DETAILED STUDY OF THE 30 JUNE 2007 LANDSLIDE ON WALL NO. 11SE-C/R7 AND THE ADJOINING HILLSIDE AT REPULSE BAY ROAD

GEO REPORT No. 287

Fugro Scott Wilson Joint Venture

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 7/2009 produced in September 2009

First published, September 2013

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Table of Contents

Table of Contents

Table of Contents

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 in print. These include guidance documents and results of comprehensive reviews. They can also be downloaded from the above website.

The 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.

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

FOREWORD

This report presents the findings of a detailed study of a landslide (Incident No. 2007/07/0050), which occurred on 30 June 2007 at the southern portion of retaining wall No. 11SE-C/R7 and the adjoining hillside below Repulse Bay Road. The landslide involved a failure volume of about 600 m^3. Most of the debris was deposited on the hillside immediately below the registered retaining wall, whilst some was deposited on an ephemeral drainage line some 30 m below Repulse Bay Road. As a result of the landslide, a section of the northbound lane and its adjacent pedestrian footway of Repulse Bay Road were undermined, and the supply of freshwater to the nearby residents was temporarily suspended. No casualties or injuries were reported as a result of the incident.

The key objectives of the detailed study were to document the facts about the landslide, present relevant background information and establish the probable causes of the failure. Recommendations for follow-up actions are reported separately.

The report was prepared as part of the Landslide Investigation Consultancy for landslides occurring in Hong Kong Island and Outlying Islands in 2006 and 2007, for the Geotechnical Engineering Office, Civil Engineering and Development Department, under Agreement No. CE 49/2005 (GE). This is one of a series of reports produced during the consultancy by Fugro Scott Wilson Joint Venture.

Y C Koo
Project Director
Fugro Scott Wilson Joint Venture

Agreement No. CE 49/2005 (GE)
Study of Landslides Occurring in Hong Kong Island and Outlying Islands in 2006 and 2007

CONTENTS

Page No.

1. INTRODUCTION

Between 4:00 a.m. and 5:00 a.m. on 30 June 2007, a landslide (Incident No. 2007/07/0050) occurred at the southern portion of retaining wall No. 11SE-C/R7 and the adjoining hillside below Repulse Bay Road during rainfall (Figures 1 & 2, and Plate 1). The landslide involved a failure volume of about 600 m^3. Most of the landslide debris was deposited on the hillside immediately below the registered retaining wall (Plate 2), whilst some was deposited on an ephemeral drainage line some 30 m below Repulse Bay Road. As a result of the failure, a section of the northbound lane and its adjacent pedestrian footway of Repulse Bay Road were undermined, and the supply of freshwater to the nearby residents was temporarily suspended. No casualties or injuries were reported as a result of the incident.

Following the landslide, Fugro Scott Wilson Joint Venture (FSW) carried out a detailed study of the landslide for the Geotechnical Engineering Office (GEO), Civil Engineering and Development Department (CEDD), under Agreement No. CE 49/2005 (GE).

The key objectives of the detailed study were to document the facts about the landslide, present relevant background information and establish the probable causes of the failure. Recommendations for follow-up actions are reported separately.

This report presents the findings of the detailed study, which comprised the following key tasks:

(a) review of all known relevant documents relating to the development history of the site and the sequence of events leading to the failure, as well as relevant documents relating to incidents of watermains burst and mains burst-induced landslides that occurred along the section of Repulse Bay Road between Wong Nai Chung Gap Road and Island Road;

(b) detailed site inspections and field measurements at the landslide site;

(c) aerial photograph interpretation (API);

(d) analysis of rainfall records;

(e) CCTV survey of cross-road drain; and

(f) diagnosis of the mechanism of the failure and the probable causes.

2. THE SITE

2.1 Site Description

The location of the June 2007 landslide site is shown in Figure 1. Wall No. 11SE-C/R7 is a west-facing, sub-vertical pointed squared rubble retaining wall, located below an elevated pedestrian footway along the downhill (western) side of

Repulse Bay Road (Figures 2 & 3, and Plate 3). It is approximately 35 m long and up to 4 m high, with 80 mm diameter weepholes provided at 1.5 m to 2.2 m spacing.

Above wall No. 11SE-C/R7 is an elevated pedestrian footway, which is supported along its downhill side by 310 mm by 310 mm concrete piers at about 7.5 m spacing (Plate 3).

To the south of retaining wall No. 11SE-C/R7 is a 30° steep west- to southwest-facing hillside, the top 4 m of which is covered with sprayed concrete (Plate 4). Further to the southeast is retaining wall No. 11SE-C/R248 (Figure 2). Both the hillside and wall No. 11SE-C/R248 are located immediately below a bend of Repulse Bay Road (Figure 2). Immediately below the hillside is slope No. 11SE-C/C755, which is located about 10 m to the southwest of wall No. 11SE-C/R7 (Figure 2). Slope No. 11SE-C/C755 is a soil cut, about 17 m long, 6 m high and 50° steep, which is covered with vegetation with occasional bare surfaces (Plate 5).

The elevated section of the pedestrian footway, which runs along the crest of wall No. 11SE-C/R7, is a 2 m wide reinforced concrete structure supported on piers at the outer edge. The on-grade section of the pedestrian footway, which is to the south of wall No. 11SE-C/R7, is about 4 m wide (Figure 2 and Plate 6). Concrete upstands (between 35 mm and 100 mm high), on which handrailings are installed, are present on both sides of the pedestrian footway (Plate 6).

Located on the uphill (eastern) side of Repulse Bay Road and opposite the June 2007 landslide is slope No. 11SE-C/C168, on which two stepped channels are present. One of these is 450 mm wide and the other is 300 mm wide (Figure 4). The 450 mm wide stepped channel is connected to a 300 mm diameter cross-road drain via a roadside open catchpit No. RB5 located at the toe of the cut slope. The 300 mm diameter cross-road drain runs towards the June 2007 landslide site. Part of this drain and its downhill discharge provisions were destroyed during the June 2007 landslide.

The section of Repulse Bay Road at the June 2007 landslide is a single two-lane carriageway at an elevation of approximately 176 mPD. The section of the road located above wall No. 11SE-C/R7 runs in a N-S direction, whilst the section to the south of wall No. 11SE-C/R7 bends into a NW-SE direction (Figure 2 and Plate 6). Located on the road pavement above the June 2007 landslide site are two gully gratings (Figure 4 and Plate 7). The downhill discharge provisions of the two gully gratings were destroyed during the June 2007 landslide.

The road falls to the south longitudinally, and to both sides laterally. Surface water flowing on the section of the road immediately above the landslide site is collected by both the roadside catchpits on the uphill side of the road (Nos. RB4 and RB5) and the gully gratings on the downhill side (Figure 4).

There is evidence of reinstatement of the road pavement following trench excavation along this section of Repulse Bay Road (Plate 6).

2.2 Water-carrying Services and Utilities

Records from Water Supplies Department (WSD), Drainage Services Department (DSD) and Buildings Department (BD) indicate that water-carrying services, in addition to the cross-road drain (see Section 2.1), are present along the section of Repulse Bay Road above the June 2007 landslide site. Details of the water-carrying services are shown in Figure 4.

Based on WSD's records and site observations, two 6-inch diameter cast iron fresh watermains, which burst on 30 June 2007, were present on the front face (one above the other) of wall No. 11SE-C/R7, below the elevated pedestrian footway (Figure 3 and Plate 3). According to WSD, the operating pressures at this location should correspond to about 60 m and 27 m of water head respectively for the two watermains. Two newly installed 150 mm diameter polyethylene fresh watermains are present beneath the southbound lane of Repulse Bay Road (Figure 4), but these were not yet in operation at the time of the June 2007 landslide (see Section 3.2).

DSD's records indicate that a 150 mm diameter foul sewer runs within 1 m of the crest of wall No. 11SE-C/R7 (Figure 4).

According to BD's records, a 6-inch diameter cast iron sewer, discharging stormwater and foul sewage from No. 5 Repulse Bay Road, is connected to a DSD's sewer manhole on Repulse Bay Road, which was destroyed by the June 2007 landslide (Figure 4).

2.3 Regional Geology

According to the Hong Kong Geological Survey (HKGS) 1:20,000 geological map sheet for the area (GCO, 1986), the June 2007 landslide site is underlain by fine- to medium-grained granite of the Mesozoic formation (Figure 5). Debris flow deposits, comprising unsorted sand, gravel, cobbles and boulders in a matrix of clay and silt, are depicted as being immediately below the landslide site. A NW-SE trending fault is shown to be located at about 310 m to the northeast of the site, and a NE-SW trending photogeological lineament is shown to be located about 415 m to the southeast.

2.4 Maintenance Responsibility

According to the Slope Maintenance Responsibility Information System (SMRIS) of the Lands Department (Lands D), wall No. 11SE-C/R7 is under the maintenance responsibility of Highways Department (HyD).

3. SITE HISTORY AND PREVIOUS INSTABILITY

3.1 General

The history of site development has been determined from an interpretation of all the available aerial photographs, together with a review of relevant documentary information and site observations. Plans showing the development history and past instability in the vicinity

of the site are shown in Figures 6 and 7 respectively. Detailed observations from the Aerial Photograph Interpretation (API) are given in Appendix A.

3.2 Site History

The earliest available aerial photographs (taken in 1924) show that the present-day location of wall No. 11SE-C/R7 spanned across a concave shallow natural depression on a west-facing natural hillside, immediately below a bend along Repulse Bay Road (Figure 6). The shallow natural depression was bounded to the north and south by two near E-W orientated spurs respectively. Anthropogenic activities, as inferred by areas of high reflectivity on the aerial photographs, took place on these spurs before 1924. An E-W trending ephemeral drainage line runs down the shallow natural depression below the present-day location of wall No. 11SE-C/R7. The section of Repulse Bay Road above the June 2007 landslide site was formed before 1924 by cutting into the hillside above and placing fill materials below. The downhill extent of fill below Repulse Bay Road varied with location and was largely along the ephemeral drainage line. This fill was generally covered with vegetation by 1945.

According to aerial photographs, the development at No. 4 Repulse Bay Road commenced sometime between 1924 and 1945.

A platform, possibly associated with anthropogenic activity that commenced before 1924, was formed on the spur to the south of wall No. 11SE-C/R7 below the area of fill. Slope No. 11SE-C/C755, which is located above this platform, was probably formed in conjunction with the construction of the platform. Between 1945 and 1961, wall No. 11SEC/R7 was probably formed as part of the road improvement works, including the provision of an elevated pedestrian footway at its crest. Fill was placed below Repulse Bay Road to the south of wall No. 11SE-C/R7, probably in conjunction with road widening. The area of fill might also have extended northward into the shallow natural depression immediately below wall No. 11SE-C/R7.

Between 1961 and 1963, the development at No. 4 Repulse Bay Road was completed. A NE-SW orientated ephemeral drainage line running down the terrain below No. 4 Repulse Bay Road, constituting a tributary to the E-W orientated ephemeral drainage line below wall No. 11SE-C/R7, is visible on the 1963 aerial photographs. Between 1974 and 1975, vegetation was established on the fill slope, which was formed around 1961 in association with road widening.

In 1977, signs of disturbance, as represented by high reflectivity on the aerial photographs, were noted below the central portion of wall No. 11SE-C/R7. The nature and extent of disturbance below the wall could not be established due to the surrounding dense vegetation cover.

Between 1983 and 1984, some anthropogenic activity below wall No. 11SE-C/R7 took place, as inferred by a reduction in the density of the vegetation cover of the hillside. According to WSD, a 375 mm diameter asbestos cement raw-water above-ground conduit was laid in 1984 on the natural terrain, some 70 m to the west and below wall No. 11SE-C/R7.

Between 1984 and 1986, No. 4 Repulse Bay Road was redeveloped.

As evident on the 1992 aerial photographs, a narrow platform, covered with vegetation and probably representing an extension to the platform constructed before 1961, was formed within the area of reduced vegetation. A surface drainage channel was probably constructed below the northern portion of wall No. 11SE-C/R7, as represented by high reflectivity in that area on the 1992 aerial photographs. Vegetation clearance was also carried out over an area at the head of the ephemeral drainage line below No. 4 Repulse Bay Road. This area became largely covered with vegetation in 1993.

By 1993, the area of reduced vegetation density, initially observed in the 1984 aerial photographs, had expanded, which was probably related to the formation of a drainage channel that flowed from the southern part of wall No. 11SE-C/R7 and entered the ephemeral drainage line initially observed on the 1924 aerial photographs. As evident from the 1993 and 1994 aerial photographs, anthropogenic activity was apparent on and above the northern portion of the narrow platform initially observed in 1992. The anthropogenic activity probably included the placement of fill material below the northern end of wall No. 11SE-C/R7. The area was subsequently covered with vegetation in 1995.

According to WSD, between April 2006 and May 2007, two 150 mm diameter polyethylene fresh watermains, together with a leakage collection system (in accordance with WSD Standard Drawings No. WSD 1.20C), were laid on the southbound lane of the section of Repulse Bay Road between No. 3 and Nos. 19-27, with an invert level at a depth of about 1.2 m below ground. The works were carried out by Costain-China Harbour-Aarsleff Joint Venture for WSD, under the supervision of Maunsell Scott Wilson Joint Venture, as part of the 'Replacement and Rehabilitation of Water Mains Stage 1 Phase 1 - Mains on Hong Kong and Lantau Islands' project, Contract No. 3/WSD/02. According to WSD, the new watermains were not yet in operation at the time of the June 2007 landslide.

3.3 Previous Instability

On 19 May 1994, when no rainfall was recorded within the day, a washout incident (No. HK 94/5/1), with a failure volume of about 45 m^3, involving mostly fill and some residual soils, occurred on a slope below Repulse Bay Road (currently known as slope No. 11SE-C/FR154, see Figure 7), about 45 m to the southeast of wall No. 11SE-C/R7. Most of the landslide debris was deposited on the hillside immediately below and some of the debris was deposited on the floor of a streamcourse, about 50 m downstream. The pedestrian footway was collapsed in the incident (Plate 8). No casualties were reported as a result of the incident. According to the incident report prepared by the GEO, the failure was attributed to a "broken water main".

On 22 January 1997, with light rainfall of 5mm recorded within the day, a washout incident (No. HK 97/1/1), involving a failure volume of about 7 m^3, occurred on the hillside adjacent to the southern portion of wall No. 11SE-C/R7 (Figure 7 and Plate 9), which was located within the area of the 2007 landslide. The pedestrian footway of the northbound lane of Repulse Bay Road was undermined by the 1997 incident. The incident also caused damage to a "375 mm" diameter cross-road drain (which is the 300 mm diameter cross-road drain now connected to roadside catchpit No. RB5, see Figure 4 and Plate 9). No casualties

were reported as a result of the washout. According to a memorandum (file ref. GCI 2/E2/1997(1)) dated 28 May 1998 from the Island Division to Landslide Investigation Division (renamed LPM Division 1 in July 2004) of the GEO, "the failure was triggered by the rupture of the WSD's 150 mm diameter water main hanging below the existing footbridge and buried at the crest of the fill slope [located to the south of wall No. 11SE-C/R7]". Most of the damages were due to local erosion of the slope at shallow depths and there were no signs of any slippage of soil mass based on site observations at that time. No field evidence of past instability at or adjoining the failure location of the 1997 incident was observed by the Island Division during the post-failure inspection.

Urgent repair works were recommended by the GEO to the HyD in January 1997. These comprised the removal of loose materials, replacement of the damaged section of the cross-road drain with the provision of 150 mm thick concrete surround and connecting the new drain "to the existing surface drain", construction of a 2 m high by 6 m long no-fines concrete buttress to support the failed section of the slope and re-construction of the 450 mm wide drainage channel at the toe of the slope, trimming of local over-steepened area, filling up of the local depressions and the failure scar with no-fines concrete and provision of sprayed concrete cover (with weepholes) to the failed area. According to HyD, the recommended slope remedial works were completed by early February 1997.

According to WSD, they do not have any records indicating that the burst watermain in the 1997 washout incident was replaced after the landslide.

The Natural Terrain Landslide Inventory (NTLI) (King, 1999), the Enhanced Natural Terrain Landslide Inventory (ENTLI) (Maunsell Fugro Scott Wilson, 2005) and the Large Landslide Study (Scott Wilson, 1999) indicate no records of landslides that occurred on the natural hillsides in the vicinity of the June 2007 landslide site. According to the API, a landslide with a failure volume of about 90 m^3 occurred sometime between October 2005 and May 2006 on the hillside along the western boundary of the platform located on the spur to the south of wall No. 11SE-C/R7 (Figures 2 & 7, and Plate 10). The failure left a scar about 10 m wide by 6 m long by 3 m deep on the hillside. Further details regarding observations made on this landslide are given in Section 6.3.

Based on the records in GEO, there were seven washout incidents (Nos. HK90/7/1, HK92/10/3, HK93/6/3, HK94/5/1, HK95/8/20, HK97/1/1 and HK2000/08/003) between 1990 and 2000 on the downhill slopes along the section of Repulse Bay Road between Wong Nai Chung Gap Road and Island Road (Figure 8). These incidents were induced by watermain burst.

4. PREVIOUS ASSESSMENT AND SLOPE WORKS

4.1 B&P Field Sheet

In December 1977, Binnie & Partners (B&P) inspected wall No. 11SE-C/R7 as registered in the 1977/78 Catalogue of Slopes, under the project entitled "Phase I Re-appraisal of Cut and Natural Slopes and Retaining Wall". At the time, the boundary of wall No. 11SE-C/R7 encompassed both the present-day walls Nos. 11SE-C/R7 and 11SE-C/R248 (see Figure 2). B&P considered the wall to be of "low" risk-to-life in the event of failure (i.e. of consequence-to-life Category 2). No signs of seepage or distress were apparent during the

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

inspection by B&P. The feature registration field sheet recorded "Iron pipes on front face" and noted the possibility of "a slip scar covered by chunam at top".

4.2 Stage 1 Study

In May 1994, the Design Division (renamed LPM Division 2 in July 2004) of the GEO completed a Stage 1 Study for wall No. 11SE-C/R7 (see Section 4.1 and Figure 2). In the report, a cross-section drawn through the present-day wall No. 11SE-C/R7 indicated that the feature was a 5 m high "reinforced concrete wall", with "pipes hanged on wall", resting on a 35° steep natural slope. No signs of distress of the slope were noted and no further action was recommended in the report.

4.3 SIFT and SIRST Studies

In 1992, the GEO initiated the "Systematic Inspection of Features in the Territory" (SIFT) project. The project aimed to search systematically for slopes not included in the 1977/78 Slope Catalogue and to update information on previously registered features by studying aerial photographs together with limited site inspections. In May 1996, the SIFT Study of wall No. 11SE-C/R7 (see Section 4.1 and Figure 2) was carried out, and the SIFT consultant recognised the feature as being of "2 units" comprising the present-day walls Nos. 11SE-C/R7 and 11SE-C/R248 respectively. In April 1998, the extent of wall No. 11SE-C/R7 was revised to the present-day boundary in the New Catalogue of Slopes, as shown in the Slope Information System of the GEO.

The present-day wall No. 11SE-C/R7 was designated as SIFT Class 'B1', i.e. a fill feature that had "been formed or substantially modified before 30.6.78". In the SIFT report, the thickness of the fill was estimated to be 3 m and the extent of the fill body at the crest was shown to stop short of the centre-line of Repulse Bay Road. The SIFT report also noted that the feature was formed before 1963, and that the consequence of failure of the feature would be the undermining of Repulse Bay Road.

In July 1994, the GEO commenced a project entitled "Systematic Identification and Registration of Slopes in the Territory" (SIRST) to update the 1977/78 Slope Catalogue. However, the record of wall No. 11SE-C/R7 could not be located in the GEO's files.

4.4 Slope Maintenance Inspections

4.4.1 Engineer Inspections

In March 1995, wall No. 11SE-C/R7 (see Section 4.1 and Figure 2), was inspected by HyD's consultants, a Joint Venture of Fugro (Hong Kong) Limited, Mouchel Asia Limited and Rendel Palmer Tritton (Asia) Limited (FMR), as part of the "Roadside Slope Inventory and Inspections" project under Agreement No. CE 29/94. In the inspection record, the subject retaining wall was described as a "concrete bored pile/caisson wall". The inspection record noted minor, probably shrinkage, cracks on the wall and bulging "in centre" of the wall, and recommended unblocking of weepholes on the wall. The inspection record considered that testing of utility services (viz. WSD's fresh watermains) was needed. The

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

consequence-to-life category was rated as "low" and the overall state of maintenance of the subject wall was classified as "Good". A slope/retaining wall record prepared by FMR, together with the inspection record, recommended "Engineer Inspections". No other recommendations were made in the slope/retaining wall record.

In September 1999, Maunsell Geotechnical Services Limited (MGSL), the consultant to HyD, carried out an Engineer Inspection (EI) for wall No. 11SE-C/R7 (Plate 11). The EI report considered that the consequence-to-life category of the wall was "low" and the overall state of maintenance was "Fair". The EI report did not identify any signs of distress on the wall or signs of leakage from the water-carrying services, and recommended Routine Maintenance Works (RMW) including unblocking weepholes, removing unplanned vegetation from the wall surface and re-pointing the deteriorated cement-mortared joints on the masonry face of the wall. "Low Priority Stability Assessment" was also recommended in the EI report. The record photograph (Plate 11) shows that the 6-inch watermains mounted on the surface of the retaining wall were probably rusted.

In March 2004, a further EI for wall No. 11SE-C/R7 was carried out for HyD by MGSL (Plate 12). The EI report considered the overall state of maintenance to be satisfactory. The EI did not identify any signs of seepage on the wall or signs of leakage from the watermains. Signs of deterioration in the form of "mortar missing or minor dislocation of isolated blocks" were recorded in the EI report. RMW recommended in the EI report included removal of undesirable vegetation from the wall surface and re-pointing of joints with missing cement-mortar on the masonry face of the wall. The March 2004 EI report also recommended a Stability Assessment of the wall to be carried out. According to HyD, "there is no such [Stability Assessment] record found" in their files subsequent to the EI. There are records indicating that minor slopes works were completed in November 2004, including removal of vegetation causing severe cracking of slope surface cover and drainage channels.

4.4.2 Routine Maintenance Inspections

Altogether nine Routine Maintenance Inspections (RMIs) had been carried out annually (with the exception of 1998) by HyD (1997, 1999 to 2001) and by their consultants (2002 to 2006) prior to the June 2007 landslide. RMW recommended by the RMIs generally included repair of pointing, unblocking of weepholes and removal of surface debris and vegetation that was causing "severe cracking of surface cover and drainage channels". Completion records of the recommended RMW were found in HyD's file records, except for those arising from the 1997 and 2005 RMIs. Record photographs taken during the RMIs in 1997 (Plate 13), 2002 (Plate 14) and 2003 (Plate 15) show that the 6-inch watermains mounted on the surface of the retaining wall were in severe rusty conditions.

4.5 Inspection and Leakage Detection of Water-carrying Services

4.5.1 Water Supplies Department

According to WSD, ten leakage detection tests were carried out between July 2003 and November 2004 on the watermains along the section of Repulse Bay Road between Wong Nai Chung Gap Road and Island Road (Figure 8). The tests were carried out by Dragages

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

et-Travaux Publics (HK) Limited, under Contract No. 20/WSD/02 entitled "Leakage Detection of Buried Water Mains Affecting Slopes - Second Five-year Cycle". One of the tests was carried out in the vicinity of the June 2007 landslide site and no leakage was detected. Of the ten leakage detection tests, only the one conducted on 13 February 2004 on a 50 mm diameter gate valve, which is about 1.8 km to the south of the June 2007 landslide site, detected leakage (see Figure 8).

4.5.2 Drainage Services Department

In response to the enquiry of the maintenance inspection records of the 150 mm diameter sewer that runs along the downhill edge of Repulse Bay Road above wall No. 11SE-C/R7, DSD advised that "the damaged [150 mm diameter] sewer had been lined. The concerned sewer at Repulse Bay Road had undertaken a CCTV survey within the past five years and no defect had been reported".

4.5.3 Highways Department

According to HyD's records, a CCTV survey of the 300 mm diameter cross-road drain, which runs towards the June 2007 landslide site (see Figure 4), was carried out on 11 November 2004 by Chevalier Pipe Technologies Limited for HyD. The survey revealed signs of distress, including cracks, fractures, breaks and a large joint displacement in the cross-road drain. Repair works to the cross-road drain, in the form of insitu internal lining, were subsequently carried out in November 2004.

5. THE 30 JUNE 2007 LANDSLIDE

According to a security guard at No. 4 Repulse Bay Road, a loud noise was heard sometime between 4:00 a.m. and 5.00 a.m. on 30 June 2007. He did not realise that a landslide had occurred until sometime between 6:00 a.m. and 7:00 a.m. when sunlight appeared. The security guard noticed the landslide site from his work place (about 40 m away) but could not ascertain the extent of the failure. The landslide was referred to the GEO by the Hong Kong Police Force (HKPF) at 8:45 a.m. on the same day.

The landslide occurred on the southern portion (about 5 m in length) of wall No.11SE-C/R7 and the adjoining hillside immediately to the south and below the downhill side of Repulse Bay Road. A small portion (about 10 m^2) of slope No. 11SE-C/C755, which was located about 10 m to the south of wall No. 11SE-C/R7, also failed in the incident.

The two 6-inch diameter watermains mounted on the face of wall No. 11SE-C/R7 were severed. Streams of high pressurised water were still jetting outward and sub-horizontally from the watermains at 9:17 a.m. on 30 June 2007 (i.e. about 5 hours after the failure, assuming that the failure occurred when the loud noise was heard by the security guard at No. 4 Repulse Bay Road), as recorded by a photograph taken by a resident site staff of a nearby GEO's Landslip Preventive Measures (LPM) site (Plate 16). According to WSD, they were notified of the watermains burst incident at 8:51 a.m. on 30 June 2007 by HKPF via telephone. After a burst watermain was substantially isolated by WSD, bursting of the other

watermain on the wall face was noted by WSD at 9:35 a.m. Both watermains were completely isolated at 12:30 p.m. on the same day.

In the landslide incident, the 150 mm diameter DSD sewer drain, the 300 mm diameter HyD cross-road drain and two gully gratings on Repulse Bay Road were destroyed.

Following the landslide incident, the undermined portion of the northbound carriageway, the unsupported section of the elevated pedestrian walkway and a DSD sewer manhole were demolished by HyD to facilitate the urgent repair works. Sprayed concrete was applied to the failure scar by HyD on 1 and 2 July 2007 respectively and rockfill was placed in the following few days to support the failure scar as part of the urgent repair works recommended by GEO.

The June 2007 landslide occurred at approximately the same location as the washout incident (No. HK 97/1/1) in 1997, and at a location about 45 m to the northwest of another previous washout incident (No. HK 94/5/1) in 1994. Both of these previous incidents were considered to have been induced by bursting of watermains (see Section 3.3 and Figure 7).

6. FIELD OBSERVATIONS FOLLOWING THE LANDSLIDE

6.1 Post-landslide Observations

FSW first inspected the June 2007 landslide site at around 1:00 p.m. on 30 June 2007. At that time, the burst watermains had been isolated by WSD and the section of the northbound lane of Repulse Bay Road was closed. Urgent landslide repair works had not yet commenced.

The landslide involved a failure volume of about 600 m^3. The failure scar was about 15 m wide by 30 m long by 4 m deep and encroached about 1 m onto the road pavement, undermining the downhill edge of the northbound lane of the road and causing some of the concrete piers supporting the elevated pedestrian footway to detach from the footway. The main scarp was about 3 m high and almost sub-vertical (Plate 4).

The landslide debris comprised mainly soil, a 5.8 m by 1.6 m by 1.8 m no-fines concrete block (covered with sprayed concrete), a DSD's sewer manhole, masonry blocks, concrete fragments, ruptured watermains, broken sewer drains, fragmented lining to the 300 mm diameter cross-road drain, together with fallen trees and vegetation.

Most of the landslide debris was deposited on the hillside immediately below the failure scar (Plates 4 & 5), and some travelled further downhill to reach a 1.2 m wide by 0.6 m deep ephemeral drainage line, along which the debris travelled another 10 m downstream before coming to rest (Figure 2 and Plate 2). The travel angle of the debris from the source to the ephemeral drainage line was about 34° (Wong & Ho, 1996). The debris deposited on the ephemeral drainage line was about 5 m wide and up to 2.5 m high and comprised mainly orange, light brown, mottled yellow sandy, gravely, CLAY/SILT with cobble- and boulder-sized fragments of rock, sprayed-concrete cover and reinforced concrete (Plate 2).

Cracking (up to 20 mm wide) and settlement (about 10 mm to 20 mm) were observed at the road pavement of the section of Repulse Bay Road above wall No. 11SE-C/R7. In

particular, a persistent crack of up to about 20 mm wide and some signs of settlement were observed along the uphill edge of the reinstated pavement to a utility trench located on the northbound lane of the road (Plate 7).

During the inspections by FSW on 30 June and 3 July 2007, the roadside open catchpit No. RB5 at the upstream end of the 300 mm diameter cross-road drain, which was aligned towards the landslide site, was temporarily plugged with sand bags by HyD to divert surface water away from the cross-road drain. No water flow was observed from the stepped channel above the catchpit.

The remaining unfailed portion of wall No. 11SE-C/R7 was about 25 m long and 4 m high, comprising squared rubble facing with 80 mm diameter weepholes provided at about 1.5 m spacing. Probing of the weepholes as part of the present study indicates that the unfailed portion of wall No. 11SE-C/R7 was about 1.48 m thick on average at 0.5 m above ground (or 3.3 m below crest), gradually reducing to an average thickness of 0.98 m at 1.8 m above ground (i.e. 2 m below crest), corresponding to a slenderness ratio of the wall being about 1.84.

6.2 Geology of the Landslide Site

The geological map and past drillhole information suggest that the site is underlain by fine- to medium-grained granite. Inspection of the site indicated that much of the steeper part of the hillside (greater than 35°) below wall No. 11SE-C/R7 was generally composed of residual soil, comprising orange, light brown mottled yellow gravely, sandy CLAY/SILT. The less steep part of the hillside (less than 35°) below the site and within the ephemeral drainage line generally comprised colluvial deposits, including numerous, fine- to medium-grained, granite boulders.

6.3 Other Observations in the Vicinity

During the post-failure inspections of the 30 June 2007 incident, a landslide, with a failure volume of about 90 m^3, was identified by FSW on the hillside at about 25 m to the southwest of the June 2007 landslide. This landslide occurred along the western boundary of a platform which is located on the spur to the south of wall No. 11SE-C/R7 (Figures 2 & 7). The failure scar measured about 10 m wide by 6 m long by 3 m deep on the hillside (Plate 10). This landslide was not reported to the GEO previously. Based on the API, the landslide probably occurred between October 2005 and May 2006 (see Section 3.3). Most of the debris was deposited on the hillside immediately below the scar, with a small proportion of the debris having travelled up to about 22 m further down slope.

There appears to be no direct relevance of the June 2007 landslide (involving a retaining wall supporting Repulse Bay Road) with this landslide since the two landslide locations were some 25 m apart.

7. POST-FAILURE CCTV SURVEY

On 5 September 2007, a CCTV survey of the 300 mm diameter cross-road drain was conducted for the present landslide study by Rodney Engineering Company Limited (REC) under the supervision of FSW. This cross-road drain is connected to the roadside catchpit No. RB5 and aligned towards the June 2007 landslide site (Figure 4).

The cross-road drain was noted to have been partially blocked by soil and vegetation debris at a location about 3.6 m from the upstream end of the drain (i.e. as measured from catchpit No. RB5) (Figure 4 and Plate 17a). This section of the drain was previously lined. A small flow (depth of water about 10 mm) was observed within the drain during the CCTV survey and water accumulated to a level of about 75 mm above the invert level immediately upstream of the collapsed location.

At the downstream side of the partially blocked location (i.e. between the partially blocked location and the cross-road drain outlet), remnants of internal lining to the drain and a fragment of ceramic pipe in a matrix of sand and gravels were present (Plate 17b). This section was not lined. No other defects of the cross-road drain were identified by the CCTV survey.

8. MOUNTING DETAILS OF 6-INCH WATERMAINS

The desk study records were examined to identify the mounting details of the two 6-inch fresh watermains installed on the front face of retaining wall No. 11SE-C/R7 prior to the 30 June 2007 failure.

From post-landslide observation by FSW and record photographs of some EI and RMI reports (Plates 13, 14 & 15), the majority of the watermains were supported by brackets mounted on the front face of retaining wall No. 11SE-C/R7. However, towards the southern end, the lower watermains was apparently supported by brackets mounted to the bottom side of the elevated pedestrian footpath and the upper watermains was apparently buried in soil, as shown by a photograph taken on landslide incident No.HK97/1/1 (Plate 18). A schematic plan showing the mounting details of these brackets is shown on Figure 9.

9. ANALYSIS OF RAINFALL RECORDS

Rainfall data were obtained from GEO automatic raingauge No. H21, which is the nearest raingauge to the site and located at Repulse Bay, located approximately 1.3 km to the south of the 2007 landslide site (Figure 1). The raingauge records and transmits rainfall data at 5-minute intervals to the Hong Kong Observatory (HKO) and the GEO.

According to the information provided by the security guard at No. 4 Repulse Bay Road, the 30 June 2007 landslide probably occurred sometime between 4:00 a.m. and 5:00 a.m (see Section 5). For the purpose of the rainfall analysis, the landslide was assumed to have occurred at 5:00 a.m. on 30 June 2007.

The daily rainfall recorded by raingauge No. H21 over the month preceding and

three days following the June 2007 landslide incident, together with the hourly rainfall for the period between 28 June and 30 June 2007, are presented in Figure 10. The maximum 24-hour and 12-hour rolling rainfall before the landslide was 90.5 mm and 70.5 mm respectively.

Table 1 presents the estimated return periods for the maximum rolling rainfall for various durations recorded by raingauge No. H21 with reference to the historical rainfall data at the HKO in Tsim Sha Tsui (Lam & Leung, 1994), and the local rainfall data of automatic raingauge No. H21 (Evans & Yu, 2001). The results show that the estimated periods for all rainfall durations preceding the landslide were less than 2 years.

The maximum rolling rainfall for the rainstorm on 30 June 2007 has been compared with the past major rainstorms between 1984 and 2006 as recorded at raingauge No. H21, which came into operation in March 1983 (Figure 11). The maximum rolling rainfall for the rainstorm on 30 June 2007 was less severe than that of the previous significant rainstorms.

10. DIAGNOSIS OF THE PROBABLE CAUSES OF THE LANDSLIDE

10.1 Site Setting

The landslide site is located below a road bend of Repulse Bay Road amid a natural drainage path. Various water-carrying utilities were present at the landslide site, including two 6-inch diameter cast iron fresh watermains mounted on the face of the subject wall No. 11SE-C/R7. As inferred from the records in the WSD's utility plan, these two 6-inch diameter watermains are probably of old construction since their sizes were recorded in imperial unit (see Figure 4). The surface of these two old watermains appeared to have severely rusted, as shown in the various photographs taken during the past EI (1999) and RMIs (1997, 2002 and 2003). Two new watermains had recently been laid beneath the southbound lane of Repulse Bay Road to replace the above two old watermains, but these were not yet in commission at the time of the June 2007 landslide (see Section 2.2). A 150 mm diameter foul sewer was also present under Repulse Bay Road at the crest of wall No. 11SE-C/R7.

The landslide occurred approximately at the same location of the previous washout incident (No. HK 97/1/1) in 1997, which was caused by the bursting of watermains (see Section 3.3).

10.2 Probable Causes and Mechanism of the Landslide

The June 2007 landslide was a major failure (volume of 600 m^3) involving a registered old retaining wall and the hillside below the wall. Given the extensive nature of the failure (15 m wide by 30 m long), it is probable that the landslide was triggered by the ingress of large quantity of water into the hillside and/or behind the retaining wall, resulting in the failure.

The rainfall preceding the landslide was light (return period of less than 2 years for all rainfall durations up to 31 days). Given this small amount of rainfall and the limited catchment above the landslide site, it is very unlikely that the rainfall alone would have been

sufficient to trigger the failure.

There is strong evidence to suggest that the landslide was probably triggered by the bursting of either one or both of the old 6-inch diameter watermains mounted on wall No. 11SE-C/R7. There has been a history of landslides in 1994 and 1997 due to rupture of the watermains at or in the vicinity of the landslide site. According to WSD, there is no record indicating that the section of the ruptured watermains was replaced after the January 1997 incident which occurred within the area of the 2007 landslide. Highly pressurised water jets were seen to be spraying sub-horizontally in a wide-spreading manner onto the failed hillside at 9:17 a.m. on 30 June 2007, about 5 hours after the failure. The large quantity of pressurised water ejected from either one or both of the watermains could have played a key role in triggering the extensive failure. This postulation is considered plausible as the old watermains were in a dilapidated condition (e.g. with severe rusting) prior to the June 2007 landslide.

The other possible sources of water were from the leakage, if any, of the 300 mm diameter cross-road drain, which runs directly towards the 2007 landslide site collecting surface water from Repulse Bay Road and the catchment area above, and the two gully gratings located at Repulse Bay Road immediately above the landslide site. However, given the small amount of rainfall recorded before the June 2007 incident and relatively small catchment areas in association with these two water-carrying utilities, any water leakage from the cross-road drain and the gully gratings (even if it did occur) would unlikely have been sufficient to trigger a landslide as extensive as the June 2007 incident.

Significant leakage from the nearby 150 mm diameter foul sewer running along the downhill edge of Repulse Bay Road above the failure site is also considered unlikely. The foul sewer concerned had been lined and no defects were reported by a CCTV survey undertaken within 5 years prior to the June 2007 landslide incident. Also, the June 2007 landslide incident occurred in the early hours between 4:00 a.m. and 5:00 a.m. when the foulwater flow would normally be small since most people were asleep at the time. Also, there was no evidence indicating the presence of foulwater in the landslide debris.

11. CONCLUSIONS

The light rainfall prior to the June 2007 incident would indicate that the landslide was probably not rain-induced. The landslide was probably caused by the bursting of either one or both of the old 6-inch diameter watermains mounted on the front face of wall No. 11SE-C/R7.

There is a history of landslides caused by rupture of these two old watermains at or in the vicinity of the 2007 landslide site (see Section 3.3). The old watermains were in a dilapidated condition with severe rusting. At the time of the June 2007 landslide, two new watermains had been installed by WSD to replace the two subject old watermains but the new watermains were not yet in operation when the landslide occurred.

Previous leakage detection test did not reveal any major leakage from the subject watermains. Sudden bursting of the old dilapidated pressurized watermains is likely to occur given progressive deterioration.

12. REFERENCES

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LIST OF TABLES

Table 1 - Maximum Rolling Rainfall at GEO Raingauge No. H21 for Selected Durations Preceding the Landslide on 30 June 2007 and the Estimated Return Periods

Duration	Maximum Rolling Rainfall (mm)	End of Period (Hours)	Estimated Return Period (Years) (See Note 2)	
			By Lam & Leung (1994)	By Evans & Yu (2001)
5 Minutes	7	5:25 a.m. on 29 June 2007	< 2	< 2
15 Minutes	17.5	5:25 a.m. on 29 June 2007	< 2	< 2
1 Hour	30.5	5:35 a.m. on 29 June 2007	< 2	< 2
2 Hours	49	5:30 a.m. on 29 June 2007	< 2	< 2
4 Hours	52.5	5:40 a.m. on 29 June 2007	< 2	< 2
12 Hours	70.5	1:10 p.m. on 29 June 2007	< 2	< 2
24 Hours	90.5	5:40 a.m. on 29 June 2007	< 2	< 2
48 Hours	124	4:50 a.m. on 30 June 2007	< 2	< 2
4 Days	161.5	1:55 a.m. on 30 June 2007	< 2	< 2
7 Days	167.5	4:50 a.m. on 30 June 2007	< 2	< 2
15 Days	171.5	4:50 a.m. on 30 June 2007	< 2	< 2
31 Days	418.5	4:50 a.m. on 30 June 2007	< 2	< 2

Notes:
(1) Maximum rolling rainfall was calculated from 5-minute rainfall data.
(2) Return periods were derived from Table 3 of Lam & Leung (1994) and Evans & Yu (2001).
(3) Based on information provided by a security guard at No. 4 Repulse Bay Road, the 30 June 2007 landslide occurred between 4:00 a.m. and 5:00 a.m. on 30 June 2007. The landslide is assumed to have occurred at 5:00 a.m. on 30 June 2007 for the purpose of rainfall analysis.
(4) The nearest GEO raingauge to the landslide site is raingauge No. H21, which is situated at about 1.3 km to the south of the landslide site.

LIST OF FIGURES

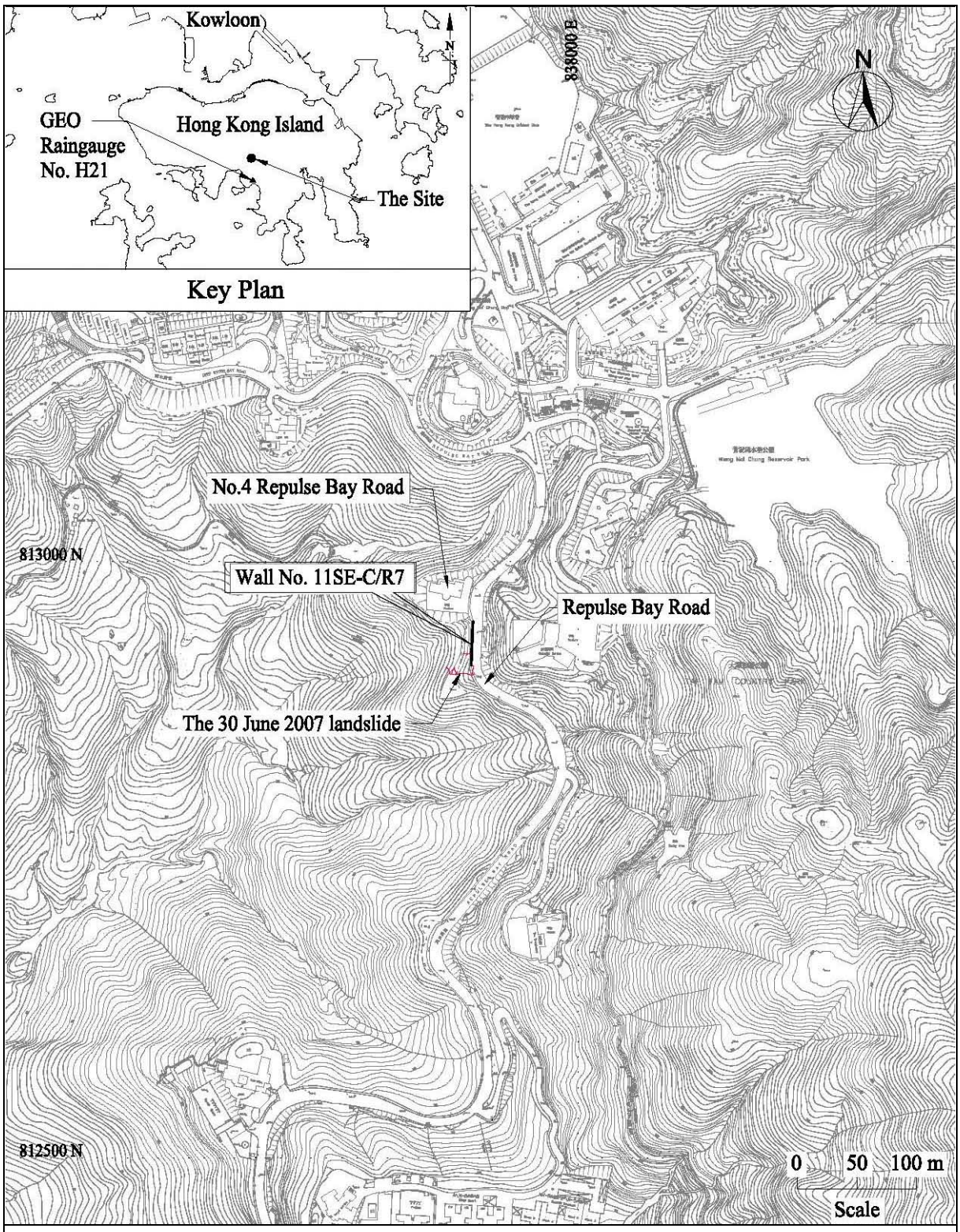
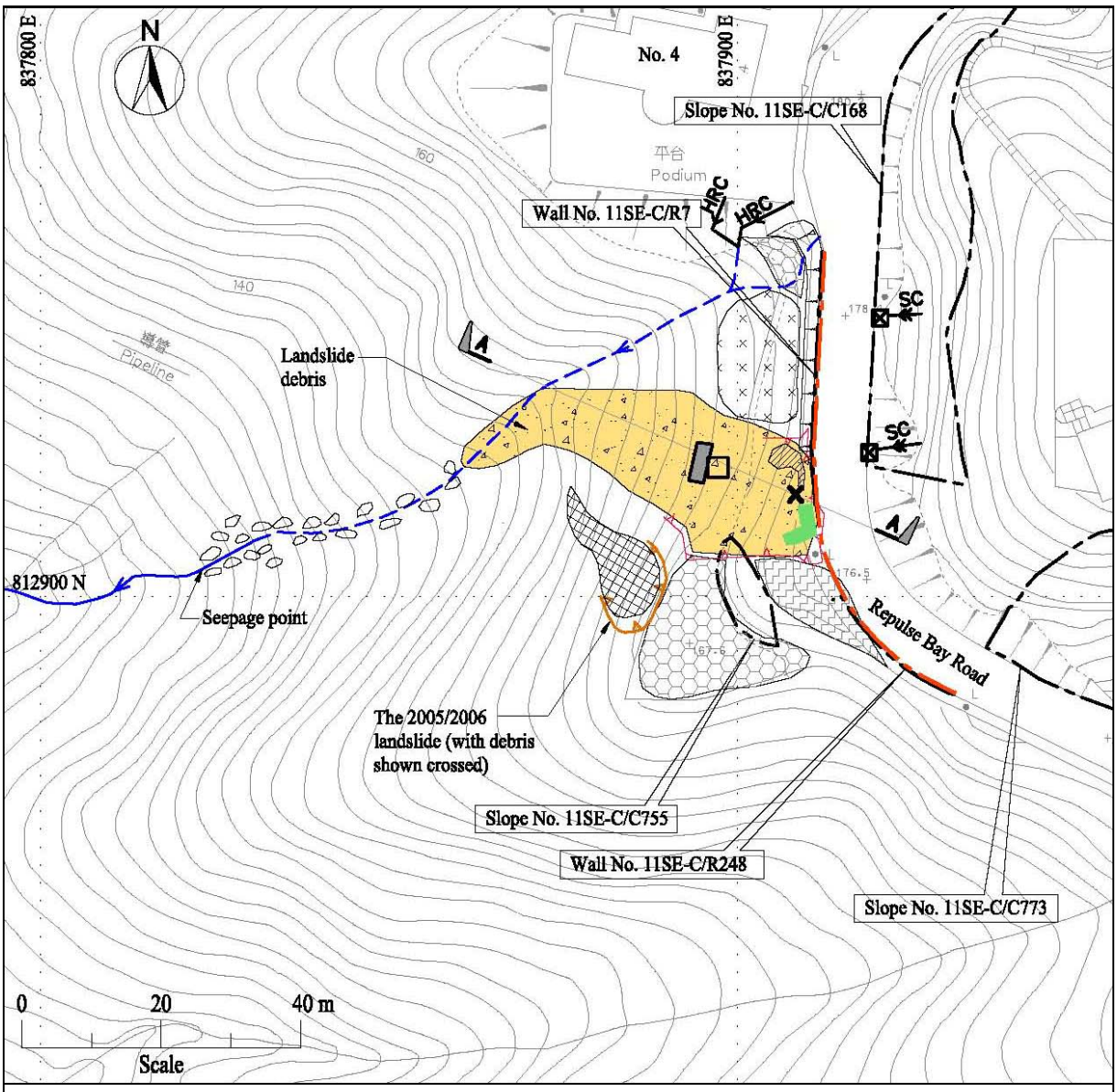


Figure 1 - Site Location Plan

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

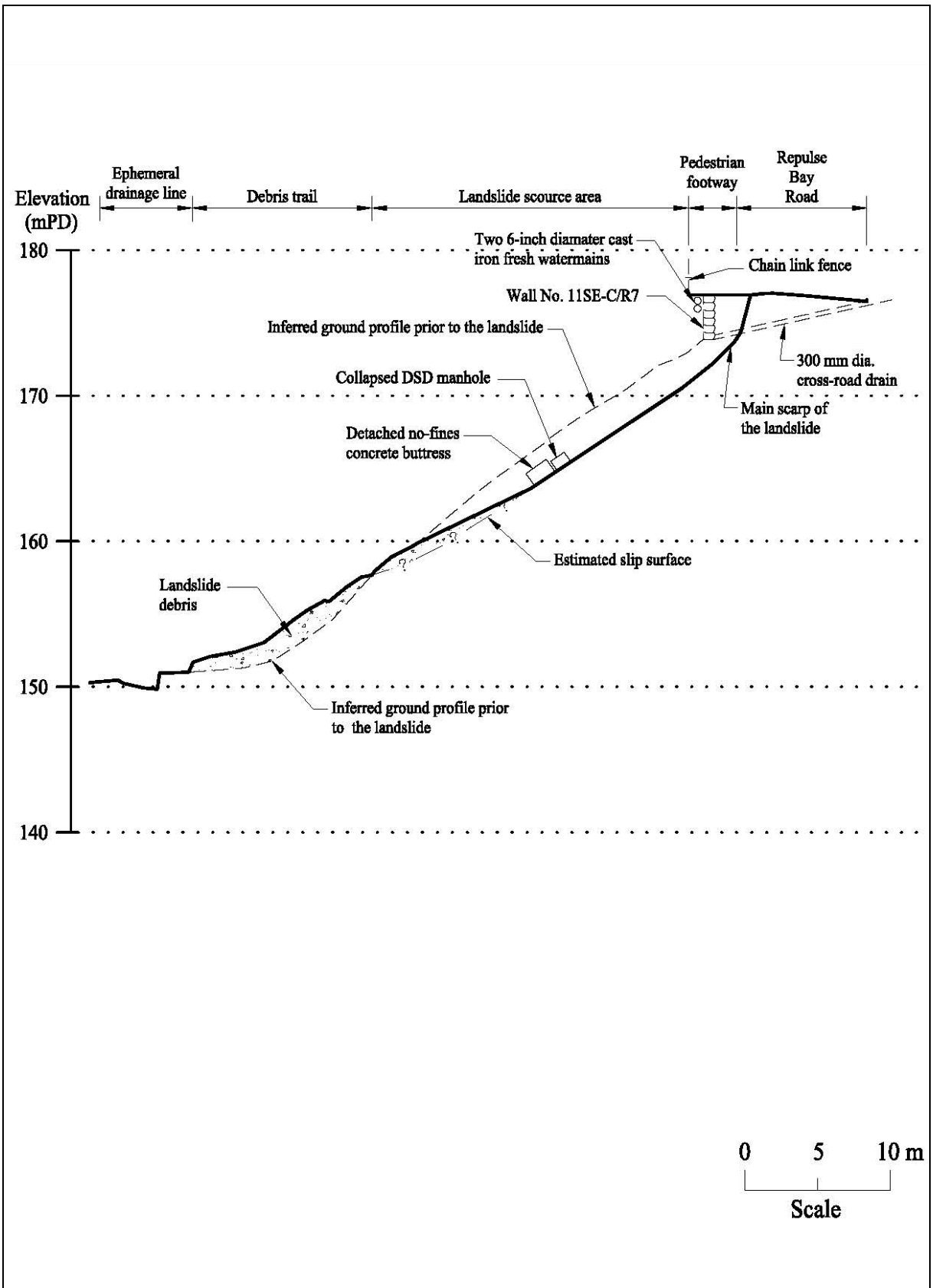


Legend:

- The 30 June 2007 landslide
- Slope reference number
- Feature boundary
- Boundary of wall No. 11SE-C/R7 prior to April 1998
- Section A - A
- The January 1997 landslide
- Eroded area filled with no-fines concrete and covered with sprayed concrete as part of the urgent repair works to the January 1997 washout incident
- Area covered by sprayed concrete
- Catchpit
- Ephemeral drainage line
- Wet channel
- Stepped channel
- Half-round channel
- No-fines concrete buttress (6 m long x 2 m wide) constructed as part of the urgent repair works to the January 1997 washout incident
- Vegetated platform
- 2007 landslide debris
- Granite boulder
- Fill body
- Collapsed DSD manhole
- Detached no-fines concrete buttress
- Vegetated area with fly-tipped material

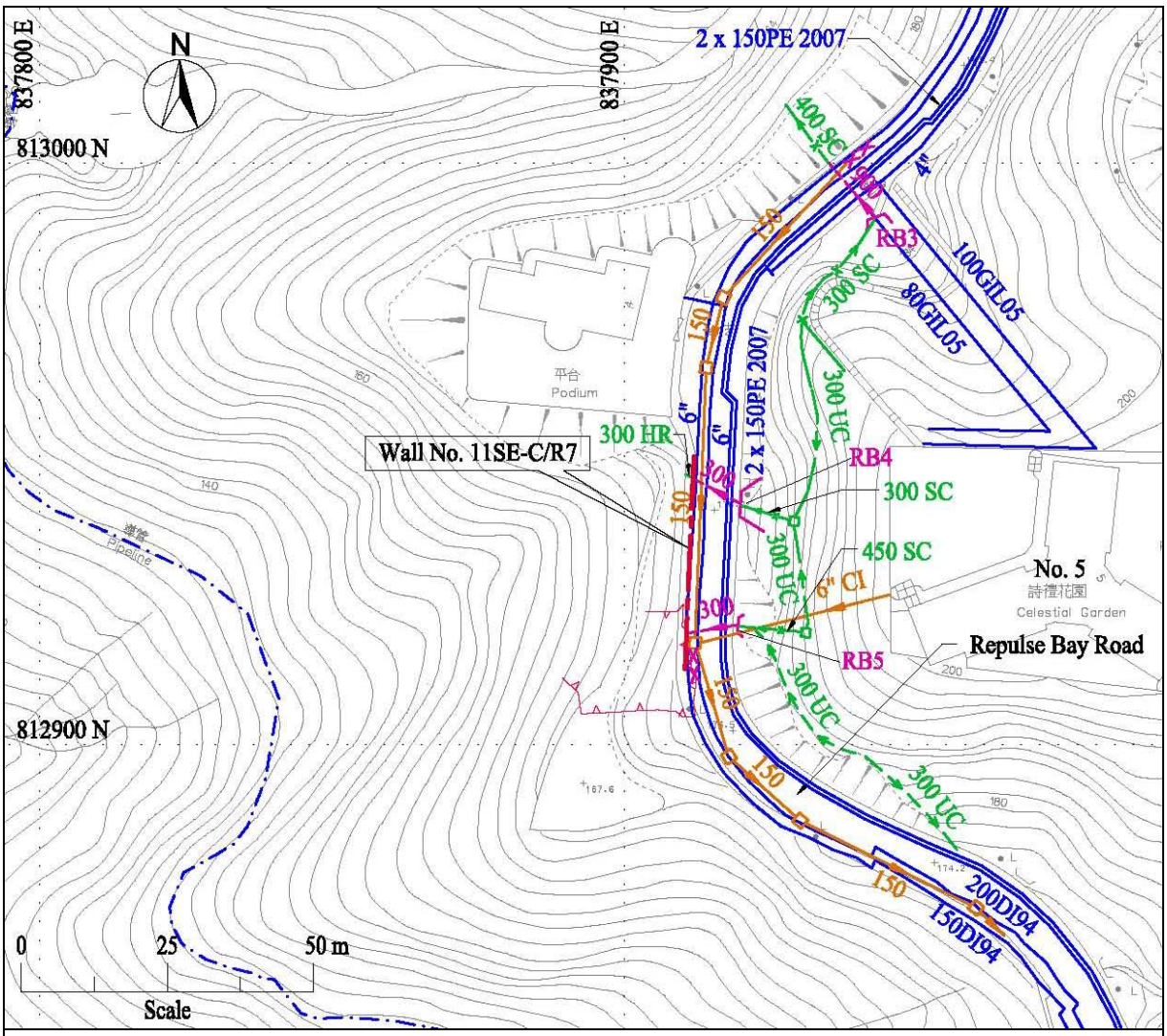
Notes: (1) Base plan is extracted from 1:1000 survey sheet No. 11SE-21A dated May 2003.
(2) See Figure 3 for Section A-A.

Figure 2 - Site Plan



Note: Refer to Figure 2 for location of Section A-A.

Figure 3 - Section A-A through the Landslide Site



Legend:

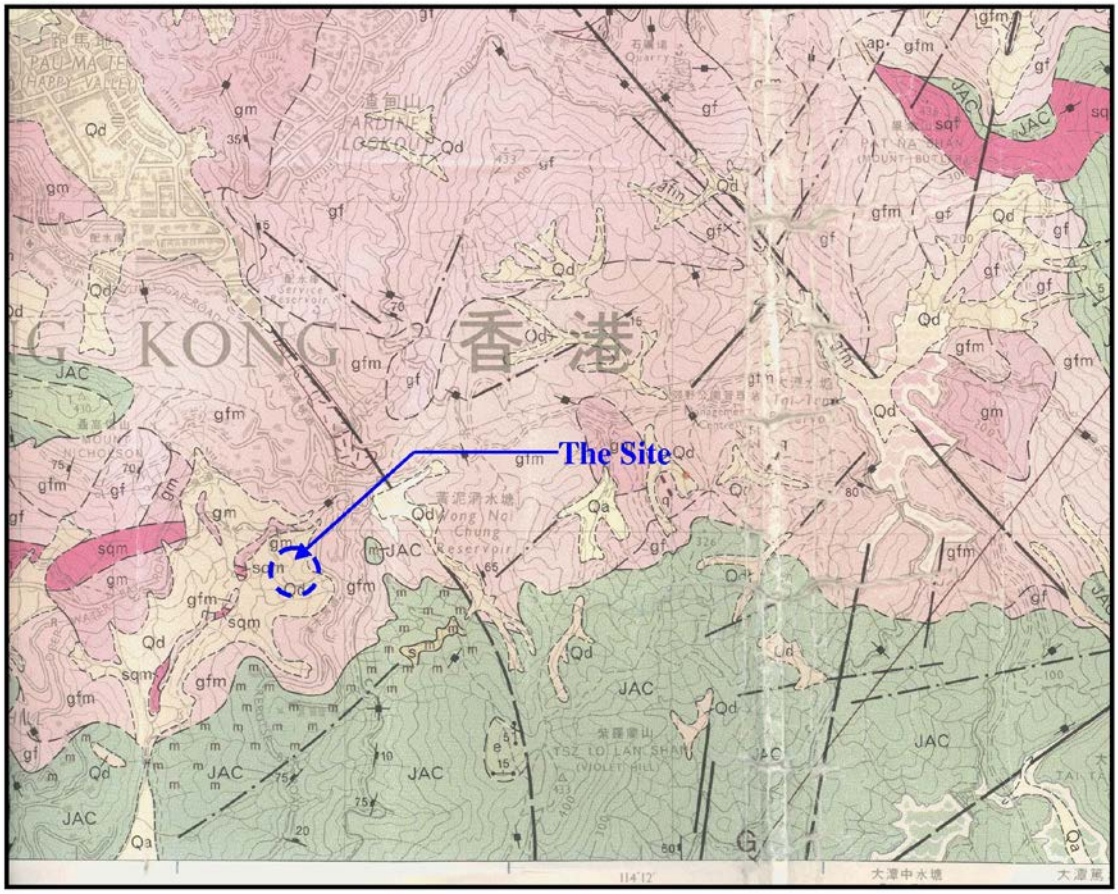
- The 30 June 2007 landslide
- Slope reference number
- Feature boundary from SIS prior to the landslide
- Fresh watermain (150DI94)*
- Above-ground raw water pipe (375AC84)*
- Gully gratings
- Catchpit
- Foul sewer (size given in mm) and associated manhole where appropriate
- 300 mm diameter cross-road drain
- U-shaped drainage channel (size given in mm)
- Stepped drainage channel (size given in mm)
- Half-round drainage channel (size given in mm)
- Catchpit No. RB3

Notes:

(1) Base plan is extracted from 1:1000 survey sheet No. 11SE-21A dated May 2003.
(2) Utilities not affected by the landslide are not shown for clarity.
(3) *data given in brackets denote size in mm (unless otherwise stated), construction material and year of construction, if known, respectively (AC: Asbestos cement DI: Ductile iron CI: Cast Iron GIL: Lined galvanised iron PE: Polyethylene).
(4) According to site observations, the two 6" fresh watermains are mounted one on top of the other on the exterior of the face of wall No. 11SE-C/R7 underneath the elevated footway.
(5) According to WSD, the two newly installed 150 mm dia. PE pipes were not yet in operation at the time of the 30 July 2007 landslide.

Figure 4 - Drainage and Water-carrying Services

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



Legend:

SUPERFICIAL DEPOSITS

- Qa — Clay/Silt, sand and gravel; Well-sorted to semi-sorted deposits (Alluvium)
- Qd — Unsorted sand, gravel, cobbles and boulders; clay/silt matrix (debris flow deposits)

SOLID GEOLOGY

- JAC — Fine ash vitric tuff
- e — Eutaxite
- s — Fine-grained granite
- gf — Sandstone
- gfm — Fine- to medium-grained granite
- gm — Medium-grained granite
- sqf — Fine-grained quartz
- sqm — Medium-grained quartz
- ap — Aplite

0 m — 1000 m

GEOLOGICAL LINES

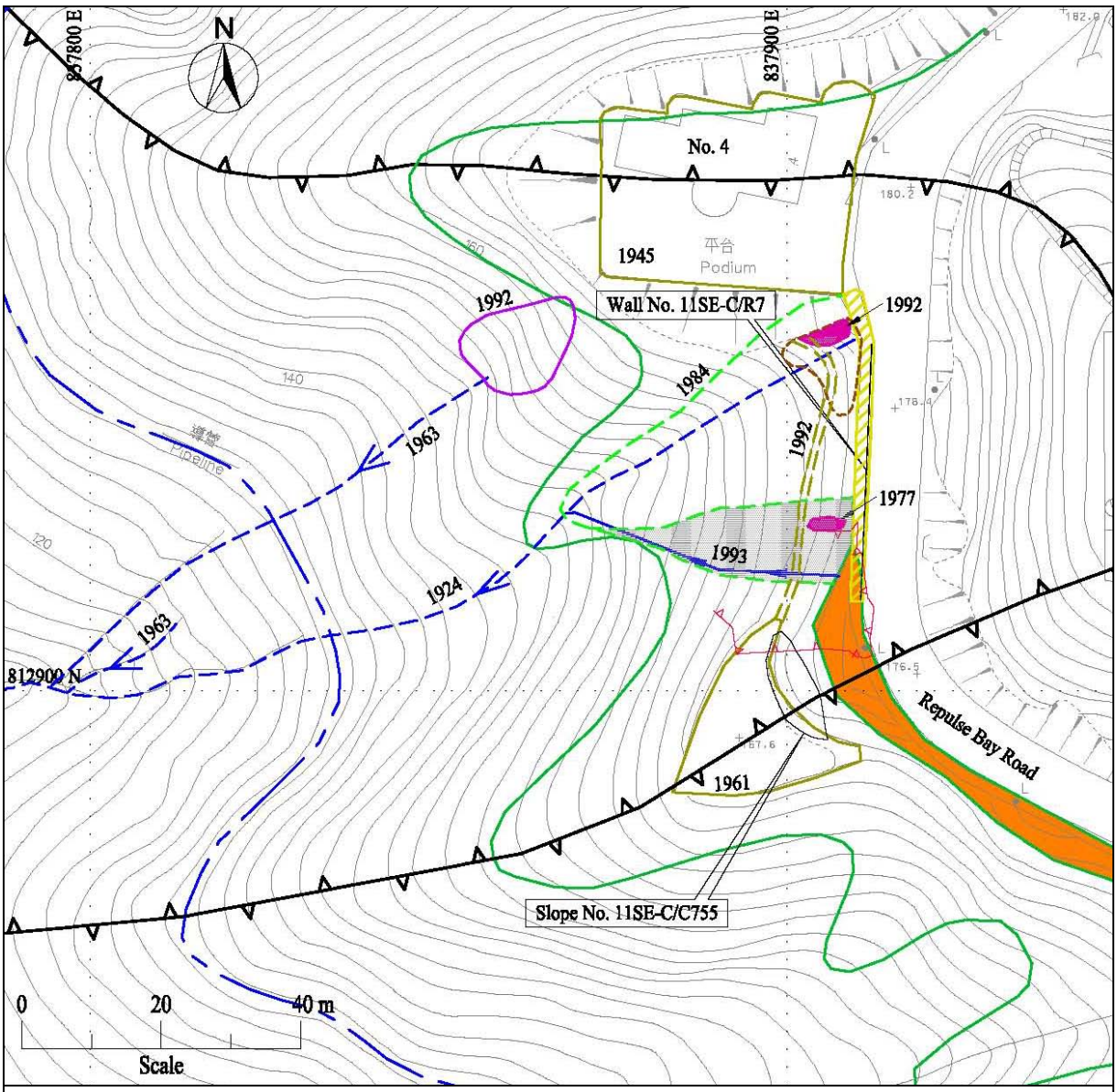
- Geological boundary, solid rock
- Photogeological lineament
- Geological boundary, superficial deposit
- Fault (crossmark indicates downthrow side)

STRUCTURAL SYMBOLS

- Horizontal Jointing/ Inclined Jointing/ Vertical Jointing

Note: Figure is extracted from Hong Kong Geological Survey, Map series HGM20, Sheet No. 11, 1:20 000 scale.

Figure 5 - Regional Geology

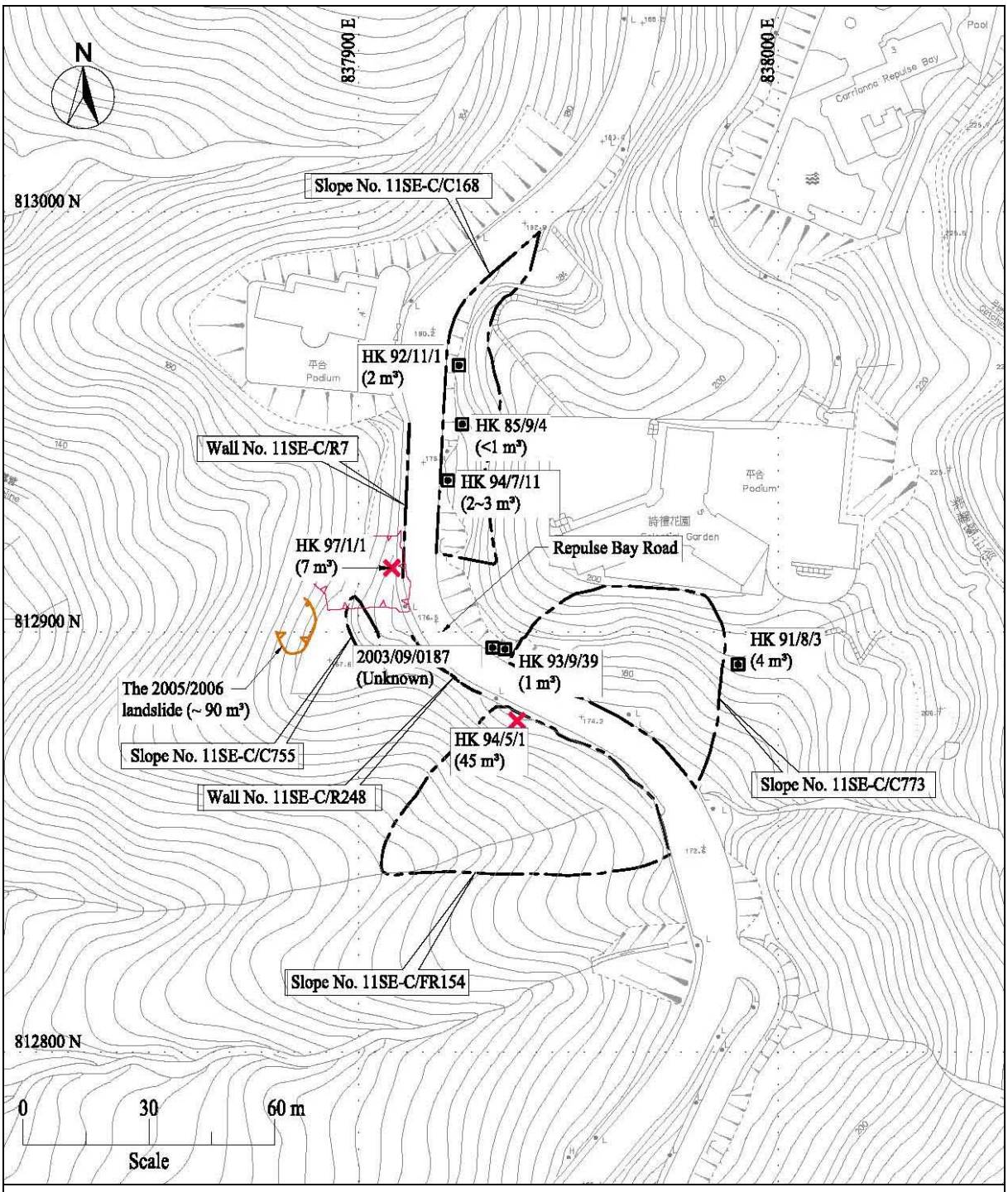


Legend:

- The 30 June 2007 landslide
- Slope reference number
- Feature boundary from SIS
- Spur visible on 1924 aerial photograph
- Downhill extent of high reflectivity below Repulse Bay Road (probably representing extent of fill material associated with road construction, etc) visible on 1924 aerial photograph
- 1924 Ephemeral drainage line visible on 1924 aerial photograph
- Man-made drainage line visible on 1993 aerial photographs
- Extent of fill material asscociated with road improvement works placed between 1945 and 1961
- 1961 Platform formed before 1961
- 375 mm diameter asbestos cement raw-water conduit laid in 1984
- Elevated pedestrain footway constructed between 1945 and 1961
- Area of anthropogenic activity between 1993 and 1994
- 1984 Area of reduced vegetation visible on 1984 aerial photographs
- 1993 Additional area of reduced vegetation visible on 1993 aerial photographs
- 1992 Narrow platform formed in 1992 probably associated with man-made drainage line
- 1977 High reflectivity visible on 1977 aerial photographs
- 1992 Area of vegetation clearance visible on 1992 aerial photographs

Note: Base plan is extracted from 1:1000 survey sheet No. 11SE-21A dated May 2003.

Figure 6 - Site Development History



Legend:

Slope No. 11SE-C/C773 — Slope reference number

The 30 June 2007 landslide

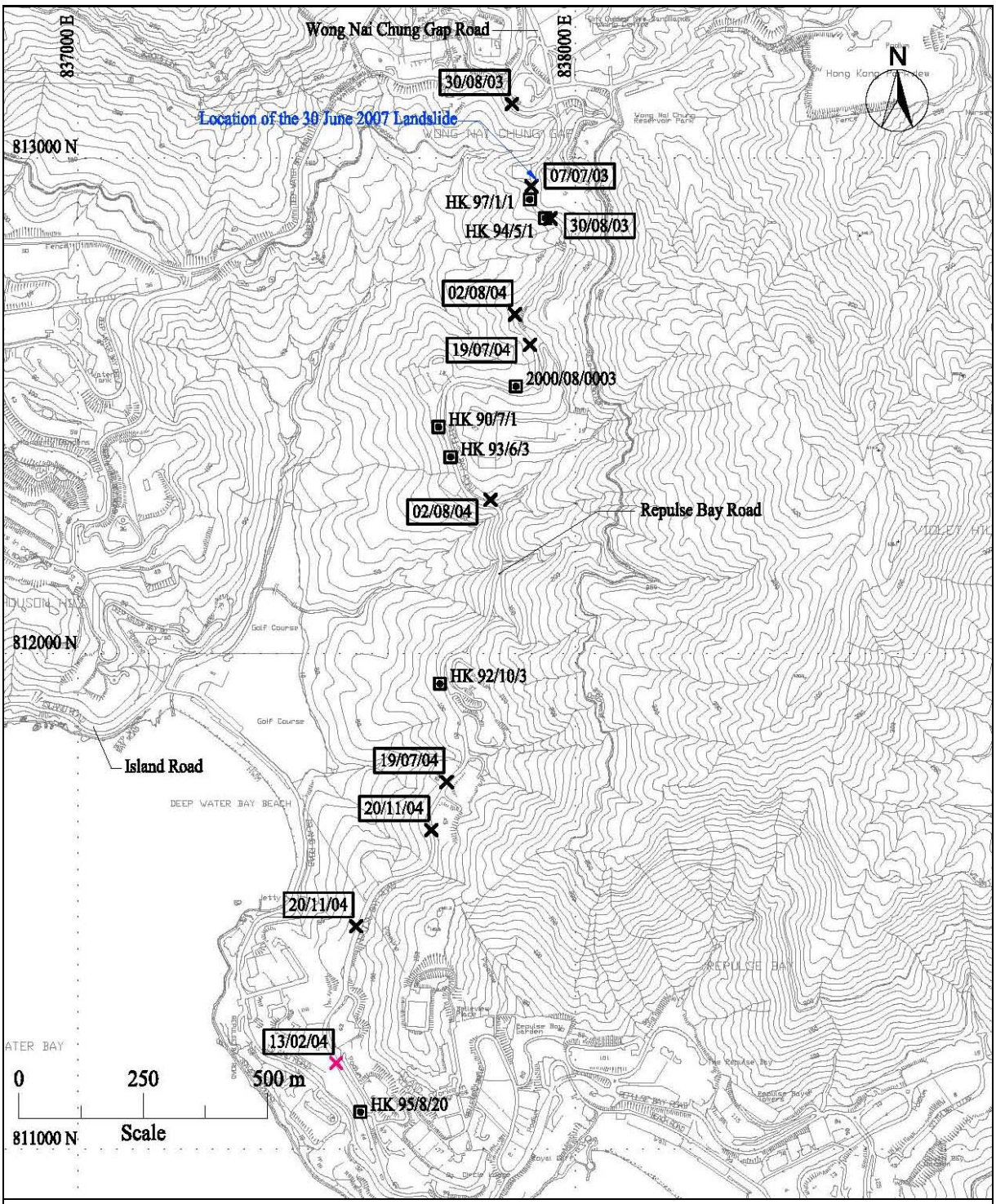
Feature boundary

HK 92/11/1 (2 m³) — Landslide incident No. HK92/11/1 (with a failure volume of 2 m³) not related to rupture/leakge of watermain

HK 94/5/1 (45 m³) — Landslide incident No. HK94/5/1 (with a failure volume of 45 m³) caused by rupture/leakge of watermain

Note: Base plan is extracted from 1:1000 survey sheet No. 11SE-21A dated May 2003.

Figure 7 - Past Instability in the Vicinity of the 30 June 2007 Landslide Site



Legend:

■	Landslide incident caused by rupture/leakage of watermain
20/11/04 ×	Leakage detection test carried out by WSD on 20 Nov 2004
13/02/04 ×	Location where leakage was detected by WSD on 13 Feb 2004

Note: Base plan is extracted from 1:5000 survey sheet No. 11SE-C, 11SW-D, 15NE-A, 15NW-B dated May 2003.

Figure 8 - Past Slope Instability Induced by Bursting of Watermains along Repulse Bay Road

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

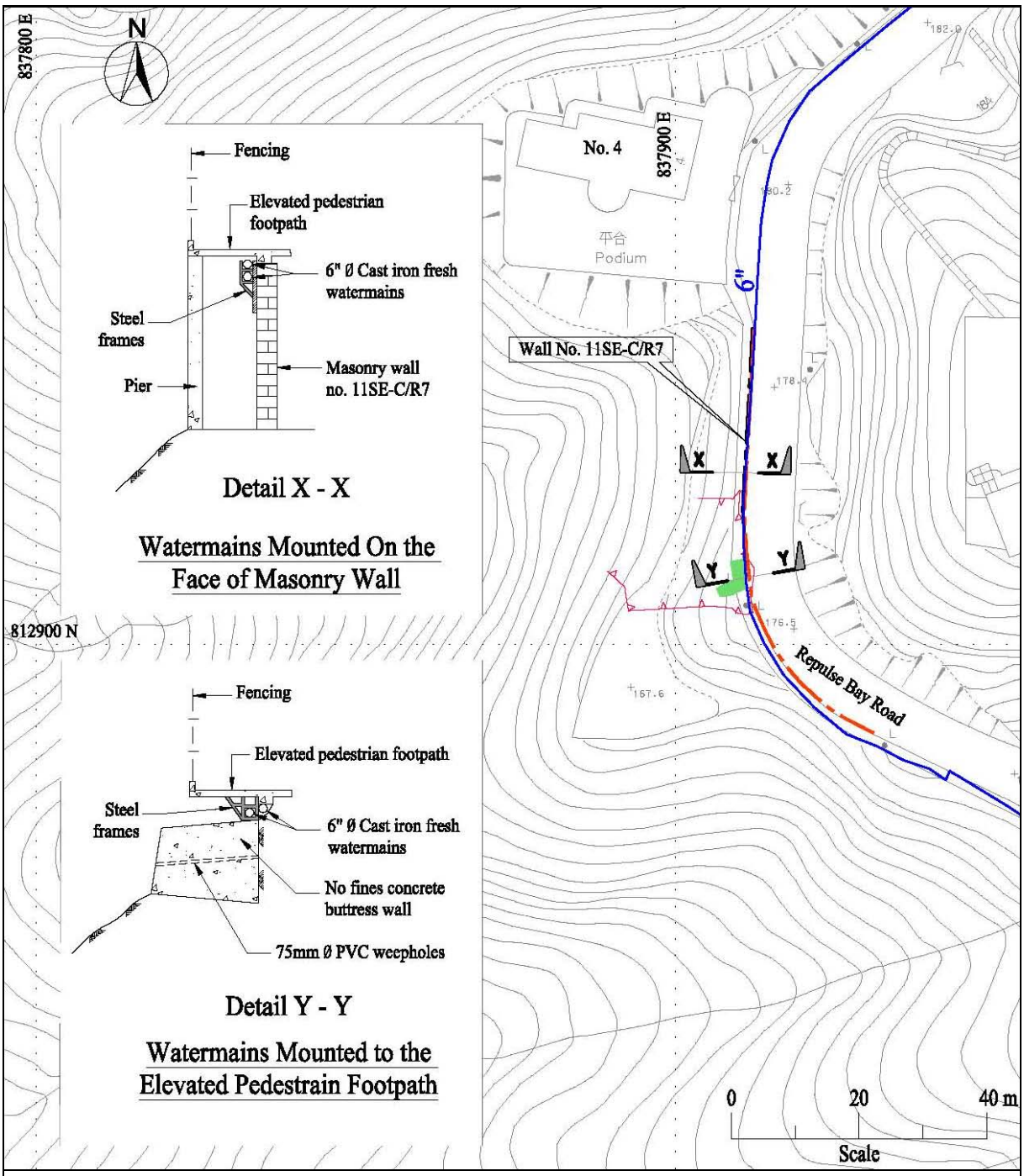


Figure 9 - Schematic Plan Showing Mounting Details of Watermains on Wall No. 11SE-C/R7

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

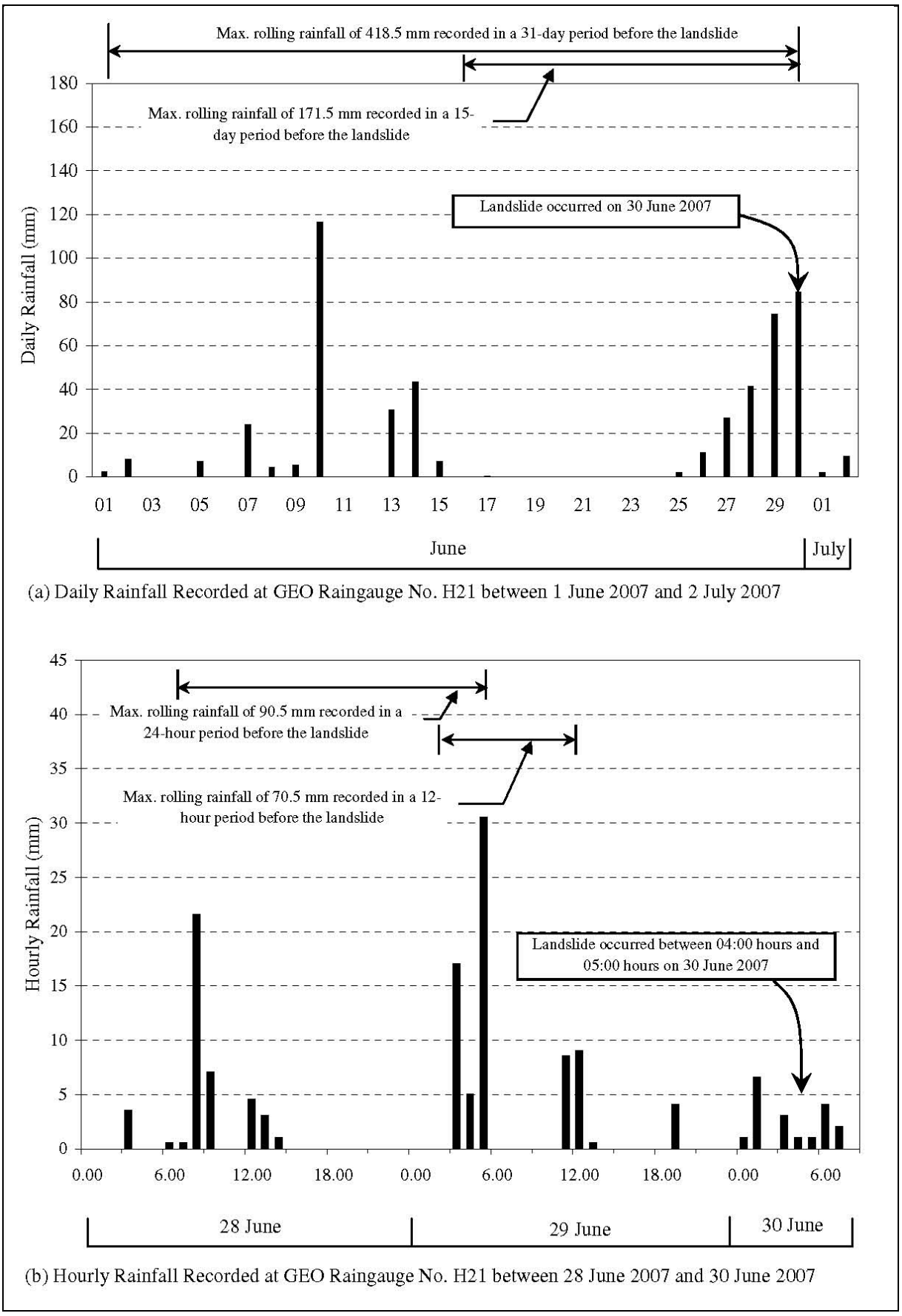
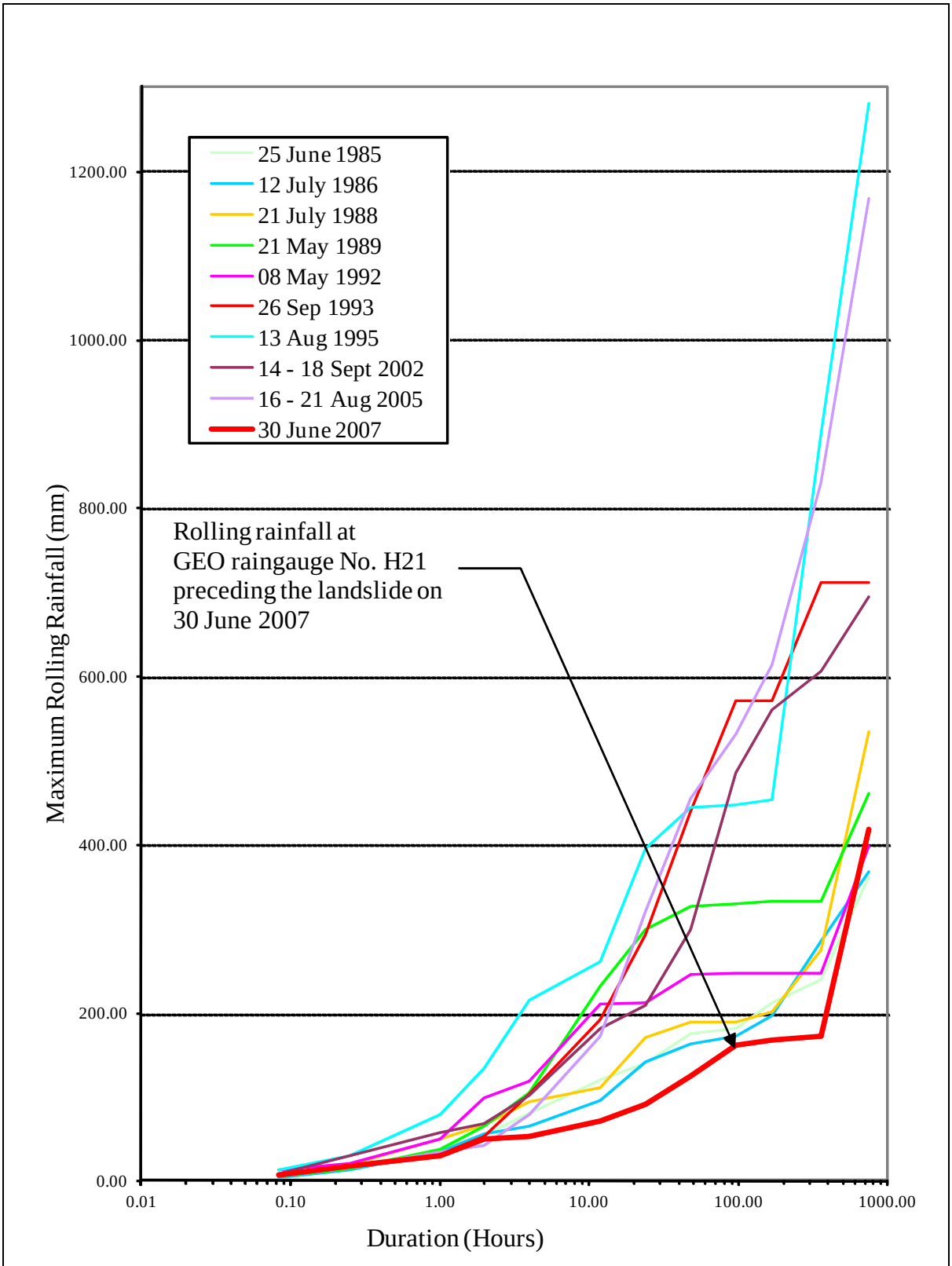


Figure 10 - Daily and Hourly Rainfall Recorded at GEO Raingauge No. H21



Note: Rainfall data are evaluated from 5-minute readings from GEO raingauge No. H21.

Figure 11 - Maximum Rolling Rainfall Preceding the Landslide Incident and Selected Previous Major Rainstorms Recorded at GEO Raingauge No. H21

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

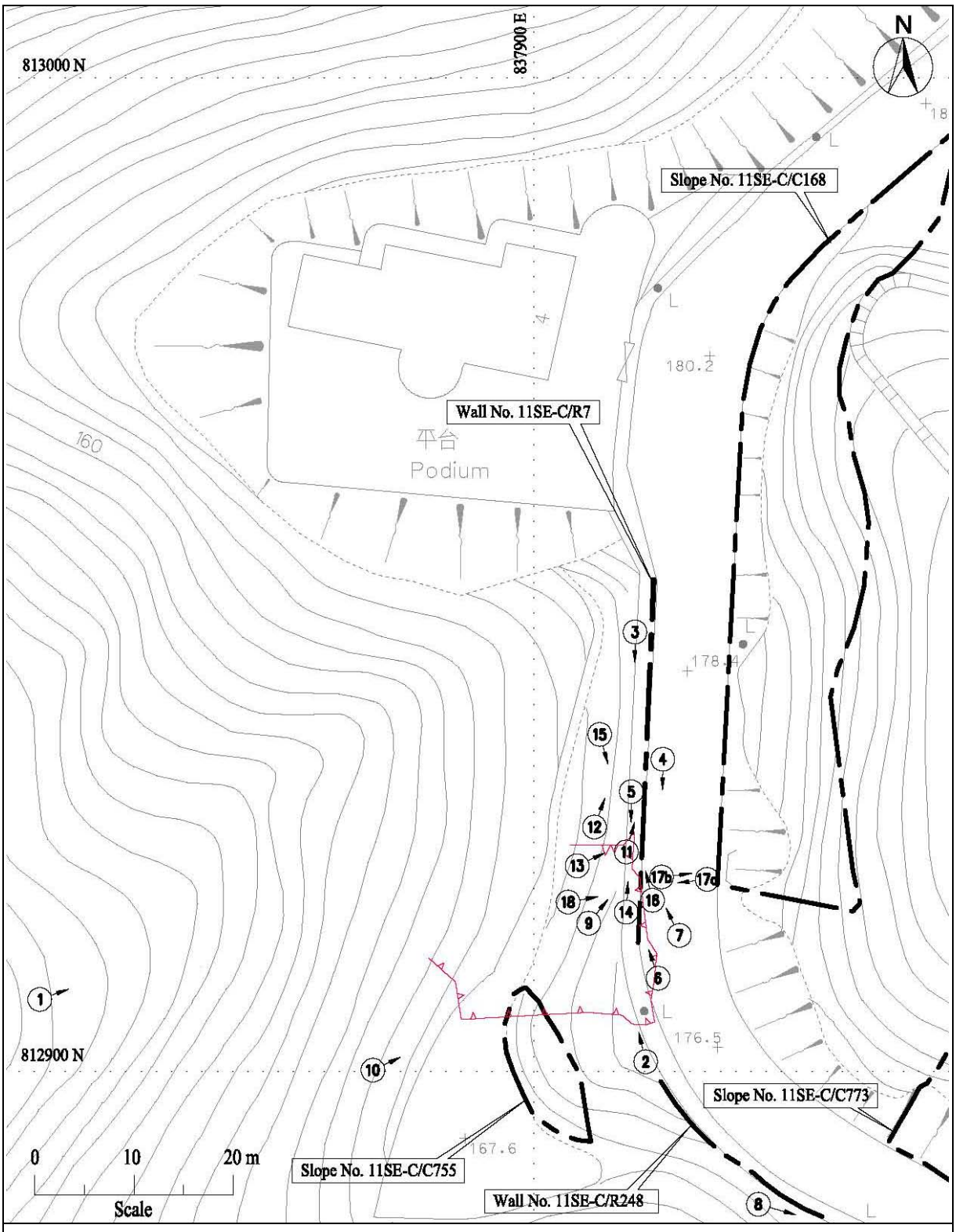


Figure 12 - Locations and Directions of Photographs

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

LIST OF PLATES

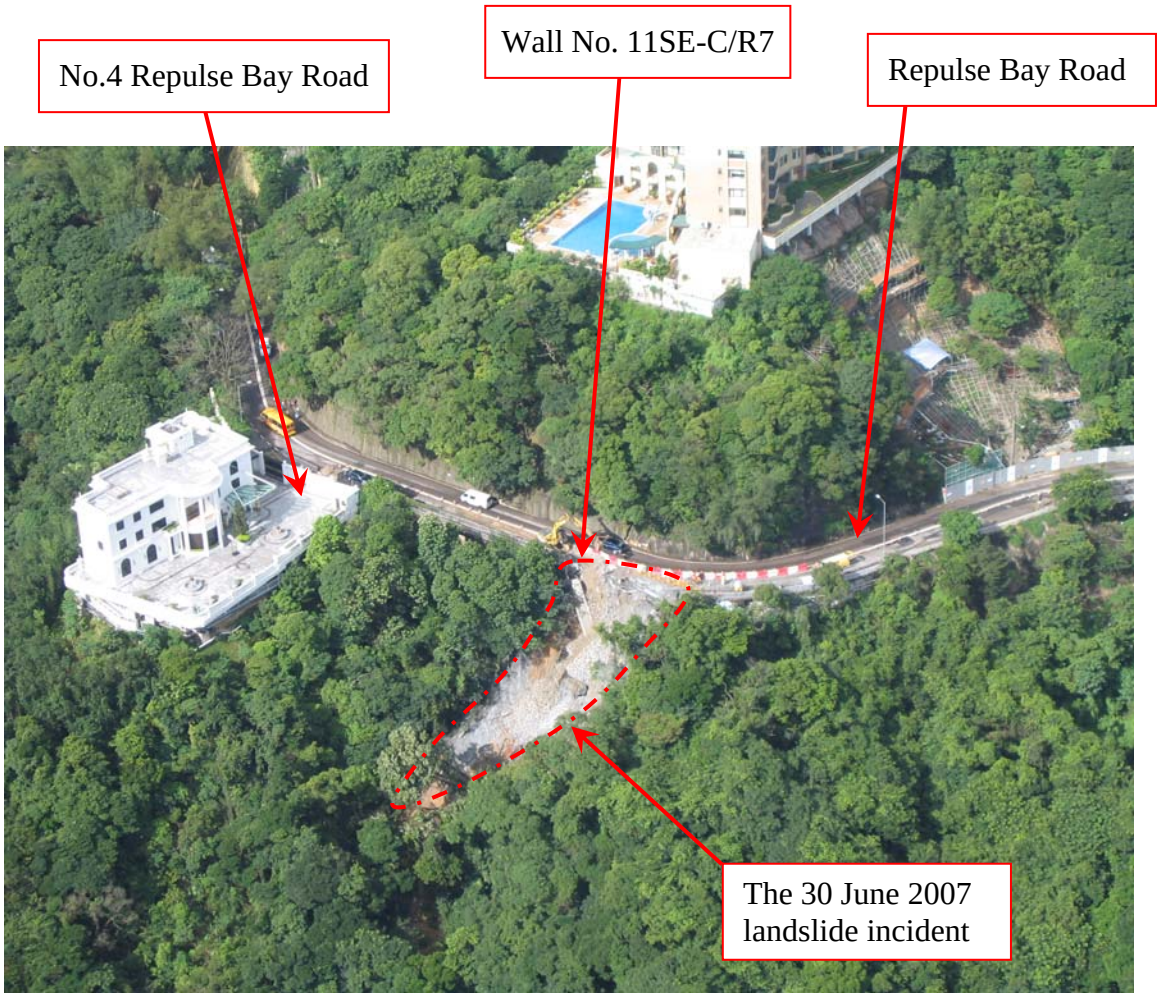


Plate 1 - Oblique Aerial View of the 30 June 2007 Landslide
(Photograph taken on 7 July 2007)

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

Plate 2 - Side View of the 30 June 2007 Landslide (Looking North)
(Photograph taken on 30 June 2007)

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

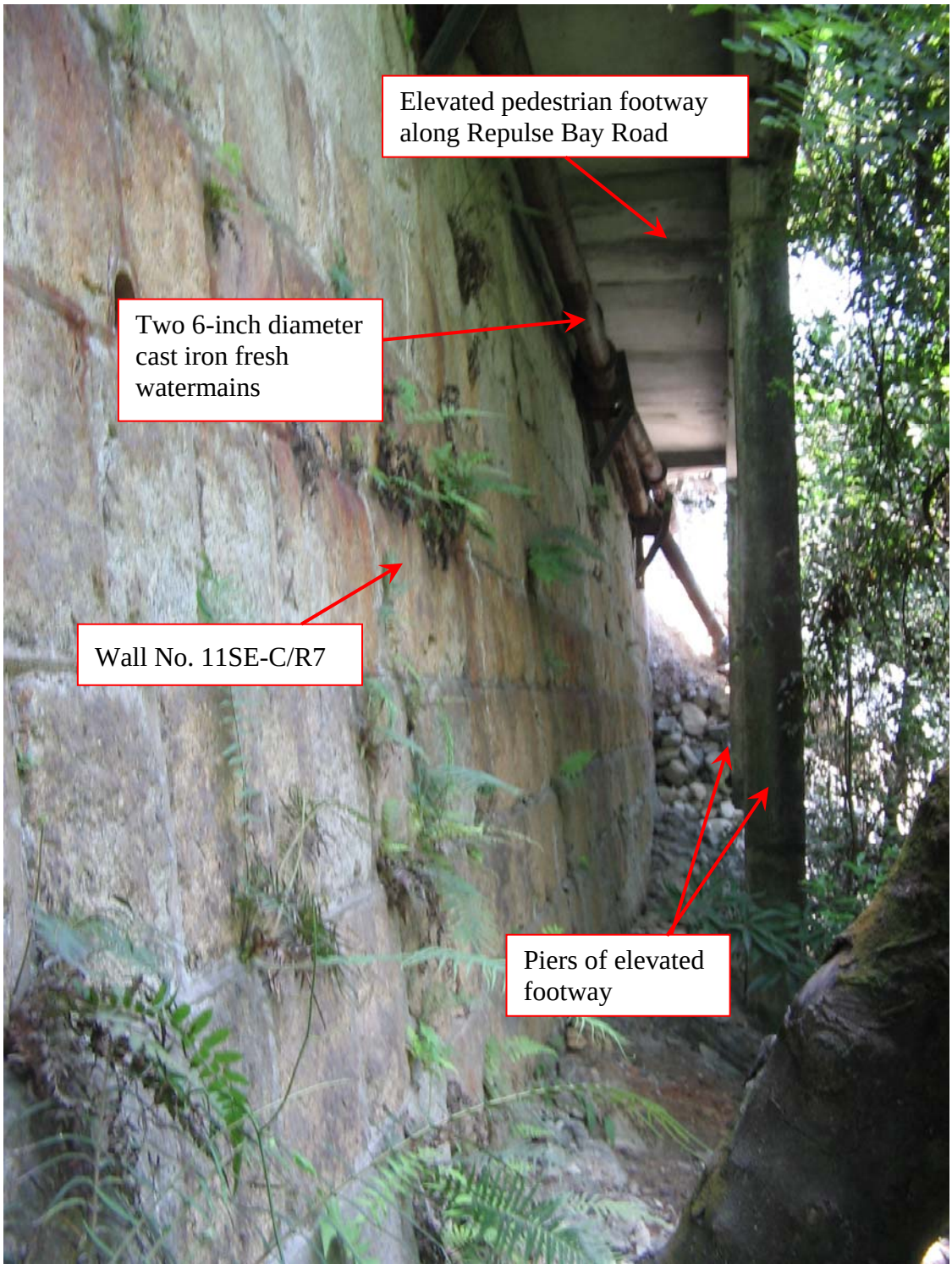


Plate 3 - General View of the Unaffected Portion of Wall No. 11SE-C/R7 (Looking South) (Photograph taken on 12 July 2007)

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

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

Plate 4 - Side View of the Upper Portion of the 30 June 2007 Landslide after Demolition of Elevated Pedestrian Pathway under HyD's Urgent Repair Works (Looking South) (Photograph taken by GEO on 30 June 2007)

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

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

Plate 5 - Side View of the Middle Portion of the 30 June 2007 Landslide (Looking South) (Photograph taken on 3 July 2007)

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

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

Plate 6 - Section of Repulse Bay Road above the 30 June 2007 Landslide (Looking North) (Photograph taken on 30 June 2007)

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

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

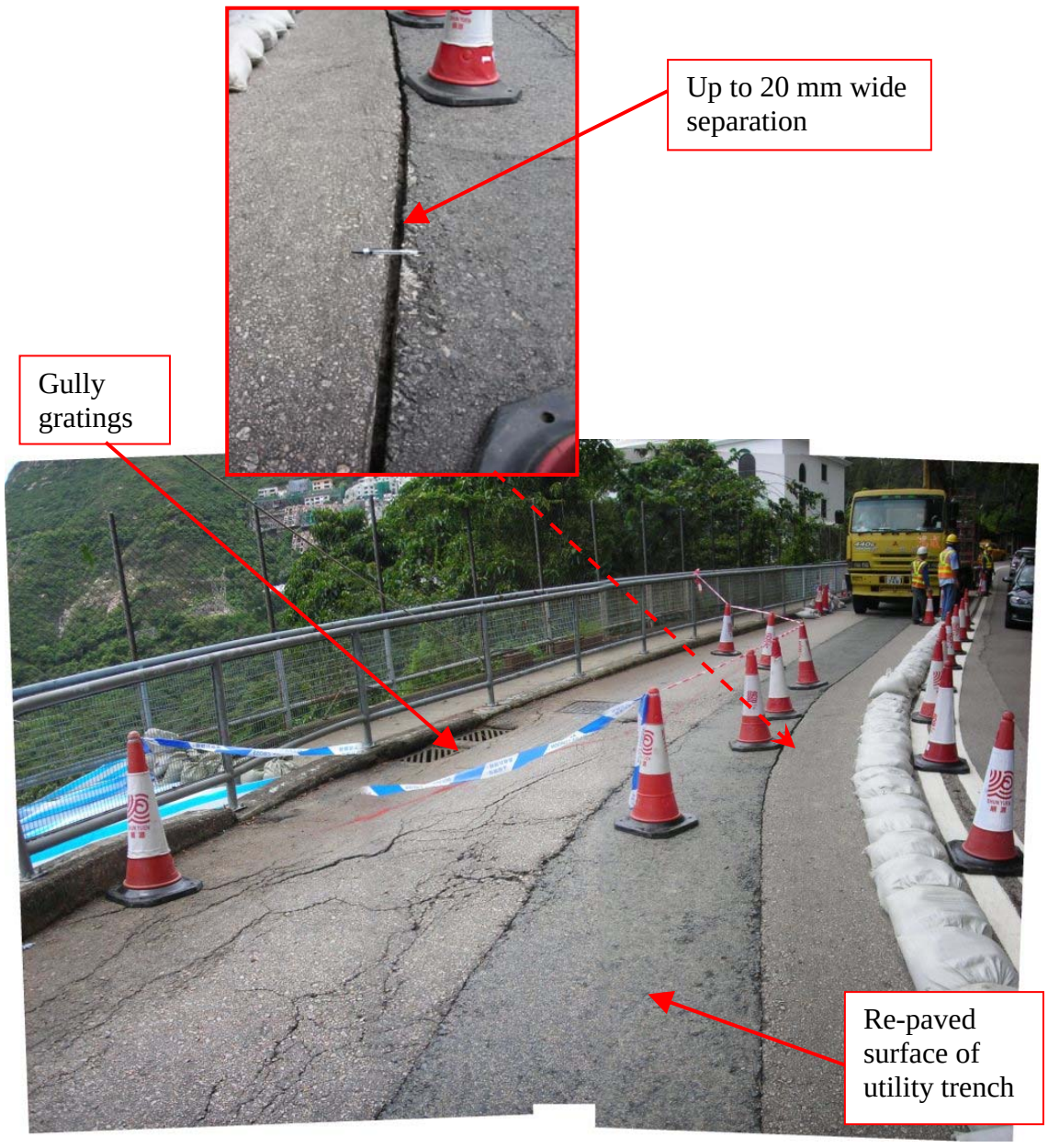


Plate 7 - Condition of the Road Pavement above the 30 June 2007 Landslide Site before HyD's Urgent Repair Works (Photograph taken on 30 June 2007)

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

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

Plate 8 - Record Photo of the May 1994 Washout Incident
(Photograph taken by GEO on 20 May 1994)

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

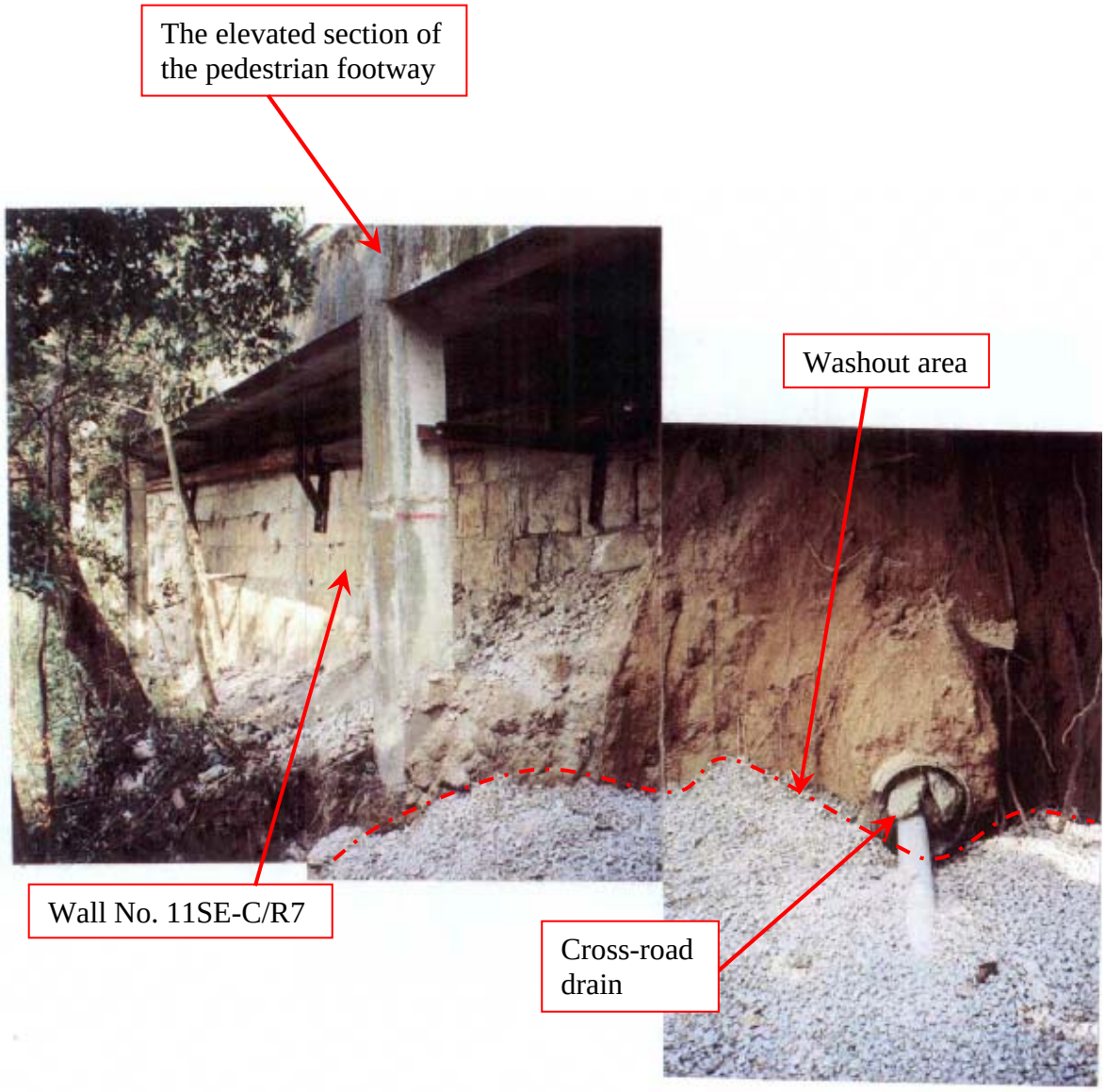


Plate 9 - Record Photo of the January 1997 Washout Incident
(Photograph taken by GEO on 27 January 1997)

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

Plate 10 - General View of the 2005/2006 Landslide below Wall No. 11SE-C/R7
(Photograph taken on 3 October 2007)

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

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

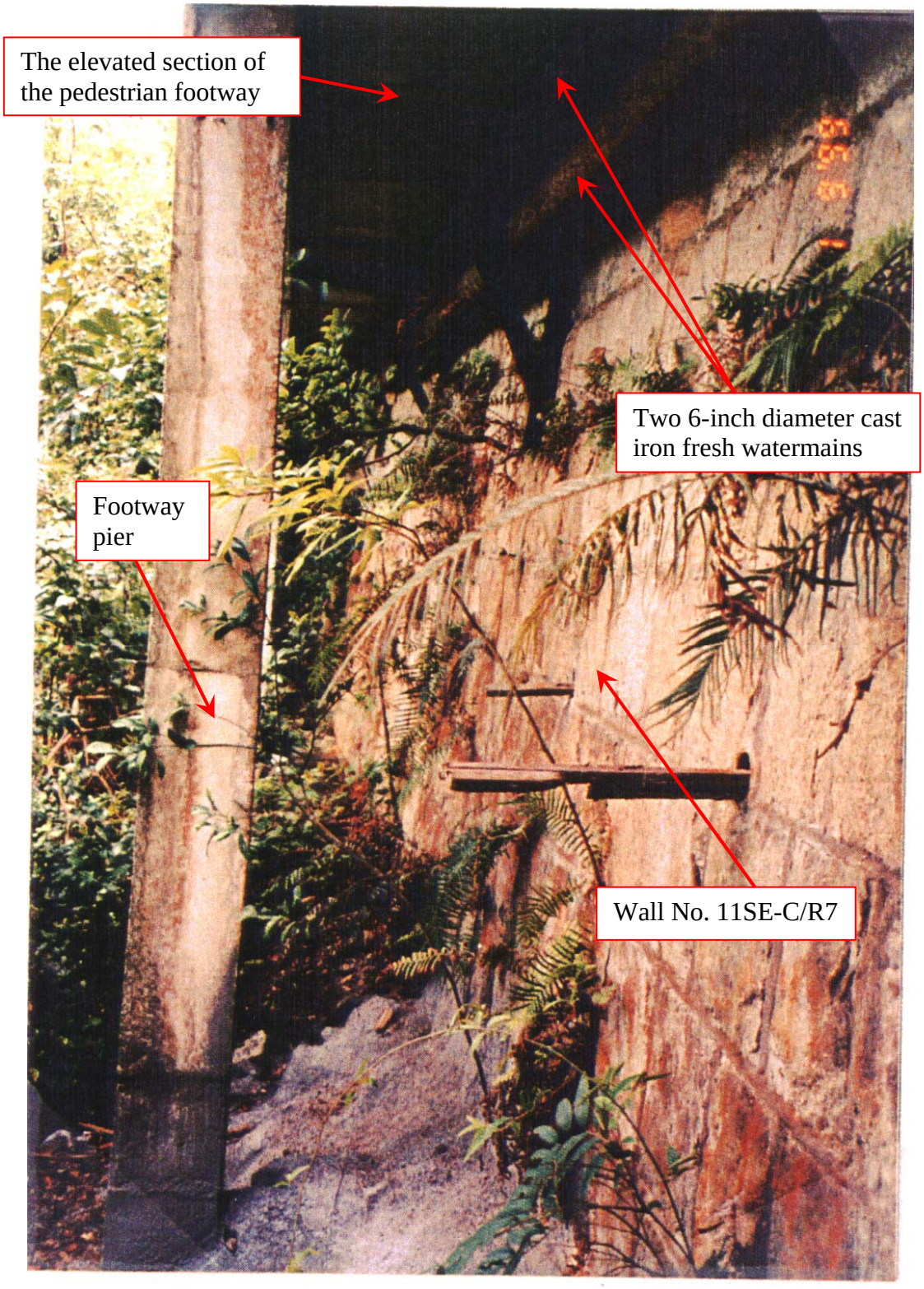


Plate 11 - Condition of Wall No. 11SE-C/R7 in September 1999
(Photograph dated 1 September 1999 extracted from HyD's EI Report)

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

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

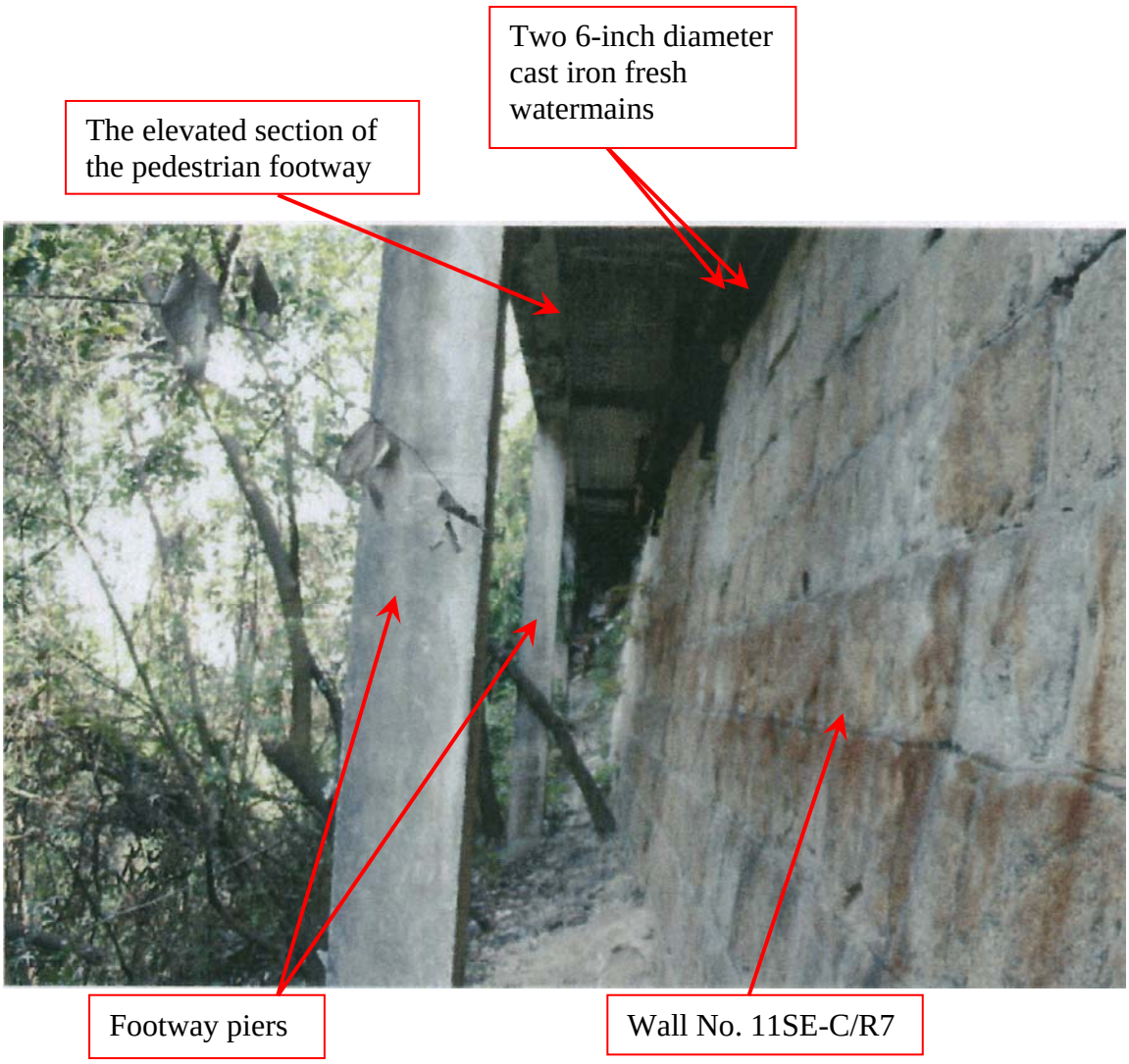


Plate 12 - Condition of Wall No. 11SE-C/R7 in March 2004
(Photograph dated 1 March 2004 extracted from HyD's EI Report)

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

Plate 13 - Condition of Wall No. 11SE-C/R7 in January 1997 (Photograph dated 10 January 1997 extracted from HyD's RMI Report)

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

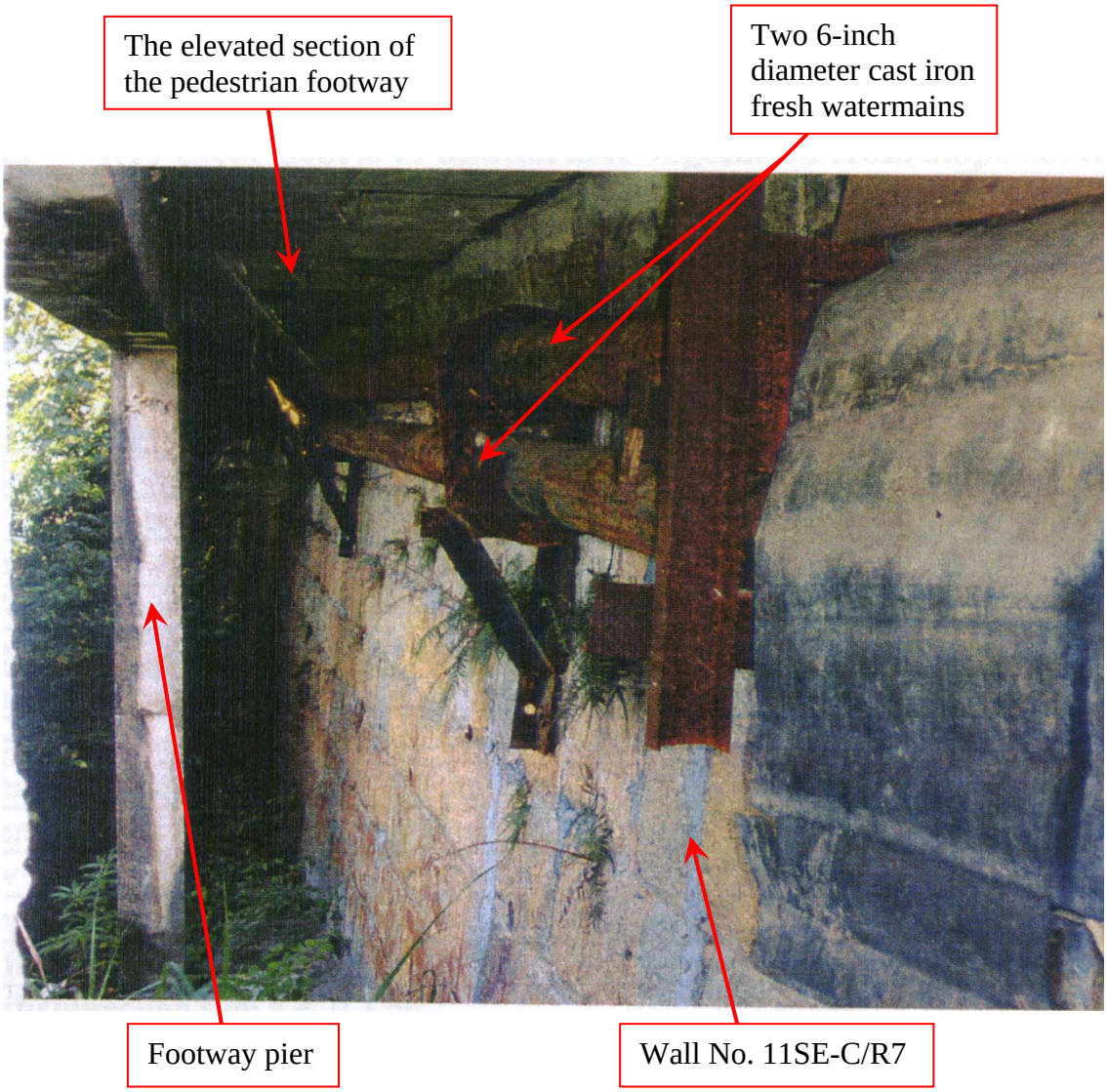


Plate 14 - Condition of Wall No. 11SE-C/R7 in September 2002 (Photograph dated 19 September 2002 extracted from HyD's RMI Report)

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

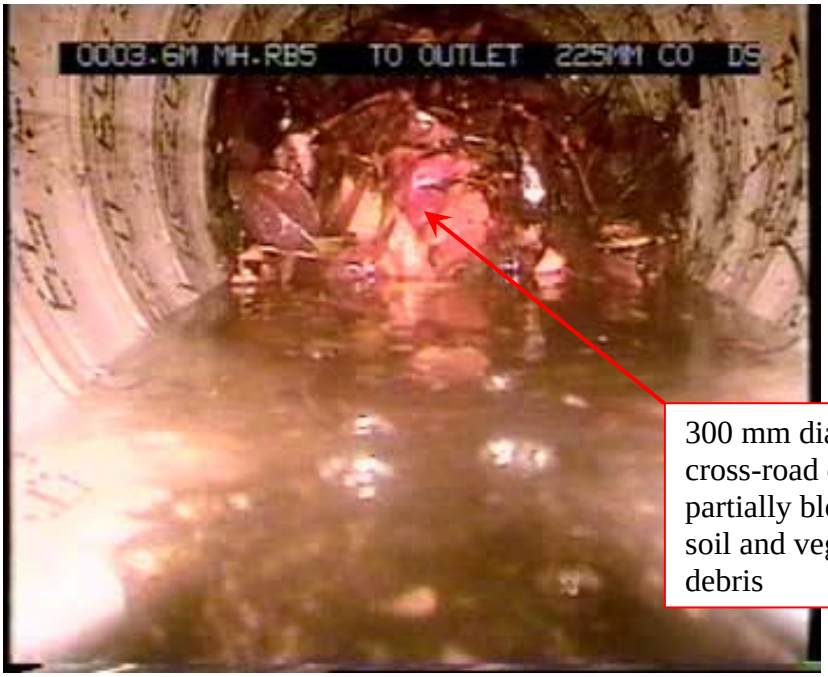
Plate 15 - Condition of Wall No. 11SE-C/R7 in August 2003 (Photograph dated 28 August 2003 extracted from HyD's RMI Report)

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

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

Plate 16 - Water Jet from the Burst Watermains
(Photograph taken by Ove Arup & Partners Hong Kong Ltd.on 30 June 2007)

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



(a) Upstream Side

(b) Downstream Side

Plate 17 - Condition of the Cross-road Drain Connected to Roadside Catchpit No. RB5 (from CCTV Survey Carried out in September 2007)

Note: See Figure 12 for location and direction of photograph

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

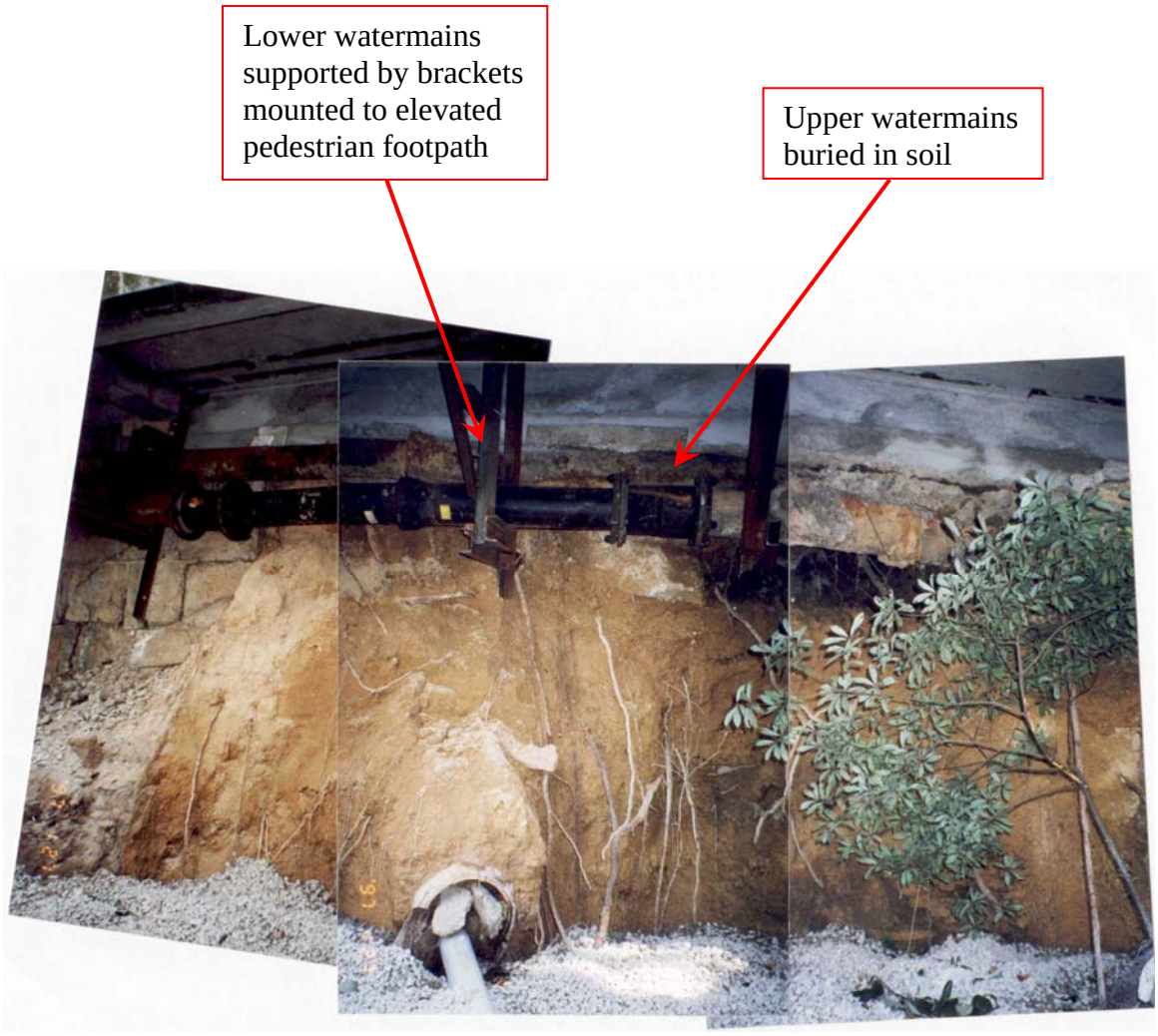


Plate 18 - Condition of Watermains in January 1997
(Photograph dated 27 January 1997 extracted from Landslide Incident Report HK97/1/1)

Note: See Figure 12 for location and direction of photograph

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

Table of Contents
Table of Contents
Table of Contents

APPENDIX A

AERIAL PHOTOGRAPH INTERPRETATION

CONTENTS

A1. DETAILED OBSERVATIONS

This appendix sets out the detailed observations made from an interpretation of aerial photographs taken between 1924 and 2006. A list of the aerial photographs studied is presented in Table A1 and an annotated plan (Figure A1) is also attached.

YEAR OBSERVATIONS

1924 High flight, moderate quality, single aerial photograph.
The registered feature associated with the landslide incident is slope No. 11SE-C/R7 (the feature) and is not visible on the photograph. Repulse Bay Road spans a shallow, concaved natural depression on the west-facing, side-slope terrain immediately above the site (the present-day location of the feature). Although, some minor cutting activity is apparent above the road, its position across a natural depression suggests much of the road pavement has been founded on fill material. It is not known whether the feature has been constructed to retain this fill material. However, the presence of fill material, inferred by high reflectivity, on the natural terrain below the road may suggest that a simple fill slope has been constructed instead. It was noted that the fill material extends further downhill in the northern part of the depression. This may suggest some channelisation caused by an E-W trending ephemeral drainage line. The natural depression is confined by two spurs, one of which is located to the north of the site and the other to the south. High reflectivity, probably associated with anthropogenic activity, is apparent on both.

1945 High flight, moderate quality, single aerial photograph.
The feature is not visible on the photograph. The fill material below Repulse Bay Road has been largely covered with vegetation. No. 4 Repulse Bay Road is under construction on the spur to the north of the site and is probably related to the anthropogenic activity initially observed in 1924.

1961 The feature is visible on the photograph. The position of the feature immediately below Repulse Bay Road is probably associated with road improvement works. An elevated pedestrian footway has been constructed at the crest of the feature. The single E-W trending ephemeral drainage line, initially observed in 1924, can be seen within the shallow, concaved natural depression below the feature. A platform, possibly associated with anthropogenic activity initially observed in 1924, has been formed on the spur to the south of the feature. Registered slope No. 11SE-C/C755, above the platform, appears to be covered in thick vegetation. Fill is apparent at its crest. This body of fill extends south along the downhill edge of Repulse Bay Road and is probably associated with road widening activity. The fill body may extend further north, into the natural depression immediately below the feature. However, the area is obscured by the heavy vegetation canopy on the adjacent hillside. High reflectivity is apparent on the hillside above Repulse Bay Road corresponding approximately to the present-day locations of slope Nos. 11SE-C/C168 and 11SE-C/C773. The high reflectivity is probably associated with slope stabilisation/improvement works, however, it could be a possible failure on the central portion of the slope. Construction works at No. 4 Repulse Bay Road continue on the spur to the north of the site. Except for two

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

YEAR OBSERVATIONS

areas of rock outcrop which are located within the natural terrain below the feature, the hillside is covered in dense vegetation.

1963 The construction works at No. 4 Repulse Bay Road are completed.

A NE-SW orientated ephemeral drainage line is apparent on the terrain below No. 4 Repulse Bay Road. It constitutes a tributary to the E-W orientated ephemeral drainage line located below the feature.

1973 No significant changes are noted.

1975 The fill slope, initially observed in 1961, has been covered in vegetation.

1976 No significant changes are noted.

1977 High reflectivity, probably representing anthropogenic activity, is apparent below the central portion of the feature. However, the nature and extent of the disturbance cannot be assessed due to the surrounding dense vegetation.

1979 Both the platform located on the spur to the south of the feature and the area of disturbance located below the feature have been obscured by vegetation.

1981 Single aerial photograph.
No significant changes are noted.

1982 Single aerial photograph.
No significant changes are noted.

1984 The platform located on the spur to the south of the site is once again visible. A pipeline traverses the natural terrain below the feature. The density of the vegetation cover below the feature has reduced and may represent anthropogenic activity below the canopy.

1986 No. 4 Repulse Bay Road has undergone redevelopment.

1987 No significant changes are noted.

1990 No significant changes are noted.

1991 No significant changes are noted.

1992 A narrow platform, covered with vegetation, is apparent within the area of reduced vegetation density, initially observed in 1984. The heavy vegetation cover suggests the platform was probably constructed sometime earlier and may represent an extension to the platform located on the spur to the south of the feature. An area of vegetation clearance is apparent at the head of the ephemeral drainage line below No. 4 Repulse Bay Road. High reflectivity, probably

YEAR OBSERVATIONS

representing a surface drainage channel, is apparent below the northern portion of the feature.

1993 The area of reduced vegetation density, initially observed in 1984 has expanded and probably relates to the formation of a drainage channel, which flows from the southern part of the feature and enters the ephemeral drainage line, initially observed in 1924, on the hillside below. Additional anthropogenic activity, possibly associated with drainage improvement works, is apparent below the northern extent of the feature.

1994 Works continue below the northern portion of the feature. A landslide (Incident No. HK 1994/05/0001) is apparent below Repulse Bay Road, to the south of the feature.

1995 The area of disturbance observed from 1992 to 1994 has been covered with vegetation. The landslide scar observed in 1994 has been covered by hard surface.

1996 No significant changes are noted.

1997 A landslide (Incident No. HK 1997/01/0001) is apparent on the terrain below the southern portion of the feature, at the head of the drainage line, initially observed in 1993. Damage to the retaining wall itself cannot be assessed. However, the failure appears to have caused limited damage to Repulse Bay Road and the elevated pedestrian walkway above. Landslide remedial works, including the application of a hard surface, have been undertaken. A dark, linear feature has developed down the centre of the highly reflective hard surfacing suggesting that surface water continues to flow down the drainage line. The locations of the 1997 landslide and the 30 June 2007 landslide are notably similar.

1998 No significant changes are noted.

1999 No significant changes are noted.

2000 No significant changes are noted.

2001 No significant changes are noted.

2002 The area of the slope remedial works associated with the 1997 landslide has been partially covered with sparse vegetation.

2003 Vegetation cover on the area of the slope remedial works associated with the 1997 landslide continues to increase.

2004 No significant changes are noted.

2005 No significant changes are noted.

YEAR	OBSERVATIONS
2006	An area of high reflectivity (probably associated with anthropogenic disturbance) is apparent on the northern portion of the platform, which is located on the spur to the south of the feature and on the terrain immediately below.

LIST OF TABLES

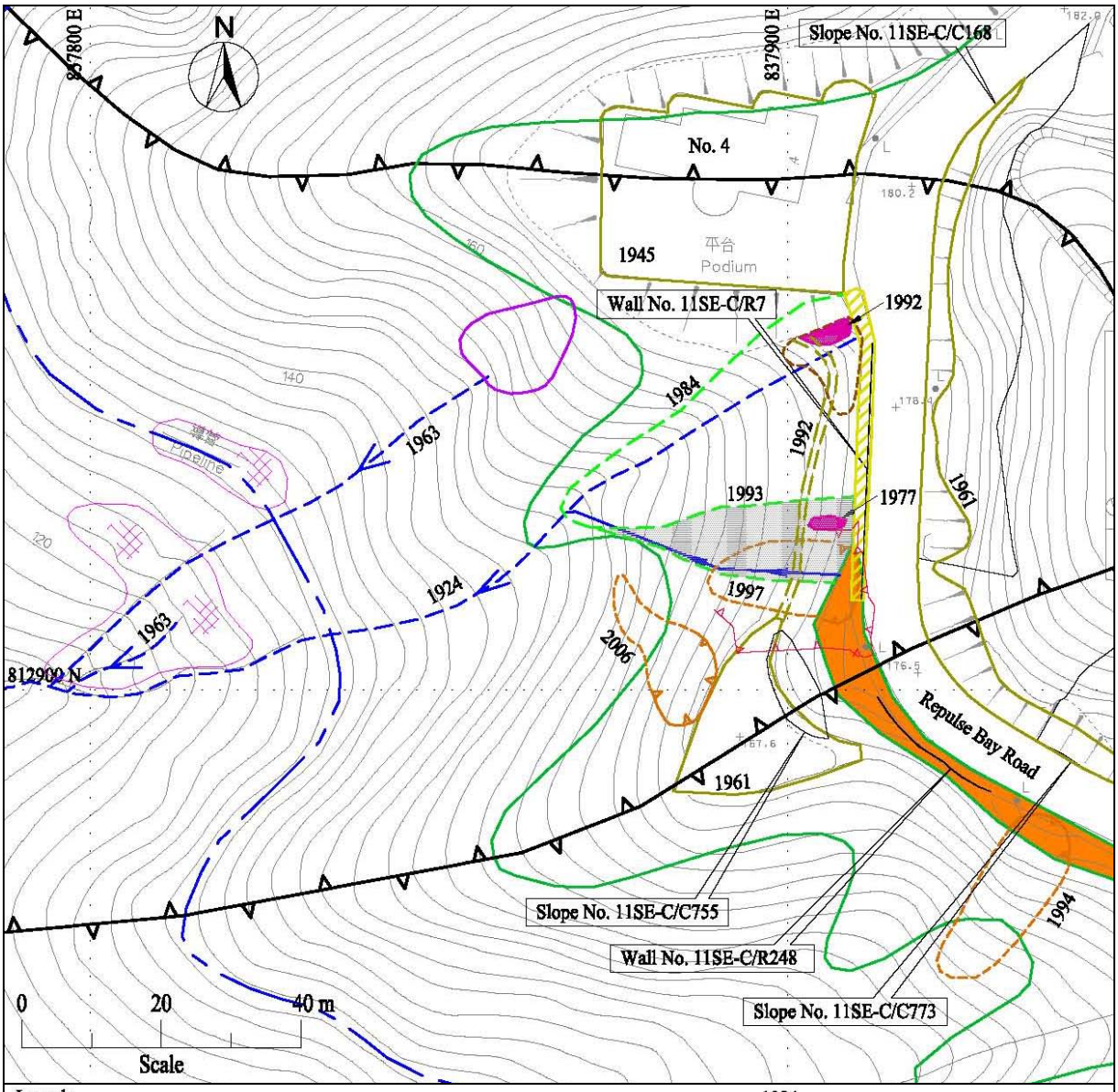
Table A1 - List of Aerial Photographs Used in Aerial Photograph Interpretation

Date Taken	Altitude (ft)	Photograph Number (Sortie Number, if any)
1924	11,100	Y47
11 November 1945	20,000	Y380
17 January 1961	30,000	Y4725-4726
23 January 1963	2,700	Y7048
20 December 1973	12,500	8056-8057
19 December 1975	12,500	11704-11705
30 June 1976	2,500	14255, 14257
6 May 1977	4,000	18239-18240
28 September 1979	5,500	27137
6 November 1979	10,000	27771-27772
4 November 1981	10,000	38969
5 January 1982	4,000	40915
2 March 1984	4,000	53725-53726
20 September 1986	4,000	A6062-6063
9 September 1987	4,000	A10377-10378
14 November 1990	4,000	A23849-23850
14 November 1990	4,000	A23869
4 October 1991	4,000	A27937-27938
12 May 1992	4,000	A31001-31002
5 December 1993	4,000	A37036-37037
17 November 1994	4,000	CN8058-8059
31 October 1995	4,000	CN11696-11697
23 October 1996	4,000	CN15533-15534
23 July 1997	4,000	CN17628-17629
23 October 1998	4,000	CN21110-21111
9 December 1999	8,000	CN25637-25638
1 November 2000	6,000	A51214-51216
27 September 2001	4,000	CW34439-34440
22 August 2001	4,000	AW52396-52397
25 October 2002	4,000	RW1581-1582
25 November 2003	4,000	CW53318-19
5 October 2004	4,000	CW60312-13
24 October 2005	4,000	CW65686-87
19 May 2006	4,000	CW71842-43

Notes:
(1) Aerial photographs are in black and white except for those prefixed with CN, CW and RW.
(2) Aerial Photographs are of good quality, with the exception of the 1924, 1945 and 1961 photographs, which are of poor to moderate quality.

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

LIST OF FIGURES



Legend :

- The 30 June 2007 landslide
- Slope reference number (Slope no. 11SE-C/C775)
- Feature boundary from SIS
- Spur visible on 1924 aerial photograph
- Downhill extent of high reflectivity below Repulse Bay Road (probably representing extent of fill material associated with road construction, etc) visible on 1924 aerial photograph
- 1924 Ephemeral drainage line visible on 1924 aerial photograph
- Man-made drainage line visible on 1993 aerial photographs
- Extent of fill material asscociated with road improvement works visible on 1961 aerial photographs
- 1997 Landslide scar and debris visible on 1997 aerial photographs
- Rock outcrop visible on 1961 aerial photographs
- 1961 Platform visible on 1961 aerial photographs
- Pipeline visible on 1984 aerial photographs
- Elevated pedestrain footway visible on 1961 aerial photographs
- 1984 Area of reduced vegetation visible on 1984 aerial photographs
- 1993 Additional area of reduced vegetation visible on 1993 aerial photographs
- 1992 Narrow platform visible on 1992 aerial photographs
- 1977 High reflectivity visible on 1977 aerial photographs
- 1992 Area of vegetation clearance visible on 1992 aerial photographs
- Area of anthropogenic activity visible on 1993 and 1994 aerial photographs

Note: Base plan is extracted from 1:1000 survey sheet No. 11SE-21A dated May 2003.

Figure A1 - API Plan

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

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。

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Table of Contents
Table of Contents
Table of Contents

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

GEOTECHNICAL MANUALS

Geotechnical Manual for Slopes, 2nd Edition (1984), 302 p. (English Version), (Reprinted, 2011).

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

GEOGUIDES

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

GEOSPECS

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

GEO PUBLICATIONS

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

GEOLOGICAL PUBLICATIONS

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

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

TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents