REVIEW OF THE 2 JUNE 2006 LANDSLIDE ON SLOPE NO. 7NE-D/FR58 ALONG MA ON SHAN TSUEN ROAD

GEO REPORT No. 236

Maunsell Geotechnical Services Limited

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

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This report is largely based on GEO Landslide Study Report No. LSR 9/2007 produced in October 2007

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PREFACE

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. The GEO Reports can be downloaded from the website of the Civil Engineering and Development Department (http://www.cedd.gov.hk) on the Internet. Printed copies are also available for some GEO Reports. For printed copies, a charge is made to cover the cost of printing.

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

R.K.S. Chan
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November 2008

FOREWORD

This report presents the findings of a review of a landslide (Incident No. 2006/06/0623) that occurred on slope No. 7NE-D/FR58 along Ma On Shan Tsuen Road on 2 June 2006 when the Landslip Warning and the Red Rainstorm Warning were in effect. The landslide involved the failure of a masonry wall and the fill slope above. The detached debris, with a volume of about 350 m^3, blocked Ma On Shan Tsuen Road, a sole access to Ma On Shan Tsuen, causing temporary closure of the road. No casualties were reported as a result of the incident.

The key objectives of the review were to document the facts about the landslide, present relevant background information and pertinent site observations made under this review. The scope of the review does not include any ground investigation or detailed diagnosis of the causes of the incident. Recommendations for follow-up actions are reported separately.

The report was prepared as part of the Landslide Investigation Consultancy for landslides occurring in Kowloon and the New Territories in 2006, for the Geotechnical Engineering Office, Civil Engineering and Development Department, under Agreement No. CE 50/2005 (GE). This is one of a series of reports produced during the consultancy by Maunsell Geotechnical Services Limited.

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Agreement No. CE 50/2005 (GE)
Study of Landslides Occurring in
Kowloon and the New Territories in
2006 - Feasibility Study

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1. INTRODUCTION

At about 2:45 p.m. on 2 June 2006 when the Landslip Warning and the Red Rainstorm Warning were in effect, a landslide (Incident No. 2006/06/0623) occurred on slope No. 7NE-D/FR58, which is situated along Ma On Shan Tsuen Road (formerly known as Leung Yau Road, see Figure 1 and Plate 1). The landslide involved the failure of a registered masonry retaining wall and the fill slope above. The detached debris, with a volume of about 350 m³, blocked Ma On Shan Tsuen Road, a sole access to Ma On Shan Tsuen, causing temporary closure of the road. No casualties were reported as a result of the incident.

Following the incident, Maunsell Geotechnical Services Limited (MGSL), the 2006 Landslide Investigation Consultant for Kowloon and the New Territories, carried out a review of the landslide for the Geotechnical Engineering Office (GEO), Civil Engineering and Development Department (CEDD), under Agreement No. CE 50/2005 (GE).

This report documents the facts about the landslide, findings of a desk study and pertinent site observations made by MGSL. The scope of this review does not include any ground investigation or detailed diagnosis of the causes of the failure.

2. THE SITE

2.1 Site Description

Slope No. 7NE-D/FR58 is a northwest facing retaining wall and fill slope located uphill of Ma On Shan Tsuen Road. The slope is bounded by another fill slope No. 7NE-D/F66 to the northeast, Ma On Shan Tsuen Road to the northwest and an unpaved access to the southeast along the crest of the slope. Ma On Shan Tsuen Road is a 5.3 m wide, single lane, two way road, which is the sole access to the Ma On Shan Tsuen (Figure 2 and Plate 1). The unpaved access above slope No. 7NE-D/FR58 varies from about 2.5 m to 5.7 m wide.

Slope No. 7NE-D/FR58 is about 55 m long with a maximum height of about 10 m. The masonry wall portion at the toe, with a face inclination of about 80° to 85°, was formed using pointed random rubble blocks (Plate 3). The height of the masonry wall increases from 0.5 m at the junction of the unpaved access and Ma On Shan Tsuen Road to a maximum of about 7.2 m near the middle portion. The masonry wall extended into the northwest corner of slope No. 7NE-D/F66 where the height of the wall was about 2.5 m and it was founded on exposed rock (Figure 2 and Plate 4). At slope No. 7NE-D/FR58, a 20 m long and maximum 3 m high vegetated fill slope was situated above the northeast portion of the wall and inclined at a maximum angle of about 35°. A 10 m wide unpaved platform is located at the crest of slopes Nos. 7NE-D/FR58 and 7NE-D/F66 (Figure 2). The platform generally has a fall towards the retaining wall. This platform leads to an abandoned mining portal which is located about 100 m to the east of slope No. 7NE-D/FR58.

Slope No. 7NE-D/F66 is a 54 m long, 12 m high, vegetated fill slope with a single batter and is inclined at an angle of 35°. Slope No. 7NE-D/C179 is a 4 m high, 52 m long cut slope above the unpaved access. The western portion comprises one batter inclined at an angle of about 65° with a 20 m long masonry wall, up to 1.8 m high at its east end (Plate 5). A 5.5 m wide unpaved platform is situated above slope No. 7NE-D/C179. Slope No.

7NE-D/C178, which is situated above this unpaved platform, is about 64 m wide with a maximum height of about 5.5 m. The slope has a single batter, which is inclined at a maximum angle of about 65°. Both slopes were covered with vegetation.

The hillside above slope No. 7NE-D/C178 is inclined at an angle of about 35° to 40° and is densely vegetated. There are no major natural streamcourses in the vicinity of the landslide but an ephemeral streamcourse is located to the east of slope No. 7NE-D/C178 (Figure 2).

There were no surface drains along the crest of the masonry wall of slope No. 7NE-D/FR58 or on slope No. 7NE-D/C178. A 900 mm wide trapezoidal channel runs along the toe of slope No. 7NE-D/FR58 and a 300 mm wide U channel is present along the toe of slope No. 7NE-D/C178 (Figure 2 and Plate 2). Weepholes of 110 mm diameter were observed on the masonry wall portion of slope No. 7NE-D/FR58 at a horizontal spacing of about 2.7 m and at heights of about 2 m and 5.7 m above the toe (Plate 3). A 2 m square by 2.5 m deep water tank is present on slope No. 7NE-D/C179 approximately 18 m to the southwest of the June 2006 landslide (Plate 5) and a 500 mm wide, partly buried U channel and two pipes are connected to it (Figure 2). The tank contained a small amount of water (<100 mm deep) and the dilapidated pipes indicated that it was unlikely to have been in use at the time of the landslide.

2.2 Water-carrying Services

Based on the information provided by the Water Supplies Department (WSD), a 150 mm diameter fresh water pipe was installed along Ma On Shan Tsuen Road (Figure 2) in 2004. According to the information provided by the Drainage Services Department (DSD), there are no public stormwater drains in the vicinity of slope No. 7NE-D/FR58.

2.3 Maintenance Responsibility and Land Status

According to the Slope Maintenance Responsibility Information System (SMRIS) of the Lands Department (Lands D), Lands D is responsible for the maintenance of slopes Nos. 7NE-D/FR58, 7NE-D/F66, 7NE-D/C178 and 7NE-D/C179. A Land Status plan obtained from Lands D indicates that these slopes and the intermediate platforms in their vicinity are located on unleased and unallocated government land.

2.4 Regional Geology

According to the Hong Kong Geological Survey (HKGS) 1:20,000 scale Solid and Superficial Geology Map Sheet No. 7 - Sha Tin (GCO, 1986), the Pre Quaternary Geology of Hong Kong (Sewell et al., 2000) and the latest information from HKGS regarding the updating of Geology Map Sheet No. 7, the landslide site is underlain by medium grained granite of the Shui Chuen O Formation. The geological map Sheet No. 7 indicates the landslide site is situated close to a contact with the fine grained Kowloon granite (Figure 3). There is a contact between the fine grained granite and sandstone and siltstone of the Bluff Head Formation, about 500 m to the southeast, where some mineral veins (quartz, magnetite

and molybdenite) are located. A northwest-southeast trending inferred fault is located about 400 m to the southwest of slope No. 7NE-D/FR58.

3. SITE HISTORY AND PAST INSTABILITIES

3.1 Site History

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

The earliest available aerial photographs (taken in 1945) show that, prior to development, the study area was located on a northwest facing natural hillside. The hillside above the site is delineated by a northwest trending, well-defined ridgeline descending from Ngau Ngak Shan and Tiu Shau Ngam. The ridgeline is less distinct near the foothill area and slope No. 7NE-D/FR58 was constructed at about 90° to a rounded spurline plunging approximately north to north northwest from the ridgeline. A series of concave and convex breaks in slopes were observed on the western side of the spurline with rock outcrops exposed below the ridgeline. Some ephemeral drainage lines are located within an area of depression on the east side of the spurline (Figure 4 and Plate A3). The original alignment of Ma On Shan Tsuen Road was located to the west of the study area (Plate A1).

The realignment works of the Ma On Shan Tsuen Road commenced in about 1949. Slopes Nos. 7NE-D/FR58, 7NE-D/C179 and 7NE-D/F66 were formed, with substantial amounts of fill placed on the hillside, some time between 1949 and 1963 to provide an access to a mine located 100 m to the east of the study area (Figure 4 and Plate A3). Slope No. 7NE-D/C178 was also formed at the same time in conjunction with a rail system for transporting spoil from the mine to the associated buildings to the west of slope No. 7NE-D/FR58 (Plate A4). The rail system and buildings were demolished in 1977 and 1981 respectively, and mining operations appear to have ceased by 1981. Since 1982, vegetation has gradually established on the slopes and the intermediate platforms. The portion of retaining wall within slope No. 7NE-D/F66 was constructed between 1985 and 1986. The strip of land between slopes Nos. 7NE-D/C178 and 7NE-D/C179 was used as an agricultural terrace in 1992 and had been abandoned by 1999 (Figure 4).

3.2 Past Instabilities

In 1995, the GEO compiled the Natural Terrain Landslide Inventory (NTLI), from the interpretation of high altitude aerial photographs dating from 1945 to 1994. According to the NTLI, there are no reported natural terrain landslides within the immediate vicinity of the study area. The nearest NTLI incident occurred about 200 m to the south of the June 2006 landslide. The GEO's Large Landslides Database contains no records of any reported large landslides within or in the vicinity of the study area.

In 2004, the GEO commenced a project to update the NTLI using low altitude aerial photographs and produced an Enhanced Natural Terrain Landslide Inventory (ENTLI). The ENTLI records 14 relict landslides on the natural hillside above the June 2006

landslide (Figure 4).

Based on API, two recent landslides occurred on slope No. 7NE-D/C178 in 1973 and 1982. No past instability was identified from API at slopes Nos. 7NE-D/FR58 and 7NE-D/C179 (Figure 4). Several relict landslide scars were observed on the hillside above the study area, which were identified under the ENTLI.

According to GEO's landslide database, there are no records of past instability at slopes Nos. 7NE-D/FR58, 7NE-D/C178, 7NE-D/C179 or in the vicinity of the study area. The nearest landslide incidents (Nos. ME92/6/18 and ME96/6/6), both of which involved minor rockfalls, occurred at the soil/rock cut slope No. 7NE-D/C175 along Ma On Shan Tsuen Road to the southwest of slope No. 7NE-D/FR58 (Figure 4), which are unrelated to the June 2006 landslide.

4. PREVIOUS ASSESSMENTS AND SLOPE MAINTENANCE

4.1 SIFT and SIRST

In 1992, the GEO initiated a project entitled "Systematic Inspection of Features in the Territory" (SIFT). Slope No. 7NE-D/FR58 was classified as SIFT Class "B1" in January 1997, i.e. a slope that had "been formed or substantially modified before 30.6.78".

In July 1997, the GEO commenced a project entitled "Systematic Identification and Registration of Slopes in the Territory" (SIRST), to update the 1977/78 Slope Catalogue. Slope No. 7NE-D/FR58 was inspected by the SIRST consultant, Binnie Consultants Limited (BCL), on 16 September 1997 (Plate 6). The inspection record noted that the wall was formed with "Random Rubble". The condition of the slope portion was assessed as "fair" and no signs of distress were identified on either the slope or the wall portion. The consequence to life (CTL) category was assessed as "3".

The Combined New Priority Classification System (CNPCS) score (which is based on information provided by the SIRST consultant) is 1.38. The width (Bw) of the wall was unknown and the instability score for the wall slenderness ratio was taken to be within the range of greater than 2.8 and less than or equal to 3.5, as a default value.

4.2 Thickness Gauging of Masonry Retaining Walls

Following the 23 July 1994 Kwun Lung Lau landslide, a programme of measuring masonry wall thickness was initiated by the GEO. In October 1995, Halcrow Asia Partnership (HAP) commenced the project "Thickness Gauging of Masonry Retaining Walls" under Agreement No. CE 9/95. Probing of weepholes was carried out under the project to gauge the thicknesses of all potentially sub-standard masonry walls in the Catalogue of Slopes at that time. About 1,500 registered retaining walls were investigated under the above agreement. Slope No. 7NE-D/FR58, which was registered on 25 February 1998, was not included under the above agreement.

During the period between October 1995 and August 1997, about 3,300 wall features were registered in the Catalogue of Slopes. These features were included in the three

consultancy agreements (Agreements Nos. CE77/97, CE78/97 and CE 79/97 done by HAP, MGSL and CM Wong & Associates (CMW) respectively) for thickness gauging under the project "Thickness Gauging of Retaining Wall and Follow-up Investigation". Since slope No. 7NE-D/FR58 was registered after the time of preparation of the list of features for these agreements, it was therefore not included in these agreements.

As many more wall features with masonry facing had been identified and registered in the Catalogue of Slopes since 1997, MGSL was engaged in November 2004 by the Slope Safety Division of the GEO for another exercise of wall thickness measurement under the project "Thickness Gauging of Retaining Walls 2004". To achieve cost-effectiveness, about 500 registered features were selected in the exercise, which was mainly targeted at features with CTL category of "1". Therefore, slope No. 7NE-D/FR58 with a CTL category of "3" was not selected.

4.3 Engineer Inspection and Routine Maintenance Inspections

A Routine Maintenance Inspection (RMI) of slope No. 7NE-D/FR58 was carried out by Lands D in September 2001. Routine Maintenance Works (RMW) including clearance of vegetation and debris from the slope surface and drainage channels, repair of cracked drainage channels and the slope surface, unblocking weepholes, repair of masonry wall pointing and removal of large loose blocks, were recommended. The RMI record indicated that "Part of [the] masonry wall moved", although no further details can be located. The RMI record also stated that "Due to very poor conditions, recommended RMW is not adequate to prevent further deterioration. Urgent PMW [preventive maintenance work] should be considered." According to Lands D, no records of follow-up works can be located.

Engineer Inspection (EI) of slope No. 7NE-D/FR58 was carried out for Lands D by the Binnie Arup Joint Venture (BAJV) in November 2001. The record of EI noted the weepholes of the wall were partly blocked and also indicated that there was a "Horizontal crack about 2m from wall top" near the eastern end of the slope (Plate 7). The vegetated slope surface was considered as "Fair" and the "Overall State of Slope Maintenance" of the slope was classified as "Fair". RMW including "Repair cracking of masonry wall surface" and "Clear obstruction in weepholes" were recommended. The requirement to "Improve surface drainage by providing a slope crest channel with upstand" was recommended as preventive maintenance work (PMW). According to Lands D, no records of follow-up works on the recommended RMW and PMW can be located.

According to the "Record of Slope or Retaining Wall" for slope No. 7NE-D/FR58 prepared by BAJV, no information regarding thickness gauging of the retaining wall is available. There was no specific requirement in the consultancy agreement for BAJV to update the CNPCS score or review the thicknesses of masonry walls of the inspected slopes, and as such no review of wall thicknesses was carried out by BAJV.

Based on the information from Lands D, there are no records of RMI, RMW or PMW between 2002 and 2004 for slope No. 7NE-D/FR58. In January 2005, Ove Arup & Partners Hong Kong Limited (OAP) carried out an RMI of the slope. No particular signs of distress were observed. RMW including "Clear drainage channels of accumulated debris", "Remove

surface debris and vegetation that has caused severe cracking of slope surface cover and drainage channels" and "Repair pointings in masonry walls" were recommended. Routine maintenance works were carried out in May 2005 subsequent to the RMI in January 2005.

According to the information from Lands D, the EI following 2001 will be in 2011 as the recommended frequency of EI for slopes with CTL Category 3 was changed from once every 5 years to once every 10 years in accordance with the revision to Geoguide 5 in 2003 (GEO, 2003).

5. THE 2 JUNE 2006 LANDSLIDE AND POST-FAILURE OBSERVATIONS

According to the incident report prepared by the GEO (Incident No. 2006/06/0623), the landslide occurred at about 2:45 p.m. on 2 June 2006 during heavy rainfall, when the Red Rainstorm Warning had been in effect for four hours. The landslide debris blocked Ma On Shan Tsuen Road, the sole access to the villages uphill, resulting in temporary closure of the road (Plate 1). No casualties were reported as a result of the incident.

Following the incident, MGSL inspected the site on 3 June 2006 and on several occasions during the course of this study.

The landslide scar was about 30 m wide by 10 m high (Figure 5 and Plate 1) with an estimated failure volume of about 350 m^3. The main scarp of the landslide was about 2 m high and inclined at an angle of about 65°, with fill material exposed (Plate 8). No signs of seepage or soil pipes were observed in the main scarp. A 19 m long portion of the masonry wall (including the location where a crack was identified by BAJV in 2001, see Section 4.3), and the fill slope above had collapsed. The landslide debris, which comprised a mixture of fill material, masonry blocks and vegetation, travelled a distance of about 6 m with a travel angle (Wong & Ho, 1996) of about 35° (Figure 5 and Plate 1). In addition, an 11 m long portion of masonry wall at the western end of slope No. 7NE-D/F66 was displaced by about 0.5 m and the fill slope above had collapsed (Plates 4 and 8). Some masonry blocks came to rest at the toe of the landslide debris (Plate 1) and a large detached wall fragment was exposed in the middle of the debris during its removal, with the original wall front facing downward (Plate 9).

The intact portion of the masonry wall to the west of the landslide was about 7.2 m high. The wall extended 0.6 m above the unpaved access as an upstand/parapet. No cracks or obvious signs of distress were observed in this portion of wall. The stem of the masonry wall was exposed at the western flank of the June 2006 landslide (Plate 10) and the thickness ranged from about 0.3 m to about 1 m with pointing throughout the thickness (Figure 5 and Plate 11). Based on the record photographs from Lands D, the wall was about 0.3 m thick at a height of about 3 m above the toe, which appeared to be a masonry facing to a steep soil/rock cut (Plate 11). It was inferred that the adjoining failed portion had a similar configuration (i.e. a 4.2 m high, 1 m thick masonry wall, with a slenderness ratio of 4.2, resting on a 3 m high soil/rock cut slope with masonry facing. See Section A-A on Figure 5). A construction joint was observed on the wall about 2 m below its crest (at the level where cracks were observed during EI in 2001, see Plates 3, 7 and 11). The weepholes were mostly clear with no signs of seepage but a large area of moss was observed near the western flank of the June 2006 landslide. Following the removal of the masonry wall in late January 2007 by

Lands D, the base of the masonry wall was examined by MGSL. Very few masonry blocks were observed in the central portion of the June 2006 landslide although a distinct boundary of soil/masonry block was identified near the western flank of landslide (Plate 12). Weephole probing of the portion of the unfailed masonry wall, located at about 7 m to the west of the 2006 landslide, showed that the thickness of the base of the wall in this portion was about 1.7 m to 1.9 m. The slenderness ratio of the masonry wall at this location was about 4 (Figure 5). Another 3 m high masonry wall, which rested on exposed rock mass, is located to the east of the June 2006 landslide within slope No. 7NE-D/F66 (Figure 2 and Plate 4). No signs of distress were observed on this wall.

There were no obvious signs of distress on the unpaved platform above the June 2006 landslide. A minor landslide/erosion scar (about 1 m^3 in volume) was observed at the east end of slope No. 7NE-D/C178 (Plate 13) and another landslide scar (about 22 m wide, 10 m high with a maximum depth of 1 m and colluvium exposed in the main scarp) was exposed at the west end of the slope (Plate 14), following the vegetation clearance in September 2006. The larger landslide does not appear to be recent. It seems to be located at approximately the same location as the 1982 landslide identified by API (Figures 2 and 4). An approximately 8 m long, 1.4 m high counterfort wall is present at the middle portion of slope No. 7NE-D/C178 (Plate 15). The counterfort wall coincides with the location of the 1973 landslide identified by API, and was probably part of the remedial works that were carried out following that incident. Seepage was observed at the counterfort wall (Plate 15) on the afternoon of 13 June 2006, some 10 hours after a Red Rainstorm Warning. A 300 mm wide U channel is located at the toe of slope No. 7NE-D/C178 in front of the counterfort wall. The excavation on slope No. 7NE-D/C179 that was identified on the 1977 aerial photographs was clearly visible after vegetation clearance (Plate 5).

Following the June 2006 landslide, Lands D carried out emergency works on slope No. 7NE-D/FR58, including trimming back the failure scar, provision of shotcrete cover and a crest channel. These works were completed in late July 2006. Lands D subsequently carried out enhanced maintenance works to the slope including the removal of fill and the masonry wall, trimming the slope to form two batters with a maximum height of 7 m, installation of soil nails (25 mm to 32 mm diameter bar at 1.5 m horizontal spacing with a maximum length of 11 m), provision of Type III raking drains (at 4.5 m horizontal spacing with a maximum length of 12 m) and installation of surface drains. The enhanced maintenance works were completed in September 2007.

6. ANALYSIS OF RAINFALL RECORDS

Rainfall data were obtained from GEO automatic raingauge No. N44, which is the nearest raingauge to the study area and is located about 1.2 km to the northeast at the roof of Lee Fung House, Lee On Estate, Ma On Shan (Figure 1). The raingauge records and transmits rainfall data at 5 minute intervals to the Hong Kong Observatory and the GEO.

According to the Incident Report prepared by the GEO, the landslide occurred at about 2:45 p.m. on 2 June 2006. The daily rainfall recorded by raingauge No. N44 over the month preceding the incident, together with the hourly rainfall readings for the period between 31 May and 2 June 2006, is presented in Figure 6.

A Red Rainstorm Warning was in effect on 2 June 2006 between 10:55 a.m. and 2:45 p.m. The maximum 12 hour and 24 hour rolling rainfall before the landslide were 185 mm and 199.5 mm respectively. The maximum 1 hour rolling rainfall was recorded as 99.5 mm between 9:45 a.m. and 10:45 a.m. on 2 June 2006 (Table 1).

Table 1 presents the estimated return periods for the maximum rolling rainfall for various durations recorded by raingauge No. N44 with reference to historical rainfall data at the Hong Kong Observatory in Tsim Sha Tsui (Lam & Leung, 1994). The results show that the 1 hour rolling rainfall of 99.5 mm before the incident was the most severe for this rainstorm, with a corresponding return period of about 8 years, whilst for other rainfall durations, the corresponding return periods range from less than 2 years to about 4 years.

The June 2006 rainstorm was also assessed with local rainfall data to evaluate the variability of rainfall due to orographic effect. Evans & Yu (2001) analysed the 5-minute rainfall data of 46 GEO automatic raingauges throughout Hong Kong for the period of 1984 to 1997 (raingauge No. N44 was not reviewed by Evans & Yu since it was established in 1999). The return periods were assessed based on the statistical parameters derived from rainfall data recorded by raingauge No. N09, which is the nearest raingauge with local statistical rainfall parameters and is located at the Meteorological Laboratory of the Chinese University of Hong Kong. The results show that the 1 hour rolling rainfall before the incident has a return period of about 11 years, which is slightly higher than that estimated by the historical rainfall data at Tsim Sha Tsui.

The maximum rolling rainfall for the 2 June 2006 rainstorm has been compared with the past major rainstorms recorded by raingauges Nos. N09 and N44, which came into operation in June 1983 and October 1999 respectively (Figure 7). It is noted that the 2 June 2006 rainstorm was less severe than most of the previous major rainstorms.

7. DISCUSSION

The June 2006 landslide on slope No. 7NE-D/FR58 involved a rain-induced failure on a portion of slope comprising a masonry wall that is founded on an oversteep (about 80°) soil/rock cut with a masonry facing. The feature was constructed before 1963 without geotechnical input. Based on the above, the wall at the failed portion has a slenderness ratio of about 4.2, which is not unduly slender. The pointing of the wall was relatively tight and compact throughout the wall thickness. The available evidence suggests that the masonry wall apparently did not exhibit prolonged signs of significant distress before its apparently brittle collapse in 2006.

Large masonry wall fragments were found within the mid-height of the landslide debris with its original wall front facing downward (Plate 9). The slip surface was exposed at the toe of the 7.2 m high section, which suggests that the failure surface did not daylight at the point where the interface between fill and decomposed granite meets the wall back. However, without a detailed investigation, the sequence of failure, the failure mode and the precise profile of the failure surface are uncertain. The pattern of the landslide debris and relative position of the large wall fragment indicate that the landslide was neither an overall rotational failure nor an overall toppling failure of the masonry wall.

The failure surface might have passed through a significant portion of the insitu ground (i.e. decomposed granite as shown in Figure 5), in which case the potentially brittle failure through the decomposed granite could have rendered the wall behave in an apparently different manner from other non-slender masonry walls retaining fill materials, viz. this wall together with the overall slope could have failed in a brittle manner without prolonged signs of significant deformation because of the above.

It should be noted that the geometry shown in Section A-A (Figure 5) could give rise to a very special circumstance that the wall failure was in effect very slender if the masonry facing over the bottom 3 m behaved as if it was part of the retaining structure. Under this scenario, the base width at the toe (where the failure surface daylighted) is very small, with a slenderness ratio of about 24. The wall may be considered to be effectively standing on a small toe and it could behave as for a very slender wall.

Alternatively, the apparent brittle nature of the collapse could have been associated with the meta-stable condition of the wall geometry to withstand deformation. Given the special geometry, this wall may have very limited capability to deform to a stable configuration as per other ordinary masonry walls that are founded on flat ground. Once this wall started to deform, it would kick out and reach an even less stable state, which could be a contributory factor for the brittle failure mode.

The collapse may also have been triggered by an initial failure of the steep cutting over the bottom 3 m, which would be sufficient to induce an overall failure given the sensitivity of the upper 4.2 m high wall section to any bearing movement. Under this scenario, the upper wall section could have failed shortly following the initial failure of the lower cutting, due to loss of support.

Given the many uncertainties, the postulated failure mode and sequence of failure can only be conjectural.

No signs of distress were observed in the remaining portion of the masonry wall, which has a thicker wall base (with a slenderness ratio of about 4) founded at the toe of the slope. The masonry wall was subsequently demolished in January 2007 during the enhanced maintenance works carried out by Lands D.

Seepage was observed on the surface of slope No. 7NE-D/C178, following a rainstorm on 13 June 2006, which shows that there could be some local concentration of surface water flow at a location above the June 2006 failure scar. The unpaved platform, the presence of the upstand/parapet on top of the masonry wall and the lack of surface drainage at the crest of the slope would probably promote ponding and concentrated water ingress into the ground behind the wall during heavy rainstorm.

The June 2006 landslide occurred during a moderate rainstorm with a return period of approximately 11 years for 1-hour duration rainfall, which was less severe than many past major rainstorms. This may indicate that the slope has undergone progressive deterioration. Possible signs of movement were first recorded by the RMI in 2001 (although no further details can be located). A crack was also observed during the 2001 EI (although this could have been associated with a construction joint near the top of the wall). No wall movement or cracks were noted in the subsequent RMI in January 2005. However, early signs of

distress on the soil/rock cut slope might have been obscured by the masonry facing, which would have offered some resistance to the development of surface expressions of the distress. Any weakness or crack development could have been exacerbated following the heavy rainfall in subsequent rainstorms (e.g. the severe rainstorm in August 2005), leaving the slope feature in a potentially metastable condition that led to the June 2006 landslide following a less severe rainstorm.

Slope No. 7NE-D/FR58, which was registered in February 1998, was not investigated under the assignments on "Thickness Gauging of Retaining Wall" in 1995 and 1997. The slope was also not selected for the assignment on "Thickness Gauging of Retaining Wall 2004" due to its low consequence to life category. The masonry wall thickness was not checked (viz. probing) during the 2001 EI, since this was not required under the EI consultancy agreement and was not a common practice for EI as it is not specifically stipulated in Geoguide 5. Hence, the actual configuration of the masonry wall (i.e. a relatively thin wall supported on an oversteep cut slope with a thin masonry facing) was not considered during the subsequent slope inspections.

8. REFERENCES

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Geotechnical Engineering Office (2003). Guide to Slope Maintenance (Geoguide 5) (Third Edition). Geotechnical Engineering Office, Civil Engineering Department, Hong Kong SAR, 132 p.

Lam, C.C. & Leung, Y.K. (1994). Extreme Rainfall Statistics and Design Rainstorm Profiles at Selected Locations in Hong Kong. Technical Note No. 86, Royal Observatory, Hong Kong, 89 p.

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

Wong, H.N. & Ho, K.K.S. (1996). Travel distance of landslide debris. Proceedings of the Seventh International Symposium on Landslides, Trondheim, Norway, vol. 1, pp 417-422.

LIST OF TABLES

Table 1 - Maximum Rolling Rainfall at GEO Raingauge No. N44 for Selected Durations Preceding the 2 June 2006 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 N09 [3] from Evans & Yu (2001)
5 Minutes	13.5	10:35 a.m. on 2 June 2006	2	3
15 Minutes	32.5	10:35 a.m. on 2 June 2006	4	3
1 Hour	99.5	10:45 a.m. on 2 June 2006	8	11
2 Hours	114.5	11:25 a.m. on 2 June 2006	3	3
4 Hours	148.0	11:10 a.m. on 2 June 2006	4	3
12 Hours	185.0	2:35 p.m. on 2 June 2006	2	2
24 Hours	199.5	1:55 p.m. on 2 June 2006	< 2	< 2
48 Hours	255.5	2:35 p.m. on 2 June 2006	2	< 2
4 Days	284.5	2:35 p.m. on 2 June 2006	< 2	< 2
7 Days	354.5	2:35 p.m. on 2 June 2006	< 2	< 2
15 Days	472.5	2:35 p.m. on 2 June 2006	< 2	< 2
31 Days	773.0	2:35 p.m. on 2 June 2006	3	2

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 extracted from Appendix B of Evans & Yu (2001) to assess the variability of rainfall due to orographic effect. Statistical parameters for raingauge No. N44 was not assessed by Evans & Yu (2001) and parameters from raingauge No. N09, which is the nearest raingauge with the local statistical rainfall parameters, was adopted.
(4) According to the incident record, the landslide occurred at about 2:45 p.m. on 2 June 2006.
(5) The nearest GEO raingauge to the landslide site is raingauge No. N44 situated at about 1.2 km to the northeast of the landslide site. GEO raingauge No. N09 is situated at about 2.2 km to the west of the landslide site.

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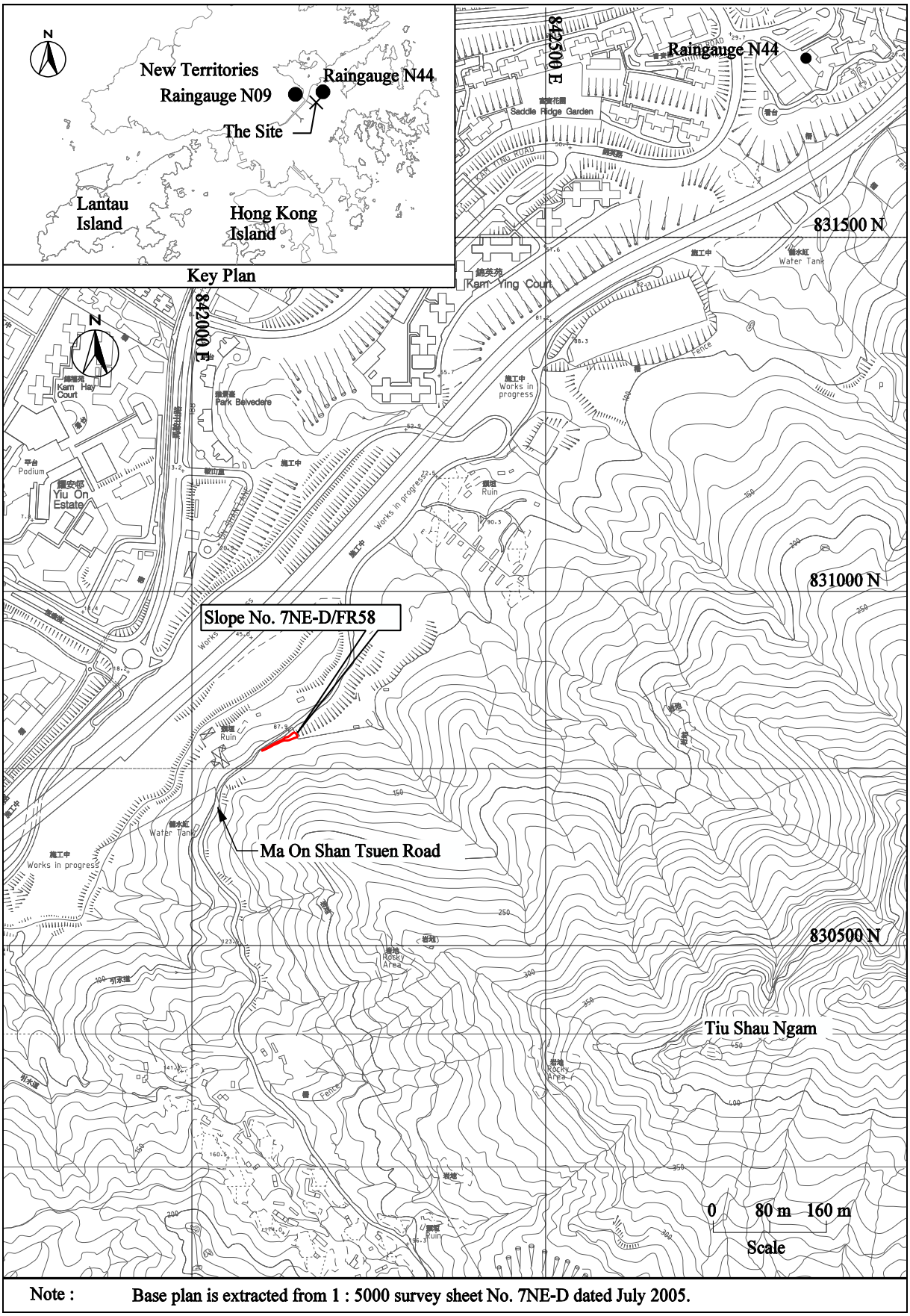

Note : Base plan is extracted from 1 : 5000 survey sheet No. 7NE-D dated July 2005.

Figure 1 - Location Plan

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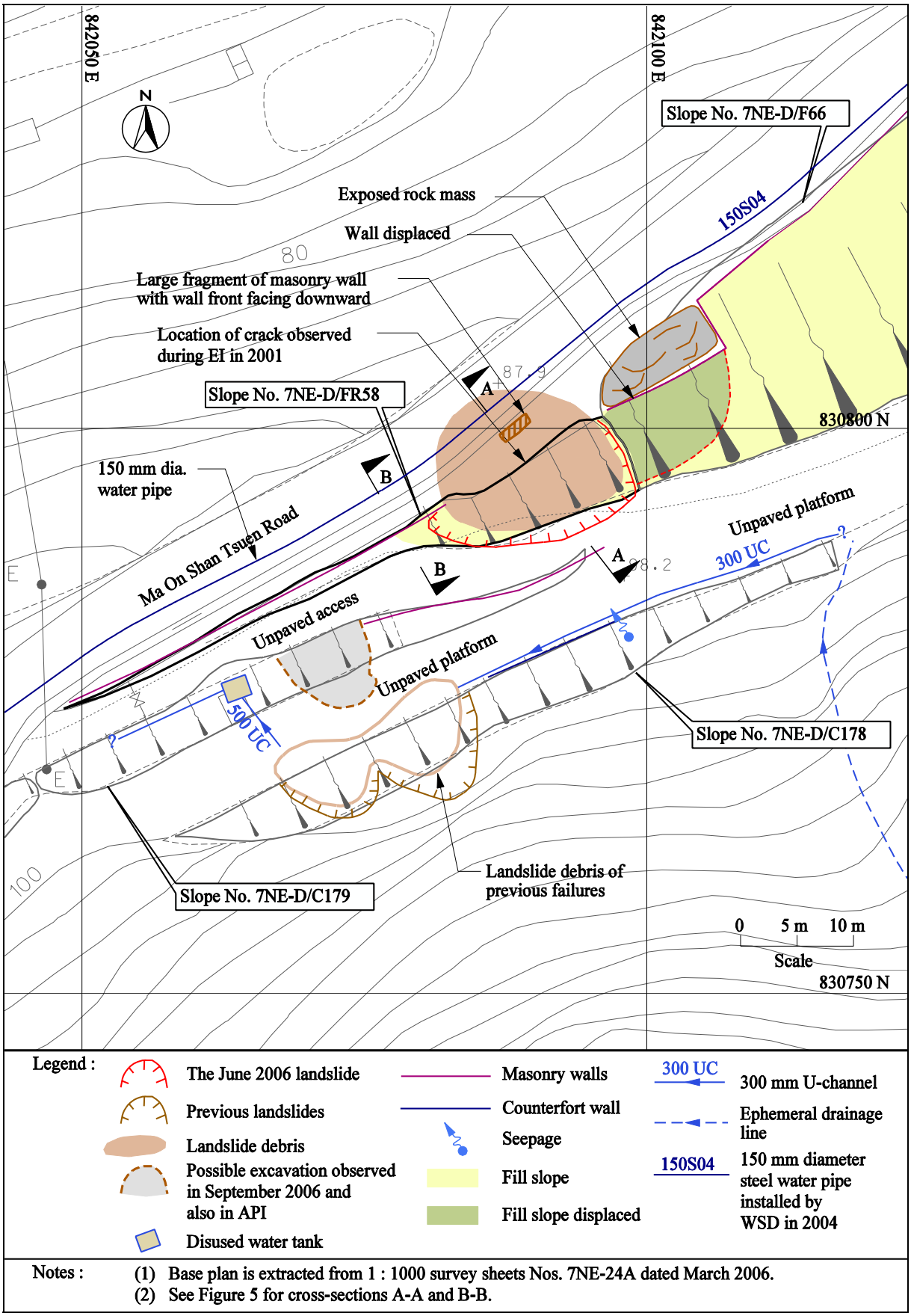

Figure 2 - Site Layout Plan and Field Observations

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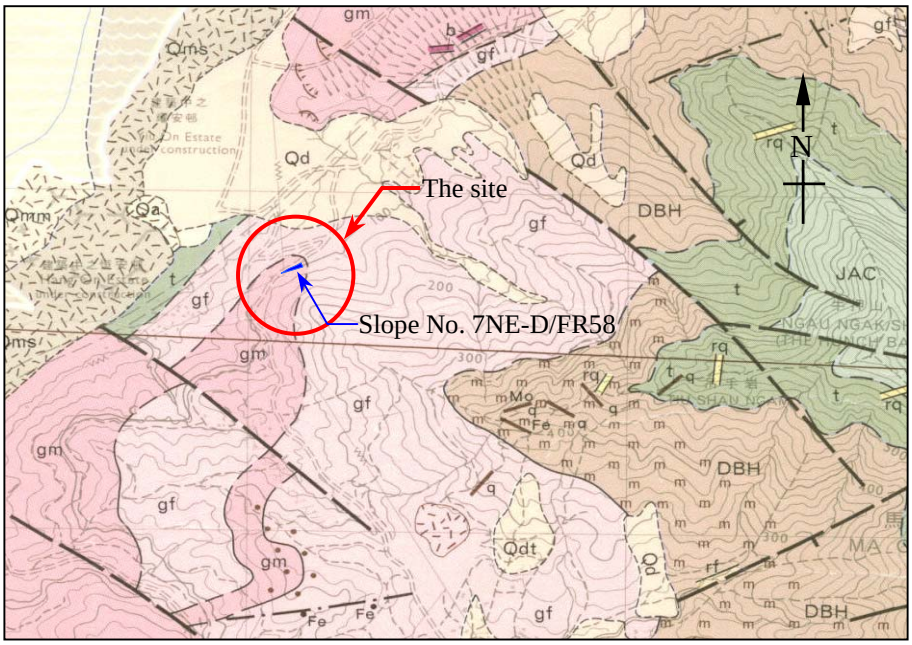

LEGEND:

SUPERFICIAL DEPOSITS

Qa	Clay/silt, sand and gravel well-sorted to semi-sorted (Alluvium)
	Fill
Qd	Unsorted sand, gravel, cobbles and boulders; clay/silt matrix (Debris flow deposits)

SOLID GEOLOGY

gf	Fine-grained granite, <2 mm
gm	Medium-grained granite, 2-6 mm
rq	Quartzphyric rhyolite
b	Basalt
JAC	Vitric tuff, with fiamme (Ap Lei Chau Formation)
t	Undifferentiated tuff and tuffite
DBH	Sandstone and Siltstone (Buff Head Formation)
m m m	Hornfels (Thermal altered rock around granite intrusions

GEOLOGICAL LINES

	Geological boundary, superficial deposits
*	Geological boundary, solid rock (* Broken lines denote uncertainty)
*	Fault (crossmark indicates downthrow side)
*	Mineral vein (* Broken lines denote uncertainty)
	Photogeological lineament

Fe	Magnetite
q	Quartz
Mo	Molybdenite

Note: Extracted from HKGS, Map Series HGM20, Sheet No. 7, 1:20 000 scale (GCO, 1986)

Figure 3 - Regional Geology

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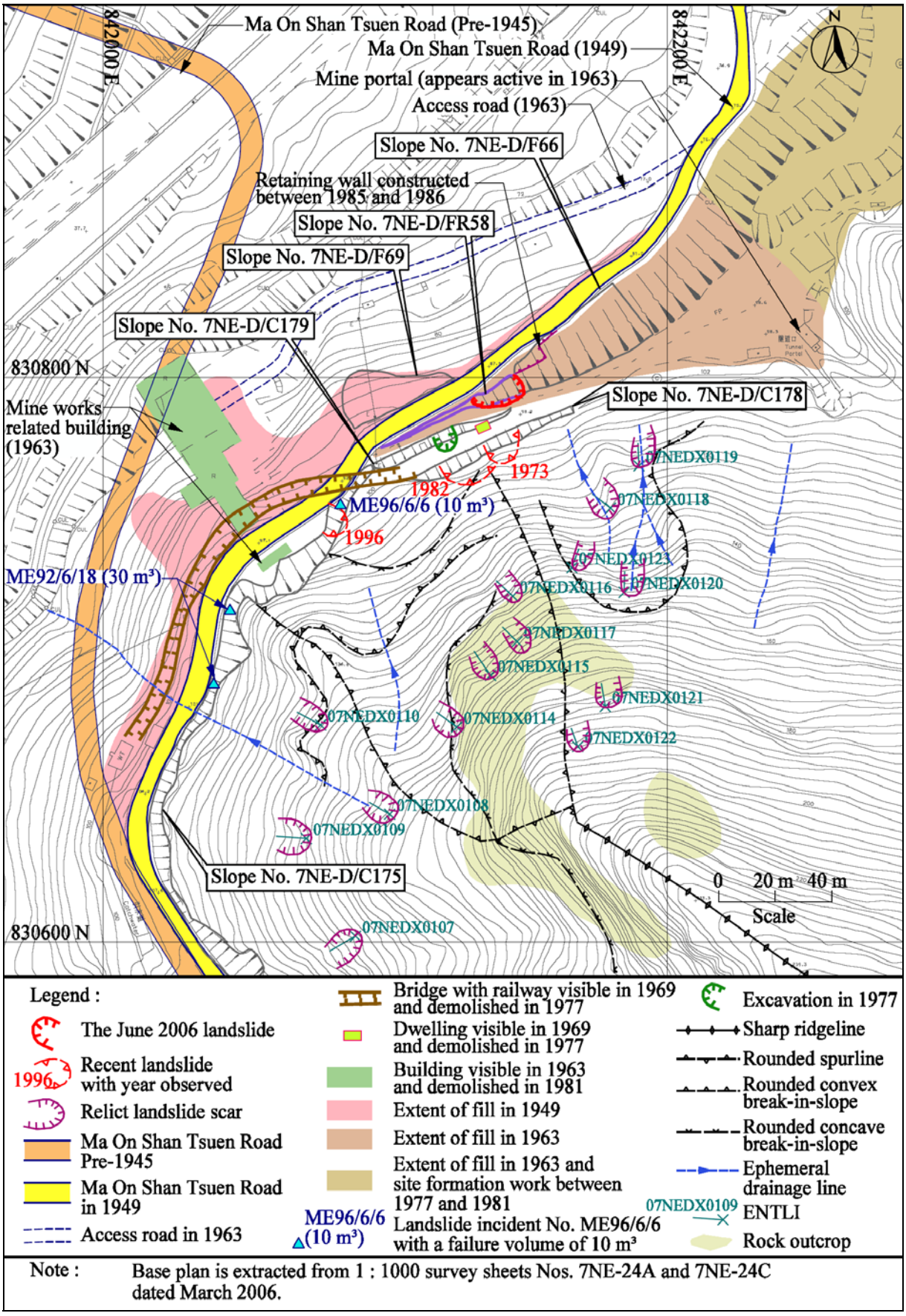

Figure 4 - Site History, Past Instabilities and Geomorphology

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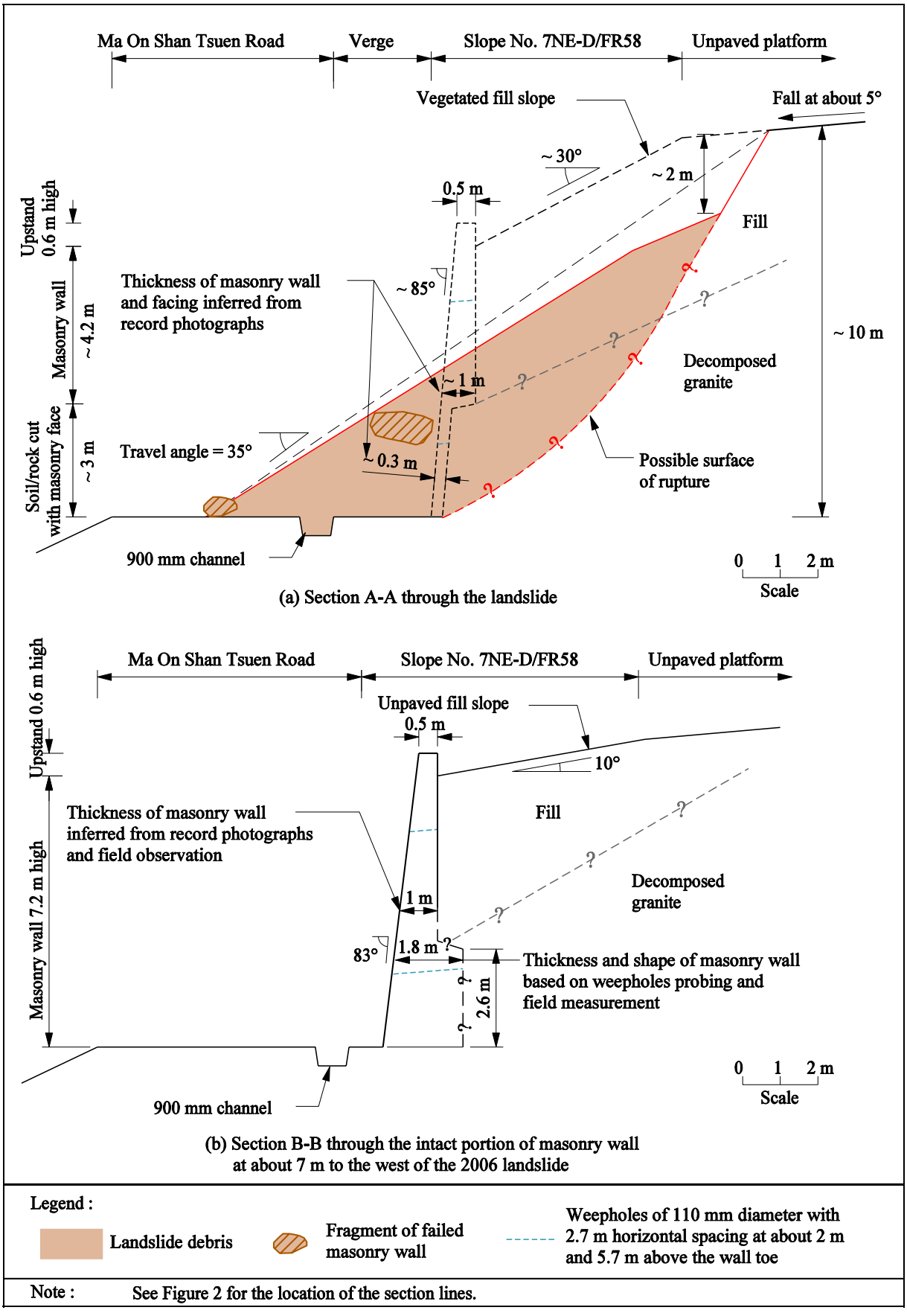

Figure 5 - Cross Sections

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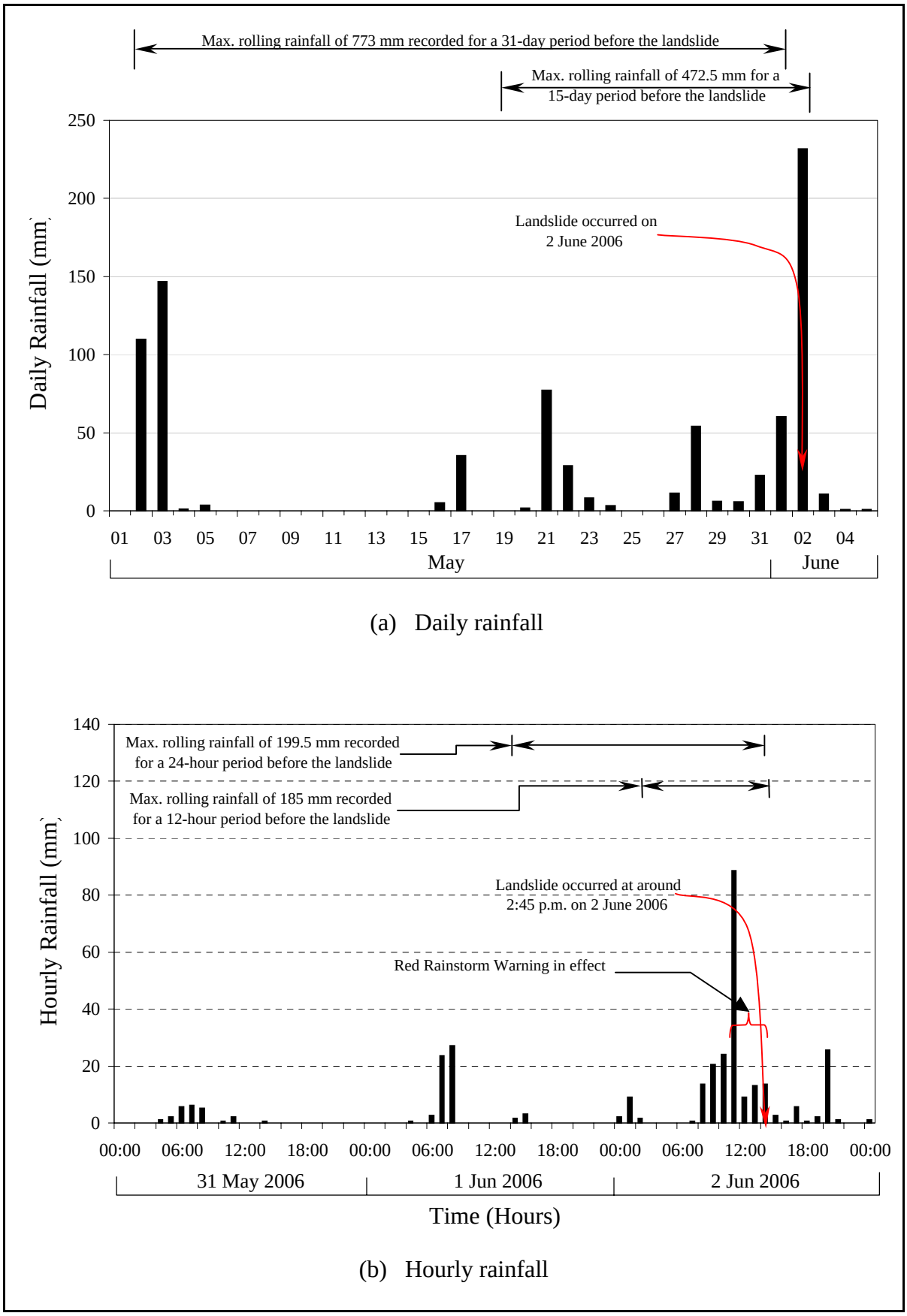

Figure 6 - Daily and Hourly Rainfall Recorded at GEO Raingauge No. N44

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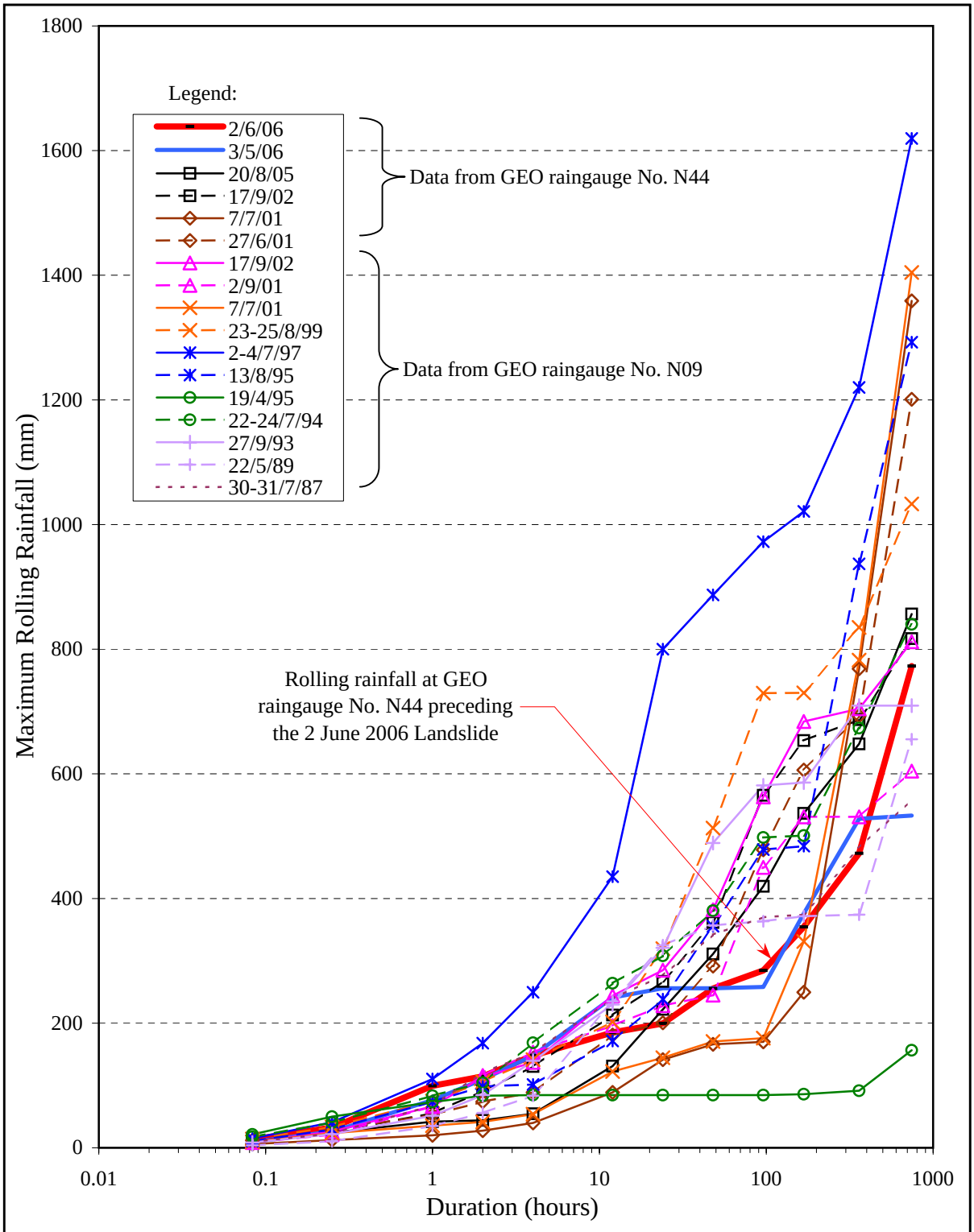

Notes: (1) Rainfall data evaluated from 5-minute readings from GEO raingauge No. N44 (about 1.2 km to the northeast of the site) and GEO raingauge No. N09 (about 2.2 km to the west).

(2) Rolling rainfall of previous rainstorms calculated at GEO raingauge No. N09 since June 1983 and at GEO raingauge No. N44 since October 1999 when the raingauges became operational.

Figure 7 - Maximum Rolling Rainfall for Previous Major Rainstorms at GEO Raingauges Nos. N09 and N44

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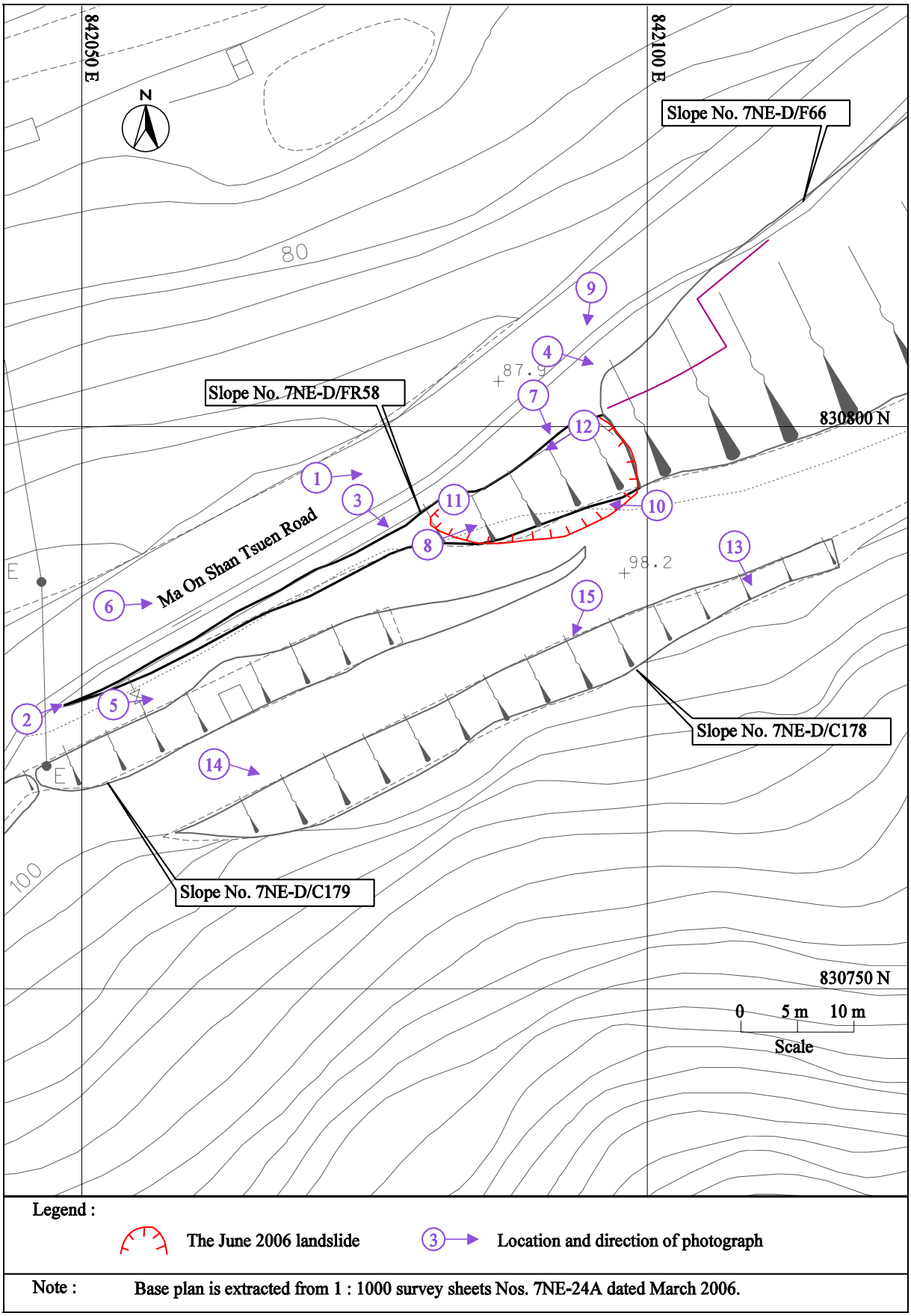

Figure 8 - Locations and Directions of Photographs Taken

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Plate 1 - General View of the 2 June 2006 Landslide on Slope No. 7NE-D/FR58
(Photograph taken by GEO on 2 June 2006)

Plate 2 - View of the Access above Slope No. 7NE-D/FR58
(Photograph taken by Lands D on 5 June 2006)

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

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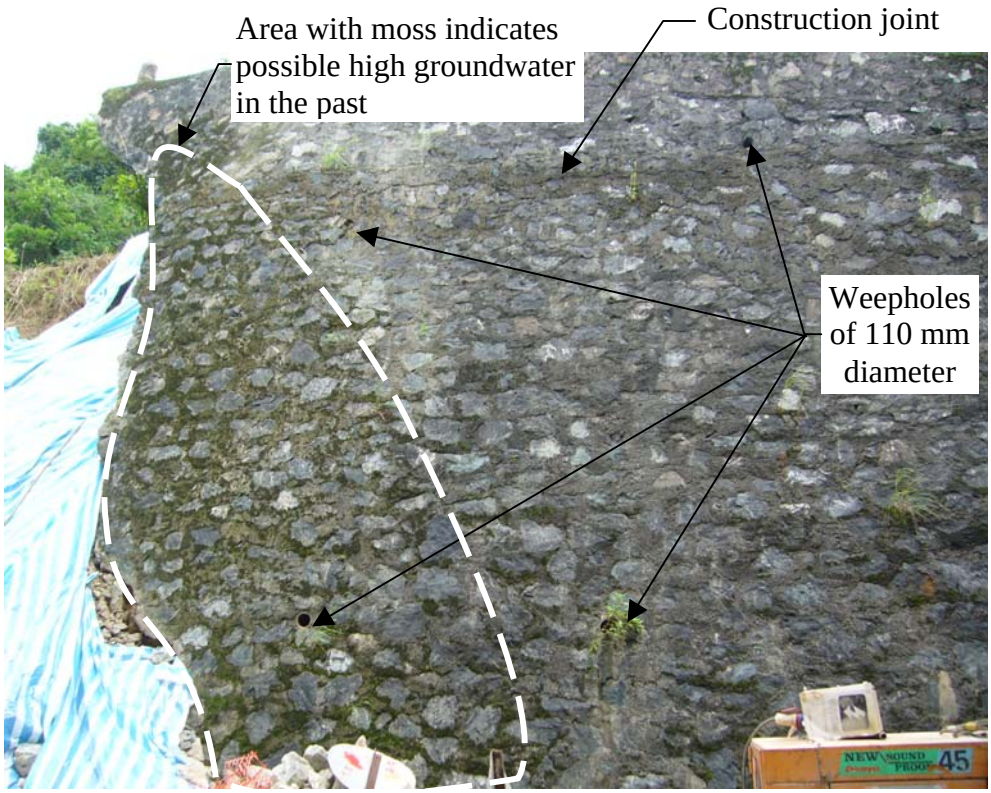

Plate 3 - Front View of the Masonry Wall Portion of Slope No. 7NE-D/FR58 (Photograph taken on 7 June 2006)

Plate 4 - Masonry Wall Extended to Slope No. 7NE-D/F66 (Photograph taken on 7 June 2006)

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

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Plate 5 - General View of Slope No. 7NE-D/C179
(Photograph taken on 7 February 2007)

Plate 6 - View of the Failure Area of Slope No.7NE-D/FR58 in 1997
(Photograph taken by BCL on 17 September 1997)

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

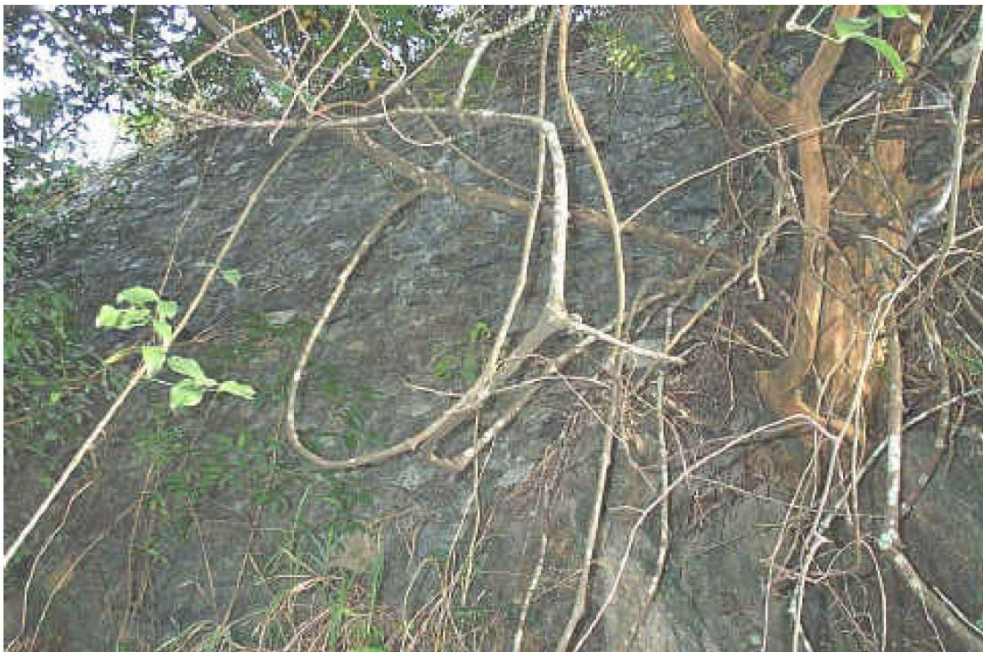

Plate 7 - Crack Observed on the Masonry Wall at the June 2006 Landslide Location
(Photograph taken by BAJV on 9 November 2001)

Plate 8 - View of the Main Scarp of the 2 June 2006 Landslide
(Photograph taken on 7 June 2006)

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

Plate 9 - View of the Landslide Debris and Masonry Wall Fragment
(Photograph taken by Lands D on 5 June 2006)

Plate 10 - View of the Exposed Wall Stem during the Urgent Repair Works
(Photograph taken by Lands D on 13 June 2006)

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

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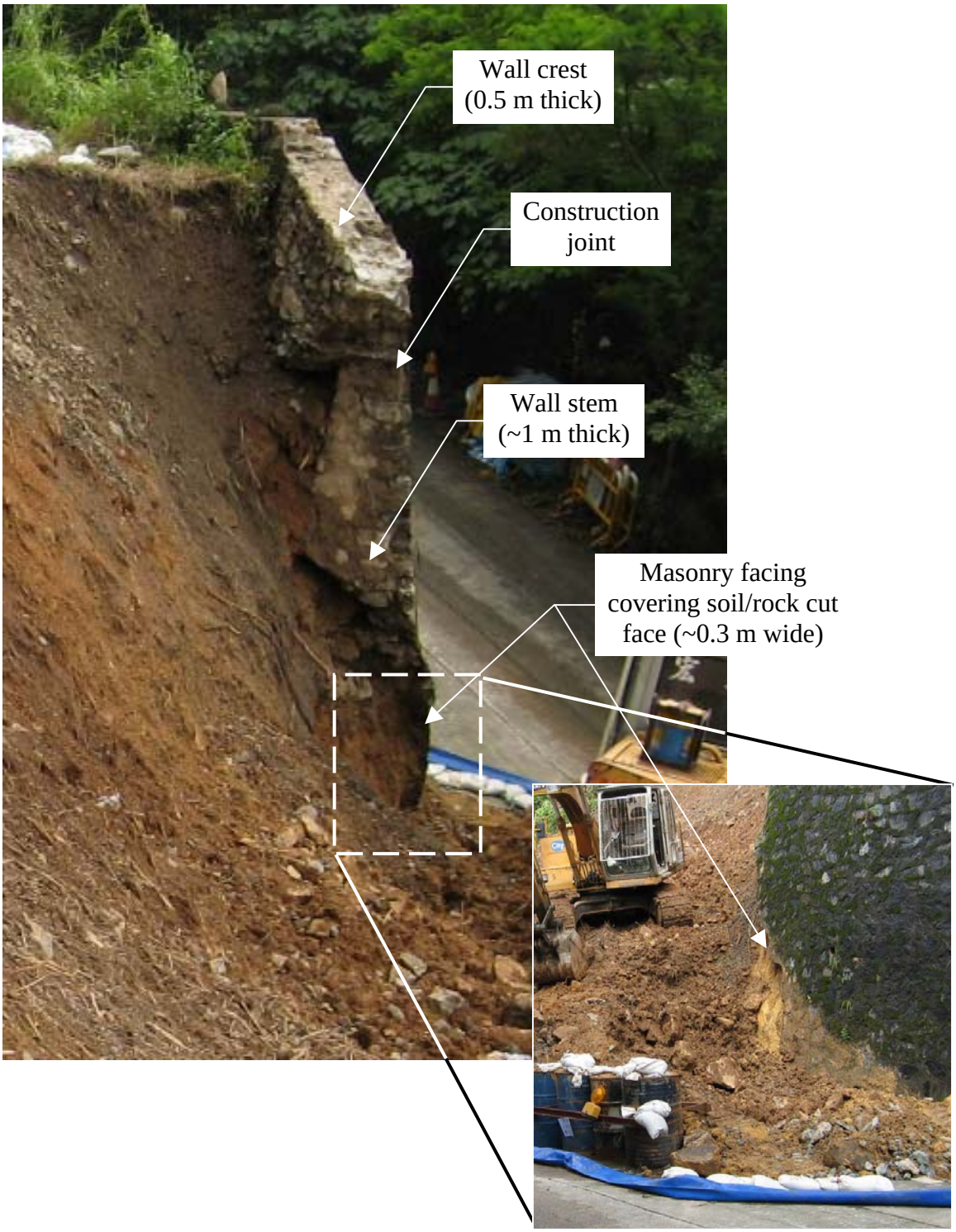

Plate 11 - Close-up View of the Exposed Wall Stem and Masonry Facing at Wall Toe
(Photograph taken by Lands D on 13 June 2006)

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

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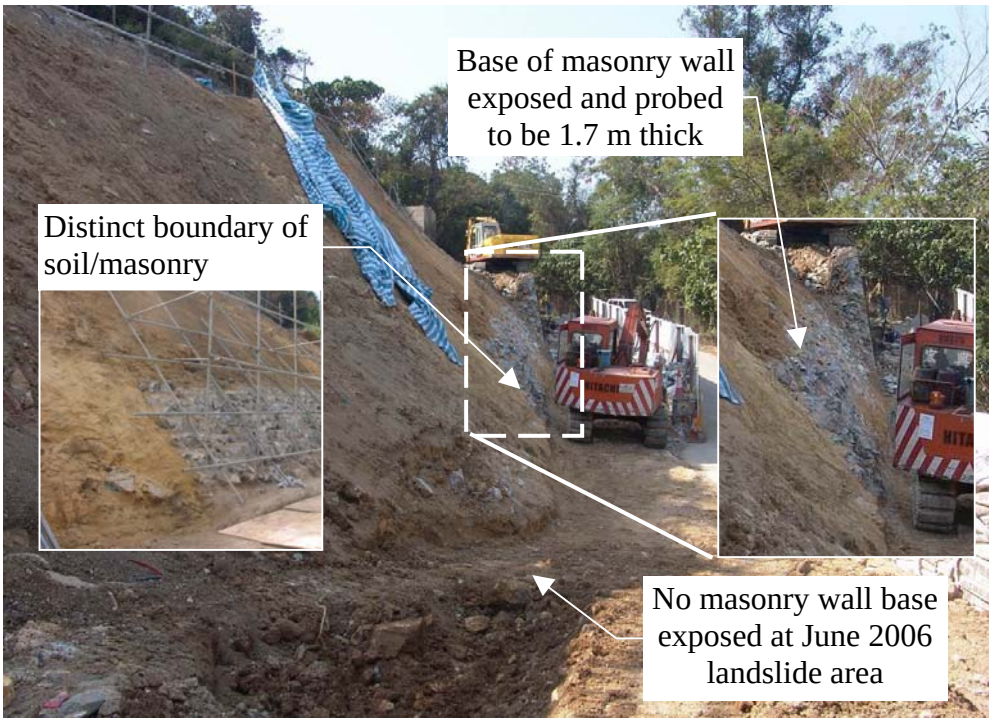

Plate 12 - View of the Masonry Wall Base during Wall Demolition
(Photograph taken by Lands D on 31 January 2007)

Plate 13 - Minor Landslide on Slope No. 7NE-D/C178
(Photograph taken on 7 June 2006)

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

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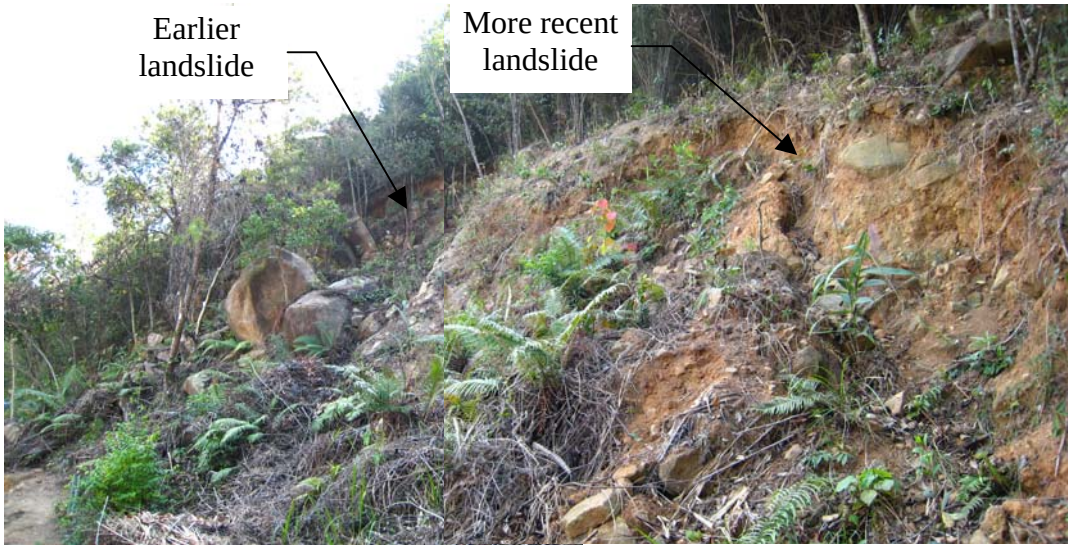

Plate 14 - Major Landslide on Slope No. 7NE-D/C178
(Photograph taken on 7 February 2007)

Plate 15 - Counterfort Wall on Slope No. 7NE-D/C178 with Active Seepage
(Photograph taken by Lands D on 13 June 2006)

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

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APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

CONTENTS

A1. DETAILED OBSERVATIONS

This appendix sets out the detailed observations made from an interpretation of aerial photographs taken between 1945 and 2005. A list of the aerial photographs reviewed is presented in Table A1 and the key observations of API are shown in Figure A1.

YEAR **OBSERVATIONS**

1945 High-flight, poor resolution aerial photographs.

The earliest available aerial photographs show that, prior to development, the study area in the vicinity of the landslide site generally comprises a vegetated, northwest-facing natural hillside. The hillside above the site is delineated by a northwest trending, well-defined ridgeline descending from Ngau Ngak Shan and Tiu Shau Ngam. The hillside downslope of this spurline is typically very steep that may be associated with the presence of rock outcrop (Figure A1).

The alignment of the Ma On Shan Tsuen Road at the time was to the west. Slope No. 7NE-D/FR58 and the portion of Ma On Shan Tsuen Road below have not been formed (Plate A1).

1949 High-flight, poor resolution aerial photographs.

The portion of Ma On Shan Tsuen Road below slope No. 7NE-D/FR58 is under formation. Fill material has been placed on downslope side of the road (Figure A1). Slope No. 7NE-D/FR58 has not been formed. A path can be observed in the vicinity of the landslide site leading to the valley to the east (where the mining tunnel portal observed in 1963) (Plate A2).

1963 Slope No. 7NE-D/FR58, which consists of a fill slope with retaining wall at its toe, has been formed and the retaining wall of the subject slope is clearly evident (Plate A3). Slope No. 7NE-D/FR58 was constructed at about 90° to a round spurline plunging approximately north to north-northwest from the ridgeline. A series of concave and convex breaks-in-slopes were observed on the western side of the spurline with rock outcrop exposed below the ridgeline. A large amount of fill has been placed on the sloping hillside during the construction of an access connecting Ma On Shan Tsuen Road to a mine to the east of the landslide site. A cluster of dwellings were formed near the portion and rail system was formed from the mining portal to slope No. 7NE-D/F66. Some structures (which appear to be the bridge pier for the flyover identified in 1969) were erected to the west of slope No. 7NE-D/C179.

Slopes Nos. 7NE-D/C178, 7NE-D/C179, 7NE-D/F69 and 7NE-D/F66 are all evident adjacent to slope No. 7NE-D/FR58, and all have been formed in association with the access road of the mine. A water tank can be observed on slope No. 7NE-D/C179.

Several relict landslides can be identified on the hillside above the landslide site. These relict landslide scars are all clearly defined by rounded convex breaks in

YEAR	OBSERVATIONS
1963 (cont'd)	slope. No evidence of associated downslope debris can be observed (Plate A3). Ephemeral streamcourse can be observed to the southeast of the subject slope. The natural streamcourses in close proximity to the subject slope are essentially ephemeral in nature (Plate A3).
1969	A bridge was constructed immediately to the southeast of slope No. 7NE-D/FR58 and between slopes Nos. 7NE-D/C178 and 7NE-D/C179. A railway is evident on the bridge and appears to be used in relation to transporting spoil from the mine to the associated buildings to the west of the subject slopes. Rock exposures are clearly visible on the hillside above (Plate A4). A hut has been built at the eastern end of the cut slope No. 7NE-D/C179. A high reflective area is observed to the northeast of the mining tunnel portal, which appears to be site formation works or open mining (Plate A4).
1973	A minor failure is observed on slope No. 7NE-D/C178. The debris is still visible and did not affect the railway track (Plate A5).
1977	The railway, the bridge and the hut at the eastern end of slope No. 7NE-D/C179 have been demolished. Vegetation began to re-grow on the landslide that was observed in 1973 but the scar is still visible (Plate A6). The site formation works to the northeast of the tunnel portal became more extensive and fill material placed in 1963 was being excavated. A haul road leading from the tunnel portal to Ma On Shan Tsuen Road was formed (Plate A6). A minor excavation is observed at slope No. 7NE-D/C179 to the south of slope No. 7NE-D/FR58. A sharp vertical cut face can be observed (Plate A6).
1979	The site formation to the northeast of the tunnel portal became less extensive and vegetation re-growth is visible near the eastern end, as well as the open area near the mining tunnel portal and the access road above the subject slope.
1981	No significant changes to the subject slope are apparent except that the vegetation density had decreased. The buildings to the west of the subject slope have been demolished. The site formation to the northeast of the tunnel portal is complete and vegetation re-growth is visible in the whole area (Plate A7).
1982	No significant changes to the subject slope are apparent except for a general increase in the vegetation density. A recent landslide can be seen to have affected slope No. 7NE-D/C178. The position of the landslide and the extent of the associated failure debris can be clearly identified (Plate A8). The excavation at slope No. 7NE-D/C179 identified in 1977 is now generally covered by vegetation.

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YEAR	OBSERVATIONS
1983	The landslide scar at slope No. 7NE-D/C178 is covered by vegetation. No other significant changes to the study area are apparent.
1984	No significant changes to the study area are apparent.
1985	No significant changes to the subject slope are apparent except a retaining wall construction near the western portion of the slope No. 7NE-D/F66.
1986	No significant changes to the subject slope are apparent. The retaining wall construction on slope No. 7NE-D/F66 is complete.
1987 - 1990	No significant changes to the study area are apparent except an increase in the vegetation density.
1992	Agricultural activities are evident on the platform between slopes Nos. 7NE-D/C178 and 7NE-D/C179.
1993 - 1996	No significant changes to the study area are apparent.
1997	A landslide has occurred within the eastern part of slope No. 7NE-D/C175. The landslide source and debris trail cannot be delineated as the area has been fully shotcreted. The shotcreted area corresponds to a landslide incident that occurred in 1996 and was recorded by the GEO (Incident No. ME96/6/6). No significant changes to other parts of the study area are apparent.
1998	No significant changes to the study area are apparent except that the vegetation density on the subject slopes had increased.
1999	The agricultural terrace between slopes Nos. 7NE-D/C178 and 7NE-D/C179 appears to have been abandoned. No significant changes to other part of the study area are apparent.
2000 - 2005	No significant changes to the study area are apparent. The construction of Ma On Shan Bypass has commenced to the north of the study area in 2001 and appeared to be completed in 2004 (Plate A9).

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LIST OF TABLES

Table A1 - List of Aerial Photographs Reviewed

Date taken	Altitude (ft)	Photograph Number
6 November 1945	5800	Y743-45
2 June 1949	20000	Y2010-12
26 January 1963	3900	Y08726-27
1969	4000	Y15692-93
14 December 1973	2500	7274-75
12 December 1977	4000	20102-03
14 September 1979	6000	26988-89
18 May 1981	4000	37618-20
28 July 1982	4000	43228-29
29 November 1983	4000	51142-43
22 October 1984	4000	56827-28
3 October 1985	4000	A2417-18
28 April 1986	4000	A4849-50
10 June 1987	4000	A9257-58
29 March 1989	8000	CN2195-96
10 January 1990	2500	A20148-50
15 April 1992	4000	A30153-54
30 May 1993	4000	A34671-72
17 October 1994	4000	A39073-74
30 August 1995	3500	CN10657-58
26 April 1996	3500	CN13318-19
27 May 1997	4000	CN17358-59
30 October 1998	4000	A48689-90
3 September 1999	5500	A49904-05
10 August 2000	3000	CN27839-40
20 September 2001	4000	CW33350-51
27 May 2002	4000	CW41364-65
27 September 2003	4000	CW50504-05
16 December 2004	4000	CW62944-45
31 October 2005	4000	CW67563-64
Note: All aerial photographs are in black and white except for those with prefix CN or CW.		

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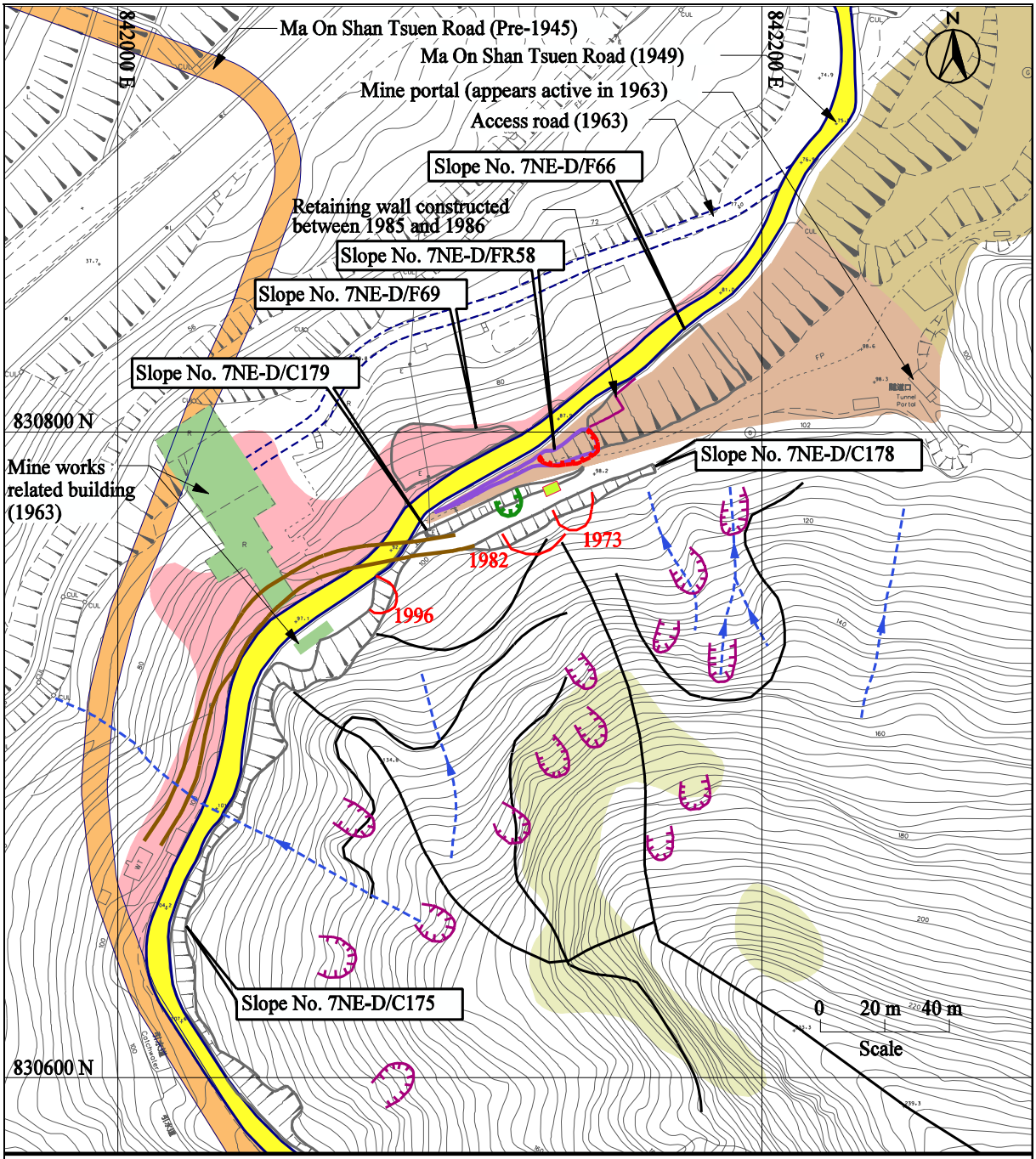

A1 - Aerial Photograph Interpretation

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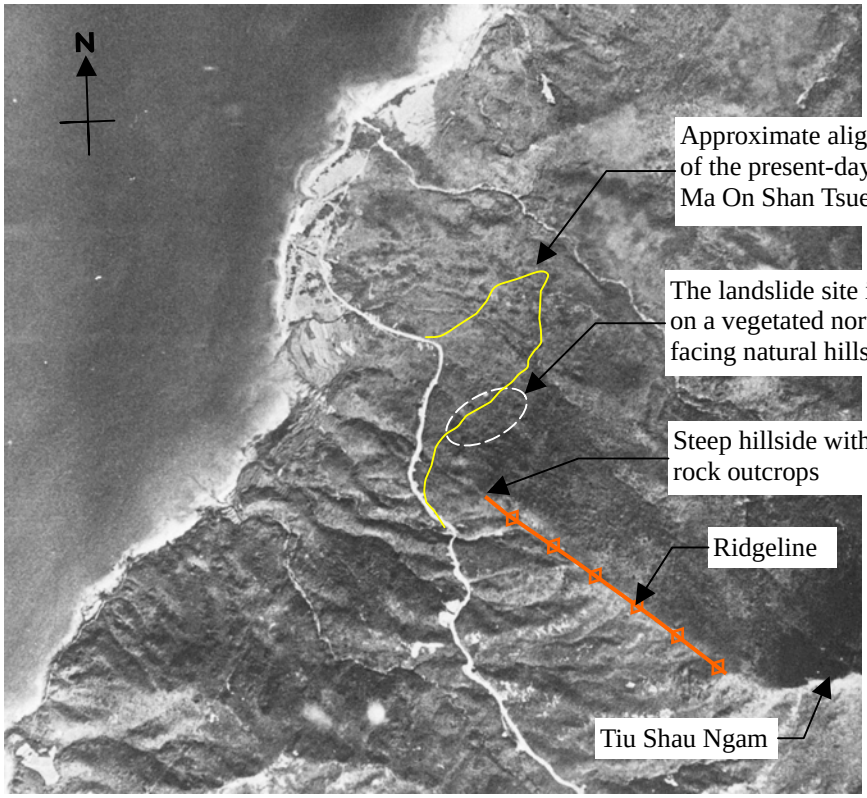

Plate A1 - Interpretation of 1945 Aerial Photograph No. Y00744

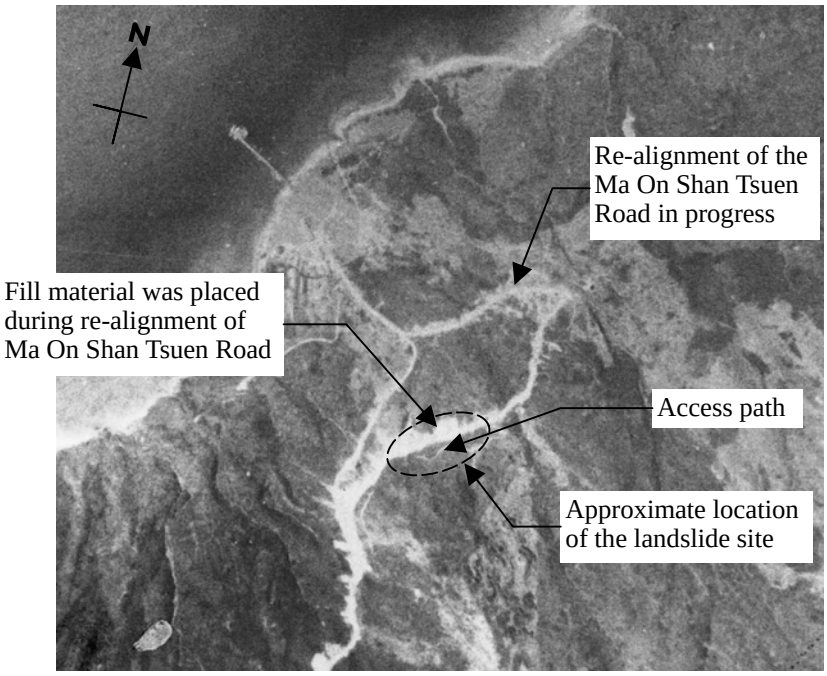

Plate A2 - Interpretation of 1949 Aerial Photograph No. Y02010

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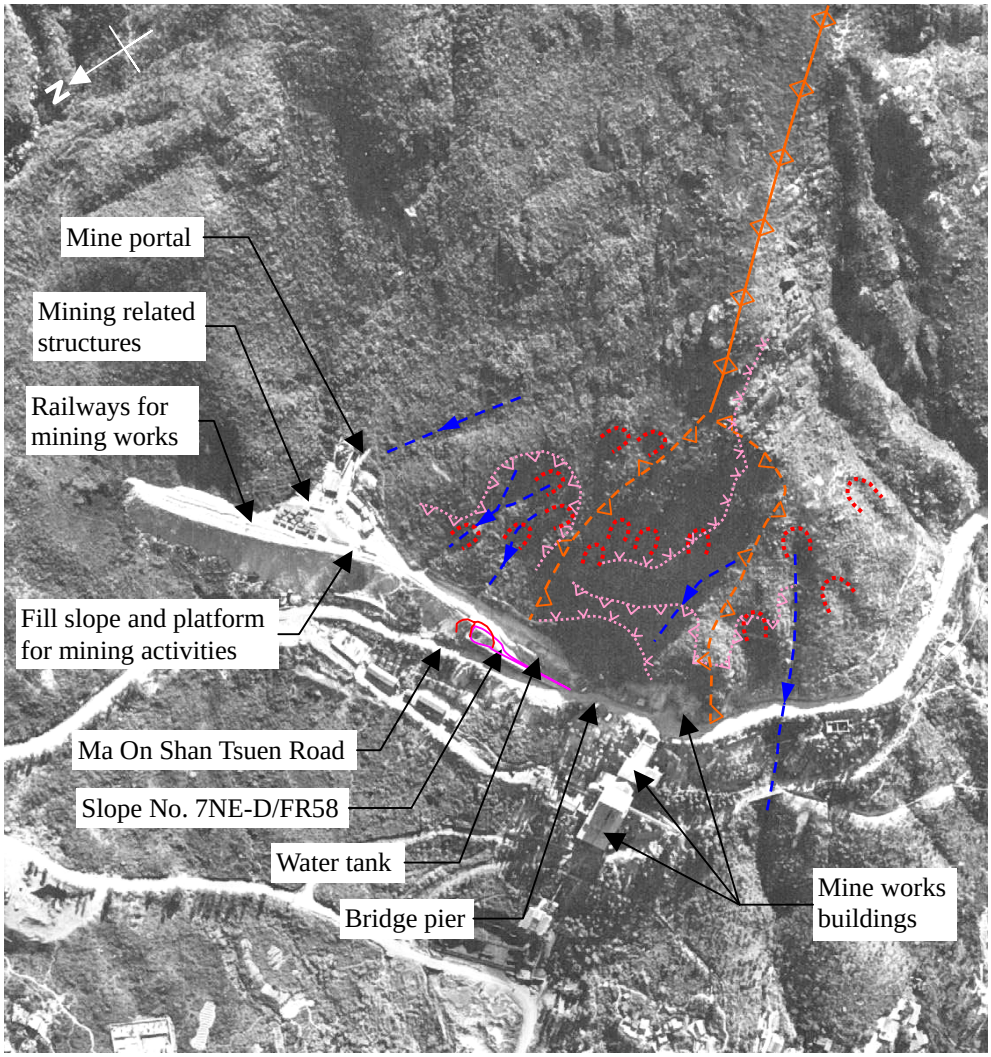

Legend:

- Sharp ridgeline
- Rounded spurline
- Streamcourse
- Ephemeral drainage line
- The 2006 landslide
- Relict landslide scar
- Concave break-in-slope
- Convex break-in-slope

Plate A3 - Interpretation of 1963 Aerial Photograph No. Y08727 and Geomorphology

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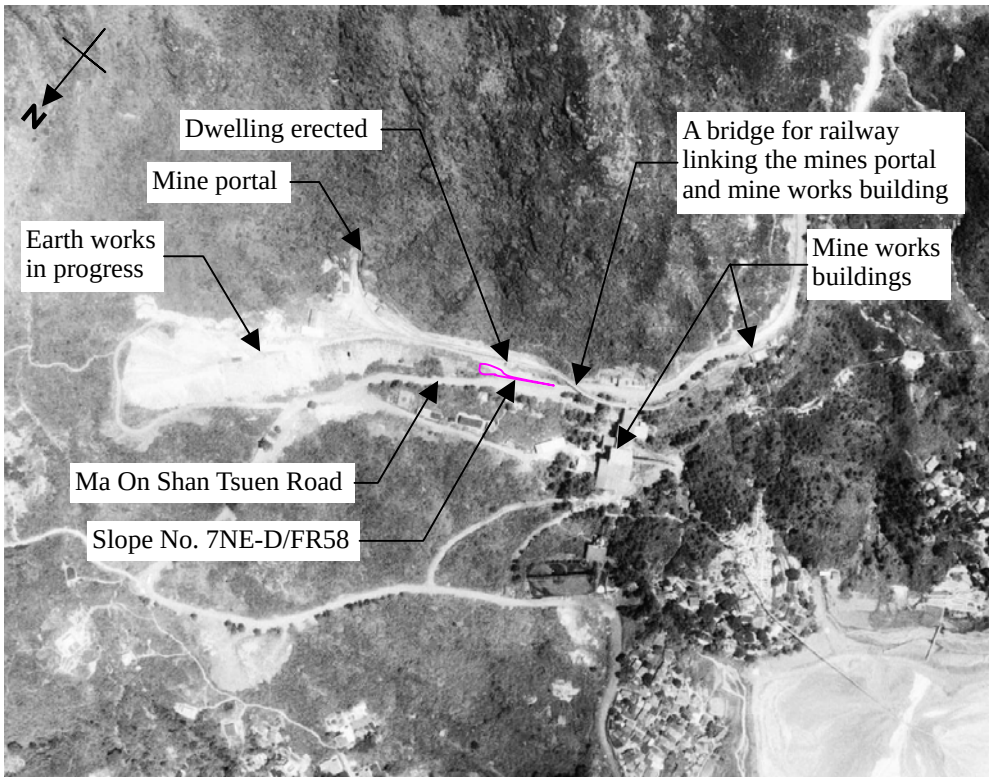

Plate A4 - Interpretation of 1969 Aerial Photograph No. Y12693

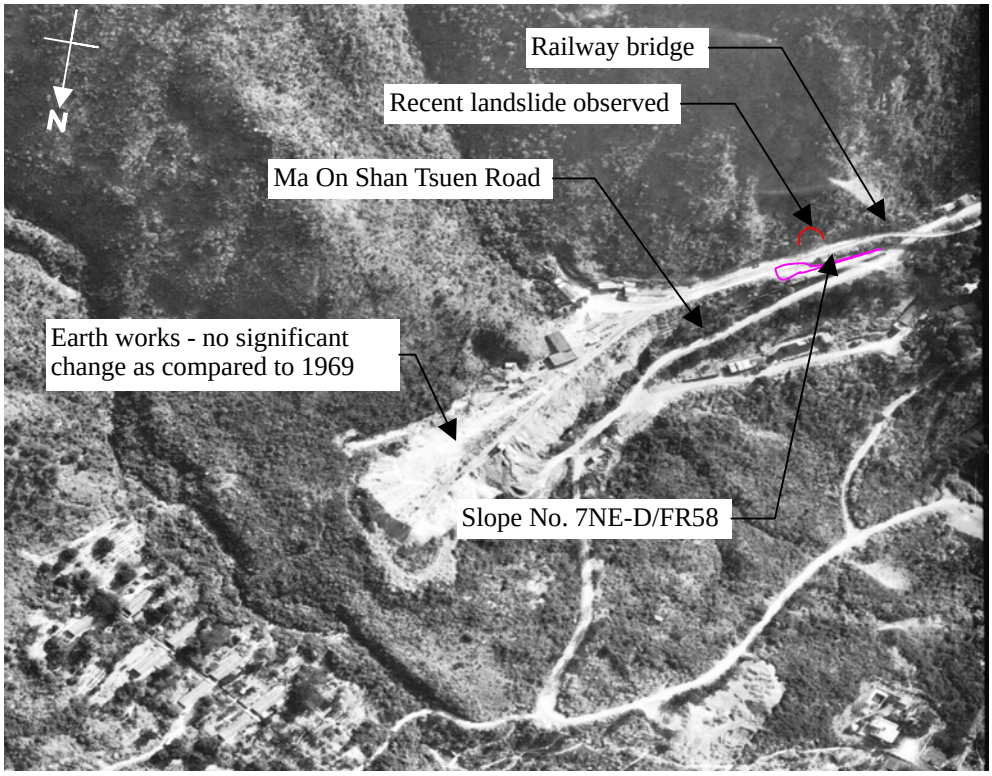

Plate A5 - Interpretation of 1973 Aerial Photograph No. 07275

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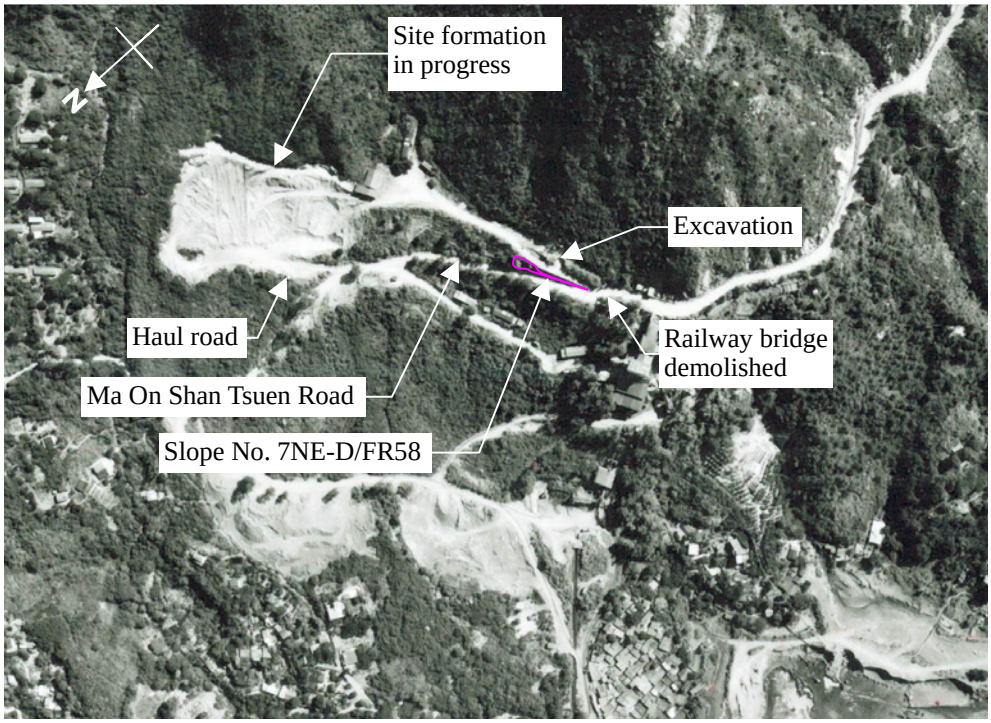

Plate A6 - Interpretation of 1977 Aerial Photograph No. 20102

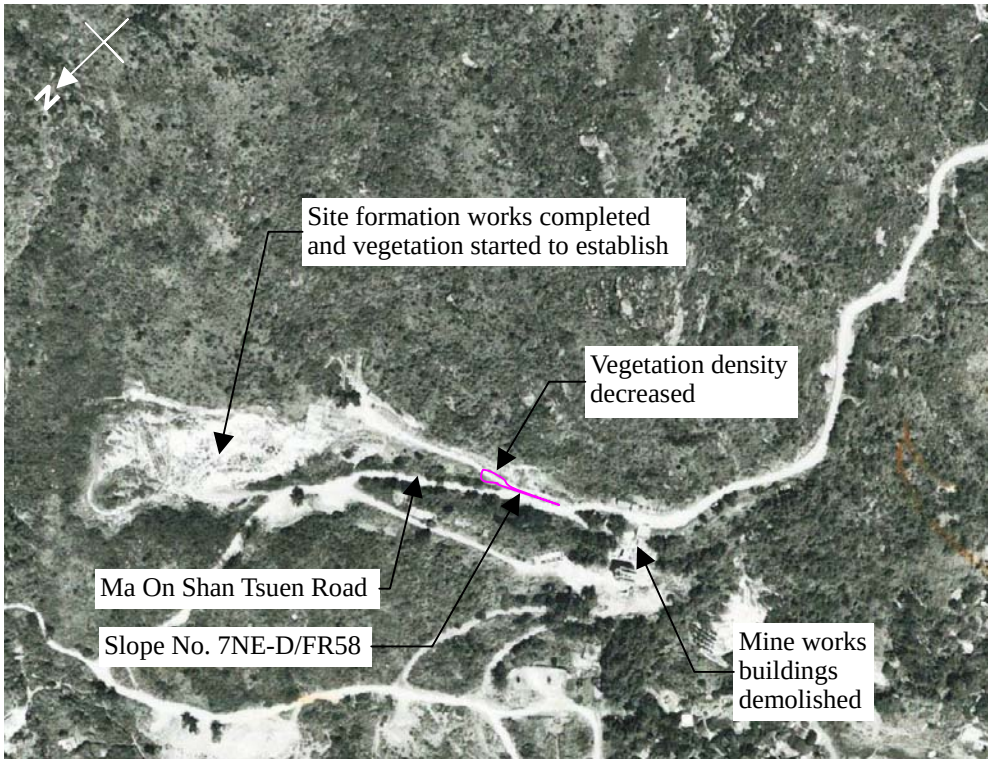

Plate A7 - Interpretation of 1981 Aerial Photograph No. 37619

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Plate A8 - Interpretation of 1982 Aerial Photograph No. 43229

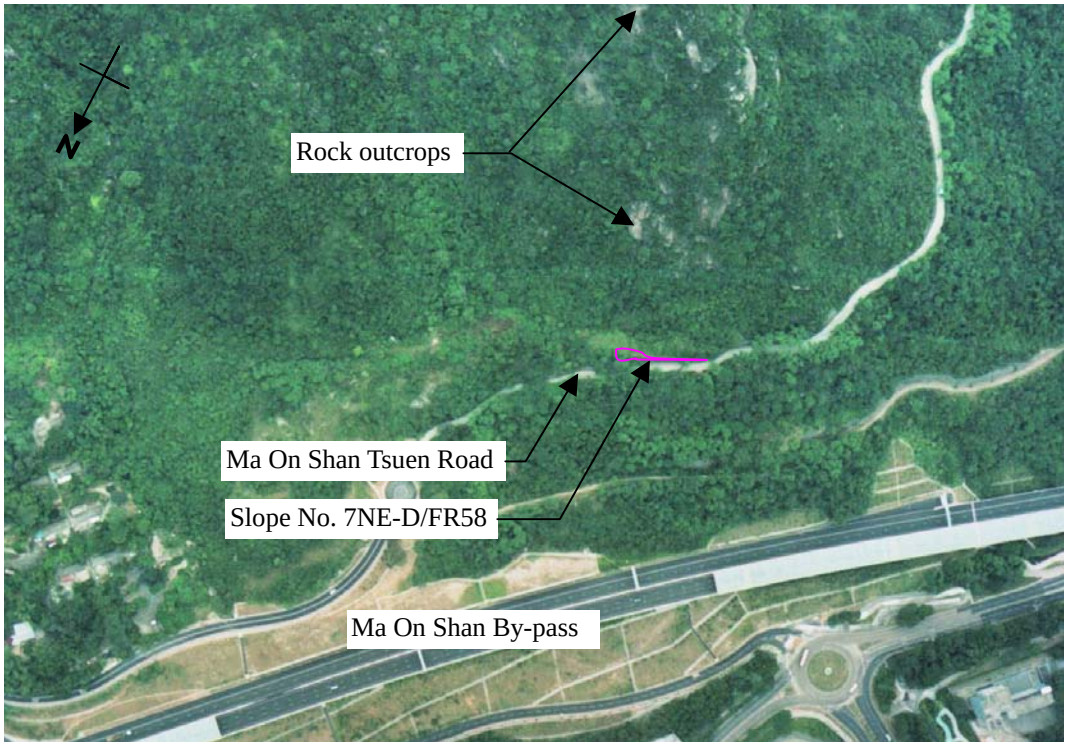

Plate A9 - Interpretation of 2005 Aerial Photograph No. CW67563

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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 maps and other publications which are free of charge) can be purchased either by:

writing to
Publications Sales Section,
Information Services Department,
Room 402, 4th Floor, Murray Building,
Garden Road, Central, Hong Kong.
Fax: (852) 2598 7482

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 submit the order online or by fax to (852) 2523 7195
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讀者可採用以下方法購買土力工程處刊物(地質圖及免費刊物除外):

書面訂購
香港中環花園道
美利大廈4樓402室
政府新聞處
刊物銷售組
傳真: (852) 2598 7482

或
- 致電政府新聞處刊物銷售小組訂購 (電話：(852) 2537 1910)
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1:100 000, 1:20 000 and 1:5 000 maps can be purchased from:

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Fax: (852) 2116 0774

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香港北角渣華道333號
北角政府合署23樓
地政總署測繪處
電話: 2231 3187
傳真: (852) 2116 0774

Requests for copies of Geological Survey Sheet Reports, publications and maps which are free of charge should be sent to:

For Geological Survey Sheet Reports and maps which are free of charge:
Chief Geotechnical Engineer/Planning,
(Attn: Hong Kong Geological Survey Section)
Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon, Hong Kong.
Tel: (852) 2762 5380
Fax: (852) 2714 0247
E-mail: jsewell@cedd.gov.hk

For other publications which are free of charge:
Chief Geotechnical Engineer/Standards and Testing,
Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon, Hong Kong.
Tel: (852) 2762 5346
Fax: (852) 2714 0275
E-mail: wmcheung@cedd.gov.hk

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香港九龍何文田公主道101號
土木工程拓展署大樓
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
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傳真: (852) 2714 0275
電子郵件: wmcheung@cedd.gov.hk

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

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GEOTECHNICAL MANUALS

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

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. 1/2000	Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls (2000), 146 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.

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