# REVIEW OF SELECTED LANDSLIDES INVOLVING SOIL-NAILED SLOPES

**GEO REPORT No. 222**

**F.H. Ng, M.F. Lau, K.W. Shum & W.M. Cheung**

**GEOTECHNICAL ENGINEERING OFFICE**
**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
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January 2008

# FOREWORD

Soil nails have been used extensively to upgrade substandard man-made slopes since the 1990's. Between 1993 and 2006, twenty-five minor landslide incidents (<50 $m^3$ in volume) have been reported on engineered soil cut slopes with permanent soil nails in Hong Kong.

The report presents the findings of a review of selected landslides involving soil-nailed slopes in Hong Kong.

The key objectives of the study are to collate the background information on failures of soil-nailed slopes and identify key areas that deserve attention in further improving the performance of soil-nailed slopes in Hong Kong.

The study was jointly undertaken by Mr. Alain F.H. Ng and Mr. Tony M.F. Lau of the Landslip Preventive Measures Division 1 and Mr. K.W. Shum and Dr. W.M. Cheung of the Standards and Testing Division. Maunsell Geotechnical Services Limited and Fugro Scott Wilson Joint Venture, the 2006 landslide investigation consultants, provide assistance in compiling the relevant case histories. All contributions are gratefully acknowledged.

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## 1. INTRODUCTION

Since the late-1980's, soil nailing has become common for upgrading substandard slopes in Hong Kong because of its simplicity and versatility. It has been used extensively for upgrading substandard soil cuts under the Landslip Preventive Measures (LPM) Programme and the Enhanced Maintenance Programme (EMP) in the last decade as well as in the formation of new cuttings under public and private development projects in Hong Kong. Soil nails are also sometimes installed to support steep temporary excavations. The recommended design methodology and guidelines on the use of soil nails in soil cut slopes in Hong Kong are given in GEO (2007a). Soil nails have also been used to upgrade loose fill slopes where there are site constraints (such as access and dense tree cover) in implementing the '3 m recompaction method', following the design guidelines given in the report by HKIE (2003). Whilst soil nailing has been generally considered as a robust means for enhancing slope stability, minor landslide incidents have been occasionally reported on slopes with soil nails.

This report presents the findings of a review of selected landslides involving engineered soil cuts with permanent soil nails, which were reported to the Geotechnical Engineering Office (GEO) between 1993 and 2006, together with three published cases in Malaysia. Failure cases during the construction phase involving slopes with temporary soil nails, together with suggestions for improvement, have been documented by Sun & Tsui (2003) and will not be covered in this review.

The key objectives of the present study are as follows:

(a) to collate published information and file records on landslides that occurred on soil-nailed slopes, and

(b) to identify key areas that deserve attention in further improving the performance of soil-nailed slopes.

## 2. SOURCES OF INFORMATION

The sources of information for the present review are as follows:

(a) GEO's landslide database, incident reports and landslide inspection records,

(b) Landslide Study Reports and Annual Landslide Review Reports published by the GEO,

(c) relevant files in the GEO, and

(d) published technical papers.

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## 3. FAILURE MODES OF SOIL-NAILED SLOPES

The failure modes of soil nailed slopes can be generally classified into two main categories (see Figure 1). The first category is external failure, where the installed soil nails are essentially within the deformed soil mass and hence the soil nails offer minimal resistance to the failure, which is basically in the form of rotation or sliding. In other words, the nails are too short and do not pass through the slip surface.

The second failure category refers to internal failure that may occur either in the active zone (namely, failure of ground around soil nail, soil nail head bearing failure, local failure between soil nails, soil nail tensile failure, and soil nail bending and shearing failure, see Figures 1(b)(i) to (iv) and (vi)), or in the passive zone (namely, soil nail pull out failure, see Figures 1(b)(v)) of a soil-nailed slope. CIRIA (2005) defines the active zone as the region in front of the potential failure plane, which contains the proximal end of the soil nails. The passive zone is defined as the resistant zone behind the potential failure plane, which contains the distal end of the soil nails with sufficient bond length to prevent the reinforcement being pulled out.

## 4. REPORTED LANDSLIDE INCIDENTS ON SOIL-NAILED SLOPES

### 4.1 General

Based on the Landslip Preventive Measures Information System (LPMIS) and the information from the GEO's Slope Safety Division and District Divisions, a total of about 3,700 soil cut slopes have been upgraded by means of soil nailing up to the end of 2006 under the LPM Programme by the GEO and the EMP by the slope maintenance departments, and in compliance with the Dangerous Hillside Orders served by the Buildings Department on private features. The maintenance responsibilities of the majority of these 3,700 slopes rest wholly or partly with Government. In addition, new man-made slopes involving soil nails have been formed under public and private development projects.

Based on the GEO's landslide database, a total of 25 landslide incidents have been reported to the GEO on soil-nailed slopes in Hong Kong between 1993 and 2006 (Table 1).

Most of the landslides on soil-nailed slopes in Hong Kong were generally of small scale, involving local shallow sliding failure or washout, with failure volumes ranging from less than 1 $m^3$ to about 35 $m^3$. Two of the three published cases in Malaysia overseas involved external failures (viz. with the slip surface located beyond the lengths of most of the soil nails) of substantial volumes, and the other case was associated with the structural failure of the slope facing.

Fifteen of the 25 reported incidents on soil-nailed slopes, together with the three overseas cases, have been reviewed in this study. The other ten cases are generally incidents without detailed documentation for an in-depth review to be carried out (e.g. very minor failures in terms of volume and with negligible consequences). A brief description of each of the landslides reviewed is presented in the following sections and the key information is summarised in Table 2.

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4.2 The 13 September 2006 Landslide on Slope No. 11SW-C/C383, Victoria Road (Incident No. 2006/09/0709)

4.2.1 The Slope

The slope is a 10 m high (maximum), south-easterly facing soil and rock cut with a 0.5 m high toe planter located along the pedestrian pavement of Victoria Road, below Caritas Wo Cheng Chung Secondary School (Figure 2).

The 40 m long south-western portion of the slope comprises two batters separated by an intermediate berm of about 0.5 m wide. The lower batter comprises a 3 m high and 80° steep rock face of slightly to moderately decomposed tuff. The upper batter comprises a 7 m high soil/rock cut exposing highly decomposed tuff inclined at about 35° and covered by vegetation. The remaining north-eastern portion of the slope is a 10 m high, 35° to 45°, vegetated soil cut in completely to highly decomposed tuff. The surface drainage system comprises a 300 mm U-channel along the slope crest, a 225 mm U-channel along the slope berm and 225 mm stepped U-channels connecting the crest and berm channels to catchpits at the slope toe. There is no recorded past instability on or in the vicinity of the slope.

The slope was originally formed in 1989/90 and was subsequently upgraded as part of the development project entitled 'Proposed Prevocational School at Northcote Close, Pokfulam' between 1999 and 2005. According to the 'Supplementary Geotechnical Assessment Report' for the re-development prepared by Hyder Consulting Ltd. in April 2003 (Hyder, 2003), a local shear zone is present in the central portion of the slope, resulting in an advanced state of weathering at that location, and groundwater seepage issuing from the rock exposures in the lower portion of the slope face is observed during wet seasons.

Based on the as-constructed drawings, eight rows of 6 m to 7 m long soil nails (with 32 mm diameter galvanised steel bars) at 1 m staggered horizontal spacing and four rows of 4.5 m long soil nails (with 20 mm diameter galvanised steel bar) at 1.5 m staggered horizontal spacing were installed in the central portion of the slope. All soil nails were installed in 125 mm diameter grouted holes inclined at 15° below the horizontal. The recessed concrete soil nail heads were 600 mm by 600 mm by 250 mm depth, with a 75 mm thick compacted soil on top. A hydroseeded surface, without erosion control mat or steel wire mesh, was provided in the central portion of the slope. Fifteen 5 m long raking drains at 2 m horizontal centres were installed at the slope toe, to deal with the continuous seepage from the toe planter near the north-eastern end of the slope, as observed by GEO's District Division during a site audit inspection for slope works in January 2005.

4.2.2 The Landslide

The minor landslide was reported to the GEO on 13 September 2006 when the Landslip Warning and the Amber Rainstorm Warning were in force. The exact timing of the failure is not known. Debris from the landslide was deposited on the pedestrian pavement. No casualties were reported as a result of the landslide.

The landslide source area was located at the central soil cut portion of the slope about 3 m above the slope toe (Plate 1). The landslide scar was about 3 m wide, 0.4 m high and

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0.4 m deep, with an estimated failure volume of about 0.5 $m^3$. A shallow washout failure involving erosion of topsoil was also observed above the landslide source area. In this incident, three soil nail heads were exposed and they did not appear to have been affected by the landslide.

A subsequent site inspection on 13 October 2006 revealed that shotcrete with weepholes had been applied to the landslide scar, extending down to the toe planter (Figure 3 and Plate 2). No seepage was observed from either the weepholes or the raking drains during the inspection. However, continuous water seepage was observed at two locations from the toe planter near the north-eastern end of the slope (Figure 3), one of which was in line with the location observed by the GEO in January 2005.

The 300 mm U-channel at the slope crest was clear at the time of the inspection. The channel has a relatively steep gradient with a sharp change in alignment above the landslide scar (Figure 3). The stone pitching covering the sloping ground above the crest of the slope was in good condition.

#### 4.2.3 Probable Causes of the Landslide

The close correlation between the rainstorm and the timing of the report of the landslide suggests that the September 2006 landslide was probably rain-induced. The landslide occurred in an area of Grade IV/V tuff that was locally in a more advanced state of weathering, possibly associated with the local shear zone as identified on the slope face.

The landslide scar is situated below an area of sloping ground covered by stone pitching. The crest drainage channel is steeply inclined with a sharp change in alignment above the landslide scar. It is postulated that the September 2006 landslide was caused by a combination of direct infiltration and possible overspill from the crest drainage channel during heavy rainfall.

### 4.3 The 26 April 2006 Landslide on Slope No. 3SE-D/C61, Tai Mei Tuk (Incident No. ArchSD/NT/2006/04/0001)

#### 4.3.1 The Slope

The soil cut, which is about 60 m long and up to 8 m high with an average angle of about 60°, is located immediately behind a storage shed of Tai Mei Tuk Country Park Management Centre (Figure 4). The slope surface is covered with grass and shrubs, together with erosion control mat and steel wire mesh (Plate 3). A 225 mm wide U-channel is located at the slope toe and a 300 mm stepped channel with upstand is located at the slope crest. Above the slope crest is natural hillside inclined at an angle of about 15°.

The slope was included in the LPM Programme in 2001. According to the Stage 3 Study Report No. S3R 84/2002 prepared by the consultants (Halcrow China Ltd., 2002), the slope upgrading works comprised prescriptive soil nails, provision of raking drains and surface drainage, replacement of the original shotcrete surface with hydroseeding together with erosion control mats and steel wire mesh. The works were completed in March 2003.

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According to the as-built records, 8 nos. of 6 m long soil nails and 157 nos. of 10 m long soil nails (comprising 25 mm diameter galvanised steel bars in 100 mm diameter grouted holes) were installed at 1 m vertical spacing and 1.5 m horizontal spacing, with inclinations varying between 20° and 40° below the horizontal. The lowest row of soil nails was installed at about 2 m above the slope toe.

### 4.3.2 The Landslide

According to the ArchSD's Incident Report, a landslide involving an estimated volume of 4 $m^3$ occurred on 26 April 2006. The landslide debris was trapped behind the steel wire mesh (Plate 3). No casualties or damage to property were reported as a result of the landslide.

The landslide scar was about 2.4 m wide by 2 m high by 0.5 m deep located near the slope toe, just below the lowest row of soil nails (Figure 5). At the time of inspection in November 2006, a no-fines concrete buttress had been constructed to backfill the landslide scar. No signs of distress or seepage from other parts of the slope were observed.

### 4.3.3 Probable Causes of the Landslide

The shallow landslide that occurred on the steep cut face below the soil nails was probably caused by wetting up of the near-surface material due to direct infiltration.

## 4.4 The August 2005 Landslide on Slope No. 15NE-A/C152, Ma Hang Prison (Incident No. 2005/08/0493)

### 4.4.1 The Slope

The slope comprises a 12 m high soil/rock cut. It consists of a 4 m high upper batter inclined at about 30° and an 8 m high lower batter typically inclined at 45° to 56°, which are separated by an 800 mm wide concrete paved berm with a 230 mm wide U-channel. Rock outcrop is exposed on the lower batter up to about 4 m high along the slope toe (Figure 6 and Plate 4). The slope is situated about 2 m behind a two-storey staff quarters at Ma Hang Prison, which was vacant at the time of the failure. Natural hillside inclined at about 25° extends above the slope crest to Stanley Gap Road.

The slope was included in the LPM Programme in 1998/99. According to the Stage 3 Study Report No. S3R 107/99 prepared by the consultants (Halcrow Asia Partnership Ltd., 2001), there were no records of past instability of the subject slope prior to the LPM works. The upgrading works, comprising soil nail installation, provision of surface drainage and replacement of the old chunam cover with vegetation and erosion control mats were completed in March 2001.

According to the as-built records, a total of 52 soil nails (25 mm diameter galvanised steel bars in 100 mm diameter grouted holes) were installed. Three rows of soil nails at 2 m centres vertical and horizontal spacing, with an inclination of 15° to the horizontal, were installed on the lower batter and one row of two nails was installed on the upper batter.

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4.4.2 The Landslide

In the morning of 29 August 2005, a landslide on the subject slope was reported to the GEO. According to the prison staff, the failure probably occurred at around 10:00 a.m. on 20 August 2005 when there was moderate rainfall. Landslide debris with a volume of about 35 $m^3$ was deposited on the open space at the rear of the vacant staff quarters. No casualties were reported as a result of the landslide.

The landslide scar was located in the central portion of the slope immediately below the berm slab and above the rock outcrop. The main scarp (maximum 1 m high) undermined the berm slab generally by about 700 mm. The scar, with dimensions of about 6 m (width) by 7 m (length) by 1.5 m (depth) maximum, extended downslope to the top of the rock outcrop. No seepage was observed at the main scarp and the exposed material was dry at the time of inspections on 30 August and 2 September 2005, at which time the weather was fine. However, seepage was noted at the soil/rock interface immediately adjacent to both sides of the scar, indicating that a perched water table is liable to build up above the interface during heavy rainfall.

Two soil nail heads (denoted as soil nail Nos. 1 and 2, with dimensions of 400 mm and 500 mm square respectively), which are about 3 m below the berm and 1.7 m apart, were exposed within the landslide scar (Figure 7). The debris immediately behind nail head No. 1 was removed to facilitate inspection. It was noted that the exposed portion of the soil nail bar was bent downward to about 30° below the horizontal. The cement grout underneath the nail bar had spalled, probably due to bending of the soil nail as a result of the landslide (Plate 5).

The landslide debris comprised brown mottled white clayey sandy SILT with some gravel-/cobble-sized rock fragments. Most of the landslide debris was deposited on the open space between the slope toe and the staff quarters, with a portion of the debris deposited within the scar and on the slope face, obscuring the lower portions of the surface of rupture. An erosion control mat was present below the landslide debris. During the landslide inspections, the debris deposited at the slope toe was found to be wet. The debris mound extended to the staff quarters building, spreading laterally over a distance of approximately 18 m at the slope toe. The travel angle of the landslide debris, measuring from the crest of the landslide scar to the edge of the building, was estimated to be about 38°.

4.4.3 Probable Causes of the Landslide

The landslide probably occurred during moderate rainfall on 20 August 2005. Since there was no evidence of overland flow or blockage of surface drainage above the landslide scar, the chance of the landslide being caused by concentrated water flow due to overspilling from surface drainage channel is considered unlikely.

Taking cognisance of the observation of persistent seepage at the soil/rock interface below the failure scar, it is likely that the landslide was triggered by the build-up of transient perched water pressure above the soil/rock interface. Water ingress through direct infiltration into the relatively gently inclined vegetated slope during moderate rainfall might have been a

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contributory factor in promoting the build-up of perched water pressure.

4.5 The 20 August 2005 Landslides on Slopes Nos. 13NE-A/C100, 13NE-A/C102 and 13NE-A/C108 near Shek Pik Reservoir (Incident Nos. 2005/8/0313a, 2005/8/313b and 2005/08/0313c)

4.5.1 The Slopes

Slope No. 13NE-A/C100

The slope is a 120 m long, north-facing soil/rock cut with a height of about 8.5 m. It is inclined at about 70° at the August 2005 landslide location. Natural hillside and slope No. 13NE-A/C99 extend above the crest of the slope. South Lantau Road is situated at the slope toe (Figure 8).

Based on GEO's landslide database, there was no past instability at slope No. 13NE-A/C100 prior to the August 2005 landslide. The slope was included in the 1999/2000 LPM Programme. According to the Stage 3 Study Report prepared by the consultants (Halcrow China Limited (HCL), 2005b), the proposed slope upgrading works comprised installation of soil nails, rock slope stabilisation works for the lower portion of the slope, reconstruction of the surface drainage system, installation of prescriptive raking drains and replacement of the shotcrete cover with hydroseeding and erosion control mat. The works were completed in October 2004.

Slope No. 13NE-A/C102

The slope is a 177 m long, northwest-facing soil cut up to about 13 m high, comprising two batters separated by an intermediate berm, with an overall inclination of about 50°. A footpath extends along the crest of the slope, above which is slope No. 13NE-A/C101 and natural hillside. South Lantau Road is situated along the slope toe (Figure 8).

Based on GEO's landslide database, two minor landslides (Incident Nos. MW92/4/9 and MW99/8/123 with failure volumes of 5 $m^3$ and 15 $m^3$ respectively) occurred on the slope in 1992 and 1999 respectively (Figure 8).

Slope No. 13NE-A/C102 was included in the 1999/2000 LPM Programme. According to the Stage 3 Study Report prepared by the consultants (HCL, 2005a), the proposed slope upgrading works comprised installation of soil nails, reconstruction of the existing surface drainage system and replacement of the shotcrete surface with hydroseeding and erosion control mat. The works were completed in April 2005.

Slope No. 13NE-A/C108

The slope is a 196 m long, northeast-facing soil/rock cut with a maximum height of about 17 m, comprising two batters separated by an intermediate berm with an overall inclination of about 55°. South Lantau Road lies along the toe of the slope (Figure 9). A footpath traverses the natural hillside above slope No. 13NE-A/C108 about 10 m above the slope crest. Fill slopes Nos. 13NE-A/F82 and 13NE-A/F83 occupy the intervening ground between the footpath and the slope crest above the western portion of the feature and a cut

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slope extends above the footpath over the eastern portion of the feature.

Based on the GEO's landslide database, three minor landslides (Incidents Nos. MW93/11/56, SP93/11/107 and SP93/11/108 with failure volumes of 10 $m^3$, 16 $m^3$ and 8 $m^3$ respectively) occurred on the slope in 1993.

Slope No. 13NE-A/C108 was included in the 1999/2000 LPM Programme. According to the Stage 3 Study Report prepared by the consultants (HCL, 2005c), the proposed works comprised regrading of the slope profile to 45° at the western portion of the slope, installation of soil nails, rock slope stabilisation and boulder treatment works at the lower portion of the slope, reconstruction of the existing surface drainage system, installation of prescriptive raking drains and replacement of the shotcrete cover with hydroseeding and erosion control mat. The slope upgrading works were completed in April 2005.

### 4.5.2 The Landslides

Slope No. 13NE-A/C100

A minor landslide occurred near the crest of the western end of the slope on 20 August 2005 (Incident No. 2005/08/0313a). The slope angle at the landslide location was about 70°. The source area of the landslide was estimated to be about 3 m wide by 5 m high and up to 1 m deep, with an estimated debris volume of about 5 $m^3$ (Figure 10 and Plate 6).

The top surfaces of the recessed concrete soil nail heads of dimensions of 400 mm by 400 mm were exposed in the landslide scar, and they did not appear to have been significantly affected by the failure. Rock was exposed along the surface of rupture near the toe of the landslide scar and over the lower portion of the slope. Debris from the landslide was deposited on the slope below the scar and along a portion of the west bound lane of South Lantau Road, which had been cleared away by the time of inspection. The landslide debris on the slope below the scar was very wet and comprised mainly brown sandy, gravelly SILT with many cobbles (C/HDT).

The area above the slope did not appear to have been affected by the landslide and no evidence of overland flow or subsurface seepage was observed during the site inspection on 23 August 2005.

Slope No. 13NE-A/C102

A minor failure occurred near the crest of the eastern end of slope No. 13NE-A/C102 on 20 August 2005 (Incident No. 2005/08/0313b). The slope angle at the failure location was between 25° and 35°. The source area of the landslide was estimated to be about 6 m wide by 3.5 m high and up to 0.5 m deep, with an estimated debris volume of about 5 $m^3$ (Figure 11 and Plate 7).

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The top surfaces of the recessed 400 mm square nail heads were exposed in the landslide scar. The nail heads did not appear to have been significantly affected by the failure. Debris from the landslide, together with erosion control mat and vegetation, was deposited on the slope below the source area. The landslide debris was very wet and comprised mainly yellowish brown sandy SILT with many gravels and cobbles (colluvium/CDT).

The surface of rupture comprised an undulating planar surface dipping out of the slope at about $30^o$. The area above the slope did not appear to have been affected by the landslide and no signs of overland flow or subsurface seepage were observed during the site inspection on 23 August 2005.

Slope No. 13NE-A/C108

Two minor landslides (Incident No. 2005/08/0313c) occurred at the crest of the upper batter at the eastern end of the feature on 20 August 2005. The landslides scars (A and B) were located at the crest of a broad depression (possibly a previous landslide scar), where the slope face was sub-vertical.

The source area of the larger landslide (Scar A) was about 2.5 m wide by 2.5 m high and up to 0.4 m deep (Figure 12 and Plate 8), with a debris volume of about 1 $m^3$. The source area of the smaller failure (Scar B) was about 1.5 m wide by 2 m high and up to 0.4 m deep, with a debris volume of about 0.5 $m^3$ (Figure 13 and Plate 9).

Debris from the landslide scars, which comprised mainly yellowish brown sandy SILT (colluvium/CDT) together with pieces of erosion control mat and vegetation, was mainly deposited on the slope below the source areas, with some debris deposited on the intermediate berm.

The vegetated slope above the slope crest (Slope No. 13NE-A/F83) did not appear to have been affected by the landslide and no evidence of overland flow or subsurface seepage was identified at the time of the site inspection on 23 August 2005. However, the U-channel at the crest of the second batter above the landslide scars was noted to have minor cracking in places.

#### 4.5.3 Probable Causes of the Landslides

The timing of the three incidents suggests that the landslides were probably triggered by the intense rainfall during 19 and 20 August 2005. These landslides comprised minor, shallow failure of the soil layer above the nail heads on the slopes. The soil nails within the landslide scars were not affected by the minor surface detachment.

Based on the field observations, direct surface infiltration and water ingress through cracks in the surface channels leading to the build-up of local transient groundwater pressures appear to have been major contributory factors to the landslides in all three cases. For Incidents Nos. 2005/08/0313a and 2005/08/0313b, other possible contributory factor may include the presence of adversely orientated relict joints.

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4.6 The 20 August 2005 Landslide on Slope No. 11SW-A/C102 below Ka Wai Man Road (Incident No. 2005/08/0306)

4.6.1 The Slope

The slope is a soil cut in completely decomposed tuff, located between Ka Wai Man Road at the crest and Victoria Road at the toe in Kennedy Town. The slope is up to about 12 m high and inclined at approximately $60^o$. A paved sitting-out area managed by the Leisure and Cultural Services Department (LCSD) extends beyond the slope crest to the edge of Ka Wai Man Road. A bus shelter is present at the slope toe near the central portion of the feature (Figure 14 and Plate 10).

The available records indicate that a number of buried services, including stormwater drains, sewers and water main, are situated along the slope crest and toe. These include a 525 mm diameter stormwater drain along the slope crest, at an offset of about 7 m and at a depth of around 3 m below the ground surface.

Slope No. 11SW-A/C102 was included in the 2003/04 LPM Programme. The Stage 3 Study Report prepared by the in-house design team of GEO (2004a) in May 2004 noted a past instability at the western end of the feature (Incident No. HK83/6/19). The slope upgrading works comprised installation of soil nails, replacement of the shotcrete cover with hydroseeding and the provision of erosion control mat and steel wire mesh.

According to the as-constructed records, soil nails (5 m to 7 m long, 25 mm diameter galvanised steel bars in 100 mm diameter grouted holes) were installed at 1.2 m to 1.5 m vertical spacing and 1.5 m to 2.0 m horizontal spacing. The nails were inclined at between 15° and 30° to the horizontal (Figure 15).

There is a 300 mm high concrete upstand along the slope crest, at which a chain-link fence is installed.

4.6.2 The Landslide

A minor landslide was reported to have occurred at about 8:30 a.m. on 20 August 2005, during which time the Amber Rainstorm Warning and Landslip Warning were in force. Debris from the landslide was deposited on the pedestrian pavement at the slope toe. No casualties were reported as a result of the landslide.

The failure occurred in the central portion of the slope and affected the full slope height. The scar was about 8 m wide by 4 m high and about 0.5 m deep (maximum). The estimated failure volume was about 3 $m^3$. The main scarp exposed yellowish brown mottled white, sandy clayey silt with boulders (colluvium). Ten nail heads were exposed within the landslide scar and they did not appear to have been affected by the landslide. The erosion control mat and the steel wire mesh at the upper portion of the landslide scar were torn, but the connecting nuts, washers and plates were still connected to the soil nail heads. Steel wire mesh was noted on the slope surface at both sides of the scar (Plate 11).

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No signs of overflow were observed from the sitting-out area at the slope crest at the time of the site inspection on 22 August 2005. Some old cracks were evident on the concrete pavement of the sitting-out area. In addition, minor differential settlement associated with the cracking was observed on the pavement immediately above the landslide scar. Some of these cracks was previously sealed by cement mortar and had re-opened up by about 1 mm to 2 mm. Cracks were also observed in tree planters.

4.6.3 Probable Causes of the Landslide

The correlation between the rainfall on 19 and 20 August 2005 and the timing of the incident suggests that the landslide was probably rain-induced. The landslide was probably caused by the wetting up of the near-surface slope-forming material below the hydroseeded surface through direct infiltration. The concrete upstand at the slope crest probably prevented significant surface erosion on the slope face. The relatively steep cut slope (60°) comprising near-surface colluvium predisposes the slope to shallow instability. Given the shallow geometry of the landslide scar, leakage from the buried water-carrying services behind the slope crest as a contributory factor to the landslide is considered unlikely.

4.7 The 20 August 2005 Landslide on Slope No. 6SE-D/CR437 above Tai Lam Chung Catchwater (Incident No. 2005/08/0504)

4.7.1 The Slope

The slope is situated immediately above the Tai Lam Chung Catchwater. It comprises a soil/rock cut up to about 30 m high, with a 2 m high catchwater sidewall at its toe. The slope portion is about 300 m long, comprising a single batter with no intermediate berm. The lower 5 m to 7 m of the slope is inclined at an angle of about 60° and the upper portion stands at about 30° to 45°. The wall portion is about 390 m long with a face angle of about 65°. Rock outcrops are exposed at three locations. Apart from the rock outcrops and the localised areas of shotcrete cover, the slope is mostly vegetated with the provision of an erosion control mat and a steel wire mesh (Figure 16). Natural hillside inclined at about 25° to 30° extends above the cut.

The slope was included in the LPM Programme in 2000. According to GEO's landslide database, no past instability was recorded on the slope prior to the August 2005 landslide. Based on GEO's natural terrain landslide inventory, three previous landslides encroached onto the slope (all occurred in 1999). The approximate locations of the landslides coincide with the crest of the slope protruding near the western part of the slope (Figure 16).

Based on the Stage 3 Study Report prepared by the LPM consultants (CM Wong & Associates Ltd, 2001), the slope upgrading works comprised soil nail installation, provision of prescriptive raking drains and surface drainage, application of a combination of rigid cover and vegetated cover, together with erosion control mat and steel wire mesh to replace the existing shotcrete surface, and rock slope treatment works to the exposed rock face. The works were completed in April 2002.

According to the as-built records, soil nails of 10 m to 15 m long (with 32 mm diameter galvanised steel bars in 100 mm diameter grouted holes) were installed in 14 rows at

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2 m centres horizontal spacing, at an inclination of 20° below the horizontal (Figure 17).

#### 4.7.2 The Landslide

On 20 August 2005, a landslide (Incident No. WSD/2005/8/3/NTW) was reported by the Water Supplies Department (WSD) to have occurred on the subject slope. The exact time of failure is not known. The landslide debris, with a volume of about 20 $m^3$, was deposited in the catchwater immediately below and partially blocked the catchwater channel. All the debris was subsequently washed away by the water flow in the channel. No casualties were reported as a result of the landslide.

The landslide scar was located at the central portion of the slope immediately above the catchwater and below a maintenance access at the slope crest, with a 400 mm wide U-channel along the uphill side of the access stairway. The crest channel has no upstand to prevent possible overspilling of surface water onto the slope below. The landslide scar was about 10.5 m wide by 7 m high with a maximum depth of 0.8 m, covering the entire slope batter. The failure scar was inclined at an angle of about 66° for the lower 5.5 m and about 25° for the top 1.5 m. There was no distinctive scarp on the landslide scar. During post-failure inspections on 27 August and 7 September 2005, no seepage was observed at the landslide scar or from the no-fines concrete buttress, which was constructed as landslide repair works.

A total of 14 nail heads (400 mm to 500 mm square in size) at about 1.5 m to 1.9 m centres horizontal spacing, together with the heads of two raking drains, were exposed within the landslide scar (Plate 12). Due to the on-going landslide repair works at the time of the inspections, the exposed concrete nail heads, steel reinforcement and the grout cores of the lower two rows of soil nails could not be closely examined. Based on the record photographs and inspection of the exposed uppermost row of soil nails, the soil beneath the nail heads was eroded and the grouting beneath was slightly exposed. There appeared to be no noticeable damage to, or deformation of, the soil nail bars.

The landslide debris had been removed at the time of the landslide inspections. As inferred from the record photographs taken by WSD, the debris within the failure scar appeared to be quite wet and remoulded and there was not much debris in the catchwater channel. Based on the field observations, the material exposed on the upper part of the landslide scar comprised yellowish brown sandy clayey silt with some gravels. Cobbles and boulders were also exposed near the edge of the maintenance access.

The crest channel was not blocked at the time of inspection. Some signs of recent water flow along a minor ephemeral drainage line towards the crest of the landslide were observed.

#### 4.7.3 Probable Causes of the Landslide

The landslide probably occurred during or after the prolonged and heavy rainfall between 19 and 20 August 2005 although the exact time of the landslide is not known. The local depression above the slope crest could have led to concentrated surface water flow on

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the hillside towards the landslide source area. The surface erosion of the bouldery colluvium at the slope crest and signs of water flow along a minor ephemeral drainage line above the cut slope indicate that the landslide was probably caused by overland flow during heavy rainfall (Plate 13). Inadequate detailing of the surface drainage provisions may be a contributory factor to the failure.

### 4.8 The August 2004 Landslide on a Soil-nailed Slope, Anderson Road Quarry (Incident No. 2004/10/0066)

#### 4.8.1 The Slope

The subject slope (unregistered at the time of the landslide) is a soil/rock cut situated near the top of the Anderson Road quarry site. The slope is about 20 m high and is inclined at an average angle of about 55°. The upper soil cut portion is about 15 m high and the lower rock cut portion is about 5 m high. At the slope crest is a 1.5 m wide concrete berm and a 375 mm U-channel. Immediately above this berm are two vegetated soil cut slopes (Nos. 11NE-B/C899 and 11NE-D/C872), which were formed under the same quarry rehabilitation project. A 10 m wide unpaved haul road runs along the toe of the subject slope (Figure 18).

The original geotechnical submission by the consultants (Binnie Black and Veatch HK Limited), which comprised the formation of new unsupported cuttings, was accepted by the GEO in 1998. During construction, the rockhead profile at the landslide area was found to be about 20 m lower than that assumed in the design. Soil nailing was therefore proposed by another consultant (SMEC Asia Limited) for the steep soil cut.

Soil nails of 14 m in length, at approximately 2 m vertical and horizontal spacings and with an inclination of 20° to the horizontal, were installed on the soil portion between November 2003 and July 2004. 400 mm square soil nail heads were provided. The slope face was protected with vegetation and erosion control mats (no steel wire mesh was prescribed).

#### 4.8.2 The Landslide

According to the Incident Report (Incident No. 2004/10/0066), the landslide was first observed by the resident site staff on 31 August 2004 during a routine site inspection after an Amber Rainstorm Warning was issued on 29 August 2004. The exact time of failure is not known. Landslide debris with a volume of about 6 $m^3$ was deposited on the haul road at the slope toe. No casualties were reported as a result of the landslide.

The landslide involved a shallow failure between the soil nail heads. The landslide scar was about 3 m wide by 8 m high by 0.6 m deep (maximum), exposing six nail heads (Figure 19 and Plate 14). The soil nails did not appear to have been affected by the landslide. No seepage from the landslide scar or from other parts of the slope was observed during the inspection in October 2004.

The material exposed on the landslide scar was weak, yellowish brown, completely decomposed coarse ash tuff comprising yellowish brown, fine sandy clay/silt. Many relict joint surfaces with slickensides and a coating of kaolin/manganese oxide and chlorite were

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observed mainly in the flanks of the landslide scar.

An approximately 200 mm diameter erosion pipe was observed at the crown of the landslide scar. Four other pipes, about 50 mm in diameter and dipping slightly downward into the slope, were also observed on the surface of slope No. 11NE-B/C899 and at various locations above the landslide scar. Three small cracks of less than 2 mm in width were observed in the paved berm above the landslide scar.

#### 4.8.3 Probable Causes of the Landslide

The landslide was probably triggered by moderate rainfall (with return period of less than two years). The presence of steep and adversely orientated relict joints in the 'active zone' of the soil-nailed slopes was a contributory factor to the shallow failure in between the nail heads. In the vicinity of the landslide, local slope bulging and signs of subsurface erosion were observed on three occasions between 2000 and 2003 by the resident site staff prior to the failure. This may indicate the presence of local adverse geological or hydrogeological conditions.

Water ingress into the vegetated slope during rainfall would have wetted up the near-surface material and reduced any soil suction. It may also have led to a transient rise of local groundwater pressure in the soil mass.

### 4.9 The 10 May 2004 landslide on Slope No. 11NE-B/C542, Mok Tse Che Road (Incident No. 2004/05/0013)

#### 4.9.1 The Slope

The slope is a northwest-facing soil cut on the uphill side of Mok Tse Che Road, near Hiram's Highways, Sai Kung. It is up to about 11 m high and inclined at between 45° and 65°. The slope is covered with hydroseeding, except for the 15 m long bare section at the northeastern end of the slope, which is about 4 m high and inclined at about 65°. The entire slope surface is covered with erosion control mat (without wire mesh netting). 300 mm wide surface channels are present along the crest and toe of the slope, except for the 15 m long section at the northeastern end of the slope (Figure 20). Natural terrain inclined at about 25° extends above the central to southern portions of the cut slope.

There are two flimsy huts (registered squatter structures) above the northeastern end of the slope.

Slope upgrading works, which comprised regrading of the slope profile from 65° to 45°, installation of 3 rows of soil nails at 2 m centres, surface drainage system and vegetated surface cover to the soil-nailed cut face, were completed by HyD in October 2002, except for the last 15 m long slope portion at the northeastern end. Subsequently, upgrading works comprising prescriptive soil nails with horizontal and vertical spacing at 1.5 m and 2.0 m centres respectively, raking drains, and replacement of the hard cover by vegetation with erosion control mat were carried out for the northeastern slope portion by a HyD's term contractor in August 2003.

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4.9.2 The Landslide

On 10 May 2004, a landslide was reported at the northeastern portion of the subject slope. The exact date of the failure is not known. The landslide involved a shallow failure (1 $m^3$ in volume) of near-surface material (comprising colluvium and saprolite) in between the nail heads at the 65°cut face. The failure scar was about 2.5 m long by 1.5 m wide by 0.4 m deep (Figure 21 and Plate 15). No casualties were reported as a result of the incident.

4.9.3 Probable Causes of the Landslide

The incident involved a shallow failure of the near-surface material between nail heads on a 65° steep cut face. The failure was probably triggered by intense short-duration rainfall, which resulted in direct infiltration and wetting up of the ground. The local low point at the slope crest may have led to concentrated surface runoff towards the failure location, thereby enhancing the infiltration into the slope. A blocked catchpit on the crest platform and the absence of a crest drainage channel above the failed portion of the slope may have exacerbated the situation.

4.10 The 13 June 2003 Landslide on Slope No. 6NE-B/C8, Fan Kam Road (Incident No. 2003/06/0126)

4.10.1 The Slope

The subject slope is a soil cut located above Fan Kam Road (Figure 22). The slope is up to about 23 m high with an average angle of about 40°. The slope surface is covered by grass and shrubs, together with erosion control mat. A 1 m wide berm with a 250 mm wide U-channel separates the slope into two batters at the northeast portion. The lowest 2.5 m of the upper batter has a steeper face angle of between 50° and 55°. The natural hillside above the cut, which is inclined at about 30°, is strewn with boulders and covered with dense vegetation comprising grass, shrubs and small trees.

The slope was included in the LPM Programme in 1996. According to the Stage 3 Study Report prepared by the consultants (Harris & Sutherland (Far East) Ltd., 1998), a slope failure occurred between 1963 and 1986 as interpreted from aerial photographs. The upgrading works, comprising the installation of 217 soil nails at 1 m vertical spacing and 4 m horizontal spacing, with an inclination of 5° to the horizontal and 600 mm square nail heads, 22 raking drains near the slope toe and replacement of the shotcrete cover with hydroseeding together with erosion control mat, were completed in March 2000.

4.10.2 The Landslide

At about 2:00 p.m. on 13 June 2003, a landslide involving an estimated volume of 3 $m^3$ occurred between the nail heads at the steeper part (50° to 55°) of the upper batter (Figure 23 and Plate 16) during moderate rainfall. No casualties were reported as a result of the landslide.

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The landslide scar was about 3 m wide by 2.8 m high by 0.4 m deep and was delineated by three nail heads. The material exposed on the scar was extremely weak, yellowish brown, completely decomposed coarse ash tuff comprising sandy silt with occasional cobbles. No signs of seepage were observed on the landslide scar at the time of site inspection on 14 June 2003.

Landslide debris, which comprised firm, yellowish brown, sandy silt with occasional cobbles of volcanic origin, intact displaced vegetation and remnants of erosion control mat, was deposited on the berm and piled up against the lower portion of the landslide scar to a height of about 1 m.

Several small dish-shaped scars and erosion pipes were found near the landslide scar and within the steeper part of the upper batter. These small scars and pipes appeared to have been in existence for some time (probably more than one year), based on their surface texture and presence of sparse vegetation and moss. It appears that the minor scars on the slope face beneath the erosion control mat might have been associated with minor near-surface detachments or local erosion, where similar minor scars are not present in other parts of the cut slope. At the time of the site inspections, no seepage was noted at these scars/holes on the slope surface.

#### 4.10.3 Probable Causes of the Landslide

The minor detachment from the cut face between the nail heads was probably caused by the wetting up of the near-surface material due to direct infiltration, which was probably predisposed to instability by the locally steeper gradient of the cut face at the failure location.

The presence of locally more weathered and weaker material in the heterogeneous weathered volcanic may be a contributory factor to the failure.

### 4.11 The 8 November 2003 Landslide on Slope No. 11SE-D/CR22, Chai Wan Road (Incident No. 2003/11/0200)

#### 4.11.1 The Slope

This is a northeast-facing soil/rock cut situated adjacent to Chai Wan Road and below the Chai Wan Swimming Pool. Slopes Nos. 11SE-D/C458 and 11SE-D/C675 are situated above the crest of the western portion of the slope (Figure 24).

The western portion of the slope has a height of about 7 m at the western extent, which rises gradually to about 20 m in the central slope portion. The geometry generally comprises two batters inclined at about 50° and separated by an intermediate berm, whereas the western-most portion comprises a single batter. The western portion of the slope is mostly covered by vegetation, with localized areas of shotcrete cover mainly on the lower portion of the slope (Plate 17), and with soil nails installed on a regular grid (about 2 m horizontally and vertically).

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The western portion of slope No. 11SE-D/CR22 (previously registered as slope No. 11SE-D/C22) was upgraded under HyD's Project entitled 'Proposed Cat. D Chai Wan Road/Wing Tai Road Traffic Improvement Scheme'. The upgrading works comprised installation of three rows of 6 m and 8 m long soil nails at 2 m horizontal spacing, a hydroseeded cover with erosion control mat to replace the chunam cover and a small toe planter wall. The upgrading works were completed in late 1993.

The eastern slope portion is about 20 m high with a shotcrete cover. The lower batter is formed in rock and the upper portion formed in soil. This slope portion was upgraded under the LPM Programme in May 1998 with soil nails and rock dowels.

4.11.2 The Landslide

A minor washout failure was reported to have occurred at the western portion of slope No. 11SE-D/CR22 at about 2:00 p.m. on 8 November 2003 during moderate rainfall. The landslide debris was deposited on the toe wall planter. No casualties were reported as a result of the landslide.

The failure scar was located at about 15 m from the western end of the slope where the slope is about 7 m high with two rows of soil nails installed. The landslide scar was located at the slope crest and extended just below the upper row of soil nails (Plate 18). The nail heads within the landslide scar did not appear to have been affected by the landslide, but the erosion control mat at the slope crest was damaged.

The landslide scar was about 3.5 m wide by 2 m high and up to about 0.5 m in depth, with a failure volume of about 1 $m^3$ to 2 $m^3$. The landslide scar exposed mainly Grade V tuff with some tree roots. No seepage was observed at the scar at the time of the site inspection on 10 November 2003 (Plate 18).

A catchpit and a 250 mm wide surface channel immediately above the failure scar were found to have been blocked by vegetation chippings and silt. The blocked catchpit is situated on the downstream side of the discharge point from the surface drainage system of slope No. 11SE-D/C458.

The maintenance contractor of ArchSD was undertaking vegetation clearance on the western slope portion at the time of the landslide. Trimmed vegetation chippings had not been totally removed from the slope face, some of which was accumulated on the intermediate berm, completely blocking the surface drainage system. Cracking was observed in the berm channel at several locations.

4.11.3 Probable Causes of the Landslide

The landslide was probably triggered by the moderate rainfall on 8 November 2003. Overspilling from the blocked drainage system was probably a key contributory factor to the washout failure.

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## 4.12 The June 2001 Landslides on Slopes Nos. 6SE-D/C52, 6SE-B/C4 and 6NE-D/C6 along Route Twisk, Tsuen Wan

### 4.12.1 The slopes

Slope No. 6SE-D/C52

The slope comprises two soil cuts at two ends with a concrete retaining wall in the middle (Figure 25). The soil cuts are typically 5 m to 10 m high with angles of between 30° and 65°. Drainage channels of sizes between 225 mm to 600 mm are present at the crest and toe of the slope. The slope is generally covered with vegetation except for some localised areas, which are covered with shotcrete or masonry facing. The slope is situated above Route Twisk. Natural hillside inclined at about 15° to 35° extends above the slope crest.

The slope was included in the LPM Programme in 1996. According to the API in the Stage 3 Study Report prepared by the consultants (Harris & Sutherland (Far East) Ltd., 1998b), one minor landslide occurred on the slope between 1967 and 1982. The slope upgrading works were completed in May 2000.

According to the as-built records, 8 m to 14 m long soil nails (with 32 mm diameter galvanised steel bars in 100 mm diameter grouted holes) were installed in up to five rows at 2.5 m to 3 m vertical spacing and 2 m to 2.5 m horizontal spacing, with an inclination of 5° to the horizontal. Raking drains of 10 m long were installed at 3 m to 5 m horizontal spacing. The upgrading works also included the provision of surface drainage, hydroseeding with erosion control mat to replace the existing hard surface cover, and shotcreting to part of the slope surface.

Slope No. 6SE-B/C4

The upper portion of this slope is covered with shotcrete and is typically 3 m to 5 m high with angles of between 20° and 35°. The lower portion is vegetated and is typically 5 m to 8 m high with angles of between 40° and 60°. No berms or drainage channels are provided between the upper and the lower portions. Drainage channels of sizes between 225 mm and 700 mm are provided at the crest and toe of the slope. The slope is situated above Route Twisk. Natural hillside inclined at about 20° extends above the slope crest (Figure 26).

The slope was included in the LPM Programme in 1996 and the Stage 3 Study Report was prepared by the consultants (HSES, 1998a). According to GEO's landslide database, two minor landslides were reported in 1989 (with failure volumes of 1 $m^3$ to 2 $m^3$). The slope upgrading works were completed in June 2000.

According to the as-built records, 8 m to 12 m long soil nails (with 32 mm diameter galvanised steel bars in 100 mm diameter grouted holes) were installed in up to five rows at 2 m to 3 m horizontal spacing, with an inclination of 5° to the horizontal. Raking drains were installed at 3 m to 4 m horizontal spacing. The upgrading works also included the provision of surface drainage, hydroseeding with erosion control mat to replace the existing hard surface cover, and shotcreting to part of the slope surface.

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Slope No. 6NE-D/C6

This soil cut slope is up to about 18 m high with face angles of between 50° and 60°. Near the western end, the slope is separated into two batters by a 3 m wide berm. Drainage channels of sizes between 225 mm and 800 mm are provided to the slope crest, on the berm and at the slope toe. The slope surface is generally covered with vegetation, except for some localised areas that are covered with shotcrete or masonry facing. The slope is situated above Route Twisk. Natural hillside inclined at about 30° extends above the slope crest (Figure 27).

The slope was included in the LPM Programme in 1996. According to the API in the Stage 3 Study Report prepared by the consultants (HSES, 1998c), two minor landslides occurred on the slope between 1986 and 1993. GEO's landslide database also contains records of a landslide (failure volume of 40 $m^3$), which occurred on the slope in 1993. The slope upgrading works were completed in February 2000.

According to the as-built records, 8 m to 14 m long soil nails (with 32 mm diameter galvanised steel bars in 100 mm diameter grouted holes) were installed in up to twelve rows at 2 m to 3 m horizontal spacing, with an inclination of 5° to the horizontal. Raking drains were installed at 3 m to 4 m horizontal spacing. The upgrading works also included surface drainage provision and hydroseeding to part of the slope surface to replace the old hard surface cover. The vegetated slope surface was covered with erosion control mat.

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4.12.2 The Landslides

Between 10 and 11 June 2001, a landslide occurred on slope No. 6SE-D/C52 and two landslides occurred on slope No. 6SE-B/C4. On 27 June 2001, another landslide occurred on slope No. 6NE-D/C6. No casualties were reported as a result of these landslides. Post-failure inspections were carried out on 16 July 2001.

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The minor landslide, with a volume of about 2 $m^3$, occurred at the southern portion of Slope No. 6SE-D/C52. The landslide scar was situated above a concrete stairway, which runs across the soil cut slope (Plate 19), and was about 3 m wide and 3 m high with a maximum depth of about 0.3 m. The material exposed in the scar was completely decomposed rhyolite, which comprised reddish brown, sandy silt/clay with occasional gravel- and cobble-sized rock fragments. The face angle at the failure location was about 45°. Prior to the failure, the slope surface was covered with vegetation and erosion control mat.

Above the slope crest, there was a small platform of approximately 1.5 m wide, with a 10° fall towards the crest of the landslide scar. This platform was covered with vegetation. A concrete slab/block of 0.8 m by 0.8 m by 0.1 m was also found on the platform and situated directly above the landslide scar. A 600 mm U-channel was located at the upslope side of the stairway.

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The two landslides that occurred on slope No. 6SE-B/C4 are labeled as Landslide A and Landslide B in Figure 26. Landslide A, with a volume of about 3 $m^3$, was situated in the lower portion of the vegetated slope. The landslide scar was about 5 m high and 3 m wide with a maximum depth of about 0.5 m. The landslide scar exposed colluvium which comprised reddish brown sandy silt/clay with gravel sized rock fragments (Plate 20). The face angle at the failure location was about 45°. On the upper portion of the slope above the landslide scar was a local depression, which tends to concentrate surface runoff towards the failure area.

Landslide B, with a volume of about 2 $m^3$, was also situated in the lower portion of the slope and was about 18 m to the north of Landslide A. The landslide scar was about 3 m high and 2.5 m wide with a maximum depth of about 0.4 m. The material exposed in the scar was completely decomposed tuff which comprised yellowish mottled red sandy silt/clay with some angular fine gravel-sized rock fragments. The face angle at the failure location was about 40°. The back scarp of Landslide B was located immediately below a rock outcrop (Plate 21).

Prior to the landslides, the vegetated slope surfaces were covered with erosion control mat. Some of the U-shaped fixing pins to the erosion control mat were found to be only 120 mm long.

The landslide that occurred near the western end of slope No. 6NE-D/C6 was about 6 m high and 2 m wide with a maximum depth of about 0.5 m, with a failure volume of about 3 $m^3$. The material exposed in the scar, comprising reddish brown sandy silt with occasional sub-angular gravels and cobbles, was completely decomposed granodiorite (Plate 22). The face angle at the failure location was about 60°. The slope surface was covered with dense vegetation and an erosion control mat prior to the landslide.

Above the landslide scar was a 3 m wide berm covered with vegetation and there was no drainage channel. A local shallow depression was found on the berm above the landslide scar.

#### 4.12.3 Probable Causes of the Landslides

The four minor landslides were probably caused by direct infiltration, which may have been exacerbated by an unfavourable site setting (see below), resulting in wetting up of the near-surface material and possible build-up of transient water pressures at shallow depths.

The vegetated platform above the landslide scar at slope No. 6SE-D/C52 would have promoted enhanced infiltration. The presence of a concrete slab/block situated on the platform and directly above the landslide scar might have concentrated surface runoff onto the slope face.

The area above Landslide A on slope No. 6SE-B/C4 had a local depression, which might have promoted concentrated surface runoff to the landslide area. No drainage measures were provided to intercept the surface runoff.

Above the landslide scar at slope No. 6NE-D/C6 was a 3 m wide vegetated berm with no surface drainage channels. In addition, the local and shallow depression on the berm would have allowed ponding, further promoting infiltration into the ground mass.

It is noted that fixing pins, instead of continuous anchorage, were used in fixing the upper edge of the erosion control mat and some of the fixing pins used were only 120 mm

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long. If the upper edge of the erosion control mat were not adequately anchored, there would be a potential for the mat to be lifted off the slope surface, allowing concentrated surface water flow underneath it. This in turn may promote surface erosion and enhanced infiltration. The requirements of continuous anchorage at the upper edge of the erosion control mat and a minimum penetration depth of 300 mm for the fixing pins were promulgated in GEO standard drawing No. GC 1063 in November 2000.

## 4.13 Failure of Soil-nailed Slopes Overseas

### 4.13.1 Failure of a 72 m High Soil-nailed Slope and Cut Slope in Malaysia

This failure case is described by Liew & Liong (2006). The subject slope is located on a high ground with reduced levels ranging from RL210 m to RL330 m, and was constructed to facilitate the formation of a new road. The site is underlain by completely decomposed shale facies (mudstones and sandstones).

The slope comprised an upper unsupported cut and a lower soil-nailed slope portion. The upper cutting was about 42 m high, consisting of seven 45° batters with a 2 m wide berm at every 6 m height intervals. The lower soil-nailed slope was about 30 m high, consisting of five batters inclined at 4:1 (76°), with 2 m wide berms provided at every 6 m height interval (Figure 28). The lower slope portion was reinforced with 12 m long soil nails. When the landslide occurred, all the soil nails, except for the soil nails at the lowest batter, had been installed.

The landslide involved the full height of the slope. During the post-failure geological mapping and subsurface investigation works, it was observed that most of the exposed materials on the slope surface were Grade III to V shale and the cut face varied from a relatively smooth surface to an irregular rough surface. No seepage was observed. The mapping revealed that the joint sets mapped at the slope surface were daylighting towards the new road and were infilled with iron oxide and silt.

Based on the rainfall records, there was no abnormally high rainfall before the failure.

Slope stability analyses were carried out using limit equilibrium and finite element methods to investigate the causes of the failure. Limit equilibrium analyses revealed that the factor of safety against global and local stability are only marginally higher than 1.0. The finite element analyses showed that the shear surface gradually developed as the excavation progressed to the lower slope batters, reflecting a progressive failure mechanism. The unfavourable geological structures probably contributed to the failure. This case study illustrates an external failure in a nailed slope, as the failure surface extends beyond the limits of the soil nails.

### 4.13.2 Failure of a 45 m High Soil-nailed Slope in Malaysia

This site is in a valley setting, with levels ranging from about RL1090 m to RL1135 m. The slope was formed to facilitate the construction of a new road. Based on the geological map, the site comprises granite and metamorphic rocks.

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The soil-nailed slope comprised a maximum of eight berms, with each of the batters inclined at 76°. The maximum height of the slope was about 45 m. It was reinforced with 12 m long soil nails, except for the highest berm where 6 m long soil nails were installed. Each batter was provided with three rows of soil nails. The horizontal spacing of the soil nails was 1.5 m centres. The slope surface was protected by 100 mm thick gunite (G25) with two layers of A6 mesh reinforcement (Figure 29).

The landslide involved a relatively shallow failure and most of the soil nails remained intact at the failed surface (Liew & Liong, 2006). No seepage was observed on the failed surface.

Rainfall records from three nearby raingauges indicated that no exceptionally heavy rainfall was recorded within the two months prior to the landslide.

Based on site observations, nail tendon failure and pull-out failure were unlikely to be the mode of the failure. The condition of the soil nails after the failure indicated that the failure might be related to the slope facing. A post-landslide assessment was carried out on the facing design. According to Liew & Liong (2006), the flexural strength and punching shear strength of the facing was grossly inadequate, which supports that facing failure is possible. The post-failure slope stability analysis results revealed that the factor of safety (FoS) of the soil-nailed slope was only 1.12. Based on the rainfall records and site inspections, Liew & Liong (2006) considered that the rainfall and the groundwater conditions were not contributory factors to the failure.

#### 4.13.3 Failure of a Soil-nailed Slope for a Hillside Development in Malaysia

This case was described by Chen (2004). A cut slope with a gradient of 45° was formed for a hillside development project. The maximum height of the cut slope is about 18 m with a toe level of RL43.3 m to the crest levels of RL61 m. Berms of about 2 m wide were provided at every 5 m vertical interval. The slope consisted mainly of residual soils. Localised slips had occurred a few years after the completion of the cut slope and soil nails with shotcrete facing were used as the slope remedial measure.

The soil-nailed portion of the slope was about 16 m high with 3 berms. The lowest and second lowest berms were strengthened by three rows of 9 m long soil nails and two rows of 6 m long soil nails respectively, with a horizontal spacing of 1.5 m to 2 m (Figure 30).

The landslide, which occurred in December 1999 following several days of heavy rainfall, was probably rain-induced. Chen (2004) concluded that the failure was primarily caused by saturation of the subsoil, which resulted in significant loss of suction in the ground mass. The soil nails were only 6 m to 9 m long, which were effective to guard against localised, superficial slip. The actual failure surface as revealed from the failure investigation was beyond the lengths of the soil nails.

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# 5. DIAGNOSIS OF LANDSLIDE INCIDENTS ON SOIL-NAILED SLOPES

## 5.1 General

Hitherto, there are no records of any major landslide (i.e. defined as a failure with a volume of detached or displaced groundmass ≥ 50 $m^3$ or where a fatality has occurred) on a soil-nailed slope in Hong Kong. All the reported failure incidents on soil-nailed slopes in Hong Kong were minor failures (with a volume of mostly well less than 50 $m^3$: 75% of the cases had a failure volume of only 4 $m^3$ or less and one case with a volume of about 35 $m^3$) on slopes with a vegetation cover (there are no reported failures on soil-nailed slopes with a hard surface cover). None of these failure cases resulted in any serious consequences.

Based on the GEO's Landslip Preventive Measures Information System (LPMIS), and information obtained from GEO's Slope Safety Division and District Divisions, some 3,700 slopes (about 2,900 are of Government maintenance responsibility, about 280 of private maintenance responsibility and about 510 of mixed maintenance responsibility) have been upgraded using soil nails as of the end of 2006. The average annual failure rates of minor and major landslides on soil-nailed slopes between 1997 and 2006 are 0.078% and 0% respectively (viz. a total of 24 minor and no major landslides between 1997 and 2006, making an overall annual failure rate of all landslides of 0.078%). As a comparison, for the same period, the average annual failure rates of minor and major landslides for engineered unsupported soil cuts are 0.067% and 0.018% respectively (viz. a total of 51 minor and 14 major landslides in 7,470 engineered unsupported soil cuts, making an overall annual failure rate for all landslides of 0.085%). The corresponding average annual failure rates for minor and major landslides on non-engineered old soil cuts (i.e. formed before the establishment of the Geotechnical Engineering Office in 1977) are 0.518% and 0.052% respectively (viz. a total of 1,096 minor and 109 major landslides in 19,098 non-engineered old soil cuts, making an overall annual failure rate for all landslides of 0.570%).

All the 15 minor landslide incidents reviewed in this study involved internal failures (see Section 3). Amongst the 15 cases, 14 were shallow active zone failures in the form of minor surface erosion or local detachments between soil nail heads, with depths ranging from 0.3 m to 1 m. Some of the soil nail heads were partially exposed in these incidents but the nail reinforcements and grout sleeves remained intact, except for the case at Ma Hang Prison (see Section 4.4), which involved bending of the soil nail reinforcement bars.

## 5.2 Key Observations

All the 15 vegetated soil-nailed slopes reviewed were steep, four of which have a gradient equal to or exceeding 45º and the other 11 exceeding 50º. Twelve of the 15 cases are associated with minor surface erosion and minor detachments (i.e. < 5 $m^3$) from the near-surface materials between the nail heads. The provision of soil nails in these cases cannot prevent these minor landslides because the failure mechanism did not involve the soil nails.

All but one of the 15 vegetated slopes has erosion control mats, and among these, three slopes have steel wire mesh installed. The steel wire meshes were able to contain the detached soil mass in one of the cases (see Section 4.3).

Thirteen of the 15 cases involved the replacement of a hard surface cover with a

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vegetated cover as part of the slope works. Eleven of these 15 slopes did not have any previous records of instability prior to upgrading.

Ten of the failure cases occurred within a fairly short period of time following completion of the works (viz. within 2 years). Post-failure inspections revealed that in seven of the ten cases, vegetation growth was only sparsely or moderately established at the time of failure, which may have played a role in the minor landslides. For the remaining three slopes with heavy vegetation, the presence of adversely orientated relict joints (for one case) and lack of surface drainage channels (for two cases) were probably key contributory factors to the failures.

It is noteworthy that none of the failures was triggered by exceptionally intense rainstorms. This may reflect the vulnerability of steep vegetated soil-nailed cut slopes to minor shallow failures.

The present review has highlighted that due attention should be given to the proper detailing of surface drainage provisions, e.g. provision of upstands or baffles for drainage channels (Hui et al, 2006), and the provision of appropriate erosion control measures (such as erosion control mats with steel wire mesh, concrete grillage, hard surfacing, etc.). The presence of local adverse geological features or relict discontinuities and adverse groundwater conditions, which can be difficult to detect and guard against in practice, can also make the slopes more susceptible to rain-induced shallow failures. The slope is also prone to shallow detachments where there are locally oversteepened profiles between the soil nail heads.

The Ma Hang Prison incident highlights the importance of properly dealing with locally high and adverse groundwater conditions (as reflected by persistent seepage) by means of adequate subsurface drainage measures to prevent possible seepage erosion.

## 6. DISCUSSION

Comparing the average annual failure rates of soil-nailed slopes with other engineered soil cuts without soil nails in Hong Kong (see Section 5.1), soil nails appear to be effective in preventing large-scale failures as so far no major failures were reported on cut slopes with permanent soil nails. In terms of minor failures, the average annual failure rate of soil-nailed slopes is of a similar order as that of engineered, unsupported soil cuts.

It is noteworthy that no landslides (either major or minor failures) have been reported on soil-nailed slopes with a hard surface cover in Hong Kong to date. In terms of performance records since the late 1980's, soil-nailed slopes with a hard surface cover have shown to be robust.

The recent trend of upgrading of substandard existing slopes favours a green slope cover (i.e. vegetated cover) from the environmental and aesthetic points of view. Replacement of hard surface covers with vegetated covers could have an adverse impact on the groundwater regime in that water ingress through direct infiltration into vegetated slopes may potentially exacerbate the build-up of transient groundwater pressure in the near-surface materials. This is probably one of the key contributing factors in the majority of the observed shallow and local failures, as more than 85% of the failure cases are of this category (see

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Section 5.2). It is not certain whether the process of replacing the hard surface cover and constructing the nail heads could have led to some local disturbance of the slope surface, which may render it vulnerable to erosion by surface runoff.

Steep soil-nailed slopes with vegetated covers have shown to be fairly vulnerable to minor failures, as the potential for shallow small detachments between soil nail heads within the active zone of the soil nail system cannot be prevented effectively by means of the soil nails. Analyses of the local stability of the soil mass in a steep slope between the soil nail heads have been carried out assuming a sliding failure mechanism, with allowance made for soil arching effects above and below the postulated failure wedge (Shiu & Chang, 2005). Fairly onerous groundwater conditions were assumed and in this event, local failures in between soil nail heads were predicted. The efficiency of the soil nails, which are typically shallowly inclined for the upgrading of substandard soil cuts in Hong Kong, is not high in so far as prevention of shallow detachment is concerned. This is because the nails are not orientated at an optimal inclination in relation to the steep slip surfaces with regard to the mobilization of tension forces in the soil nails. The effectiveness of soil nails with regard to the orientations would have an impact on the arching effects on the soil mass in between the soil nails. In case of shallow failures on a steep vegetated soil-nailed slope, there is little horizontal displacement to mobilize the tensile forces in the nail bars and hence their effectiveness in stabilising potential vertical/subvertical failure surfaces may be limited. The situation is exacerbated in the case of vegetated slopes whereby the surface of a steep slope is not protected by a hard cover and any soil suction that could have built up may be locally reduced or removed by water ingress through direct infiltration.

Martin (2000) cautioned against the potential over-reliance on soil nails by designers without earthworks for upgrading soil cut slopes. He highlighted that care is needed against the indiscriminate use of soil nails for localized steep back scars, overhangs, disturbed ground from previous relict instability, and other areas of possible stress concentration or high erosion potential. The case studies reported in Malaysia serve as a reminder that sizeable failures could occur in soil-nailed slopes where the geotechnical engineering and engineering geological input at the ground investigation and design stages was inadequate.

The report by CIRIA (2005) notes that a "soft" facing incorporating "geogrids, cellular geofabrics, geosynthetic sheet, light metallic mesh/fabric or degradable coir mats" could be used where the slope face is gentle but these should not be used for slopes "steeper than the angle at which the soil forming the slope surface is stable naturally". CIRIA (op cit) suggests that for steep slopes, flexible/hard structural facings, such as coated metallic mesh, proprietary heavy rock meshes, reinforced sprayed concrete and cast-in-situ concrete or precast concrete panels would provide long-term stability of the slope face by transferring the soil loads from the facings to the soil nail heads.

Shiu & Chang (2005) note that local instability of the soil between heads could occur on steep slopes, particularly when the soil is saturated. HA68/94 (Department of Transport, 1994) suggests that netting and pins could be used to prevent superficial 'sloughing' of the soil from happening. Shiu & Chang (op cit) note that "the prescriptive method [steel wire mesh] used in LPM works is similar to that recommended in HA 68/94". Based on a performance assessment of greening techniques on slopes in Hong Kong, Lui & Shiu (2006) also conclude that "Use of steel wire mesh in conjunction with non-degradable erosion control mat provides a more effective means of controlling surface erosion". The steel mesh is

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usually stretched slightly and anchored onto the concrete nail heads. This helps to ensure that the erosion control mat is in good contact with the slope surface.

The current guidelines promulgated by the GEO (e.g. GEO, 2007b; GEO, 2000; Wong et al, 1999) generally promote the use of a non-tensioned steel wire mesh in conjunction with an erosion control mat for steep soil-nailed slopes (e.g. with a gradient exceeding $45^{o}$), and the provision of a hard cover for very steep cuts (e.g. with a gradient exceeding $55^{o}$) with soil nails. This prescriptive detailing is similar to that suggested by the Department of Transport (1994). However, it appears that steel wire mesh has apparently not been provided in some of the soil-nailed cuts covered by the present review.

Measures that could be considered for mitigating the risk of minor failures in the active zone of steep vegetated soil-nailed slopes in Hong Kong include the following:

(a) provision of proprietary tensioned wire mesh, in conjunction with erosion control mat, to support the exposed slope face and transfer the soil loading to the nails (e.g. Flum & Rüegger, 2004; Rüegger et al, 2001),

(b) enlargement of the soil nail heads (already adopted in GEO (2004c) to enhance the stability of slopes and ensure sufficient confinement at the slope surfaces to prevent movement and disintegration of the groundmass within the active zone),

(c) provision of grillage beams to tie together the nail heads,

(d) use of fibre reinforced soil system as a soft facing (e.g. Mak, 2004),

(e) provision of ‘secondary’ (shorter) soil nails in between the ‘primary’ soil nails to reinforce the active zone, and

(f) use of actively stressed soil nails (Barley, 2004).

Items (a), (d) and (f) involve proprietary products. Tensioned wire meshes have recently been used in isolated LPM projects for rock cuts but not soil cuts. Some pilot local experience has been obtained with actively stressed soil nails through trial installations (Ho et al, 2007).

Application of tensioned wire mesh is potentially subject to constraints posed by the slope conditions, e.g. might be difficult to transfer the confining effect of the tensioned wire mesh onto the slope surface where the slope surface is highly uneven. The use of grillage beams would divide a steep soil-nailed slope into compartments which would facilitate greening and at the same time help to prevent failures in between the soil nails and surface erosion. However, they are not easy to construct in a steep slope with a lot of existing trees that needed to be preserved.

All the measures suggested above can be provided at a cost. The overall cost-

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effectiveness of the individual measures (including both capital cost and life-cycle cost such as maintenance cost) for a particular slope would need to be balanced against the risk involved and the risk reduction by the designer, along with other relevant considerations such as the need of long-term monitoring requirements, track record of local applications, etc.

The present review has shown that the vast majority of the reported failures involved shallow and local failures with small debris volumes and negligible or very minor consequences. Many of the cases involved replacement of a hard cover with a vegetated cover, together with soil nail installation. The remedial works required generally comprised minor patching up or other inexpensive repair works. The annual frequency of occurrence of minor failures in soil-nailed slopes is not that high, and both the consequence-to-life and the economic consequence are not high. In view of the correspondingly low perceived risk level involved, it may not be cost-effective to substantially upgrade the surface protection requirements across the board for all vegetated soil-nailed slopes. The chance of minor failures on vegetated slopes would be further reduced by paying due attention to the proper detailing of slope surface and subsurface drainage provisions, together with appropriate surface protection measures (e.g. use of appropriate erosion control mats and steel wire meshes). In addition to this, designers should also incorporate suitable mitigation measures (e.g. debris traps, toe barriers or buffer zones) as an integral part of the slope design, where practicable, to cater for possible minor detachments due to local adverse geological or hydrogeological conditions.

Designers should examine the need for more robust surface protection system on a case-by-case basis, pending the development of a cost-effective and robust vegetated cover detailing that could reduce the chance of shallow minor failures. More robust surface protection measures should be considered if there are known geological weaknesses or adverse relict joints at shallow depths (e.g. observed during construction), particularly for slopes affecting a sensitive facility where the risk of even a minor failure is not considered tolerable.

It is noted that 80% of the steeply inclined slopes (say, > $45^{o}$) covered by this review did not have any steel wire mesh. The provision of steel wire mesh, consistent with the current guidelines by the GEO, may contribute to further supplement the confinement effect of the recently enlarged soil nail heads (in accordance with GEO (2007c)) to a certain degree and could help to reduce the consequence of failure, particularly minor detachments (Shiu & Chang, 2005). Such simple and cost-effective measures should be more widely used, especially for steep slopes.

From the aesthetics point of view, designers generally tend to favour the use of recessed nail heads. Typical details are shown in a standard drawing issued by CEDD, as reproduced in Figure 31. However, there is another school of thought that does not advocate the use of recessed nail heads for routine applications. Concerns have been raised by some practitioners with regard to the stability of the backfill placed in hessian bags above the concrete nail heads in the long run (viz. hessian would degrade after a few years and the backfill may get washed out, especially for the enlarged nail heads; for many slopes, shrubs and small trees may quickly replace the grass and disguise the nail heads, making the recessed nail heads redundant, which would incur additional costs and time). In principle, the designer should carefully consider, on a case-by-case basis, the need for recessed soil nail heads and the appropriate detailing of the backfill above the recessed heads.

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Sections 4.2, 4.4 and 4.5 give examples of failures involving the surface layer of material above the nail heads where steel wire mesh had not been provided. To date, there has been no report of any significant failure associated with the backfill where it has been constructed in accordance with the standard drawing (i.e. with steel wire mesh), albeit the experience with the use of such detailing may be limited.

## 7. CONCLUSIONS

Based on the overall diagnostic review presented in this report, the following key conclusions are made for the failure of soil-nailed slopes in Hong Kong:

(a) From 1997 to 2006, the average annual failure rate of minor landslides on soil-nailed slopes is about 0.078%. No major failure (volume $\geq$ 50 $m^3$) on soil-nailed slopes has been reported in Hong Kong since the introduction of soil nails for slope upgrading in the late 1980's.

(b) There is as yet no reported failure (minor or major instability) on soil-nailed slopes with a hard surface cover.

(c) All the reported failures on vegetated soil-nailed slopes involved local and minor erosion or detachment from shallow depths in the near-surface material within the active zone of the soil nail system, none of which resulted in serious consequences or necessitated substantial and costly repair works. Many of these slopes previously had a hard surface cover, which was replaced by vegetation when soil nails were installed.

(d) Many of the reported failures occurred on steep soil-nailed slopes with the provision of erosion control mats but without a wire mesh. The current guidance issued by the GEO promulgates to the more extensive use of a steel wire mesh in conjunction with an erosion control mat, which may help to reduce the risk of minor shallow failures.

(e) The risk of minor failures within the active zone of a vegetated soil-nailed slope may be reduced by paying due attention to the proper detailing of the slope surface and subsurface drainage provisions.

(f) Where judged necessary, a variety of measures may be considered by the designers to enhance the robustness of the vegetated cover of a soil-nailed slope. However, the applicability and cost-effectiveness of the measures warrant careful review, on a case-by-case basis, with regard to the tolerability of the risk of local and minor detachments.

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| Site Location & Slope No. | Incident No. | Date of Completion of Works (month/year) | Date of Failure | Failure Volume ($m^3$) |
|---|---|---|---|---|
| Victoria Road, Caritas Wo Cheng Chung Secondary School 11SW-C/C383 | 2006/09/0709 | 8/2005 | 13/9/2006 | 0.5 |
| Behind Tai Mei Tuk Country Park Management Centre 3SE-D/C61 | ArchSD/NT/2006/04/0001 | 3/2003 | 26/4/2006 | 4 |
| Ma Hang Prison 15NE-A/C152 | 2005/08/0493 | 3/2001 | 20/8/2005 | 35 |
| South Lantau Road, Shek Pik Reservoir, Lantau Island 13 NE-A/C100 | 2005/08/0313a | 10/2004 | 20/8/2005 | 5 |
| South Lantau Road, Shek Pik Reservoir, Lantau Island 13 NE-A/C102 | 2005/08/0313b | 4/2005 | 20/8/2005 | 5 |
| South Lantau Road, Shek Pik Reservoir, Lantau Island 13 NE-A/C108 (2 scars) | 2005/08/0313c | 4/2005 | 20/8/2005 | 1.5 + 0.5 |
| Ka Wai Man Road, Kennedy Town 11SW-A/C102 | 2005/08/0306 | 12/2004 | 20/8/2005 | 3 |
| Section M of Tai Lam Chung Catchwater 6SE-D/CR437 | 2005/08/0504 | 4/2002 | 20/8/2005 | 20 |
| Anderson Road Quarry Sau Mau Ping | 2004/10/0066 | 7/2004 | 31/8/2004 | 6 |
| Mok Tse Che, Sai Kung 11NE-B/C542 | 2004/05/0013 | 8/2003 | (Reported on 10/5/2004) | 1 |
| Fan Kam Road, Pak Heung 6NE-B/C 8 | 2003/06/0126 | 3/2000 | 13/6/2003 | 3 |
| Chai Wan Road 11SE-D/CR22 | 2003/11/0200 | 5/1994 | 8/11/2003 | 2 |
| Route Twisk 6SE-D/C52 | --- | 5/2000 | 10/6/2001 | 2 |

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Table 1 - List of Reported Soil-nailed Slope Failures between 1993 and 2006 (Page 2 of 2)

| Site Location & Slope No. | Incident No. | Date of Completion of Works (month/year) | Date of Failure | Failure Volume ($m^3$) |
|---|---|---|---|---|
| Route Twisk<br>6SE-B/C4 (2 scars) | --- | 6/2000 | 10/6/2001 | 2 + 2 |
| Route Twisk<br>6NE-D/C6 | --- | 2/2000 | 27/6/2001 | 3 |
| Mount Kellett Road, The Peak*<br>11SW-C/C681 | 2006/07/660 | 6/1996 | 16/7/2006 | 0.2 |
| Lei Pui Street near Junction with Shek Pai Street *<br>7SW-C/CR1045 | 2005/08/451 | 3/2002 | 20/8/2005 | 3 |
| Shu On Terrace, Tsuen Wan *<br>6SE-C/CR323 | 2005/07/0255 | 5/2003 | 8/7/2005 | 1.2 |
| Hong Kong Zoological & Botanical Garden *<br>11SW-B/CR5 | 2005/06/0205 | 2/2005 | 24/6/2005 | 2 |
| Shing Mun Country Park *<br>7SW-C/C820 | AF2003/09/1037 (AFCD/NT/2003/ 09/0001) | 2/2003 | 8/9/2003 | 3 |
| Rear of TWGH C Y Ma Charity Fund Practical School *<br>6NE-A/C1 | AD2003/10/1038 (ArchSD/TC/001) | 10/1998 | 30/10/2003 | 14 |
| O King Road, Lam Tin *<br>11SE-B/C590 | ME2002/10/0144 | 2001-2002 | (Reported in 10/2002) | 2 |
| Tai Hang Road *<br>11SE-C/C54 | HK2001/06/002 | 4/2001 | 8/6/2001 | 0.1 (Boulder fall) |
| Castle Peak Road, Ting Kau *<br>6SE-C/C689 | MW2001/02/002 | late 1990's | 14/2/2001 | 2 |
| No.14 Shuen Wan Chim Uk, Ting Kok Road *<br>3SE-C/C23 | ME93/9/32 | 7/1991 | 26/9/1993 | 10 |

Notes : (1) Cases marked with an asterisk (*) are not selected for review.
(2) A total of 25 landslides occurred between 1993 and 2006.

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Table 2 - Summary of Selected Failure Cases Reviewed (Page 1 of 4)

| **Incident No., Site Location & Slope No. (Date of Completion)** | **Date of Failure** | **Slope Angle** | **Slope Height (m)** | **Slope Surface Treatment (Vegetation Condition)** | **Details of Soil Nails** | **Type/Mode* of Failure (Failure Volume)** | **Dimension of Scar/ Soil Type** | **Possible Contributory Factors to Failure** | | | **Remarks** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | **Surface runoff/ Infiltration** | **Adverse Geology/ Hydrogeology/ Site Setting** | **Poor Detailing** | |
| 2006/09/0709<br>Victoria Road, Caritas Wo Cheng Chung Secondary School<br>11SW-C/C383<br>(8/2005) | 13/9/2006 | 45° | 10 | Hydroseeding without erosion control mat and wire mesh<br>(Sparsely vegetated) | Drillhole : Ø 125 mm<br>Steel bar: Ø 20 & 32 mm<br>Length : 4.5 m-7 m<br>Vert. spacing : 1.5 m<br>Horiz. spacing : 1.5 m<br>Nail Head : 0.6 m sq. (recessed) | Landslide<br>(Washout failure)<br>(0.5 $m^3$)<br>Mode : b(iii) | Width : 3 m<br>Length : 0.4 m<br>Depth : 0.4 m<br>CDV | Direct surface infiltration and possible overflow from the crest channel. | Locally more advanced weathering, possibly associated with a local shear zone. | The crest channel is both steeply inclined and has a sharp change in alignment above the scar.<br>Absence of wire mesh for recessed nail heads. | Soil nails remained intact. |
| ArchSD/NT/2006/04/0001<br>Behind Tai Mei Tuk Country Park Management Centre<br>3SE-D/C61<br>(3/2003) | 26/4/2006 | 60° | 8 | Hydroseeding with erosion control mat and wire mesh<br>(Heavily vegetated) | Drillhole : Ø 100 mm<br>Steel bar : Ø 25 mm<br>Length : 6 m-10 m<br>Vert. spacing : 1.0 m<br>Horiz. spacing : 1.5 m<br>Nail Head: unknown (recessed) | Landslide<br>(4 $m^3$)<br>Mode : b(iii) | Width : 2.4 m<br>Length : 2 m<br>Depth : 0.5 m<br>CDV | Direct surface infiltration. | | | Soil nails remained intact and debris was contained by wire mesh.<br>Hard surface cover was replaced with vegetated cover. |
| 2005/08/0493<br>Ma Hang Prison<br>15NE-A/C152<br>(3/2001) | 20/8/2005 | 45°-56° | 12 | Hydroseeding with erosion control mat<br>(Moderately vegetated) | Drillhole : Ø 100 mm<br>Steel bar : Ø 25 mm<br>Length : 9 m<br>Vert. spacing : 2 m-3 m<br>Horiz. spacing : 2 m<br>Nail Head: 0.4 m- 0.5 m sq. (recessed) | Landslide<br>(35 $m^3$)<br>Mode : b(i) & b(vi) | Width : 6 m<br>Length : 7 m<br>Depth : 1.5 m<br>CDV | Direct surface infiltration. | | Absence of wire mesh for recessed nail heads for steep slope face > 45°. | Two soil nails were bent. The cement grout underneath the soil nail spalled.<br>Hard surface cover was replaced with vegetated cover. |
| 2005/08/0313a<br>South Lantau Road, Shek Pik Reservoir, Lantau<br>13NE-A/C100<br>(10/2004) | 20/8/2005 | 70° | 8.5 | Hydroseeding with erosion control mat<br>(Heavily vegetated) | Drillhole : Ø 100 mm<br>Steel bar : Ø 25 mm<br>Length : 8 m-10 m<br>Vert. spacing: 2 m<br>Horiz. spacing: 2 m<br>Nail Head : 0.4 m sq. (recessed) | Landslide<br>(5 $m^3$)<br>Mode : b(i) | Width : 3 m<br>Length : 5 m<br>Depth : 1 m<br>C/HDV | Direct surface infiltration and water ingress through a cracked surface channel. | Presence of adversely orientated relict joints. | Absence of wire mesh for recessed nail heads for steep slope face > 45°. | Soil nails remained intact.<br>Hard surface cover was replaced with vegetated cover. |
| 2005/08/0313b<br>South Lantau Road, Shek Pik Reservoir, Lantau<br>13NE-A/C102<br>(4/2005) | 20/8/2005 | 50° | 13 | Hydroseeding with erosion control mat<br>(Moderately vegetated) | Drillhole : Ø 100 mm<br>Steel bar : Ø 25 mm<br>Length : 7 m-10 m<br>Vert. spacing: 2 m<br>Horiz. spacing: 2 m<br>Nail Head : 0.4 m sq. (recessed) | Landslide<br>(5 $m^3$)<br>Mode : b(i) | Width : 6 m<br>Length : 3.5 m<br>Depth : 0.5 m<br>C/HDV | Direct surface infiltration and water ingress through a cracked surface channel. | Presence of adversely orientated relict joints. | Absence of wire mesh for recessed nail heads for steep slope face > 45°. | Soil nails remained intact.<br>Hard surface cover was replaced with vegetated cover. |

* See Figure 1 for various failure modes of soil nailed slopes



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# Table 2 - Summary of Selected Failure Cases Reviewed (Page 2 of 4)

| Incident No., Site Location & Slope No. (Date of Completion) | Date of Failure | Slope Angle | Slope Height (m) | Slope Surface Treatment (Vegetation Condition) | Details of Soil Nails | Type/Mode* of Failure (Failure Volume) | Dimension of Scar/ Soil Type | Possible Contributory Factors to Failure | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Surface runoff/ Infiltration | Adverse Geology/ Hydrogeology/ Site Setting | Poor Detailing | |
| 2005/08/0313c<br>South Lantau Road, Shek Pik Reservoir, Lantau<br>13NE-A/C108<br>(4/2005) | 20/8/2005 | 55° | 17 | Hydroseeding with erosion control mat (Moderately vegetated) | Drillhole : Ø 100 mm<br>Steel bar : Ø 32 mm<br>Length : 16 m<br>Vert. spacing: 2 m<br>Horiz. spacing: 2 m<br>Nail Head : 0.4 m sq. (recessed) | Scar A<br>Landslide<br>(1.5 $m^3$)<br>Mode : b(i)<br><br>Scar B<br>Landslide<br>(0.5 $m^3$)<br>Mode : b(i) | Scar A<br>Width : 2.5 m<br>Length : 2.5 m<br>Depth : 0.4 m<br>CDV<br><br>Scar B<br>Width : 1.5 m<br>Length : 2.0 m<br>Depth : 0.4 m<br>CDV | Direct surface infiltration and water ingress through a cracked surface channel. | | Absence of wire mesh for recessed nail heads for steep slope face > 45°. | Soil nails remained intact.<br><br>Hard surface cover was replaced with vegetated cover. |
| 2005/08/0306<br>Ka Wai Man Road, Kennedy Town<br>11SW-A/C102<br>(12/2004) | 20/8/2005 | 60° | 12 | Hydroseeding with erosion control mat and wire mesh (Moderately vegetated) | Drillhole : Ø 100 mm<br>Steel bar : Ø 25 mm<br>Length : 5 m-7 m<br>Vert. spacing: 1.2 m-1.5m<br>Horiz. spacing: 1.5 m-2m<br>Nail Head : 0.4 m sq. (flushed) | Surface erosion<br>(3 $m^3$)<br>Mode : b(i) | Width : 8 m<br>Length : 4 m<br>Depth : 0.5 m<br><br>Colluvium/ CDT | Direct surface infiltration. | | | Soil nails remained intact.<br><br>Hard surface cover was replaced with vegetated cover. |
| 2005/08/0504<br>Section M of Tai Lam Chung Catchwater<br>6SE-D/CR437<br>(4/2002) | 20/8/2005 | 25° (upper portion)<br>66° (lower portion) | 8 (30 m max.) | Hydroseeding with erosion control mat and wire mesh (Heavily vegetated) | Drillhole : Ø 100 mm<br>Steel bar : Ø 32 mm<br>Length : 10 m-15 m<br>Vert. spacing: 1 m - 2 m<br>Horiz. spacing: 2 m<br>Nail Head : 0.4 m-0.5 m sq. (recessed) | Landslide (Washout failure)<br>(20 $m^3$)<br>Mode : b(i) | Width : 10.5 m<br>Length : 7 m<br>Depth : 0.8 m<br><br>CDV | Overland flow during heavy rainfall. | Local depression on the hillside above the slope might have directed the surface water through a minor ephemeral drainage line to the crest channel, which overspilled onto the slope. | No upstand wall or baffle wall provided at crest channel. | Soil nails remained intact.<br><br>Hard surface cover was replaced with vegetated cover. |
| 2004/10/0066<br>Anderson Road Quarry, Sau Mau Ping<br>(CIP, 7/2004) | 31/8/2004 | 54° | 20 (Soil cut 15 m high) | Vegetated slope surface with erosion control mats (Moderately vegetated) | Length : 14 m<br>Vert. spacing: 2 m<br>Horiz. spacing: 2 m<br>Nail Head : 0.4 m sq. (flushed) | Landslide<br>(6 $m^3$)<br>Mode : b(i) | Width : 3 m<br>Length : 8 m<br>Depth : 0.6 m<br><br>CDV | Probable presence of concentrated subsurface flow at the crown of the scar. | Steep and adversely orientated relict joints on the failure scar.<br><br>Possible opening up of relict joints due to stress relief, which might have enhanced water ingress and build-up of cleft water pressure. | Absence of wire mesh for steep slope face > 45°. | Soil nails remained intact. |

* See Figure 1 for various failure modes of soil nailed slopes



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## Table 2 - Summary of Selected Failure Cases Reviewed (Page 3 of 4)

| Incident No., Site Location & Slope No. (Date of Completion) | Date of Failure | Slope Angle | Slope Height (m) | Slope Surface Treatment (Vegetation Condition) | Details of Soil Nails | Type/Mode* of Failure (Failure Volume) | Dimension of Scar/ Soil Type | Possible Contributory Factors to Failure | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Surface runoff/ Infiltration | Adverse Geology/ Hydrogeology/ Site Setting | Poor Detailing | |
| 2004/05/0013<br>Mok Tse Che, Sai Kung<br>11NE-B/C542<br>(8/2003) | Exact date of failure not known. Failure reported on 10/5/2004. | 65° | 4<br>(11 max.) | Hydroseeding with erosion control mat<br>(Moderately vegetated) | Drillhole : Ø 100 mm<br>Steel bar : Ø 25 mm<br>Length : 4.5 m<br>Vert. spacing : 2 m<br>Horiz. spacing : 1.5 m<br>Nail Head : 0.4 m sq. (flushed) | Surface erosion<br>($1 m^3$)<br><br>Mode : b(i) | Width : 1.5 m<br>Length : 2.5 m<br>Depth : 0.4 m<br><br>CDT | Surface runoff due to absence of a crest channel. | Local low point at slope crest may have led to concentrated surface runoff to the failure location. | Absence of wire mesh for steep slope face > 45°. | Soil nails remained intact.<br><br>The proposed crest channel was not constructed.<br><br>Hard surface cover was replaced with vegetated cover. |
| 2003/06/0126<br>Fan Kam Road, Pak Heung<br>6NE-B/C8<br>(3/2000) | 13/6/2003 | 40°<br>(locally 55° where landslide occurred) | 23 | Hydroseeding with erosion control mat<br>(Heavily vegetated) | Drillhole : Ø 100 mm<br>Steel bar : Ø 32 mm<br>Length : 8 m-11 m<br>Vert. spacing: 1 m<br>Horiz. spacing: 4 m<br>Nail Head : 0.6 m sq. (flushed) | Landslide<br>($3 m^3$)<br><br>Mode : b(i) | Width : 3.0 m<br>Length : 2.8 m<br>Depth : 0.4 m<br><br>Colluvium/ CDV | Direct surface infiltration. | Presence of locally more weathered and weak material. | Excessive horizontal spacing (4m) between soil nails.<br><br>Absence of wire mesh for steep slope face > 45°. | Soil nails remained intact.<br><br>Local steep gradient of soil cut ( 55°).<br><br>Hard surface cover was replaced with vegetated cover. |
| 2003/11/0200<br>Chai Wan Road<br>11SE-D/CR22<br>(5/1994) | 8/11/2003 | 50° | 7<br>(20 max.) | Hydroseeding with erosion control mat<br>(Sparsely vegetated) | Length : 6 m-8 m<br>Vert. spacing: 2 m<br>Horiz. spacing: 2 m<br>(nail head flushed) | Landslide<br>(Washout failure)<br>($2 m^3$)<br><br>Mode : b(i) | Width : 3.5m<br>Length : 2 m<br>Depth : 0.5 m<br><br>CDV | Overspilling from blocked drainage channel above the scar. | | Absence of wire mesh for steep slope face > 45°. | Soil nails remained intact.<br><br>Hard surface cover was replaced with vegetated cover. |
| Route Twisk<br>6SE-D/C52<br>(5/2000) | 10/6/2001 | 35°-65°<br>(about 45° where landslide occurred) | 5-10 | Hydroseeding with erosion control mat<br>(Moderately vegetated) | Drillhole : Ø 100 mm<br>Steel bar : Ø 32 mm<br>Length : 8 m-14 m<br>Vert. spacing: 1 m<br>Horiz. spacing: 2.5 m-3 m<br>Nail Head : 0.5 m-0.75 m sq. (flushed) | Landslide<br>($2 m^3$)<br><br>Mode : b(i) | Width : 3.0 m<br>Length : 3.0 m<br>Depth : 0.3 m<br><br>CD<br>Rhyolite | Direct surface infiltration. | The vegetated platform above the landslide scar might have promoted enhanced infiltration. | Absence of wire mesh for steep slope face > 45°. | Soil nails remained intact.<br><br>Hard surface cover was replaced with vegetated cover. |

* See Figure 1 for various failure modes of soil nailed slopes




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Table 2 - Summary of Selected Failure Cases Reviewed (Page 4 of 4)

| Incident No., Site Location & Slope No. (Date of Completion) | Date of Failure | Slope Angle | Slope Height (m) | Slope Surface Treatment (Vegetation Condition) | Details of Soil Nails | Type/Mode* of Failure (Failure Volume) | Dimension of Scar/ Soil Type | Possible Contributory Factors to Failure | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Surface runoff/ Infiltration | Adverse Geology/ Hydrogeology/ Site Setting | Poor Detailing | |
| Route Twisk 6SE-B/C4 (6/2000) | 10/6/2001 | 40°-60° | 5-8 | Hydroseeding with erosion control mat (Heavily vegetated) | Drillhole : Ø 100 mm<br>Steel bar : Ø 32 mm<br>Length : 8 m-12 m<br>Vert. spacing: 1 m<br>Horiz. spacing: 2 m-3m<br>Nail Head : 0.6 m-0.8 m sq. (flushed) | Scar A<br>Landslide<br>($2\ m^3$)<br><br>Mode : b(i) | Scar A<br>Width : 3.0 m<br>Length : 5.0 m<br>Depth : 0.5 m<br><br>Colluvium | Direct surface infiltration. | A local depression above the failure scar might have promoted concentrated surface runoff to the landslide area. | No drainage measures provided to intercept surface runoff.<br><br>Absence of wire mesh for steep slope face > 45°. | Soil nails remained intact.<br><br>Hard surface cover was replaced with vegetated cover. |
| | | | | | | Scar B<br>Landslide<br>($2\ m^3$)<br><br>Mode : b(i) | Scar B<br>Width : 2.5 m<br>Length : 3.0 m<br>Depth : 0.4 m<br><br>Colluvium | Direct surface infiltration. | | | |
| Route Twisk 6NE-D/C6 (2/2000) | 27/6/2001 | 50°-60° | 18 | Hydroseeding with erosion control mat (Heavily vegetated) | Drillhole : Ø 100 mm<br>Steel bar : Ø 32 mm<br>Length : 8 m-14 m<br>Vert. spacing: 1 m-2 m<br>Horiz. spacing: 2 m-3 m<br>Nail Head : 0.5 m-0.8 m sq. (flushed) | Landslide<br>($3\ m^3$)<br><br>Mode : b(i) | Width : 2.0 m<br>Length : 6.0 m<br>Depth : 0.5 m<br><br>CD Granodiorite | Direct surface infiltration. | A shallow depression on the berm above the failure scar might have allowed ponding and promoted enhanced infiltration. | A 3 m wide vegetated intermediate berm with no surface drainage provision is located above the landslide.<br><br>Absence of wire mesh for steep slope face > 45°. | Soil nails remained intact.<br><br>Hard surface cover was replaced with vegetated cover. |

* See Figure 1 for various failure modes of soil nailed slopes



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# LIST OF FIGURES




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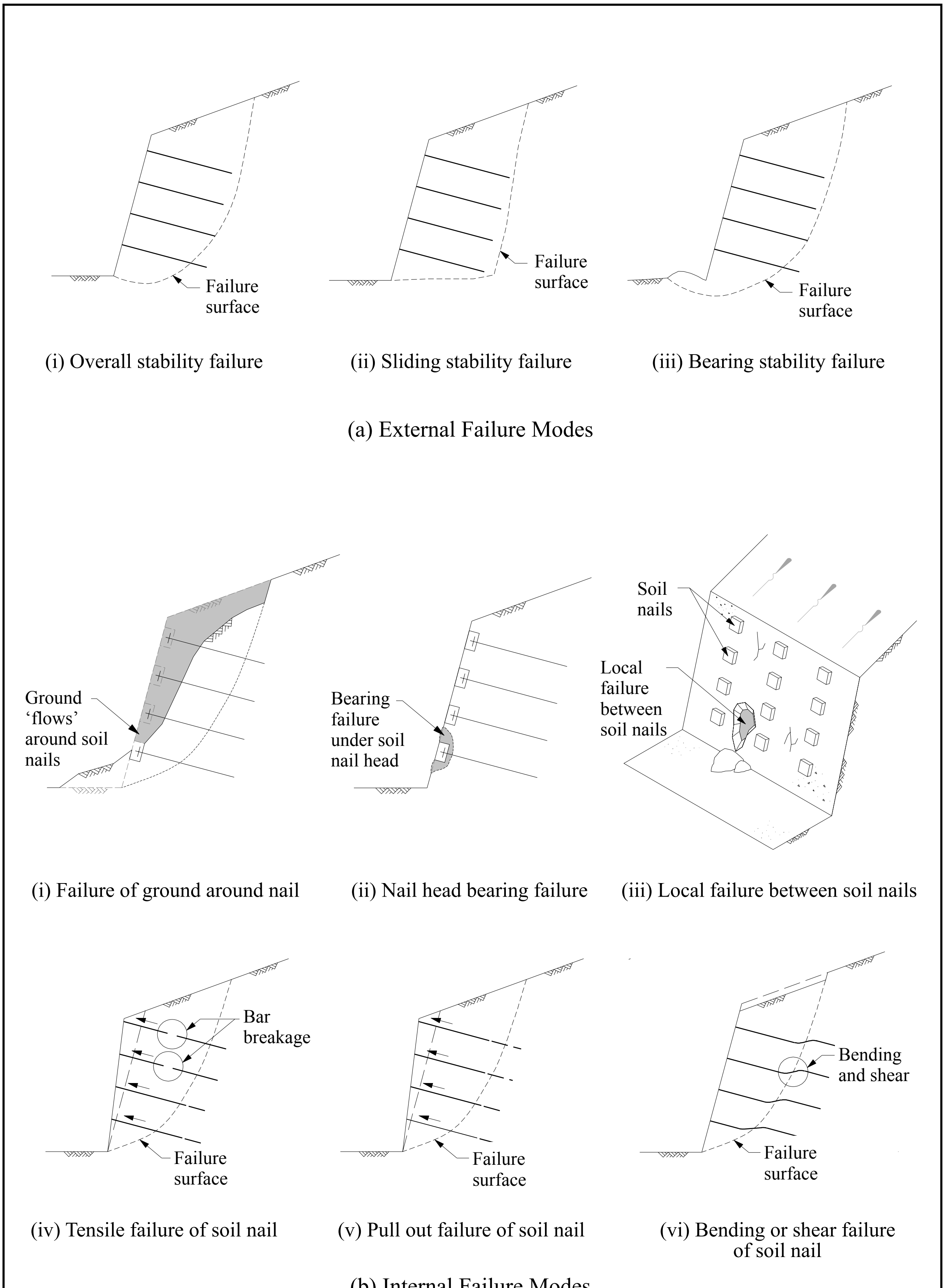


Figure 1 – Various Failure Modes of Soil-nailed Slopes

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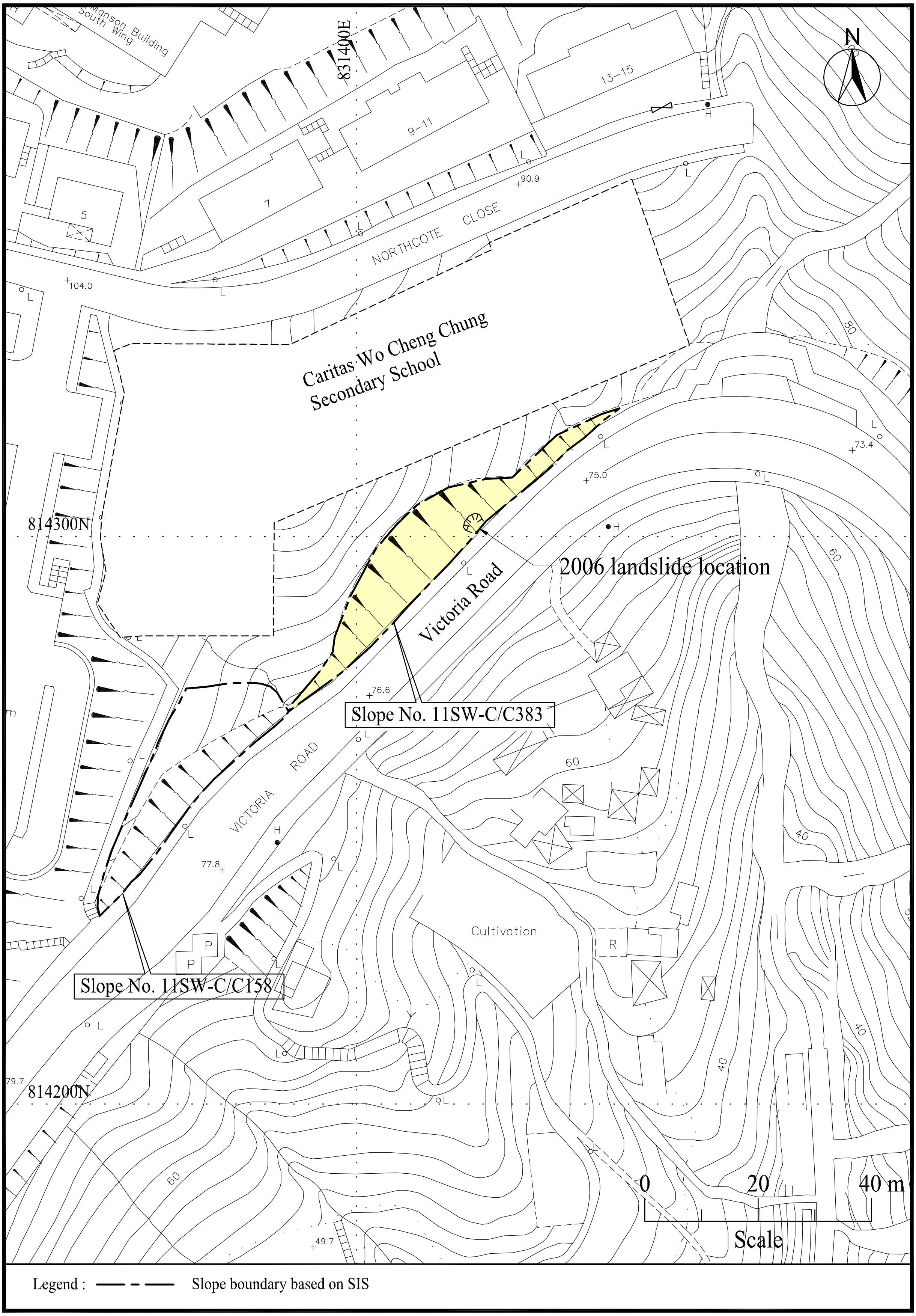


Figure 2 - Site Location Plan (Slope No. 11SW-C/C383)

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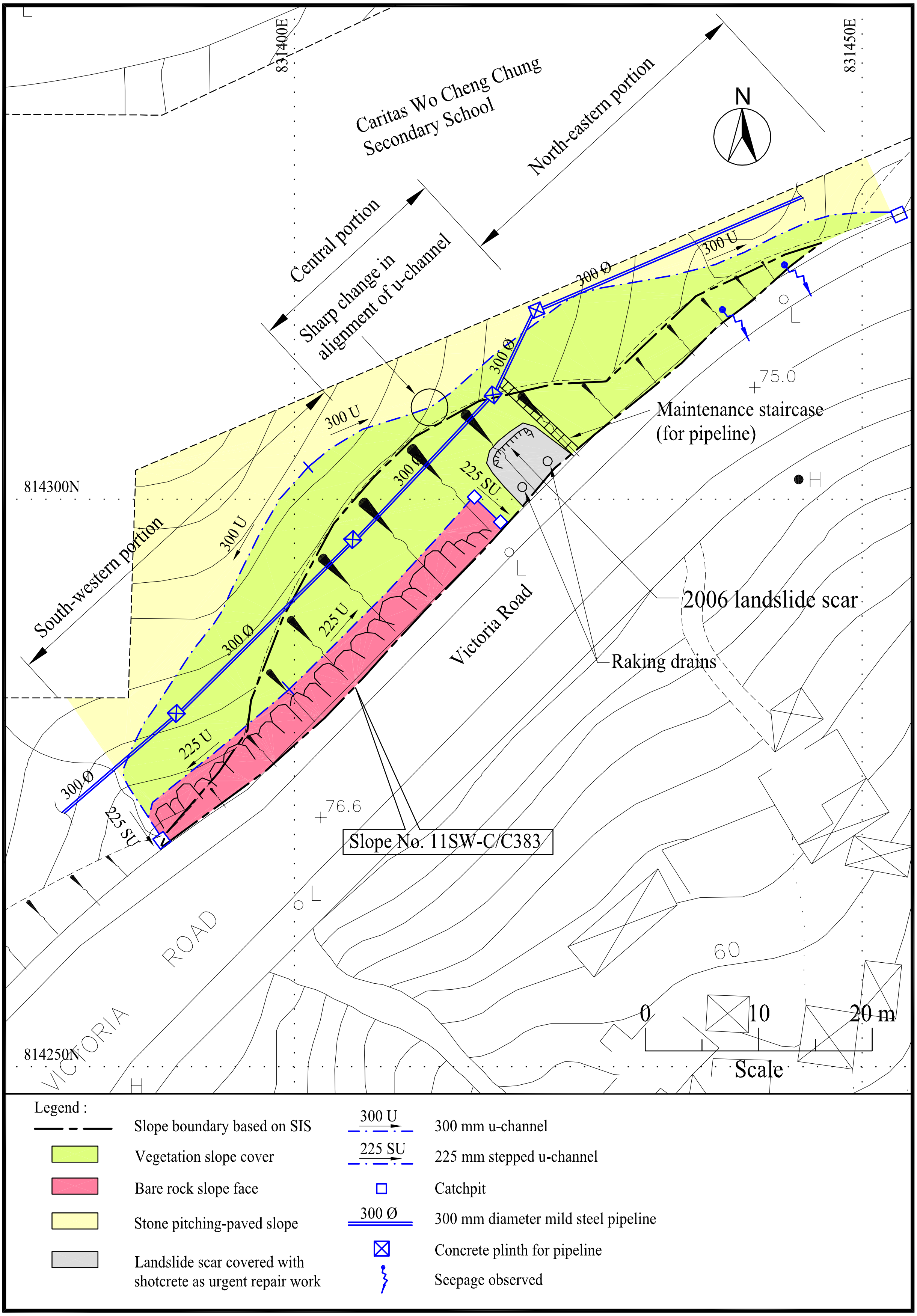


Figure 3 - Site Plan and Field Observations (Slope No. 11SW-C/C383)

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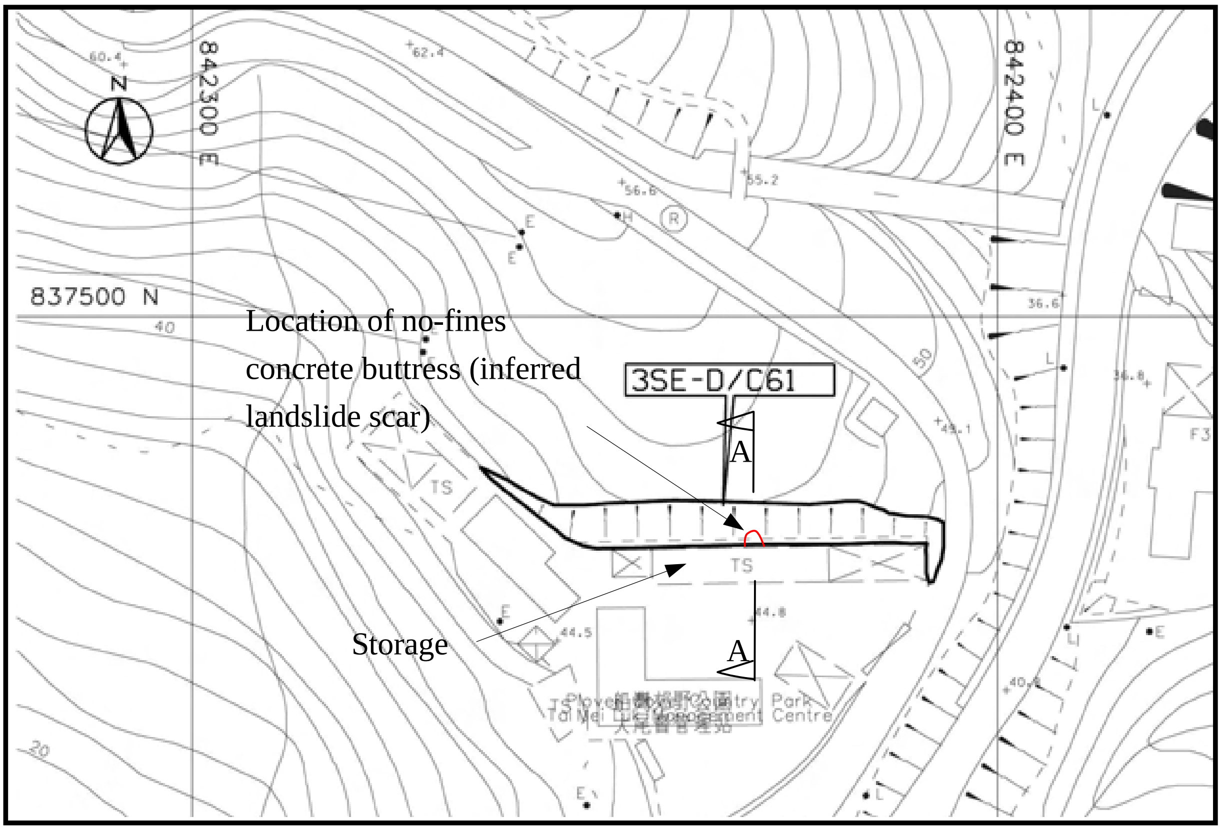


Figure 4 – Site Layout Plan (Slope No. 3SE-D/C61)

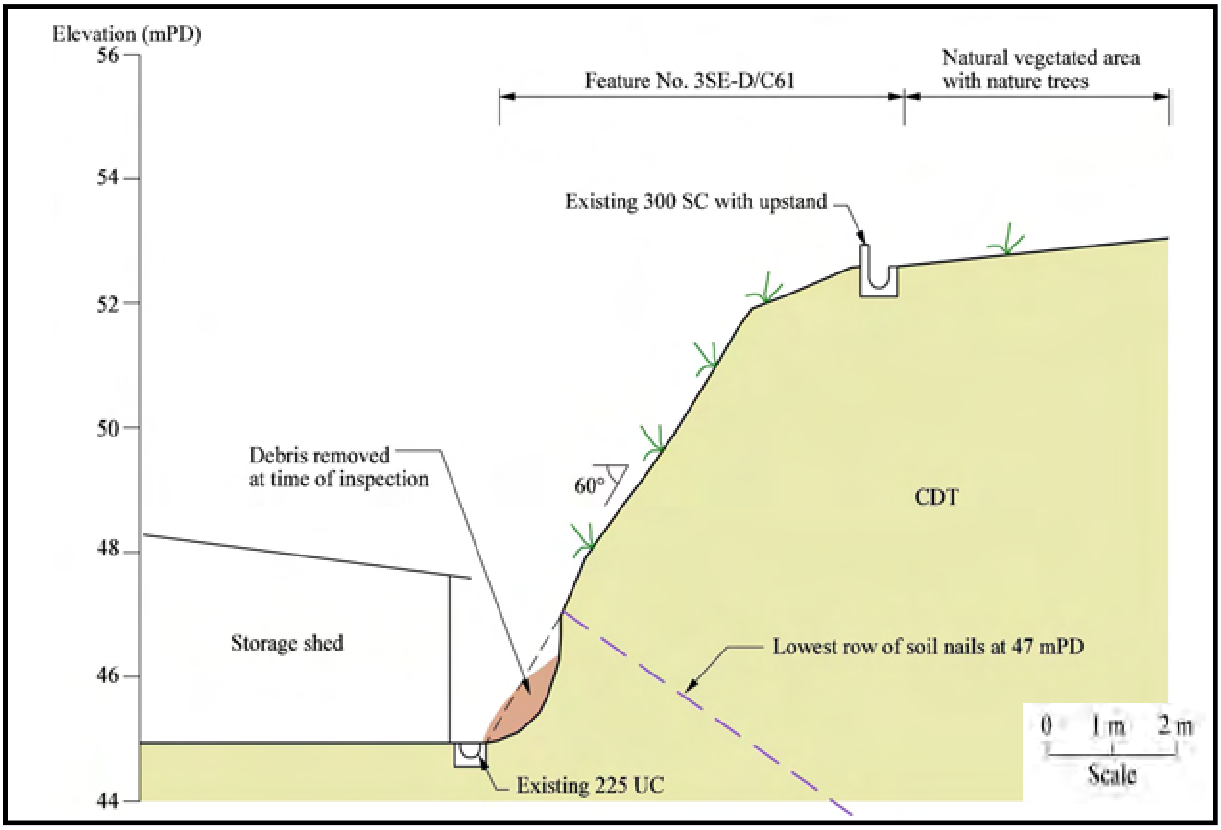


Figure 5 – Cross Section A – A (Slope No. 3SE-D/C61)

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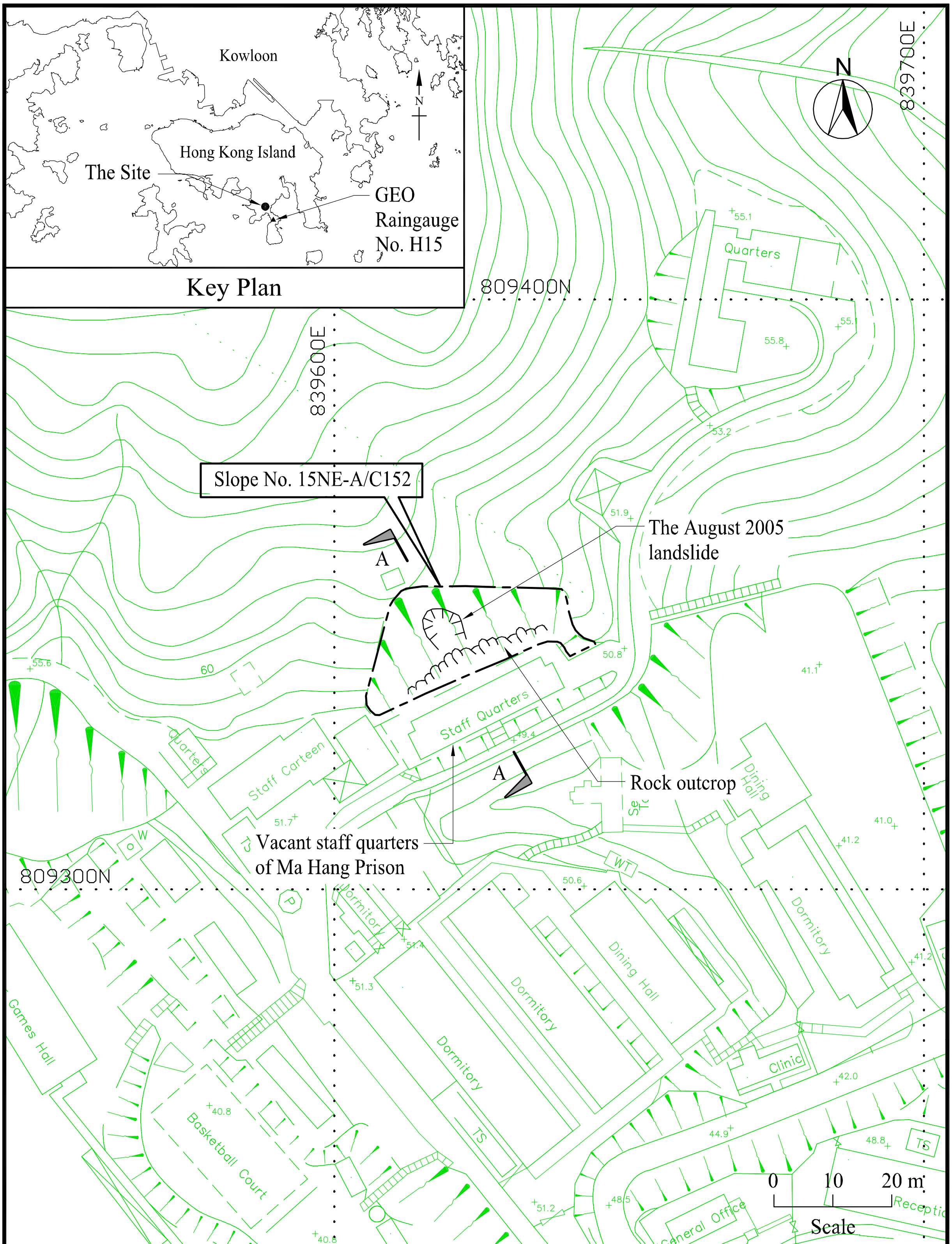


Legend :

Slope boundary

Slope No. 15NE-A/C152 Slope reference number

Notes:
(1) Base plan is extracted from 1 : 1000 survey sheet No. 15NE-12A dated May 2003.
(2) Slope boundary is taken from pre-landslide records in the GEO's SIS.

Figure 6 - Site Location Plan (Slope No. 15NE-A/C152)

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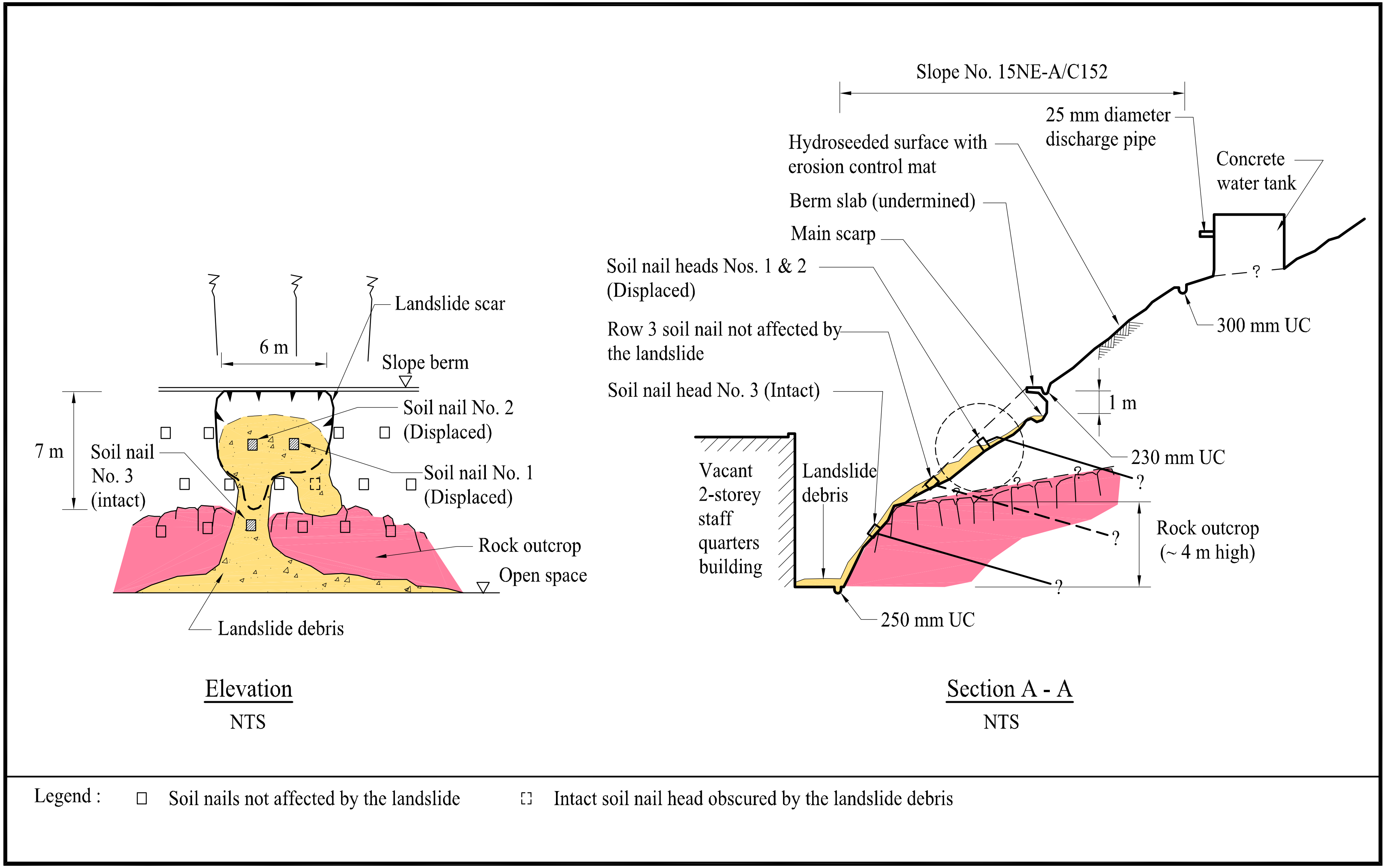


Figure 7 - Section A - A and Elevation View (Slope No. 15NE-A/C152)




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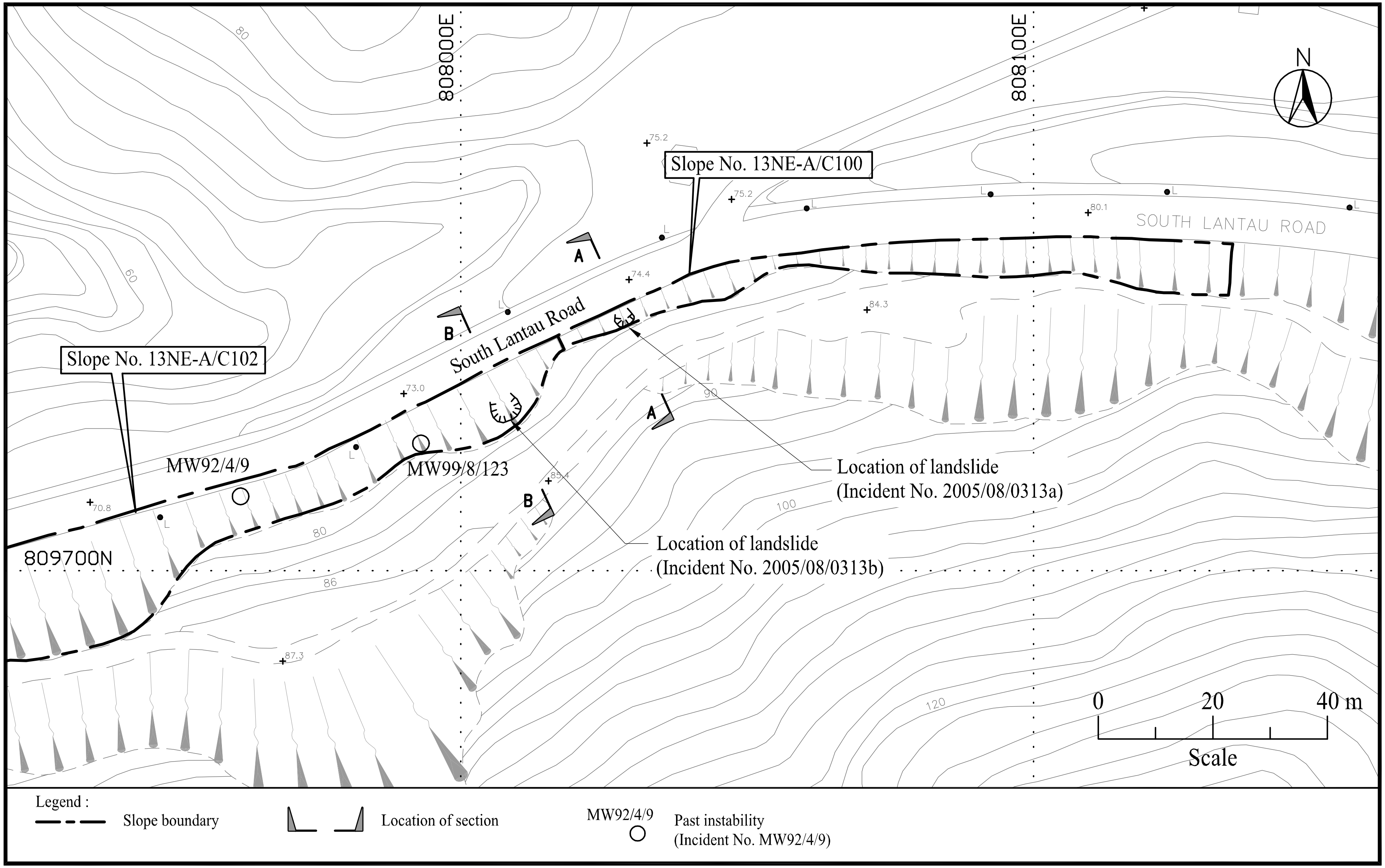


Figure 8 - Site Plan (Slope Nos. 13NE-A/C100 and 13NE-A/C102)



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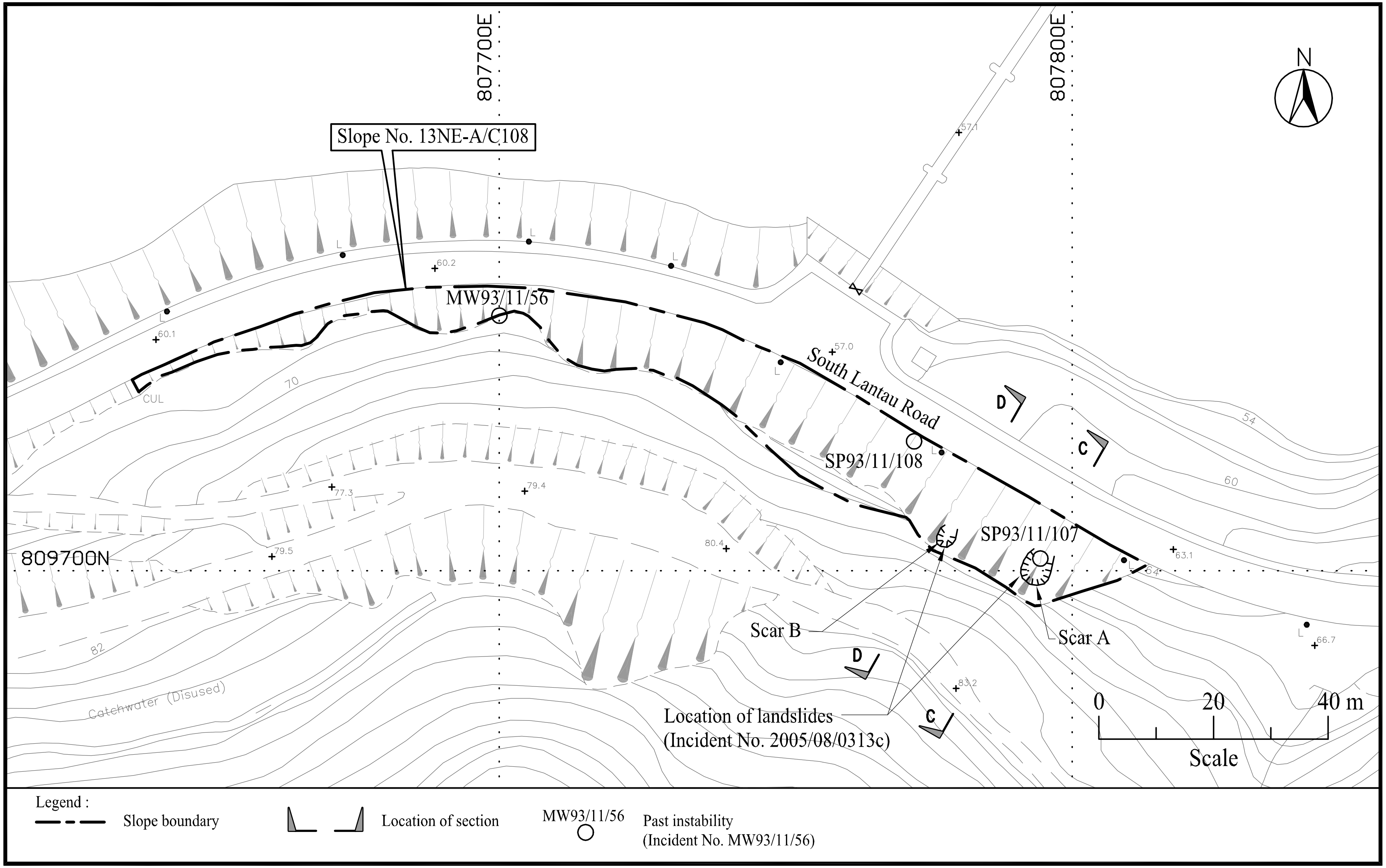


Figure 9 - Site Plan (Slope No. 13NE-A/C108)



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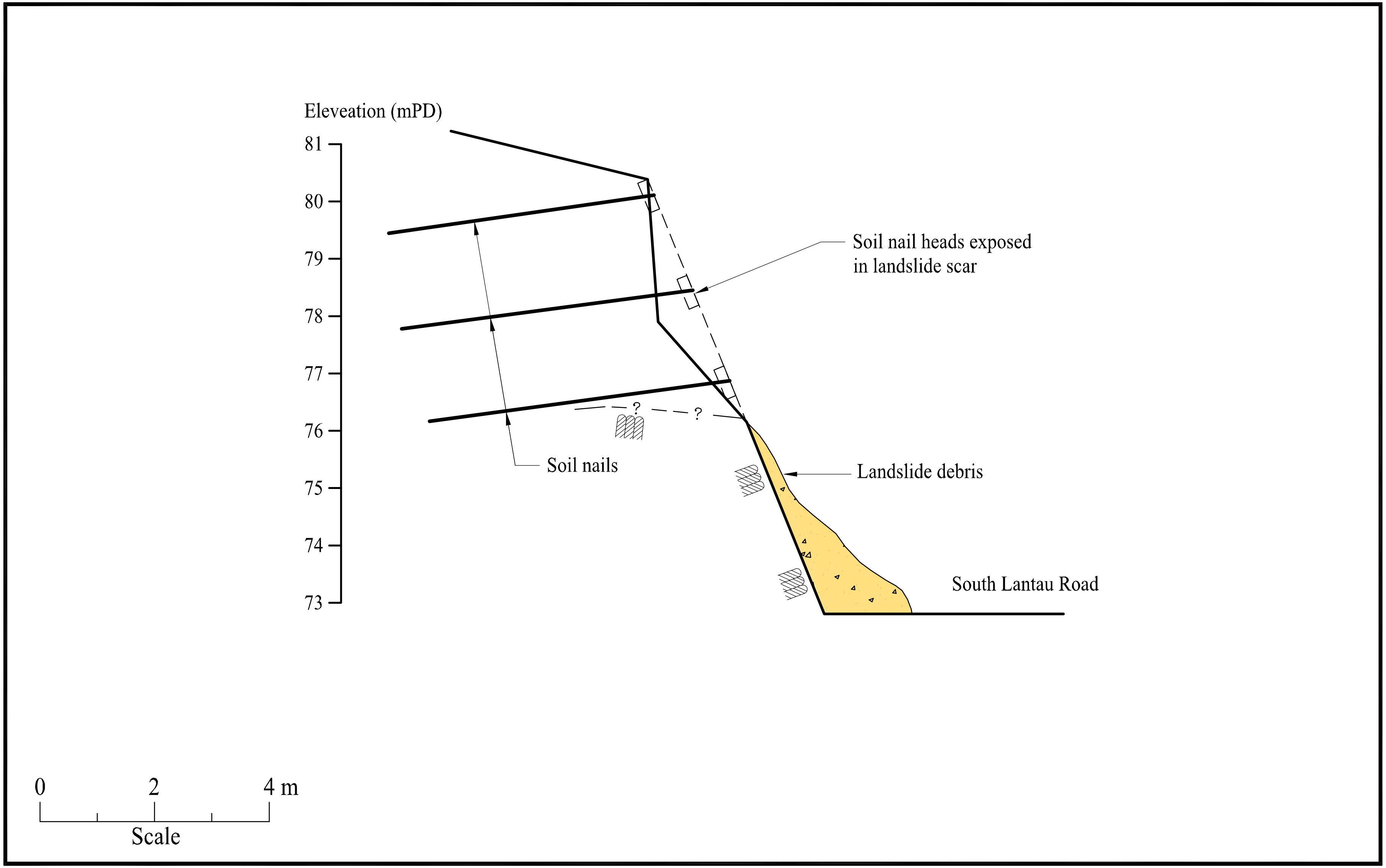


Figure 10 - Section through Landslide Scar at Slope No. 13NE-A/C100 (Section A - A in Figure 8)



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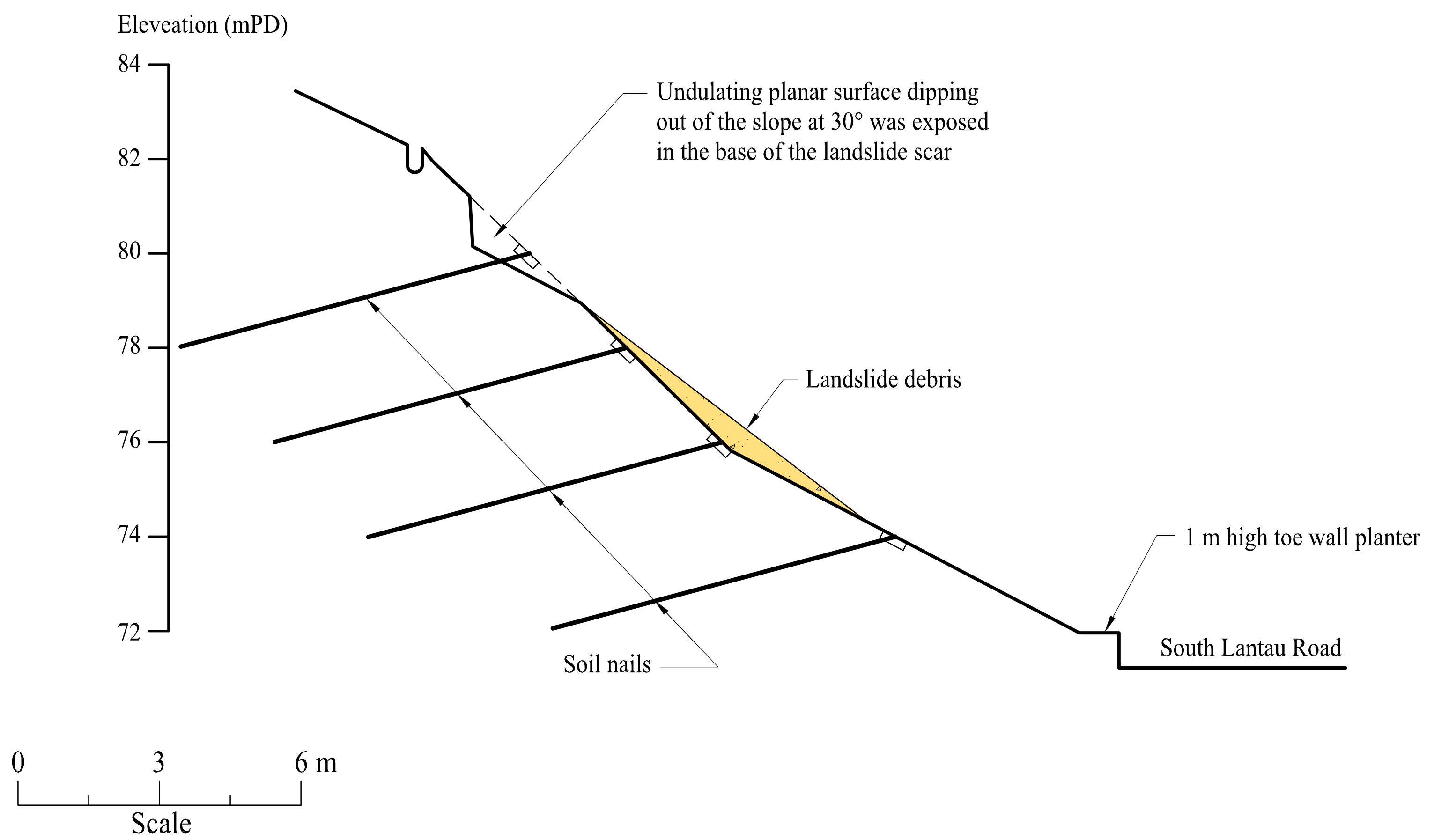


Figure 11 - Section through Landslide Scar at Slope No. 13NE-A/C102 (Section B - B in Figure 8)

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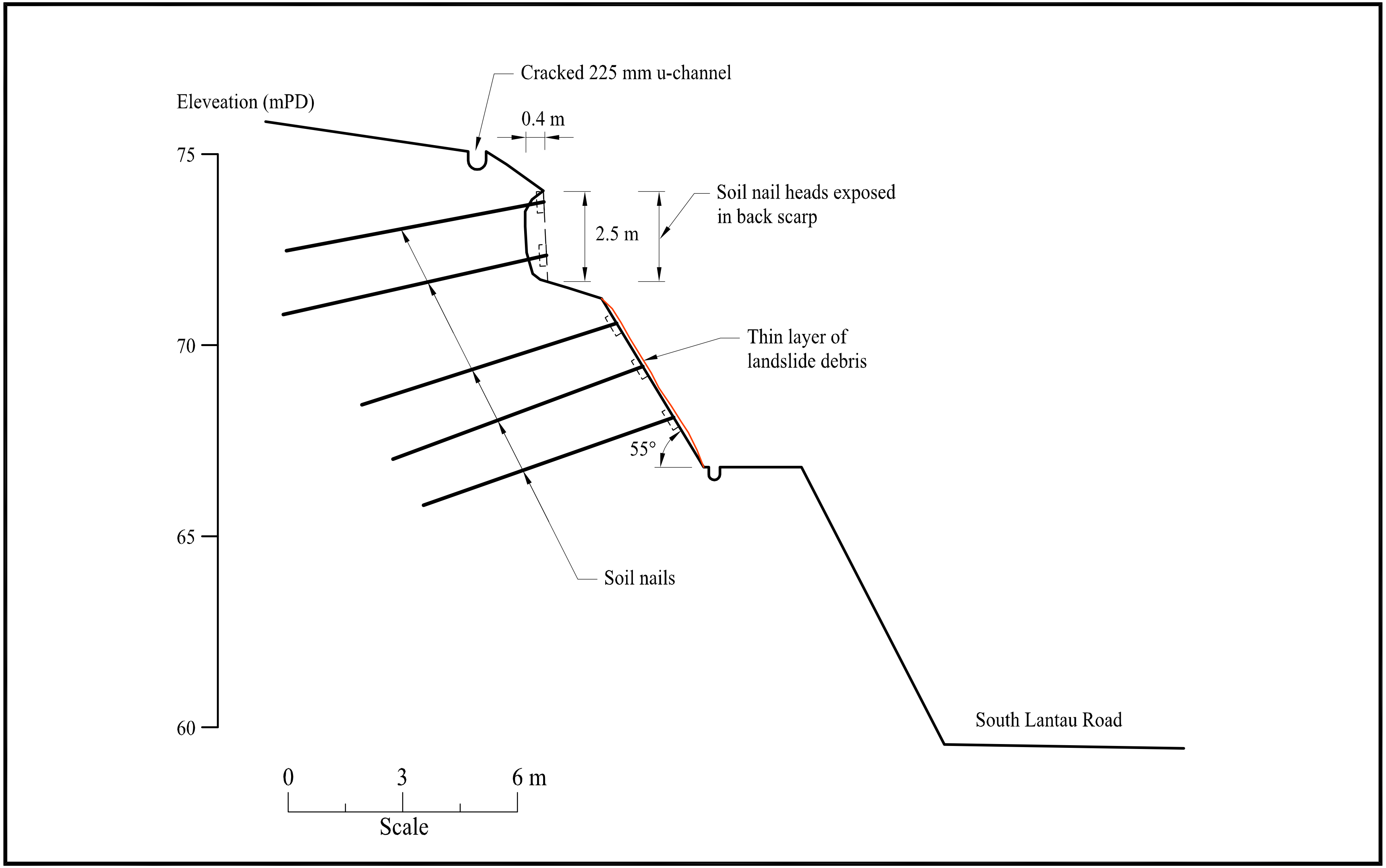


Figure 12 - Section through Landslide Scar A at Slope No. 13NE-A/C108 (Section C - C in Figure 9)



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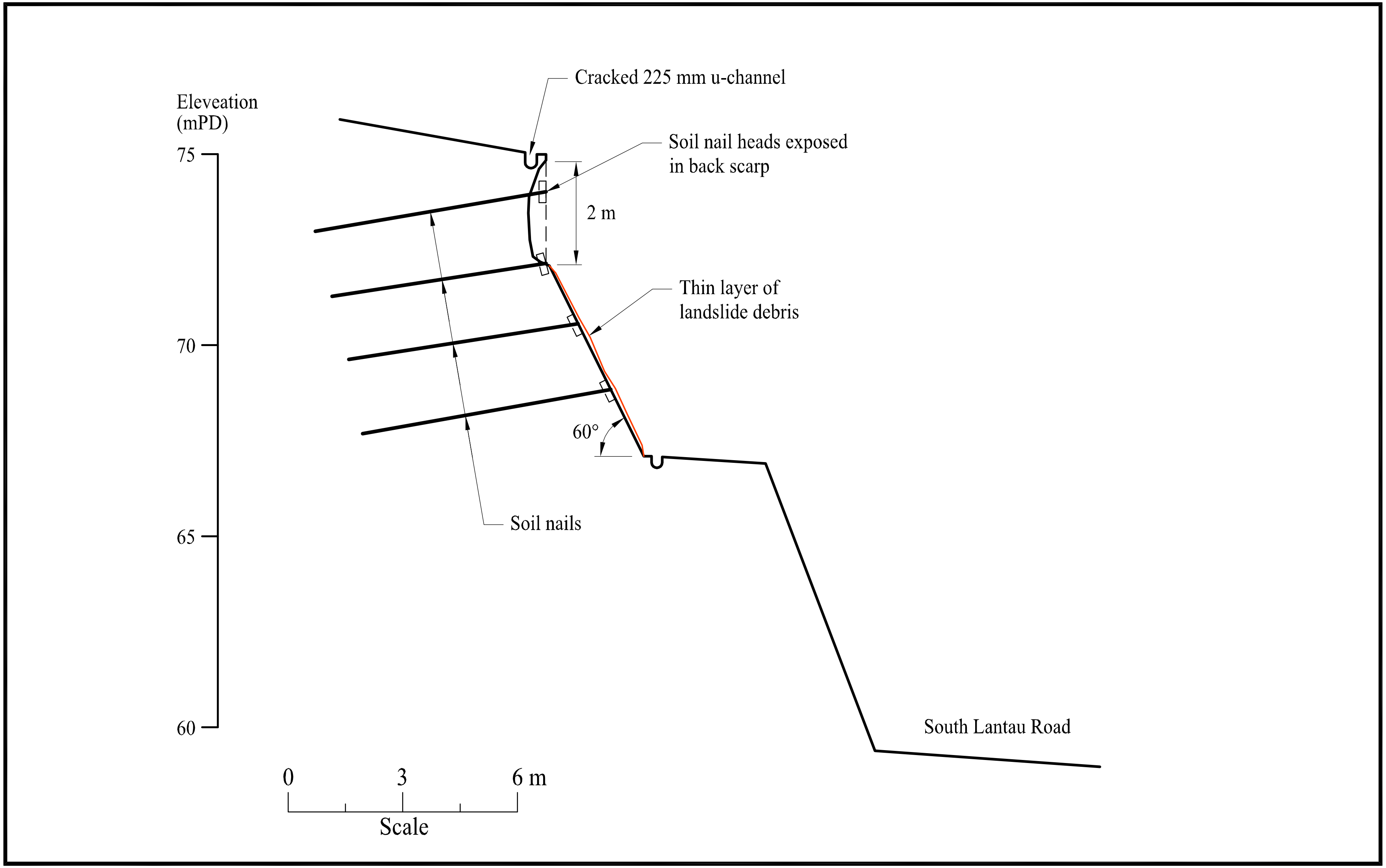


Figure 13 - Section through Landslide Scar B at Slope No. 13NE-A/C108 (Section D - D in Figure 9)

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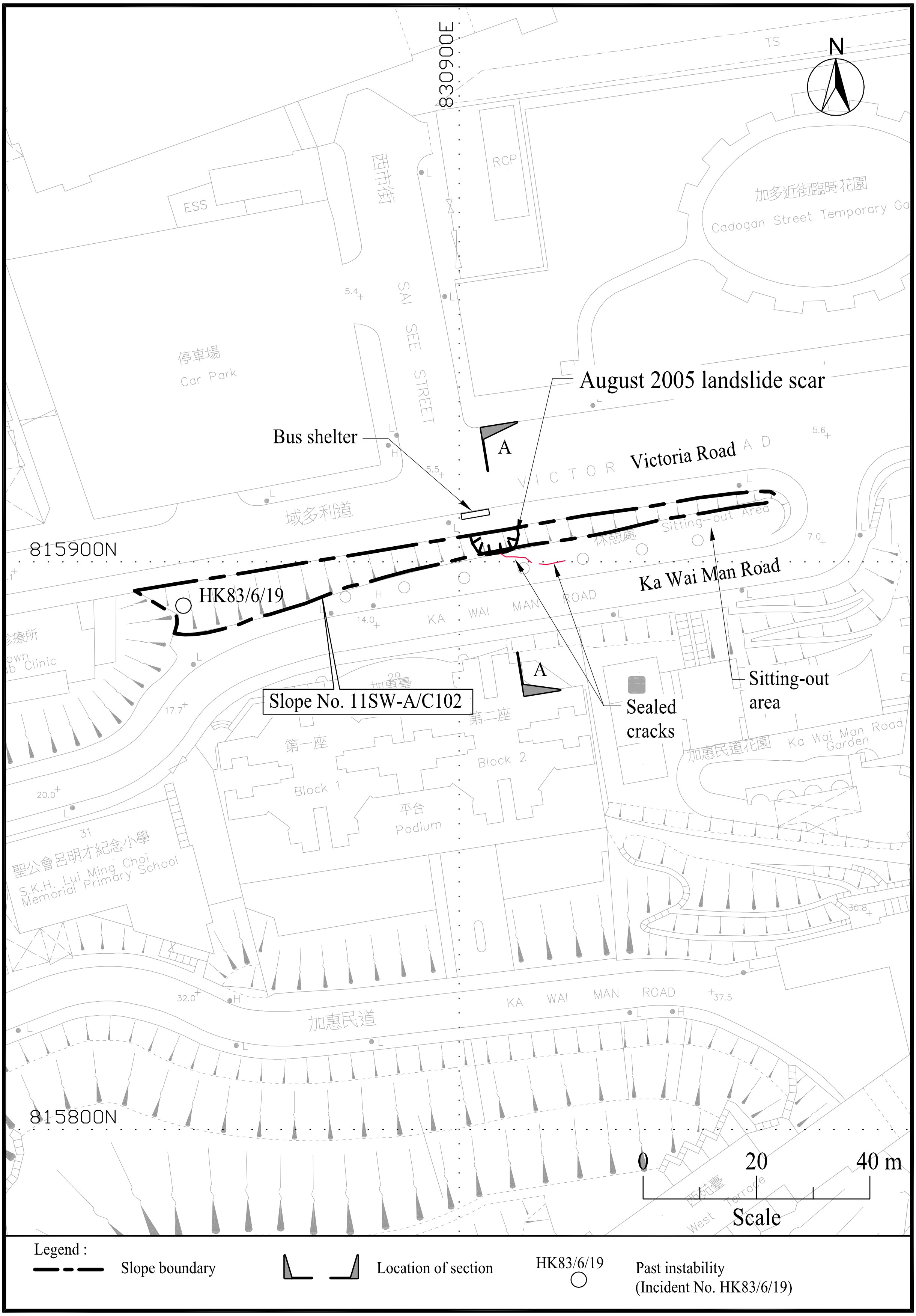


Figure 14 - Site Location Plan (Slope No. 11SW-A/C102)

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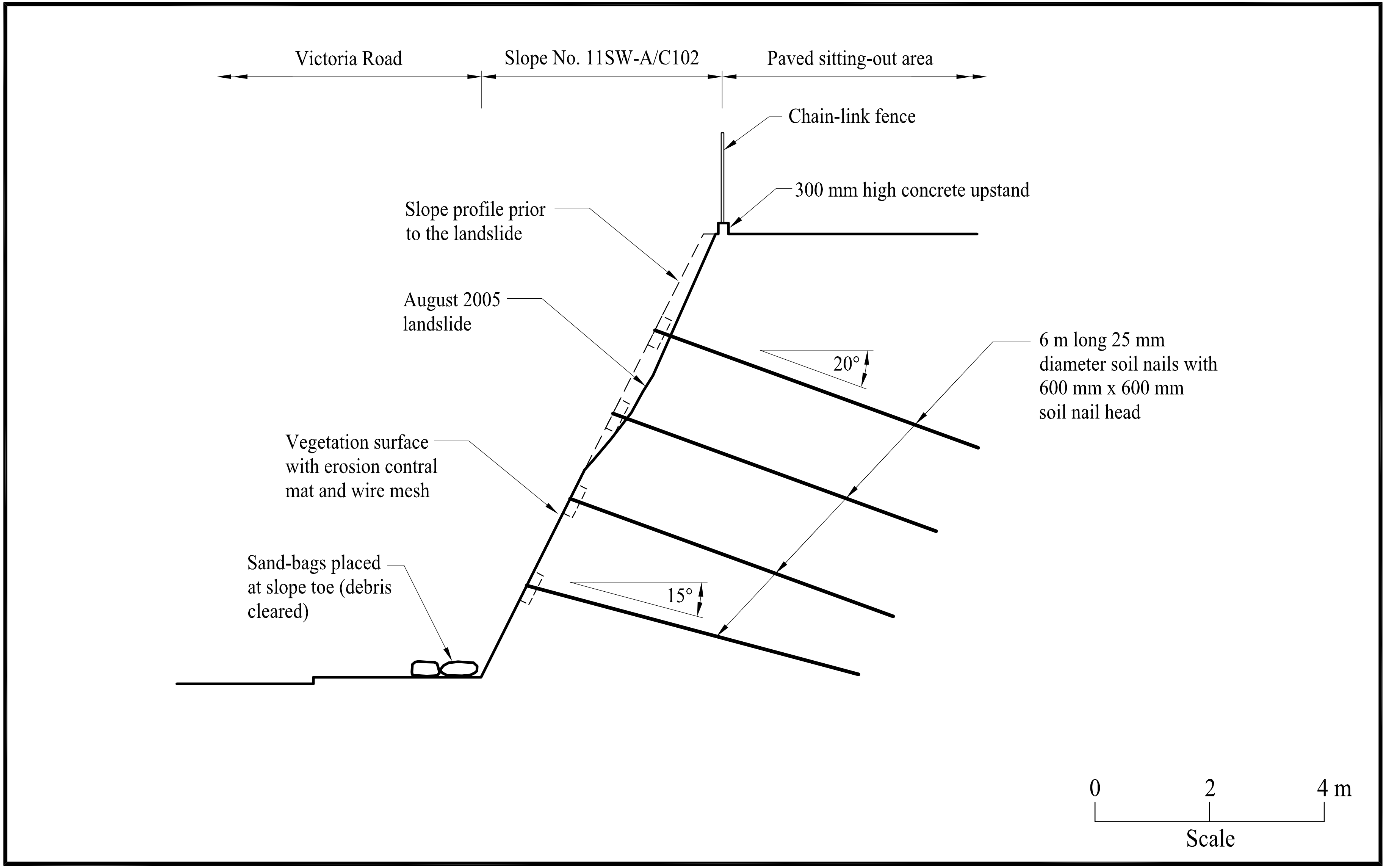


Figure 15 - Section A - A (Slope No. 11SW-A/C102)

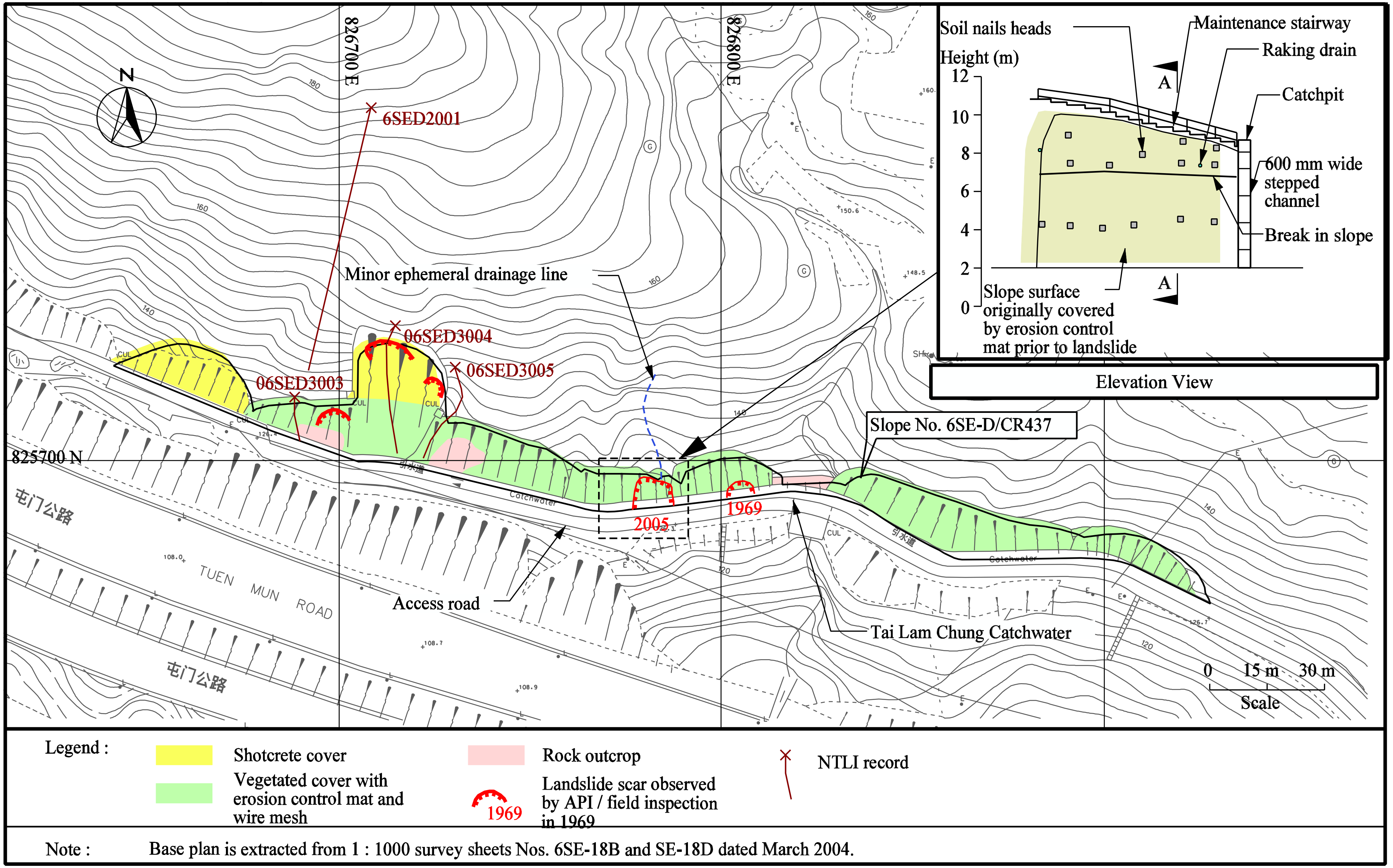


Figure 16 - Site Plan (Slope No. 6SE-D/CR437)



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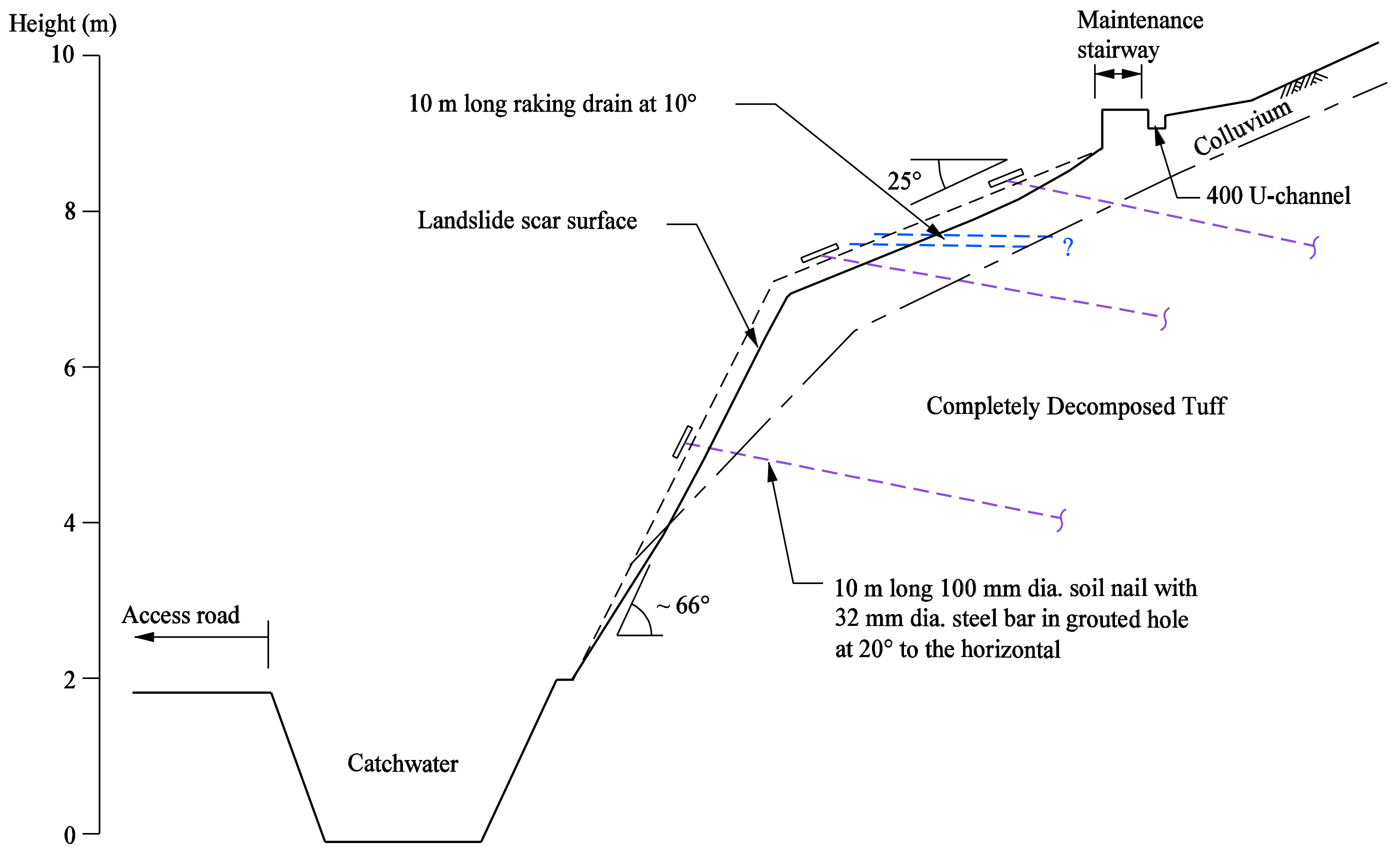


Figure 17 - Section A-A (Slope No. 6SE-D/CR437)



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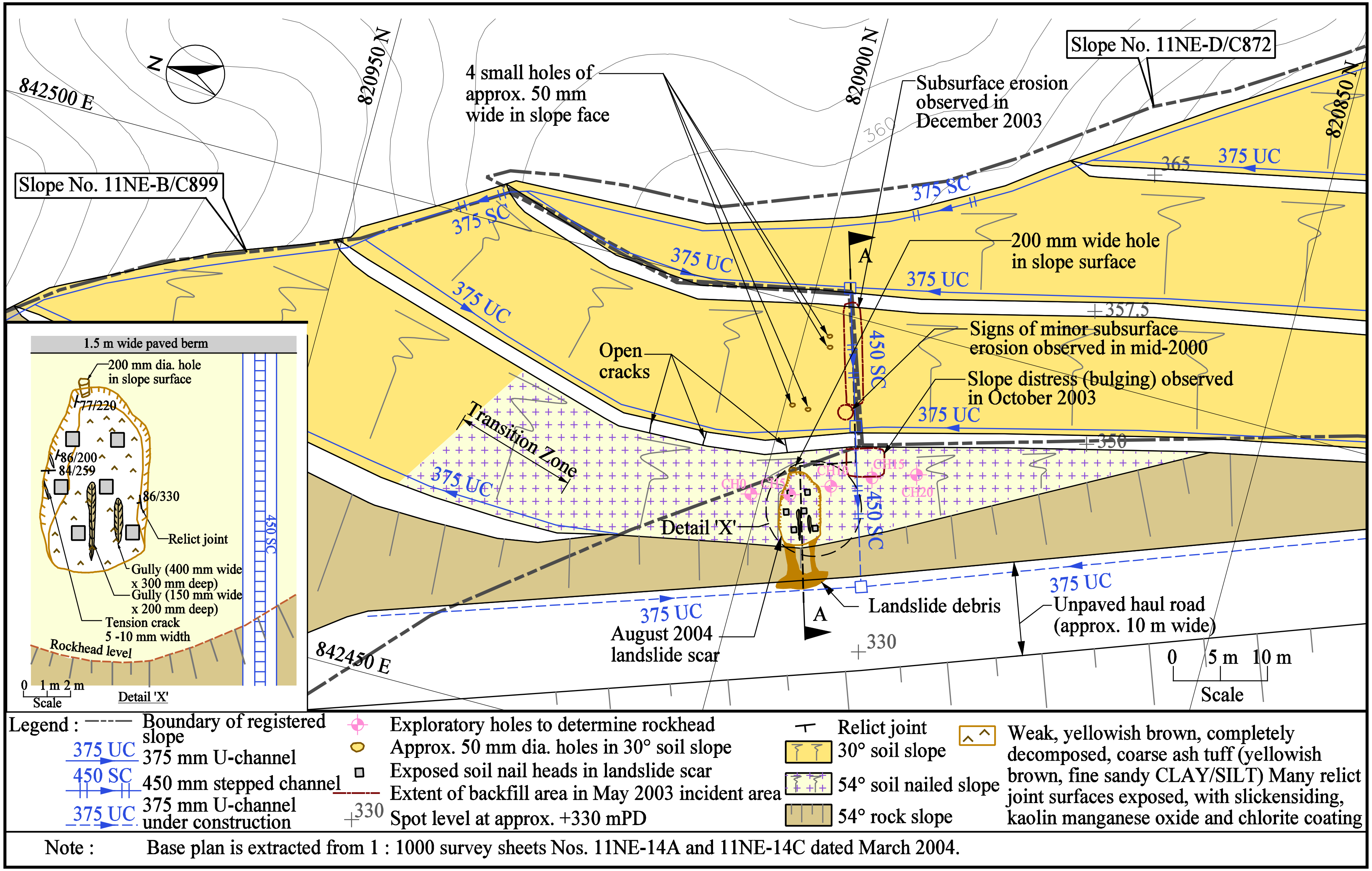
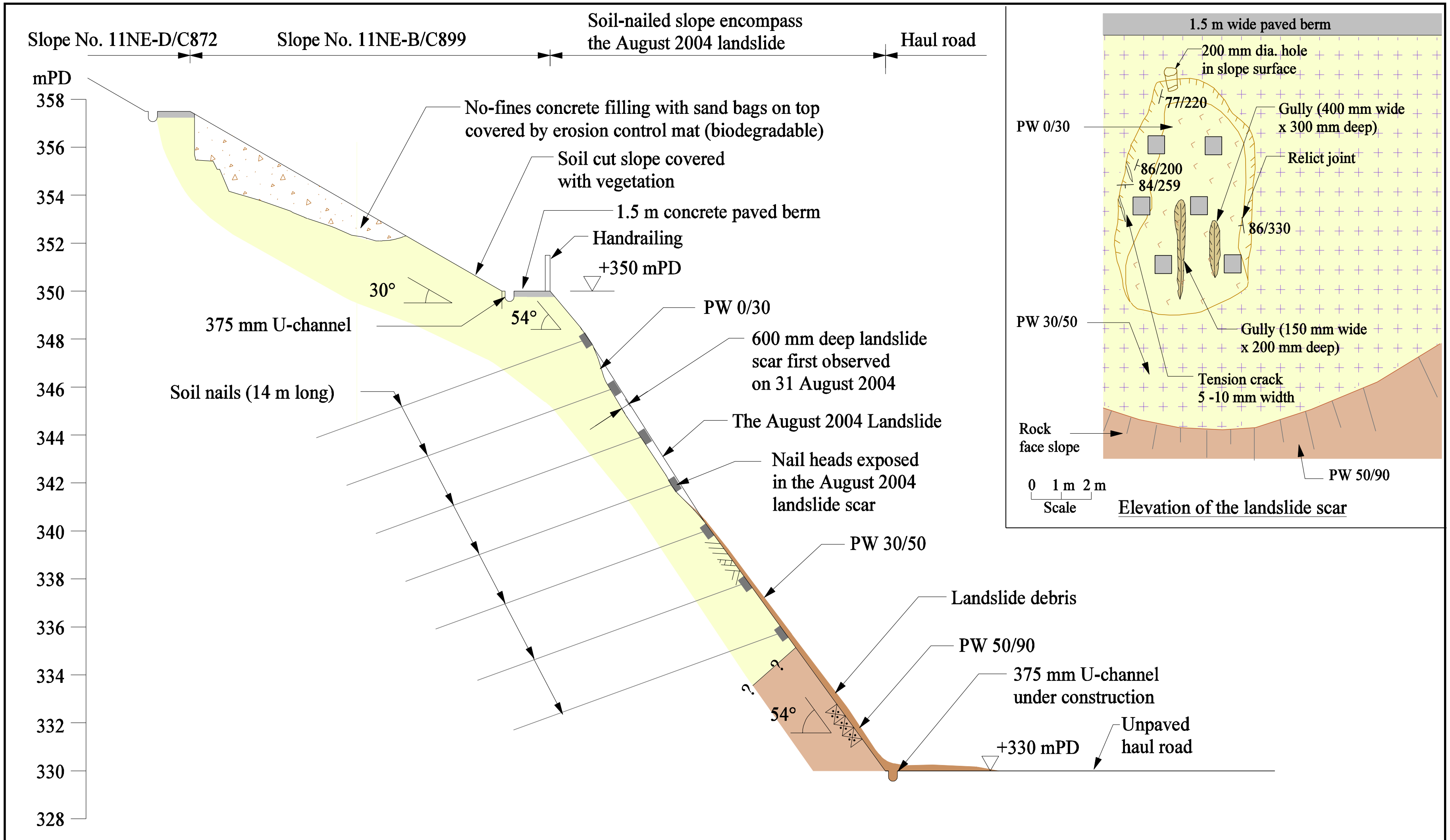



Figure 18 - Site Plan of the August 2004 Landslide at Anderson Road




Notes : (1) See Figure 1 for location of Section A-A.
(2) Soil nail length based on SMEC's drawing Nos. J195A/D/002E, 001A and 003C submitted to ME division on 2 Oct 2003.

Figure 19 - Section A-A through the August 2004 Landslide Site



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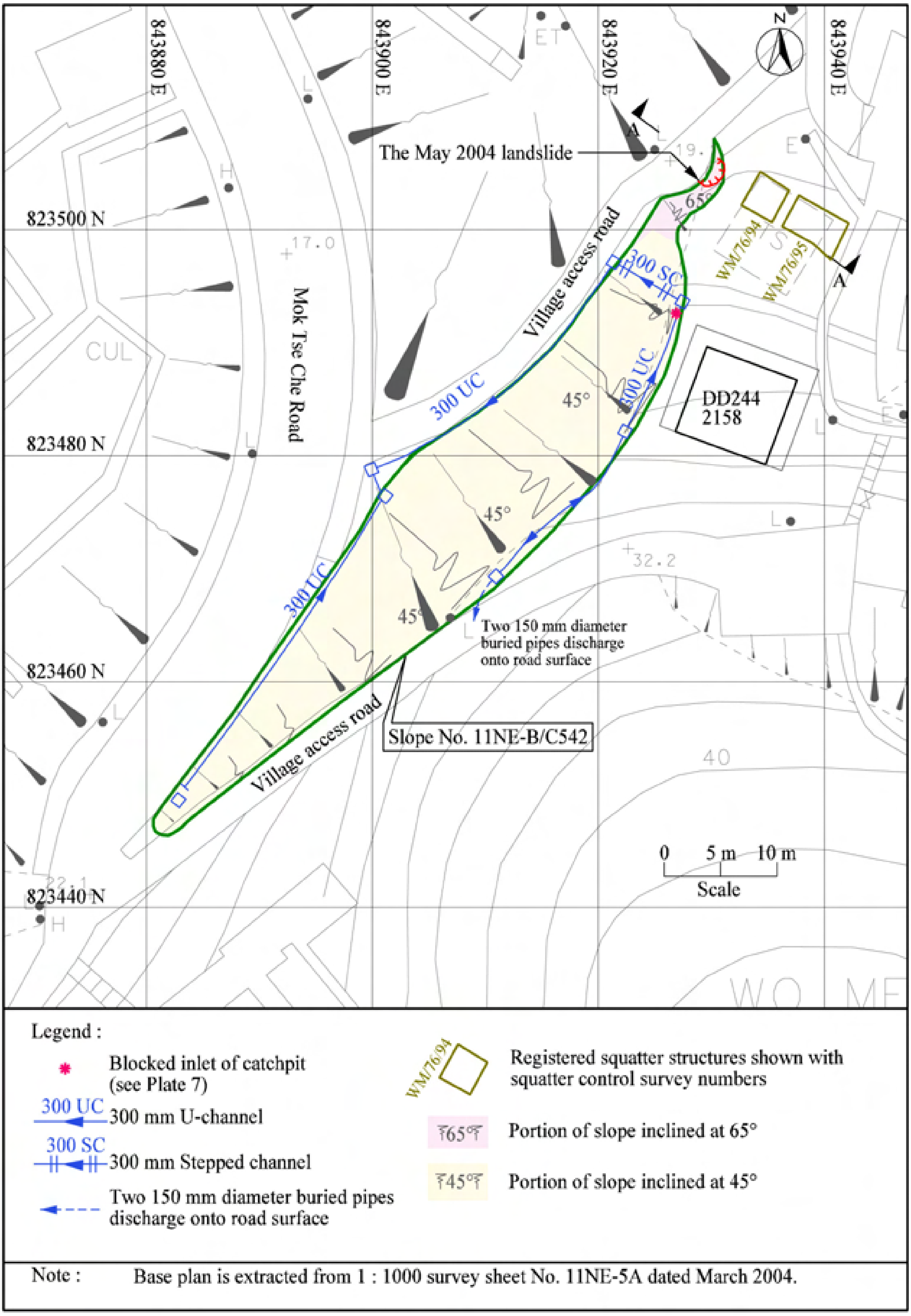


Figure 20 – Site Location Plan (Slope No. 11NE-B/C542)

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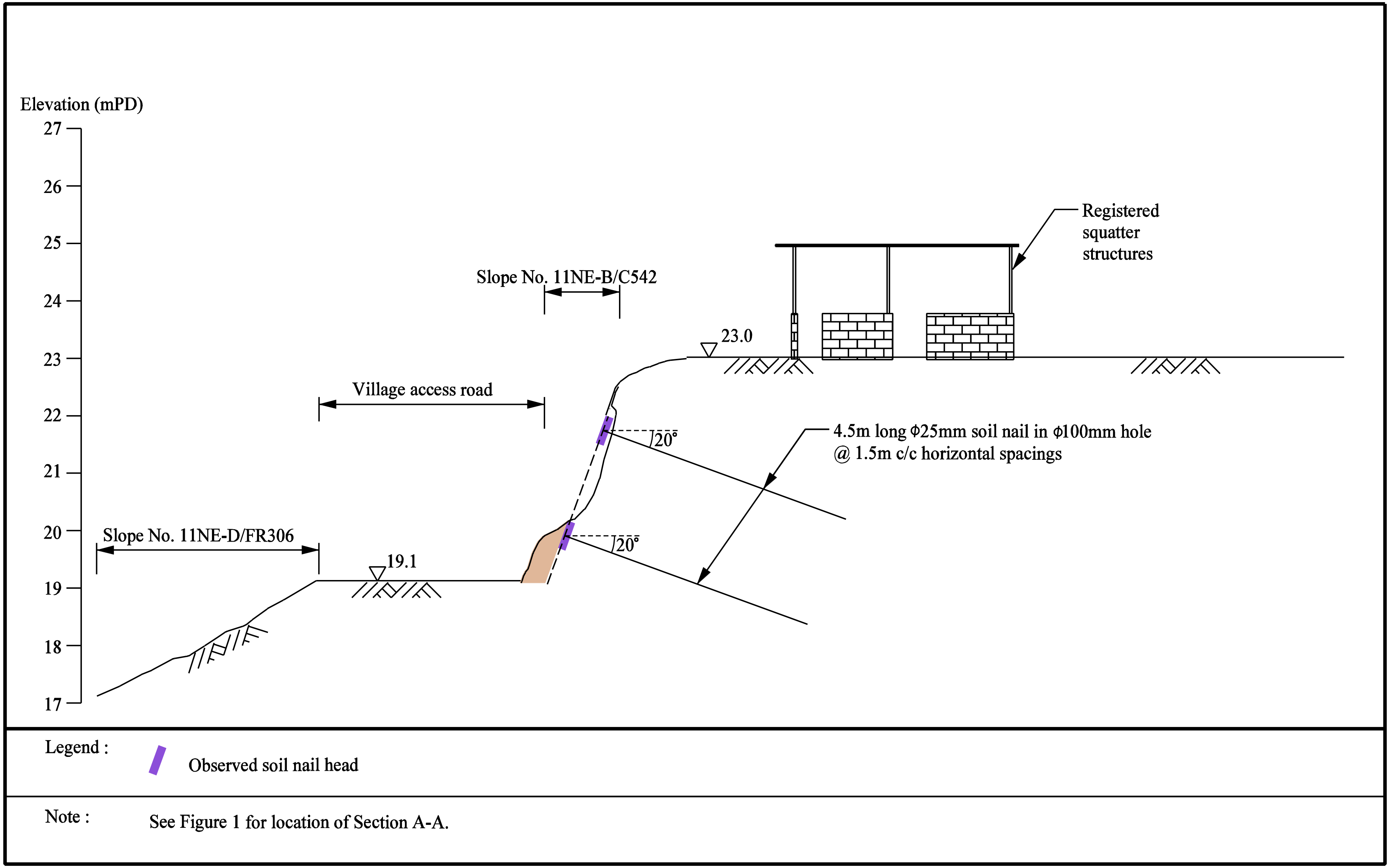


Figure 21 - Section A-A through the May 2004 Landslide ( Slope No. 11NE-B/C542)



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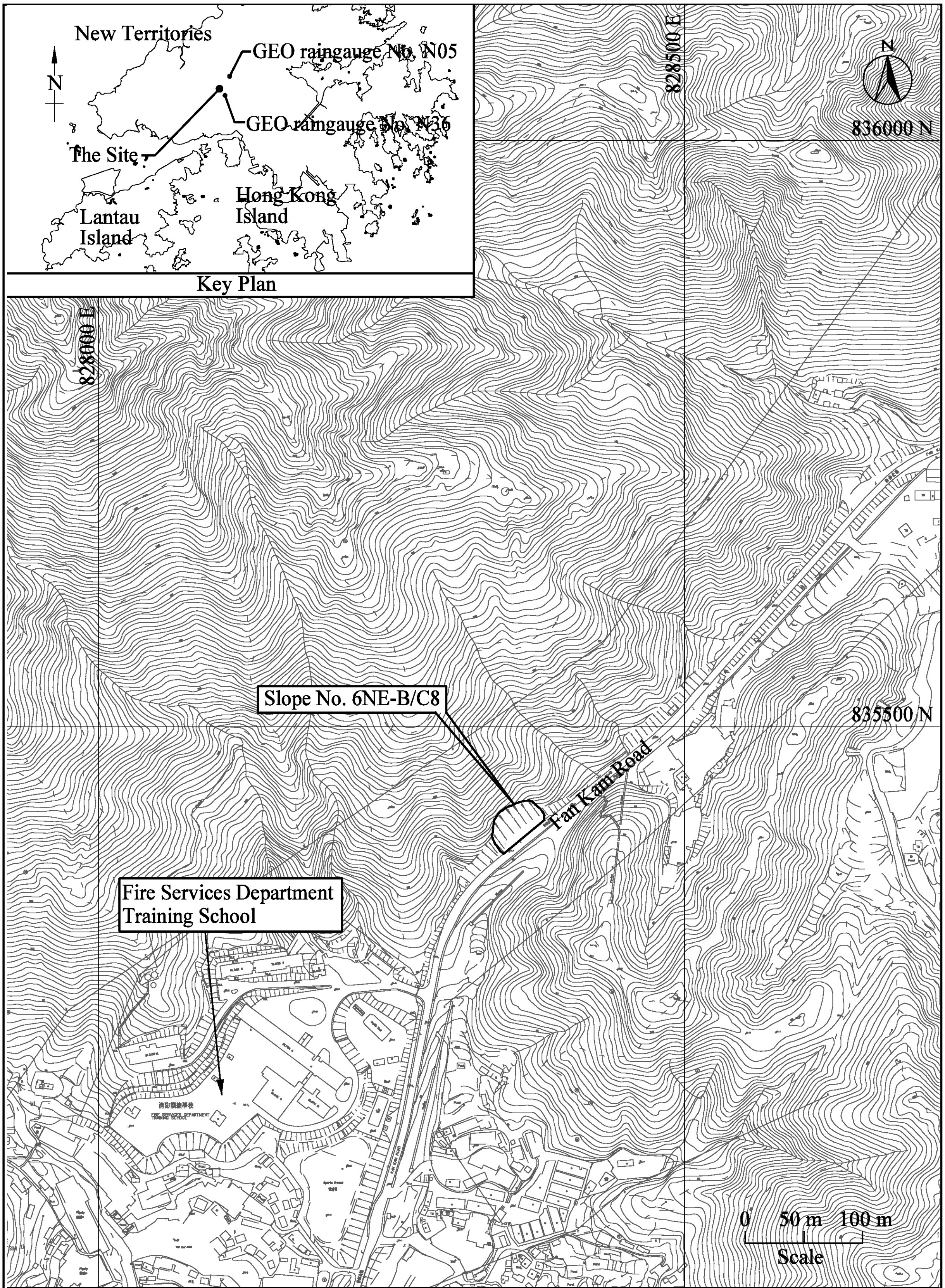


Note : Base plan is extracted from 1 : 1000 survey sheets Nos. 2SE-24D, 2SE-25C, 6NE-4B, 6NE-4D, 6NE-5A and 6NE-5C dated June 2002.

Figure 22 –Site Location Plan (Slope No. 6NE-B/C8)

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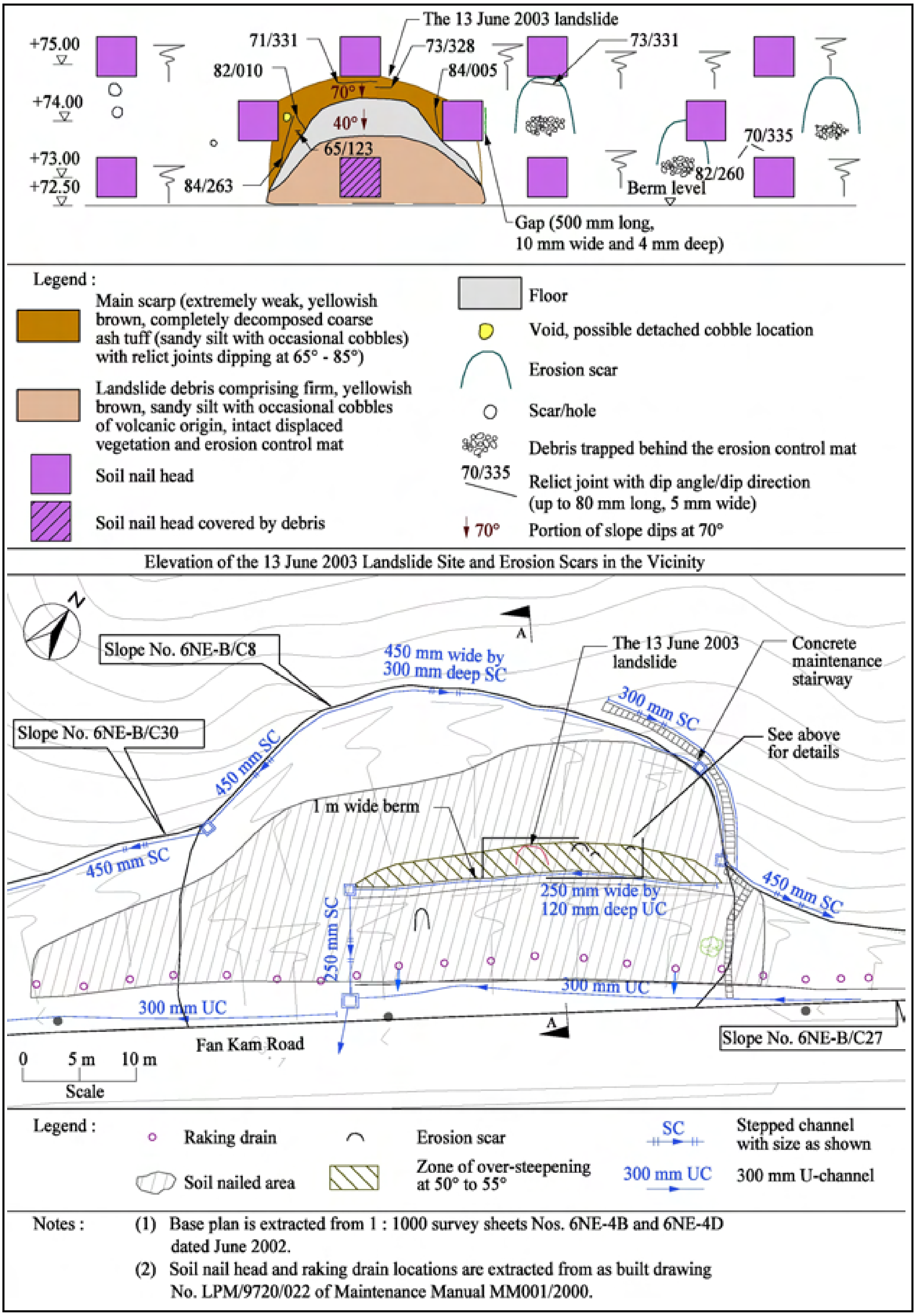


Figure 23 – Site Observations (Slope No. 6NE-B/C8)

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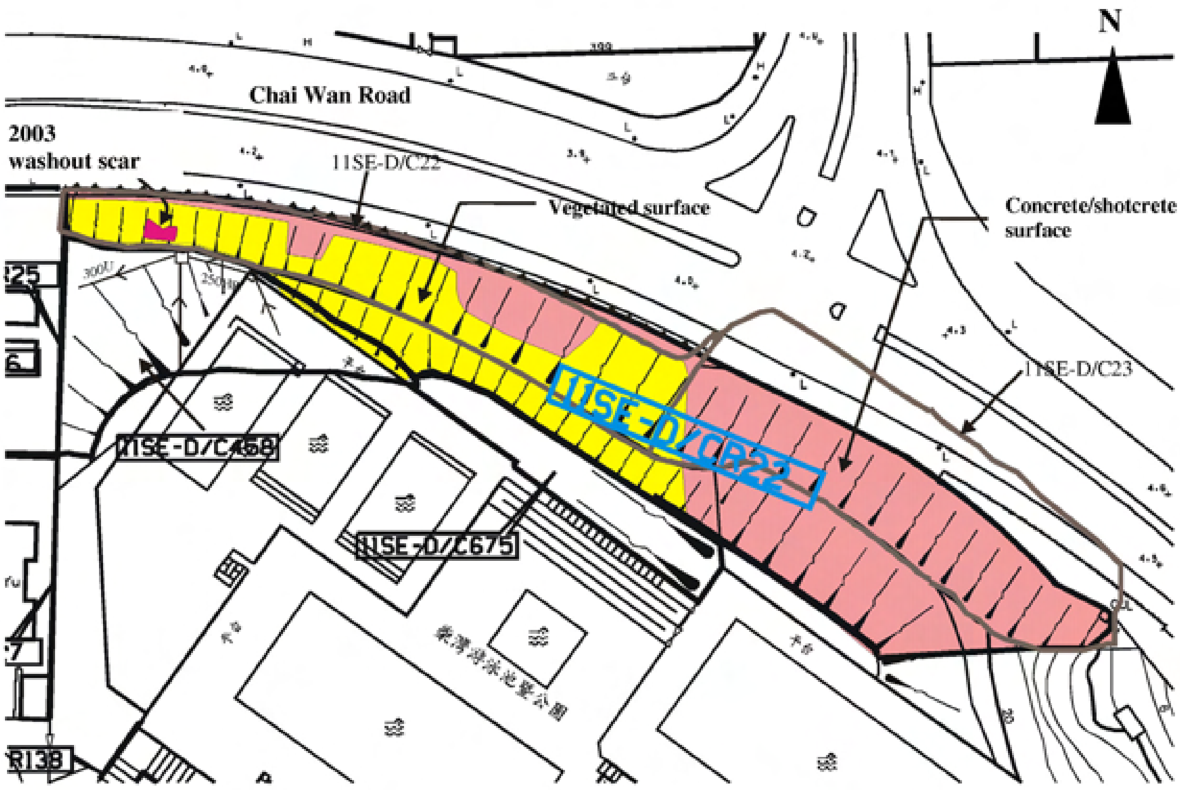


Legend:

| | | | |
|---|---|---|---|
| (black line) | Feature Boundary | (toe wall symbol) | Toe Wall Planter |
| (grey line) | Old Cat. Feature Boundary | (square) | Catchpit |
| 300 U → | 300mm U-Channel | | |
| 250 HR → | 250mm Half-round Channel | | |

Figure 24 – Site Location Plan (Slope No. 11SE-D/C22)

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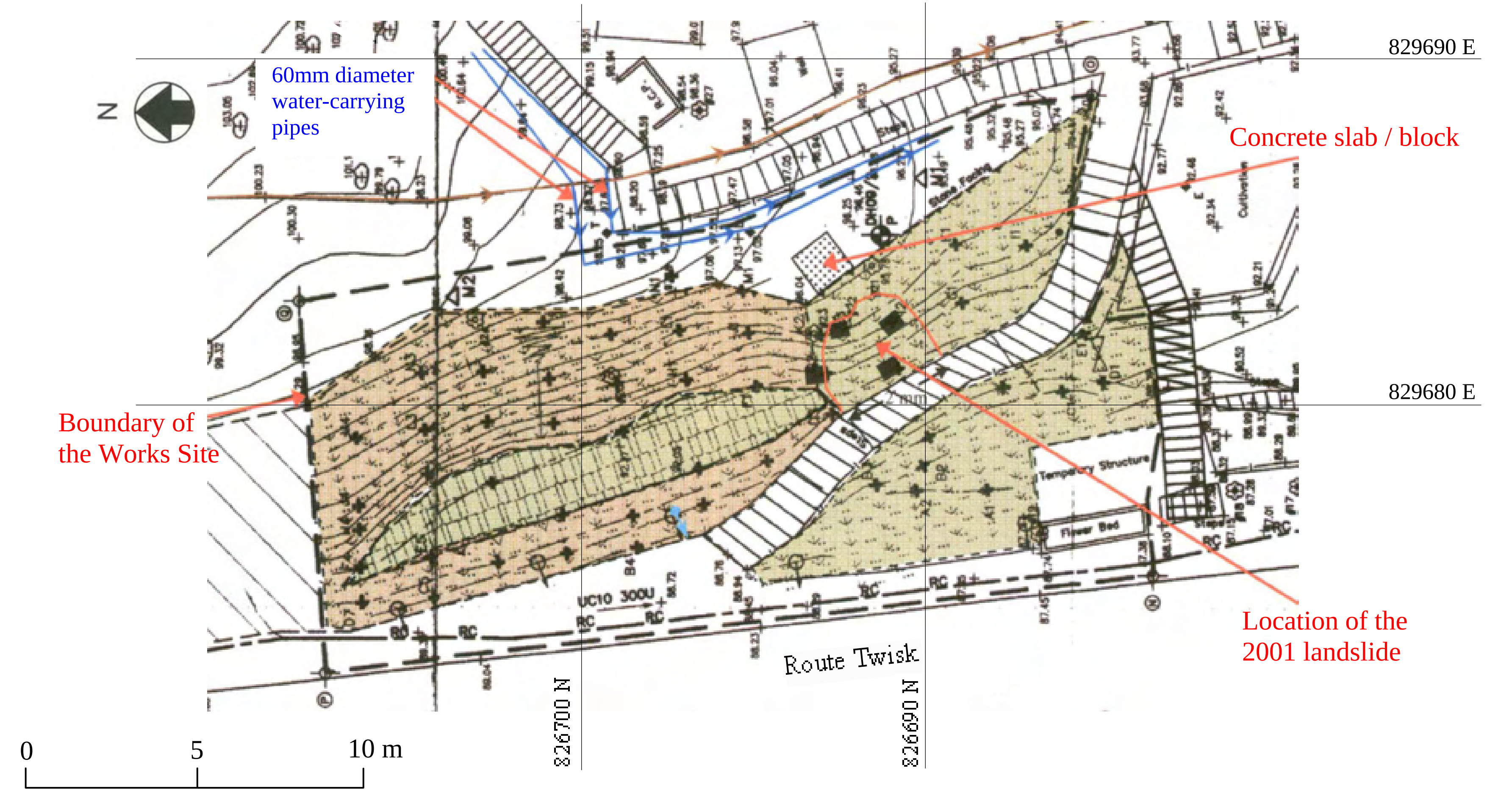


Legend:

Masonry Facing | Vegetated Cover | Soil Nail | Raking Drain | Exposed Soil Nail Head | Seepage

Note: (1) Base map extracted from As-constructed Drawing No. LPM/9720/176 in Maintenance Manual No. MM007/2000
(2) Alignments of water pipes extracted from Drawing No. LPM/97/20/173 in Stage 3 Study Report No. S3R111/97

Figure 25 – The 2001 Landslide on Slope No.6SE-D/C52



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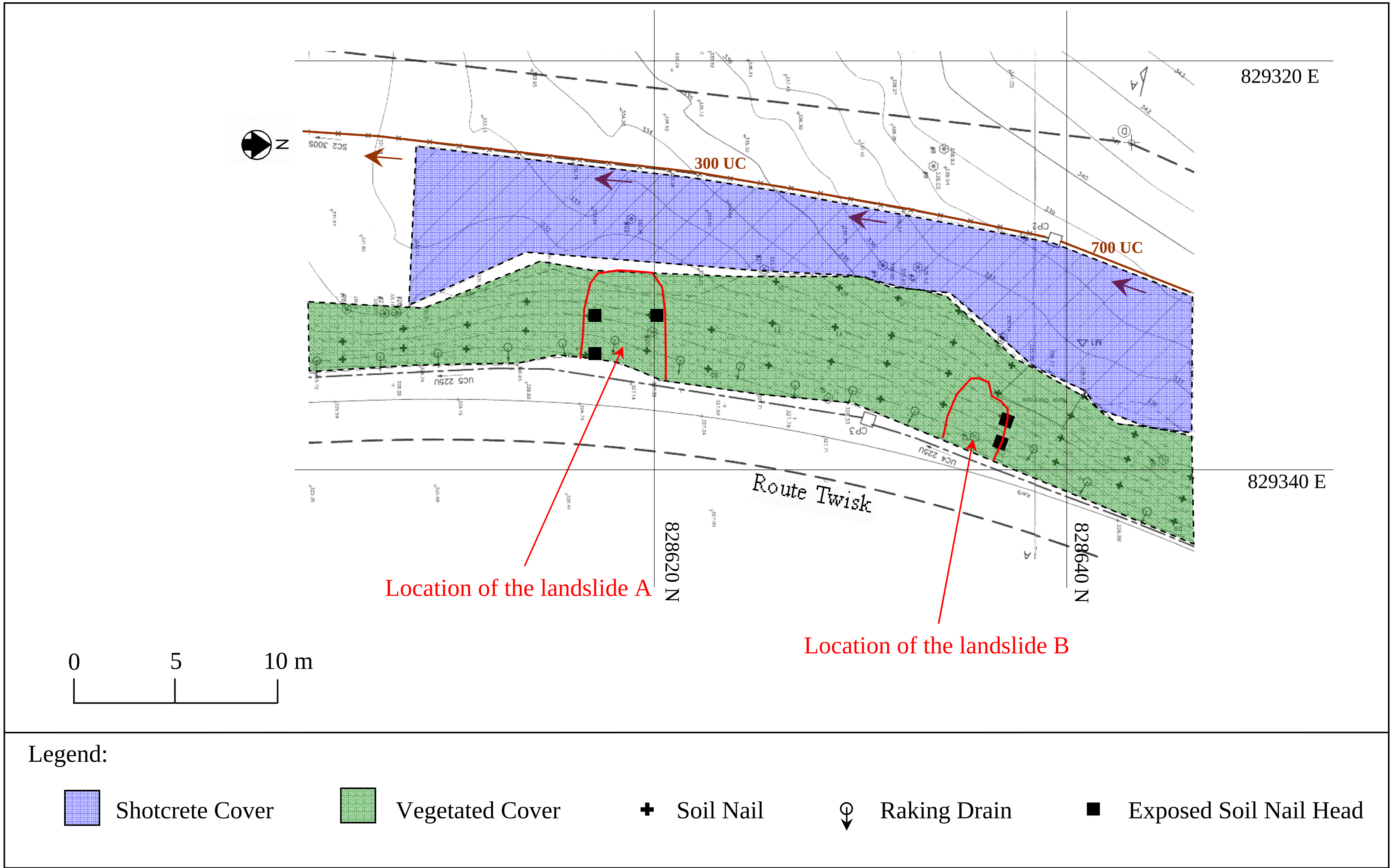


Note: Base map extracted from As-constructed Drawing No. LPM/9720/153 in Maintenance Manual No. MM5/2000

Figure 26 – The 2001 Landslide on Slope No. 6SE-B/C4




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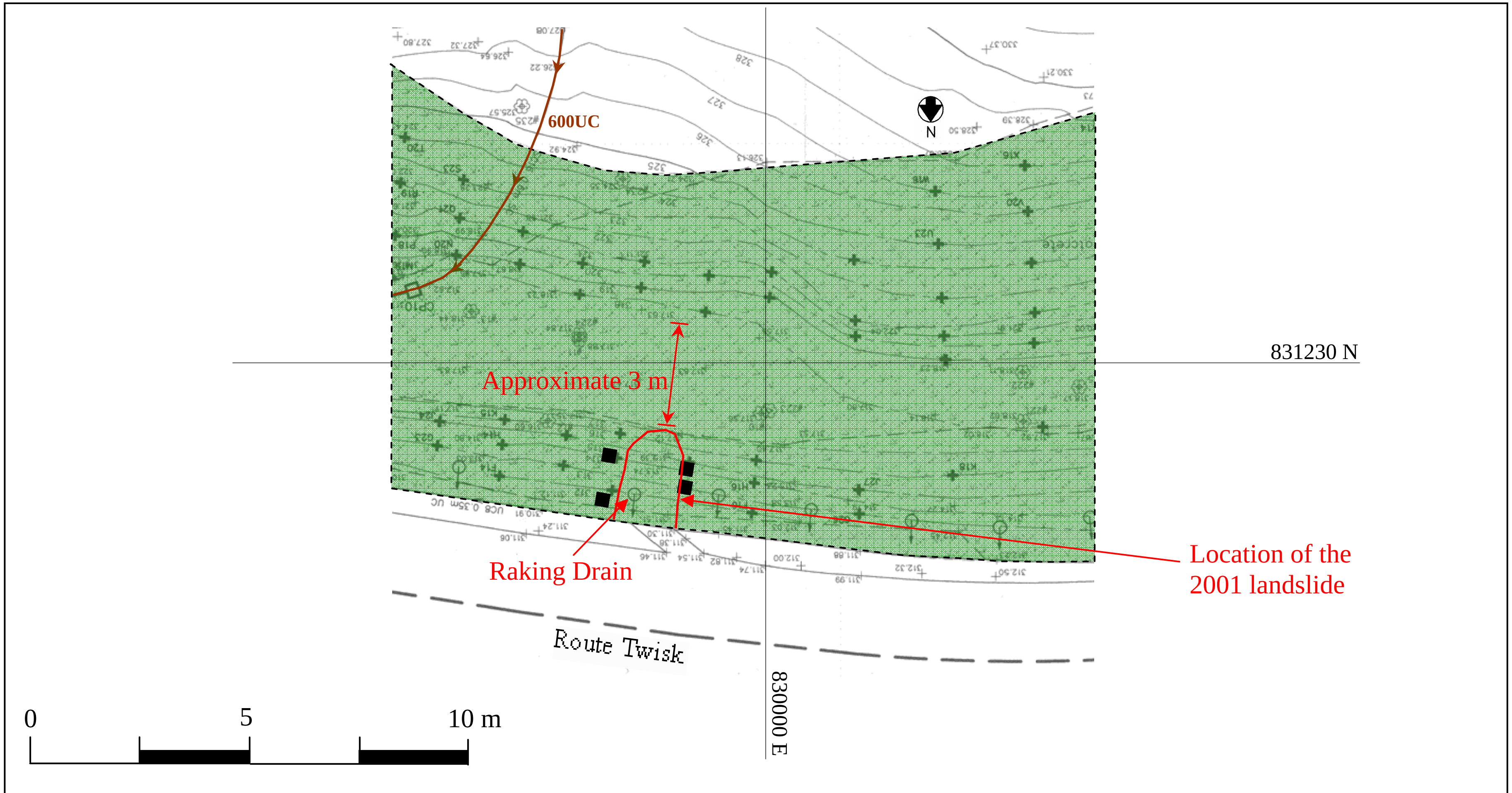


Legend:

Vegetated Cover | Soil Nail | Raking Drain | Exposed Soil Nail Head

Note: Base map extracted from As-constructed Drawing No. LPM/9720/078 in Maintenance Manual No. MM003/2000

Figure 27 – The 2001 Landslide on Slope No. 6NE-D/C6




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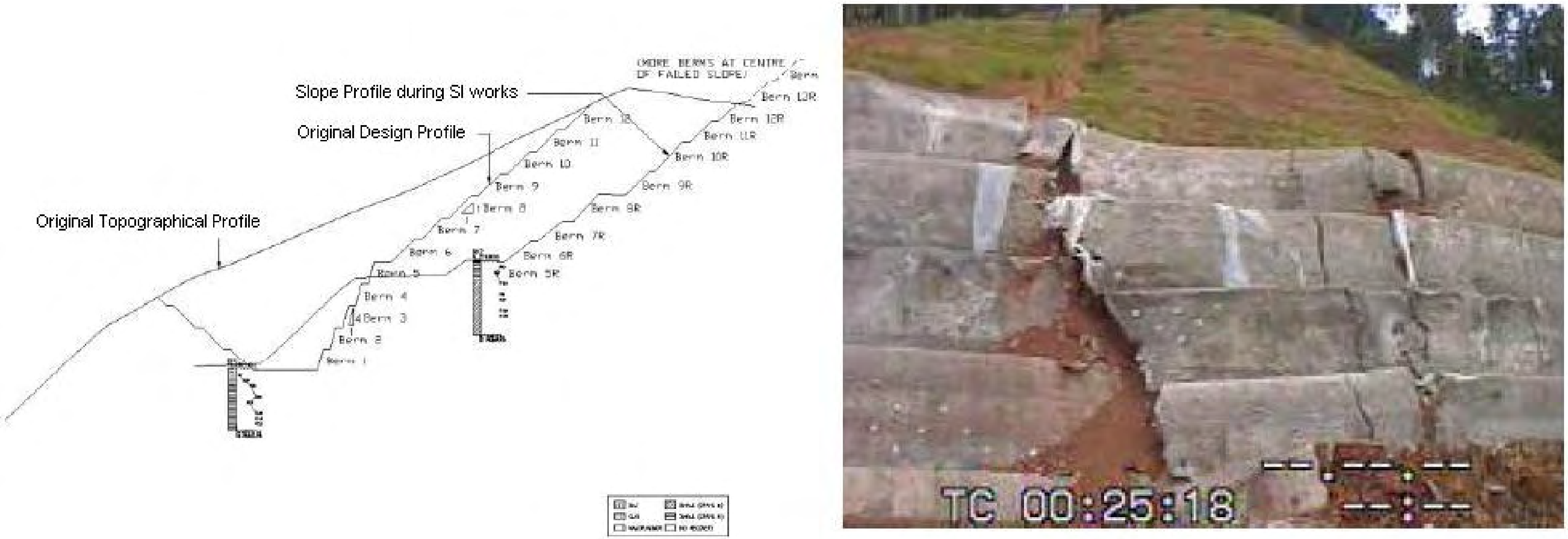


Figure 28 - Cross Section of the 72 m High Soil-nailed Slope (Extracted from Liew & Liong (2006))



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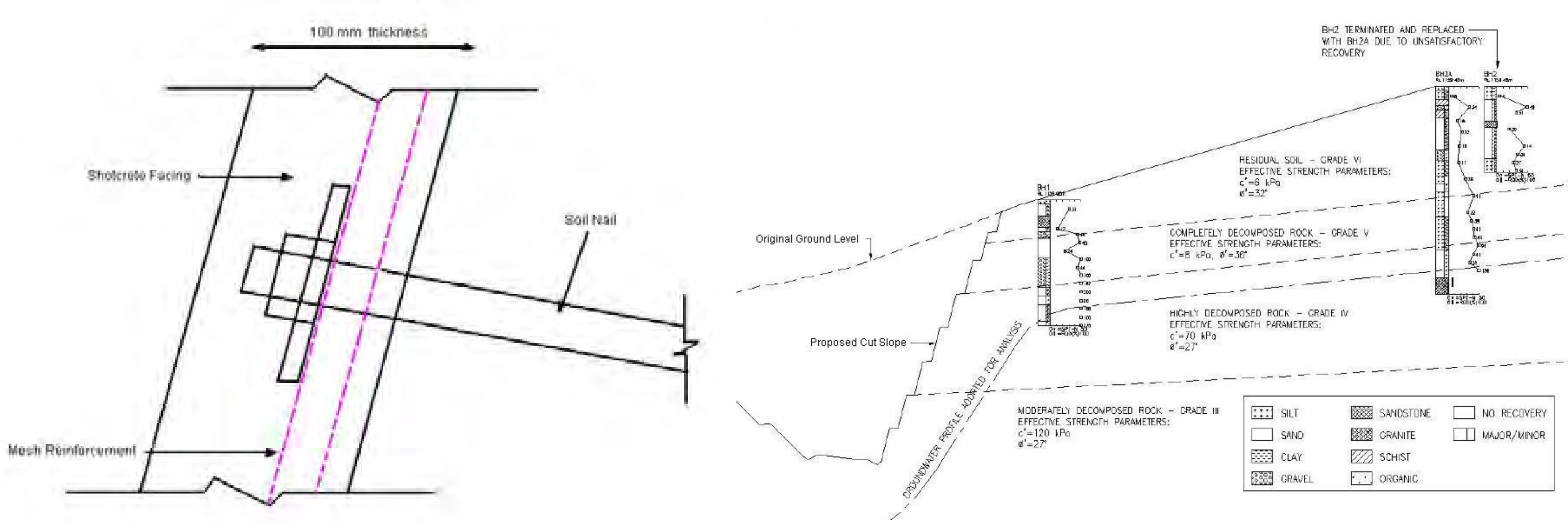



Figure 29 - Cross Section of the 45 m High Soil-nailed Slope and Details of the Gunite Facing (Extracted from Liew & Liong (2006))

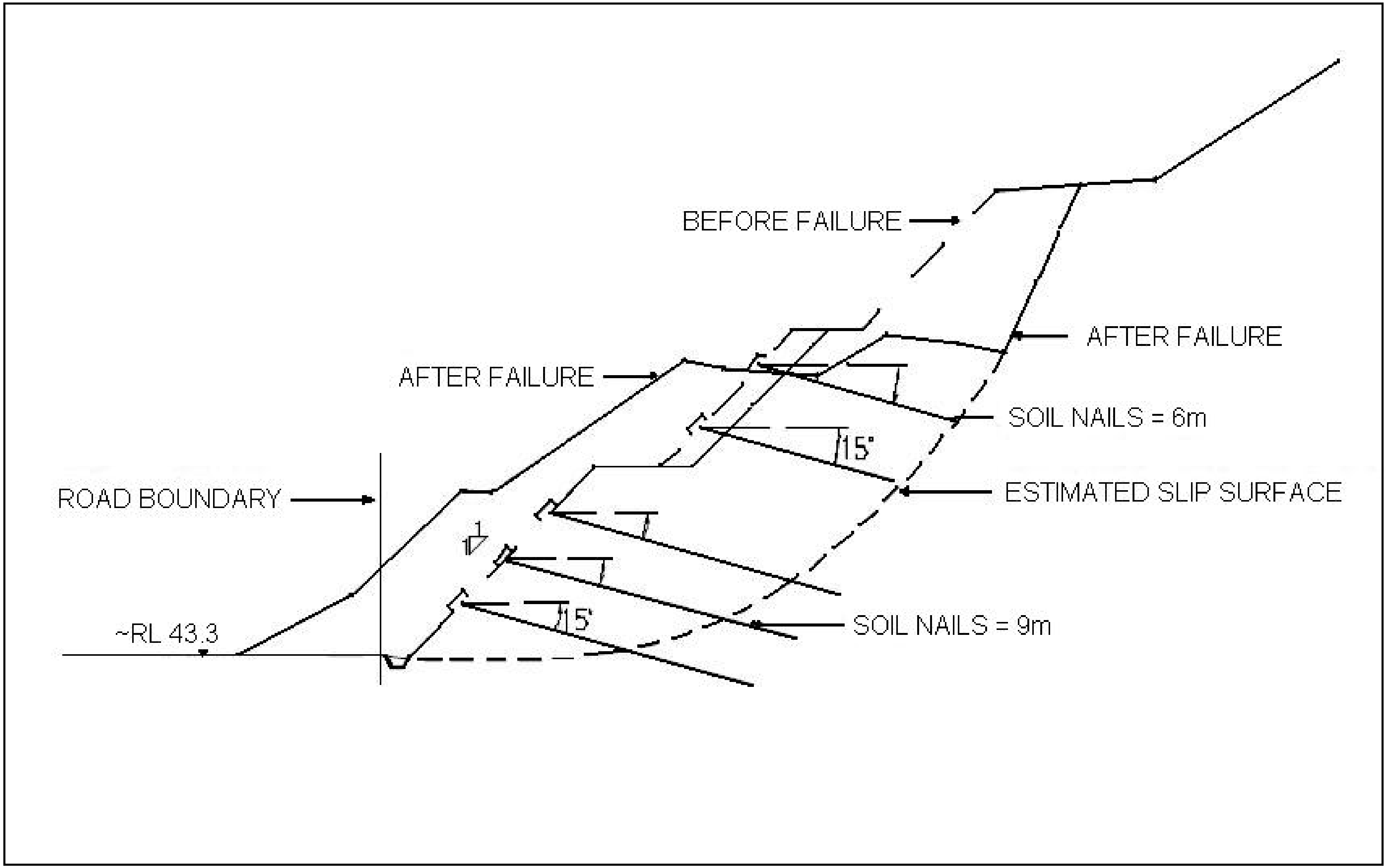
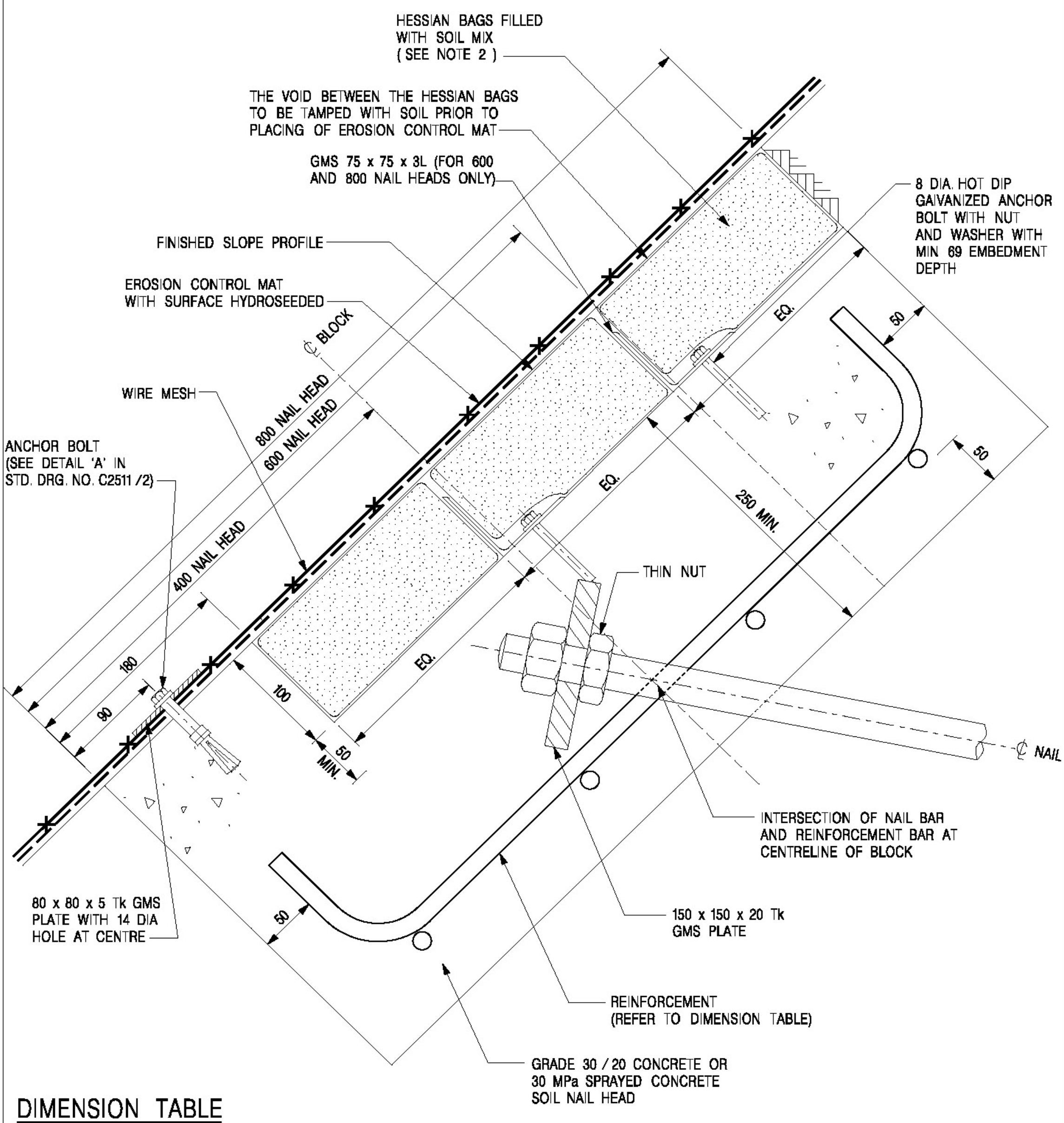



Figure 30 - Cross Section of the 18 m High Soil-nailed Slope (Extracted from Chen(2004))




## DIMENSION TABLE

| NAIL HEAD SIZE (mm) | REINFORCEMENT |
|---|---|
| 400 x 400 | 3T16 U BARS BOTHWAYS |
| 600 x 600 | 3T16 U BARS BOTHWAYS |
| 800 x 800 | 4T16 U BARS BOTHWAYS |

TYPICAL SECTION

SCALE 1 : 5

NOTES:

1. ALL DIMENSIONS ARE IN MILLIMETRES.
2. FOR EVERY 200 x 200 x 100 Tk BAG OF SOIL MIX, INCORPORATE 50 g OF PRE-PLANTING FERTILIZER AND 10 g OF WATER RETAINING CRYSTALS.

| REF. | REVISION | SIGNATURE | DATE |
|---|---|---|---|
| A | DETAILS FOR ANCHOR BOLT REVISED. GMS ADDED FOR STEEL WORKS. | Original Signed | 08.2007 |

DETAILS OF RECESSED SOIL NAIL HEAD (SHEET 1 OF 2)

CEDD CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT

SCALE AS SHOWN

DATE DEC 2005

DRAWING NO. C2106 /4A

興土木 利民生 齊拓展 創明天

We bring the best engineering to life

Figure 31 - Details of Recessed Soil Nail Head

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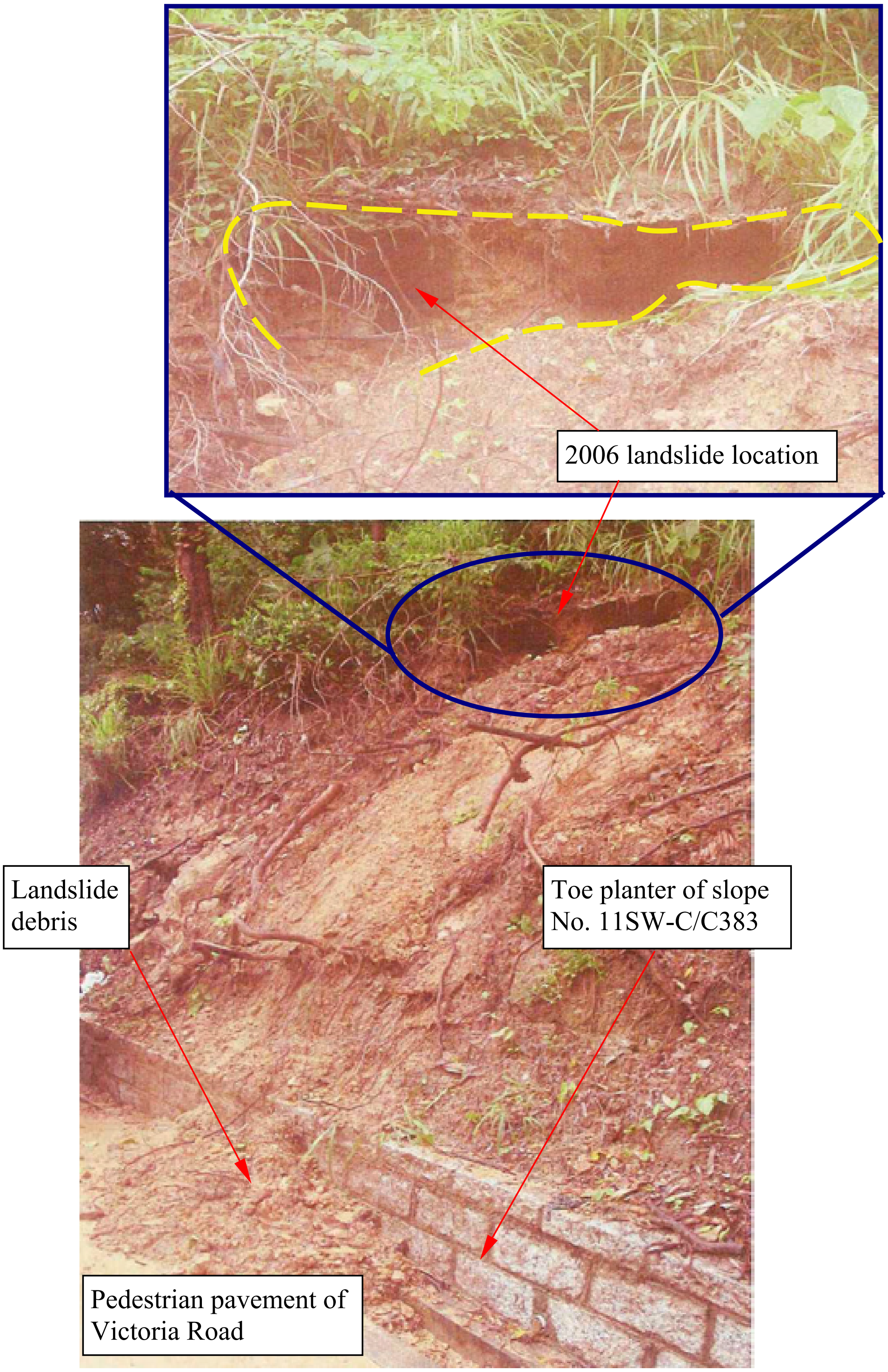


Plate 1 – View of the September 2006 Landslide on Slope No. 11SW-C/C383
(Extracted from Incident Report No. 2006/09/0709 from the GEO)

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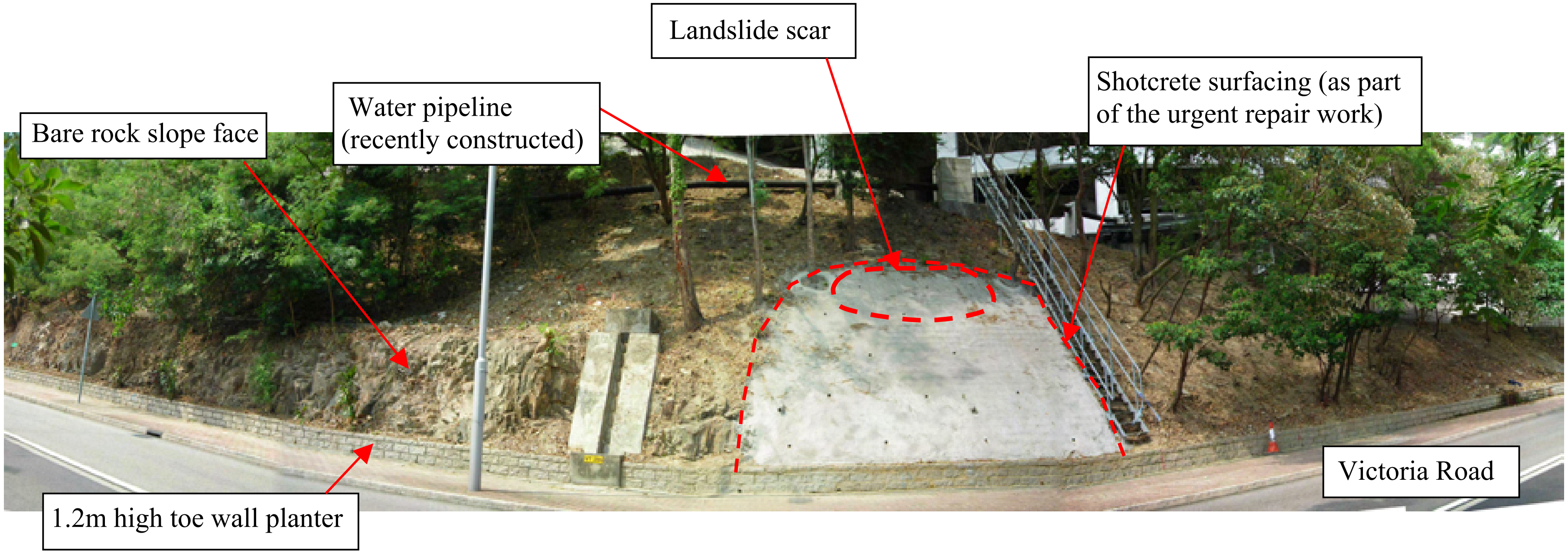


Plate 2 - General View of Slope No. 11SW-C/C383  (Photograph taken on 13 October 2006)



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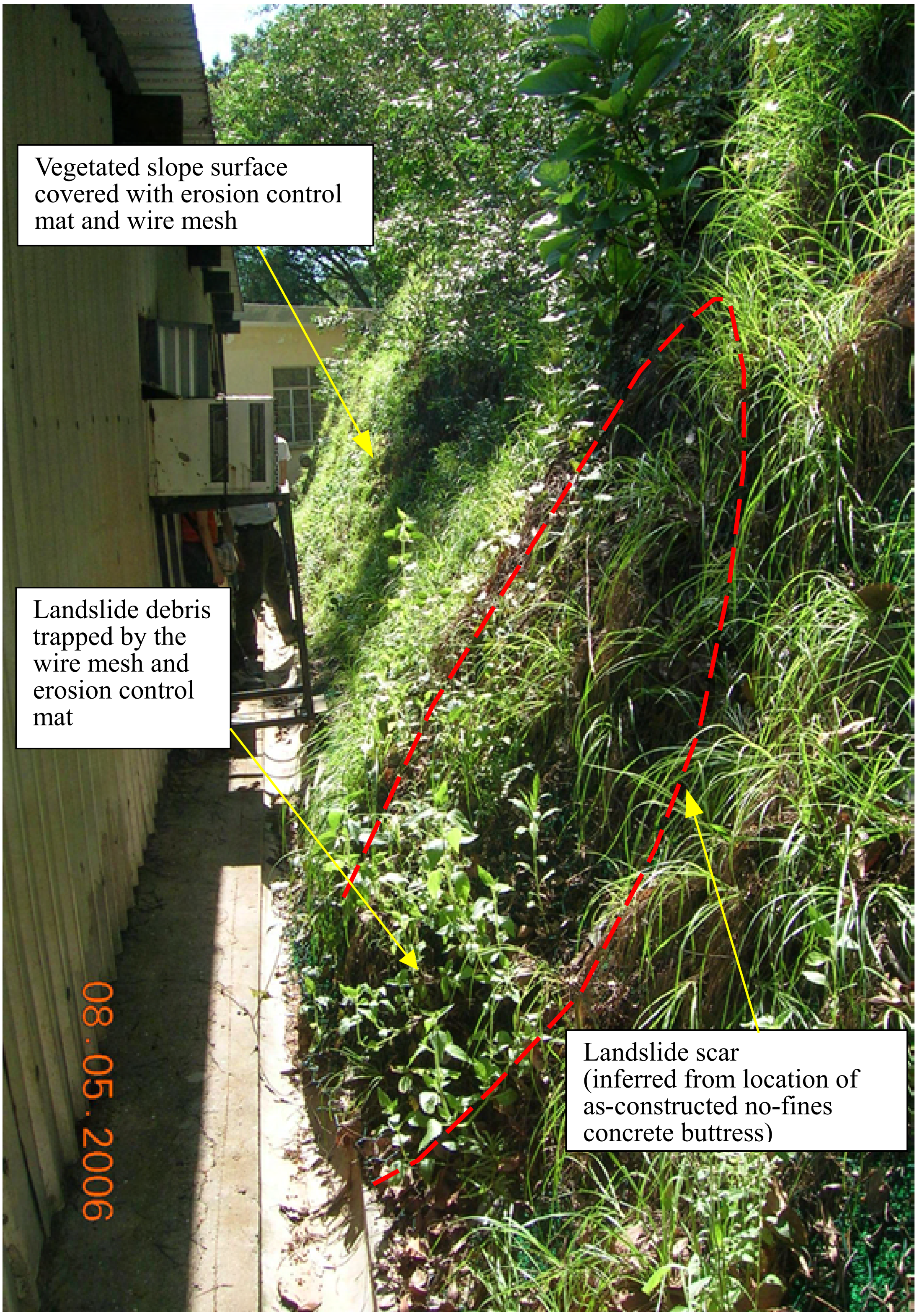


Plate 3 - View of Landslide Scar and Landslide Debris on Slope No. 3SE-D/C61
(Photograph taken by ArchSD on 8 May 2006)

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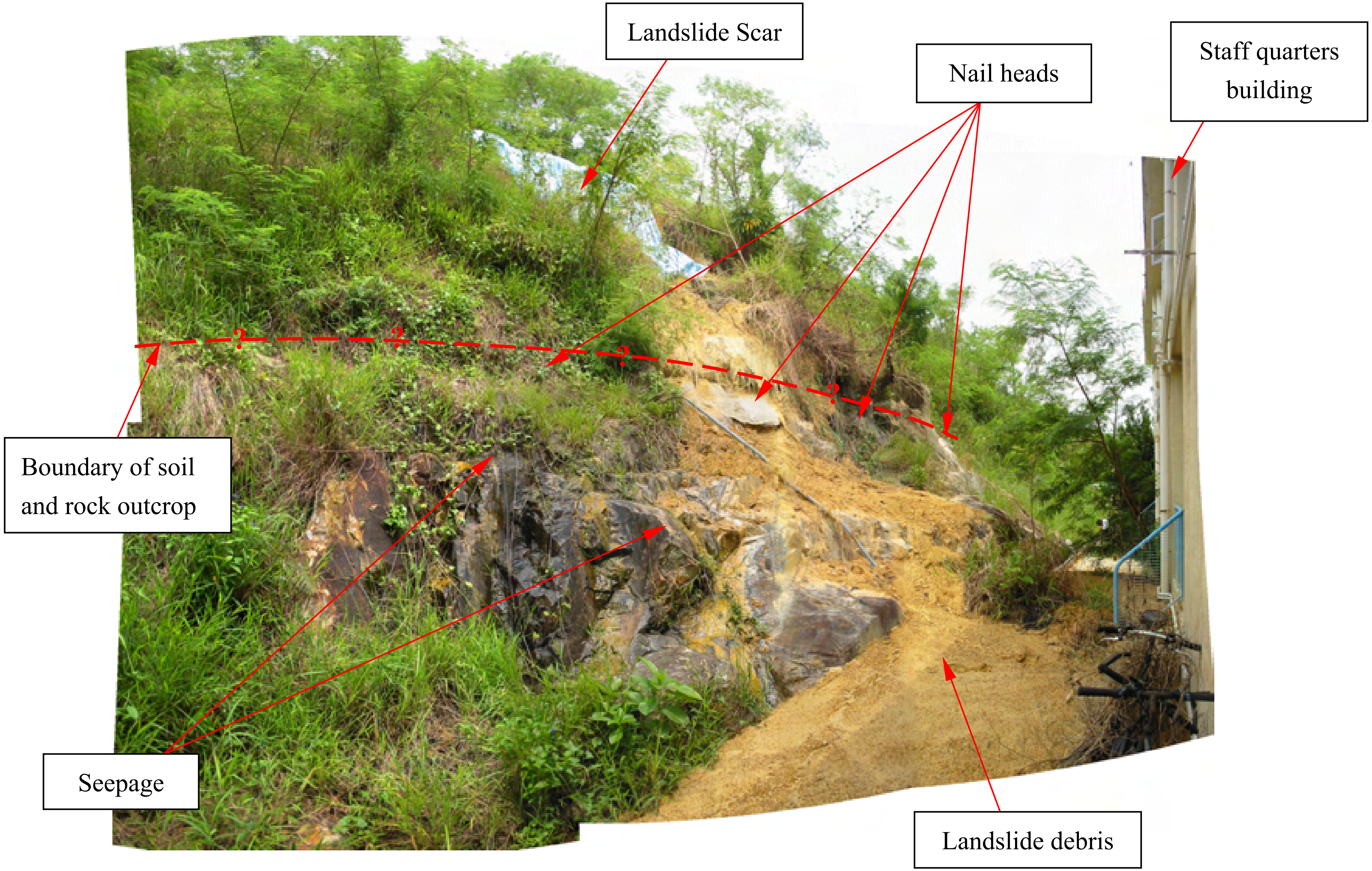


Plate 4 – View from Toe of Slope No. 15NE-A/C152 Looking North East (Photograph taken on 2 September 2005)



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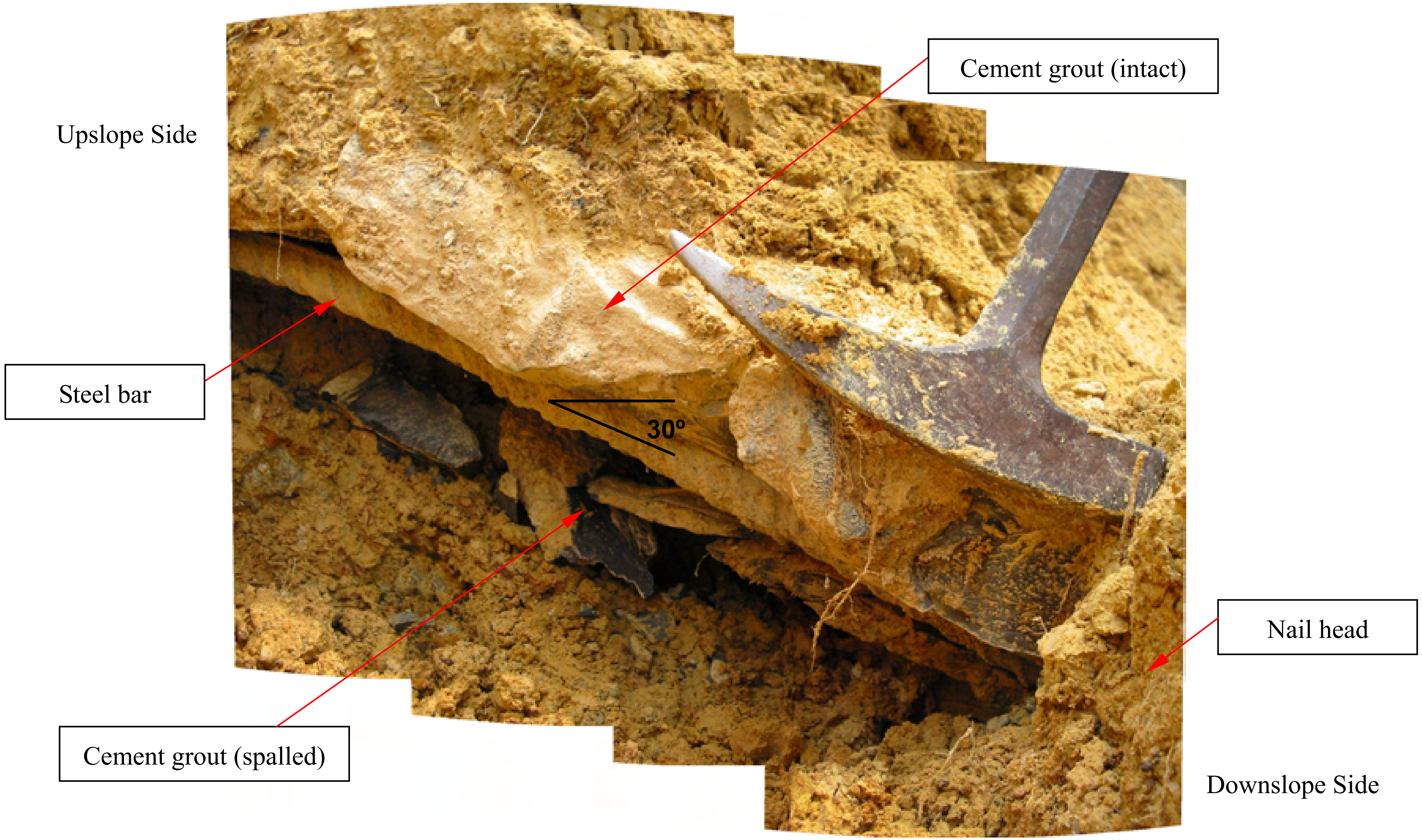


Plate 5 – Close-up View of Soil Nail No. 1 (Photograph taken on 2 September 2005)



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Plate 6 – General View of Scar at Feature No. 13NE-A/C100
(Photographs Taken on 23 August 2005)

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Plate 7 – General View of Scar at Feature No. 13NE-A/C102
(Photograph Taken on 23 August 2005)

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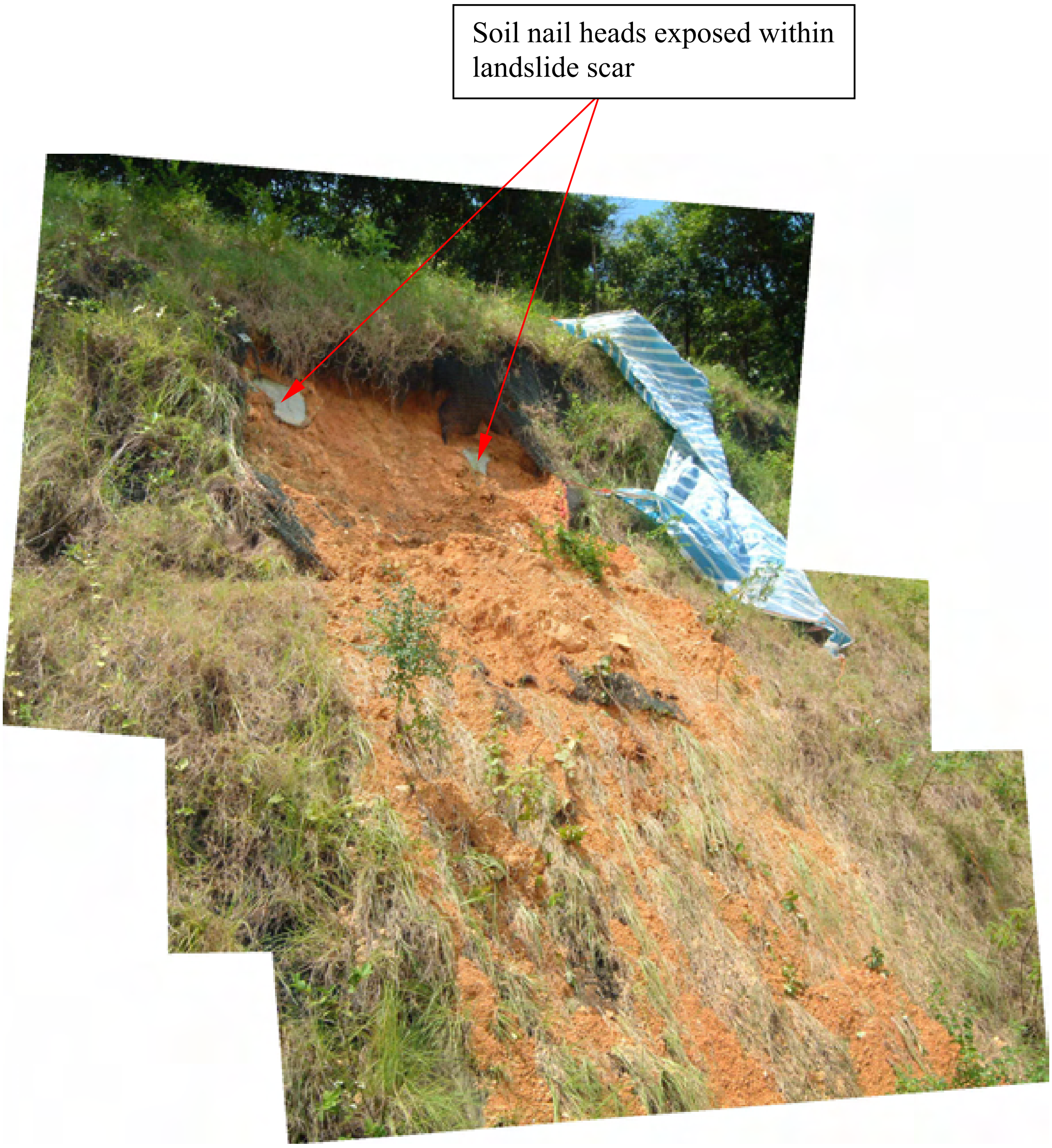


Plate 8 – General View of Scar A at Feature No. 13NE-A/C108
(Photographs Taken on 23 August 2005)

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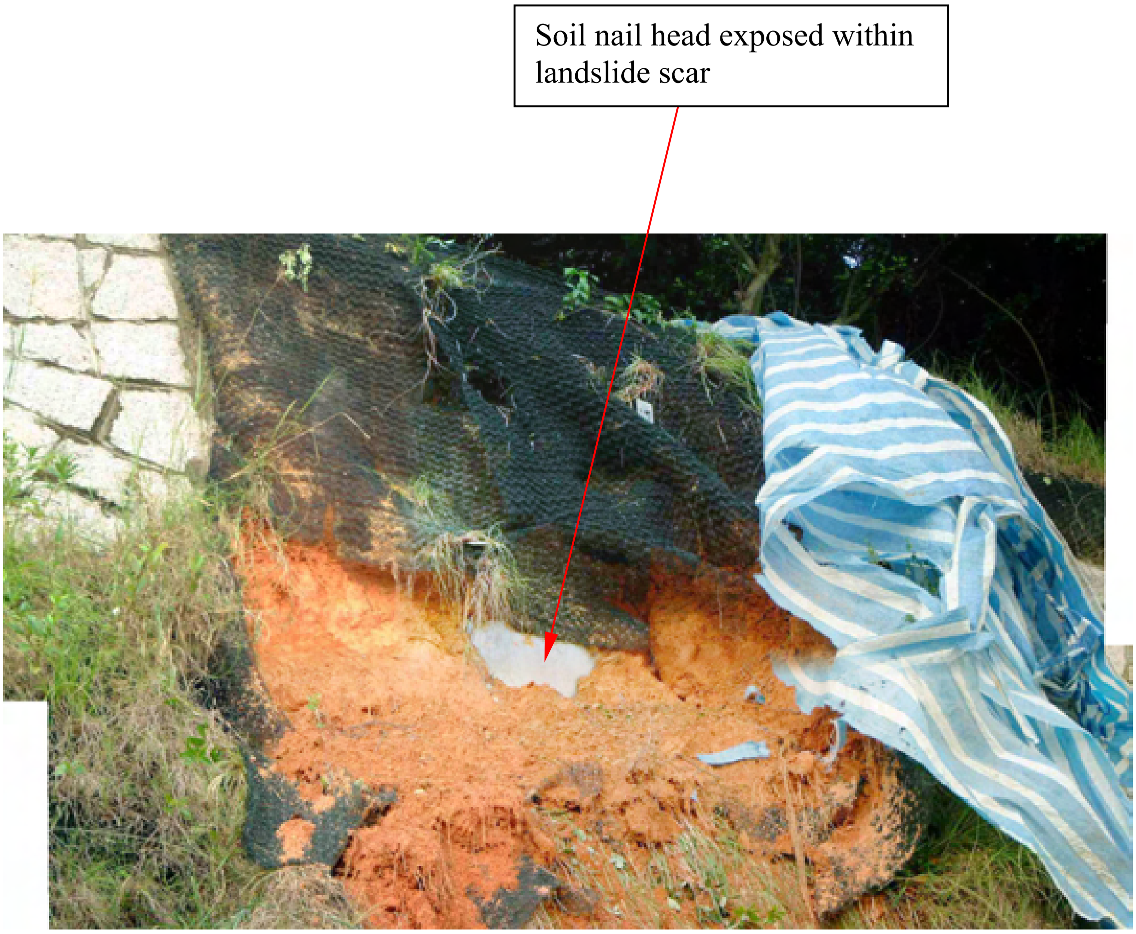


Plate 9 – General View of Scar B at Feature No. 13NE-A/C108
(Photographs Taken on 23 August 2005)

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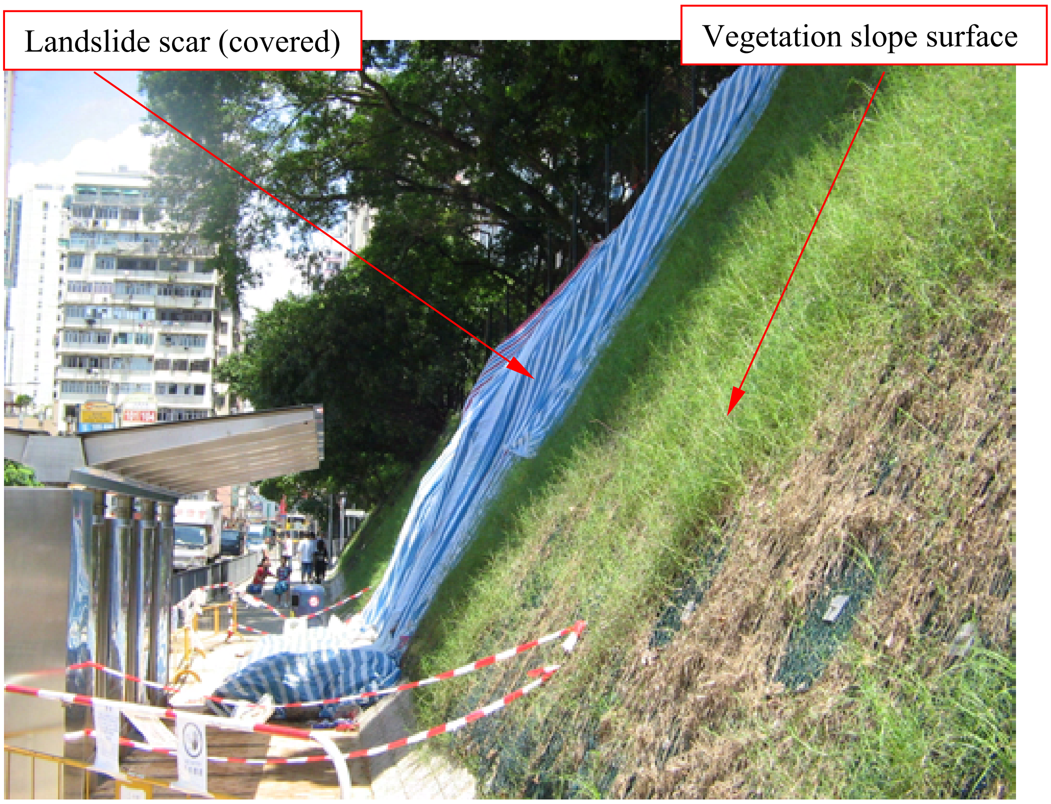


Plate 10 - General View of the August 2005 Landslide (Slope No. 11SW-A/C102)
(Photograph taken on 22 August 2005)

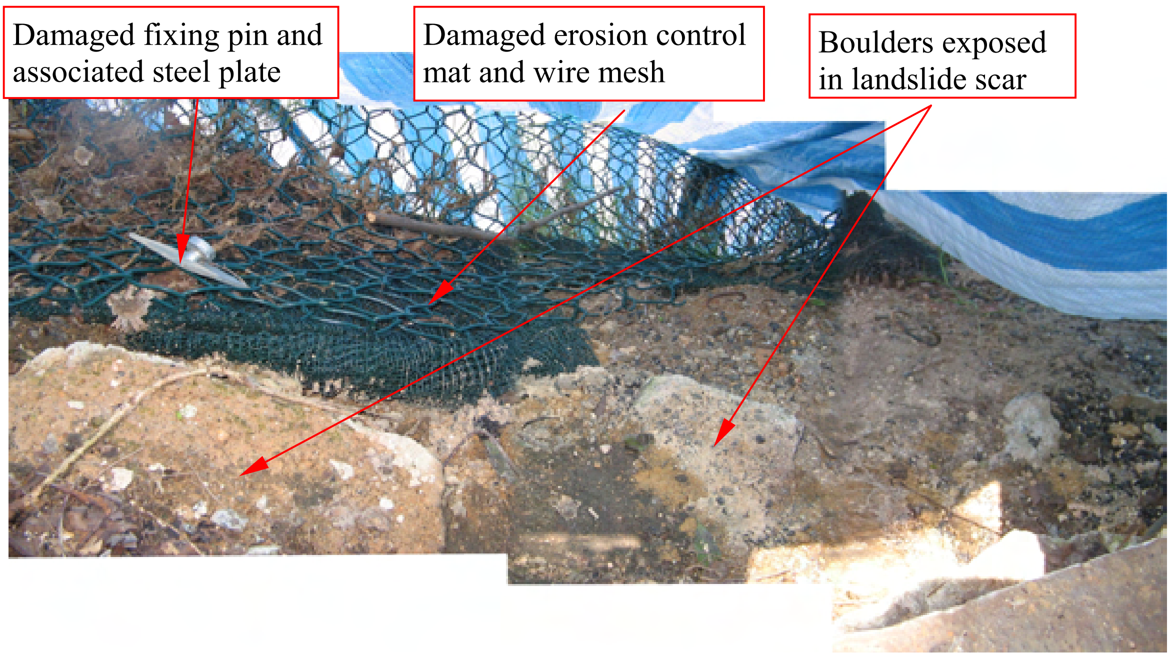


Plate 11 - View of Landslide Scar at Slope Crest (Slope No. 11SW-A/C102
(Photograph taken on 22 August 2005)

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Plate 12 - General View of the Landslide at Tai Lam Chung Catchwater


Plate 13 - View of the Upper Portion of the Landslide Scar

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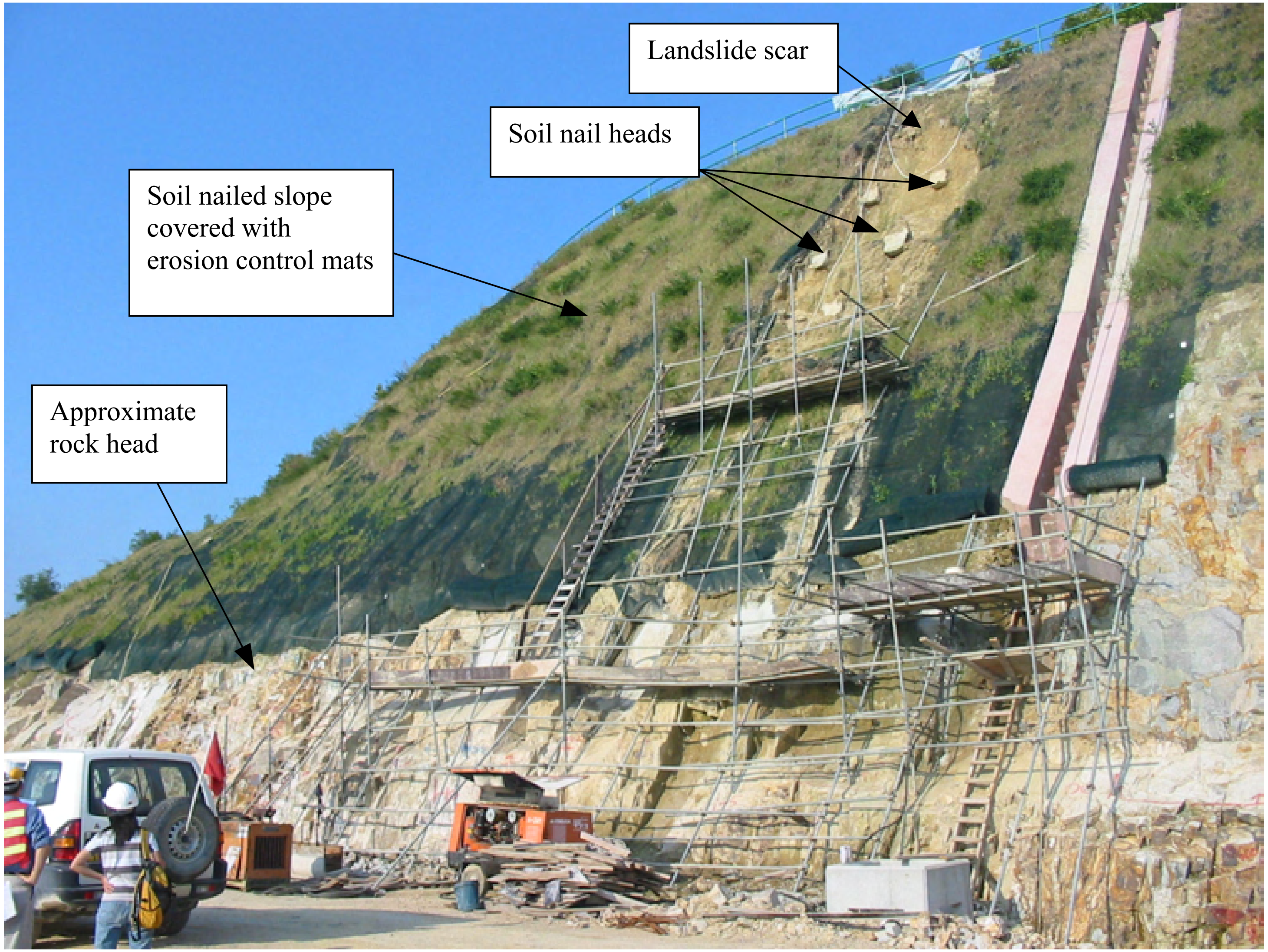


Plate 14 – General View of the August 2004 Landslide at Anderson Road (Photograph taken on 5 October 2004)



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Plate 15 -The May 2004 Landslide on the Northeastern End of Slope No. 11NE-B/C542
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Plate 16 - View of the Erosion Scars on Slope No. 6NE-B/C8 above the Berm
(Photograph taken on 14 June 2003)

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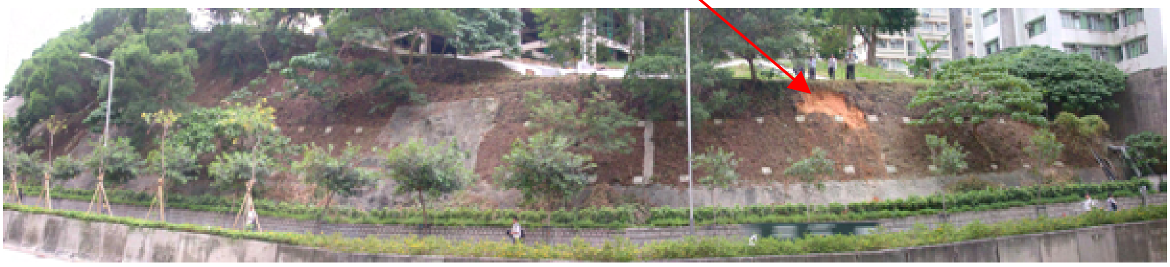


Plate 17 - General View of the Landslide (Slope No. 11SE-D/C22)
(Photograph taken on 10 November 2003)


Plate 18 - General View of the Landslide Scar on Slope No. 11SE-D/C22
(Photograph taken on 10 November 2003)

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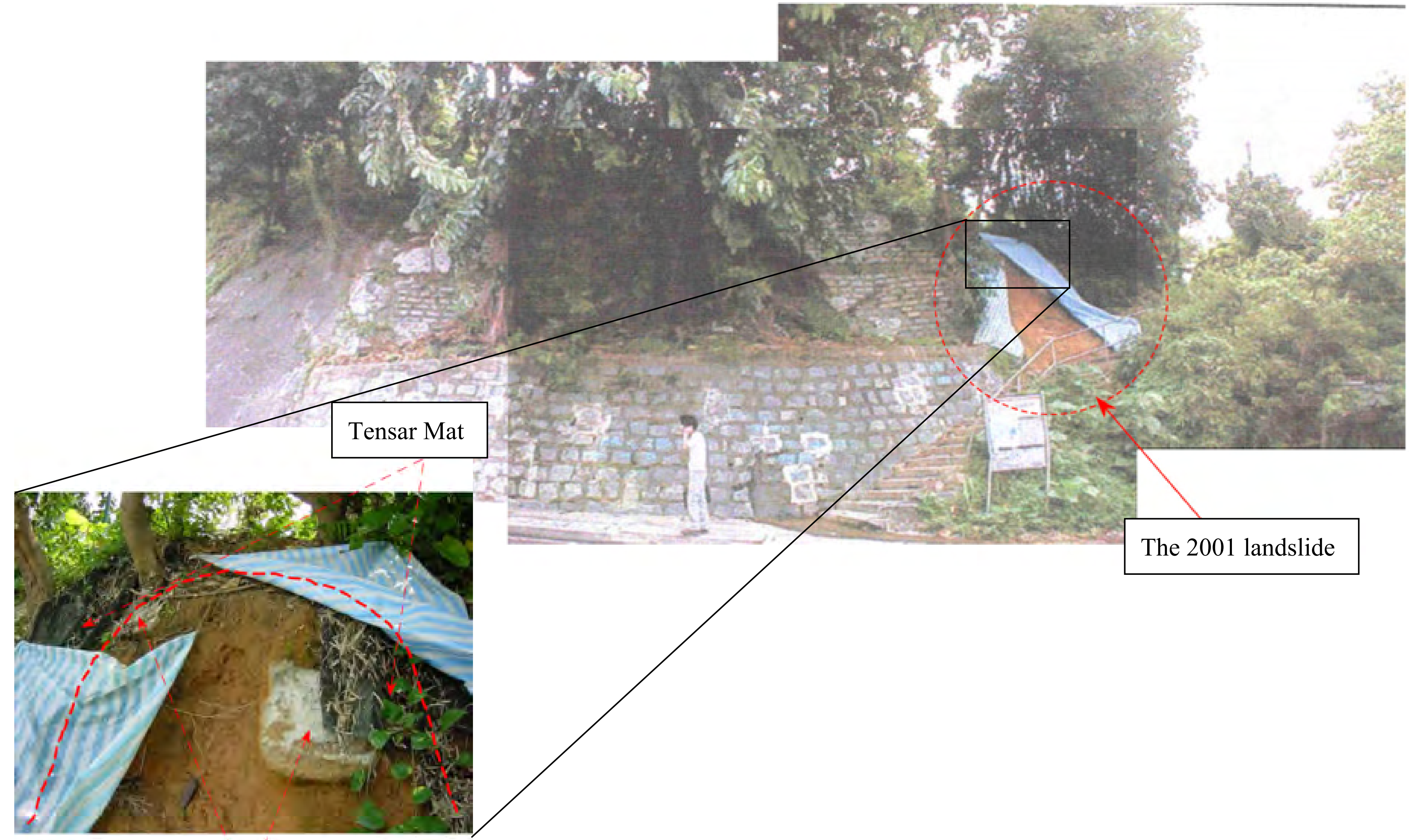


Plate 19 - General View of the Southern Portion of Slope No. 6SE-D/C52
(Photograph taken on 4 July 2001)



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Plate 20 - Elevation View of Landslide A on Slope No. 6SE-B/C4
(Photograph taken on 10 July 2001)

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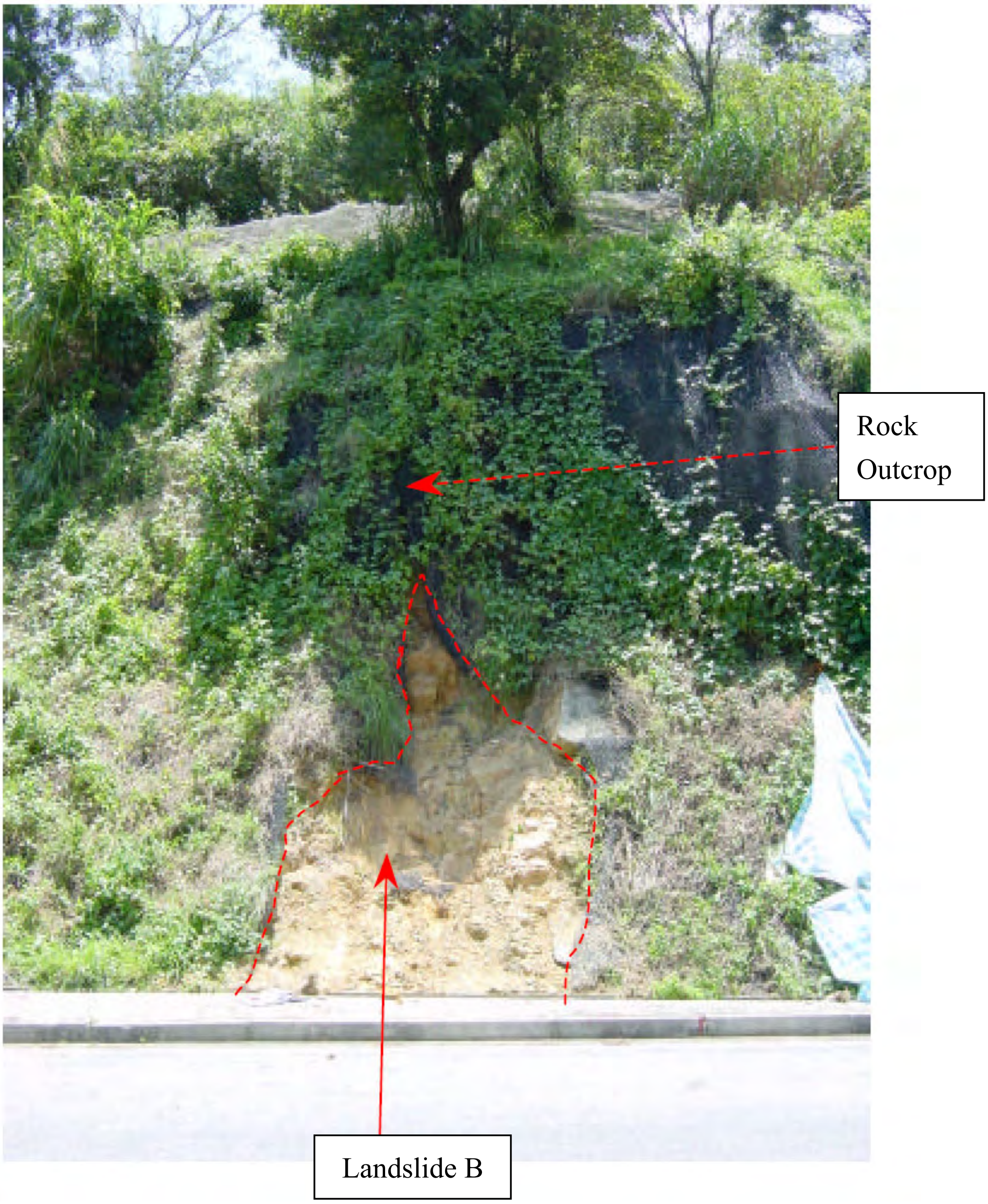


Plate 21 - Elevation View of Landslide B on Slope No. 6SE-B/C4
(Photograph taken on 10 July 2001)

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Plate 22 - Elevation View of the 2001 Landslide on Slope No. 6NE-D/C6
(Photograph taken on 10 July 2001)

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# GEO PUBLICATIONS AND ORDERING INFORMATION
# 土力工程處刊物及訂購資料

A selected list of major GEO publications is given in the next page. An up-to-date full list of GEO publications can be found at the CEDD Website http://www.cedd.gov.hk on the Internet under "Publications". Abstracts for the documents can also be found at the same website. Technical Guidance Notes are published on the CEDD Website from time to time to provide updates to GEO publications prior to their next revision.

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# 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, 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. |

## GEOSPECS

| | |
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| 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

| | |
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| GCO Publication No. 1/90 | Review of Design Methods for Excavations (1990), 187 p. (Reprinted, 2002). |
| GEO Publication No. 1/93 | Review of Granular and Geotextile Filters (1993), 141 p. |
| GEO Publication No. 1/2000 | Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls (2000), 146 p. |
| GEO Publication No. 1/2006 | Foundation Design and Construction (2006), 376 p. |
| GEO Publication No. 1/2007 | Engineering Geological Practice in Hong Kong (2007), 278 p. |

## GEOLOGICAL PUBLICATIONS

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

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

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| | |
|---|---|
| TGN 1 | Technical Guidance Documents |