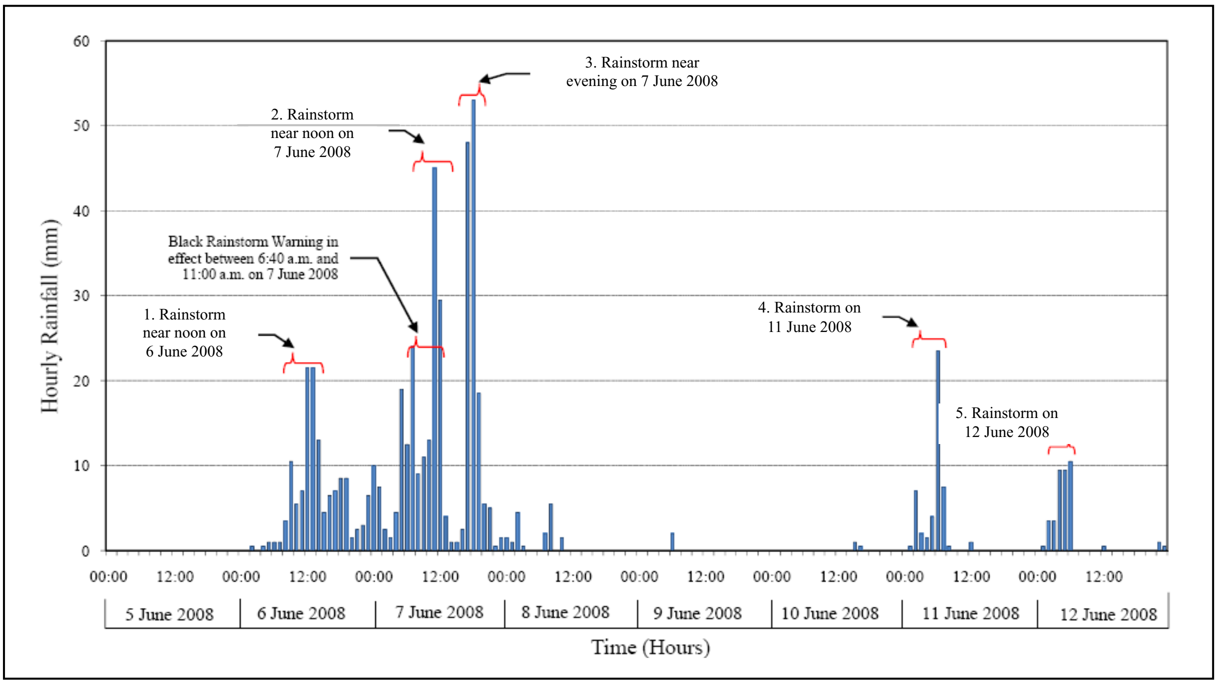

Figure 7.1 Five Rainstorms Recorded by GEO Raingauge No. N45 before 12 June 2008

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For the purpose of the rainfall analysis, the landslide was assumed to have occurred at 7:15 p.m. on 7 June 2008 (Figure 7.2). With reference to historical rainfall data at the HKO in Tsim Sha Tsui where records began in 1884 (Lam & Leung, 1994) and local rainfall data from raingauge No. N45 (Evans & Yu, 2001), the short duration rainfall of the 7 June 2008 rainstorm had a return period of less than 6 years (Table 7.1).

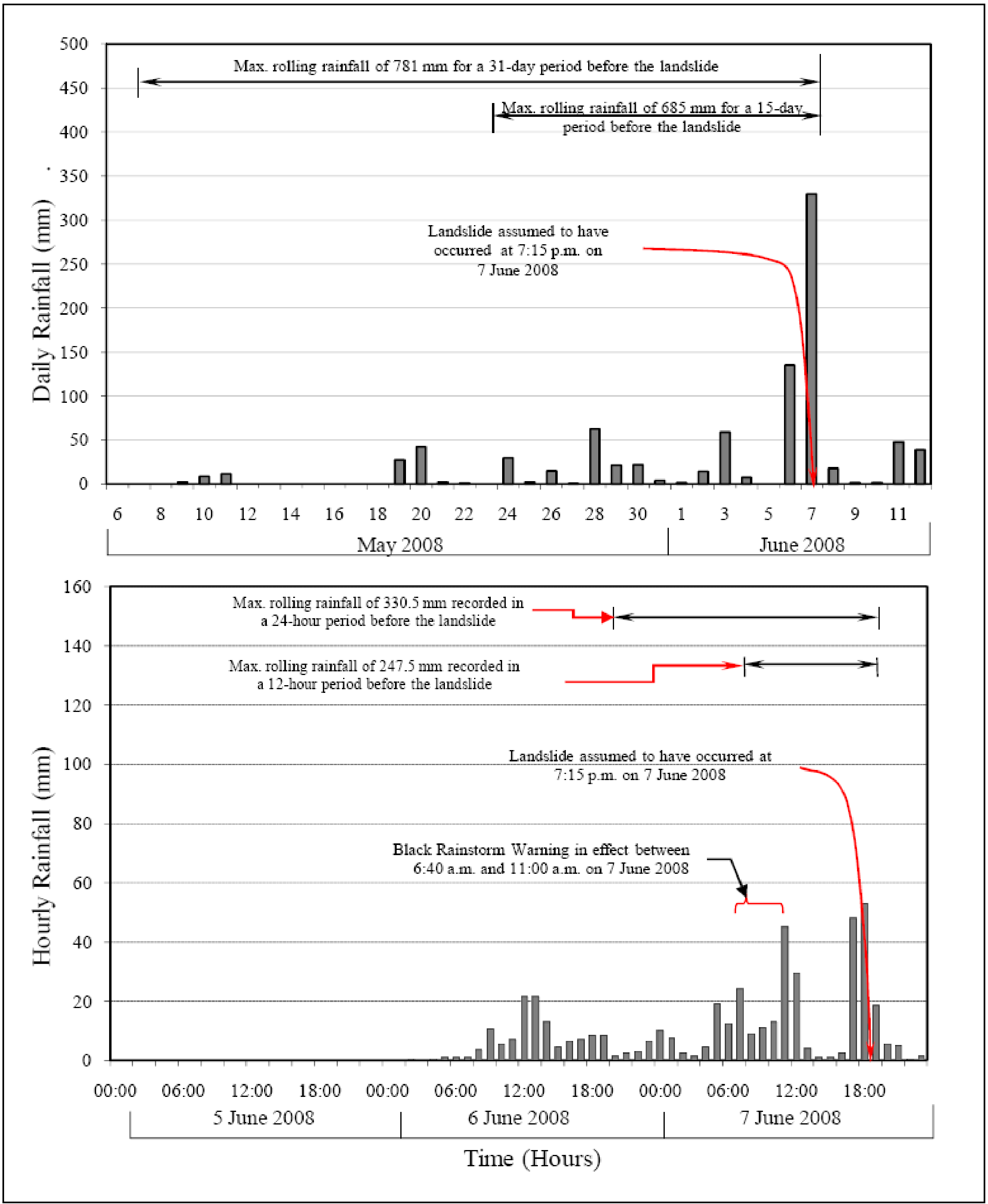

Figure 7.2 Daily and Hourly Rainfall Records at GEO Raingauge No. N45

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Table 7.1 Maximum Rolling Rainfall at GEO Raingauge No. N45 for Selected Durations Preceding the June 2008 Landslide and the Estimated Return Periods

Duration	Maximum Rolling Rainfall (mm) (see Note 2)	End of Period for a Rainfall Cut-off Time at 7:15 p.m. on 7 June 2008	Estimated Return Period (Years)	
			Lam & Leung (1994) (see Note 3)	Evans & Yu (2001) (see Note 4)
5 Minutes	9.5	5:45 p.m. on 7 June 2008	< 2	< 2
15 Minutes	24.5	5:55 p.m. on 7 June 2008	< 2	< 2
1 Hour	64.0	6:30 p.m. on 7 June 2008	< 2	2
2 Hours	112.0	7:15 p.m. on 7 June 2008	3	6
4 Hours	116.0	7:15 p.m. on 7 June 2008	2	3
12 Hours	247.5	7:10 p.m. on 7 June 2008	5	5
24 Hours	330.5	7:15 p.m. on 7 June 2008	6	7
48 Hours	445.5	7:15 p.m. on 7 June 2008	11	8
4 Days	455.0	7:15 p.m. on 7 June 2008	6	4
7 Days	528.5	7:15 p.m. on 7 June 2008	7	6
15 Days	685.0	7:15 p.m. on 7 June 2008	7	5
31 Days	781.0	7:15 p.m. on 7 June 2008	4	3

Notes:
(1) The nearest GEO raingauge to the landslide site is raingauge No. N45 situated at about 410 m to the southeast of the landslide site, while raingauge No. N05 is the second closest situated at about 4 km to the northwest of the landslide site.
(2) Maximum rolling rainfall was calculated from 5-minute rainfall data.
(3) Return periods were derived from the statistical parameters extracted from Table 3 of Lam & Leung (1994).
(4) Return periods were also derived from the statistical parameters of raingauge No. N05 from Appendix B of and Evans & Yu (2001) to access the spatial variability of rainfall as rainage No. N45 does not have rainfall records preceding 1999.

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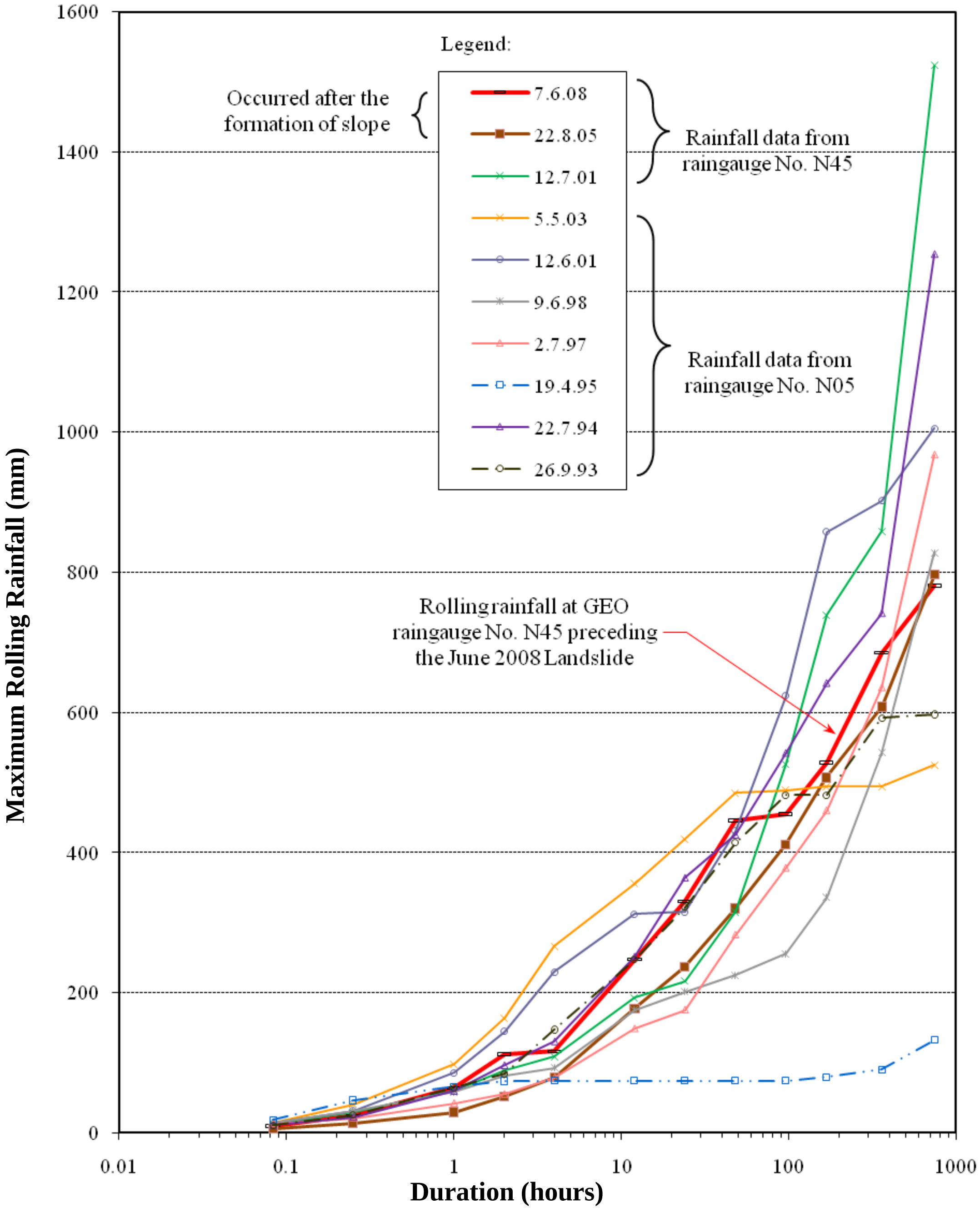
The rainstorm of 7 June 2008 has been compared with previous major rainstorms recorded at raingauge No. N45. The results indicate that the 7 June 2008 rainstorm was the most severe that the upper batter of the slope (where the June 2008 landslide occurred) had experienced after its formation between June 2004 and April 2005 (Figure 7.3). Other rainstorms that had occurred prior to June 2004 were also shown in Figure 7.3 for reference. Further details of the rainfall analysis are given in Appendix C.



Notes: (1) Rainfall data was evaluated from 5-minute readings from GEO raingauges Nos. N45 and N05, which are located at about 0.4 km to the southeast and 4 km to the northwest of the site respectively.
(2) Rolling rainfall of previous rainstorms was calculated since March 1983 and October 1999 for GEO raingauges Nos. N05 and N45 respectively when the raingauges became operational.

Figure 7.3 Maximum Rolling Rainfall for Previous Major Rainstorms at GEO Raingauges Nos. N05 and N45

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8 Discussion

The landslide may have been triggered by saturation of the near surface CDGr, during the rainstorm of 7 June 2008, although the rainfall was not particularly heavy with a return period less than 10 years. The presence of adversely oriented relict joints in the CDGr, coupled with the steepness (60°) of the slope profile would have been a key contributory factor to the failure. A 4 m high unsupported local portion near the crest of the slope could have also contributed to the failure.

The landslide was minor, shallow (0.5 m deep) and not mobile. The debris was largely deposited on the slope or retained by the erosion control mat, with negligible consequences. This reaffirms the robustness of soil nails for use in slope upgrading works to prevent large scale instability. In this regard, the overall performance of the soil-nail slope is considered satisfactory. On the other hand, it seems to show that occurrence of minor failures arising from local weak geological materials in the near surface groundmass of a vegetated soil-nailed slope is very difficult to guard against. The provision of surface protective measures such as the use of wire mesh or hard cover for steep slopes, as recommended in GEO Publication No. 1/2000 (GEO, 2000), could have enhanced the local stability of the slope.

The consultants responsible for the design review considered that the change in slope angle of the upper batter from 52° to 60° in 2003 (Section 4.2 refers) did not constitute a major design change and did not submit the design amendment to the GEO for vetting. The GEO might have referred the consultants to the above-mentioned guideline in light of the steepness of the slope profile had the design amendment been submitted for vetting.

9 Conclusion

A 20 m^3 landslide occurred on a steep (60^o), vegetated, soil-nailed, cut slope (No. 7NE-A/C167). The landslide involved a minor failure primarily due to local adversely oriented relict joint in the near surface groundmass, coupled with a steep slope profile. A 4 m high unsupported local portion near the crest of the slope could also have contributed to the failure. The overall performance of the soil-nail slope is considered satisfactory. This reaffirms the robustness of soil nails for use in slope upgrading works to prevent large scale instability.

Occurrence of minor failures arising from local weak geological materials in the near surface groundmass is very difficult to guard against. An alternative approach to deal with the problem is to introduce protective measures to cater for possible local detachments.

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Appendix A

Aerial Photograph Interpretation

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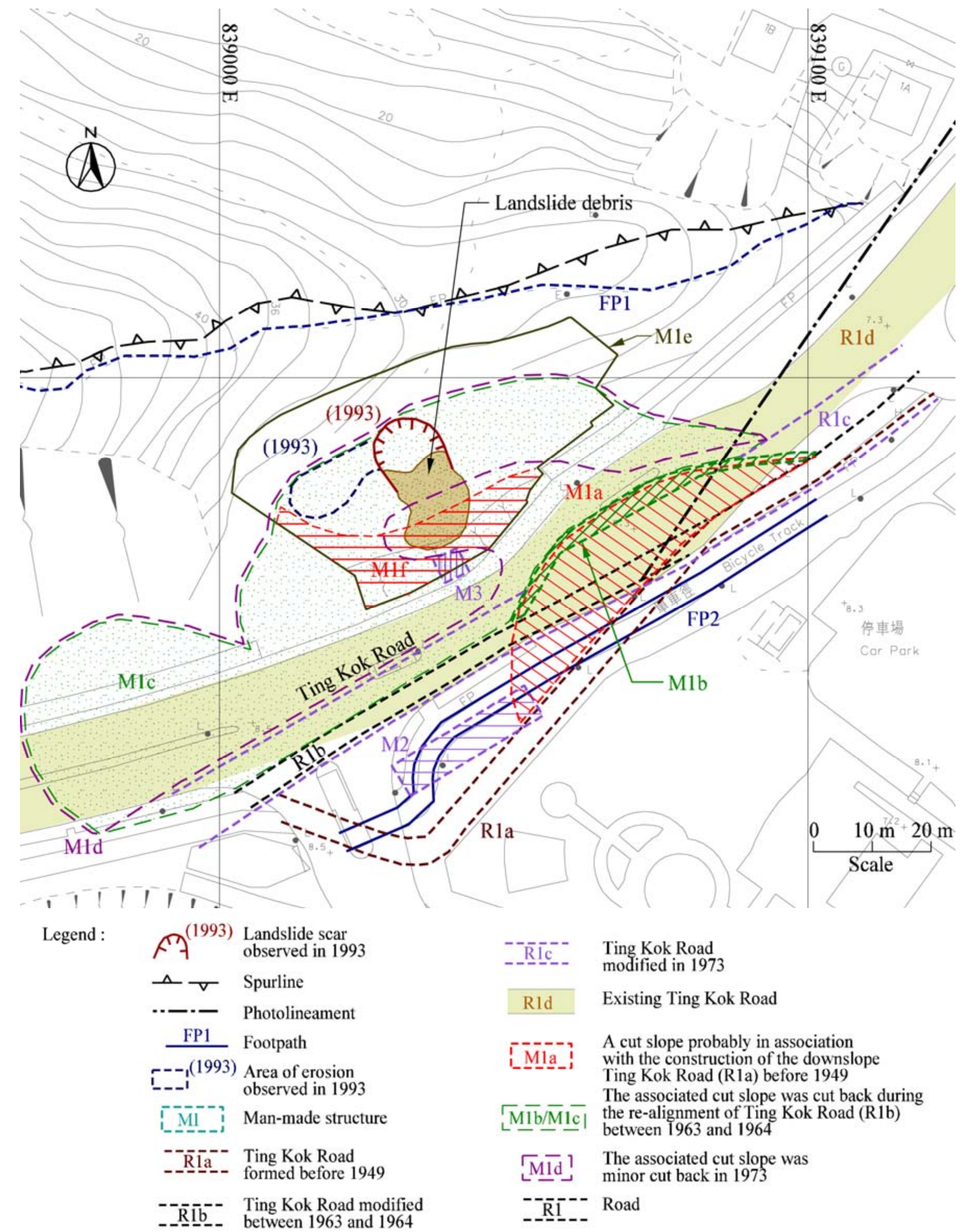
This appendix sets out the detailed observations made from an interpretation of aerial photographs taken between 1949 and 2006. Main observations of the API are illustrated in Figure A1.



Note: Base plan is extracted from 1:1000 survey sheets Nos. 7NE-1B and 7NE-2A dated March 2008.

Figure A1 Aerial Photograph Interpretation

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Year	Observations
1949	Single aerial photograph precludes detailed interpretation. The study area is located on the southeastern flank of an east to northeast trending spurline near the coastal area of Tolo Harbour. The terrain is generally covered by moderately dense vegetation. The area whereon the study feature is located predominantly comprises quasi-natural terrain. Feature No. 7NE-A/C167 has not yet been constructed. Former Ting Kok Road (R1a) is evident downslope from the future location of the study feature. The configuration of the road appears to be different from that presently shown on the 1:1,000 topographic baseplan, suggesting subsequent modification is to be undertaken. A cut slope (M1a) probably in association with the construction of the downslope Ting Kok Road (R1a) is apparent (Figure A1).
1963	The study feature has not yet been constructed. Former Ting Kok Road has been modified into R1b. The southwestern portion of the associated cut slope has been cut back as M1b during the re-alignment of the downslope Ting Kok Road (Figure A1). An unpaved access path (FP1) running along the spurline can now be clearly observed immediately upslope form the future location of the study feature (Figure A1).
1964	The study feature has not yet been constructed. The cut slope feature (M1b) has been cut back further, forming a cut slope (M1c). Bare slope surface is evident (Figure A1). A minor rectangular structure (M2) is evident adjacent to Ting Kok Road (R1b).
1973	The study feature has not yet been constructed. The minor rectangular structure (M2, Figure A1) has been demolished. Ting Kok Road has been widened from R1b to R1c (Figure A1). The cut slope (M1c) appears to have been cut further back and modified into M1d. Sparse vegetation is now evident on the slope surface of the slope M1d (Figure A1).
1975	Single high-flight aerial photograph precludes detailed interpretation. No discernible changes to the location of the study feature are apparent due to the poor resolution aerial photograph and the lack of stereoscopic coverage.
1976	No significant changes to the location of the study feature are apparent.

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Year	Observations
1979	Single high-flight aerial photograph precludes detailed interpretation. No significant changes to the location of the study feature are apparent.
1980	Single aerial photograph precludes detailed interpretation. No significant changes to the location of the study feature are apparent.
1982	Single aerial photograph precludes detailed interpretation. No significant changes to the location of the study feature are apparent.
1984	No significant changes to the location of the study feature are apparent.
1985	Single aerial photograph precludes detailed interpretation. No significant changes to the location of the study feature are apparent.
1986	The study feature has not yet been constructed. The cut slope (M1d) is covered by moderately dense vegetation (Figure A1).
1987	Single aerial photograph precludes detailed interpretation. No significant changes to the location of the study feature are apparent.
1988	Single aerial photograph precludes detailed interpretation. No significant changes to the location of the study feature are apparent.
1989	Single aerial photograph precludes detailed interpretation. Part of Ting Kok Road located downslope from the southwestern end of the study feature appears to be highly reflective; suggesting some forms of road modification works is underway.
1990	Single aerial photograph precludes detailed interpretation. The study feature has not yet been constructed. The road modification works downslope from the southwestern end of the study feature are still underway.
1991	The study feature has not yet been constructed. The road modification works have generally been completed. A new access path (FP2) is evident adjacent to Ting Kok Road (R1c, Figure A1).
1992	Single aerial photograph precludes detailed interpretation. No significant changes to the location of the study feature are apparent.
1993	The study feature has not yet been constructed. A landslide occurs in 1993 within the oversteepened section of the cut slope (M1d, Figure A1), which appears to be a shallow slope failure over a wide surface (12 m wide by 8 m long) with possible structural-control. The fallen landslide debris was accumulated at the slope toe. In addition, an area of sheet

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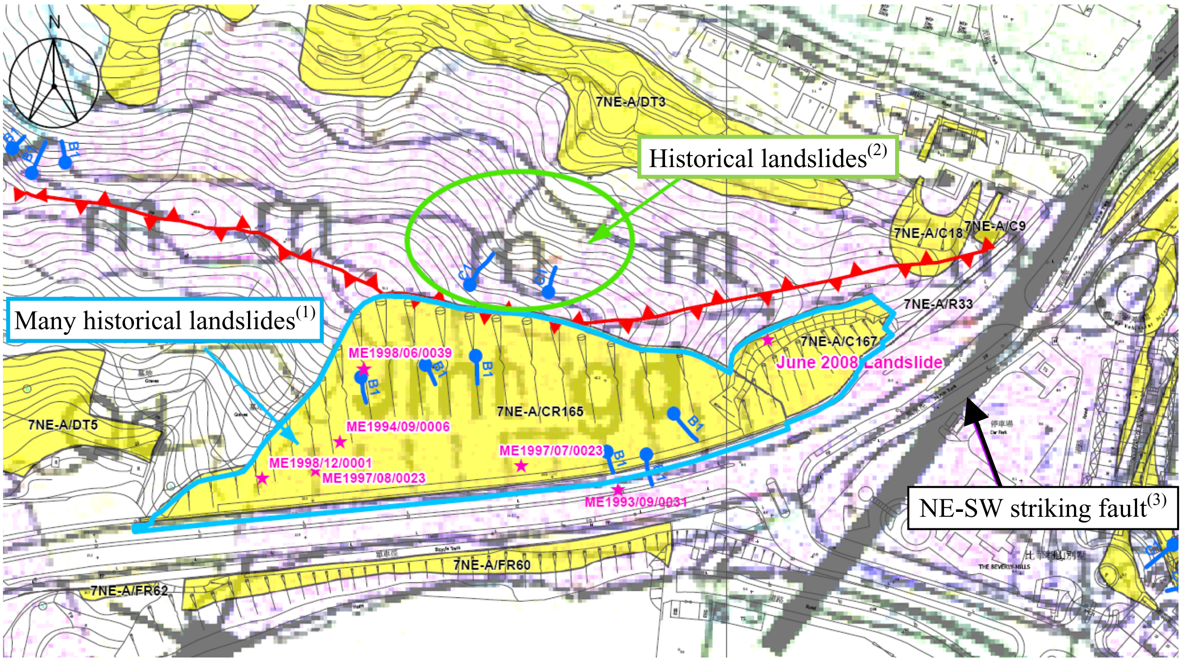
Year **Observations**

erosion can be discerned within the oversteepened slope portion immediately adjacent to the landslide scar.

The failure occurred at a location about 10 m to the east of the June 2008 landslide. The northeast-southwest orientation of the back scarp appears to be similar to that of a fault (shown as a northeast-southwest (NE-SW) striking photolineament in aerial photograph) identified at approximately 60 m to the southeast, suggesting possible structural-control of the failure by the presence of the fault.

The possible influence of the fault on the structural geology of the regional terrain is further supported by the occurrence of many historical landslides (including relict and landslide incidents after 1993) on the adjacent south-facing slope (No. 7NE-A/CR165) contrast to a few landslides identified within the north-facing slope to the north of the spurline (Figure A2).

The 1993 aerial photograph is given in Figure A3.



Legend:

Landslide incident (Incident No.) | ENTLI Relict (Class) | Registered features (Slope No.) | Spurline

Notes: (1) A cluster of past instabilities were identified on the south-facing slopes (i.e. on adjacent slope No. 7NE-A/CR165).

(2) A relatively small number of landslide records were evident to the north of the local spurline.

(3) The northeast-southwest (NE-SW) striking fault in 1:20000 geological plan (Sheet 7 updated version) appears to be a photolineament in API.

Figure A2 Occurrence of Many Historical Landslides on South-facing Slope Contrast to a Few Landslides within North-facing Slope

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Note: **Base plan is extracted from 1:1000 survey sheets Nos. 7NE-1B and 7NE-2A dated March 2008.**

Figure A3 Aerial Photograph Taken in October 1993

Year	Observations
1994	The study feature has not yet been constructed. Shotcreted surface is evident at the toe of the middle and southwestern portion of M1d (Figure A1).
1995	Single aerial photograph precludes detailed interpretation. No significant changes to the location of the study feature are apparent.
1997	Single aerial photograph precludes detailed interpretation. No significant changes to the location of the study feature are apparent.
1998	Single aerial photograph precludes detailed interpretation. No significant changes to the location of the study feature are apparent.
1999	No significant changes to the location of the study feature are apparent.
2000	Single aerial photograph precludes detailed interpretation. No significant changes to the location of the study feature are apparent.
2001	Single aerial photograph precludes detailed interpretation. No significant changes to the location of the study feature are apparent.
Oct. 2002	The study feature has not yet been constructed. No significant changes to the location of the study feature are apparent.
Nov. 2003	The construction of the study feature has been recently commenced. The study feature (M1e, Figure A1), excluding the upper batter, is being formed by cutting into the adjacent hillside (Figure A4). The formation of the study feature (M1e, Figure A1) is in association with road widening works of Ting Kok Road (from R1c to R1d, Figure A1).
June 2004	Single aerial photograph precludes detailed interpretation. The lower berm was probably used as the haul road and can be clearly seen from the photograph (Figure A4). Not much change to the upper batter is noted. The widening works of Ting Kok Road (R1d) is underway. Meanwhile, the old Ting Kok Road (R1c) is still in use during the road widening works (Figure A1).
April 2005	The construction of the study feature is underway. The two concrete berms can be clearly seen in the photograph (Figure A4). Slope works are evident on the south-westernmost portion (M1f, Figure A1) and lower portion of the subject feature (Figure A4). The widening works of Ting Kok Road (R1d) has generally completed except some minor works are still underway. The old Ting Kok Road (R1c) appears to have been incorporated into the new Ting Kok Road (R1d). A temporary structure (M3) is evident at the southwestern toe of the study feature (Figure A1).

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Aerial photograph taken in November 2003

Aerial photograph taken in June 2004

Aerial photograph taken in April 2005

Figure A4 Abstracts of Aerial Photographs Taken in November 2003, June 2004 and April 2005 during the Widening of Ting Kok Road

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Year	**Observations**
2006	Single aerial photograph precludes detailed interpretation. The construction of the study feature has been completed. Light vegetation growth is evident on the slope face. The entire study feature No. 7NE-A/C167 appears to have been completed adjacent to Ting Kok Road. The study feature consists of a maximum three batters with an average slope angle of about 45°. Artificial surface drainage system is evident on the study feature. The widening works of Ting Kok Road (R1d) have been completed and the road is now in use. The temporary structure (M3) located at the southwestern toe of the study feature has been removed (Figure A1).

A list of the aerial photographs studied is presented in Table A1.

Table A1 List of Aerial Photographs Used in Aerial Photograph Interpretation (Sheet 1 of 2)

Year	Photograph No.	Flight Height
1949	Y01979	5800’
1963	Y09678	3900’
1964	Y13033-4	12500’
1973	7439, 7910	2000’, 12500’
1975	Y16267	12500’
1976	12454, 16454-5	4000’, 12500’
1979	28489	10000’
1980	29178, 33036	5000’, 4000’
1982	42506	2000’
1984	53897-8	4000’
1985	67071	4000’
1986	A04539-40	4000’
1987	A09220	4000’
1988	A15587, A15610	4000’, 4000’
1989	A18480	4000’

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Table A1 List of Aerial Photographs Used in Aerial Photograph Interpretation (Sheet 2 of 2)

Year	Photograph No.	Flight Height
1990	A23365, A23376	4000’, 4000’
1991	A27196, A28734-5	4000’, 10000’
1992	A30264	4000’
1993	A34749, CN4654-5	4000’, 4000’
1994	A39787	4000’
1995	CN10113, CN12842	3200’, 3500’
1997	CN16873, CN16881, CN19217	3500’, 3500’, 10000’
1998	A48742	3500’
1999	A50141-2	4000’
2000	CN26705	4000’
2001	CW32968	4000’
2002	CW44618-9	8000’
2003	CW52309-10	4000’
2004	CW57422	2500’
2005	CW64218-9	2500’
2006	CS03343, CS03463	6000’, 6000’

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

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Appendix B

Previous Submissions

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B.1 Previous Submissions/Records/Results

B.1.1 Background of the Project

In 1995, Maunsell Consultants Asia Limited (MCAL) was commissioned by the former Territory Development Department (TDD) (later merged with the Civil Engineering Department and renamed as the Civil Engineering and Development Department (CEDD) in 2004) to undertake the design of Ting Kong Road Upgrading – Stage I Phase II (hereinafter the “project”).

Slope No. 7NE-A/C167 was one of the slopes formed in the road widening project by cutting into an existing slope and the natural terrain above. The Contract commenced on 27 September 2002. The Contractor was China Road and Bridge Corporation.

B.1.2 Geotechnical Submissions/Records Related to the Study Slope

Maunsell Geotechnical Services Limited (MGSL), the geotechnical consultant of MCAL, submitted the first geotechnical design submission for the project to the Mainland East (ME) Division of the Geotechnical Engineering Office (GEO) on 28 April 1999. In this submission, no geotechnical design related to slope No. 7NE-A/C167 was included. In 2002, MGSL submitted the design for slope No. 7NE-A/C167, for which the upper batter where the June 2008 landslide occurred was formed between June 2004 and April 2005. The soil nail construction for the slope was carried between 2003 and 2006.

Two routine maintenance inspections had been carried out since then. Table B1 gives a summary of the submissions/correspondences/records related to slope No. 7NE-A/C167.

Table B1 Geotechnical Related Records for Slope No. 7NE-A/C167 (Sheet 1 of 2)

Date/Year	Report (Reference)	Details Contained
1984	Site Investigation Final Report (Lam Geotechnics Limited ,1984)	Drillhole record for drillhole No. TK1/25 (located at about 15 m to the north of the study slope, Figure 2.2).
1985	Site Investigation Report (Gammon (Hong Kong) Limited, 1985)	Drillhole record for drillhole No. TK2/10 (located at about 7 m to the north of the study slope, Figure 2.2).
1999	Final Field Work Report (Enpack (Hong Kong) Limited, 1999)	Drillhole and groundwater monitoring record for drillhole No. E7 (located at on the middle batter of the study slope, Figure 2.2).

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Table B1 Geotechnical Related Records for Slope No. 7NE-A/C167 (Sheet 2 of 2)

Date/Year	Report (Reference)	Details Contained
2002	Ground Investigation Report (Geotechnics & Concrete Engineering (Hong Kong) Limited, 2002)	Drillhole records for drillholes Nos. SDH-8 and SDH-9 (located at slope toe and crest of the study slope respectively, Figure 2.2).
30 Apr. 2002	Geotechnical Submission Supplementary No. 1 (MGSL, 2002)	Interpretation of ground investigation results, laboratory testing results, and proposed geotechnical parameters for CDGr and HDGr.
31 May 2002	Geotechnical Submission Amendment No. 2 (MGSL, 2002a)	Design of slope using geotechnical parameters given in Supplementary No. 1, which included slope stability analysis and design of soil nails.
30 Oct. 2002		GEO indicated that they had no adverse geotechnical comments on the submissions.
23 Feb. 2003	Category I site inspection	Category I site inspection noted topographic difference between existing and design slope profiles and recommended a design review for the slope.
3 Mar. 2003	Design Review (Internal memorandum of MGSL)	Stability check carried out for section 4-4 (Figures 2.2 and 4.2) and the calculated factor of safety was 1.403 (minimum). No design amendment was made to the GEO as the design review was not considered as a major design change.
15 Dec. 2006		Checking Certificate (Ref. No. GEO/ME 042/2006) issued.
15 Oct. 2007 and 30 Apr. 2008	Routine Maintenance Inspections	Some channels and catchpits were partially blocked by debris, but no blockage was observed in the channel directly below the June 2008 landslide location. Unplanned vegetation was noted on slope in area near the June 2008 landslide location. Clearance of the blockage was completed within two weeks after the inspections.

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B.2 Geological Profile of the Study Slope

B.2.1 Ground Investigation Results

There are four drillholes (Nos. TK2/10, E7, SDH-8 and SDH-9) at or near the study slope (Figure 4.1). The drillholes revealed that bedrock at or near the subject slope comprised moderately/slightly decomposed granodiorite (MDGr/SDGr). No tuff/tuffite was encountered in the drillholes. Apparently, the geological profile/section for the design of the slope in "Amendment No. 2" prepared by MGSL in May 2002 was based on drillholes Nos. TK2/10 and E7.

A 1 m thick colluviums, which was encountered in drillhole No. E7, was removed as part of the slope works. The underlying completely decomposed granodiorite (CDGr) was red mottled white and greyish, sandy, clayey SILT. The drillhole terminated at +5.6 mPD (i.e. 6 m below ground level).

No colluvium was revealed from drillhole No. TK2/10. The CDGr layer was about 15 m thick and described as "sandy SILT". Beneath the CDGr was a 3.7 m thick completely to highly decomposed granodiorite (C/HDGr), also silty in nature. The underlying bedrock was MDGr/SDGr. Closely spaced joints with various dip angles were noted in the bedrock.

The other two drillholes (Nos. SDH-8 and SDH-9) undertaken after the first design submission submitted in 2002 was also reviewed as part of the study. Similar CDGr and HDGr were noted from both drillholes. However, before reaching the bedrock in both drillholes, corestones were present within the C/HDGr. Closely-spaced joints with various dip angles (10° to 20°, 40° to 50°, 50° to 60° and 65° to 75°) were found in some corestones, as well as in the highly to moderately decomposed granodiorite (H/MDGr) layer. The joints were described as rough undulating, narrow, iron and manganese oxide stained and some were kaolin infilled. This is consistent with the impression packer test carried out at about 19.5 mPD to 21.1 mPD in drillhole No. SDH-8, in which five out of the seven joint sets (42/239, 72/347, 40/249, 23/248, 45/069, 55/046 and 23/297) measured were kaolin coated. Altered granodiorite and fault breccias were also noted in drillhole No. SDH-8 between 2 mPD to -8 mPD, which suggested possible alteration due to the nearby contact zone, at this location.

B.2.2 Laboratory Tests Results

Designed shear strength parameters for the study slope were determined based on single and multi-stage consolidated undrained triaxial compression tests carried out on two mazier samples collected from drillhole No. E7. Other tests included moisture content, particle size distribution (PSD) and Atterberg limit tests. The tests were carried out by Gammon (Hong Kong) Ltd., Hong Kong Testing Co. Ltd and Soil & Materials Engineering Co. Ltd. from 1984 to 1999.

The designed shear strength parameters for CDGr and HDGr were determined to be $c' = 5$ kPa, $\phi' = 35°$, and $c' = 5$ kPa, $\phi' = 37°$ respectively (see p'-q plots extracted from the geotechnical submission (MGSL, 2002) as shown in Figures B1 and B2).

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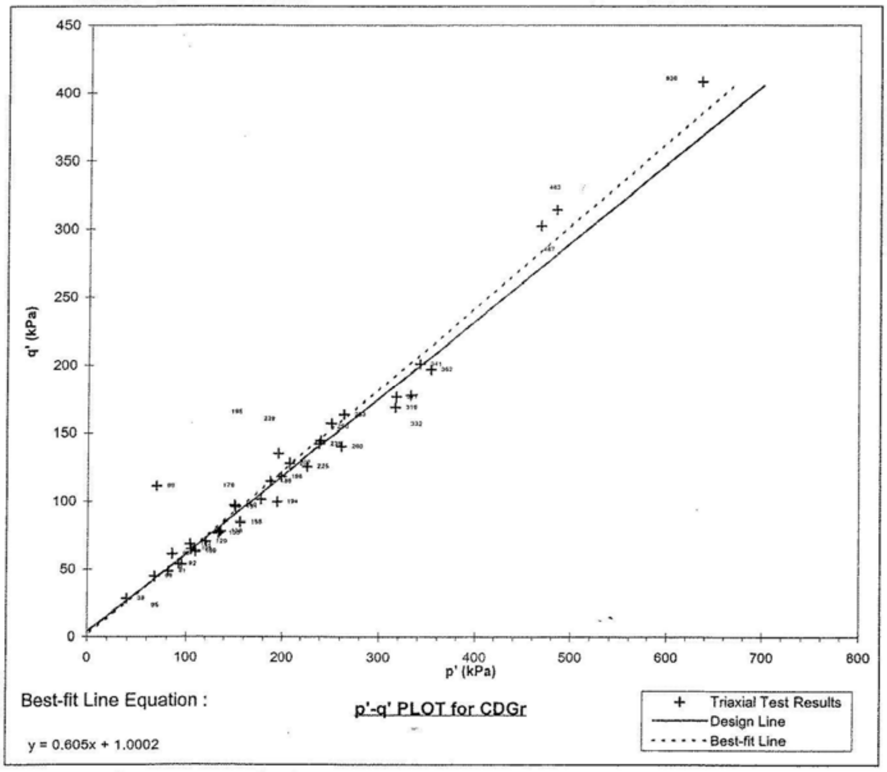

Figure B1 **p'-q Plot for CDGr (Extracted from Ting Kok Road Upgrading Stage I Phase III, Geotechnical Submission, Supplementary No. 1 (MGSL, 2002))**

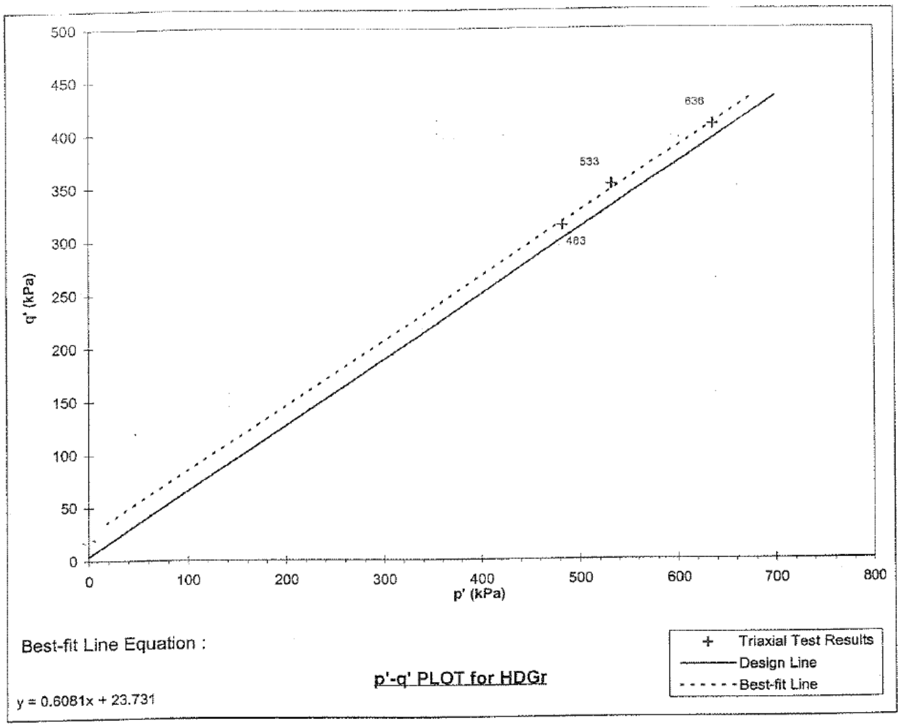

Figure B2 **p'-q Plot for HDGr (Extracted from Ting Kok Road Upgrading Stage I Phase III, Geotechnical Submission, Supplementary No. 1 (MGSL, 2002))**

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B.2.3 Groundwater Conditions

A piezometer was installed just above bedrock in drillhole No. E7 (with a tip level of +6.12 mPD). The groundwater monitoring data in August 1999 and between September 2000 and August 2001 showed that the piezometer was dry.

Piezometers were also installed within drillholes Nos. SDH-8 and SDH-9 (Figure 2.2), just above bedrock with the tip level at -3.57 mPD and +8.81 mPD respectively. The results in June 2002 showed that the groundwater table was about 400 mm above the bedrock level.

B.2.4 Design Geological Model

The original and revised design geological profiles are given in Figure 4.1 and Figure 4.2 respectively. In both profiles, corestones were conservatively taken to be part of CDGr or C/HDGr. The design groundwater table was assumed to be 3 m above the bedrock level (i.e. about 10 m below ground level) for a ten-year return period rainfall. No perched water table was assumed in the analyses. The most critical slip surface was assumed to pass through the slope toe in both the original and revised design geological profiles, and soil nails of 16 m to 20 m long (maximum 7 m embedment into bedrock) at 1.5 m to 2 m centre-to-centre were required to achieve a minimum factor of safety (FoS) of 1.4 in all slips.

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Appendix C

Detailed Rainfall Analysis

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This appendix sets out the detailed observations made from an interpretation of rainfall data obtained from GEO automatic raingauge No. N45, which is located about 410 m to the southeast of the landslide site (Figure 2.1).

According to the incident record, the landslide was reported on 12 June 2008. As the exact date and time of the landslide is not known, an analysis was carried out to deduce the maximum rolling 1-hour, 2-hour and 4-hour rainfall (which are the most probable short-duration rainfall that could have led to shallow failure, or failure due to perched water table) for the five rainstorms preceding 12 June 2008 (Figure 7.1). The result shows that the rainstorm that happened in the evening of 7 June 2008, gives the highest return periods for maximum rolling 1-hour, 2-hour and 4-hour rainfall, with reference to historical rainfall data at the HKO in Tsim Sha Tsui where records began in 1884 (Lam & Leung, 1994), and among the three durations of rolling rainfall recorded by the raingauge, a rainfall duration of 2 hours was the most critical, with a corresponding return period of about 3 years (Table C1).

The return periods were also assessed based on the statistical parameters derived by Evans & Yu (2001) for rainfall data recorded by raingauge No. N05 between 1984 and 1997 (i.e. the nearest GEO raingauge to the landslide site with historical rainfall data prior to October 1999). The rainfall duration of 2 hours was also the most critical, with a corresponding return period of about 6 years (Table C1).

Table C1 Maximum Rolling Rainfall at GEO Raingauge No. N45 for Selected Durations Among Various Rainstorms Preceding the 12 June 2008 Reported Landslide and the Estimated Return Periods

Duration	Maximum Rolling Rainfall (mm) (see Note 1)	End of Period	Estimated Return Period (Years)	
			Lam & Leung (1994) (see Note 2)	Evans & Yu (2001) (see Note 3)
1 Hour	64.0	6:30 p.m. on 7 June 2008	1.6	2
2 Hours	112.0	7:15 p.m. on 7 June 2008	3	6
4 Hours	126.5	9:15 p.m. on 7 June 2008	2	3

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. N05 from Appendix B of and Evans & Yu (2001) to access the spatial variability of rainfall as rainage No. N45 does not have rainfall records preceding 1999.

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Based on the above analysis, the landslide was assumed to have occurred at 7:15 p.m. on 7 June 2008. The hourly rainfall recorded by raingauge No. N45 over the month preceding the 7 June 2008 evening rainstorm, together with the hourly rainfall readings for the period between 5 and 7 June 2008, are presented in Figure 7.2. Traditional rainfall analysis of the return periods for various durations of rolling rainfall recorded by raingauge No. N45, with reference to both statistical parameters extracted from Lam & Leung (1994) and Evans & Yu (2001) has also been carried out. The result shows that a rainfall duration of 2 days was the most critical (with a corresponding return period of about 11 years, Table 7.3).

The rainstorm that happened in the evening of 7 June 2008 has been compared with the previous major rainfall recorded at raingauge No. N45 since it came into operation in October 1999. As raingauge No. N45 did not have rainfall data preceding October 1999, the maximum rolling rainfall for the rainstorm has also been compared with the previous major rainfall recorded by raingauge No. N05, which came into operation in March 1983 (Figure 7.3).

As observed from Figure 7.3, the 7 June 2008 rainstorm is less severe than or comparable to four previous major rainstorms in September 1993, July 1994, June 2001 and May 2003 at this landslide site, for rainfall duration of 1 hour to 4 hours. However, according to API, the upper batter of the slope (where the June 2008 failure occurred) was probably formed between June 2004 and April 2005 (Figure A4). Hence, the 7 June 2008 evening rainstorm was likely the most severe rainstorm hitting the landslide site since its formation, for rainfall durations between 1 hour to 4 hours.

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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:

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