REVIEW OF INCIDENTS INVOLVING SLOPES AFFECTED BY LEAKAGE OF WATER-CARRYING SERVICES

GEO REPORT No. 203

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CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT

THE GOVERNMENT OF THE HONG KONG

SPECIAL ADMINISTRATIVE REGION

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PREFACE

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

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

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

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FOREWORD

This report presents the findings of an overall review of selected notable incidents involving slopes affected by leakage of water-carrying services. Areas that warrant attention are identified and follow-up actions are recommended.

This report was prepared by Mr T.H.H. Hui, Mr S.M. Tam and Dr H.W. Sun of the Landslip Preventive Measures Division 1 under my supervision. Maunsell Geotechnical Services Limited, the 2003 landslide investigation consultant, provided valuable support in the compilation of the information on the case histories. Their contribution and assistance are gratefully acknowledged.

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1. INTRODUCTION

The potential adverse effects of leakage on slope stability were highlighted by the Mid-levels Study (GCO, 1982) and reinforced by the 1994 Kwun Lung Lau landslide, which resulted in five fatalities and three serious injuries. The systematic landslide investigation programme introduced by the Geotechnical Engineering Office (GEO) in 1997 has further identified a number of notable incidents involving slopes affected by leakage (or bursting) of buried water-carrying services.

To enhance the current practice and contribute to reducing the risk of slope failures caused by leakage from water-carrying services, an overall review of relevant incidents in recent years has been carried out in order to identify areas that warrant attention and improvement. This report presents the findings of the review and suggests some recommended follow-up actions.

2. SOURCES OF INFORMATION

The currently available guidelines relating to potential leakage from buried services affecting slopes includes:

(a) Code of Practice on Inspection & Maintenance of Water Carrying Services Affecting Slopes (Works Branch, 1996),

(b) Geotechnical Manual for Slopes (GCO, 1984),

(c) PNAP 183 “Keeping Buried Services out of Slopes” (Buildings Department, 1995),

(d) PNAP 205 “Code of Practice on Inspection and Maintenance of Water Carrying Services Affecting Slopes” (Buildings Department, 1996),

(e) GEO’s 'Advice Note to Government Departments responsible for Water-Carrying Services, on actions with regard to Leakages, to avoid Risk of Slope or Retaining Wall Failures', see Appendix A (GEO, 2000a),

(f) GEO District Handbook Practice Note No. 121 “Geotechnical Checking of Water Main Works” (GEO, 2000c), and

(g) Guide to Slope Maintenance (GEO, 2003).

Other sources of information referred to for the present review include the following:

(a) GEO Landslide Incident Reports and Landslip Cards,

(b) GEO Landslide Study Reports (LSRs) (see Table 1),

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(c) annual diagnostic reports on the review of landslides published by the GEO for post-1997 landslide incidents, and

(d) relevant files in the GEO and information provided by other Government Departments.

The present review is based primarily on a desk study, which comprises a systematic examination of all the available records and published information. It should be noted that some cases covered under this review were not the subject of previous detailed investigations and hence some relevant information may not be readily available. Notwithstanding this, the present overall review has allowed a broad appreciation of the key areas that deserve attention.

3. OVERVIEW OF STATISTICS OF LANDSLIDES INVOLVING WATER-CARRYING SERVICES

A global review of the available landslide data has been undertaken. The available information, the majority of which was collected during emergency inspections by GEO staff, is subject to constraints in terms of data quality. For example, information on the types of water-carrying services is not available for most of the cases where water-carrying services were involved in the incidents. Also, whether a landslide was primarily caused by leakage from water-carrying services, or whether the services were severed by a rain-induced landslide, cannot be established with much confidence in most cases because the vast majority of the landslide incidents were not investigated in detail. Notwithstanding the above, a preliminary review of the data has been carried out to examine the general picture. However, the constraints on data quality should be borne in mind and the observations made should be treated with caution.

Between 1984 and 2004, there are 206 landslide incidents involving water-carrying services in the immediate vicinity of the slopes of concern. Amongst the 206 landslide incidents, 44 were major (i.e. with a failure volume ≥ 50 m^3). The temporal distribution of the relevant incidents is presented in Figure 1.

Of the 206 landslide incidents, 110 (33% of which are major) affected slope features registered in the Government's Slope Catalogue. The corresponding consequence-to-life categories of the affected slopes are presented in Figure 2. In total, 15 major failures affected consequence-to-life category 1 slopes from 1984 to 2004. This corresponds to an average annual occurrence of less than one major failure affecting a consequence-to-life category 1 slope involving water-carrying services in the immediate vicinity. It is also noted that since 2001 there have been no major landslides involving registered consequence-to-life category 1 slopes with water-carrying services in the immediate vicinity.

4. NOTABLE INCIDENTS INVOLVING LEAKAGE OF WATER-CARRYING SERVICES

4.1 General

Thirteen notable incidents involving slopes affected by leakage (or bursting) of water-carrying services have been reviewed. The review has focused on the more recent

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notable cases that occurred after 1997 and has not included some other landslide incidents whereby leakage from water-carrying services was only a minor contributory factor in the failure.

4.2 The 8 February 1998 Landslide at Hang Lok Lane
(GEO Incident No. MW98/2/1: A large-scale landslide involving leakage from a 3-inch pressurised fresh water main resulted in temporary evacuation of 143 residents)

On 8 February 1998 (i.e. during the dry season), a large-scale landslide (about 1,100 m^3 in volume) occurred on an non-engineered soil cut slope. The landslide was probably caused by leakage from a 20-year old, 3-inch diameter pressurised fresh water main (Figure 3 and Plate 1) and a 36-m long section of the slope, together with a section of Hang Lok Lane above the slope, collapsed as a result of the landslide. A total of 143 residents of the buildings above the landslide had to be evacuated temporarily.

Close examination of the exposed 3-inch galvanized iron fresh water pipe indicated rusting and pitting around a screw joint (Plates 2 and 3). The water pipe was buried at a minimum depth of about 340 mm below the ground surface.

Four days before the collapse, a resident observed seepage at the toe of the slope for the first time. A drop in the pressure of the water supply was noticed one day later, indicating that the leakage from the water pipe probably occurred gradually for a few days before the failure.

According to the Water Supplies Department (WSD), visual inspections and leakage tests, which comprised night flow tests and sounding tests, were carried out between January and September 1997, and leakage was not detected at that time. On 7 February 1998 (the day before the failure), following a complaint from the residents of Hang Lok Lane, WSD excavated some pits for visual inspection and no leakage was identified.

The landslide investigation (FSWJV, 1998) concluded that the failure was probably triggered by the ingress of a significant amount of water leaking from the old buried water main. It was diagnosed that the leakage might have been caused by deterioration of the water main over time and possible damage to the shallow water main due to loading by heavy vehicles and subsidence of fill under the road.

This incident highlights that leakage from an ageing buried water-carrying services may not necessarily have obvious surface expressions at the ground surface, which emphasises the importance of attention to other indicators, such as low supply main pressure, a new or sudden increase in seepage from a slope, etc. The incident also serves as a reminder that buried services at shallow depths are liable to be damaged by loading or vibration from heavy vehicles and that landslides caused by leakage alone can be of a significant scale.

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4.3 The 9 April 1998 Distress at Slope No. 11NE-D/F10 below Hiu Kwong Street
(GEO Incident No. CK98/4/1: Significant slope distress involving localised bulging and cracking of the shotcrete cover of an old fill slope (which was previously treated with a recompacted surface cap in the late 1970's), as a result of leakage from a 400 mm diameter pressurised saltwater main at the slope crest)

The slope was originally formed by end-tipping fill to a depth of more than 10 m into a valley in the mid-1960's. Following a failure in 1976, the slope was upgraded in 1977 by placing a compacted fill cap with a thickness of 3 m to 6 m thick over the pre-existing old fill.

The slope has a history of leakage from buried services. A major failure occurred in 1984 due to leakage from a water main. Since 1984, the slope has been subjected to progressive deterioration with the development of distress and intermittent movement.

Since early February 1998, continuous seepage was observed from the weepholes at the slope toe, which was subsequently found to be associated with leakage from a 400 mm diameter pressurised saltwater main above the slope crest (see Plate 4). On 9 April 1998, significant distress in the form of local cracking, displacement and bulging of the shotcrete cover was observed in the upper portion of the fill slope (Figure 4, Plates 5 and 6). The saltwater main was one of several major water-carrying services (two pressurised fresh water mains, two stormwater drains and one foulwater sewer) located on a large depth of old fill below Hiu Kwong Street, and the slope posed a hazard to a school building located directly below the toe.

The incident serves to highlight the potential vulnerability to leakage from buried services in a fill slope treated with a newly formed compacted fill cap which overlies a large depth of untreated loose fill, especially where there is a potential for water ingress into, and build-up of groundwater pressure within, the loose fill leading to ground movement and reduction in the safety margin of the slope.

4.4 The 14 January 2000 Landslide at Slope No. 11NW-A/FR84 below Castle Peak Road near Kau Wah Keng Village
(GEO Incident No. MW2000/1/7: Major internal erosion and severe distress of an upgraded fill slope caused by leakage from a 900 mm diameter pressurised water main)

On 14 January 2000, major internal erosion and severe distress (involving about 700 m^3 of material) were observed on the fill slope, which was previously upgraded in 1982. The cause was probably associated with leakage from a 900 mm diameter pressurised water main (Figure 5 and Plate 7) that had apparently been encased in a concrete trough as part of the leakage collection/detection system constructed during the slope upgrading works (Figure 6).

The leakage from the pressurised water main resulted in concentrated water ingress into the fill slope through a 150 mm diameter hole at the invert of the concrete trough (Plate 8). Inadequate connection (i.e. poor sealing) between the drain pipe and the trough also played a contributory role by allowing additional water ingress into the slope following dislocation of connection, which was probably caused by the development of local movement as the slope wetted up.

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This incident emphasises the need for proper design and detailing of the ducting system for water-carrying services and the importance of proper documentary records and recommended inspection procedures in the slope maintenance manual.

4.5 The 27 August 2000 Landslide below Castle Peak Road near Lai Chi Kok Hospital
(GEO Incident No. MW2000/8/9: A washout incident involving the erosion and disturbance of a recently upgraded fill slope caused by the bursting of a 150 mm diameter pressurised old water main below the recompacted fill cap)

The washout incident (about 10 m^3 in volume, discounting the associated disturbance and loosening of the recompacted fill cap) occurred on a recently upgraded fill slope (Figure 7 and Plate 9), which was caused by the bursting of an old (>50 years), pressurised cast iron fresh water main (Plate 10) that traversed the slope within the loose fill and below the recompacted fill cap. The slope upgrading works, comprising surface re-compaction of the existing loose fill and provision of a drainage filter blanket, were completed about six months before the incident.

No detailed investigation or survey of subsurface water-carrying services was carried out prior to commencement of works. During the construction stage, a valve chamber of the fresh water main was identified in the loose fill just below (<1 m) the extent of the proposed excavation works. It was considered that diversion of the water main was not warranted and that the water main would not affect, or be affected, by the slope works. No precautionary measures were considered necessary to protect the water main during the re-compaction works.

The main burst incident was probably the result of progressive deterioration of an old installation, which had become significantly dilapidated and severely corroded. The water main was subsequently diverted by WSD after the incident.

This incident serves to highlight the importance of a sufficiently detailed assessment of all the water-carrying services that may affect a slope during the investigation stage and a thorough examination of the feasibility of diverting existing services. The need to consider in detail the possibility of a potentially adverse impact of slope works on existing services is emphasised.

4.6 The 18 June 2000 Seepage Incident at Slope No. 11SW-A/R625 and Ground Subsidence behind Slope No. 11SW-A/FR12 near Oaklands Avenue
(Significant leakage from an old, large diameter stormwater drain resulted in major subsurface erosion in an non-engineered fill slope and ground subsidence above slope crest)

This incident involved significant leakage from an old concrete stormwater drain that had been constructed in the mid-1960's (Figure 8 and Plate 11) and ranged from 600 mm to 1200 mm in diameter. The drain collected surface water flow from the Po Shan Stream. The incident resulted in major subsurface erosion and local ground subsidence above the slope crest.

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CCTV surveys carried out following the 2000 incident revealed defects (i.e. collapsed invert and a break at a pipe joint) in the section of the drain underneath fill slope No. 11SW-A/FR12 and at the connection to a manhole on Oaklands Avenue (Plate 12). Seepage from the broken drain was probably directed to the back of retaining wall No. 11SW-A/R625 along a network of soil erosion pipes within the colluvium, thus resulting in a strong outflow of muddy water from the weepholes in the wall. The defects in the drain were probably the result of progressive deterioration over the long period of time that it has been in service.

This incident highlights the importance of identifying the full extent of significant subsurface erosion caused by major leakages, and assessing its potential impact on slope stability and slope performance in terms of serviceability.

4.7 The 14 December 2001 Landslide at a Fill Slope below Pokfield Road
(GEO Incident No. 2001/12/0123: A washout incident on an non-engineered old fill slope involving the bursting of an uncharted, pressurised fresh water pipe above the slope crest)

The washout incident (about 30 m³ in volume) involved the erosion of an unregistered (but registerable) loose fill slope below Pokfield Road due to the bursting of an 80 mm diameter, uncharted pressurised fresh water pipe.

The uncharted fresh water pipe (Figure 9, Plates 13 and 14) was located at a sharp bend on Pokfield Road above the old fill slope. The water pipe was likely to branch off the 250 mm diameter fresh water main supplying the area (Plate 15) and probably used to supply water to the now abandoned squatter areas below the fill slope before the 1970's. According to WSD's investigation subsequent to the incident, the burst of the water pipe was caused by external erosion of the galvanized iron pipe body, which was more than 20 years old and was in a dilapidated state.

The water pipe was uncharted in that it was not included in WSD's mains record plans. Based on WSD's advice, leakage from the corroded and uncharted water pipe probably occurred for some time prior to the burst. Water ingress arising from the leakage would have wetted up the ground mass and probably resulted in the local build-up of groundwater pressures.

This incident serves to highlight the hazard posed by leakage from aged and uncharted water-carrying services, especially in a loose fill slope setting which is liable to suffer mobile landslides following prolonged water ingress.

4.8 The 7 June 1999 Landslide at Slope No. 7NE-C/C23 below Benjamin Franklin Centre, Chinese University
(A landslide on an engineered slope involving the leakage from a 75 mm diameter pressurised fire service main at the slope crest)

This landslide (about 30 m³ in volume) occurred on a cut slope that was previously assessed as being up to the required standards (Figure 10 and Plate 16). The failure, partly controlled by adversely orientated joints with weak infill, was triggered primarily by leakage

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from a 75 mm diameter galvanized iron fire services pipe at the slope crest (Plates 17 and 18). Four days before the incident when there was no rainfall, minor seepage was observed to be issuing from the lower batter of the slope at the location of the subsequent failure. The leakage probably occurred for some time prior to the failure.

This incident serves as a reminder that leakage from services can lead to the failure of an engineered slope and that there can be tell-tale signs of possible leakage in the form of new seepage during a dry period prior to the landslide.

4.9 The 11 June 1998 Landslide on the Natural Hillside behind No. 7C Bowen Road
(GEO Incident No. HK98/6/8: A landslide on a natural hillside caused by the combined effect of rainfall and leakage from an exposed 40 mm diameter pressurised freshwater main, resulting in some minor damage to the residential building below and temporary evacuation of the residents of five flats)

This minor landslide (about 10 m^3 in volume) on a natural hillside was probably caused by the leakage from an exposed 40 mm pressurised freshwater main along the outer edge of a WSD access road at the slope crest leading to a service reservoir (Figure 11, Plates 19 and 20). The landslide caused minor damage to the residential building below and the residents of five flats were temporarily evacuated following the incident.

There is no evidence of any landslides on the natural hillside over the past several decades based on examination of the available aerial photographs. The environmental effect associated with leakage from the man-made installations, which provided a source of concentrated water ingress into the ground mass, wetting up the soil and reducing its shear strength, probably played a key role in causing the natural terrain landslide.

The detailing of the joints in the water pipe (i.e. 'union joints', or sometimes referred to as 'simple joints') near the crest of the failed natural hillside comprises a coupler for plain-ended pipes (without threading, welding or flanging), and involves tightening the cap nut (with internal threads in the coupler) and squeezing a rubber ring to form a 'watertight' joint and hold the two sections of pipe together (Plate 21). This type of joint can sustain a limited amount of movement.

It was not certain as to whether the leakage was caused by ground movement prior to the landslide resulting in distress to the water main, or whether the leakage occurred in the absence of adverse effects on the water main due to any ground movement prior to the landslide.

This incident highlights the fact that leakage of pressurised water-carrying pipes can lead to failure of natural hillsides. The corresponding potential safety risk posed to developments below a natural hillside (particularly where the natural hillside is of marginal stability and the site setting is adverse) deserves attention. It is noteworthy that as the water main was not adjacent to a catalogued man-made slopes, it was not included in the scope of the exercise on systematic leakage detection of water-carrying services by the responsible Department.

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4.10 The 1 September 2001 Landslide at Slope No. 11NE-B/FR249 below No. 56 Denon Terrace, Tseng Lan Shue

(GEO Incident No. 2001/09/0066: A landslide involving prolonged, intermittent discharge from an unauthorised 100 mm diameter foul water pipe on a fill slope that was previously assessed as being up to the required geotechnical standard)

This landslide (about 50 m^3 in volume) was probably caused by a combination of rainfall and prolonged leakage from an unauthorised, 100 mm diameter, UPVC foul water pipe, affecting primarily a fill slope, which was assessed as being up to the required geotechnical standard (although the presence of loose fill was not known at the time of the previous assessment). An inhabited, registered squatter dwelling comprising a substantial structure located at the slope toe was severely damaged by the landslide (Figure 12 and Plate 22) and the residents were subsequently permanently evacuated.

Site evidence suggests that the unauthorised foul water pipe was likely to have been broken for some time prior to the landslide and that the break was probably caused by illegal dumping of construction debris. Prolonged intermittent discharge from the broken foul water pipe was probably the primary contributory factor to the failure. Another unauthorised 150 mm diameter UPVC pipe collecting surface runoff from the building platform above the slope crest was observed to be discharging directly onto another part of the fill slope outside the landslide scar (Plate 23).

This incident serves as a reminder of the potential hazards posed by uncontrolled discharge from unauthorised water-carrying pipes onto slopes.

4.11 The 4 June 1997 Landslide at Chung Shan Terrace, Lai King Hill Road

(GEO Incident No. MW97/6/15: A large-scale landslide involving the mobile failure of an old, non-engineered, fill slope resulted in complete blockage of Lai King Hill Road and an access road to Chung Shan Terrace)

This large-scale landslide (about 450 m^3 in volume) involved the mobile failure of an old fill slope (formed in the 1930's) and resulted in the complete blockage of Lai King Hill Road and an access road to Chung Shan Terrace. The landslide debris travelled across the access road at the toe and struck a passing vehicle but fortunately no casualties were reported.

The landslide was probably triggered by heavy rainfall with leakage from a 150 mm privately-owned buried water pipe being diagnosed as a key contributory factor. The water pipe was installed at the private development at the slope crest in 1995 to accept both stormwater and foulwater from the buildings (Figure 13 and Plate 24). Tracer tests carried out for the landslide investigation revealed that leakage from the 150 mm water pipe seeped directly into the landslide scar. The effects of leakage from the water pipe were probably exacerbated by the presence of a buried old, retaining wall at about mid-slope, which acted as a dam to groundwater flow. The landslide debris was mobile with a travel angle of about 18°.

The incident was a 'near-miss' with casualties being narrowly avoided and it highlights the hazard posed by sudden sizeable and mobile failure of old loose fill slopes given infiltration resulting from leakage as one of the sources of water ingress.

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4.12 The 17 February 2003 Seepage Incident at Retaining Wall No. 11SW-B/R69 behind Nos. 40 to 52 Wyndham Street

(Heavy seepage observed from the weepholes of a 12 m high old, non-engineered, private masonry wall adjacent to a private building. The seepage was associated with leakage from a 450 mm pressurised water main located about 18 m from the wall crest.)

This case study was described by the Drainage Services Department (DSD, 2003) in their departmental newsletter (see Appendix B).

On 17 February 2003, heavy seepage was reported by the local residents to be ‘jetting out’ from weepholes at about the mid-height of a 12 m high old masonry wall (Figure 14, Plates 25 and 26). Subsequently, WSD carried out chemical tests on samples of the seepage and the results indicated that “the seepage is neither potable nor salt water”. According to WSD, they had also carried out leakage detection tests for “all water mains located in the vicinity” of the masonry wall and no signs of leakage from a water main were identified.

The incident was then referred to the Drainage Services Department (DSD) for further investigation. In response, DSD carried out a comprehensive leakage investigation. This included dye tracer tests of the stormwater and foulwater drains, together with the catchwater, up to 100 m away from the wall, CCTV surveys, monitoring of seepage rates during day-time and night-time to establish the flow pattern, and collection of samples for chemical/organic tests.

DSD specifically approached the GEO for an assessment of the stability of the masonry wall given the strong seepage at mid-height of the wall. They also requested WSD to carry out leakage tests of their mains in the vicinity of the wall and sought assistance from the Buildings Department to inspect pipes and water tanks of the private buildings in the vicinity.

According to the information given in Appendix B, WSD reported that the seepage comprised contaminated fresh water based on their preliminary test results and it was considered by WSD that the source of the seepage was probably discharge from the nearby residential buildings. As a follow-up action, water supply to the adjacent private buildings was shut down in early March 2003. Notwithstanding this, no reduction in the seepage rate from the masonry wall was observed and an alternative source of leakage had to be identified. At about the same time, another complainant alleged that the leakage water had seeped into the basement A/C plant room and that he was concerned about the corresponding hazards.

On 10 March 2003, DSD noticed an unexpectedly high water level in a manhole at Arbuthnot Road, approximately 18 m behind the masonry wall. DSD carried out chemical tests on the water samples, which confirmed that the source was fresh water. This was immediately referred to WSD, who subsequently dug inspection pits in the vicinity. This identified a damaged 450 mm diameter pressurised buried water main (located about 1.5 m below ground surface) next to the manhole, which was eventually confirmed to be the source of the seepage ‘jetting out’ from the old masonry wall.

This incident serves to highlight the importance of prompt and coordinated action by the various responsible parties in locating the source of leakage, especially where a high-consequence slope feature is involved.

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4.13 The 23 November 2004 Water Main Burst Incident at Slope No. 11NE-D/CR15 at Sau Fung Street, Sau Mau Ping

(GEO Incident No. 2004/11/0068: The incident involved the bursting of a 375 mm diameter pressurised, asbestos cement, saltwater main above the crest of an engineered slope feature. Copious amounts of muddy water completely flooded the playground and ground floor of St. Matthew's Lutheran School below.)

At about 12:30 p.m. on 23 November 2004, bursting of a 375 mm diameter pressurised, asbestos cement, saltwater main at about 2 m below ground surface occurred at Sau Fung Street some 6 m beyond the crest of an engineered slope feature (Figure 15 and Plates 27 to 29). A 70 m long section of the block-paved footway on the south side of Sau Fung Street was affected. Copious amounts of water gushed from the burst water main for about an hour, mostly from subsurface seepage, and overtopped the 12 m high caisson wall at the lower portion of the slope. The water flow completely flooded the playground and ground floor of St. Matthew's Lutheran School below.

The water supply was shut down at about 1:30 p.m. Video footage taken by the school showed that the flow rate from the burst water main increased substantially following an initial period of low to moderate flow and that the initially clear discharge became very muddy, indicating the onset of significant internal soil erosion. Based on the post-failure observations, erosion pipes of up to 0.5 m diameter were found in the fill material near the slope surface.

According to WSD, there was no record of any past leakage or bursting of the concerned water main in the vicinity of the slope feature.

This incident highlights the possible havoc that can be brought about by bursting of pressurised, brittle pipes and the need for prompt follow-up action to contain the damage and prevent escalation of the potential consequences.

4.14 The November 2004 Saltwater Main Leakage Incident at Slope No. 11NW-A/FR1 below Tai Po Road

(Seepage occurring from an engineered fill slope. Subsequent investigation and laboratory tests indicated that the source of leakage was from a UPVC saltwater main above the slope crest.)

In November 2004, seepage was noted by WSD's consultant on the uppermost batter of an engineered fill slope below Tai Po Road (Figure 16), which was upgraded by Highways Department (HyD) as part of the Tai Po Road improvement works between 1988 and 1990.

As indicated in WSD's record plans, there is a 150 mm diameter fresh water main and a 100 mm diameter UPVC saltwater main constructed in the early 1990's about 7 m from the slope crest. WSD subsequently carried out leakage detection testing using the leak noise correlation technique on these two mains and the results suggested no signs of leakage. WSD also conducted site chemical tests on samples of the seepage water, which indicated that the seepage was neither potable nor salt water.

In December 2004, the incident was referred to the GEO for further investigation. Site inspection by the GEO noted a wetted area of about 5 m by 35 m within the middle portion of

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the uppermost slope batter (Plates 30 and 31). Additional water samples were collected for laboratory chemical tests. The results indicated that the seepage had a high concentration of chloride ion, suggesting that the seepage might be salt water. In early January 2005, WSD's consultant noted leakages from the saltwater main above the slope crest after observation of leakage from a valve, some distance away. The seepage from the slope ceased after completion of repair works to the saltwater main by WSD in January 2005.

This incident highlights the possible limitations of site chemical tests in helping to identify the actual source of leakage. Also, the leakage was from a pipe that is relatively new and was apparently observed about one month after the commonly used leakage noise correlation technique confirmed the absence of leakage at the time of testing.

5. DISCUSSION

5.1 General

A review of selected case studies in recent years has reaffirmed that uncontrolled leakage from water-carrying services can adversely affect the stability of engineered man-made slopes and non-engineered man-made slopes, as well as natural hillsides.

The consequences of landslides caused by leakage of buried water-carrying services can be severe as the failures can be sizeable and can involve fast-moving debris, given the possibility of a significant build-up of groundwater pressures prior to collapse. Although in most cases there will be some prior observable warning of a potential failure following prolonged leakage from services (e.g. new or sudden increase in seepage), in practice this may go un-noticed without close inspections. Abrupt slope failures caused by major leakage (or bursting) giving rise to mobile debris are possible. The failure mechanisms may involve liquefaction of loose material (e.g. collapse of metastable loose fill or loose colluvium upon water ingress), collapse of thin masonry walls (as in the case of the 1994 Kwun Lung Lau landslide), major washouts caused by bursting of pressurised mains, or possible blow-out type failures associated with the sudden release of a large build-up of groundwater pressure (e.g. Bolton et al, 2003).

The cases covered in this review indicate that the zones of influence of leakage from water-carrying services (Table 2) can range from being close to the slope to being a considerable distance away, which is likely to be a function of the hydrogeological setting of a given site and whether the water-carrying services of concern are pressurised or not. The use of simple empirical correlations between the zone of influence and, say, the slope height is generally crude and the limitations should be borne in mind, as highlighted in the publication by Works Branch (1996).

Leakages from buried water-carrying services located within loose fill can adversely affect the stability or performance of fill slopes that have been provided with a 3 m thick recompacted fill cap (which is generally regarded as being up to the required safety standards), particularly where loose fill remains below the recompacted cap. Due attention should be given to mitigating the potential hazard of water ingress into the underlying loose fill arising from leaky services.

Key observations highlighted by the present review are discussed below.

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5.2 Investigation, Design and Construction Stages

In slope assessment/upgrading projects, the detailed examination and investigation of water-carrying services adjacent to slopes are sometimes taken to be the responsibility of the works contractors and hence left to the construction stage. There may be room to enhance practice in this respect from a technical point of view. An integrated site assessment, including an evaluation of all possible water pathways affecting the slope (including buried services, cross-road culverts, effect of topographical conditions on local surface water flow, etc.) should preferably be carried out during the investigation/design stage. In addition to the establishment of the basic data on the nature, dimensions and alignment of all known services, other key information, such as leakage history, findings of leakage tests, age, construction details (including pipe material and jointing as well as details of ducting systems if present), operational pressure in the case of a pressurised pipe, etc., should also be established as far as possible. In this regard, it is important to obtain all the latest relevant information.

The need for a thorough examination of the prevailing maintenance condition of the water-carrying services together with confirmation of details, such as pipe alignment where appropriate, should be carefully considered. Techniques that can be used for the above purposes include CCTV survey. Pipe detection equipment or geophysical surveys may prove useful in checking for possible presence of uncharted pipes, especially in sites with abandoned old developments or abandoned squatters dwellings in the vicinity as established from old maps or aerial photographs.

Diversion of water-carrying services away from a slope, if feasible, is generally the most appropriate option (i.e. hazard elimination) from a slope stability point of view and this should be pursued rigorously, especially for high-consequence slopes. Where a ducting system is to be provided for the water-carrying services as a precautionary measure instead of diversion, due attention should be given to the proper detailing of the ducting system, including the discharge points. A defective ducting system which could lead to concentrated water ingress into the slope due to leakage, is liable to give rise to a false sense of security. Common approaches in conventional practice involve the use of a trench lined with geotextile and backfilled with 10 mm single-sized aggregates (WSD Standard Drawing No. 1.20C, see Appendix C) or the construction of a concrete trough. The detailing should consider the robustness of the proposed system, including the discharge points, taking into account the site setting, nature of the water-carrying services and the seriousness of the consequence in the event of a slope failure. For example, the use of no-fines concrete to embed the perforated UPVC drainage pipes may be liable to result in partial blockage of the pipes.

At sites where ground movements or stress concentration to the buried services are envisaged (e.g. pipes traversing a valley infilled with a large depth of loose material without proper compaction or pipes with inadequate cover and subject to heavy vehicular traffic loading), damage and leakage of the pipes may recur from time to time. This may increase the rate of deterioration of the water-carrying services. The situation is exacerbated if the pipe is old and comprises brittle material (such as asbestos cement), especially with poor jointing detailing/arrangement and insufficient thrust blocks at bends.

The hazards of leakage on slope stability may not be satisfactorily resolved by means of geotechnical engineering measures alone, particularly for major water-carrying installations. Where appropriate, consideration should be given to integrating the upgrading works for

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substandard slopes and the necessary improvement works for existing water-carrying services (e.g. under the LPM Programme), if diversion is not a feasible option, to facilitate the coordinated action. This would call for close liaison between the concerned parties at an early stage of the project.

Current practice with regard to installation of buried water-carrying services is generally to surround the pipes with backfill with limited compaction in order to control the compaction stresses on the pipes and avoid damage. This is followed by the placement of a well-compacted soil fill cap, e.g. with a minimum of 95% relative compaction as stipulated in the General Specification for Civil Engineering Works (Hong Kong Government, 1992). However, the capping layer is sometimes subject to inadequate compaction (possibly because of concerns about potential damage to the pipe caused by 'over-compaction', in which case the backfill is liable to lead to subsequent settlement and cracking, which in turn can more readily allow water ingress into the slope. Close site control of the backfilling operation is called for. Possible improvement to the detailing may involve the provision of protective measures above the pipe (e.g. a blinding layer or precast blocks such as concrete or Rubbersoil), where considered appropriate, to prevent damage to the pipe potentially caused by compaction of the capping layer.

5.3 Follow-up to Sudden Seepages or Suspected Leakages

As a follow-up to the Hang Lok Lane incident (Section 4.2), an Advice Note (see Appendix A) was issued by the GEO in 2000 to Government Departments responsible for water-carrying services on actions with regard to suspected leakages leading to potential slope failure. Where the source of continued leakage cannot be located in a timely manner for immediate repair, the inspecting geotechnical engineer should consider the need for, and practicality of, repeated inspections of the affected slope feature with sustained seepage to review if there are signs of progressive deterioration, which may be brought about by continued water ingress and possible internal erosion, particularly for high-consequence slopes. Close liaison should be maintained with the Government Departments responsible for slope maintenance (or Buildings Department for private slopes) with regard to the need for precautionary measures, e.g. cordoning off selected areas, warning signage, etc. More drastic actions, such as consideration of the need for lane closure or temporary evacuation of buildings, may need to be considered where there is specific knowledge about the affected slope feature that may give rise to cause for concern, e.g. a thin and old masonry wall that is liable to collapse in a brittle manner without much prior warning.

The more recent landslide incidents involving slopes affected by water-carrying services covered in this review were mainly concerned with services close to the slope crest. However, the possible risk of water-carrying services at a significant distance away from the slope crest having a potential adverse impact on slope stability should always be borne in mind, especially for high-consequence slopes. Guidance on the potential zone of influence with respect to a slope is given in the “Code of Practice on Inspection & Maintenance of Water Carrying Services” (Works Branch, 1996), and more detailed guidance is presented in the GEO’s Advice Note, which has been reproduced in Appendix A. It is noted that in the 13 cases reviewed in this study, the proximity of the leaky services (Table 2) was within the potential zone of influence as highlighted in the above GEO’s Advice Note (viz. within 20 m or a distance corresponding to the height of the feature, whichever is larger). Where sudden and persistent seepage from a slope feature is observed, it is reasonable to give priority

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attention to those water-carrying services in close proximity to the slope crest (say, nominally within a distance equal to the vertical height of the feature as a rule of thumb). Where this initial check fails to locate the sources of possible leakage, the search should be progressively extended to other water-carrying services further away. The possibility of the source of the leakage being located at a significant distance away from the affected slope feature should be borne in mind, as exemplified by the 1994 Kwun Lung Lau landslide disaster.

In the case of the 2003 Wyndham Street incident, it took some three weeks to pin down the leaking water main since the first report of strong seepage from an old masonry wall by the general public. In the event, the leakage (at 18 m away from the slope crest) was not identified through a systematic investigation by the party responsible for the water main. It was fortuitous that the continued strong seepage did not lead to instability of the old 12 m high masonry wall in a built-up area, which otherwise could have resulted in serious consequences. There is merit to review the scope for enhanced coordination between Government Departments and the need for elaborated guidance on comprehensive and prompt checking for suspected leakages, particularly where the stability of high-consequence slopes and public safety are potentially at stake.

Major or prolonged leakage from buried water-carrying services, or bursting of pressurised pipes, is liable to lead to significant internal erosion of the ground mass. If significant internal soil erosion occurs, it can be difficult to locate the erosion pipes and treat them properly, especially where they are at great depth. Major internal erosion can adversely affect the hydrogeological setting of a slope and render it more vulnerable to rain-induced failure. Also, there may be the possibility of collapse of significant erosion pipes, which could complicate the groundwater flow and lead to build-up of local water pressures as well as ground settlement.

In two of the incidents reviewed, 'simple' chemical tests on samples of seepage obtained from the slopes gave negative results, whereas subsequently the water-carrying services were confirmed to be leaking. In one of the cases, subsequent laboratory tests on water samples indicated a high concentration of chloride, which contradicted the results of the 'simple' site chemical tests and was consistent with the subsequent findings of a leaky saltwater main.

According to the WSD, there are limitations in the current 'simple' chemical tests used on site to check for leakages, particularly in cases where the potable water or salt water is 'contaminated', e.g. with groundwater, etc. The current 'simple' chemical tests can provide indicative results promptly on site, which is probably adequate for the majority of the cases. However, based on the present review, there would seem to be scope for examining the need for further guidance on a suitable testing strategy (e.g. a staged approach) for certain circumstances, such as where all the current suite of 'simple' chemical tests by the various authorities have apparently failed to identify the source of leakage and yet the leakage still persists.

5.4 Water-carrying Services Affecting Natural Hillsides Close to Developments

Apart from man-made slopes, the stability of natural hillsides can also be adversely affected by leakage from water-carrying services. It is noted that some water-carrying services in close proximity to natural hillsides flanking developments and major roads may not necessarily fall within the current scope of the systematic inspection and maintenance programme for water-carrying services adjoining slopes as these are not catalogued slopes. Such a hillside setting could pose a potential hazard of quasi-natural hillside failure, which may be triggered by pipe leakage or pipe bursting, especially where the natural hillside is of marginal stability. The scale of this potential problem is not known based on currently available information.

6. CONCLUSIONS AND RECOMMENDATIONS

An overall review of the recent notable incidents involving slopes affected by leakage of water-carrying services re-affirms the importance of paying due attention to the corresponding potential slope hazards, as leakage has affected not only non-engineered man-made slopes but also engineered man-made slopes and natural hillsides. The findings indicate that the key problems are generally associated with ageing pipes, inadequate investigation of the adjacent water-carrying services during the design stage of the slope upgrading works, together with inadequate attention to detailing.

The present review points to the need for attention to be given to the following areas:

Technical Considerations and Detailing

(a) Review the detailing of leakage collection/detection systems for buried services affecting slopes and promulgate guidance on improved robustness as appropriate.

(b) Review the reliability and resolution of the current chemical test methods, and examine the need for further guidance on the adoption of a suitable testing strategy (e.g. a staged approach) where appropriate.

(c) Where there are buried water-carrying services in close proximity to a high-consequence slope, prescriptive raking drains should be considered as a contingency measure to minimise the potential adverse effects of leakage.

(d) The use of pipe joints that are prone to differential ground movement should be treated with extreme caution, especially in a vulnerable site setting (e.g. sites underlain by a large depth of loose fill of variable thicknesses, e.g. across an infilled valley) involving high-consequence slopes.

(e) Potential leakage from buried water-carrying services located within loose fill can adversely affect fill slopes that have been provided with a 3 m thick recompacted fill cap, particularly where loose fill remains below the recompacted cap. Due attention should be given to mitigating the potential hazard of water ingress into the underlying loose fill arising from leaky services.

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(f) Close site control of the operation of backfilling to trenches for water-carrying services is called for to avoid potential problems of water ingress through inadequately compacted backfilling material.

(g) Care should be exercised in ensuring that the adequacy of the investigation of the zone of influence following bursting of water-carrying services, especially where pressurised water mains are involved, so that proper treatment works can be carried out.

Maintenance

(a) It would be prudent for the EI to review any new information on the leakage history of the adjacent water-carrying services since the previous EI.

System Aspects

(a) Promulgate to practitioners the good practice of providing feedback on information relating to the actual locations of buried services if these are different to that shown on existing drawings (including uncharted and/or abandoned drains, information on leakage collection/detection systems, etc.) for the relevant authorities to update their records.

(b) Review the maintenance and updating of information related to water-carrying services in the Slope Information System.

(c) Review the need for updating of the GEO’s 'Advice Note to Government Departments responsible for Water-Carrying Services, on Actions with regard to Leakages, to avoid Risk of Slope or Retaining Wall Failures', which was issued in May 2000.

(d) Consider the practicality of incorporating selected water-carrying services in close proximity to natural hillsides affecting developments into the programme of systematic inspections and maintenance in addition to those in close proximity to catalogued man-made slopes.

(e) Consideration should be given to integrating the upgrading works for substandard slopes and the necessary improvement works for buried water-carrying services in close proximity to a slope (if diversion is not feasible), where appropriate, in order to facilitate coordinated action.

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Table 1 - List of Incidents Involving Leakage or Bursting of Buried Water-carrying Services

GEO Incident No.	Date of Incident	Title of Report	Study Report No.
MW98/2/1	8 February 1998	Detailed Study of the Landslide at Hang Lok Lane on 8 February 1998	LSR 15/98
CK98/4/1	9 April 1998	Detailed Study of the Distress Observed in Slope No. 11NE-D/F10 below Hiu Kwong Street, Sau Mau Ping on 9 April 1998	LSR 4/99
MW2000/1/7	14 January 2000	Detailed Study of the Landslide on Slope No. 11NW-A/FR84 below Castle Peak Road near Kau Wah Keng Village	LSR 10/2001
MW2000/8/9	27 August 2000	Detailed Study of the 27 August 2000 Landslide Incident at Slope No. 11NW-A/FR43 below Castle Peak Road near Lai Chi Kok Hospital	LSR 1/2002
Nil	18 June 2000	Detailed Study of the Seepage Incident at Feature No. 11SW-A/R625 and Ground Subsidence behind Slope No. 11SW-A/FR12 near Oaklands Avenue on 18 June 2000	LSR 2/2002
2001/12/0123	14 December 2001	Detailed Study of the 14 December 2001 Washout Incident below Pokfield Road, Kennedy Town (Revision 1).	LSR 7/2002
Nil	7 June 1999	Detailed Study of the Landslide below the Benjamin Franklin Centre, Chinese University of Hong Kong on 7 June 1999	LSR 4/2000
HK98/6/8	11 June 1998	Detailed Study of the Landslide behind 7C Bowen Road on 11 June 1998	LSR 19/99
2001/09/0066	1 September 2001	Detailed Study of the 1 September 2001 Landslide on Slope No. 11NE-B/FR249 below No. 56 Denon Terrace, Tseng Lan Shue, Sai Kung	LSR 3/2003
MW97/6/15	4 June 1997	Detailed Study of the Landslide at Chung Shan Terrace, Lai King Hill Road on 4 June 1997.	LSR 3/98
Nil	17 February 2003	The 17 February 2003 Seepage Incident at Retaining Wall No. 11SW B/R69 behind Nos. 40 to 52 Wyndham Street	DSD Channel (DSD Newsletter)
2004/11/0068	23 November 2004	The 23 November 2004 Water Main Burst Incident at Slope No. 11NE-D/CR15 at Sau Fung Street, Sau Mau Ping	MGSL ROLI and Brief note
Nil	November 2004	The November 2004 Leakage Incident Affecting Slope No. 11NW-A/FR1 below Tai Po Road	MGSL ROLI and Brief note

Table 2 - Correlation Between the Location of Leakage and Slope Height (Sheet 1 of 2)

Case	Maximum Height of Slope Feature (H)	Horizontal Distance between Leaking point and Slope Crest (L)	Pipe/Drain information	Height/Distance (L/H)
The 23 July 1994 Landslide at Kwun Lung Lau	10.6 m	~40 m	150 mm ø concrete stormwater drain	3.8
The 8 February 1998 Landslide at Hang Lok Lane	9 m	~3 m	~75 mm ø pressurised GI fresh water main	0.33
The 9 April 1998 Distress below Hiu Kwong Street	30 m	~20 m	400 mm ø pressurised saltwater main	0.66
The 14 January 2000 Landslide below Castle Peak Road near Kau Wah Keng Village	22.5 m	Within slope	900 mm ø pressurised steel water main	-
The 27 August 2000 Landslide below Castle Peak Road near Lai Chi Kok Hospital	~7.5	Within slope	150 mm ø pressurised cast iron water main	-
The 18 June 2000 Seepage and Ground Subsidence Incident near Oaklands Avenue	15 m (11SW-A/FR12)	Within slope No. 11SW-A/FR12	600 mm to 1200 mm ø concrete stormwater drain	-
	7.5 m (11SW-A/R625)	26 m from Feature No. 11SW-A/R625		3.5
The 14 December 2001 Landslide below Pokfield Road	23.2 m	~3.5 m	80 mm ø pressurised fresh water main	0.15
The 7 June 1999 Landslide at Chinese University	14.5 m	~6 m	75 mm GI fire services main	0.4

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Table 2 - Correlation Between the Location of Leakage and Slope Height (Sheet 2 of 2)

Case	Maximum Height of Slope Feature (H)	Horizontal Distance between Leaking point and Slope Crest (L)	Pipe/Drain information	Height/Distance (L/H)
The 1 September 2001 Landslide at Denon Terrace, Tseng Lan Shue	5 m	Within slope	100 mm ø UPVC foul water pipe	-
The 4 June 1997 Landslide at Chung Shan Terrace	22 m	~5 m	150 mm ø UPVC pipe	0.23
The 17 February 2003 Seepage Incident at Wyndham Street	12 m	~18 m	450 mm ø CI fresh water pipe	1.5
The 23 November 2004 Water Main Burst Incident at Sau Mau Ping	18 m	~ 5 m	375 mm ø pressurised asbestos cement saltwater main	0.28
The November 2004 Saltwater Main Leakage Incident below Tai Po Road	44 m	~ 7 m	100 mm ø UPVC saltwater main	0.16

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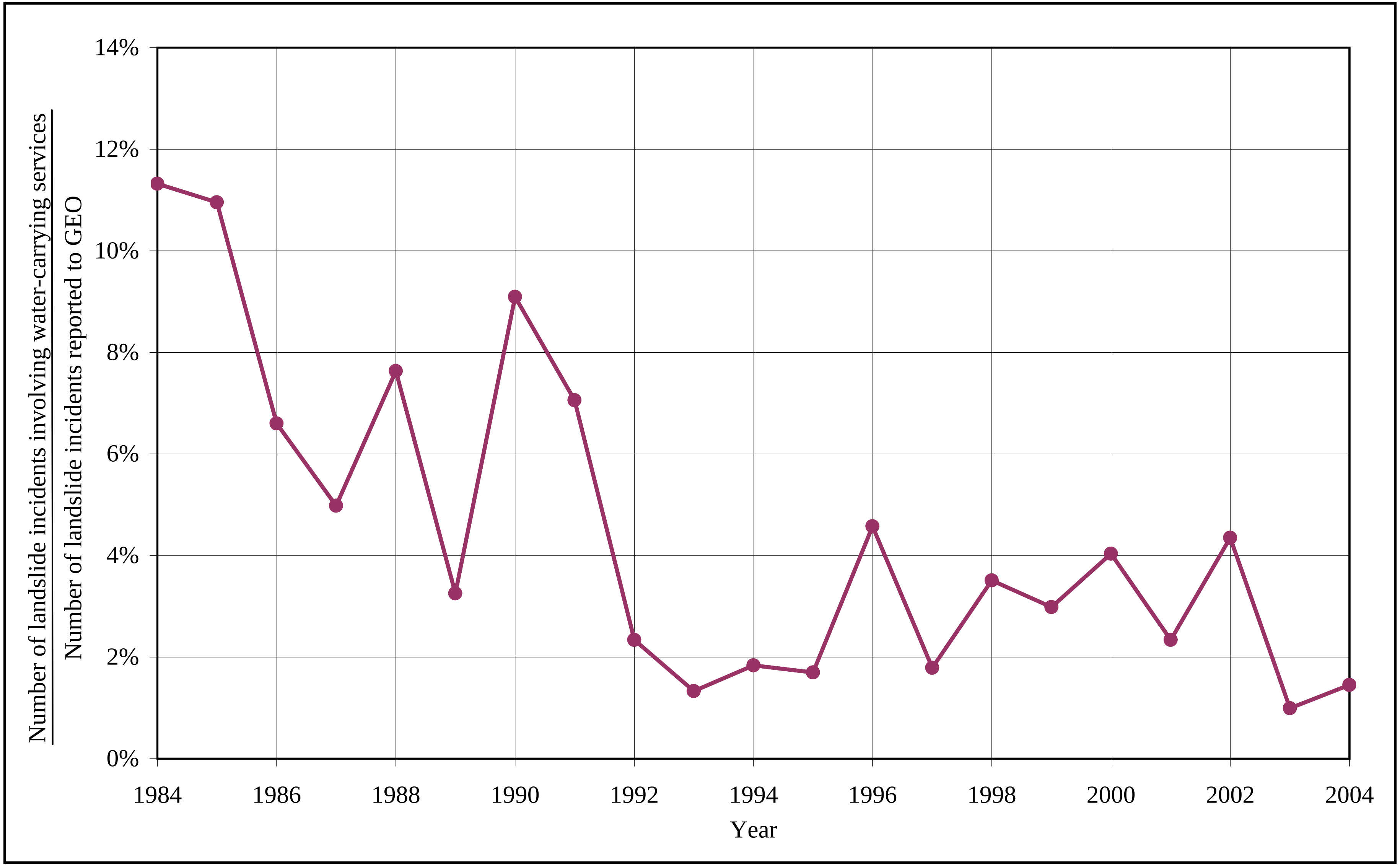

Figure 1 - Landslide Incidents Involving Water-carrying Services

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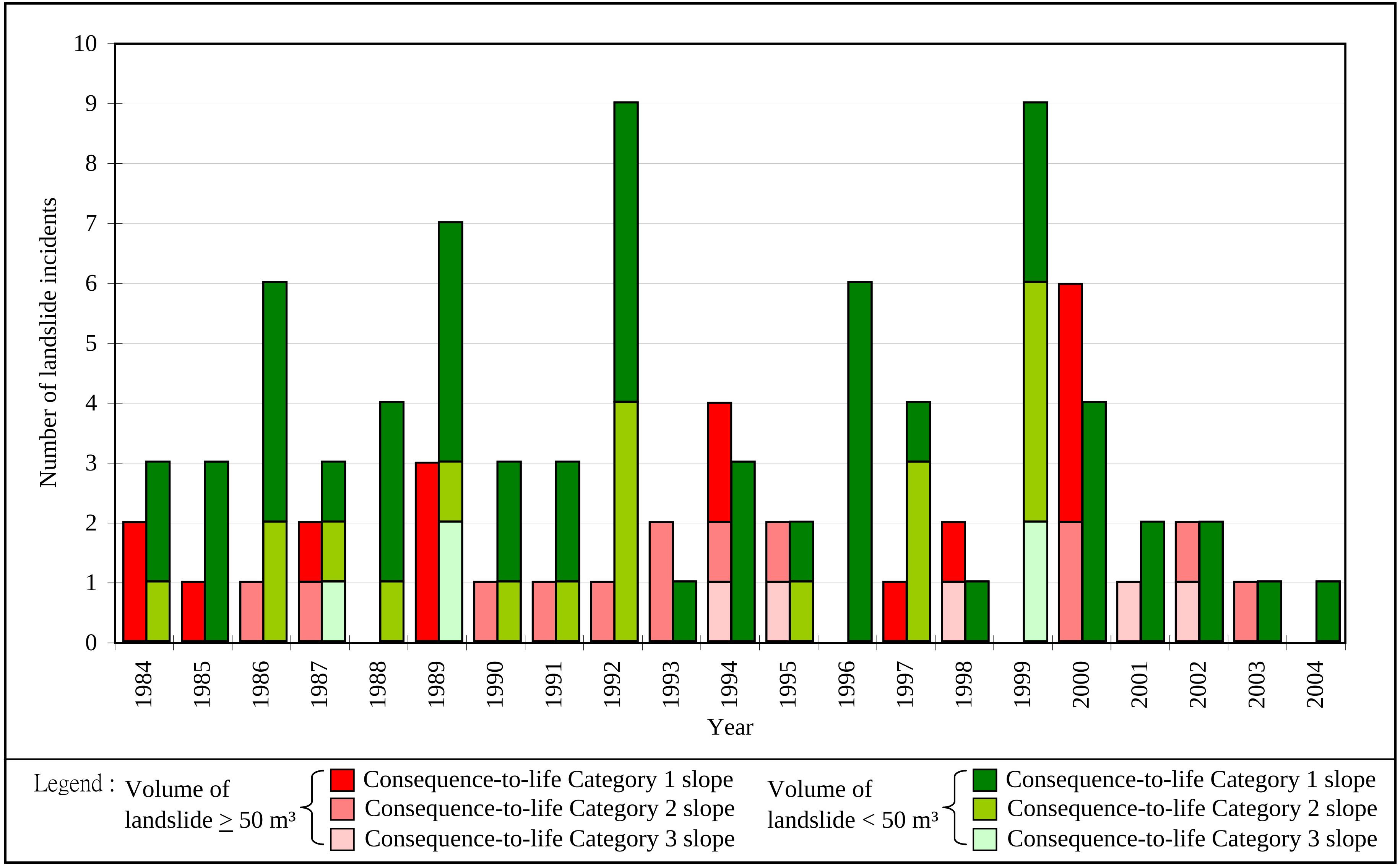

Figure 2 - Consequence-to-life Category of Registered Slopes for Landslide Incidents Involving Water-carrying Services

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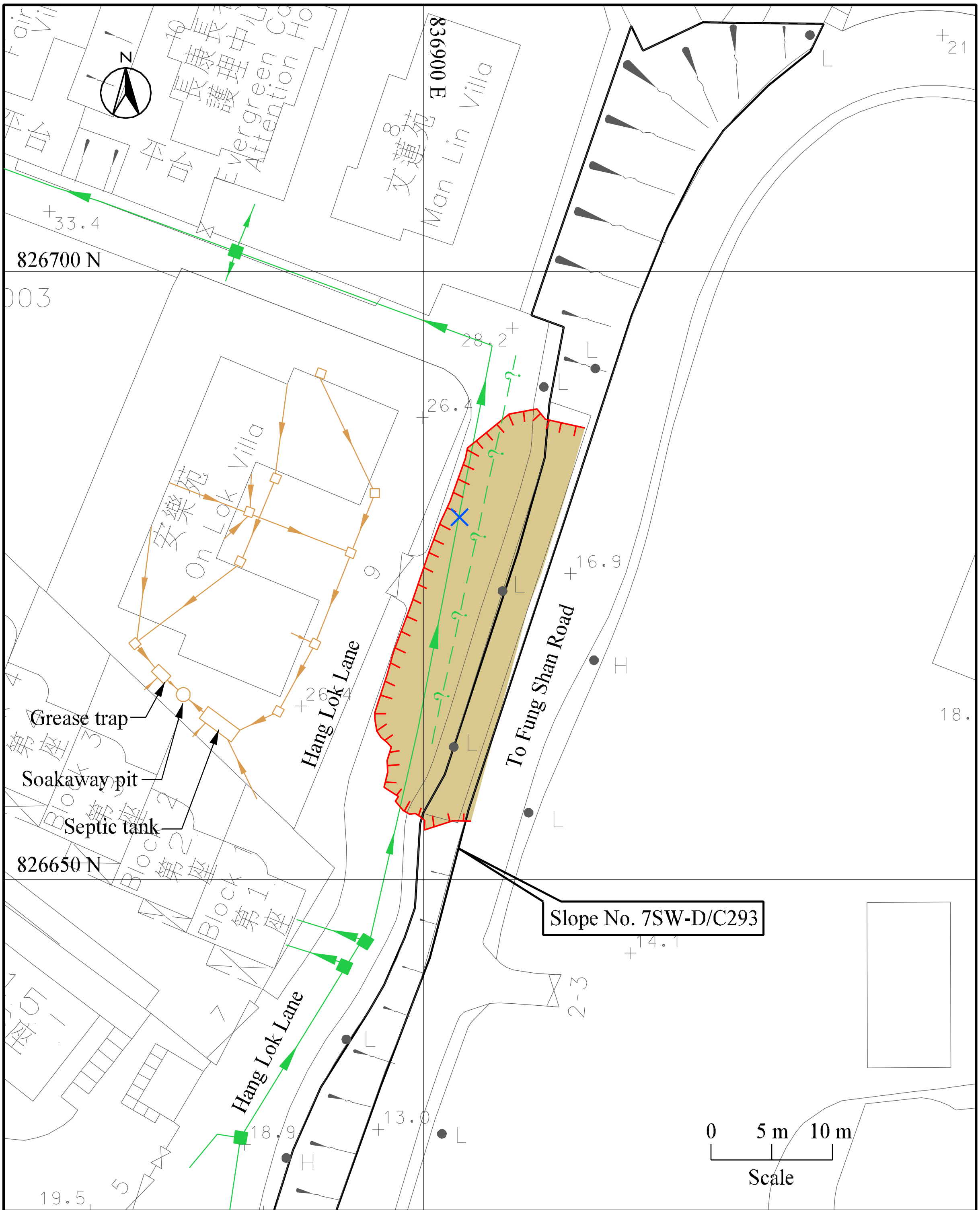

Legend :

- Location of bursting
- Landslide scar
- Alignment of underground 150 mm dia. water pipe inside On Lok Villa
- Probable alignment of 75 mm (3-inch) dia. G.I pressurised fresh water main
- Probable alignment of 50 mm (2-inch) dia. water pipe

Note : This figure is based on information extracted from Landslide Study Report No. LSR 15/98.

Figure 3 - The 8 February 1998 Landslide at Hang Lok Lane

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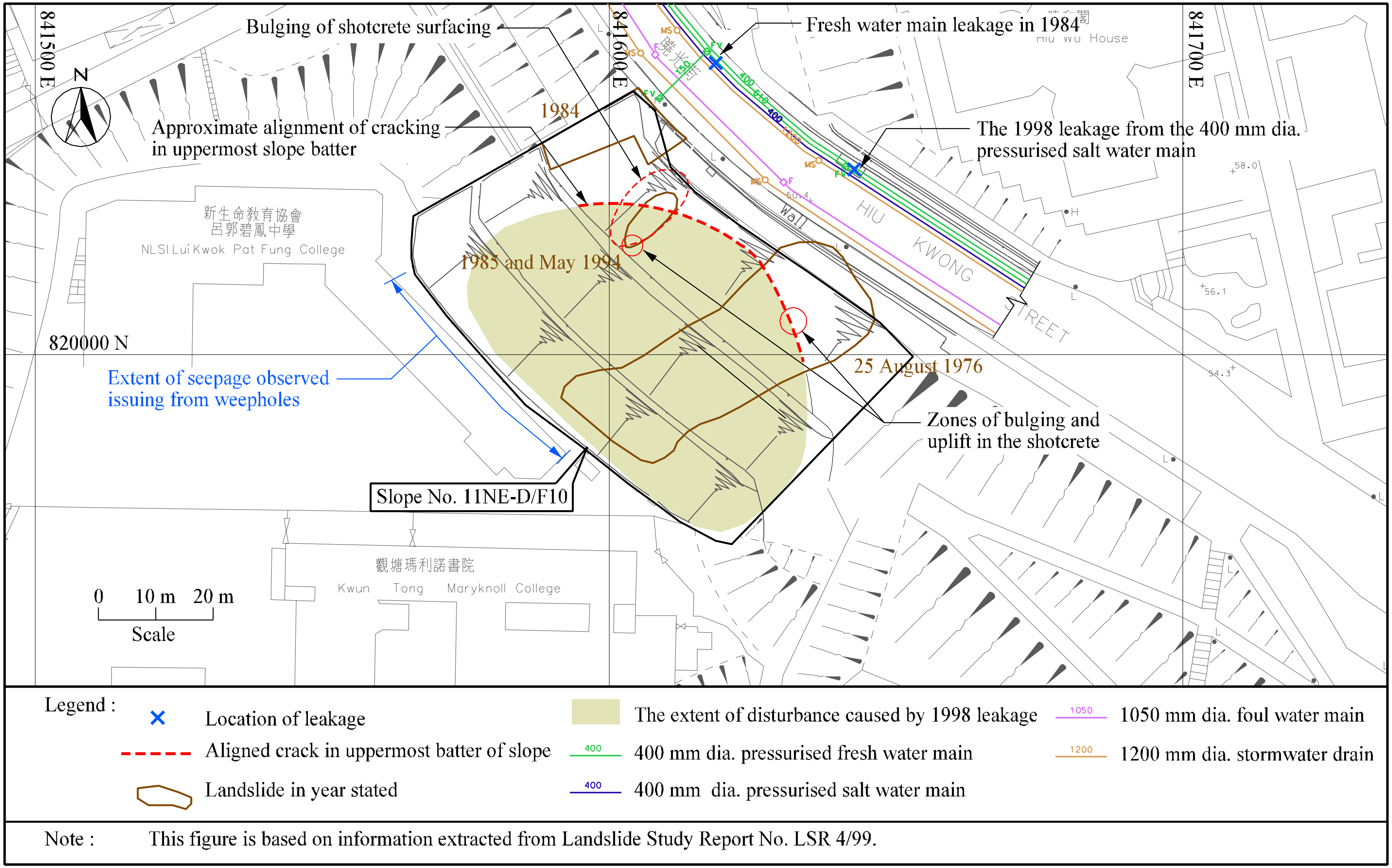

Figure 4 - The 9 April 1998 Distress at Slope No. 11NE-D/F10 below Hiu Kwong Street

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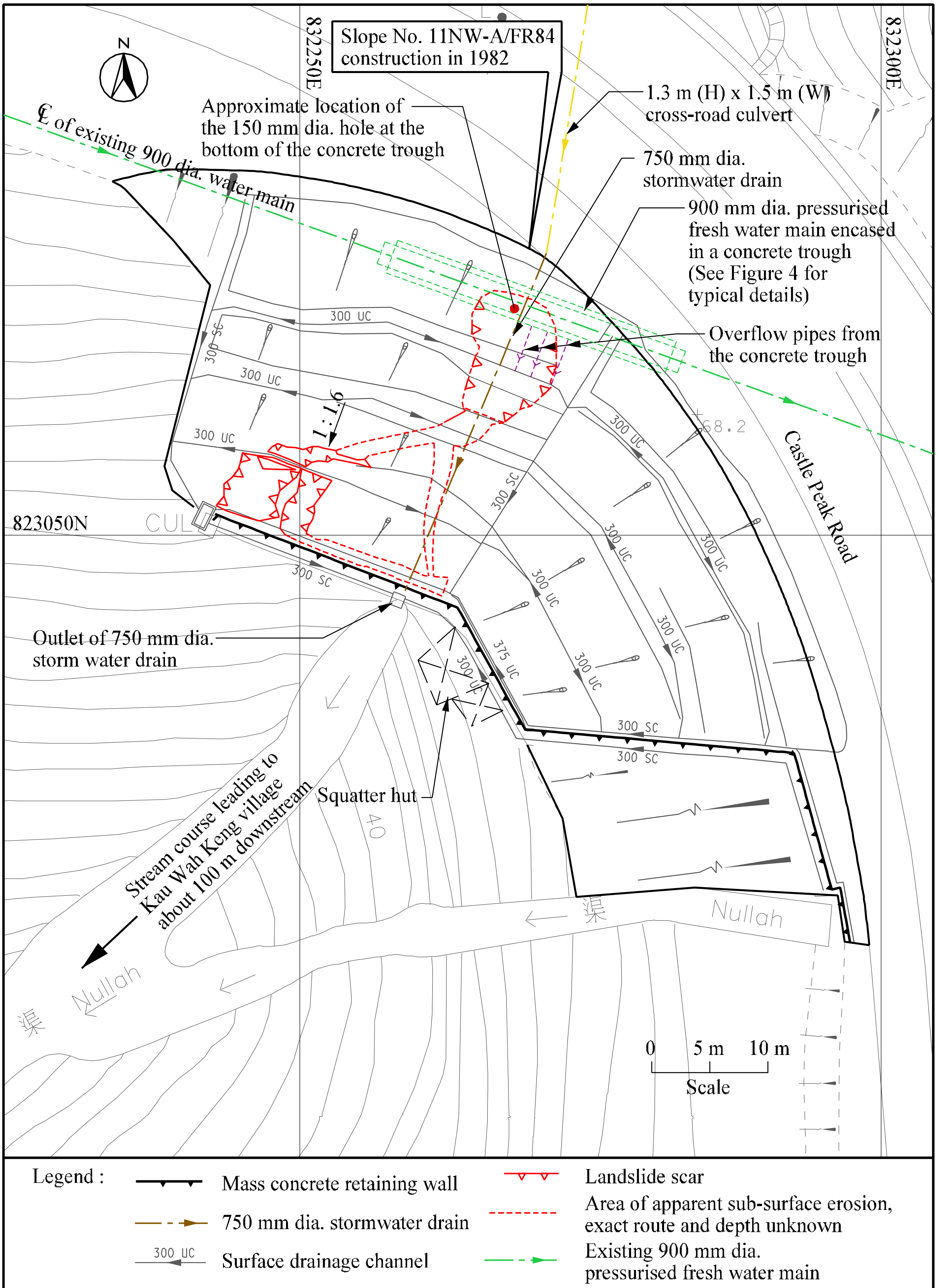

Note : This figure is based on information extracted from Landslide Study Report No. LSR 10/2001.

Figure 5 - The 14 January 2002 Landslide at Slope No. 11NW-A/FR84 below Castle Peak Road near Kau Wah Keng Village

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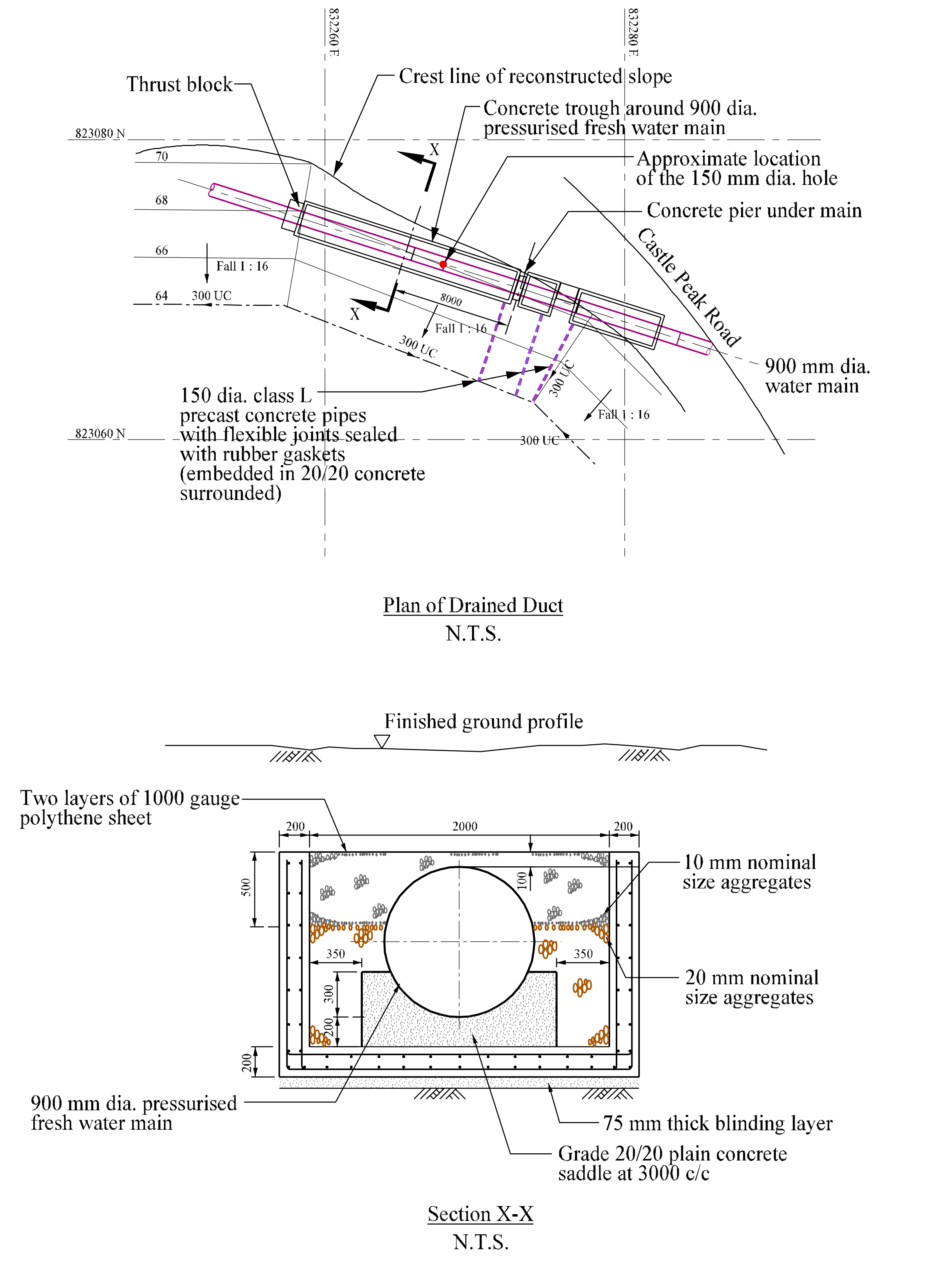

Note : This figure is based on information extracted from Landslide Study Report No. LSR 10/2001.

Figure 6 - Details of Leakage Collection/Detection System near Kau Wah Keng Village

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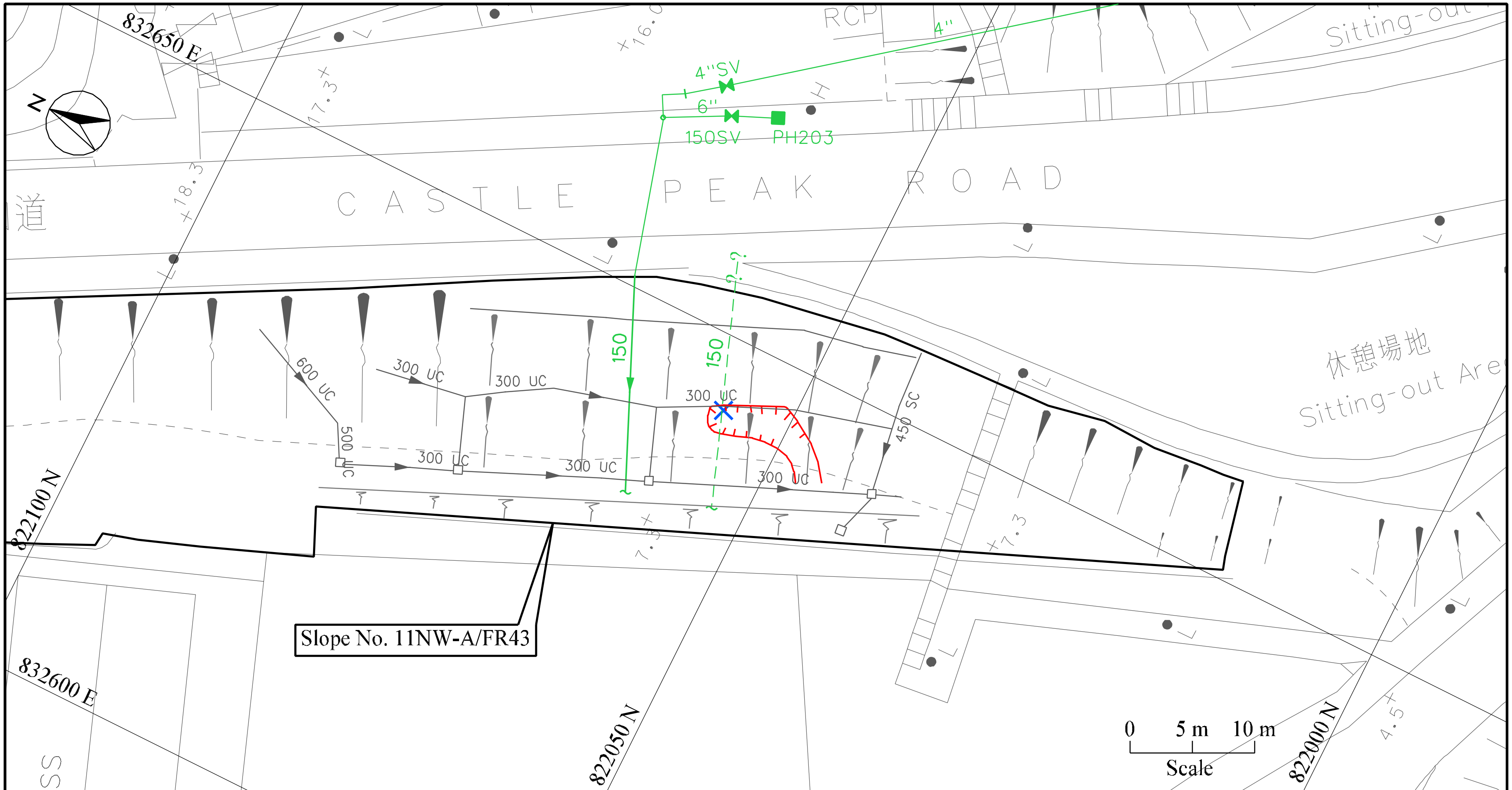

Legend :

Location of leakage	150 mm dia. pressurised fresh water main based on WSD record	300 UC	300 mm U-channel
Landslide scar	150 mm dia. pressurised fresh water main not shown on WSD record		

Note : This figure is based on information extracted from Landslide Study Report No. LSR 1/2002.

Figure 7 - The 27 August 2000 Landslide below Castle Peak Road near Lai Chi Kok Hospital

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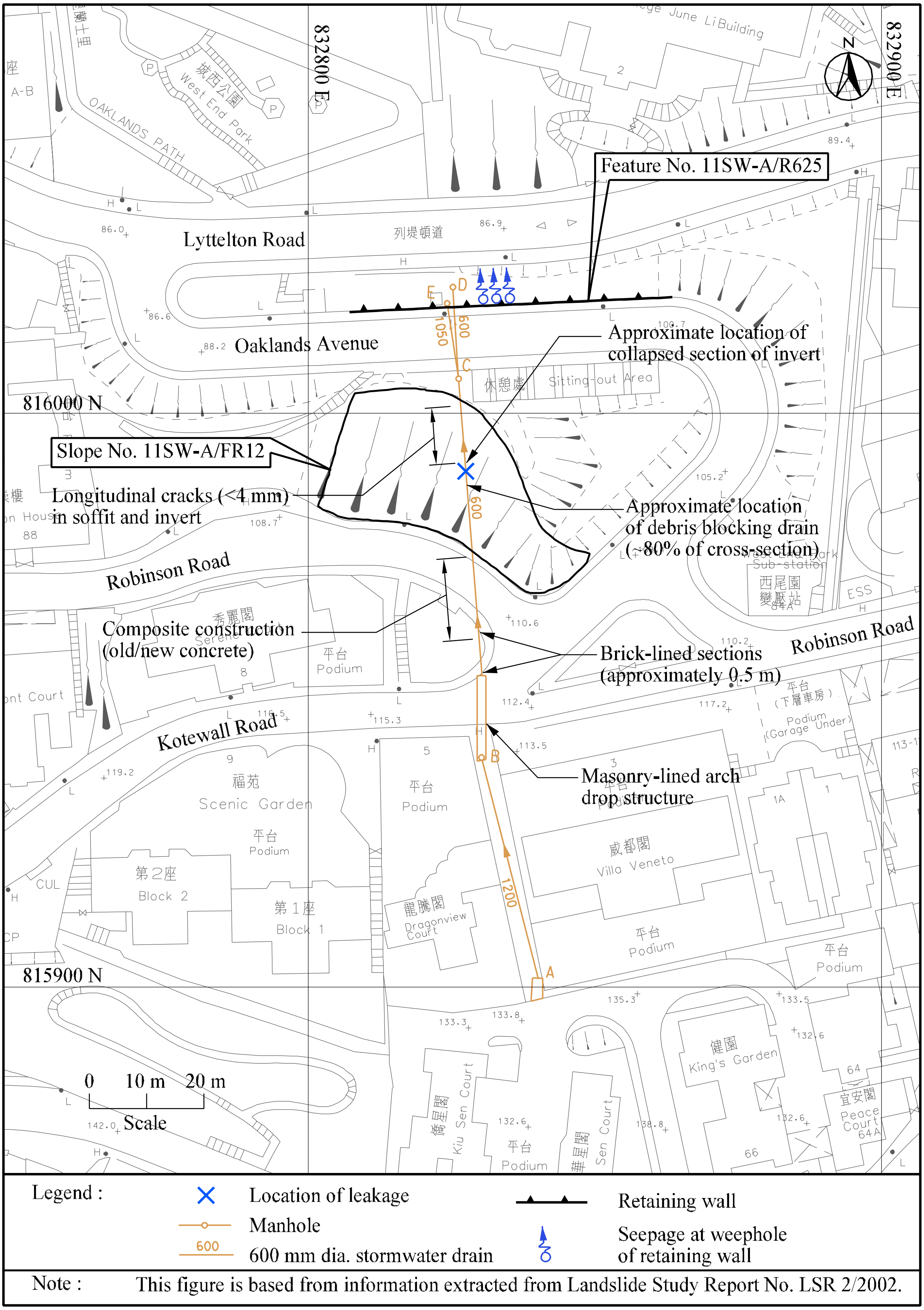

Figure 8 - The 18 June 2000 Seepage Incident at Slope No. 11SW-A/R625 and Ground Subsidence behind Slope No. 11SW-A/FR12 near Oaklands Avenue

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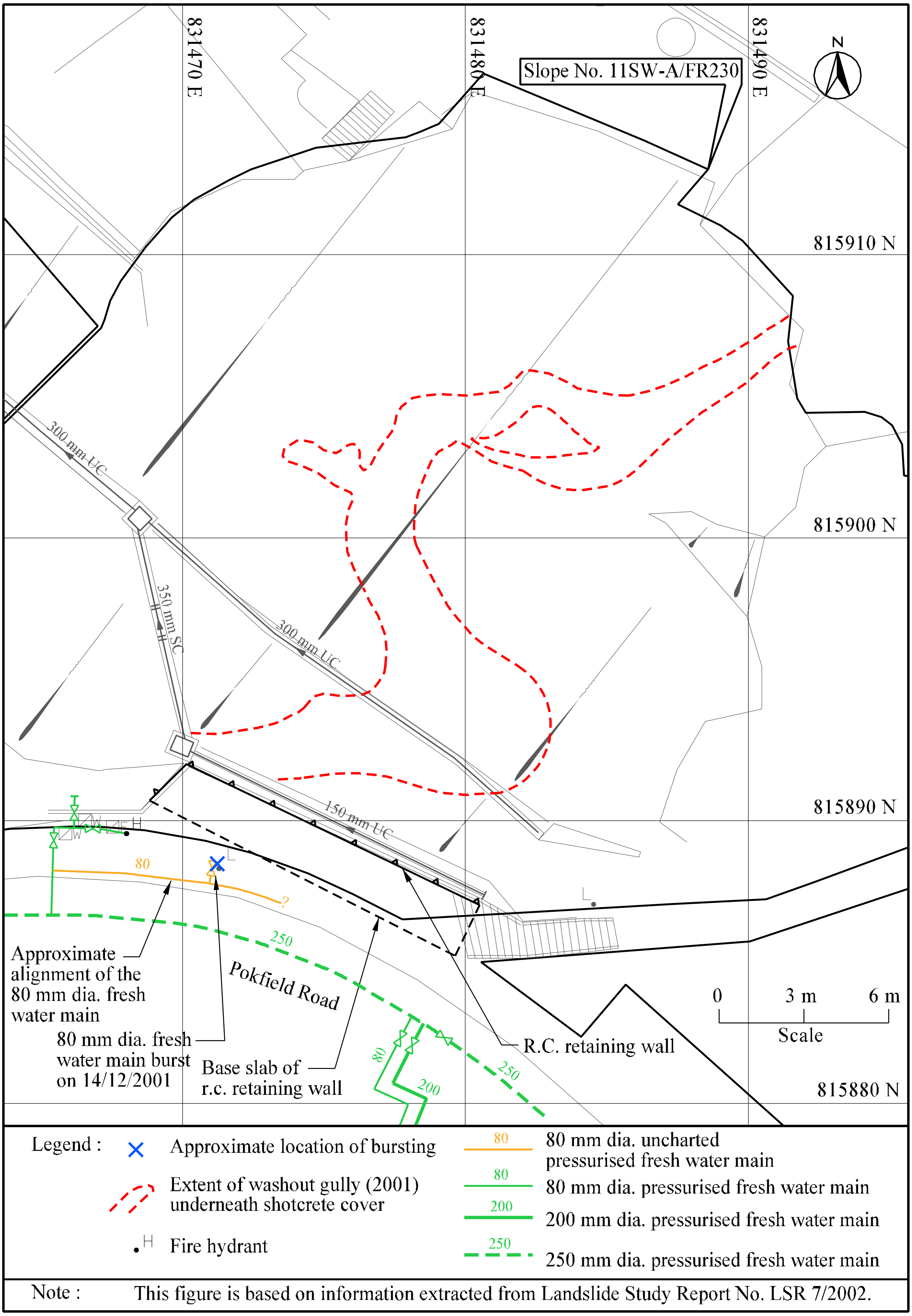

Figure 9 - The 14 December 2001 Landslide at a Fill Slope below Pokfield Road

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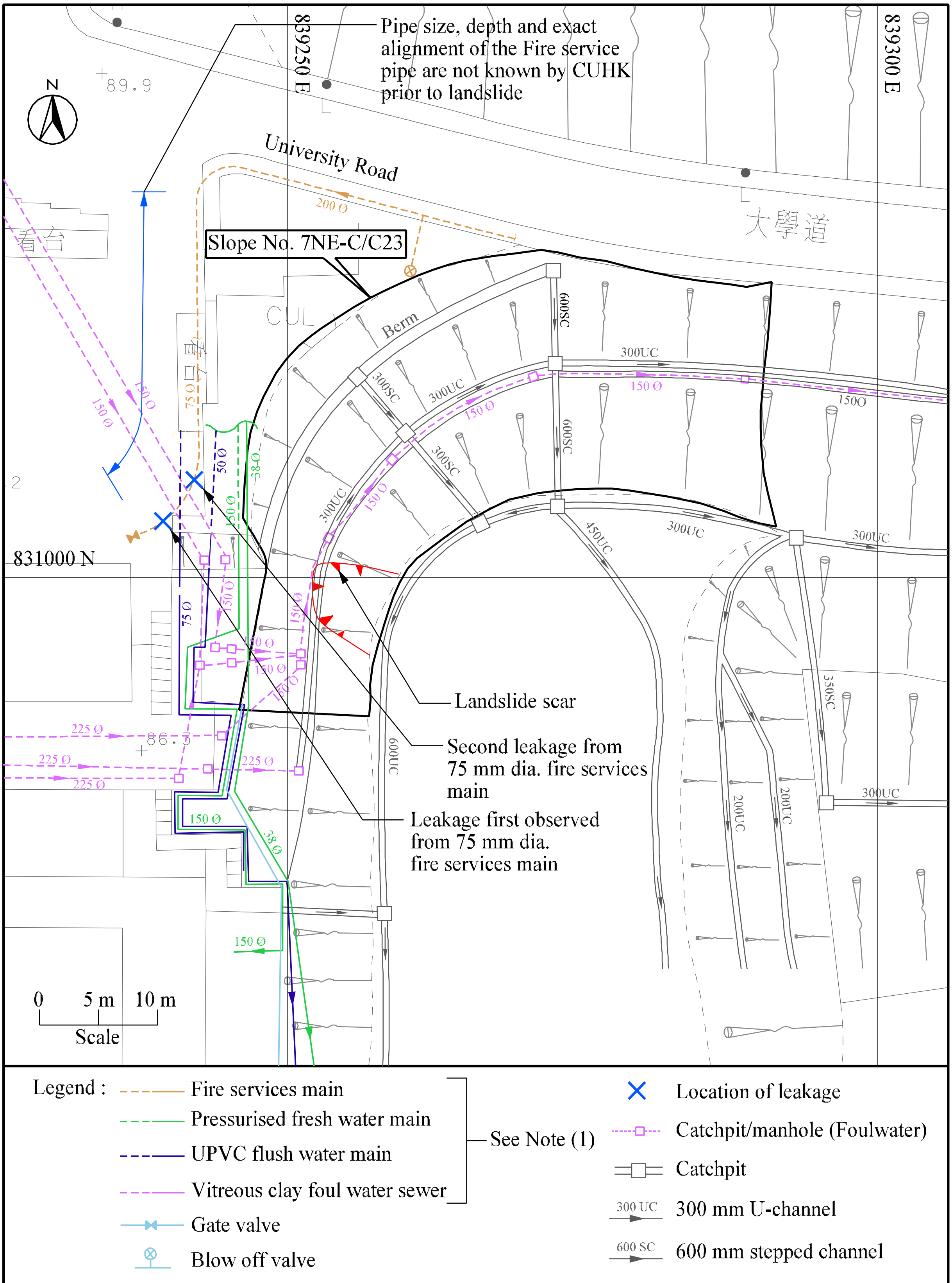

Notes :
(1) Solid line indicates above ground services, dashed line indicates buried service.
(2) This figure is based on information extracted from Landslide Study Report No. LSR4/2000.

Figure 10 - The 7 June 1999 Landslide at Slope No. 7NE-C/C23 below Benjamin Franklin Centre, Chinese University

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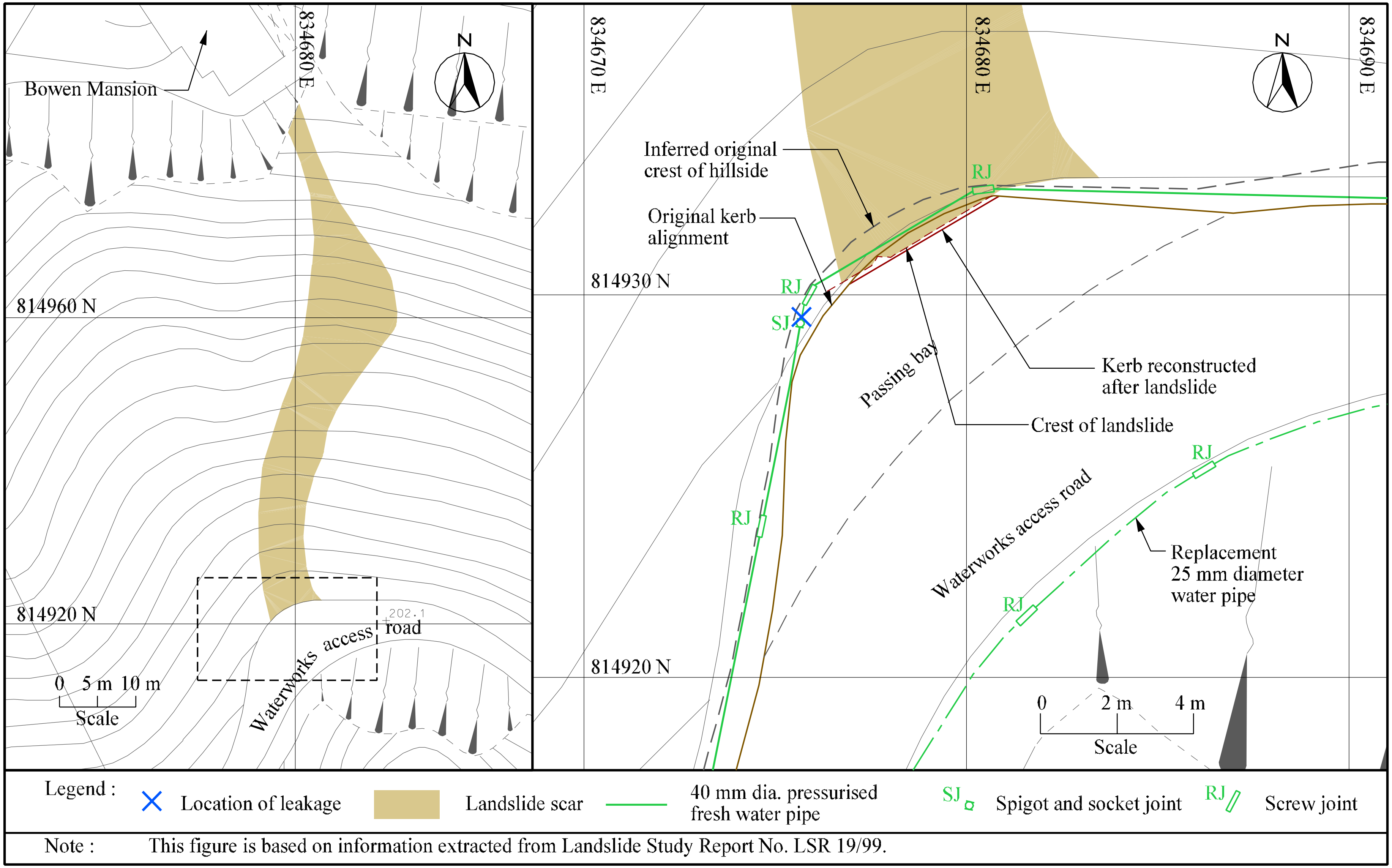

Figure 11 - The 11 June 1998 Landslide on the Natural Hillside behind No. 7C Bowen Road

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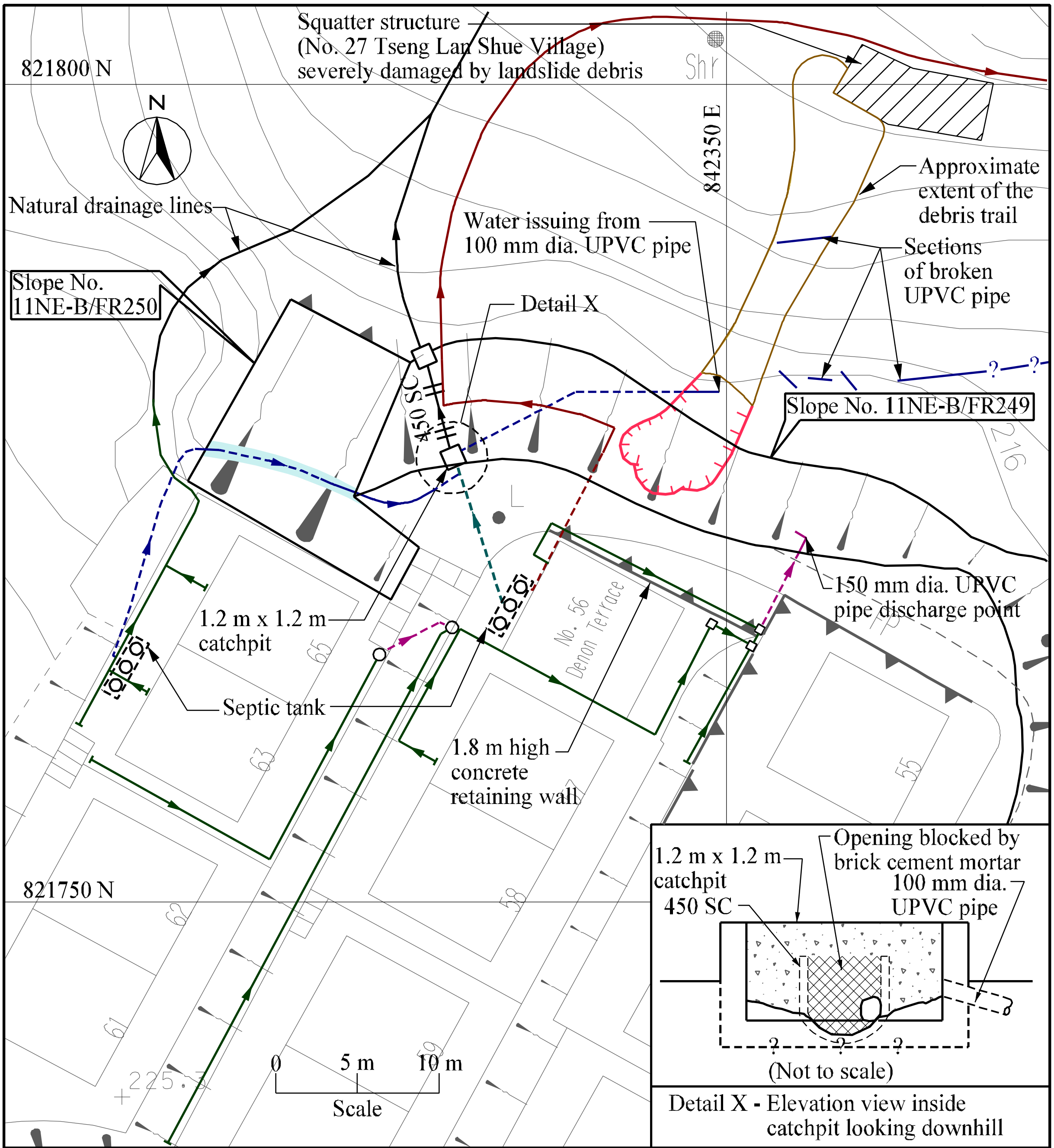

Legend :

	Landslide scar		225 mm U-channel
	Feature boundary		75 mm dia. UPVC pipe [1]
	Retaining wall		100 mm dia. UPVC pipe [1]
	Catchpits		150 mm dia. UPVC pipe [1]
450 SC	450 mm stepped channel		Probable alignment of duct (approx. 250 mm x 250 mm)

Probable unauthorised construction

Notes :
(1) Dotted lines denote possible alignment of buried pipes.
(2) This figure is based on information extracted from Landslide Study Report No. LSR 3/2003.

Figure 12 - The 1 September 2001 Landslide at Slope No. 11NE-B/FR249 below No. 56 Denon Terrace, Tseng Lan Shue

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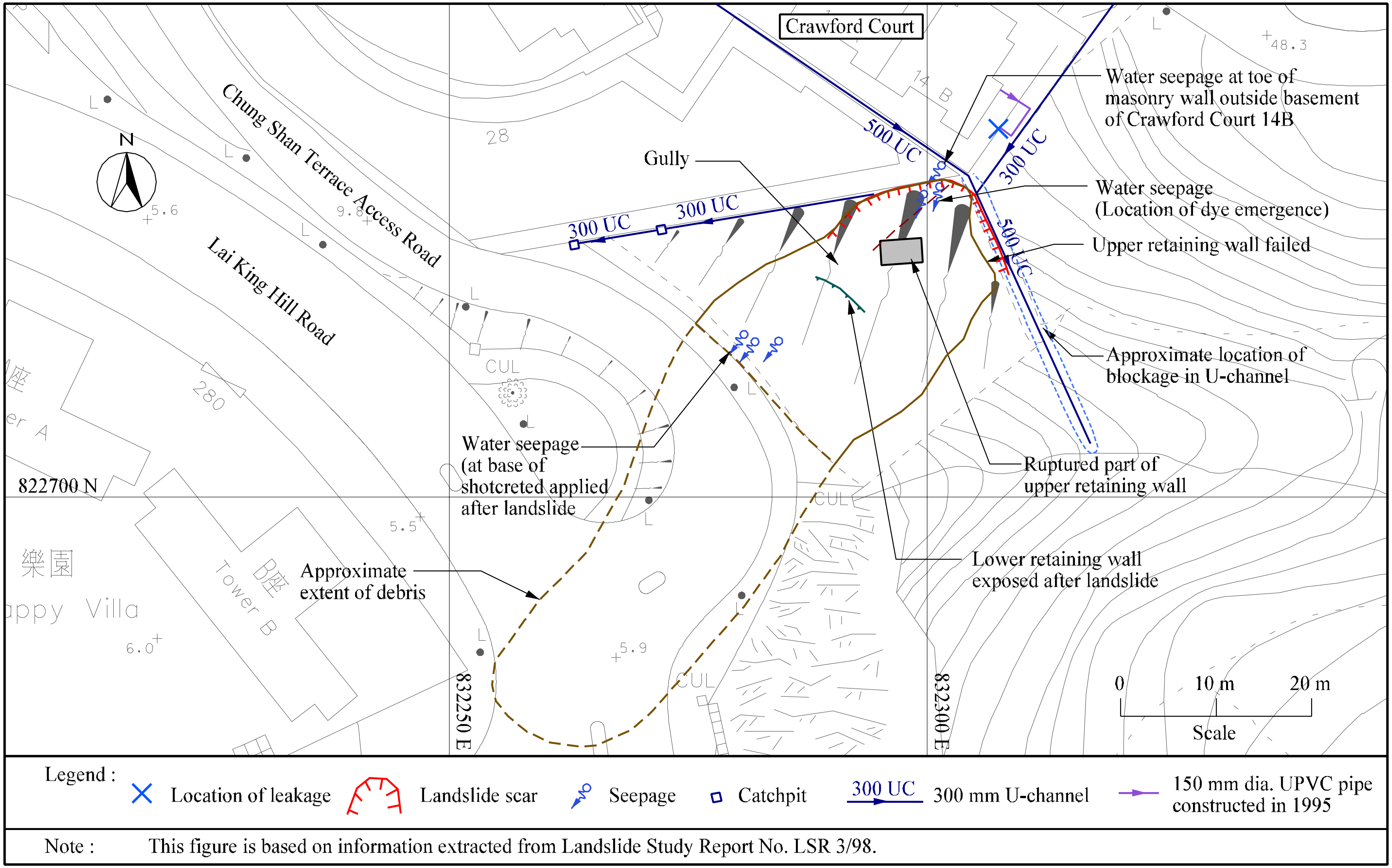

Figure 13 - The 4 June 1997 Landslide at Chung Shan Terrace, Lai King Hill Road

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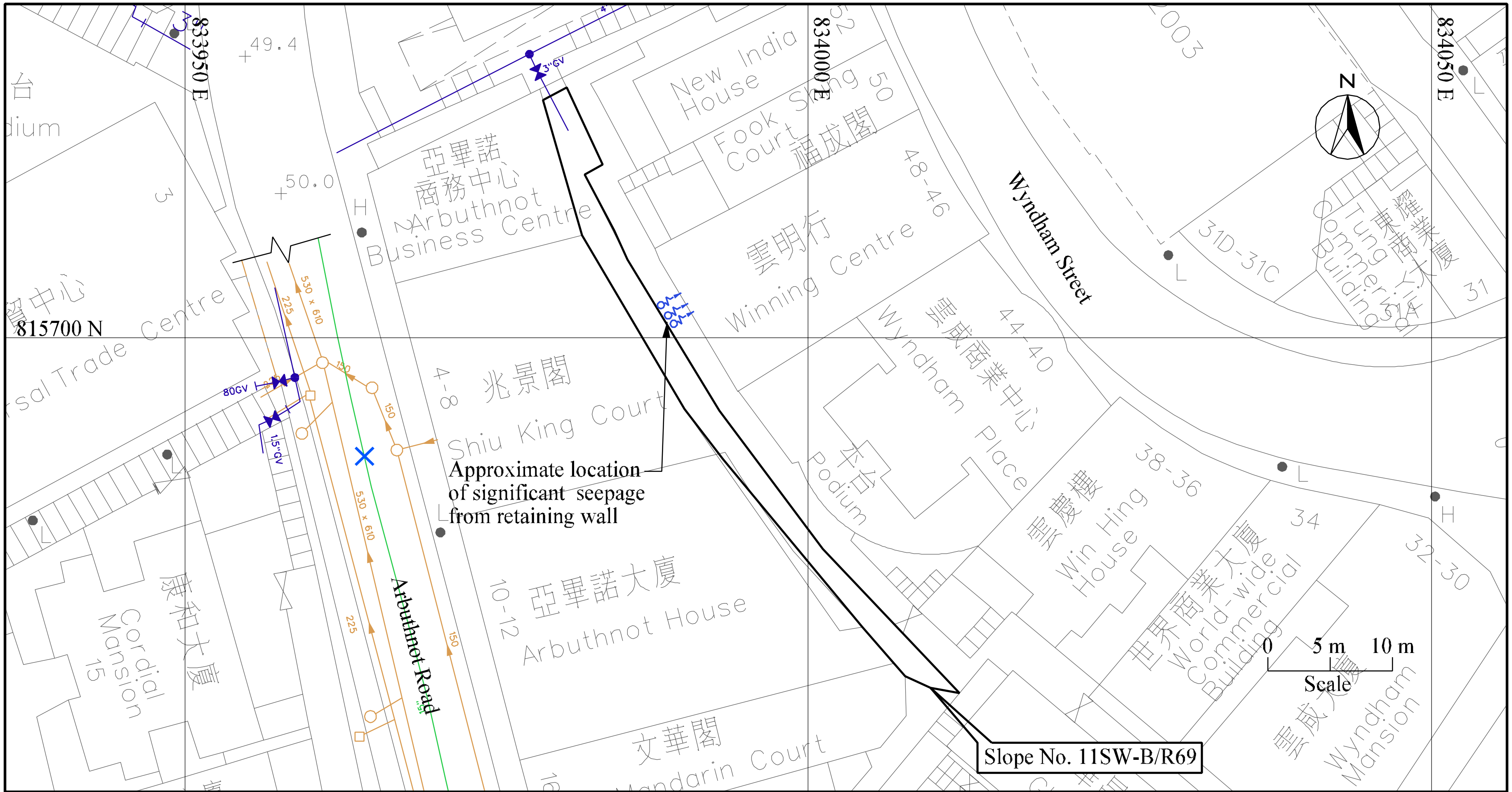

Legend :
- 150 mm dia. stormwater drains and manholes
- 225 mm dia. foul water drains and manholes
- 450 mm dia. cast iron pressurised fresh water main
- 80 mm dia. UPVC pressurised salt water main
- Approximate location of water main burst
- Seepage

Note : Base plan is extracted from 1 : 1000 survey sheet No. 11SW-8D dated March 2004.

Figure 14 - The 17 February 2003 Seepage Incident at Retaining Wall No. 11SW-B/R69 behind Nos. 40 to 52 Wyndham Street

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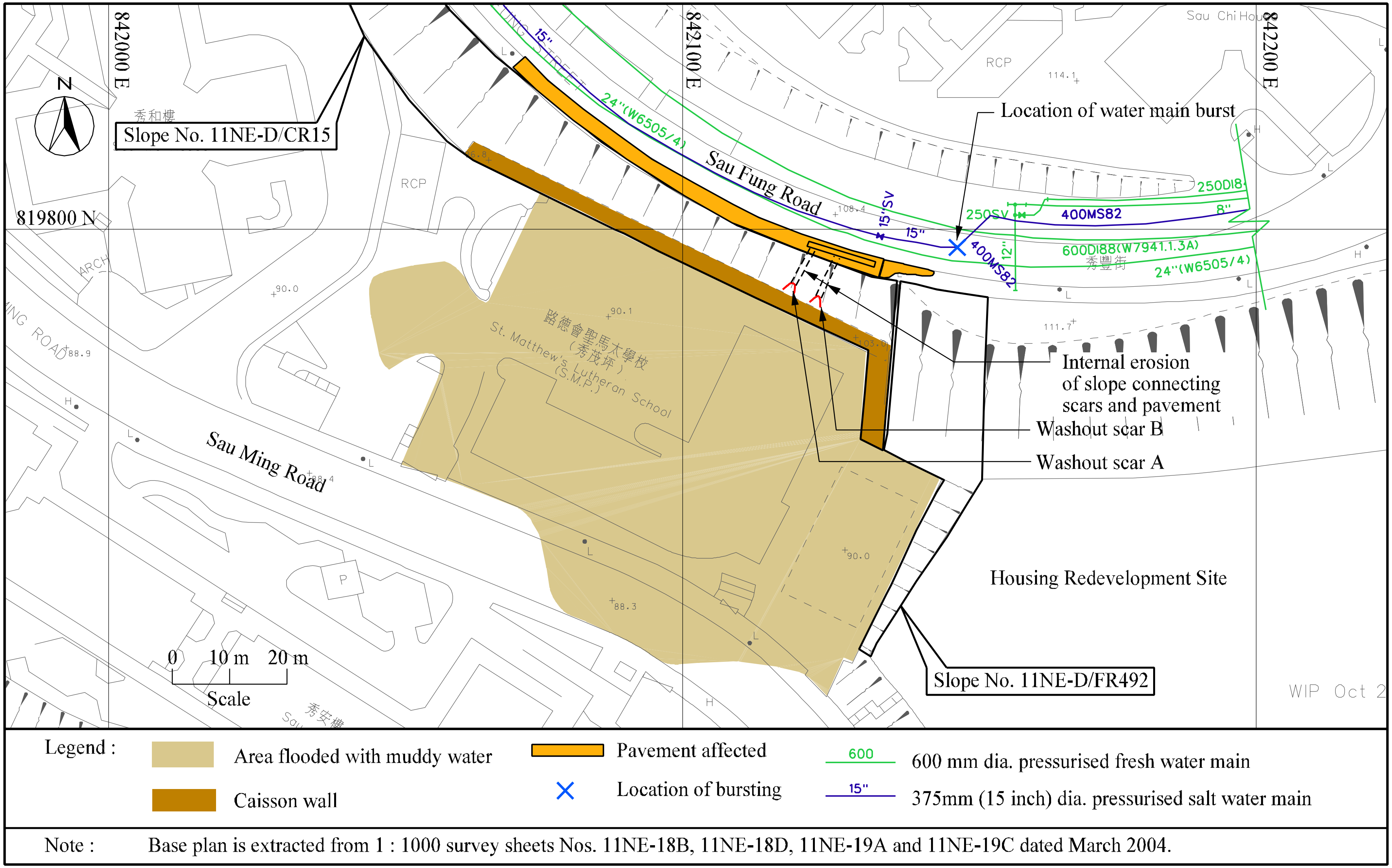

Figure 15 - The 23 November 2004 Water Main Burst Incident at Slope No. 11NE-D/CR15 at Sau Fung Street, Sau Mau Ping

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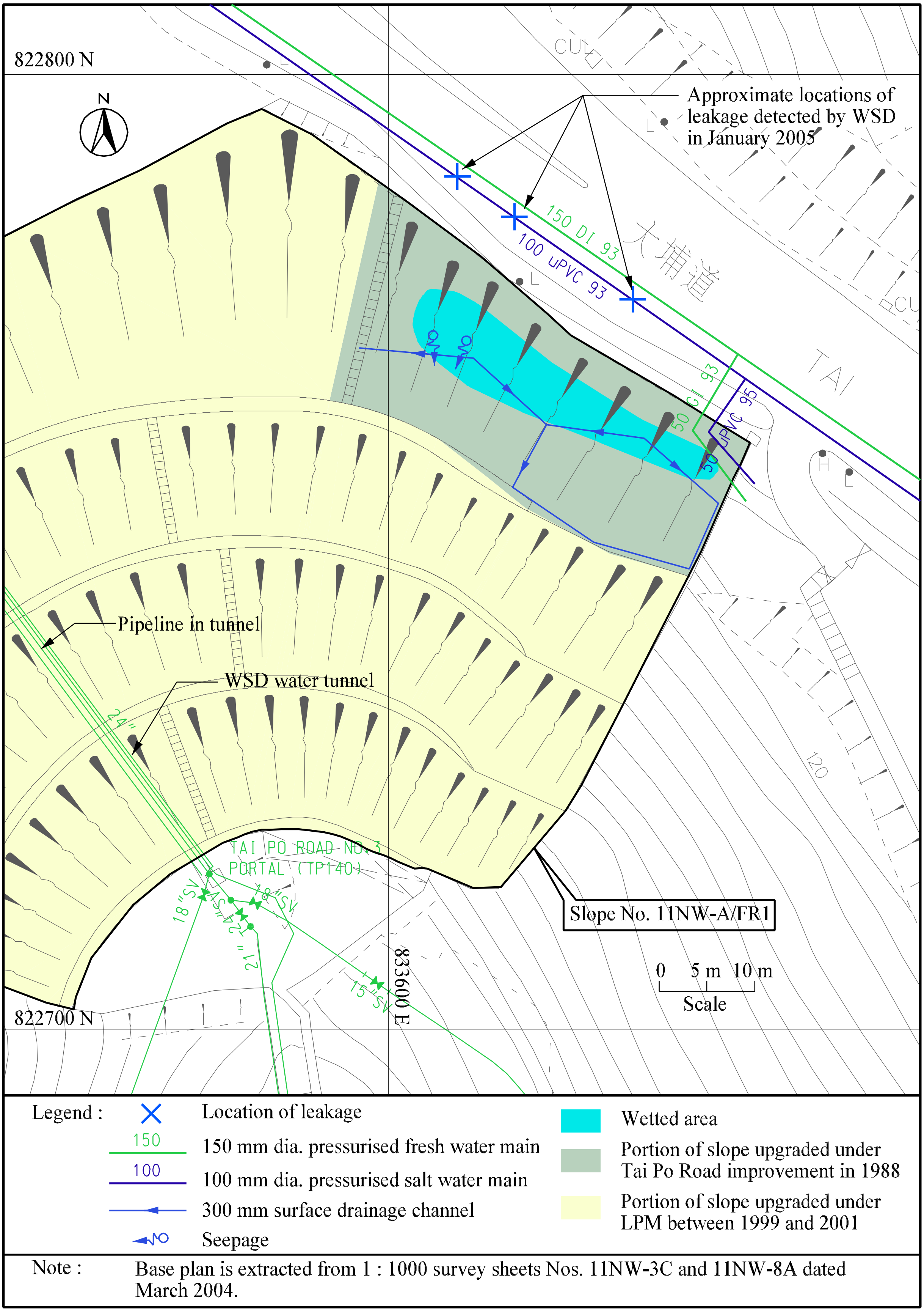

Figure 16 - The November 2004 Saltwater Main Leakage Incident at Slope No. 11NW-A/FR1 below Tai Po Road

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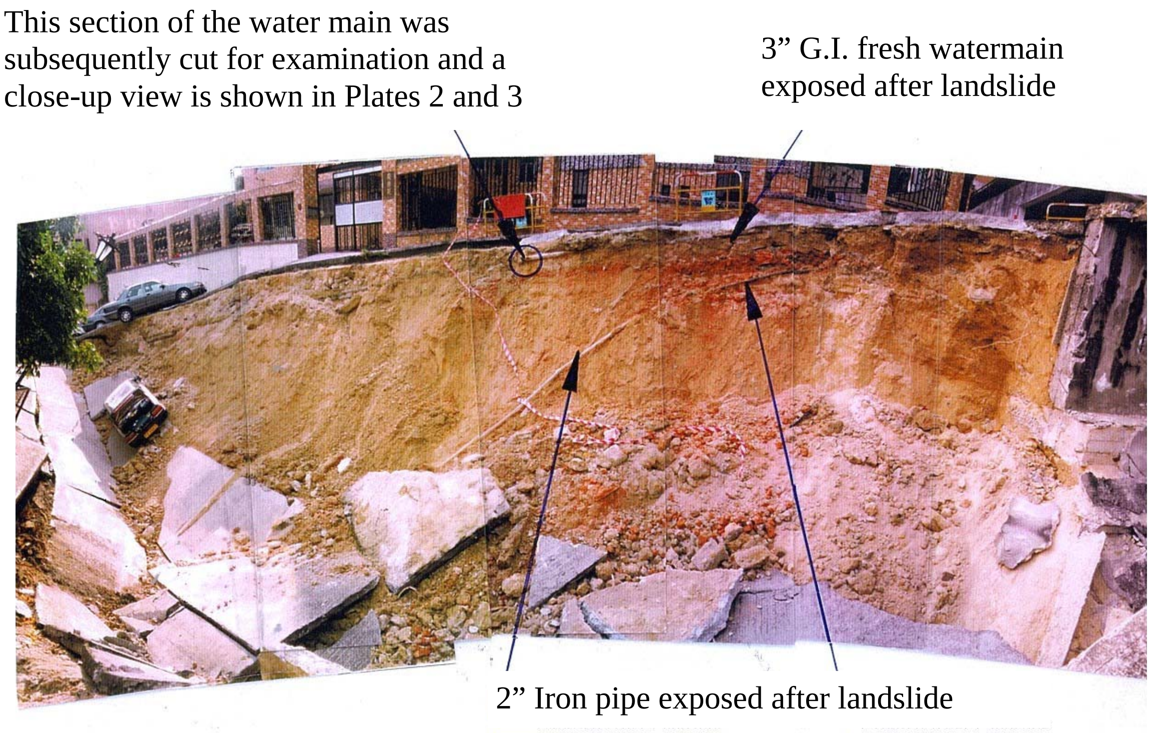

Plate 1 - The Landslide Scar and the Exposed Water-carrying Services - Hang Lok Lane
(Photograph taken on 8 February 1998)

Plate 2 - Close-up View Showing Rusting Stains on the Underside of Pipe Surface - Hang Lok Lane
(Photograph taken on 27 March 1998)

Note: Photographs extracted from Landslide Study Reports

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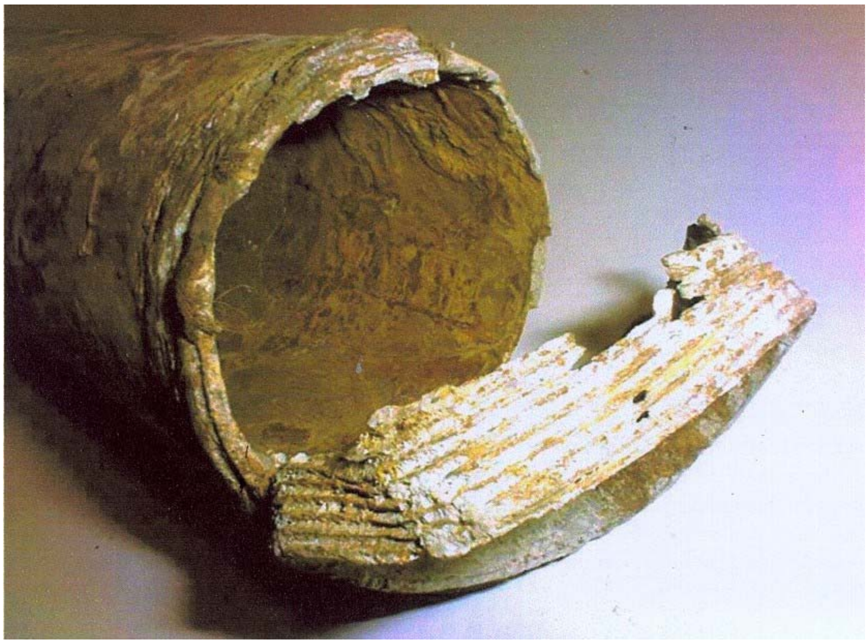

Plate 3 - Close-up View Showing Severe Rusting and
Pin-Holes at the Screw Joint - Hang Lok Lane
(Photograph taken on 27 March 1998)

Plate 4 - View of Exploratory Pit Opened at the Location of Leak in Water
Main along Northern Side of Hiu Kwong Street
(Note blue hose for de-watering. Photograph taken on 14 April 1998)

Note: Photographs extracted from Landslide Study Reports

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Plate 5 - View of the Zone of Cracking and Bulging
in Shotcrete - Hiu Kwong Street
(Photograph taken on 14 April 1998)

Plate 6 - Downslope View of the Zone of Bulging
at Upper Batter - Hiu Kwong Street
(Photograph taken on 5 May 1998)

Note: Photographs extracted from Landslide Study Reports

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Plate 7 - View of Main Scar and the Leakage Collection Trough - Kau Wah Keng Village (Photograph taken on 26 January 2000)

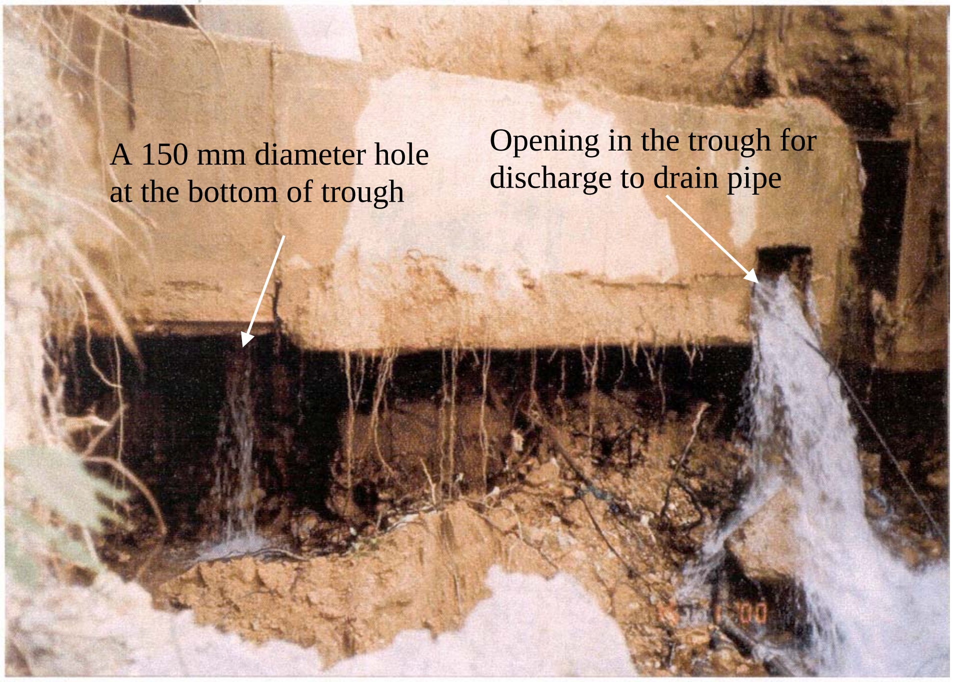

Plate 8 - View of Water Discharging from Leakage Collection Trough - Kau Wah Keng Village (Photograph taken on 14 January 2000)

Note: Photographs extracted from Landslide Study Reports

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Plate 9 - General View of the Landslide Scar - Lai Chi Kok Hospital
(Photograph taken on 28 August 2000)

Plate 10 - The 150 mm Heavily Corroded Water Pipe near the Footpath at Slope Toe - Lai Chi Kok Hospital
(Photograph taken on 9 September 2000)

Note: Photographs extracted from Landslide Study Reports

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Plate 11 - View of Water Issuing from Weepholes in Retaining Wall No. 11SW-A/R625 - Oaklands Avenue (Photograph taken on 18 June 2000)

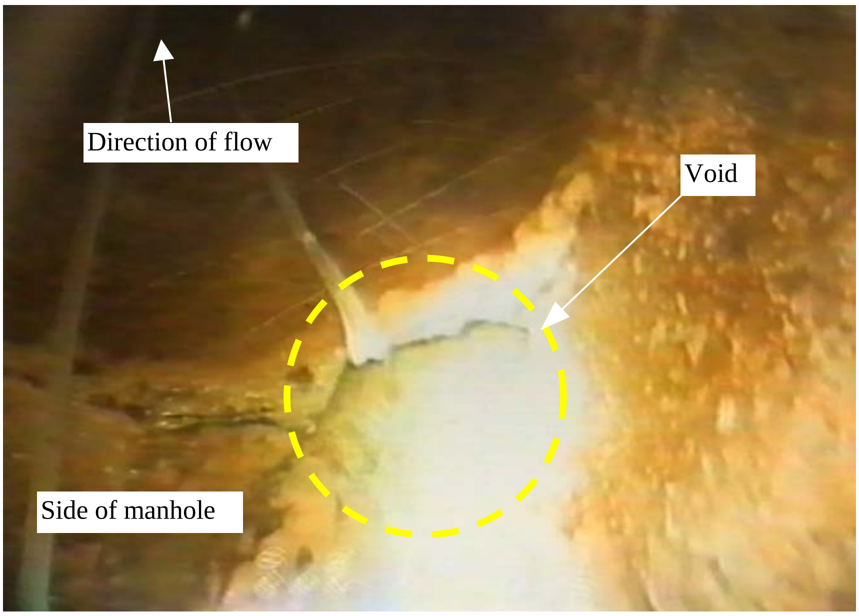

Plate 12 - View of Leakage Through Void at Connection Between Manhole and Stormwater Drain - Oaklands Avenue (Captured from CCTV Video taken on 19 June 2000)

Note: Photographs extracted from Landslide Study Reports

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Plate 13 - Washout of Soil from underneath the Shotcrete Cover - Pokfield Road (Photograph taken on 4 February 2002)

Plate 14 - View of the Erosion Gully After Removing the Shotcrete Cover - Pokfield Road (Photograph taken on 25 February 2002)

Note: Photographs extracted from Landslide Study Reports

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Plate 15 - The Uncharted Water Pipe - Pokfield Road
(Photograph taken on 14 December 2001)

Plate 16 - General View of the Landslide - Chinese University
(Photograph taken on 15 June 1999)

Note: Photographs extracted from Landslide Study Reports

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Plate 17 - Leakage Identified from a 75 mm Diameter Galvanized Iron Fire Services Pipe at the Crest of the Slope - Chinese University (Photograph taken on 6 July 1999)

Plate 18 - Additional Leakage in the 75 mm Diameter Fire Services Pipe Identified During Pavement Repair Works - Chinese University (Photograph taken on 29 July 1999)

Note: Photographs extracted from Landslide Study Reports

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Plate 19 - General View of the Landslide - Bowen Road
(Photograph taken on 11 June 1998)

Note: Photographs extracted from Landslide Study Reports

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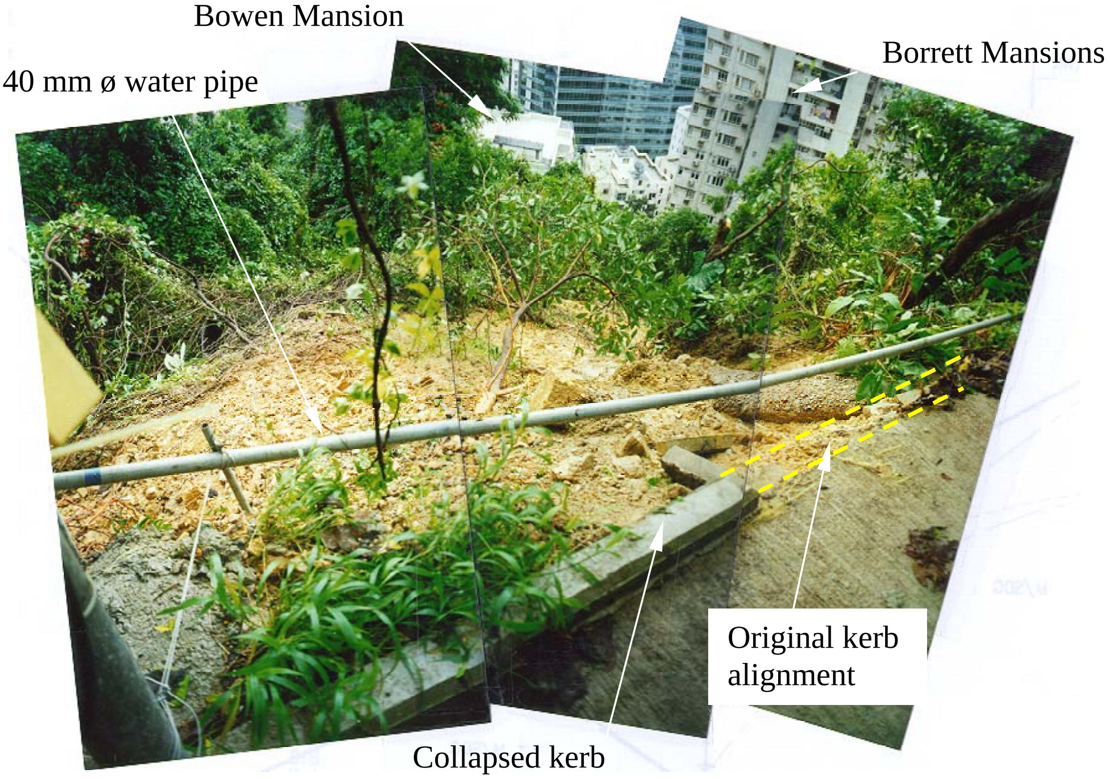

Plate 20 - General View of the Landslide Scar near the Crest - Bowen Road (Photograph taken on 11 June 1998)

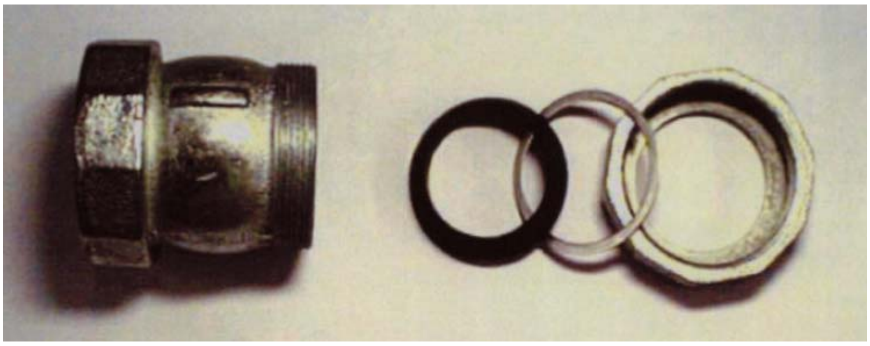

Plate 21 - Details of 'union joint'

Note: Photographs extracted from Landslide Study Reports

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Plate 22 - General View of the Landslide - Denon Terrace
(Photograph taken on 3 September 2001)

Note: Photographs extracted from Landslide Study Reports

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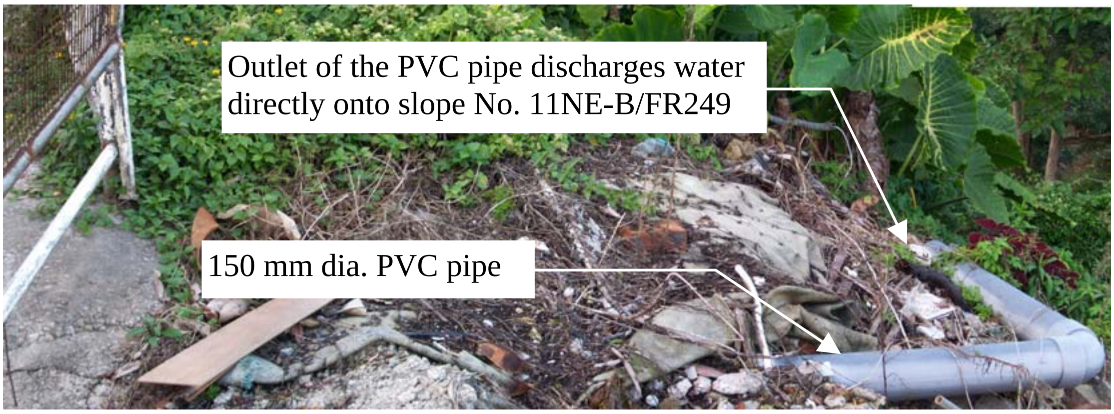

Plate 23 - View of the 150 mm Diameter PVC Pipe on Slope No. 11NE-B/FR249 - Denon Terrace (Photograph taken on 21 December 2001)

Plate 24 - General View of the Landslide - Chung Shan Terrace (Photograph taken on 5 June 1997)

Note: Photographs extracted from Landslide Study Reports

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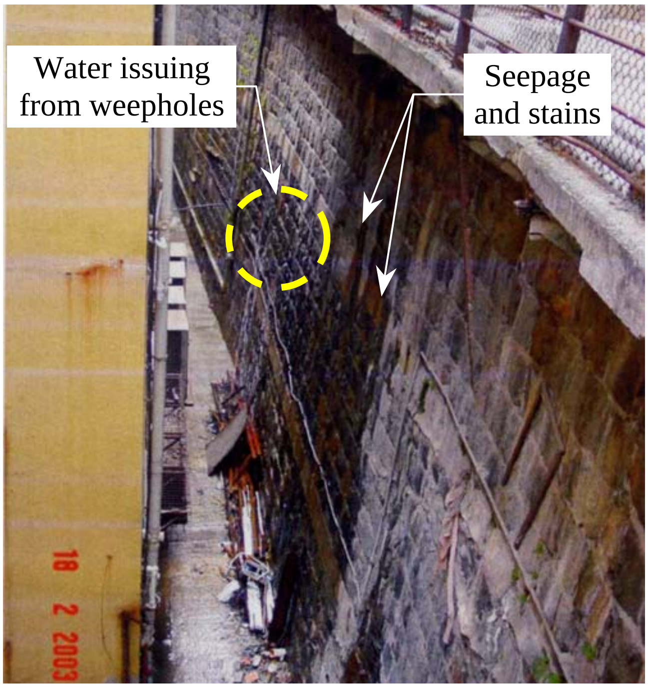

Plate 25 - View of the Masonry Retaining Wall No. 11SW-B/R69 behind Nos. 40 to 52 Wyndham Street (Photograph taken on 18 February 2003)

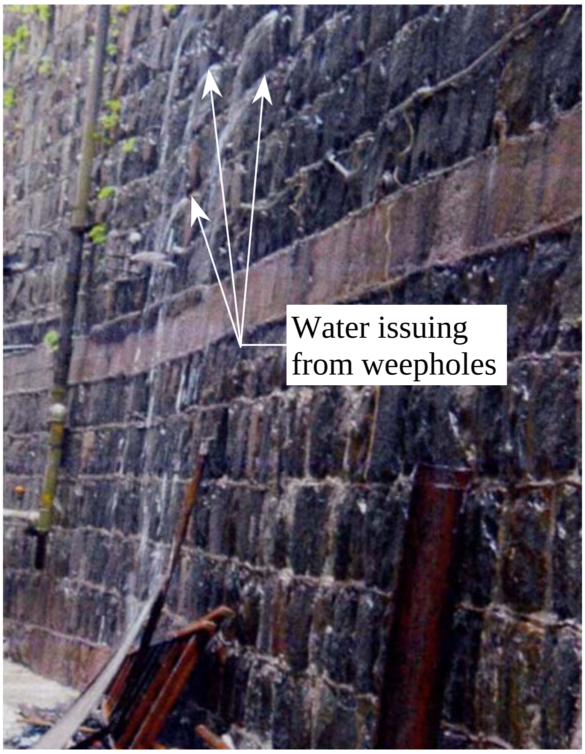

Plate 26 - Close-up View of Water Issuing from the Weepholes of the Masonry Wall - Wyndham Street (Photograph taken on 18 February 2003)

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Plate 27 - General View of Muddy Water Discharging from Slope No. 11NE-D/CR15 - Sau Mau Ping (Photograph taken on 23 November 2004)

Plate 28 - General View of the Washout Scars at Slope No. 11NE-D/CR15 - Sau Mau Ping (Photograph taken on 24 November 2004)

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Plate 29 - Close-up View of Broken Saltwater Main - Sau Mau Ping
(Photograph taken on 23 November 2004)

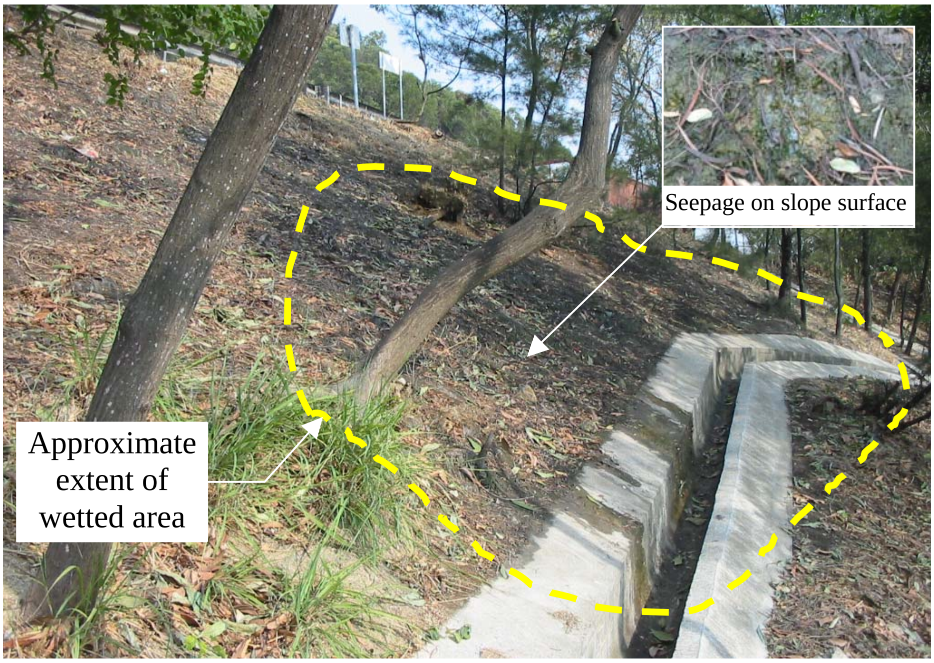

Plate 30 - General View of the Wetted Slope Face of
Slope No. 11NW-A/FR1 - Tai Po Road
(Photograph taken on 6 January 2005)

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Plate 31 - Continuous Seepage at Cracked Surface Channel - Tai Po Road
(Photograph taken on 6 January 2005)

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APPENDIX A

GEO's 'Advice Note to Government Departments responsible for Water-Carrying Services, on actions with regard to Leakages, to avoid Risk of Slope or Retaining Wall Failures'

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Advice Note to Government Departments
responsible for Water-Carrying Services, on Actions
with regard to Leakages, to avoid Risk of Slope or Retaining Wall Failures

(This Advice Note is intended to be given to personnel
responsible for attending, in the field,
to reports of actual or suspected leakage)

1. If there is an actual leak, or strong suspicion of a leak (including strong suspicion arising from reports of low supply pressure) at a location where there are natural or man-made slopes or retaining walls within **20 m** or **1 H** (where H = Slope or wall height) whichever is larger, down slope of the leak (but subject to a maximum of 40 m in the case of a natural slope), the department responsible for the water-carrying services should take prompt actions to prevent the situation from further deterioration. The inspection personnel should first undertake a site reconnaissance to observe any signs of potential problems, and take the following actions as appropriate together with other actions required in accordance with the concerned departments' internal guidelines and procedures:

   (i) suspend water supply upstream of the leak (in the case of a pressure main), or arrange to divert the flow (in the case of a stormwater drain or sewer). Both actions may need to be taken if there is uncertainty as to the source of the leak.

   (ii) if there is any significant sign of ground movement, such as subsidence or cracking indicating **imminent** collapse of a slope or retaining wall which could endanger lives and/or property,

   - call Police, to initiate any evacuation of occupied buildings and/or cordoning-off the affected area.

   - notify the Department responsible for the carrying out of emergency repair to the slopes/retaining walls, through their emergency system, for immediate attendance.

   - notify the Geotechnical Engineering Office (GEO) immediately for advice on emergency measures (see contact details in para. 2 below)

   (iii) in less serious circumstances than those referred to in (ii) above, but where there are nevertheless observed signs of potential problems, including some ground settlement, cracking of a slope/retaining wall or seepage/flow out of a slope/retaining wall surface, the department responsible for maintenance of the slope/retaining wall should be informed to request their EI Consultant or their geotechnical staff to give advice on any necessary actions. The GEO should also be informed of the incidents and actions taken/planned.

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(iv) investigate the cause of leakage.

(v) proceed with repair works, with consideration of adopting permanent measures (e.g. re-routing or diverting away from slopes and retaining walls) to avoid possible repetition of similar events in future as per Section 7 of Code of Practice for Inspection and Maintenance of Water-Carrying Services Affecting Slopes.

2. Contacts in GEO:

- during office hours, the appropriate GEO district division, Tel. No.:

Island Division	:	2762 5283
Mainland East Division	:	2762 5248
Mainland West Division	:	2762 5219

[location plan showing boundaries of the district divisions attached (Annex I).]

- after office hours, GEO pager duty officer,
Pager No.: 7116 3388 call 4554 (HK Island)
call 6780 (Kowloon and New Territories)
(only when condition in 1(ii) occurs)

- during a declared emergency such as Landslip Warning, the GEO Emergency Control Centre Tel. No.: 2762 5251 or 2762 5252 (only when condition in 1(ii) occurs)

Geotechncial Engineering Office
Civil Engineering Department
25 May 2000

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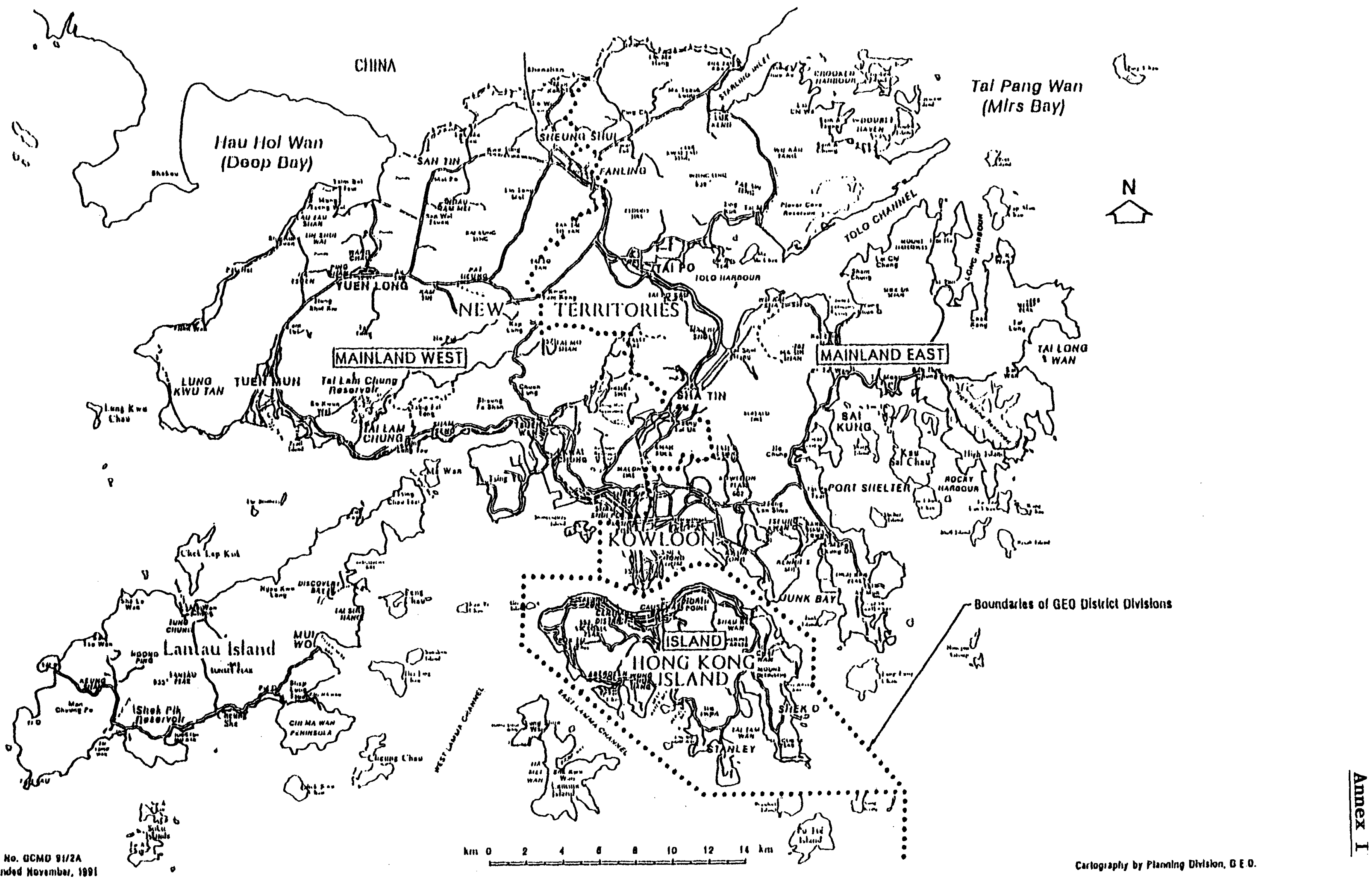
Annex I

TERRITORY OF HONG KONG SHOWING GEO DISTRICT DIVISION BOUNDARIES



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APPENDIX B

DSD Newsletter: DSD Channel - 23 Issue, September 2003
(Extract pp. 6-7)

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分部快訊

雲咸街後巷護土牆嚴重滲水事件

(一) 接獲投訴

在今年2月中的某一天，我們接到從渠務投訴熱線轉來的緊急求助來電，報稱在中環半山雲咸街後巷護土牆出現嚴重滲水，數根水柱從護土牆排水孔射出來。

(二) 潛在危險

我們不敢怠慢，隨即趕赴現場，察看究竟。投訴人稱曾於早前告知水務署，惟該署未能找出滲水源頭，故求助於渠務署，投訴人多達四個，他們均來自管理公司和樓宇保養機構。當我們抵達事發地點一看，不由得從心底裡打個冷顫------那筆直的護土牆高約三層樓，乃幾十年前建造的麻石砌牆，其上矗立了數座樓高十多層的樓宇，面向雲咸街後巷，緊貼一列商業大廈，背靠亞畢諾道斜路。若然任由水湧沖擊護土牆結構而令麻石砌牆崩塌下來，後果就不堪設想了。

中環雲咸街後巷
護土牆嚴重滲水

(三) 立即行動

我們迅即採取了下列步驟，以助查驗工作：

- 在附近各條渠管放置測漏色粉，包括行人路或馬路上的雨水渠和污水渠，無一遺漏。
- 在半山區集水區入口處(近明愛中心)放置測漏色粉。
- 在地圖上劃出方圓半徑100米之範圍作深入查探。
- 通知土力工程署勘察整個護土牆的結構安全，並評估風險。
- 聯同屋宇署進入附近樓宇，協助檢查室內渠管和水缸等設備。
- 聯繫水務署，籲請加緊水管測漏和勘探爆喉工作。
- 到鄰近大廈天台作高空鳥瞰，查看有否遺漏之可疑設施，如泳池、山坡排水系統等。
- 在日間和晚上實地視察溢出水柱的強弱，評估其可能來源。
- 抽取滲水樣本，作食水、鹹水和生化試驗，分析水質。

我們也十分重視市民的訴求，故此擬定每隔一天與眾位投訴人聯絡，匯報調查進展，讓他們知道多個有關政府部門正努力不懈地尋找漏水來源，並借此加強公眾對我們的信心，釋去他們的疑慮。這也是不可忽略的一環。

肇事護土牆上的住宅大廈

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(四) 部門合作

據水務署表示，初步化驗結果顯示有食水成份，並評定為"受污染的自來水"，其水質含有清潔劑、亞摩尼亞和極微量氯氣的成份，即可能來自家居使用後的自來水，如清潔碗碟或洗澡後的水，再經污水渠排出屋外，故此水務署曾要求屋宇署和渠務署協助跟進。

本部門在管理公司幫助下，進入肇事護土牆上的數個居住單位，作色粉滲漏測試，並無發現樓宇內通往公共渠井的雨水渠和污水渠有任何滲漏現象。

我們亦主動聯絡屋宇署，協助他們勘查大廈排水設施，上至天台，下至地庫停車場，甚至連貯水箱也要查看。最後，屋宇署於三月初的某天，知會有關大廈住戶，暫停食水和沖廁水的供應，但護土牆仍舊出水如注，並無減退跡象。

至此，其中一位投訴人指出，水已滲透地底流入其地庫電錶房，或會產生觸電危險。

(五) 渠務工作

在整個過程裡，渠務署並無停止過檢驗各公用渠管，並以視像錄影，細心和重複地審視，遇有損毀的渠管，迅即加以修補。此外，我們也動員直屬員工隊，進行檢查渠井工作。

本部門的主管，除經常與前線人員商討工作進展外，也親身到現場作實地巡視，協助盡快找出滲水來源，以免情況惡化。同時，他也鼓勵我們動用一切可用資源，務求在最短時間內將危機化解。

(六) 轉機出現

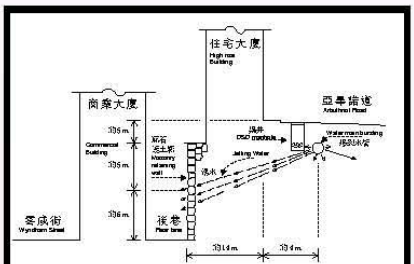
正當茫無頭緒，苦無對策之際，在3月10日上午，我們在亞畢諾道馬路上其中一個渠井內發現不尋常的水位上升情況，經即時測試，證實井內的水為食用自來水，懷疑食水從爆裂的水管射進我們的渠井裡，故立即通知水務署。

修妥後的護土牆

當天下午，水務署就在那渠井旁進行挖掘，嘗試尋找爆裂水管的位置。及至晚上，在井旁不遠，距地面約一米半的深處，發現一條直徑450毫米的破裂食水管，正在噴出大量食水，食水湧入泥土，穿過亞畢諾道的樓房地基，向著雲咸街後巷護土牆穿透而出，正好解釋了護土牆嚴重滲水的原因。

(七) 問題解決

水務署的同事由下午開始封路搶修，並通宵工作，將該水管修補妥當，於翌日清晨重開道路。自此之後，護土牆再沒有滲漏了。在搶修期間，水務署的總工程師親臨監督工程進度，可見他們非常重視是次事件，和護土牆滲水的危險。



雲咸街後巷護土牆滲水示意圖
(Water Leakage from Retaining Wall at Rear Lane of Wyndham Street)

借此多謝本部門各同事的辛勞，你們鍥而不捨地尋找，細心檢查，並與各部門緊密聯繫溝通，交換資料，將我們的發現，在最短時間內通知相關部門合力解除危機，給市民良好的形象。

香港及離島渠務部

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APPENDIX C

WSD Standard Drawing No. 1.20C
- Leakage Collection System

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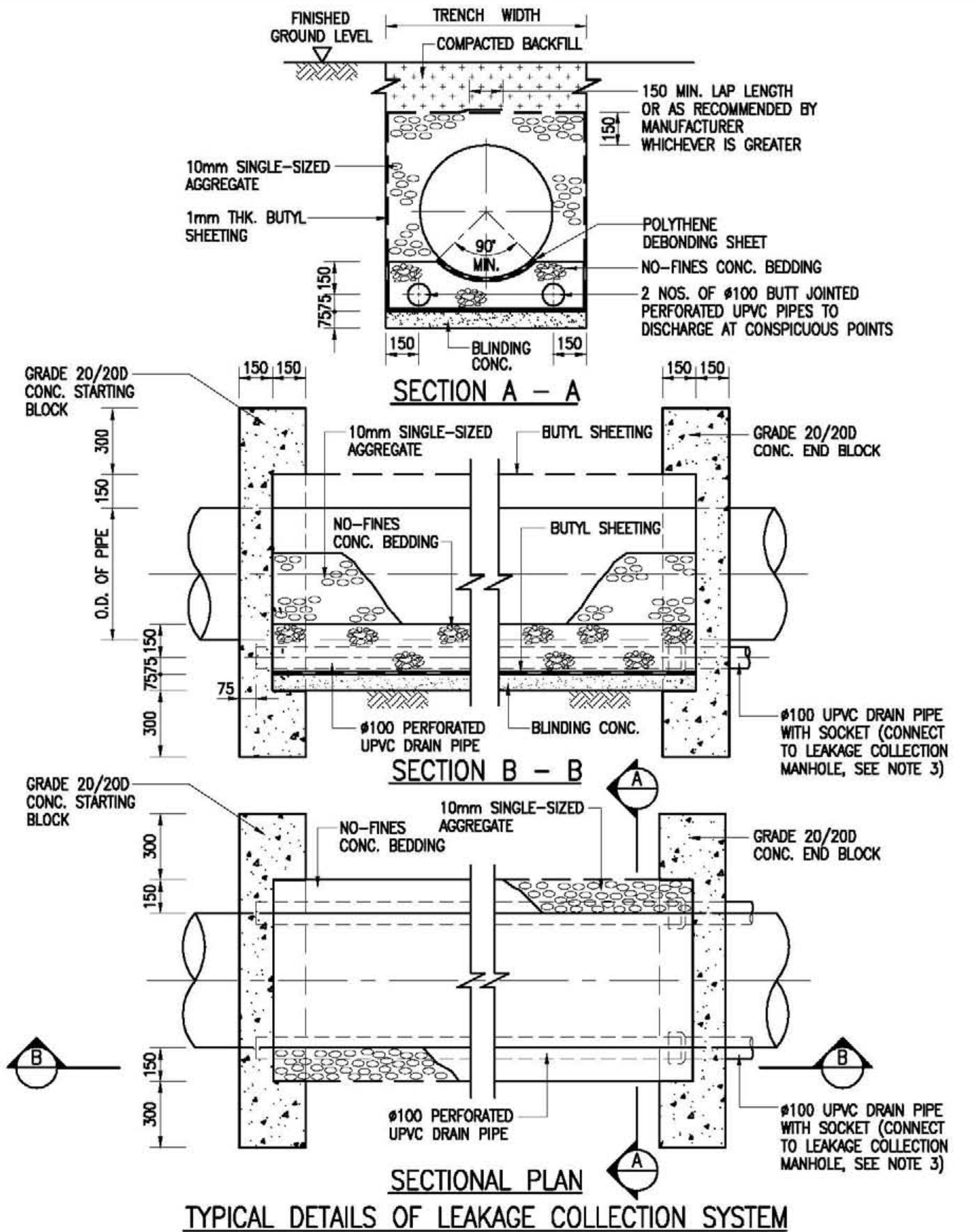

TYPICAL DETAILS OF LEAKAGE COLLECTION SYSTEM

REF.	REVISION	APPROVED	DATE
C	RE-FORMATTED TO CSWP	W.K. CHIU	5/9/03
B	GENERAL REVISION	W.K. CHIU	6/12/01
A	GENERAL REVISION	W.K. CHIU	16/12/99

0 500 1000 mm
1 : 25 SCALE BAR

LEAKAGE COLLECTION SYSTEM

水務署 Water Supplies Department

APPROVED	G.C. LEE AD/NW	DRAWING NO. CSWP
DATE	9/6/92	WSD 1.20C (SHEET 1 OF 3)
SCALE	1 : 25	

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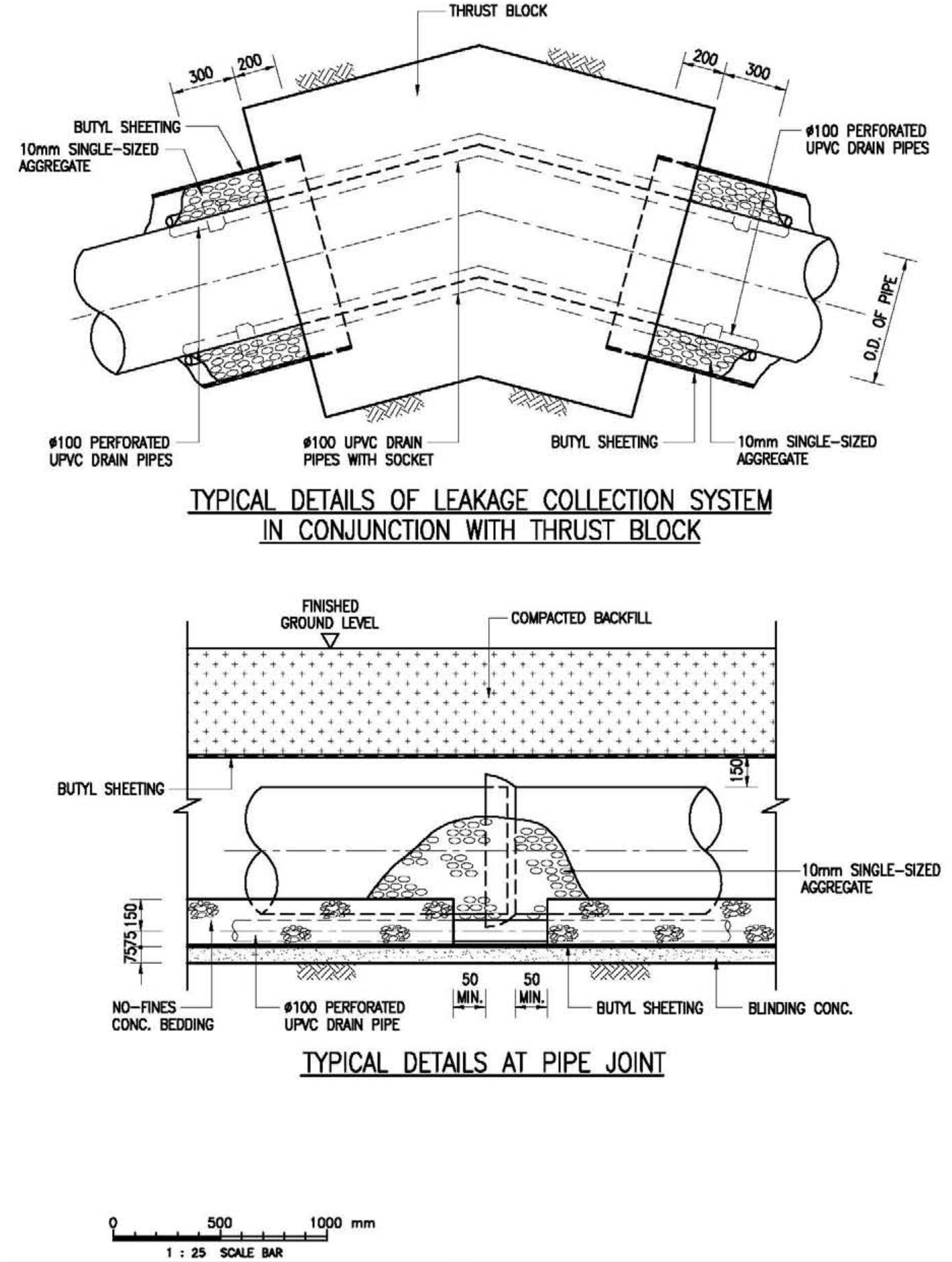

LEAKAGE COLLECTION SYSTEM

水 務 署
Water Supplies Department

APPROVED	G.C. LEE AD/NW	DRAWING NO.	CSWP
DATE	9/6/92	WSD 1.20C (SHEET 2 OF 3)	
SCALE	1 : 25		

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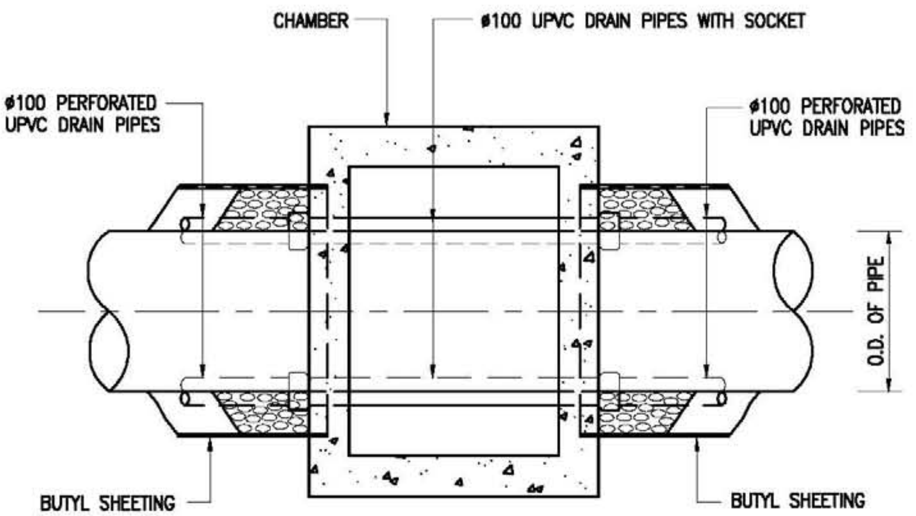
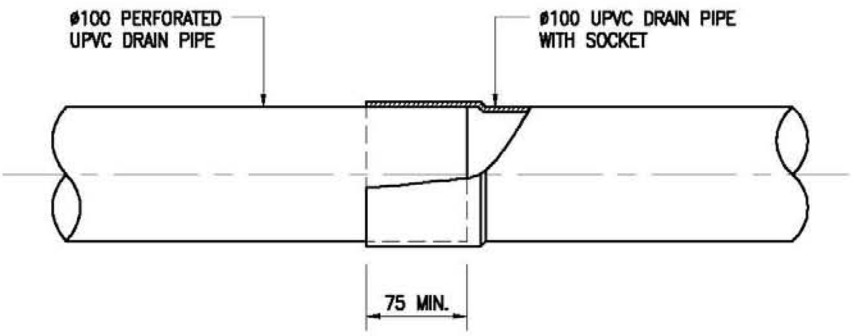


TYPICAL DETAILS OF LEAKAGE COLLECTION SYSTEM IN CONJUNCTION WITH CHAMBER

SCALE 1 : 25



TYPICAL JOINTING DETAILS OF UPVC PIPE

SCALE 1 : 5

NOTES :

1. ALL DIMENSIONS ARE IN MILLIMETRES.
2. THE DIMENSIONS OF THRUST BLOCK AND CHAMBER SHALL BE AS SPECIFIED ON CONTRACT DRAWINGS.
3. FOR DETAILS OF LEAKAGE COLLECTION MANHOLE REFER TO DRG. NO. WSD 1.38.

0 50 100 150 200 250 mm
1 : 5 SCALE BAR

0 500 1000 mm
1 : 25 SCALE BAR

LEAKAGE COLLECTION SYSTEM	水務署 Water Supplies Department		
	APPROVED	G.C. LEE AD/NW	DRAWING NO. CSWP
	DATE	9/6/92	WSD 1.20C
	SCALE	1 : 25 OR AS SHOWN	(SHEET 3 OF 3)

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

GEOTECHNICAL MANUALS

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

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.

GEOLOGICAL PUBLICATIONS

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

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

TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents

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