# REPORT ON THE 22 MAY 2013 LANDSLIDE ON A FILL SLOPE AT A CONSTRUCTION SITE ABOVE LEE ON ROAD, SAU MAU PING


*Fugro Scott Wilson Joint Venture*

*for*

*Geotechnical Engineering Office*

*Civil Engineering and Development Department*

*The Government of The Hong Kong Special Administrative Region*



December 2013

(minor amendments made in November 2020)

## Executive Summary

This report presents the findings of a detailed investigation of the 22 May 2013 landslide on a fill slope above Lee On Road, Sau Mau Ping. The fill slope was under construction as part of the Development at Anderson Road (DAR) project. No casualty was reported as a result of the incident.

The landslide incident involved a 530 $m^3$ washout failure of a fill slope, Slope B6, under an intense rainfall. At the time of failure, the slope filling works had been completed but the surface cover and surface drainage measures were yet to be implemented. Most of the landslide debris was deposited on Lee On Road with some debris washed down further to the junction of Lee On Road and Shun On Road. The landslide resulted in temporary closure of Lee On Road for two days.

The key objectives of this study were to establish the probable causes and mechanism of the landslide. The study included interviewing eye-witnesses, field inspections, ground investigation and review of related design and construction records of the DAR project.

Based on the findings, the landslide was a washout failure. It resulted from the site drainage provisions at the time of the failure not being efficient in conveying surface runoff off site and thereby being overwhelmed by the large volume of surface runoff arising from the intense rainfall in the early morning of 22 May 2013. This led to ponding over an extensive area behind an earth bund at the crest of the slope. The earth bund, which was intended to prevent the overspilling of surface runoff onto the fill slope, was subsequently breached, discharging a large amount of surface water onto the fill slope below, resulting in the washout failure.

# Contents

## 1 Introduction

In the early morning of 22 May 2013, a landslide incident (Landslide Incident No. 2013/05/1293) occurred at the construction site for the Development at Anderson Road (DAR) project, above Lee On Road, Sau Mau Ping (Figure 1.1 and Plate 1). The landslide occurred on a fill slope (Slope B6) which was under construction (Plate 2). The estimated failure volume was about 530 $m^3$ with the majority of the landslide debris deposited on Lee On Road. The landslide resulted in the temporary closure of both lanes of Lee On Road for two days. No casualty was reported as a result of the incident.

Fugro Scott Wilson Joint Venture (FSW) has been engaged by the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department (CEDD) to establish the probable causes and mechanism of the landslide.

The investigation was conducted from May 2013 to November 2013 and comprised the following key tasks:

(a) review of all known relevant documents relating to the design and construction of the site,

(b) interviews with eye-witnesses of the landslide,

(c) detailed observations and measurements in the vicinity of the landslide site,

(d) interpretation of aerial photographs relating to the site,

(e) execution of ground investigation to establish the subsurface conditions,

(f) analysis of the rainfall records,

(g) engineering analyses of the site drainage provisions at the time of the landslide, and

(h) diagnosis of the probable causes of the landslide.

This report documents the findings. The findings have been reviewed by an independent reviewer, Professor John Burland of Imperial College London. On 22 May 2013, distress of a reinforced fill wall structure also occurred in the DAR site. The investigation of the distress is covered in a separate report.

## 2 Site Description

### 2.1 General

The DAR project is to provide usable land of about 20 hectares for constructing public housing, and government and public facilities at the site. Under the project, site formation and associated infrastructure works, including roads, drains and upgrading of existing slopes, were being carried out. The DAR site is bounded by Anderson Road to the northeast, Sau

Mau Ping Road to the southwest, Po Lam Road to the south, and Lee On Road and Shun On Road to the west (Figure 1.1). Construction works for the DAR project commenced in January 2008 and are scheduled for completion in 2014. At the time of the landslide, some of the platforms including Platforms A1 and B had been formed, whereas the road works including Roads L1 and L2 and the slope works including the formation of Slope B6 were under construction.

The DAR project is managed by the Civil Engineering Office of the CEDD. The Contractor and the Consultant for the DAR project are China State Construction Engineering (HK) Limited (CSCE) and Ove Arup and Partners Hong Kong Limited (OAP) respectively.

## 2.2 Site Setting

Slope B6 is located at the northwestern part of the DAR project site (Figure 1.1) above the crest of Slope 11NE-D/C30 (Figure 2.1) and is inclined towards Lee On Road to the west.

Slope B6 is situated within a westerly facing catchment encompassing a minor ephemeral drainage line (Figure 2.1). At the time of the landslide, the three batters of Slope B6 had been formed with an overall slope height of 17 m (from +133 mPD at the toe to +150 mPD at the crest). The lower two batters comprised compacted rockfill with a slope angle of $22^o$ whilst the upper batter was compacted soil fill with a slope angle of $30^o$ (Figure 2.1). At the time of the landslide, the filling works of Slope B6 had been completed, but the slope surfacing and the surface drainage system were still to be installed (Plate 3). The surface of Slope B6 was bare, with the rockfill and soil fill exposed.

Prior to the landslide, a 1 m high temporary earth bund had been formed along the crest of Slope B6 (Figure 2.1 and Plate 4). A 225 mm diameter UPVC pipe was installed in the southern end of the bund to discharge any water accumulating behind the bund to the surface drainage system of Slope 11NE-D/C30.

Immediately above the crest of Slope B6 was an area where an access road (Road L2) would be constructed at a later stage under the DAR project (Figure 2.1). The Road L2 area was separated from Slope B6 by the 1 m high temporary earth bund. At the time of the landslide, Road L2 was not yet completed (Plates 4 and 5). The Road L2 area was formed to around +149 mPD to +150 mPD which happened to be a topographical low-point within the northwestern part of the DAR site (Plate 5).

Upslope of the Road L2 area was a large development platform (Platform B) formed under the DAR project (Figures 1.1 and 2.1). Platform B was formed over two levels, the lower of which had been formed at +151 mPD. A system of U-channels together with intervening sand traps had been constructed along the southern and western periphery of the platform (Plates 4 and 5). The size of the peripheral U-channels ranged from 525 mm to 750 mm. Another system of 300 mm U-channels and associated catchpits beyond the edge of the platform was under construction at the time of the landslide (Plate 4). Details of the surface drainage in the vicinity of Slope B6 are further discussed in Section 5.

The crest area of Slope B6 including the Road L2 area and Platform B was exposed at the time of the landslide.

## 3 Description of the Landslide

The following descriptions of the landslide have been collated mainly from the field observations together with witness accounts and records from the CEDD, the Contractor and the Consultant.

The landslide probably occurred around 4:00 a.m. on 22 May 2013, and lasted until about 4:30 a.m. This timeframe is determined based on the account of a resident at the nearby On Yat House, Shun On Estate (Figure 3.1), who heard a loud noise coming from Slope B6 shortly after 4:00 a.m. on 22 May 2013. The time of the landslide is consistent with the Police records which showed that the 999 call centre first received a report of landslide at 4:17 a.m. from a member of the public.

By about 4:30 a.m., the police officer attending the scene noted that some 2 m high landslide debris had already been deposited on Lee On Road and that no further landslide debris came down from the slope. He also reported much water coming down from the slope, "like a waterfall". A similar phenomenon was captured in a video footage taken by another eye-witness, which showed a torrent of water containing substantial rock pieces discharging down the slope onto Lee On Road shortly after the landslide. The 30-minute video footage showed that the debris was deposited on the road progressively (Plate 6).

The landslide debris mainly comprised rockfill materials mixed with soil. Most of the landslide debris was deposited on Lee On Road and some travelled further to the junction of Lee On Road and Shun On Road (Figure 3.1 and Plate 7). Some debris was trapped by a temporary rockfall fence at the toe of Slope B6 (Figure 3.2 and Plate 8).

The landslide resulted in a curve-shaped scar on the southern side of Slope B6 (Plate 2). The scar was about 17 m high, about 2.5 m deep on average, with a maximum width of 14 m (Figure 3.1 and Plate 2). In-situ strata were exposed over the basal surface and the southern flank of the landslide scar (Plate 9). A geotextile layer was also observed at the base of the rockfill.

Post-failure inspection observed that a 5 m span of the earth bund at its southern end immediately above the landslide scar had been breached (Plate 10). A few hours after the landslide (at about 9:00 a.m. on 22 May 2013), ponding over an extensive area was observed at the crest area of Slope B6 (Plates 2 and 11, and Figure 3.1) with a significant amount of water running through the breach in the earth bund, discharging onto the landslide scar at Slope B6 below (Figure 3.1 and Plates 7, 10 and 12).

No significant signs of distress or instability were observed on the unfailed part of Slope B6. Only minor surface erosion gullies were noted on the upper soil fill batter of the slope (Plates 2 and 9).

## 4 Analysis of Rainfall Records

Rainfall data was obtained from the nearest GEO automatic raingauge No. K04 which is located about 0.7 km north of the landslide (Figure 1.1). The raingauge records rainfall data at 5-minute intervals. The daily rainfall recorded by raingauge No. K04 from

22 April 2013 to 22 May 2013 and the hourly rainfall readings from 0:00 a.m. on 21 May 2013 to 10:00 a.m. on 22 May 2013 are shown in Figure 4.1. In addition, the DAR site also has its own raingauge which is located further away, at about 1.3 km southeast of the landslide location, and only records rainfall data at 15-minute intervals (Figure 1.1). Therefore, data from this raingauge have not been used in the rainfall analysis.

Table 4.1 presents the estimated return periods for the maximum rolling rainfall for various durations recorded by raingauge No. K04 following the approach described by Tang & Cheung (2011). The results of the analyses show that the return period corresponding to a 1-hour maximum rolling rainfall of 135 mm was more than 200 years.

The maximum rolling rainfall of the 22 May 2013 rainstorm has been compared with previous major rainstorms recorded at raingauge No. K04 (Figure 4.2). The 1-hour intensity of the 22 May 2013 rainstorm during the landslide was the most severe rainstorm recorded by raingauge No. K04 since it came into operation in 1980.

## 5 Site Catchment and Drainage

### 5.1 Catchment of the Site

Assessment of the site topography shows that the crest of Slope B6 was located at the lowest point within the northwestern part of the DAR site. Surface runoff accumulated at the crest of Slope B6 came from an extensive catchment area covering the northwestern part of the DAR site, and a section of Anderson Road together with a small area of adjacent natural terrain and part of the Anderson Road Quarry (Figure 5.1).

The northwestern part of the DAR site comprised mainly levelled platforms (Platform A1, Platform A2 and Platform B) and the adjoining ground, with an estimated catchment area of 126,600 $m^2$.

The section of the Anderson Road abutting the northwestern part of DAR site is 6 m wide and concrete paved. Cross-road drains underneath Anderson Road discharge flow from Anderson Road to the DAR site. Approximately a 7,200 $m^2$ area of Anderson Road, and adjacent sloping terrain is estimated to have contributed runoff to the DAR site below as shown in Figure 5.1.

In addition, an approximate 23,700 $m^2$ area of the Anderson Road Quarry adjoining Anderson Road is estimated to have contributed surface runoff to Anderson Road and/or the DAR site below as shown in Figure 5.1. Post-failure inspection revealed that there is no evidence of other significant source of water coming from the Anderson Road Quarry including the quarry lagoon (Plate 13), which is used to store surface runoff within the quarry.

### 5.2 Site Drainage Arrangements

Based on the Contractor's latest temporary drainage design prior to the landslide (submitted to the Consultant on 9 May 2013), a series of U-channels, including a 900 mm U-channel along the crest of Slope B6, were to be provided (Figure 5.2). However, the channels over the northwestern portion of the DAR site were under construction at the time of the incident. Based on record photos and post-failure inspections, the crest area of Slope B6 was built with a 1 m high temporary earth bund and equipped with a standby electric pump apparently provided for temporary drainage purposes (Plates 4 and 19).

At the time of the landslide, the main drainage constructed over the northwestern portion of the DAR site comprised a series of U-channels and intervening sand traps along the periphery of Platform B (ranging in size from 525 mm to 750 mm) as shown in Figure 5.3. These drainage measures were part of the permanent drainage system for the DAR project (Figure 5.3). At Platform B, the U-channels generally have a fall of less than 1 in 220 in a herringbone fashion towards the sand traps (Figure 5.4(b)). The sand traps are intended to discharge flow into the drainage network under Road L2 as part of the permanent drainage system (Figure 5.3). Limited drainage works under Road L2 were constructed at the time of the landslide. Only one of the constructed sand traps (ST15 in Figure 5.3) was connected to the 2.5 m wide cascade channel, the main site drainage outlet (Figure 5.4). Given the as-built fall direction of these U-channels, surface flow against the invert fall would occur at some sections of U-channels (Figure 5.4), hampering the flow efficiency and capacity of these channels under the temporary drainage condition. The estimated size of the catchment for the platform U-channels was about 93,100 $m^2$ (i.e. Catchment 1 as shown in Figure 5.1).

Post-failure inspections and review of construction records revealed disconnection and signs of blockage with standing water at the U-channels at Platform B (Figure 5.4 and Plates 14 to 16), which could further hamper the flow efficiency and capacity of the U-channels. It is probable that a proportion of the surface runoff generated from Platform B could have overflowed from the U-channels onto the crest area of Slope B6, which was a low point of the DAR site. Signs of channel flooding were observed at the crest of Slope B6 (Plate 11) and overflow was also observed from the U-channel between sand traps ST15 and ST16 onto the toe of the haul road (Figure 5.1 and Plate 17).

Runoff from Platforms A1 and A2 and Road L2 in the northwestern part of the DAR site (i.e. Catchment 2 in Figure 5.1) was another source of water reaching the crest area of Slope B6. The estimated size of the catchment was about 64,400 $m^2$. The site drainage system in this area was under construction at the time of the landslide and was not functional. The runoff would have flowed along a temporary haul road (Road L2) leading towards the crest area of Slope B6, which was a low point on the site.

As discussed above, the crest area of Slope B6 was provided with a 1 m high temporary earth bund and a 225 mm diameter UPVC pipe connected to the surface drainage system of an adjacent slope (Plate 18). The standby electric pump was provided to pump out water accumulated at the crest area of Slope B6 back to the nearby periphery U-channels along Platform B (Plate 19). However, according to the Contractor, the pump was not in operation at the time of the landslide.

# 6 Design and Construction of Slope B6

## 6.1 Design of Slope B6

Slope B6 was designed as a 17 m high fill slope formed in three slope batters with a gradient of $22^\circ$ to $30^\circ$ (Figure 6.1). The lower two batters were formed with rockfill and the upper batter with soil fill. A surface drainage system comprising 300 mm U-channels along the slope crest and berms, and 300 mm stepped channels along the northern and southern perimeters of the slope was proposed. Benching of the in-situ ground was specified and an internal drainage blanket comprising prefabricated drain, geotextile and filter pipes was proposed at the in-situ ground/fill interface. The rockfill portions were to be covered by a layer of top soil and the final surface of Slope B6 would be hydroseeded and erosion control matting would also be provided.

The design of Slope B6 was in line with the current standards.

## 6.2 Construction of Slope B6

The construction of Slope B6 commenced around November 2010 and the slope filling works were substantially completed in February 2013 (Plate 3). Construction records showed that benching was provided at the base of the slope (Plate 20). According to the Contractor’s method statement, vibratory roller was used for compaction of the fill materials. In-situ density tests conducted by the Government Public Works Laboratories showed the compacted soil fill complied with the specifications.

# 7 Subsurface Conditions at Slope B6

Previous ground investigation (GI) records in the vicinity of Slope B6 include four drillholes and two trial pits (Figure 7.1). GI records indicate that the fill was likely to be underlain by around 8 m thick saprolite with bedrock at around +137 mPD below the slope crest. Groundwater monitoring records near the slope crest indicate that the groundwater (between 28 March 1998 and 4 April 1998) was below +147 mPD, some 3 m below the slope crest.

Additional post-failure ground investigation comprising 3 trial pits was undertaken on Slope B6 (Figure 7.1). Significant seepage was not observed in any of these trial pits.

# 8 Diagnosis of the Landslide

The landslide at Slope B6 occurred over a period from about 4:00 a.m. to 4:30 a.m. on 22 May 2013 during an intense rainfall. In view of the close correlation of the time of the landslide with the intense rainfall, the landslide is considered to be a rain-induced failure. The mechanism probably involved a washout failure, taking into account the curved shape of the landslide scar and that a large, concentrated discharge of surface water had overtopped Slope B6.

Findings of a topographical assessment indicate that the surface runoff reaching the crest of Slope B6 largely came from the extensive catchment of Platforms A1, A2 and Platform B (Figure 5.1) within the DAR site, with a combined catchment area of about 157,500 $m^2$. Given the large catchment involved and the intense rainfall on 22 May 2013, the site drainage provisions in the area were unable to effectively discharge all the surface water and a large amount of surface water could have reached the crest area of Slope B6. The site drainage provisions at the time of the failure were not efficient in conveying surface runoff off site (Section 5.2).

Results of an assessment indicate that such a large inflow would have well exceeded the capacity that could be handled by the 225 mm diameter UPVC pipe installed at the crest of Slope B6 (Appendix A). As a result, extensive ponding would have occurred at the slope crest behind the earth bund which was subsequently breached, discharging a large volume of water onto Slope B6 and causing the washout failure. The failure process is consistent with the video footage, which was recorded by an eye-witness, showing a substantial amount of water discharging down Slope B6 shortly after the landslide and that the discharge continued for several hours after the landslide.

Although Slope B6 was under construction and the surface cover and surface drainage system of Slope B6 were yet to be completed at the time of the failure, there is no evidence suggesting that the design and construction of Slope B6 has contributed to the failure. Also, there were no premonitory signs of instability on the day preceding the failure. The possibility of development of high water pressure within the fill body of the slope has also been considered, but this is unlikely given the high permeability of the rockfill materials and the presence of an internal drainage system in the soil fill portion of the slope.

## 9 Conclusions

On 22 May 2013, a 530 $m^3$ landslide occurred over a period from around 4:00 a.m. to 4:30 a.m. at a 17 m high fill slope (Slope B6), which was under construction within the DAR site. The landslide resulted in temporary closure of Lee On Road for two days. No casualty was reported.

The landslide involved a washout failure caused by the intense 22 May 2013 rainstorm. The site drainage provisions at the time of the failure were not efficient in conveying surface runoff off site and were overwhelmed by the large volume of surface runoff reaching Slope B6, which was at a topographic low spot. The majority of surface runoff probably came from the extensive catchment areas within the DAR site. The surface runoff contribution from Anderson Road and Anderson Road Quarry is considered relatively minor.

There was no evidence to suggest that the design and construction of Slope B6 contributed to the failure.

## 10 References

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Tang, C. S. C. & Cheung, S. P. Y. (2011). *Frequency Analysis of Extreme Rainfall Values (GEO Report 261).* Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong, 209 p.

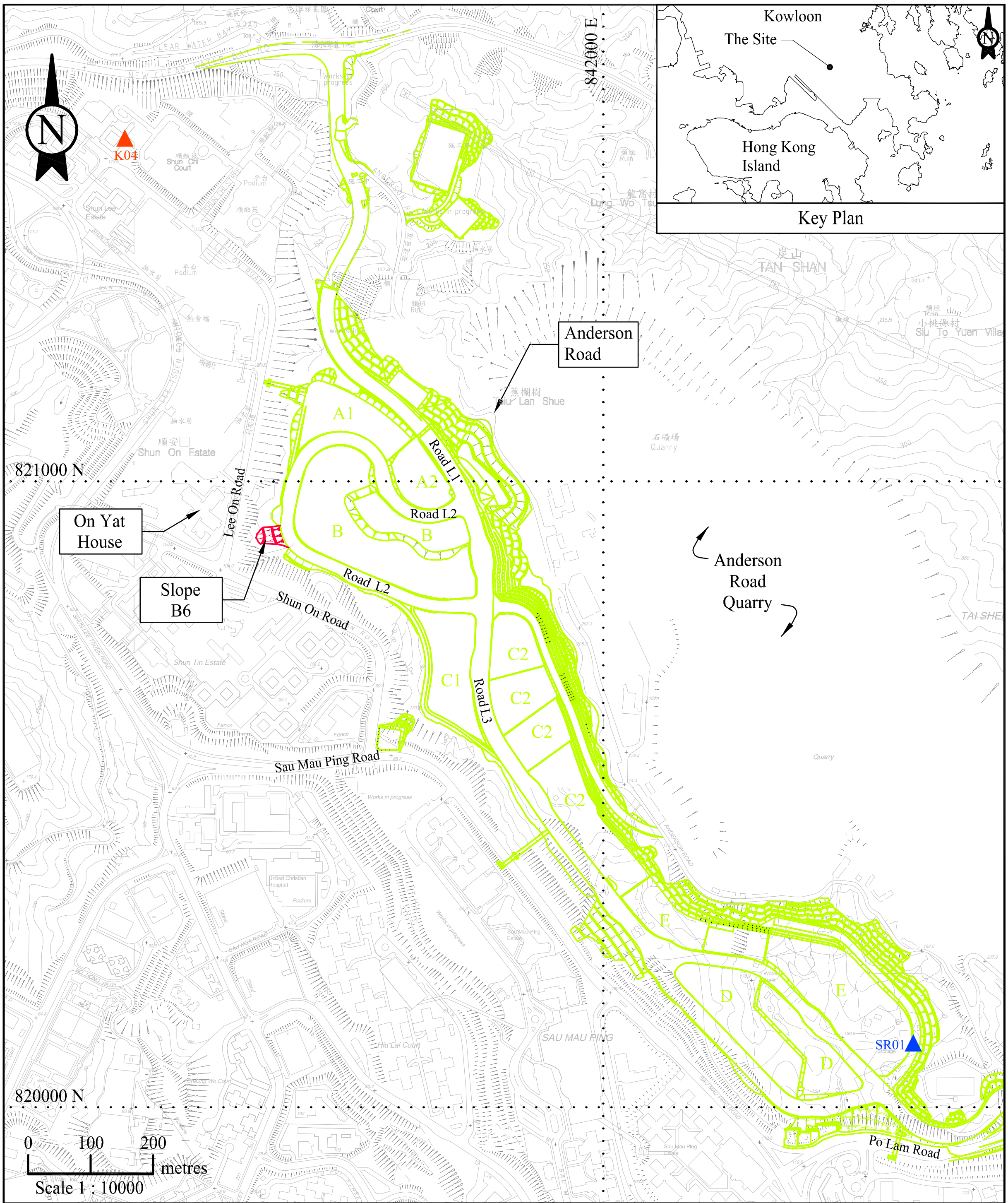
# List of Tables

**Table 4.1 Maximum Rolling Rainfall at GEO Raingauge No. K04 for Selected Durations Preceding the 22 May 2013 Landslide and Estimated Return Periods**

| Duration | Maximum Rolling Rainfall (mm) | End of Period | Estimated Return Period (Years) |
|---|---|---|---|
| 5 minutes | 17.5 | 4:30 a.m. on 22 May 2013 | 19 |
| 15 minutes | 45.0 | 4:30 a.m. on 22 May 2013 | 43 |
| 30 minutes | 73.0 | 4:30 a.m. on 22 May 2013 | 33 |
| 1 hour | 135.0 | 4:30 a.m. on 22 May 2013 | 228 |
| 2 hours | 139.5 | 4:30 a.m. on 22 May 2013 | 13 |
| 4 hours | 148.5 | 4:30 a.m. on 22 May 2013 | 4 |
| 12 hours | 149.0 | 4:30 a.m. on 22 May 2013 | <2 |
| 24 hours | 169.0 | 4:30 a.m. on 22 May 2013 | <2 |

Notes:
(1) Maximum rolling rainfall was calculated from 5-minute rainfall data.
(2) The DAR site raingauge recorded an hourly rainfall of 95.5 mm between 3:30 a.m. and 4:30 a.m. on 22 May 2013.
(3) Rainfall with durations more than 24 hours have a return period of less than 2 years.

# List of Figures




Legend :

| | | | |
|---|---|---|---|
| K04 | GEO Raingauge No. K04 | B | Platform B within DAR site |
| SR01 | DAR Raingauge No. SR01 | | |

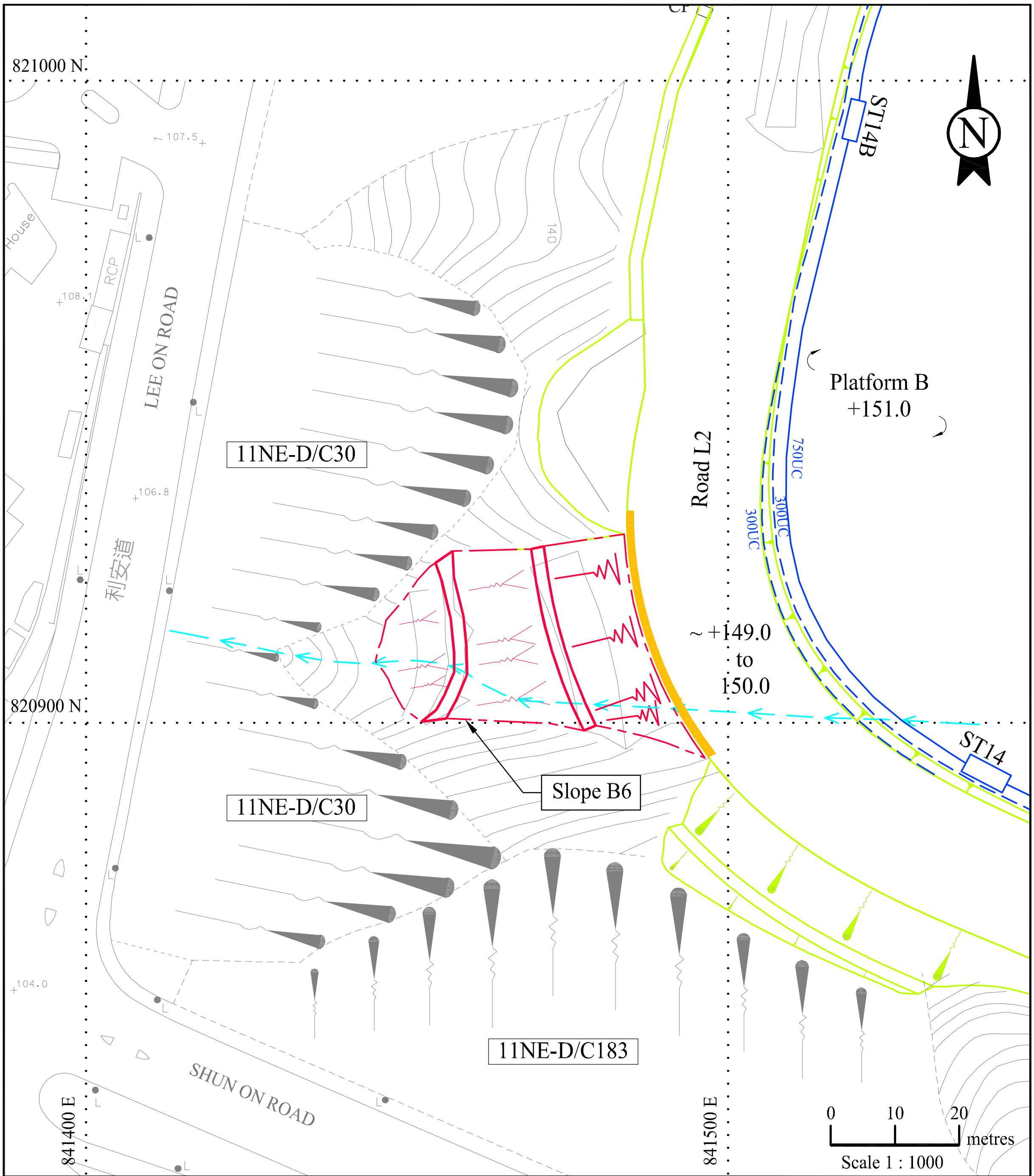
Notes :

(1) Base map is extracted from Survey Sheet Nos. 11NE-13B, 13D and 11NE-18B.

(2) Proposed development layout (in green) is extracted from CEDD plan provided by OAP.

(3) Proposed development works were partially completed at the time of the 22 May 2013 landslide.

**Figure 1.1 Key Plan for the Development at Anderson Road Project**




Legend :

| | | | | | |
|---|---|---|---|---|---|
| (red dash-dot line) | Slope B6 boundary | (cyan dashed arrow) | Previous ephemeral drainage line | 750UC | 750 mm U-channel |
| 11NE-D/C30 | Slope No. 11NE-D/C30 | (symbol) | Rockfill | 300UC | 300 mm U-channel (under construction) |
| (orange bar) | Earth bund (Top level at ~ +150.9 mPD) | (symbol) | Soil fill | ST14 | Sand trap No. ST14 |

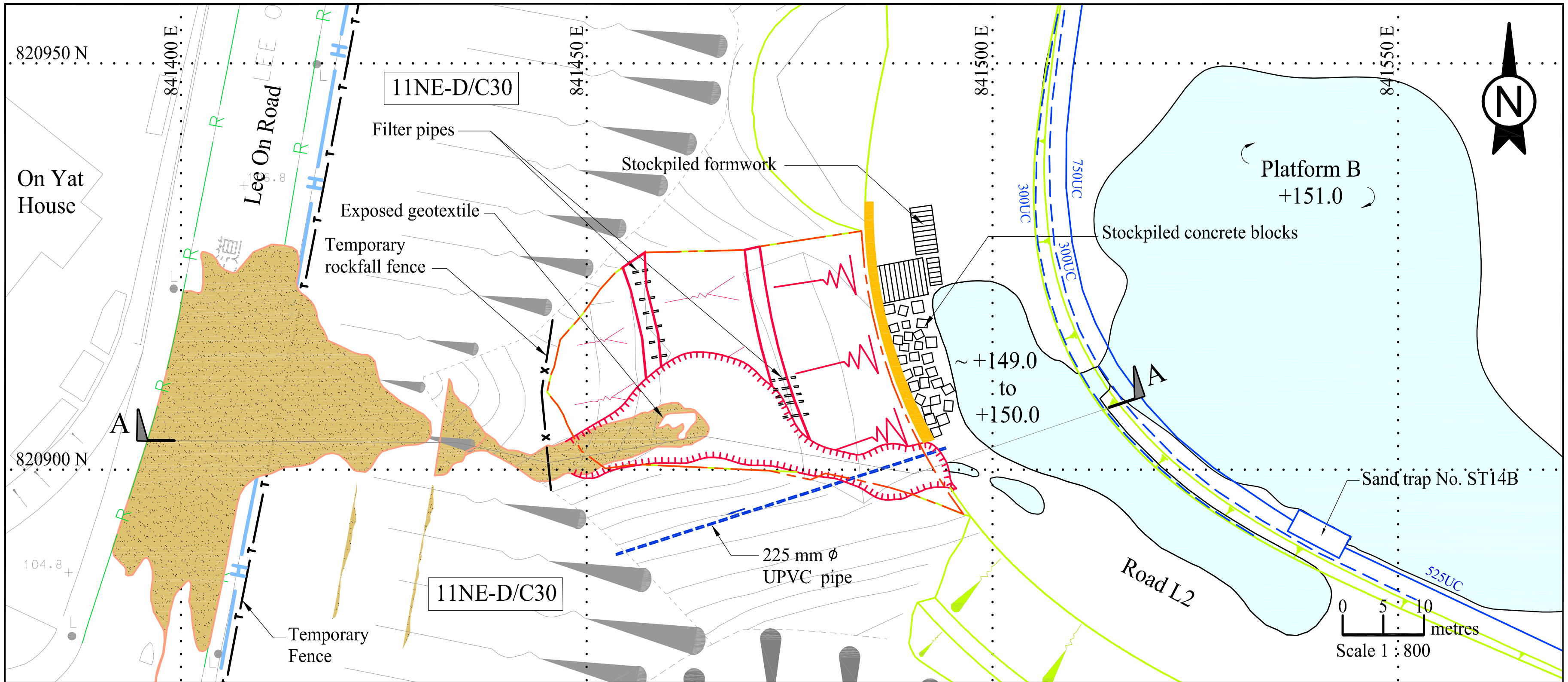
Notes :

(1) Base map is extracted from Survey Sheet No. 11NE-13D.

(2) Proposed development layout (in green) is extracted from CEDD plan provided by OAP.

(3) Proposed development works for Road L2 were in progress at the time of the 22 May 2013 landslide.

**Figure 2.1 Layout Plan of Slope B6**



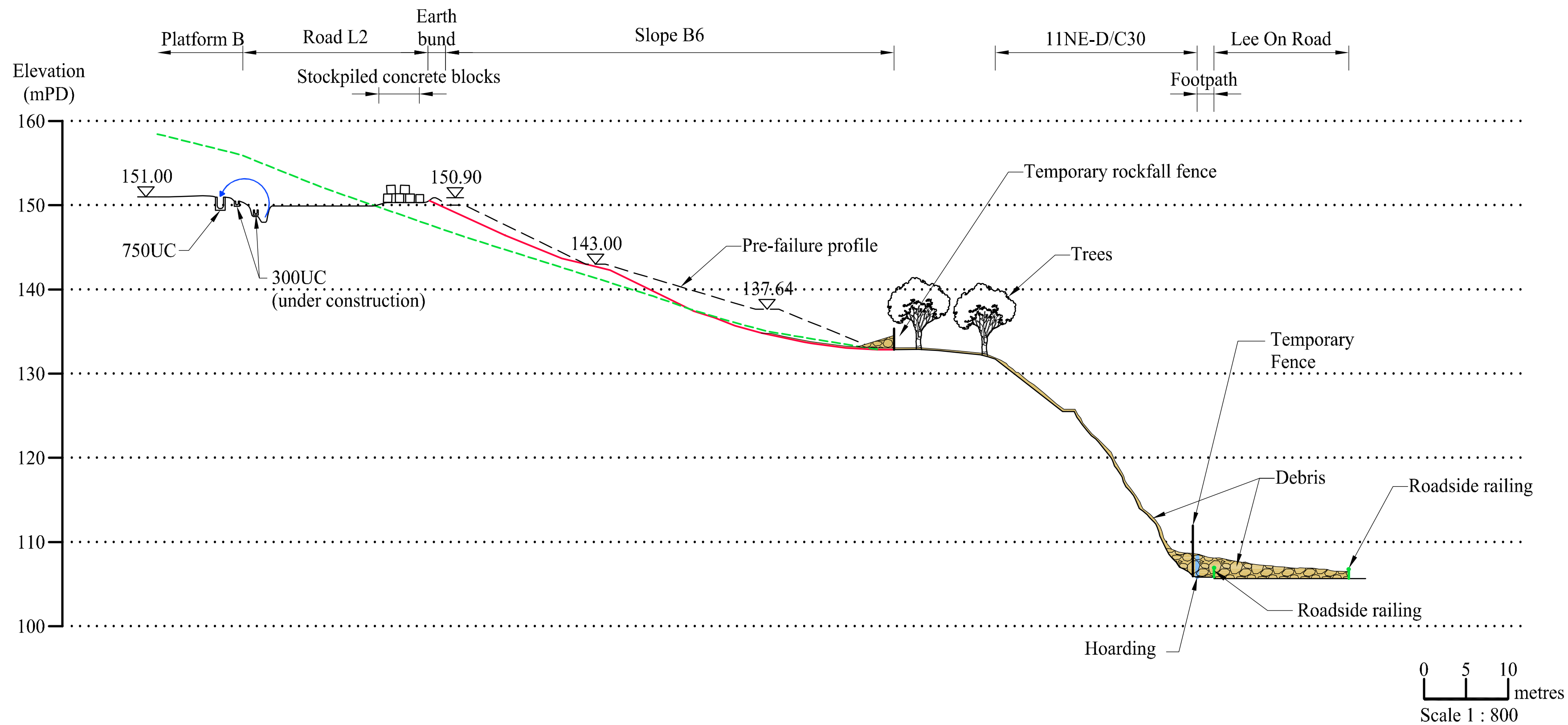

Legend :

| | | | | | |
|---|---|---|---|---|---|
| Slope B6 boundary | Water ponding observed at around 9:00 am. on 22 May 2013 | Hoarding | Rockfill | 750UC | 750 mm U-channel |
| 11NE-D/C30 Slope No. 11NE-D/C30 | Landslide debris | Roadside railing | Soil fill | 300UC | 300 mm U-channel (under construction) |
| A A Cross-section | Landslide scar | Earth bund (top surface at about 150.9 mPD) | | | |

Notes :

(1) Base map is extracted from Survey Sheet No. 11NE-13D.
(2) Proposed development layout (in green) is extracted from CEDD plan provided by OAP.
(3) Road L2 was under construction at the time of the the 22 May 2013 landslide.
(4) For cross-section, see Figure 3.2.

**Figure 3.1 Plan of the 22 May 2013 Landslide at Slope B6**




Legend :

- Ground profile after the 22 May 2013 landslide (red solid line)
- Approximate pre-failure profile (black dashed line)
- Pre-development ground profile (green dashed line)
- Standby pump arrangement (not operating at the time of landslide) (blue arrow)

Notes :

(1) Ground profile after the 22 May 2013 landslide is based on post-failure survey (CSCE, 2013), CEDD Survey Division's 29 May 2013 digital terrain model and post-failure photographs.
(2) Pre-failure profile is based on Contractor's design profile and January 2013 survey data provided by OAP.
(3) For location of cross-section, see Figure 3.1.

**Figure 3.2 Cross-section A-A of the Landslide at Slope B6**

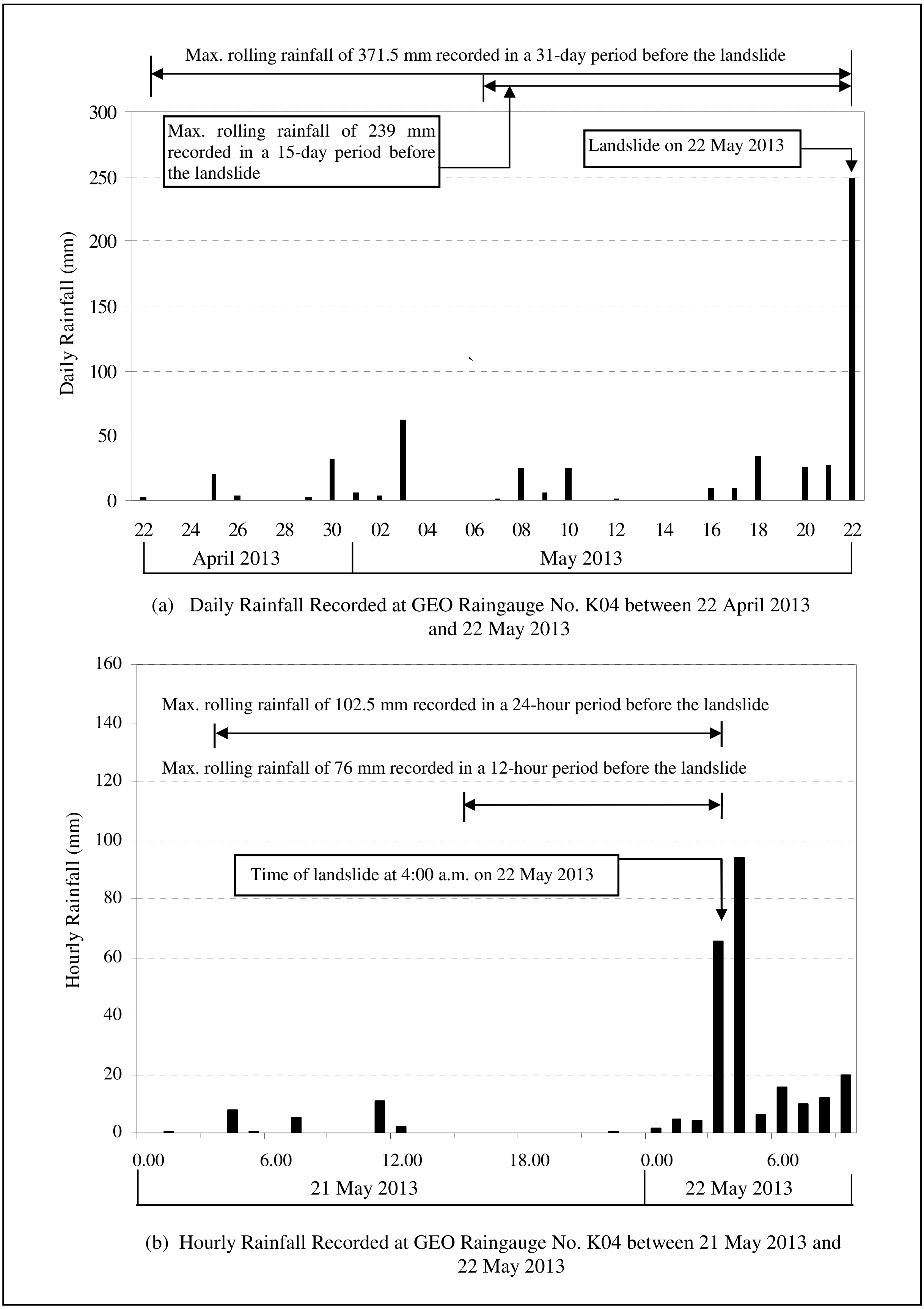
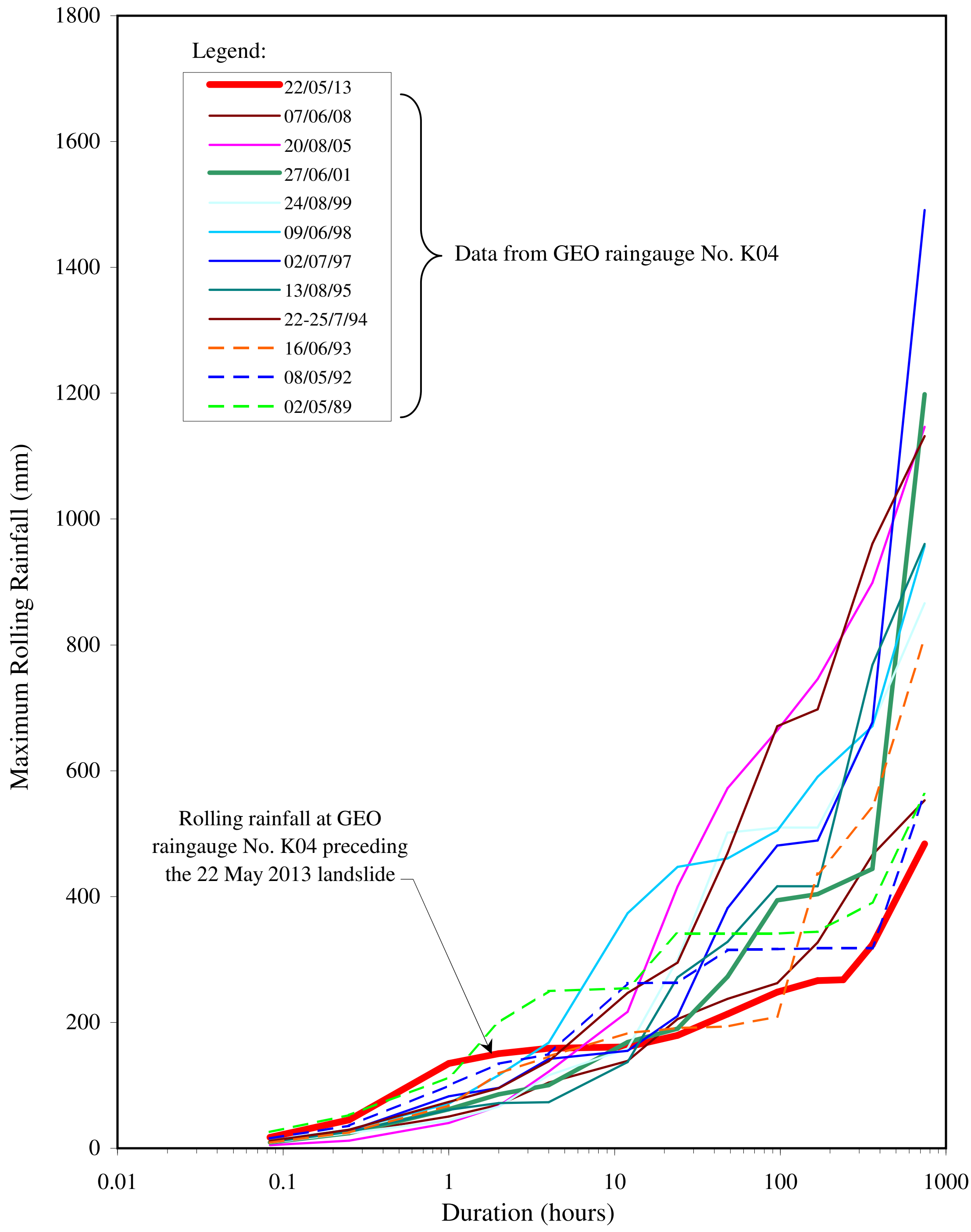
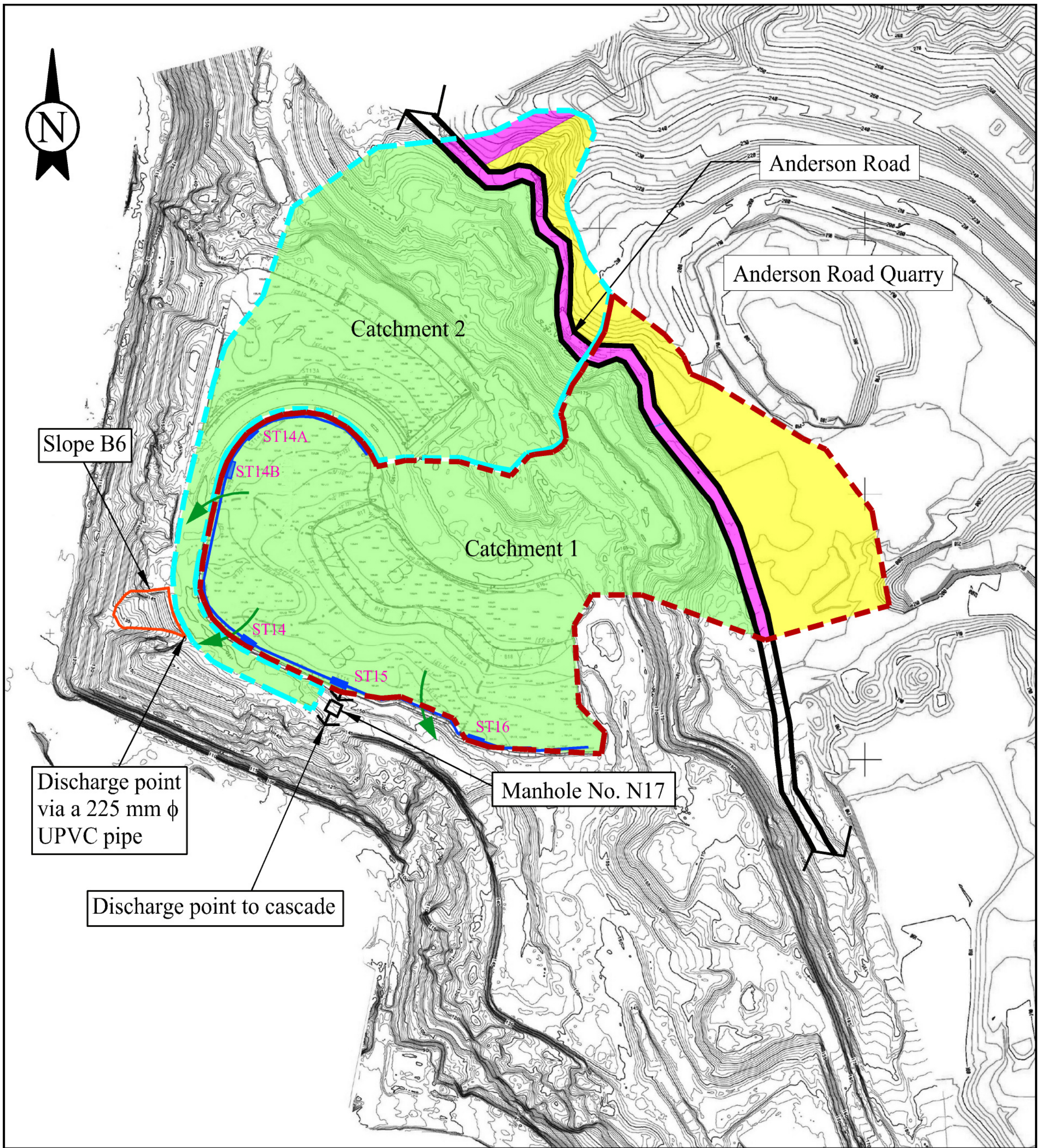



**Figure 4.1 Daily and Hourly Rainfall Recorded at GEO Raingauge No. K04 in May 2013**




Note: Rainfall data was evaluated from 5-minute readings from GEO raingauge No. K04 (about 650 m to the north of Slope B6).

**Figure 4.2 Maximum Rolling Rainfall for Previous Major Rainstorms at GEO Raingauge No. K04**

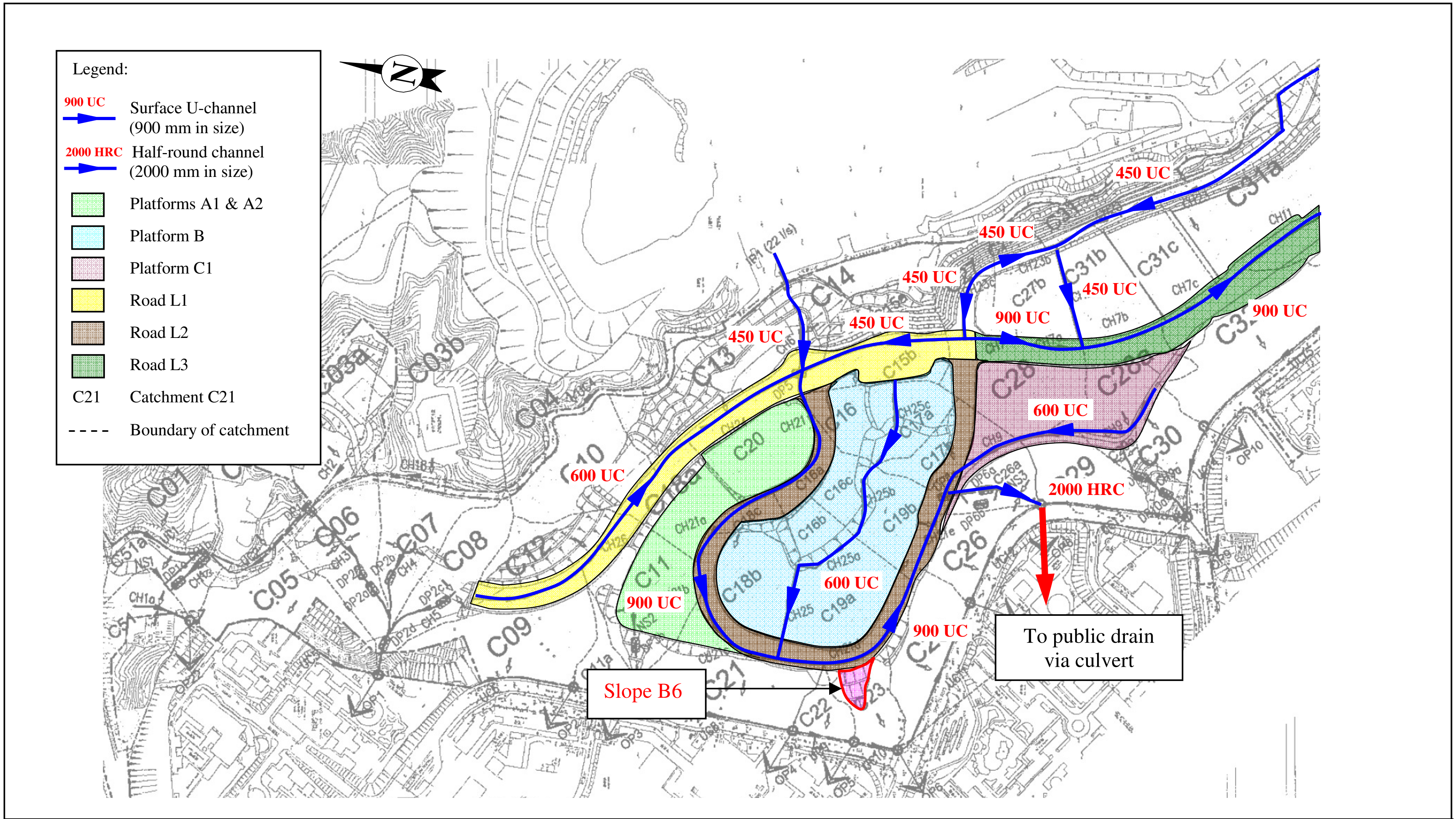



Legend :

- Catchment 1 (Area = 93,100 $m^2$)
- Catchment 2 (Area = 64,400 $m^2$)
- Catchment contribution from Platforms A1, A2 and B and adjoining ground (Area = 126,600 $m^2$)
- Catchment contribution from Anderson Road and adjacent sloping terrain (Area = 7,200 $m^2$)
- Platform channels
- ST14 Sand trap ST14
- Possible overflow
- Catchment contribution from the Anderson Road Quarry (Area = 23,700 $m^2$)

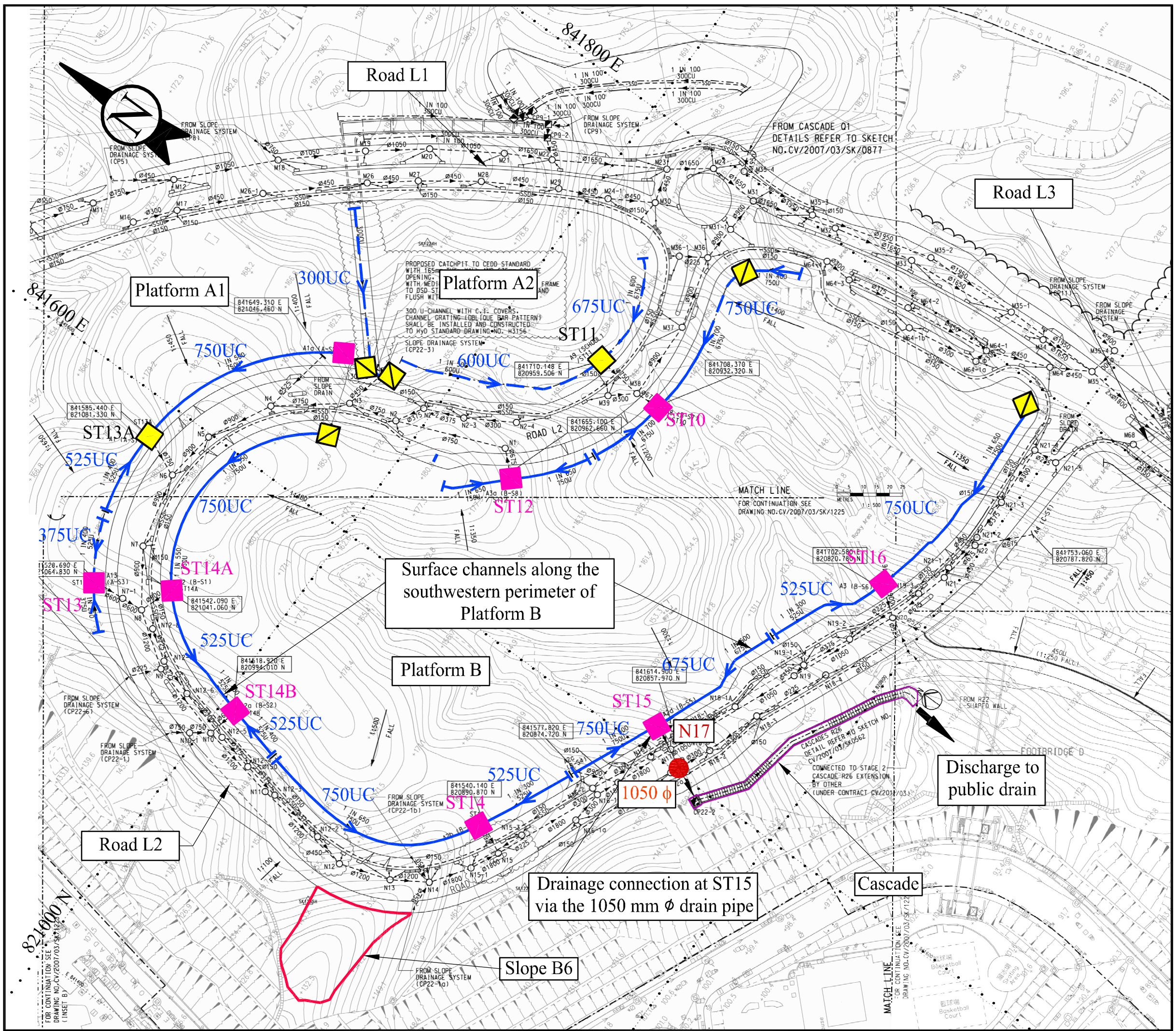
Note : Topographic base plan is compiled from Drawing No. UA130022-SK03 prepared by Survey Division of CEDD in May 2013, Drawing No. KWP/MS195/01 prepared by the Contractor of the Anderson Road Quarry in April 2013 and topographic surveys by OAP on Platform A1 and Platform B on 16 May 2013.

**Figure 5.1 Catchment Boundary near Slope B6**




Note: The base plan is extracted from Sketch No. SK-TDS-01 (rev. F) of the Temporary Drainage Design Submission (Report ref. R385/02 rev. F) dated 26 April 2013.

**Figure 5.2 Schematic Layout Plan of Temporary Site Drainage Design**

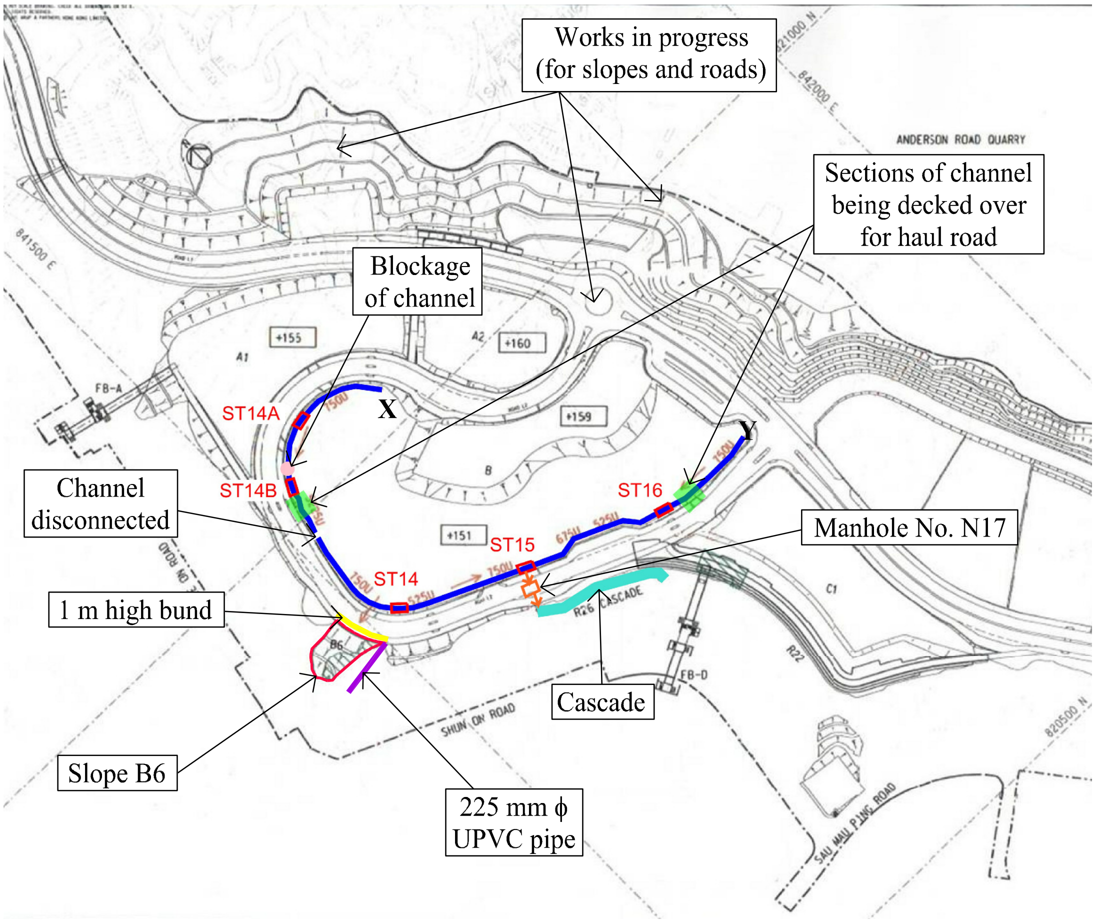



Legend :

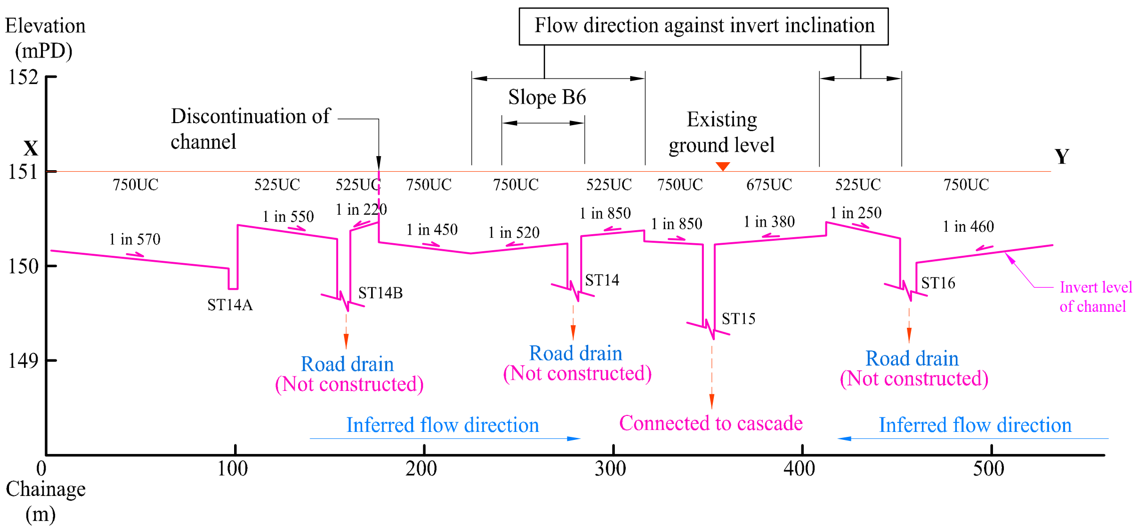
| | |
|---|---|
| 750 UC | As-constructed 750 mm U-channel on platform |
| ST15 | As-constructed sand trap No. ST15 |
| N17 | As-constructed manhole No. N17 |
| 1050 ϕ | As-constructed 1050 mm dia. underground drain pipe |
| 600 UC | Proposed 600 mm U-channel on platform (not yet constructed at the time of the 22 May 2013 landslide) |
| | Change in U-channel size and flow direction |
| | Proposed catchpit (not yet constructed) |
| ST11 | Proposed sand trap No. ST11 (not yet constructed) |
| | Proposed road drains (not yet constructed) |

Note : Base map is extracted from the DAR Drainage Layout Plans Sketch Nos. CV/2007/03/SK/1224 (Rev. H), CV/2007/03/SK/1225 (Rev. H) and CV/2007/03/SK/1226 (Rev. I).

**Figure 5.3 Layout Plan of Proposed Permanent Drainage Works**



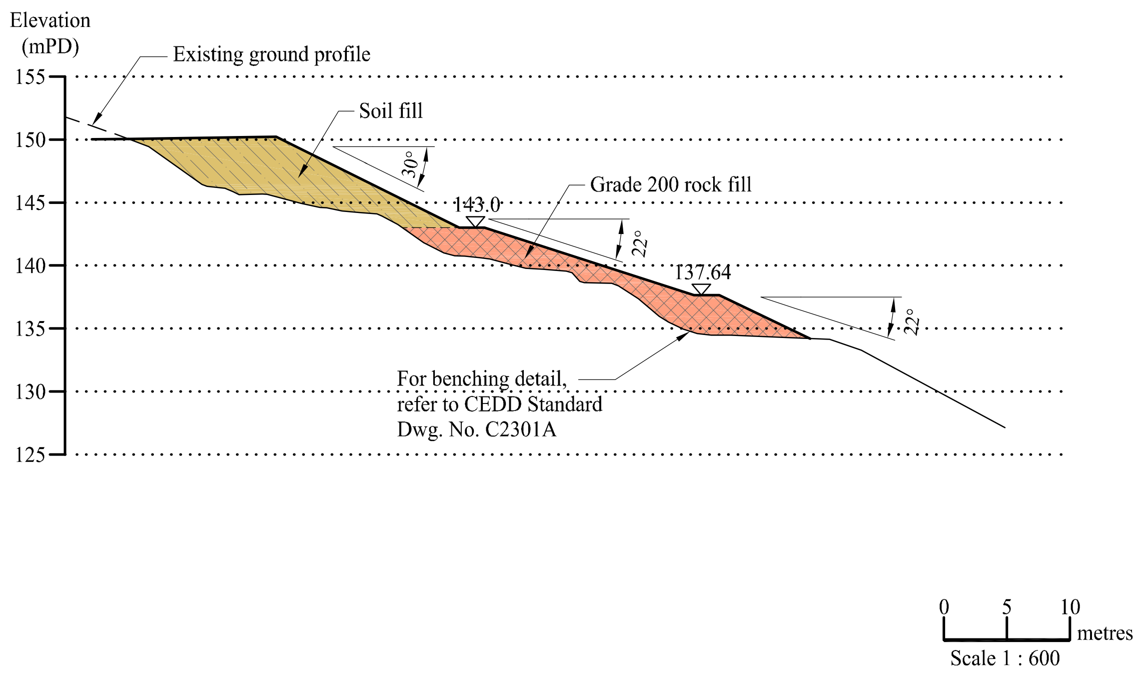

(a) Schematic Layout of the As-constructed Surface Drainage Works as Part of the Permanent Drainage Works




(b) Longitudinal Profile X-Y Along Platform Drain

Note : For Figure (b), vertical scale is exaggerated.

**Figure 5.4 Schematic Layout of As-constructed Surface Drainage System at Platform B**




Note : Details extracted from Sketch Nos. SK-849A (CSCE, 2012).

**Figure 6.1 Typical Cross-section of Slope B6**

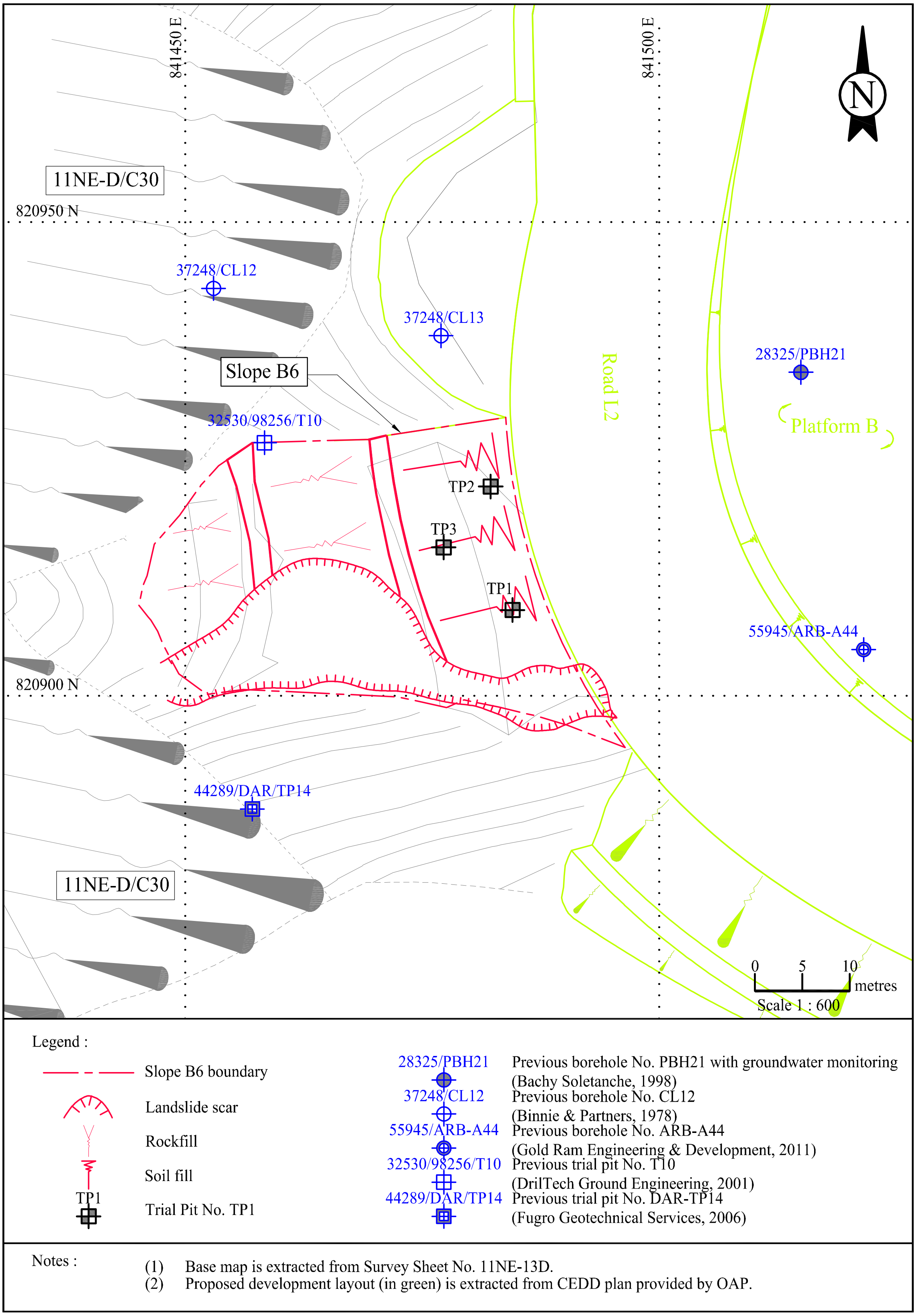
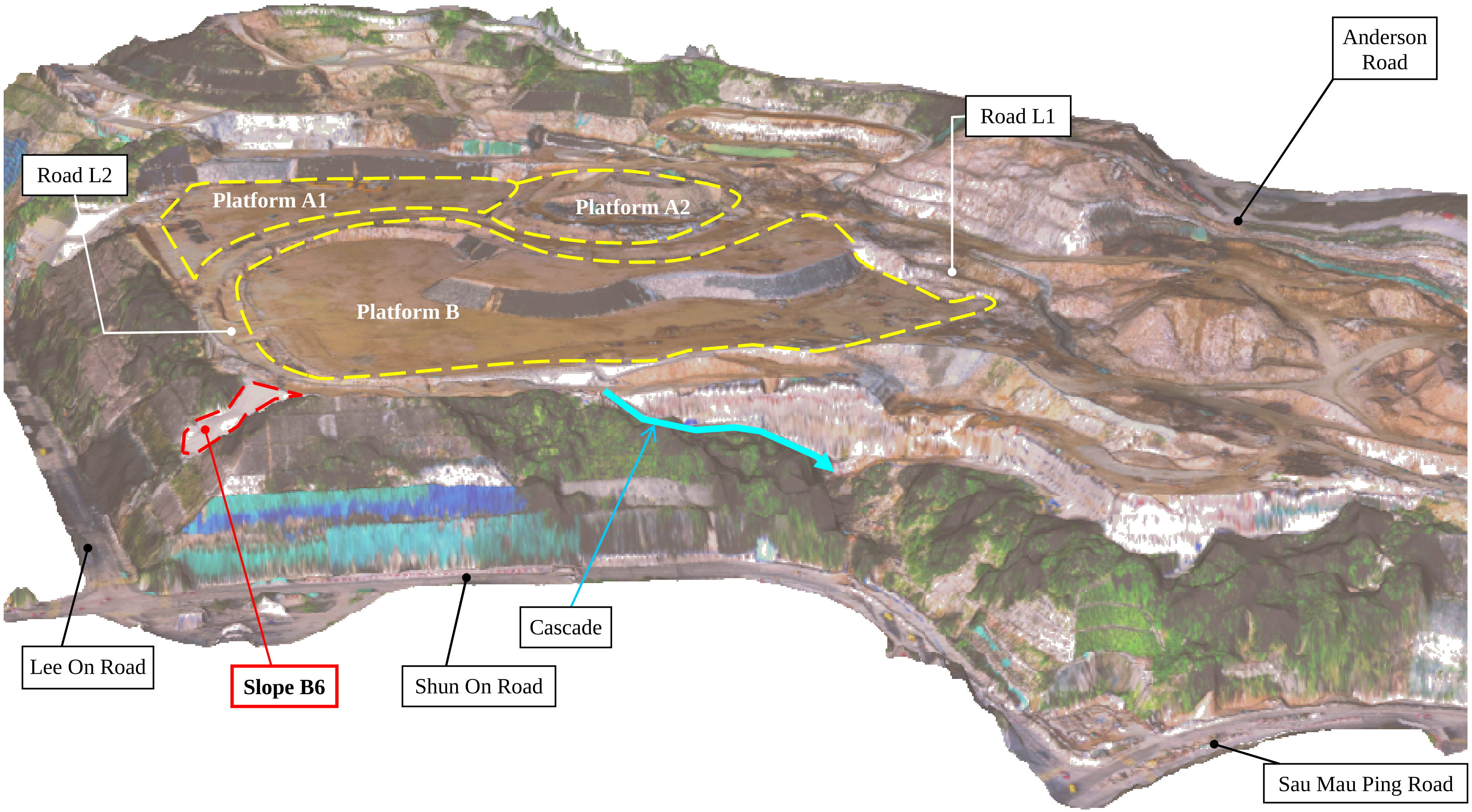



**Figure 7.1 Ground Investigation Plan at Slope B6**

## List of Plates




Note: The digital terrain model was prepared by Survey Division, CEDD using aerial photographs taken between 23 May 2013 and 29 May 2013.

**Plate 1 Digital Terrain Model of the Northwestern Part of the DAR Site**

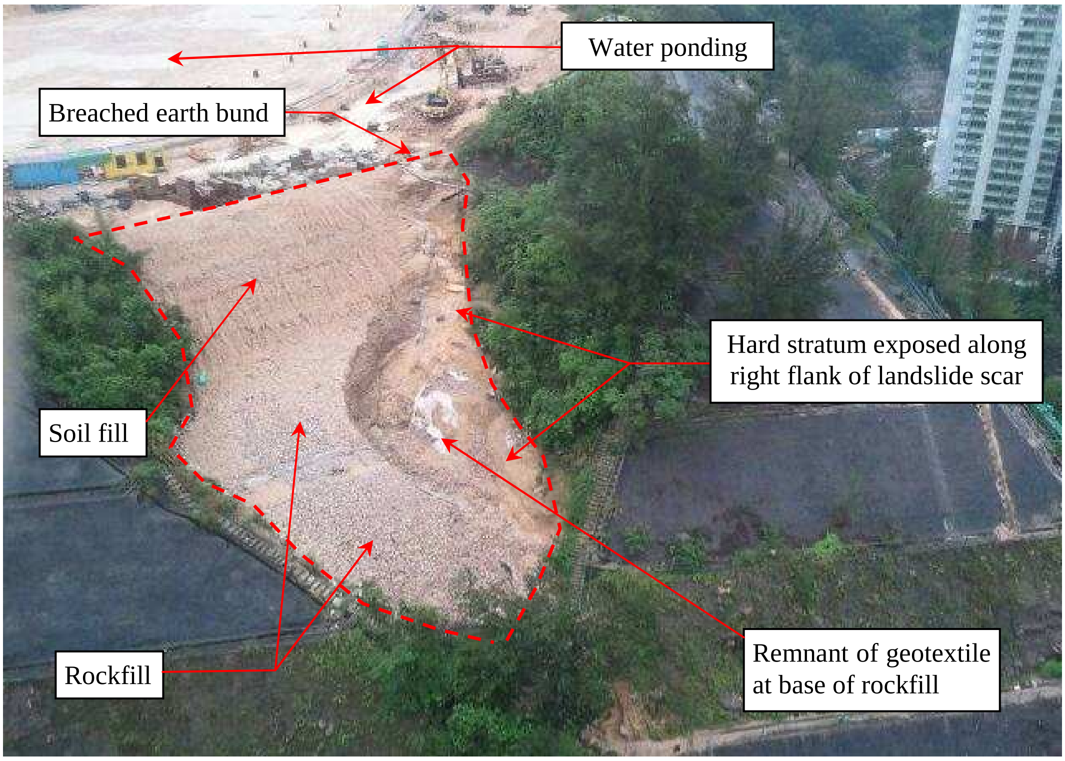



**Plate 2 Oblique Aerial View of the 22 May 2013 Landslide at Slope B6 (Photograph taken on 22 May 2013)**


(a) Condition of Slope B6 (Photograph taken on 5 April 2013)


(b) Condition of Slope B6 (Photograph taken on 30 April 2013)

**Plate 3 Conditions of Slope B6 prior to the 22 May 2013 Landslide**


**Plate 4 Condition of the Crest Area of Slope B6 prior to the 22 May 2013 Landslide (Photograph taken on 9 May 2013)**

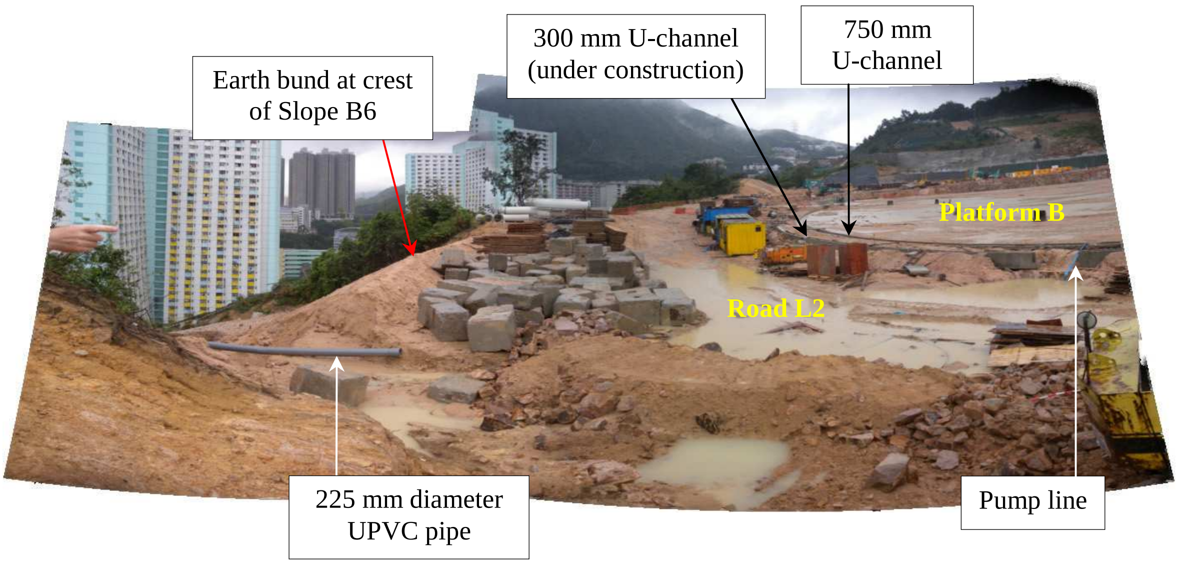
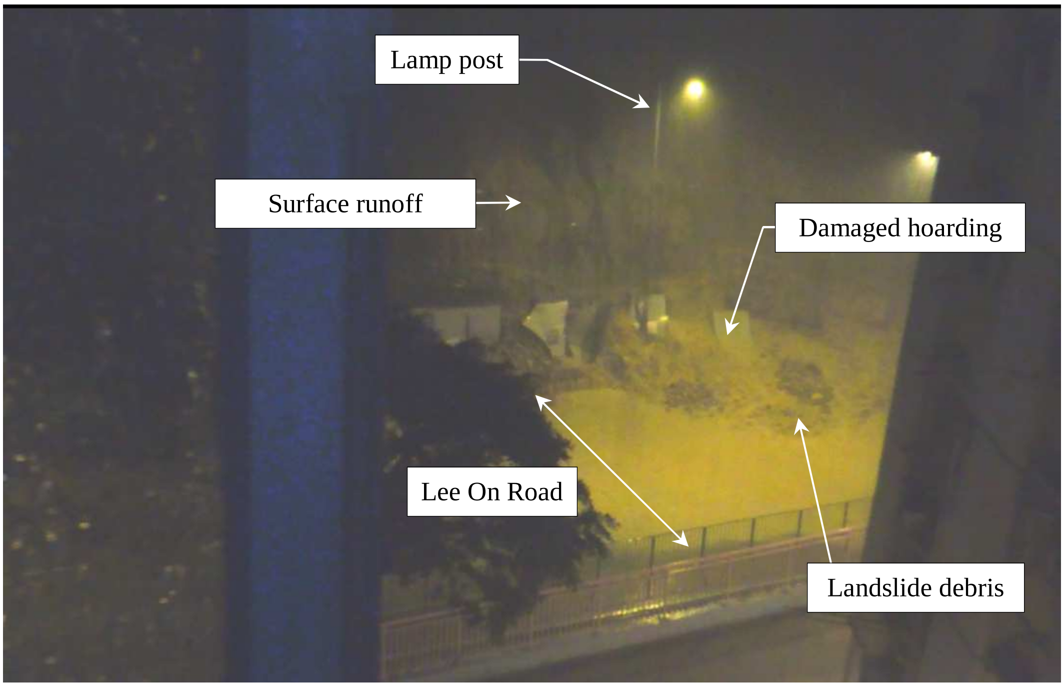
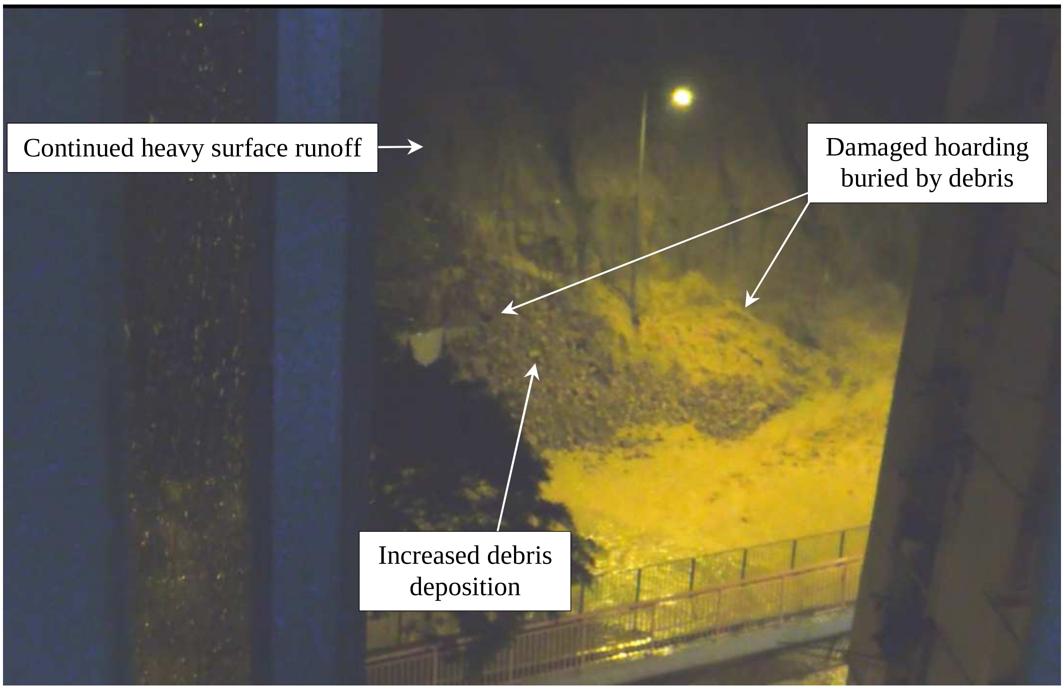



**Plate 5 Topographical Low Point at the Crest of Slope B6 (Photographs taken on 23 May 2013)**




(a) Initial Stage of Failure (Exact Time Unknown)




(b) Increased Debris Deposition 18 minutes after (a) (Exact Time Unknown)

**Plate 6 Surface Runoff and Progressive Landslide Debris Deposition on Lee On Road (Captured from Witness Video Recording on 22 May 2013)**

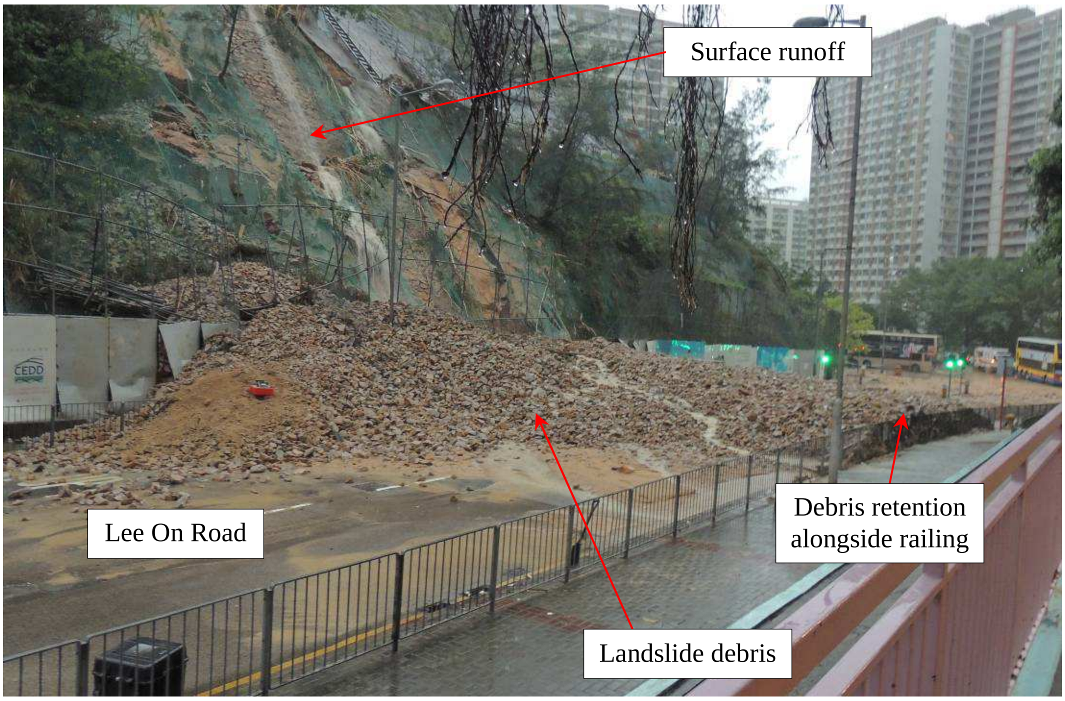



**Plate 7 Debris on Lee On Road (Photograph taken on 22 May 2013)**

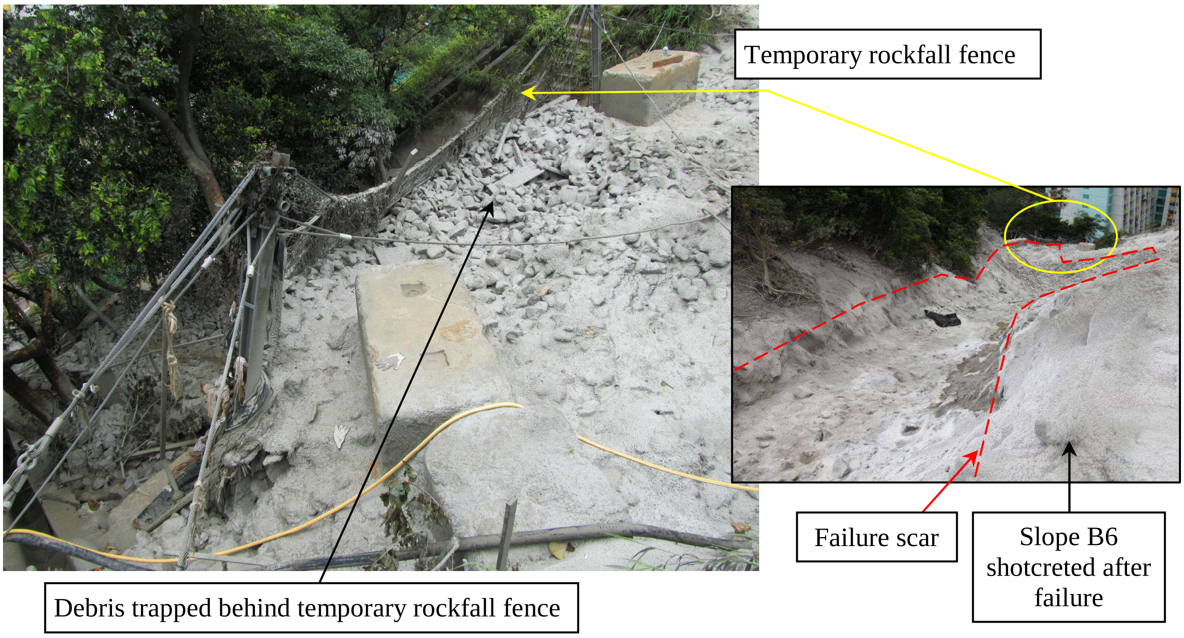



**Plate 8 Debris Trapped by the Temporary Rockfall Fence (Photographs taken on 22 May 2013)**


**Plate 9 Landslide Scar at Slope B6 (Photograph taken on 22 May 2013)**

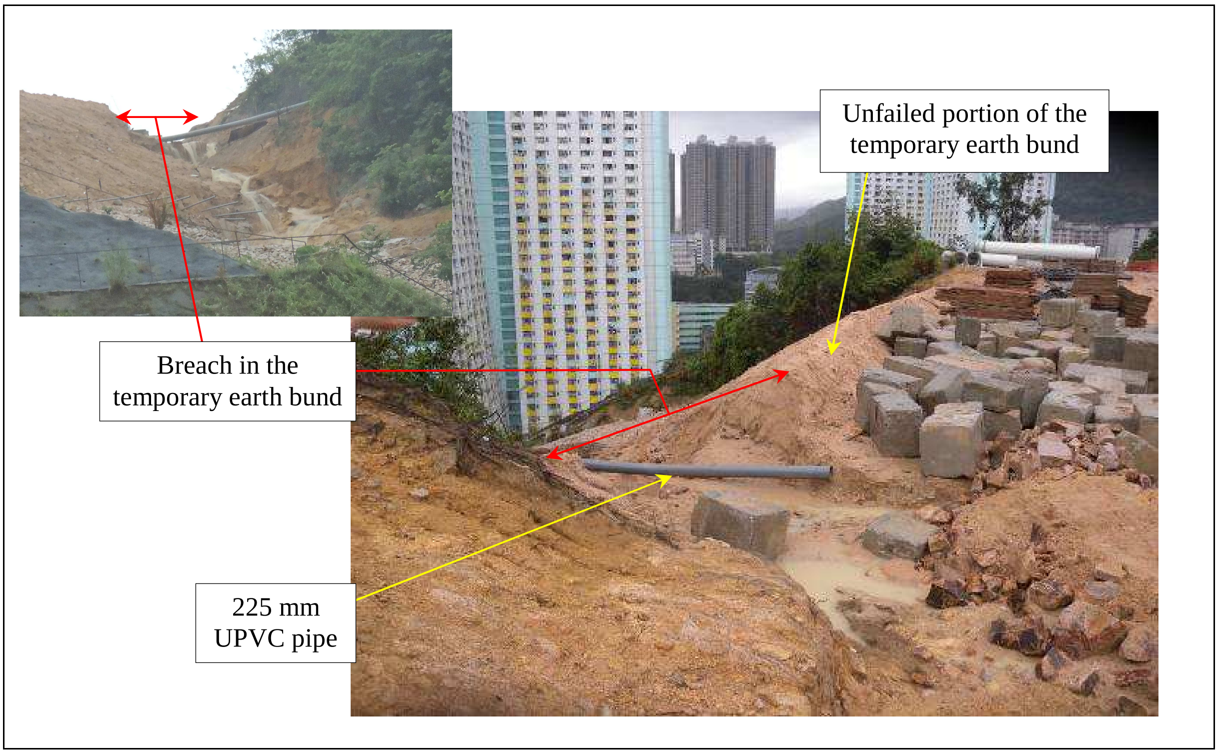



**Plate 10 Breach in the Temporary Earth Bund at the Crest of Slope B6 (Photographs taken on 22 May 2013)**

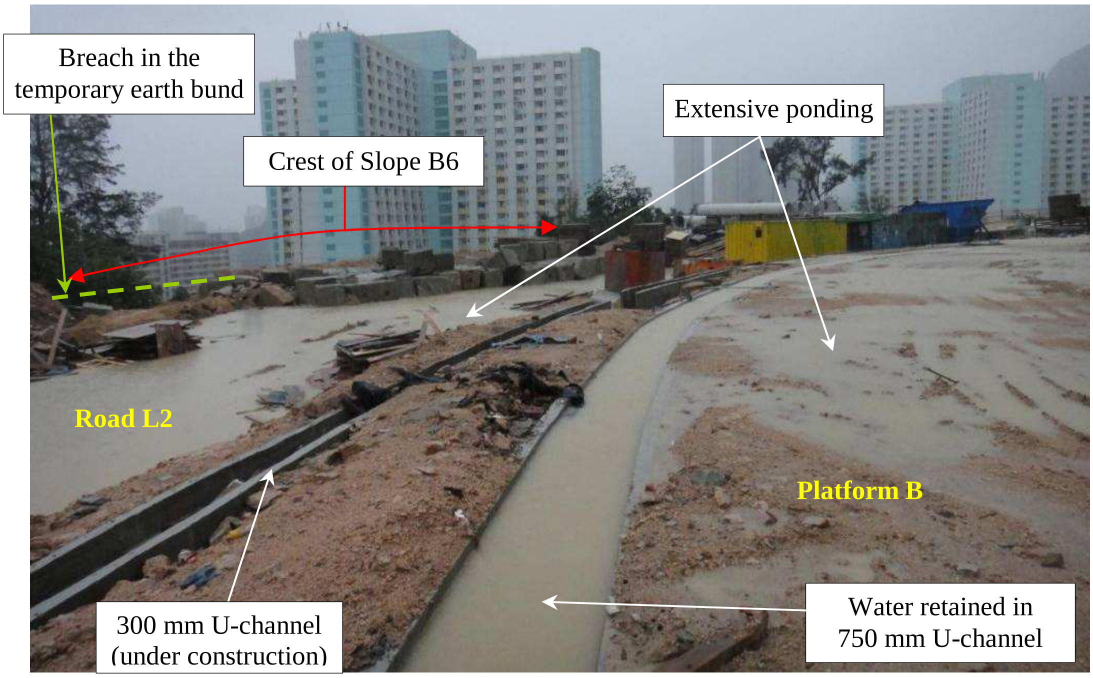



**Plate 11 Crest Area of Slope B6 after the 22 May 2013 Landslide (Photograph taken at about 9:00 am on 22 May 2013)**

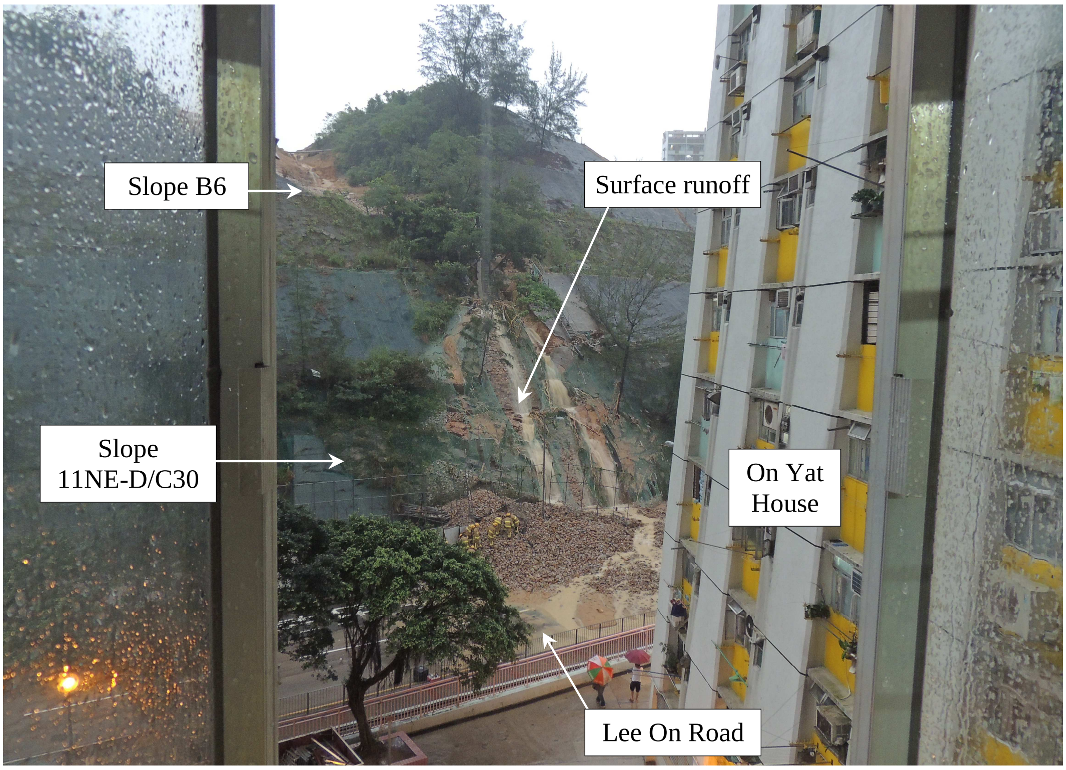



**Plate 12 Continued Runoff over Slope B6 (Photograph taken by Witness around 6:20 a.m. on 22 May 2013)**

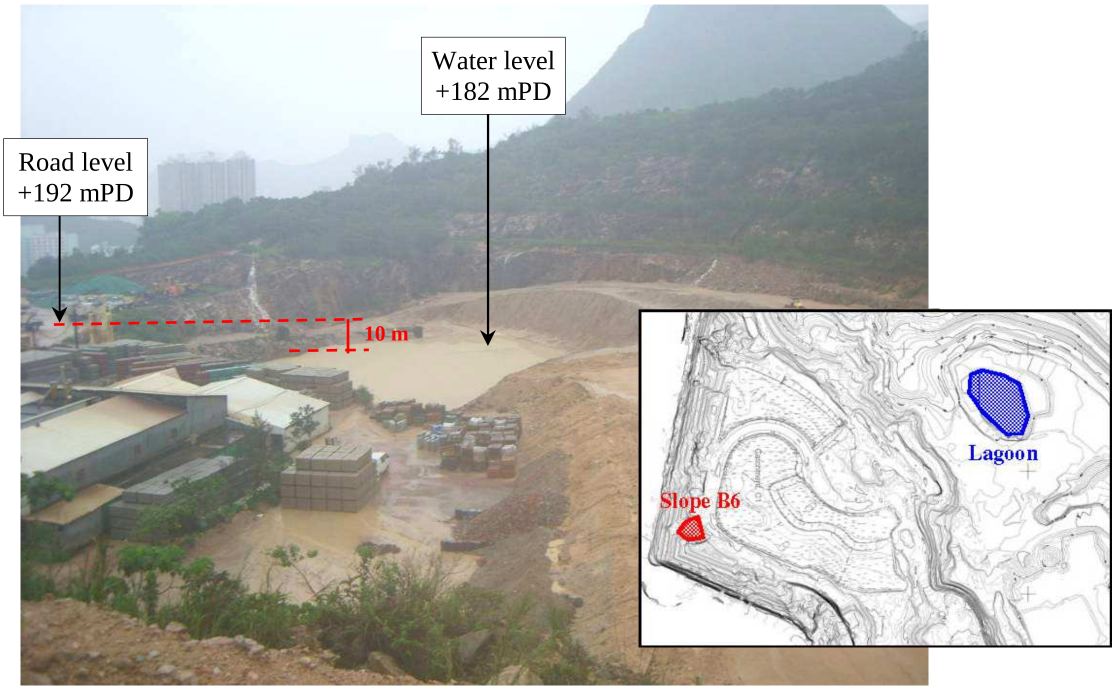



**Plate 13 Condition of the Lagoon within the Anderson Road Quarry above the Northwestern Part of the DAR Site (Photograph taken in the morning of 22 May 2013)**

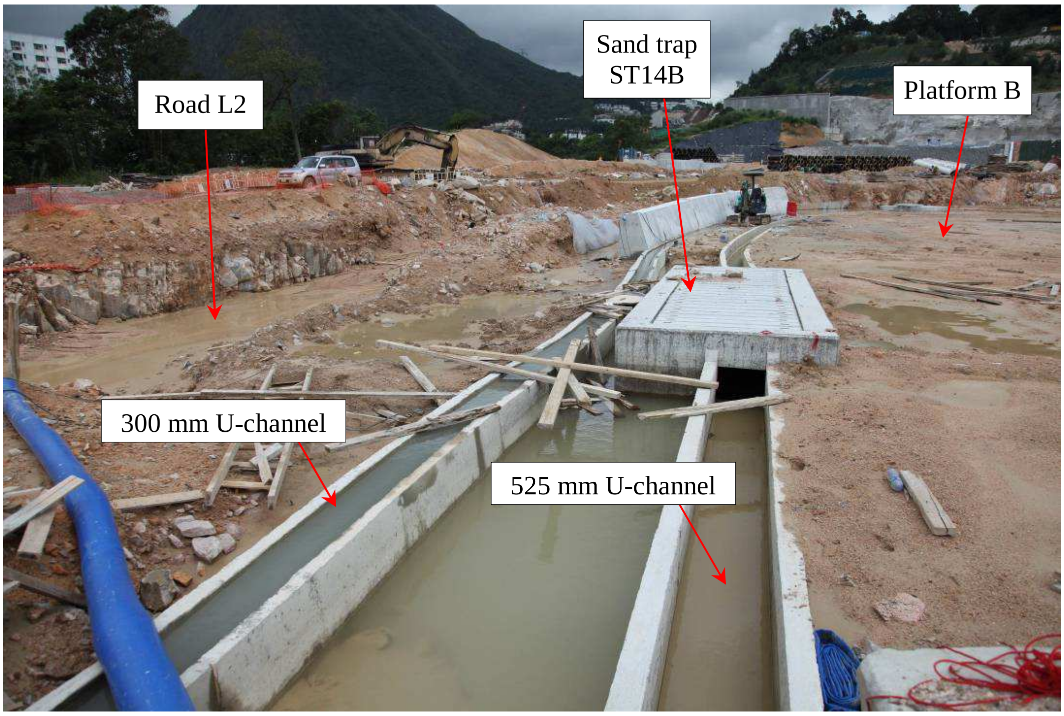



**Plate 14 Signs of Blockage (with standing water) at 525 mm U-channel on the Downstream Side of Sand Trap ST14B (Photograph taken on 23 May 2013)**

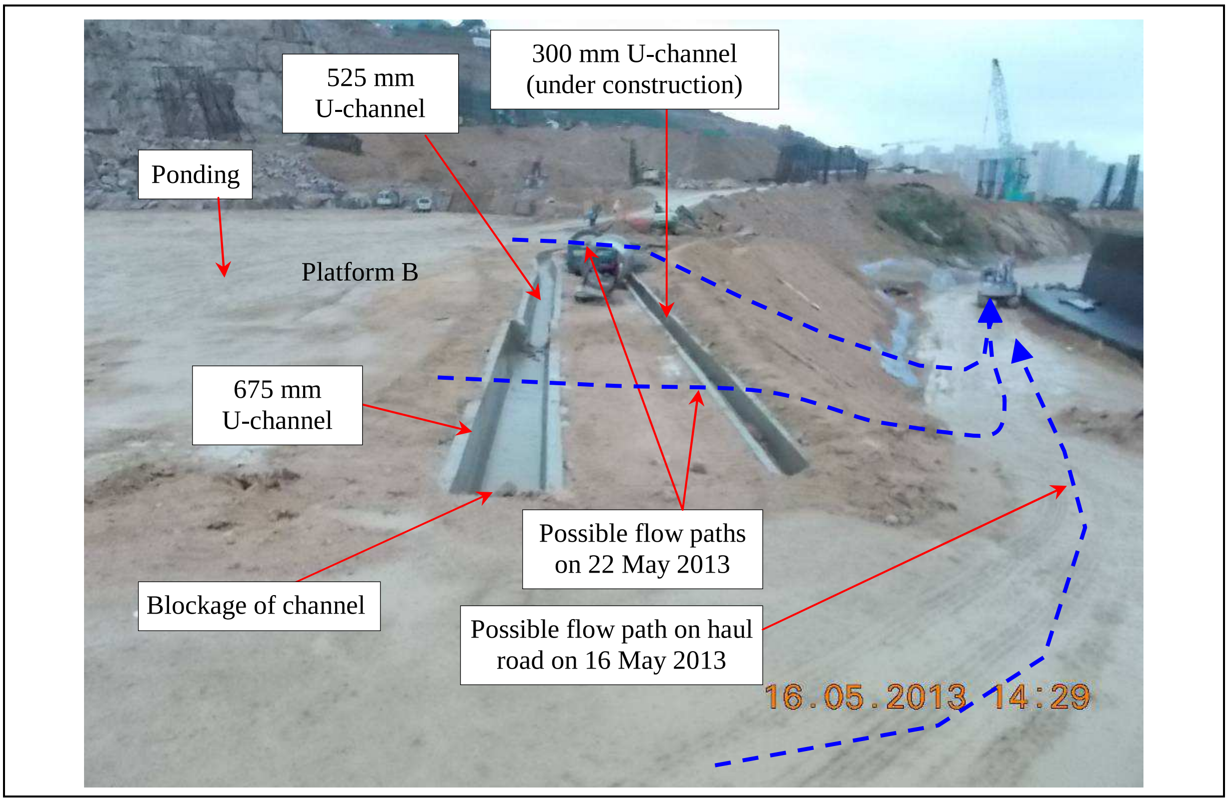



**Plate 15 Temporary Haul Road over the 675 mm U-channel between Sand Traps ST15 and ST16 (Photograph taken on 16 May 2013)**

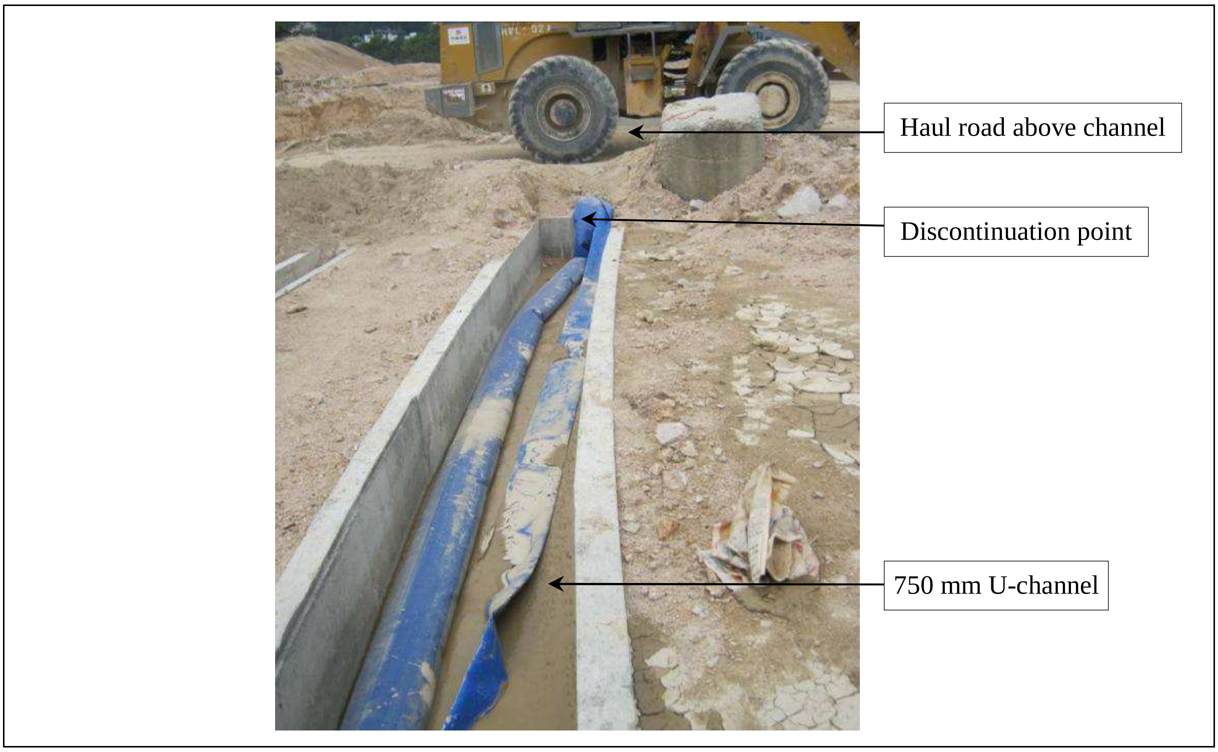



**Plate 16 Discontinuation of Channel adjacent to Haul Road near Sand Trap ST14 (Photograph taken on 24 May 2013)**


**Plate 17 Significant Overland Flow from Platform B between Sand Traps ST15 and ST16 (Photograph taken around 9:00 a.m. on 22 May 2013)**

**Plate 18 Discharge of 225 mm Diameter UPVC Pipe to Surface Drainage System of Slope 11NE-D/C30 (Photograph taken on 25 May 2013)**


**Plate 19 Standby Pump Provided at the Crest Area of Slope B6 (Photograph taken on 22 May 2013)**


**Plate 20 General View of Slope B6 before Backfilling (Photographs taken on 25 February 2011)**

# Appendix A

# Drainage Assessment

# Contents

## A.1 Catchment Characteristics

The catchment that could contribute surface runoff to the crest of Slope B6 is shown in Figure A1. Runoff in Catchment 1 was intended to be discharged at the cascade via a system of U-channels around the western and southern periphery of Platform B. Runoff in Catchment 2 directly flowed towards and accumulated at the low-point at the crest of Slope B6. However, any overflow from the U-channels of Catchment 1 would flow towards and accumulate at two low points: one at the crest of Slope B6 and the other at the backyard of a reinforced fill wall under construction to the south of Platform B (Figure A1).

The majority of the ground surface in Catchments 1 and 2 was bare soil (either compacted soil fill or saprolite). The runoff coefficient of the catchment is dependent on the permeability, gradient and retention capability characteristics of the ground surface (DSD, 2013), the rainfall intensity and the antecedent rainfall. Given the high intensity of the rainfall in the early morning of 22 May 2013 (see Section 4 of the main text) and the shallow bedrock in the area, the runoff coefficient could be relatively high. Runoff coefficients ranging from 0.4 to 0.9 have been adopted in the assessment of surface runoff.

## A.2 Assessment of Surface Runoff and Flow Capacity of Drains

The surface runoff of the catchment has been calculated as follows:

$$Q = \frac{K\, i\, A}{3600}$$

where Q = surface runoff (ℓ/s),
i = actual rainfall intensity (mm/hr),
A = area of catchment ($m^2$), and
K = runoff coefficient.

The actual rainfall intensity given has been determined from the 5-minute rainfall data collected from GEO raingauge no. K04 located approximately 0.7 km from Slope B6. The surface runoff has been calculated with various runoff coefficients as summarized in Table A1.

Surface runoff from Catchment 1 was discharged offsite via the U-channels on Platform B and the cascade in front of Walls R22 and R26. The flow capacity of the U-channels has been determined from Figure 8.7 of the Geotechnical Manual for Slopes (GEO, 1984) and is summarized in Table A2.

The actual flow in the 750 mm U-channel and 675 mm U-channel is likely to be less than that given in Table A2 because the adjoining U-channels that discharge into these two channels are smaller in size and the invert gradient of some of them dipped away from these two channels.

Comparing the surface runoff in Table A1 and the flow capacity of the surface drains in Table A2, it can be seen that the total flow capacity (1.034 $m^3$/s) is below the surface runoff generated from Catchment 1 (1.40 to 3.14 $m^3$/s) for the range of runoff coefficients considered.

Surface runoff from Catchment 2 was discharged offsite via the 225 mm diameter UPVC pipe installed in the bund at the crest of Slope B6. The flow capacity of the pipe has been estimated from Manning's equation. Assuming an invert gradient of 1 in 18 and a roughness coefficient of 0.01, the flow capacity of the pipe is 0.132 $m^3/s$. The flow capacity is below the surface runoff generated from Catchment 2 (0.97 to 2.17 $m^3/s$) for the range of runoff coefficients considered. Overflow of surface water from Platform B towards the low point at the crest of Slope B6 would further increase the runoff in Catchment 2.

It indicates that the drainage provisions on the northwestern portion of the DAR site were unable to cope with the surface runoff arising from the intense rainfall in the early morning of 22 May 2013.

## A.3 References

Drainage Services Department (2013). *Stormwater Drainage Manual (with Eurocodes incorporated) – Planning, Design and Management (Fourth Edition).* Drainage Services Department, Hong Kong, 172 p.

Geotechnical Engineering Office (1984). *Geotechnical Manual for Slopes (Second Edition).* Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong, 302 p.

# List of Tables

**Table A1 Surface Runoff for Selected Runoff Coefficients**

| Runoff Coefficient | Catchment 1 Surface Runoff ($m^3/s$) | Catchment 2 Surface Runoff ($m^3/s$) | Total Surface Runoff ($m^3/s$) |
|---|---|---|---|
| 0.9 | 3.14 | 2.17 | 5.31 |
| 0.4 | 1.40 | 0.97 | 2.37 |

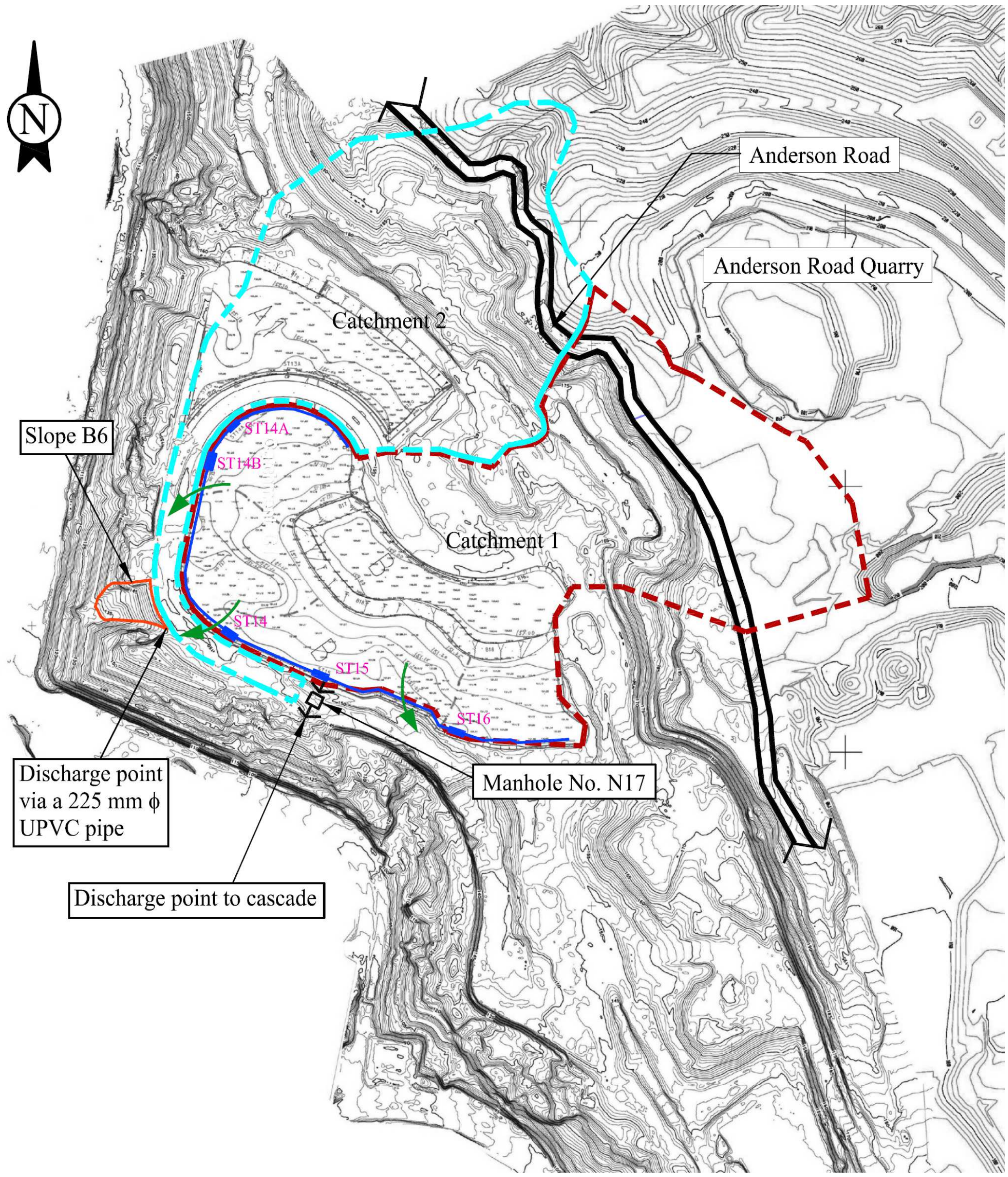
Note: Surface runoff has been calculated using a rainfall intensity of 135 mm/hr (3:30 a.m. to 4:30 a.m.) recorded at GEO raingauge no. K04.

**Table A2 Flow Capacity of Surface Drains in the Northwestern Portion of the DAR Site**

| Surface Drainage Measure | Flow Capacity ($m^3/s$) | Assumptions |
|---|---|---|
| 750 mm U-channel to ST15 | 0.467 | invert gradient 1 in 850 |
| 675 mm U-channel to ST15 | 0.567 | invert gradient 1 in 380 |
| (Total) | 1.034 | - |

Note: Refer to Figure 5.4 of the main text for location of discharge points

# List of Figures




Legend:

Catchment 1 (Area = 93,100 $m^2$)

Catchment 2 (Area = 64,400 $m^2$)

Platform channels

ST14 Sand trap ST14

Possible overflow

Note: Topographic base plan is compiled from Drawing No. UA130022-SK03 prepared by the Survey Division of CEDD in May 2013, Drawing No. KWP/MS195/01 prepared by the Contractor of the Anderson Road Quarry in April 2013 and topographic surveys by OAP on Platform A1 and Platform B on 16 May 2013.

**Figure A1 Catchment Characteristics**