Detailed Study of the 8 and 14 September 2023 Landslides on Slope No. 11SE-D/F47 at Shek O Road, Shek O

GEO Report No. 376

Fugro (Hong Kong) Limited

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.

Raymond W M Cheung
Head, Geotechnical Engineering Office
December 2024

Foreword

This report presents the findings of a detailed study of landslides (Incident No. 2023/09/3265) that occurred at a roadside registered fill slope (slope No. 11SE-D/F47) at Shek O Road, Shek O, following rainstorms on 8 and 14 September 2023. The first landslide occurred on the morning of 8 September 2023, during which both Black Rainstorm Warning and Landslip Warning were in effect. The landslide was a sliding failure with an estimated volume of about 650 m^3. As a result, a section of the northbound lane of Shek O Road collapsed, and most of the landslide debris was deposited below the failure scar. The second landslide happened on the morning of 14 September 2023, when a Red Rainstorm Warning was in effect. The landslide was a washout failure with an estimated volume of about 126 m^3. The previously closed northbound lane collapsed again, including the newly placed rockfill of post-landslide emergency repair works for the first landslide. No casualties were reported, but the blockage of Shek O Road isolated hundreds of residents from Shek O.

The key objectives of the study were to document the facts about the landslides, present relevant background information and establish the probable causes of the landslides. The discussion and views expressed in this report are not intended to establish the existence of any duty of law on the part of the Government of the Hong Kong Special Administrative Region (HKSARG), its employees or agents, contractors, their employees or agents, or subcontractors, or any other party. This report neither determines nor implies liability towards any organisation or individual except so far as necessary to achieve the said objectives.

We gratefully acknowledge assistance from the Civil Aid Service, the Survey Division of the Civil Engineering and Development Department and the Highways Department, as well as the technical support provided by AECOM Asia Company Limited, the 2022 to 2024 Landslide Investigation Consultants.

This report was prepared for the Geotechnical Engineering Office of the Civil Engineering and Development Department under Agreement No. CE 29/2021 (GE). This is one of a series of reports produced during the consultancy by Fugro (Hong Kong) Limited. Unless otherwise agreed in writing, Fugro (Hong Kong) Limited accepts no responsibility for any use of, or reliance on any contents of this Report by any person other than HKSARG or its employees or agents and shall not be liable to any person other than HKSARG or its employees or agents, on any ground, for any loss, damage or expense arising from such use or reliance.

Y C KOO
Project Director
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Agreement No. CE 29/2021 (GE)
Study of Landslides Occurring on Hong Kong Island and Outlying Islands between 2022 and 2024 – Feasibility Study

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1 Introduction

At 9:34 a.m. on 8 September 2023, a major landslide (Incident No. 2023/09/3265) was reported to have occurred at a roadside registered fill slope (slope No. 11SE-D/F47) (referred to as “the fill slope” unless otherwise specified) located underneath Shek O Road, Shek O, when Black Rainstorm Warning and Landslip Warning were in effect. However, the exact time of failure is unknown. The landslide involved a sliding failure with an estimated volume of about 650 m^3. As a result, a section of the northbound lane of Shek O Road collapsed. Landslide debris was deposited below the failure scar, and some of the debris was directed away by surface water on a rocky natural stream course downhill (Figures 1.1 and 1.2).

Another major landslide was reported to have occurred at 8:00 a.m. on 14 September 2023 during a Red Rainstorm Warning. It involved a washout failure with an estimated volume of about 126 m^3. Landslide debris was deposited at the slope toe, and some travelled further downhill along the rocky natural stream course. The previously closed northbound lane collapsed again, including the newly placed rockfill of post-landslide emergency repair works for the landslide on 8 September 2023 (Figures 1.1 and 1.3). No casualties were reported, but the blockage of Shek O Road isolated hundreds of residents from Shek O. The media widely reported these incidents.

Following the landslides, Fugro (Hong Kong) Limited (Fugro) carried out a detailed study of the landslides for the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department (CEDD) under Agreement No. CE 29/2021 (GE). Fugro received assistance from the Civil Aid Service (CAS), the Survey Division of the CEDD and the Highways Department (HyD), as well as technical support provided by AECOM Asia Company Limited, the 2022 to 2024 Landslide Investigation Consultants, under Agreement No. CE 30/2021 (GE).

The key objectives of the study were to document the facts about the landslides, present relevant background information, and establish the probable causes of the landslides. This report presents the findings of the study, which consists of the following tasks:

(a) a review of all known relevant documents relating to the fill slope,

(b) topographic surveys, site inspections and field measurements at the landslide site,

(c) geological mapping,

(d) aerial photograph interpretation (API),

(e) analyses of rainfall records,

(f) slope stability back-analyses, and

(g) a diagnosis of the probable causes of the landslides.

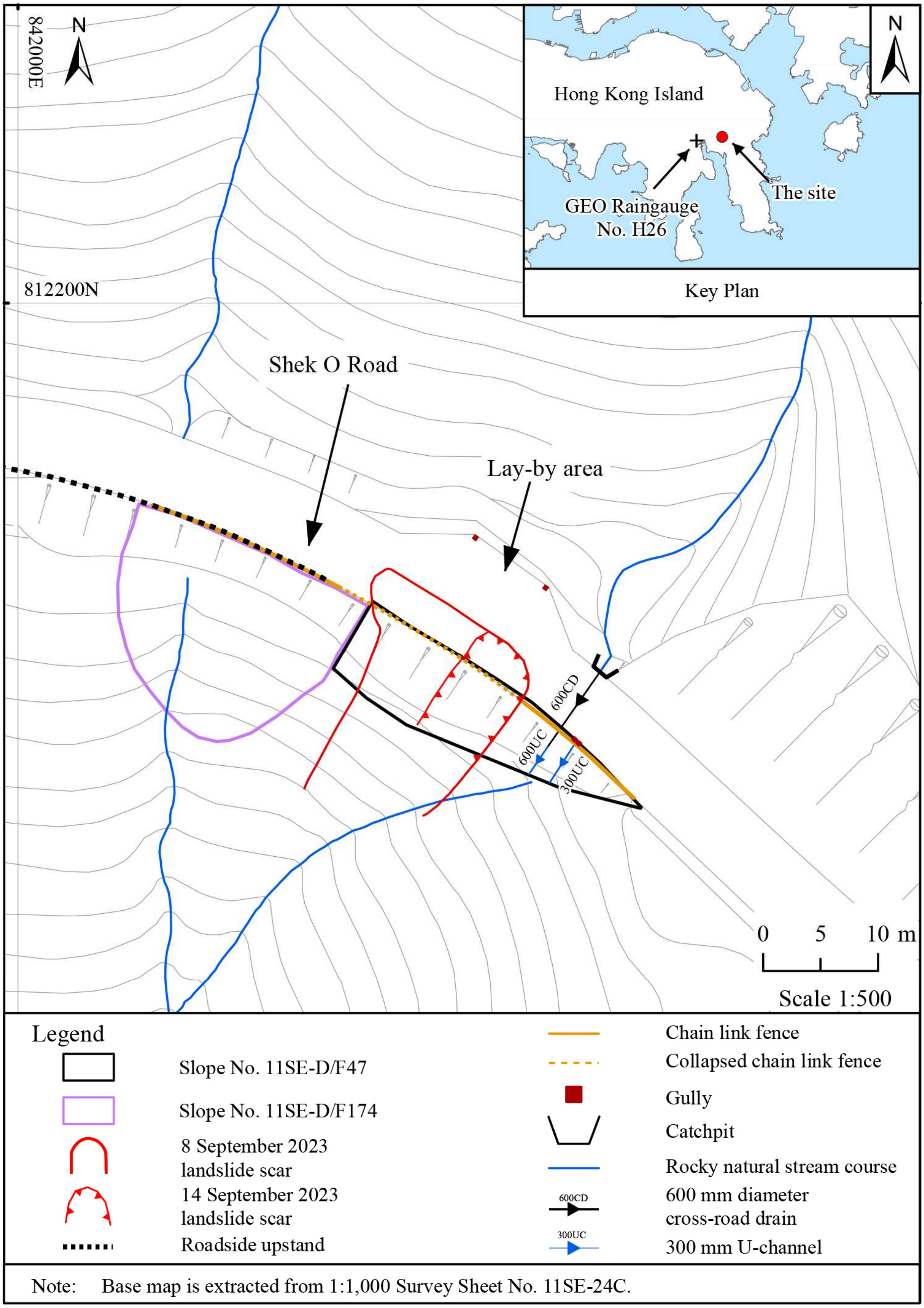


Figure 1.1 Location Plan

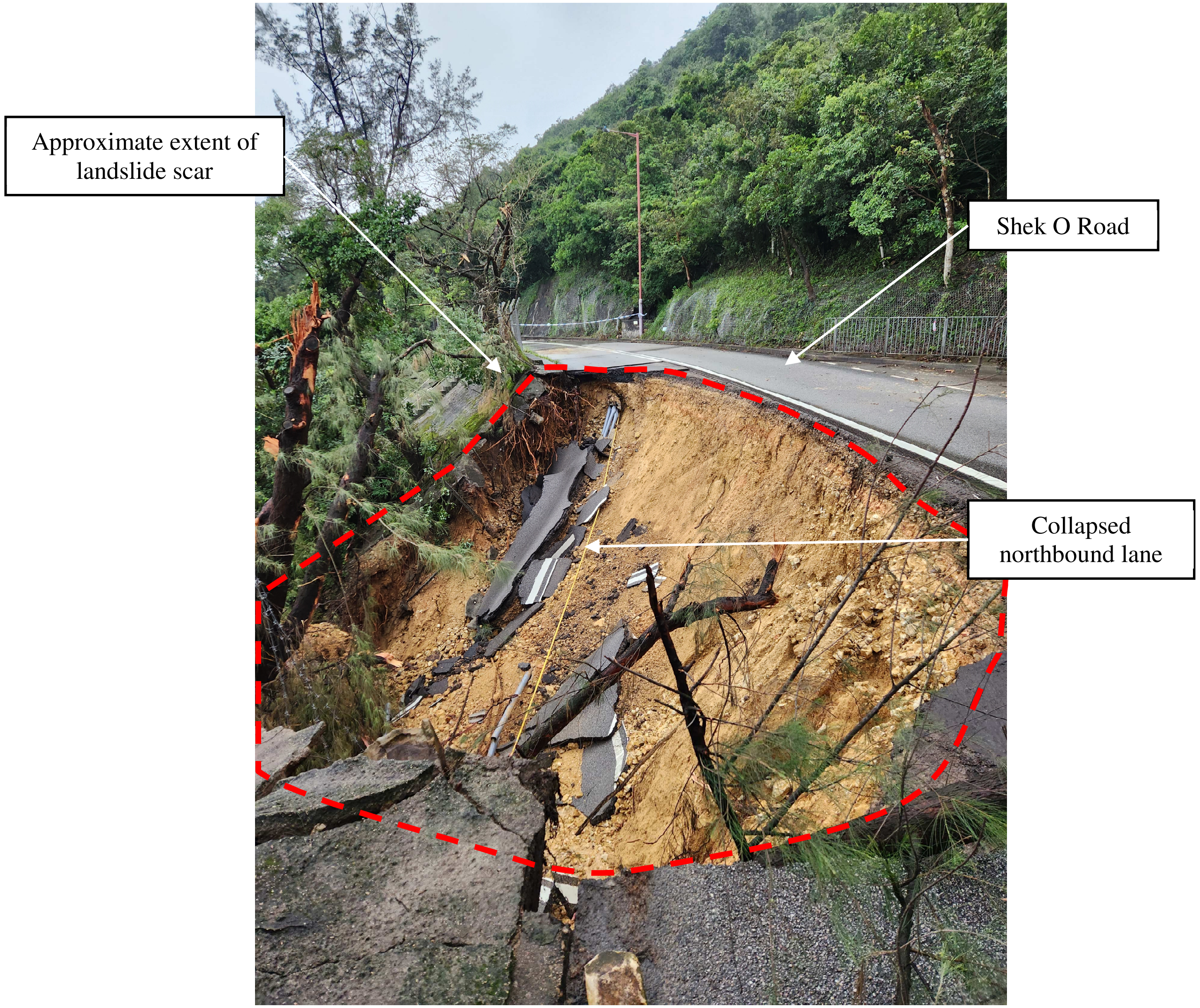


Figure 1.2 General View of the Landslide on 8 September 2023 (Photograph Taken on 8 September 2023)

Figure 1.3 General View of the Landslide on 14 September 2023 (Photograph Taken on 14 September 2023)

2 The Site

2.1 Site Description

Two landslides occurred at the fill slope which is located underneath Shek O Road (Figure 1.1). The fill slope is about 25 m long and has an average gradient of about 38° with a maximum height of 10 m. The entire slope surface was covered with shotcrete and unplanned vegetation prior to the occurrence of the landslides.

Shek O Road is a two-lane, two-way carriageway that runs immediately along the slope crest and slightly descends to the southeast. A chain link fence separates it from the fill slope. Surface water from the upslope natural hillside flows along the rocky natural stream course and is intercepted by a 600 mm diameter cross-road drain next to a lay-by area. The surface water ultimately flows underneath Shek O Road to a 600 mm U-channel on the fill slope to the rocky natural stream course downhill towards a catchwater of Tai Tam Tuk Reservoir. The area around the lay-by and Shek O Road has gullies to collect surface water, discharging to a 300 mm U-channel on the fill slope. Apart from the 300 mm and 600 mm U-channels, no surface channels, raking drains, roadside upstands, and drainage blankets have been built on the fill slope to direct surface runoff on the slope surface and intercept subsurface flow.

There is another roadside fill slope located to the northwest with a maximum height of 11 m, which is registered as slope No. 11SE-D/F174. This slope was a part of the fill slope before a landslide occurred in August 1995. After the landslide, remedial works were carried out on the failed portion of the fill slope (to be discussed in Section 3.2.3). This failed portion was later registered as slope No. 11SE-D/F174. At the crest of this slope, there is a roadside upstand to direct surface runoff on Shek O Road away from the slope.

2.2 Maintenance Responsibility

According to the Slope Maintenance Responsibility Information System of the Lands Department, the fill slope falls within Government Land, and the maintenance responsibility rests with the HyD.

2.3 Regional Geology

The Hong Kong Geological Survey 1:20,000 scale Solid and Superficial Geology Sheet No. 11 – Hong Kong and Kowloon (GEO, 2012) shows that the solid geology of the landslide site is composed of cretaceous fine ash vitric tuff (Kra_fvt) of the Ap Lei Chau Formation (Figure 2.1). No major geological structures are recorded at the landslide site, but two bedding measurements of vertical joints are recorded; one to the west-southwest and the other to east-southeast of the fill slope.

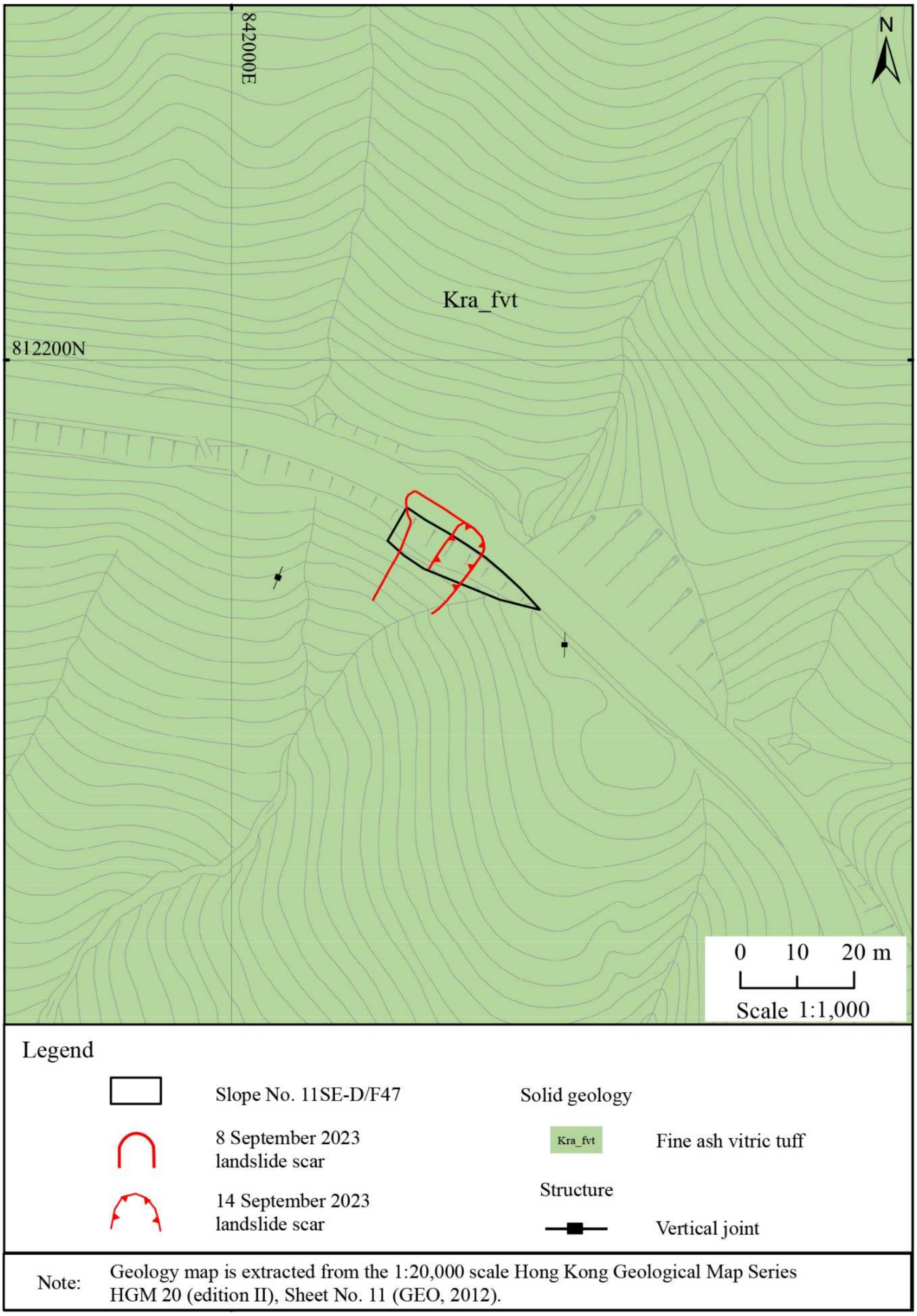


Figure 2.1 Regional Geology

3 Site History, Past Slope Instabilities and Relevant Records

3.1 Site History

The site history has been determined from the interpretation of available aerial photographs in conjunction with a review of previous slope repair works, past slope instabilities, and other documentary information. Appendix A summarises detailed accounts of observations from the API.

The earliest available aerial photographs taken in 1924 show that the fill slope was formed during the construction of Shek O Road (Figure 3.1). The hillside above the fill slope was covered with moderately dense vegetation. It had a concave terrain with several well-defined drainage lines that trended to the southwest in a dendritic pattern. The fill slope was located in a valley that was bounded by steep south- to southwest-sloping, rounded spurlines. The rocky natural stream course descended from the natural hillside to the fill slope.

Minor improvements were made to Shek O Road, such as constructing the lay-by area opposite to the fill slope in 1961. Slope remedial works were carried out in 1995 following landslide incident No. HK95/8/31 and between 2016 and 2017 following landslide incident No. 2016/11/1997. No significant changes have been observed after 2017.

3.2 Past Slope Instabilities

3.2.1 Enhanced Natural Terrain Landslide Inventory

The Enhanced Natural Terrain Landslide Inventory database has no records of natural terrain landslides within or in the vicinity of the fill slope (Figure 3.2).

3.2.2 Large Landslide Database

The GEO's Large Landslide Database (Scott Wilson, 1999) shows that there are no large landslides within or in the vicinity of the fill slope (Figure 3.2).

3.2.3 Reported Landslide Incidents

The GEO's landslide database shows that two reported landslide incidents, namely Incident Nos. HK95/8/31 and 2016/11/1997, occurred near the landslide site (Figure 3.2).

On 13 August 1995, Incident No. HK95/8/31 occurred at the present-day registered fill slope No. 11SE-D/F174, which was part of the fill slope when the failure occurred (Figure 3.3). The slip initiated from the fill slope below Shek O Road and took down a section of the northbound lane with an estimated failure volume of about 120 m^3. The incident report suggested that direct infiltration could be a possible cause of the landslide. The failed slope portion was later backfilled with rockfill and registered as slope No. 11SE-D/F174.

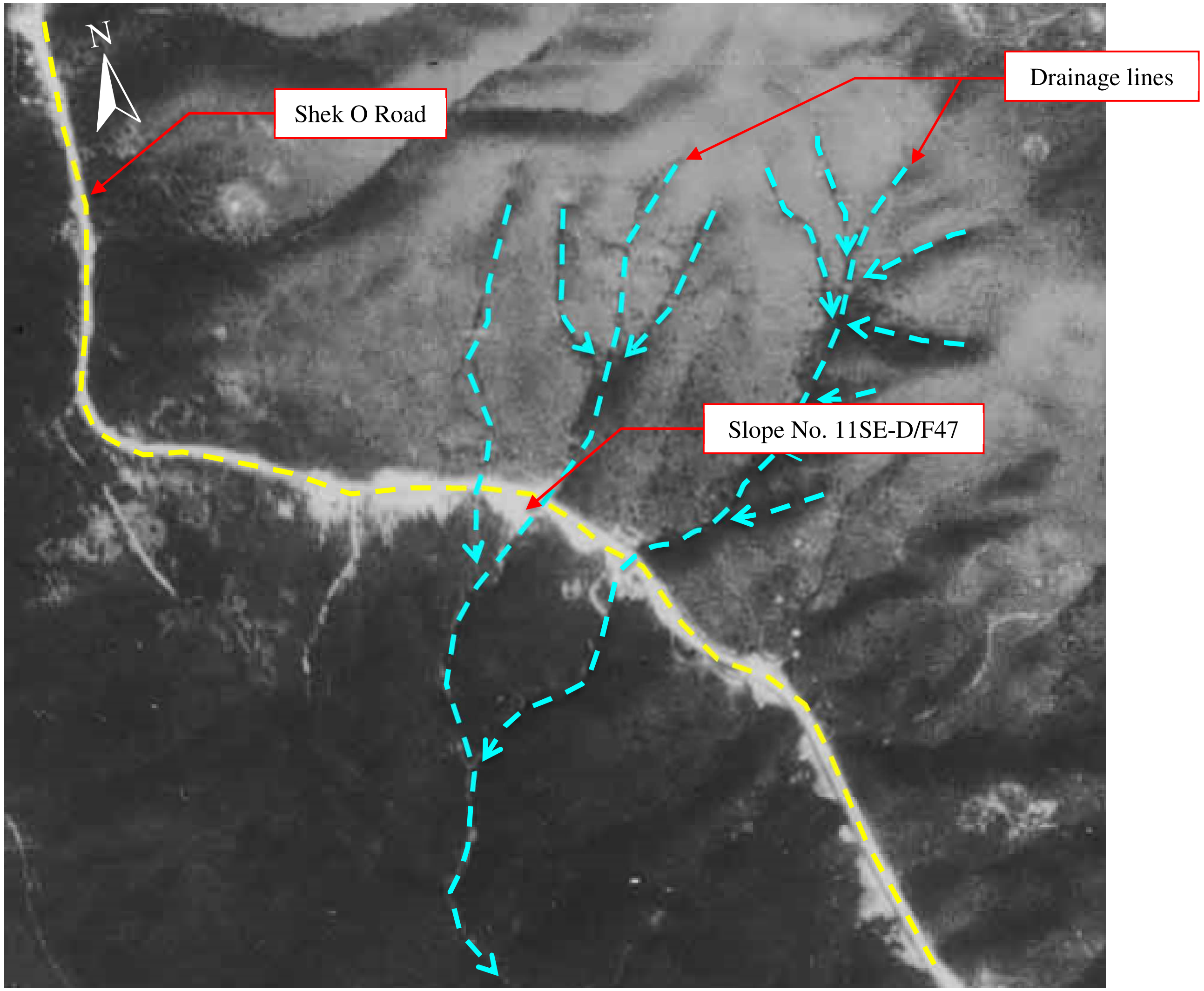


Figure 3.1 Aerial Photographs Taken in 1924

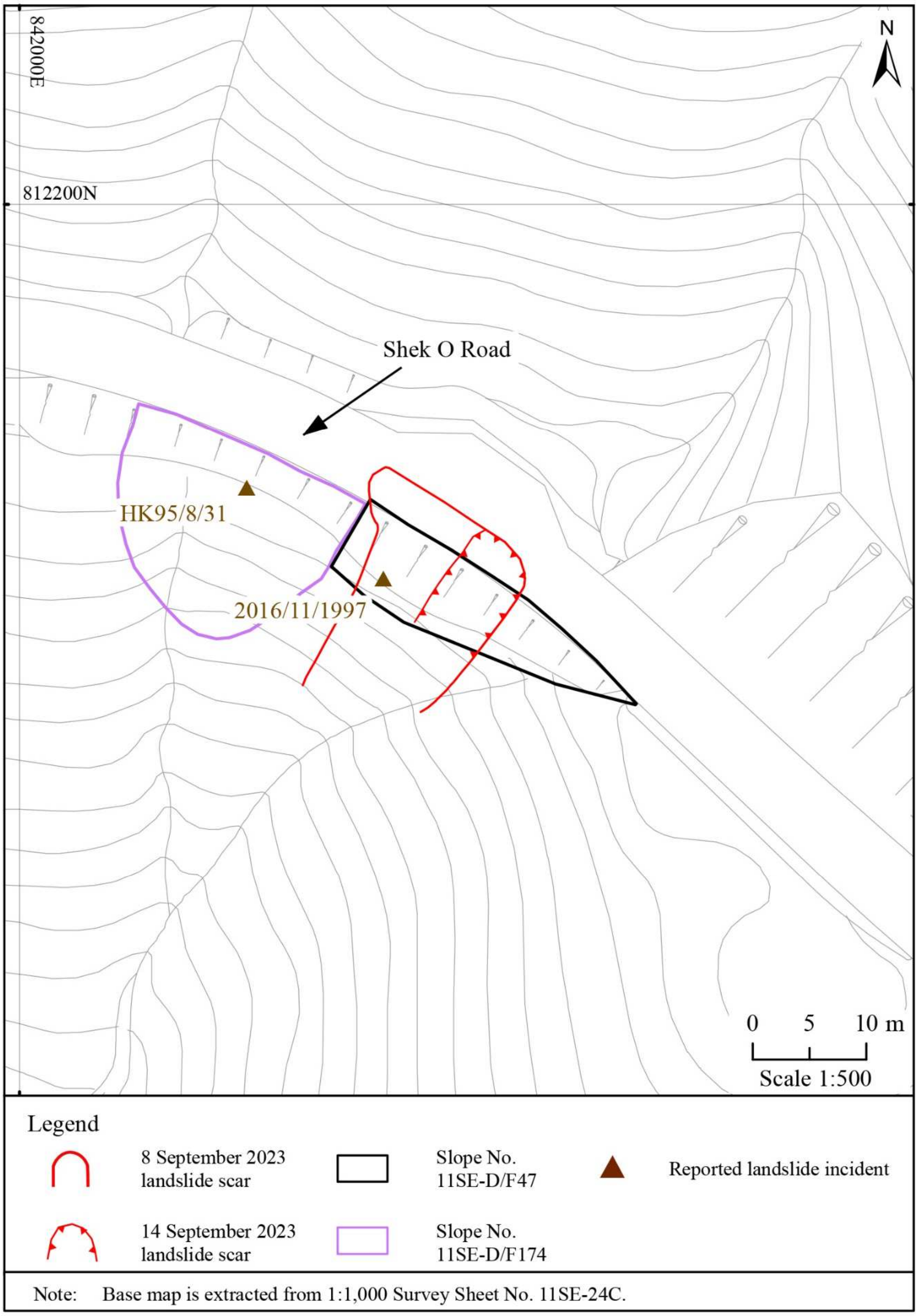


Figure 3.2 Past Slope Instabilities

Figure 3.3 The 1995 Landslide (Photograph Taken on 13 August 1995)

On 19 October 2016, Incident No. 2016/11/1997 occurred at the fill slope, with an estimated failure volume of about 60 m^3 (Figure 3.4). The incident report revealed that a large amount of surface runoff might have accumulated on Shek O Road due to the partial blockage of a culvert upslope and the complete blockage of gullies east of the 2016 incident location. The absence of a concrete upstand on the road led to overspilling of concentrated surface water onto the fill slope through the cracked shotcrete cover, resulted in the failure. Subsequently, the failed slope portion was repaired by backfilling no-fines concrete.

Figure 3.4 The 2016 Landslide (Photograph Taken on 29 November 2016)

3.2.4 Historical Landslide Catchment

No existing Historical Landslide Catchments are in the vicinity of the fill slope (Figure 3.2).

3.3 Previous Assessment and Inspections

3.3.1 Preliminary Studies for the Special Investigation into Fill Slopes

Binnie and Partners (HK) Consulting Engineers conducted preliminary studies for the special investigation into fill slopes over the territory, including the fill slope, in October 1977 (Binnie & Partners, 1977). No signs of distress or seepages were observed during their inspection. The study recommended clearing and repairing drains along Shek O Road.

3.3.2 LPM Study

In 1996, the GEO included the fill slope in the Landslip Preventive Measures (LPM) Programme for a detailed study (known as the LPM Study). GEO's consultants, Binnie Consultants Limited (Binnie), conducted the study to evaluate the stability of the fill slope and recommend any necessary preventive or upgrading works.

The study involved a desk study, visual inspections, a site-specific ground investigation with groundwater monitoring and sand replacement tests, laboratory testing and stability assessment. The stability assessment was based on the site-specific shear strength parameters of fill and colluvium, and an assumed design groundwater level of 1 m above the measured groundwater level, corresponding to rainfall with a 10-year return period. The assessment showed that the fill slope had adequate factors of safety against failure under the design scenarios.

Binnie determined that the fill material originated from blasted rocks, consisting of cobbles and boulders with a silty sand and gravel matrix. They concluded that the fill material was not susceptible to liquefaction due to the presence of relatively coarse material, a relative compaction of the fill material ranging from 88% to 92% (to be discussed in Section 3.3.3), and a shotcrete cover reducing infiltration. Binnie recommended regular inspection, proper maintenance of existing shotcrete surfacing, and examination of cross-road drain and road drains to prevent slope deterioration and ensure proper discharge of surface runoff across the fill slope. No further study was required for the fill slope (Binnie, 1997).

3.3.3 Ground Investigation

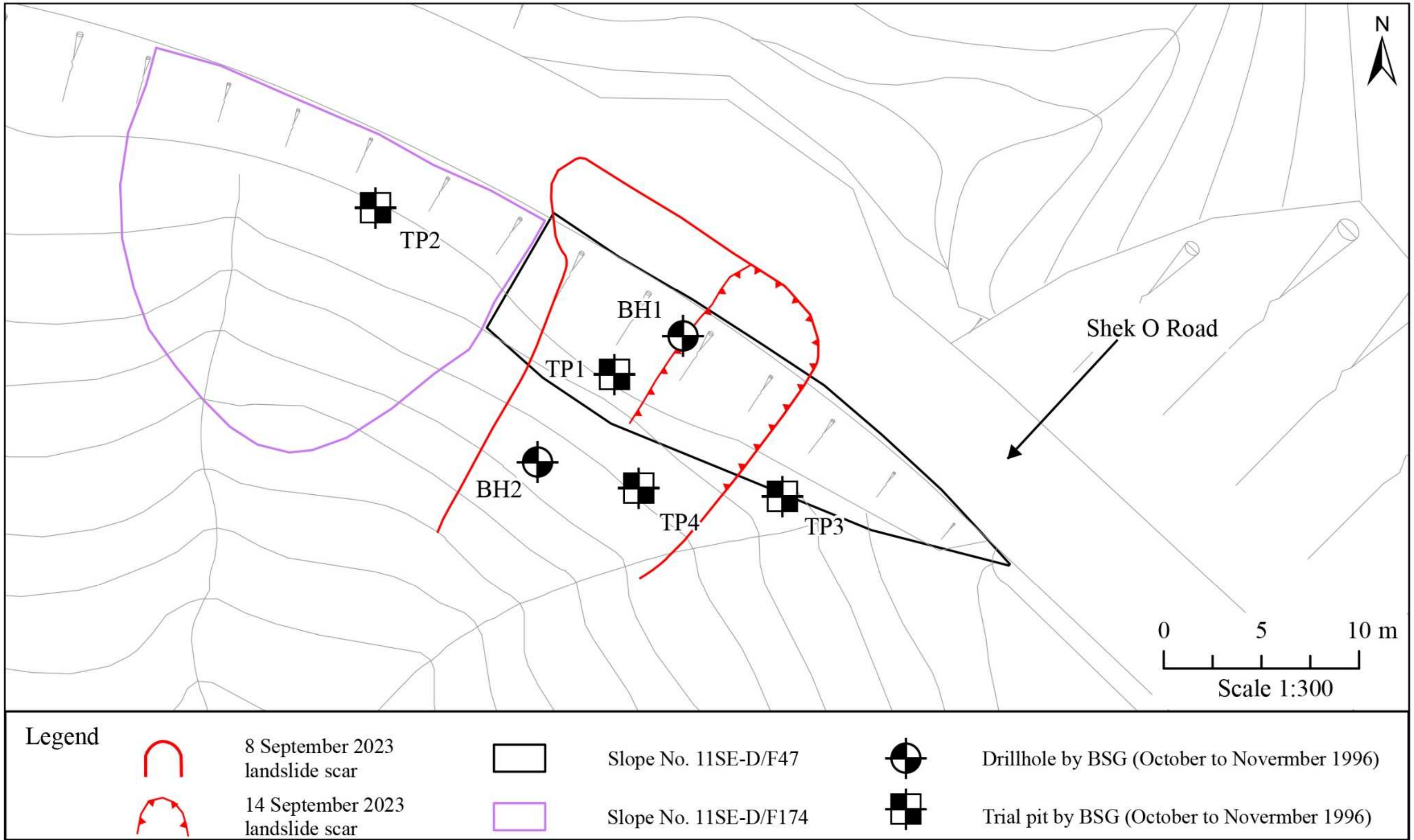
As part of the LPM Study (Section 3.3.2), Bachy Soletanche Group conducted the site-specific ground investigation for the fill slope and the adjacent slope No. 11SE-D/F174 between October and November 1996 (BSG, 1997). The main objectives of the investigation were to assess geological and groundwater conditions and collect soil samples for laboratory testing. The ground investigation comprised two vertical drillholes (BH1 and BH2) and four trial pits (TP1 to TP4) at different locations (Figure 3.6).

The drillholes and trial pits revealed that the landslide site is underlain by fill and colluvium followed by moderately to slightly decomposed tuff (M/SDT), i.e. the bedrock. No notable adverse geological features were found from the ground investigation. Sand replacement tests were performed in trial pits to determine the in-situ properties of the fill material. The tests revealed the relative compaction of the fill material ranging from 88% to 92%, indicating that the fill material was moderately compacted.

3.3.4 Maintenance Inspections

The last Engineer Inspection (EI) was carried out by the HyD in February 2020. According to the EI records, the shotcrete cover was in fair condition, with clear weepholes and drainage channels. No signs of distress or seepage were noted during the inspection. The Routine Maintenance Inspection was conducted on the fill slope in November 2022 with maintenance works recommended, including clearing drainage channels and removing surface debris and vegetation. However, after the maintenance works were completed, several persistent cracks were observed on the shotcrete cover in November 2022 (Figure 3.5).

Figure 3.5 Surface Condition of Slope No. 11SE-D/F47 after Maintenance Works (Photograph Taken on 4 November 2022)



Note: Base map is extracted from 1:1,000 Survey Sheet No. 11SE-24C.

Figure 3.6 Locations of Previous Ground Investigation Stations

4 Description of the Landslides

The following description of the landslides has been collated from field observations, records of the incident by the Police and the HyD, and post-landslide inspections made by the GEO. As there were no eyewitnesses, the exact failure times for the landslides are unknown.

At 9:34 a.m. on 8 September 2023, the Police reported the first landslide when both Black Rainstorm Warning and Landslip Warning were in effect. As a result of the landslide, a section of the northbound lane of Shek O Road collapsed, and both lanes had to be closed subsequently. After the landslide, emergency repair works began on the failed slope portion, including the placement of rockfill. The northbound lane was re-opened on 10 September 2023 after the repair works were completed.

The HyD reported the second landslide at 8:00 a.m. on 14 September 2023, during the Red Rainstorm Warning. The landslide further collapsed the northbound lane of Shek O Road, which had previously been repaired with the rockfill. As a result, both lanes had to be closed again. Following the emergency repair, the northbound lane was re-opened on 15 September 2023.

5 Post-landslide Observations and Investigation

5.1 Field Observations

Key post-landslide observations are summarised below based primarily on inspections and field mapping undertaken by the GEO, Fugro and the counterpart landslide investigation consultants, AECOM, between September 2023 and January 2024. The CAS provided assistance during the inspections and field mapping. As part of the landslide inspections, the Survey Division of the CEDD and the HyD used unmanned aerial vehicles (UAVs) to carry out topographic surveys of the landslide site.

5.1.1 The First Landslide on 8 September 2023

On 8 September 2023, a landslide occurred at the fill slope underneath Shek O Road during a severe rainstorm (Figure 5.1). A section of the northbound lane of Shek O Road collapsed due to a sliding failure of the fill slope (Figure 5.2).

The landslide scar was estimated to be about 20 m long and 16 m wide. The landslide was deep-seated, with a maximum depth of 5 m below the pre-failure slope surface and an estimated failure volume of about 650 m^3. The main scarp had an inclination of around 60° to 65°, and exposed mainly fill and locally colluvium above the bedrock on the southeastern flank of the landslide scar (Figures 5.3 and 5.4). The lower part of the main scarp was covered up by the landslide debris. As inferred from the flanks of the landslide scar, the source floor was close to the interface between colluvium and bedrock with a gradient of about 28° to 30°. While several broken uPVC pipes were exposed on both flanks of the landslide scar, no water flows from the pipe outlets were observed.

The debris from the landslide, including fill, colluvium, uprooted trees, broken fragments of shotcrete cover, collapsed chain link fence and pavement of the northbound lane, was deposited at the slope toe, giving a debris travel distance of about 30 m and a debris travel angle of about 30°. This relatively low debris mobility is comparable to typical rain-induced landslides involving a failure volume of about 600 m^3 and a debris travel angle ranging from 30° to 35° as discussed by Wong & Ho (1996a). Some debris entered the rocky natural stream course and was directed downhill.

The 600 mm diameter cross-road drain was intended to divert surface water from the natural hillside uphill across the fill slope into the rocky natural stream course downhill. However, at the time of the incident, the upslope catchpit, inlet of the cross-road drain and roadside gullies were substantially blocked by foliage and debris (Figure 5.5). This caused surface water from the natural hillside to overflow onto Shek O Road and the lay-by area above the fill slope, as suggested by the ponding of muddy water observed the day after the landslide (Figure 5.6).

Due to the slightly sloping gradient of Shek O Road, absence of the roadside upstand and blocked roadside gullies, uncontrolled concentrated surface water flowed along Shek O Road towards the fill slope that was located at a topographical low point (Figure 5.7). Cracked shotcrete cover was evident on the adjacent slope No. 11SE-D/F174 (Figure 5.8).

As part of the emergency repair works, the landslide scar was later covered by the rockfill (Figure 5.9).

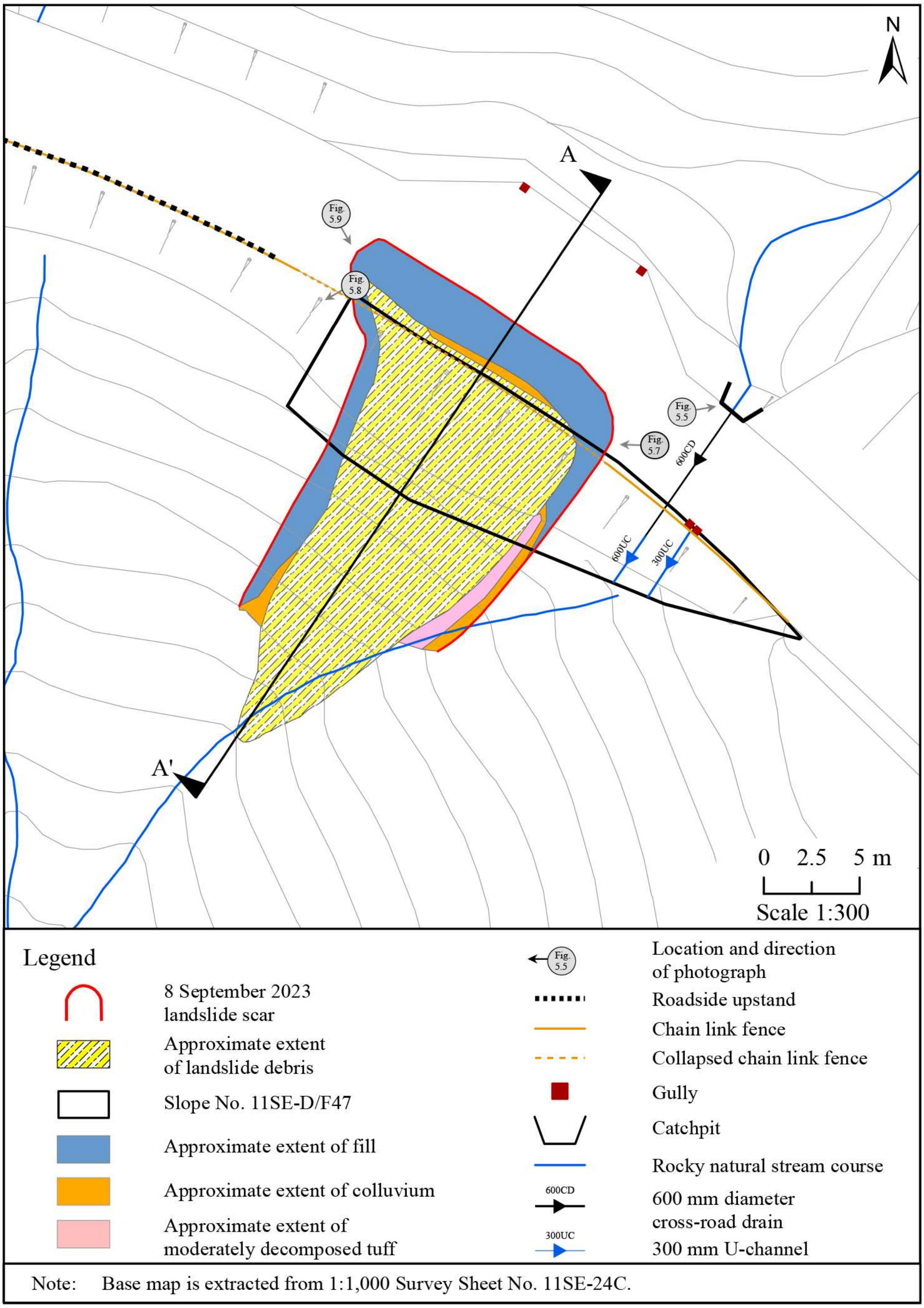


Figure 5.1 Post-landslide Observations of the Landslide on 8 September 2023

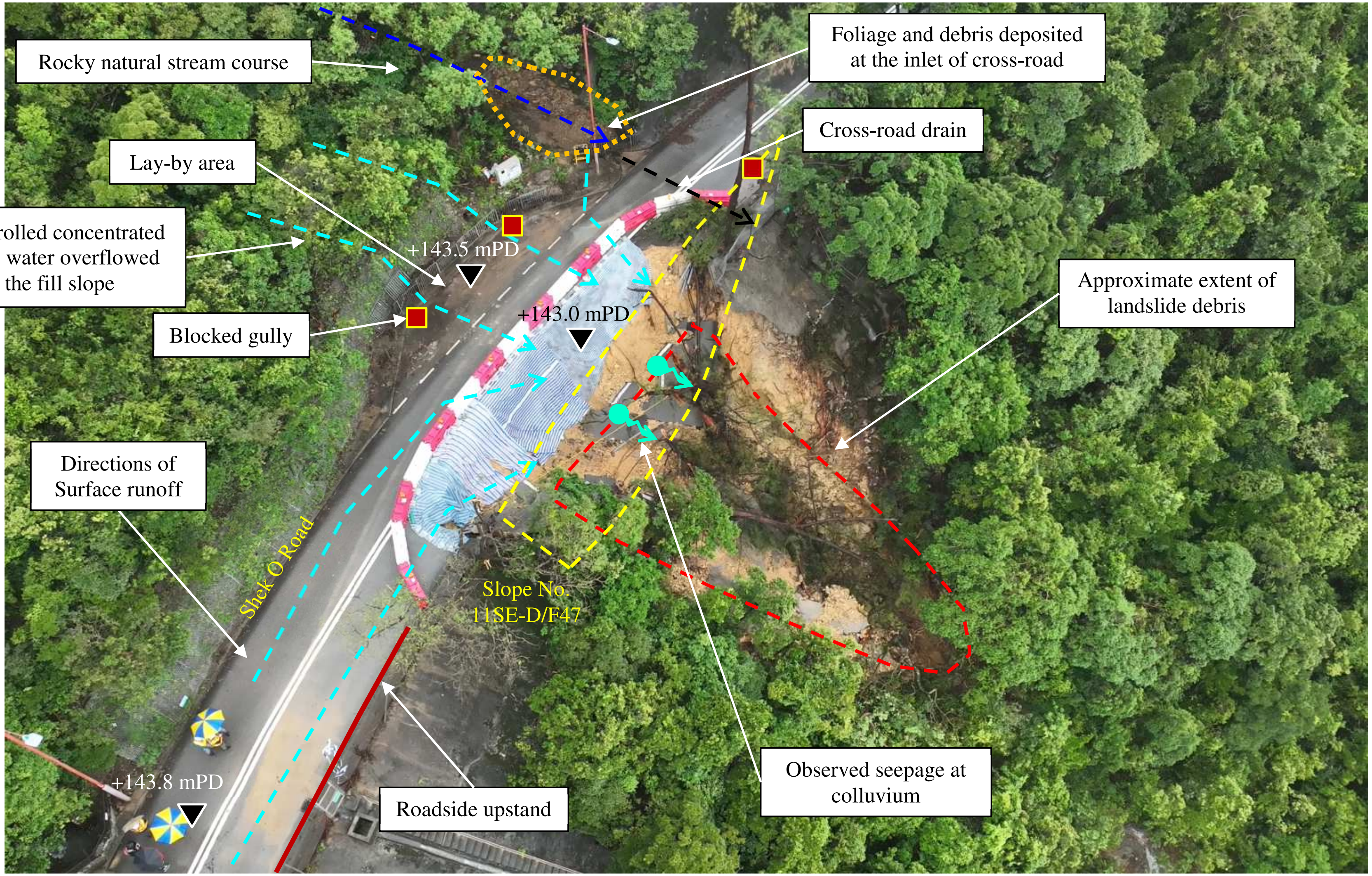


Figure 5.2 Aerial View of the Landslide on 8 September 2023 (Photograph Taken on 9 September 2023)

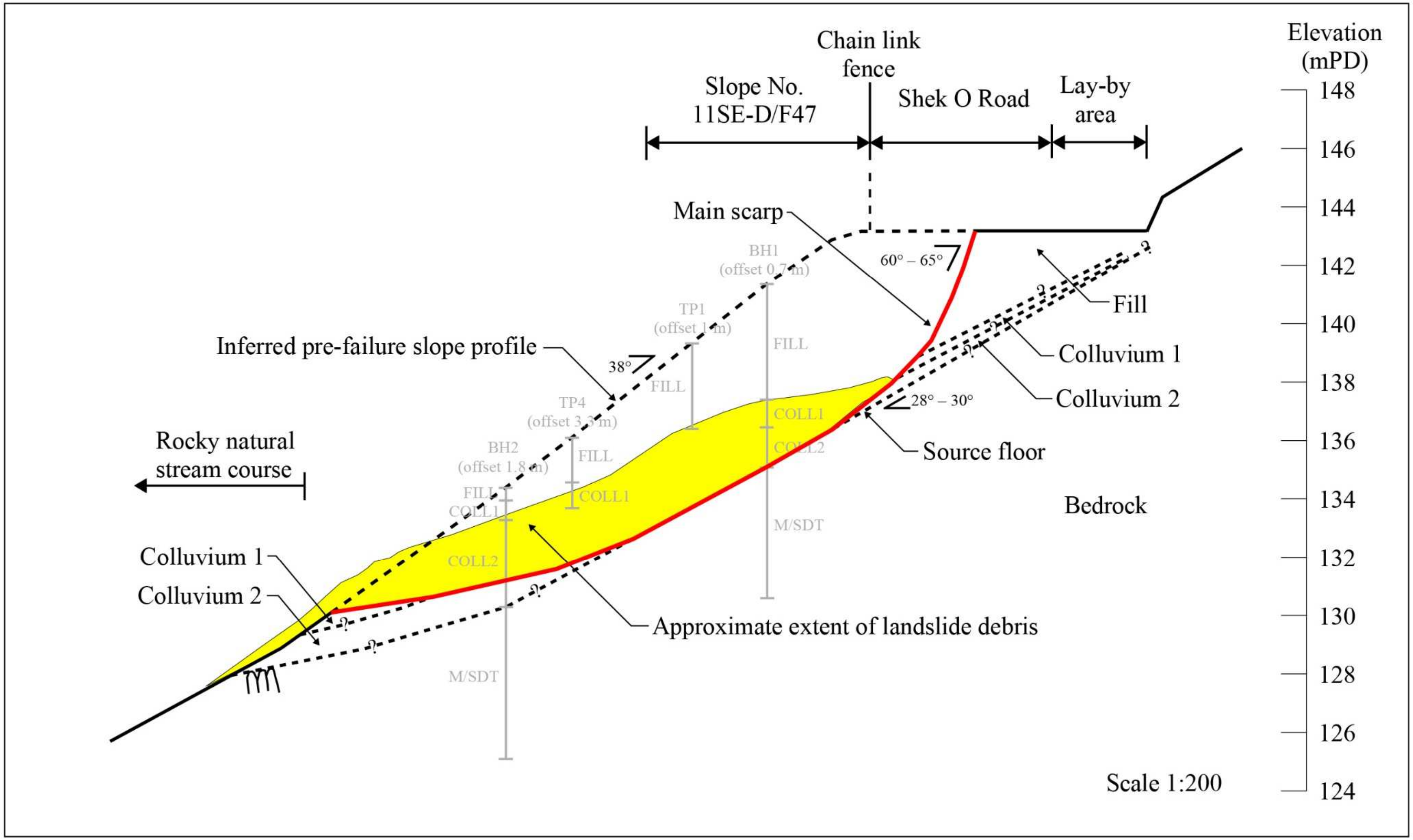


Figure 5.3 Cross-section A-A' through the Landslide Scar on 8 September 2023

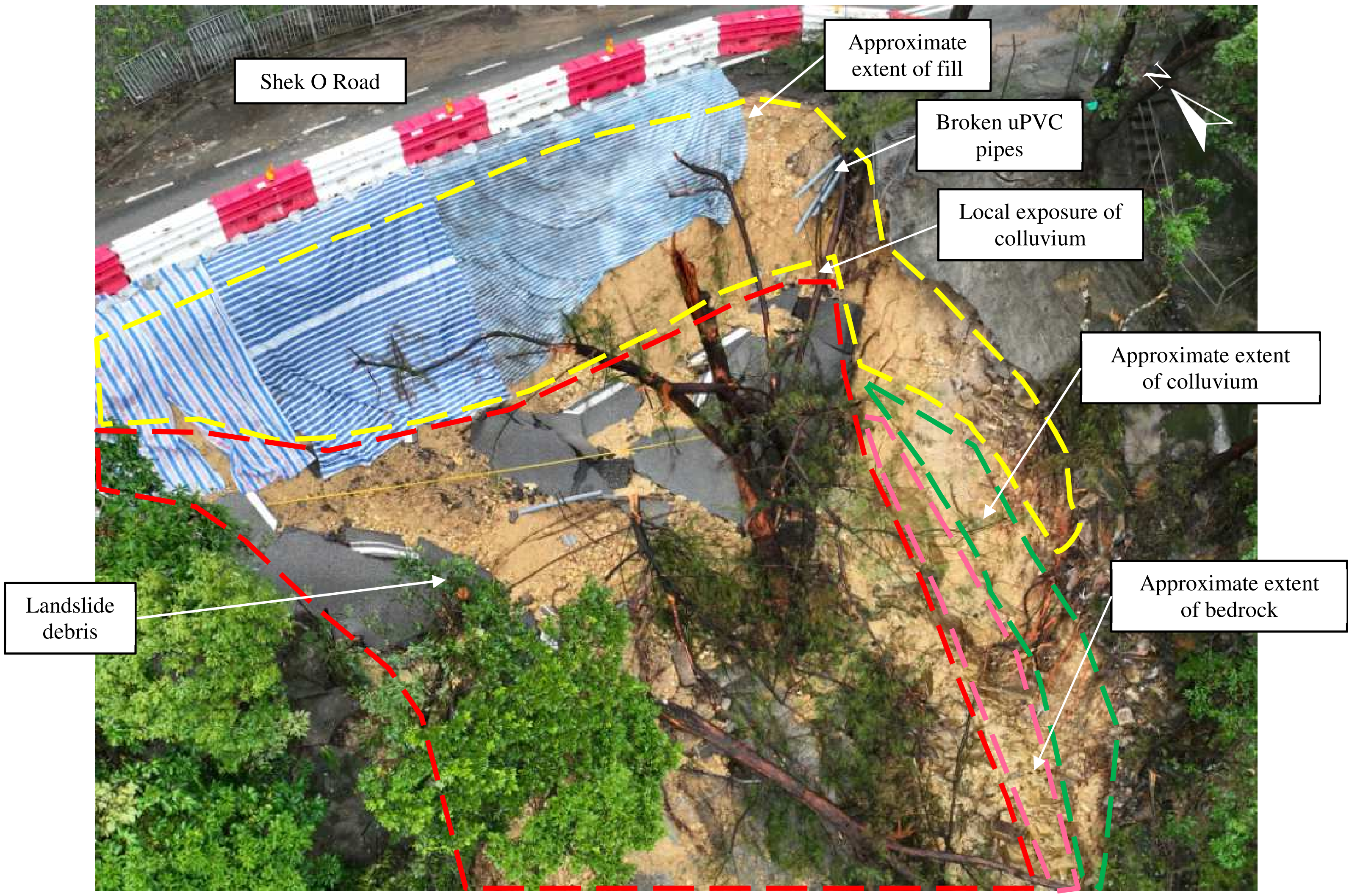


Figure 5.4 General View of the Landslide Scar (Photograph Taken on 9 September 2023)

Figure 5.5 Blocked Catchpit of the Upslope Rocky Natural Stream Course (Photograph Taken on 9 September 2023)

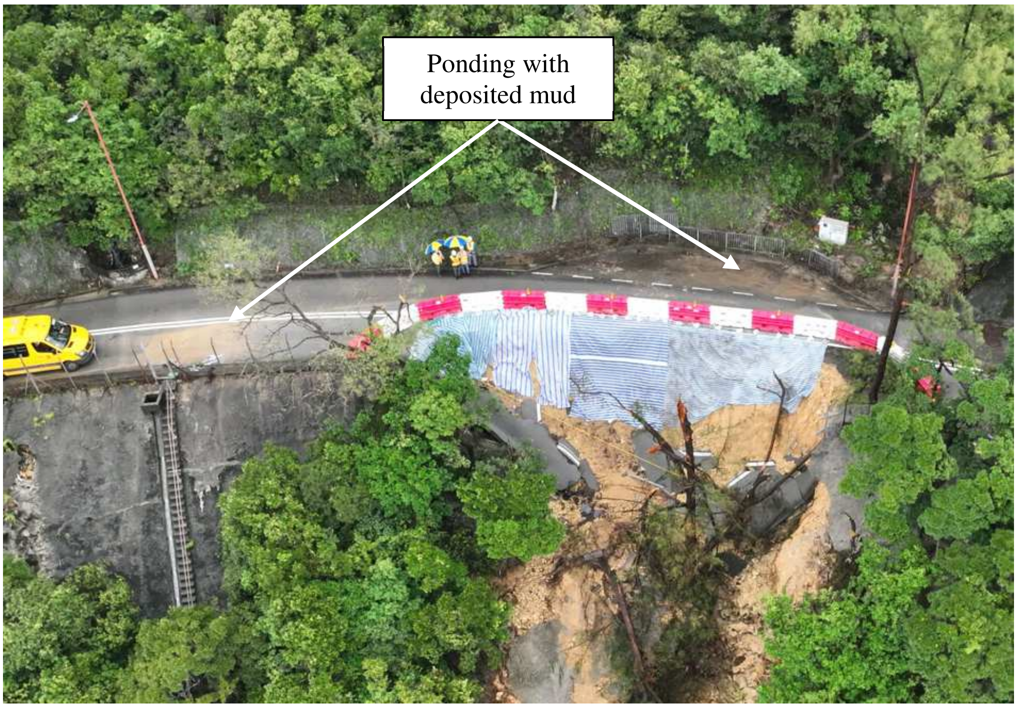


Figure 5.6 Ponding on Shek O Road (Photograph Taken on 9 September 2023)

Courtesy to the South China Morning Post

Figure 5.7 Significant Overland Flow from Shek O Road towards the Fill Slope (Photograph Taken on 8 September 2023)

Figure 5.8 Cracked Shotcrete Cover on Slope No. 11SE-D/F174 (Photograph Taken on 9 September 2023)

Figure 5.9 Rockfill on the Landslide Scar (Photograph Taken on 11 September 2023)

5.1.2 The Second Landslide on 14 September 2023

On 14 September 2023, another landslide occurred at the fill slope, affecting the rockfill placed as part of the emergency repair works following the previous landslide on 8 September 2023. The landslide was a washout failure of the rockfill and the underlying fill and colluvium (Figures 5.10 and 5.11). The landslide originated from the newly placed rockfill with a gradient of about 50°, and an estimated failure volume was about 126 m^3.

The landslide scar was about 7 m wide, 10 m long, and 2.5 m deep at maximum, with the main scarp inclined at about 65°. The scar exposed fill, colluvium and locally bedrock of MDT (Figures 5.12 and 5.13). Signs of seepage were evident on the source floor at the interface between colluvium and bedrock.

The landslide debris, including fill and colluvium, newly placed rockfill, road pavement, and plastic water-filled road barriers, piled up at the immediate toe. The debris travelled 20 m with a debris travel angle of about 34°. The debris travel angle is compatible with previous washout failures of 35° for a failure volume of about 100 m^3 (Wong et al, 1997). Some debris also travelled further downslope along the rocky natural stream course.

The blockage of the cross-road drain caused significant ponding on the catchpit of the upslope rocky natural stream course (Figure 5.14). On the morning of 14 September 2023, the ponding water was observed overspilled and flooded Shek O Road, as shown in Figure 5.15 and Video B1 of Appendix B. The area near the crest of the landslide scar was situated at the topographical low point, and no roadside upstand was built at this location. With the blocked roadside gullies (Figures 5.16 and 5.17), surface water overflowed onto the repaired fill slope and eroded the rockfill.

Persistent water flow from the weepholes and raking drains was observed on nearby cut slopes along the southbound lane of Shek O Road (Figure 5.18).

5.2 Site-specific Geology

The geology of the landslide site was established based on the findings from the published geological information (Section 2.3), API (Section 3.1), previous ground investigation information (Section 3.3.3), and field observations (Section 5.1). The pre-landslide ground surface was established using the Light Detection and Ranging (LiDAR) survey data collected in 2020.

Figures 5.3 and 5.12 illustrate the geological profiles of the site along two representative cross-sections A-A' and B-B' through the landslide scar. Fill was encountered in drillholes (BH1 and BH2) and trial pits (TP1, TP3 and TP4), which were within the landslide scars. The fill comprises clayey, silty SAND to sandy, silty CLAY with angular to subrounded gravel, cobbles of rock fragments, boulders and concrete fragments. This unit has a thickness of up to 3.5 m, followed by a layer of colluvium up to 3 m thick.

The colluvium layer has two separate layers, with the top layer being silty to clayey SAND to sandy CLAY (colluvium 1) and the lower layer being silty to clayey GRAVEL with cobble to silty to clayey SAND with gravel (colluvium 2). These layers contain subangular coarse gravel and cobbles of rock fragments with occasional boulders. They overly in-situ weathered tuff, i.e. bedrock, grading from MDT to SDT. The bedrock dips at about 30° along a northeast-to-southwest direction.

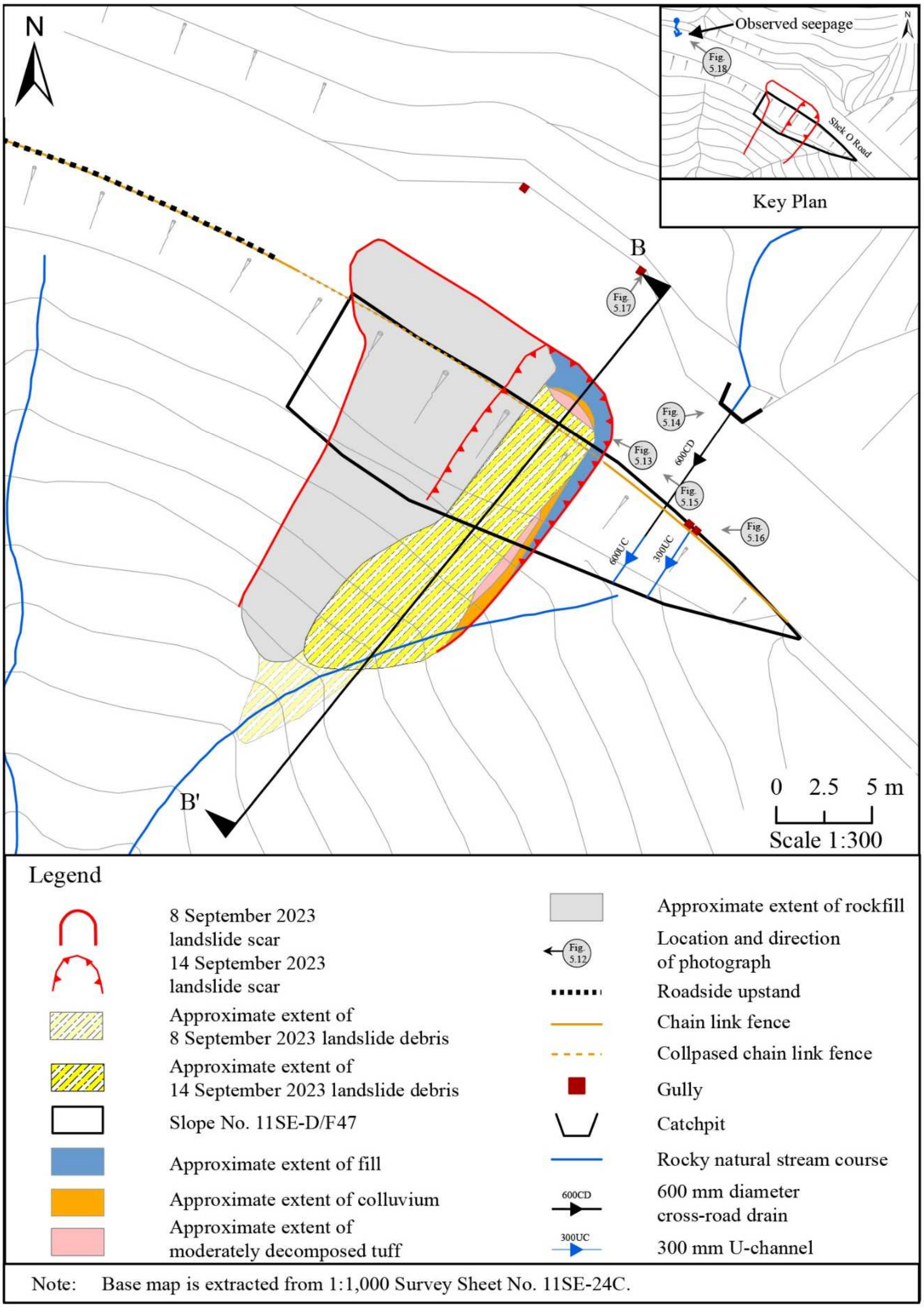


Figure 5.10 Post-landslide Observations of the Landslide Scar on 14 September 2023

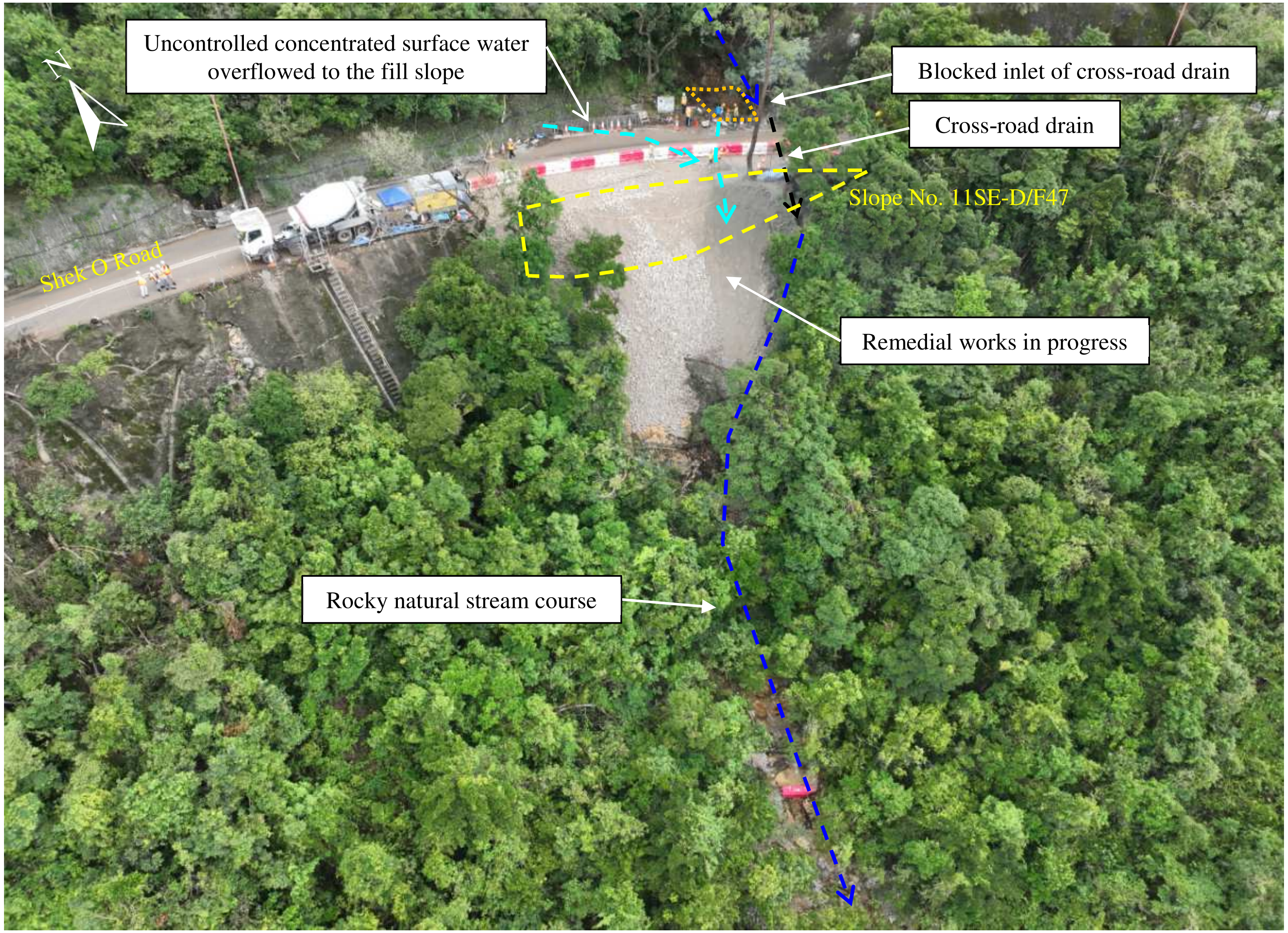


Figure 5.11 Aerial View of the Landslide on 14 September 2023 (Photograph Taken on 18 September 2023)

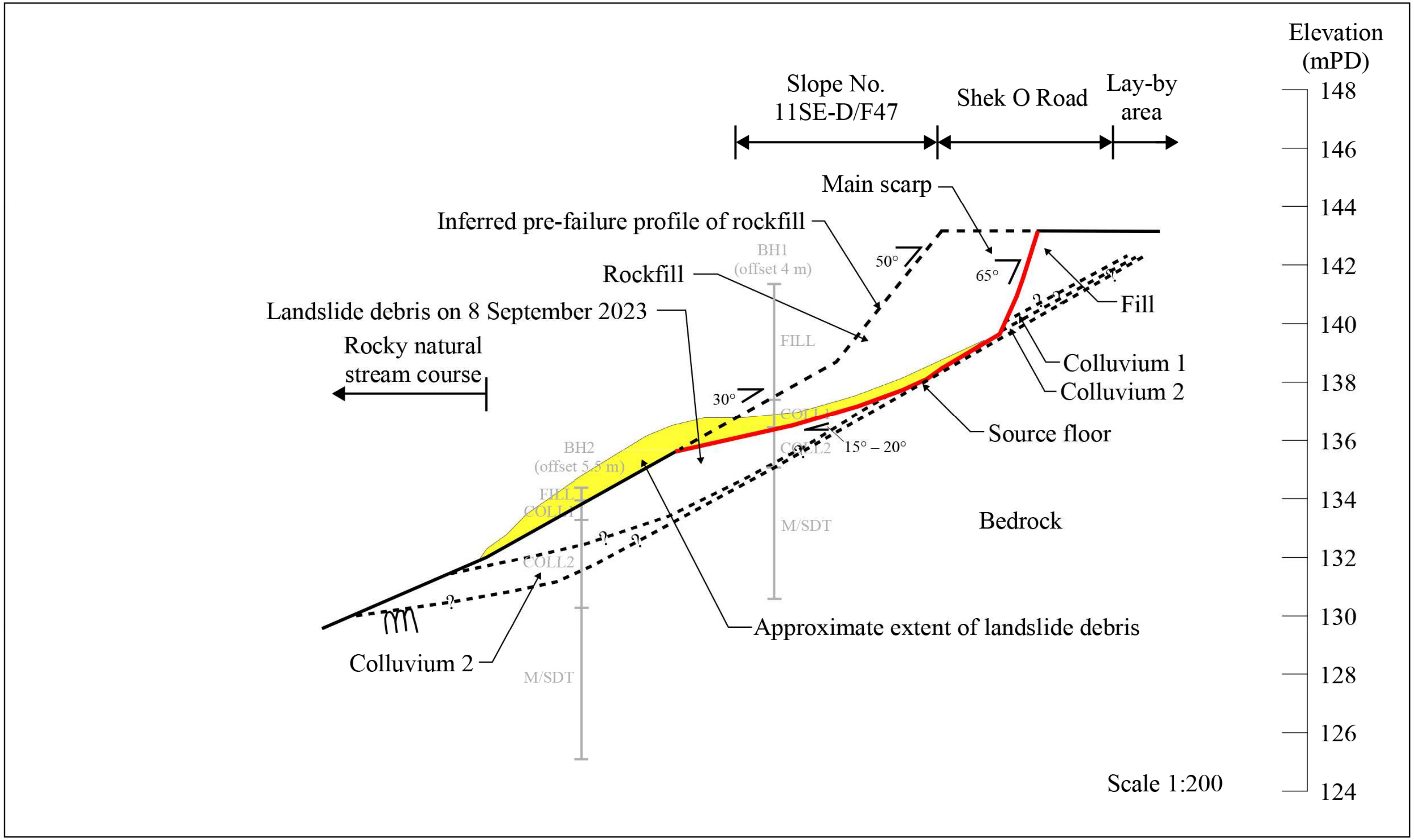


Figure 5.12 Cross-section B-B' through the Landslide Scar on 14 September 2023

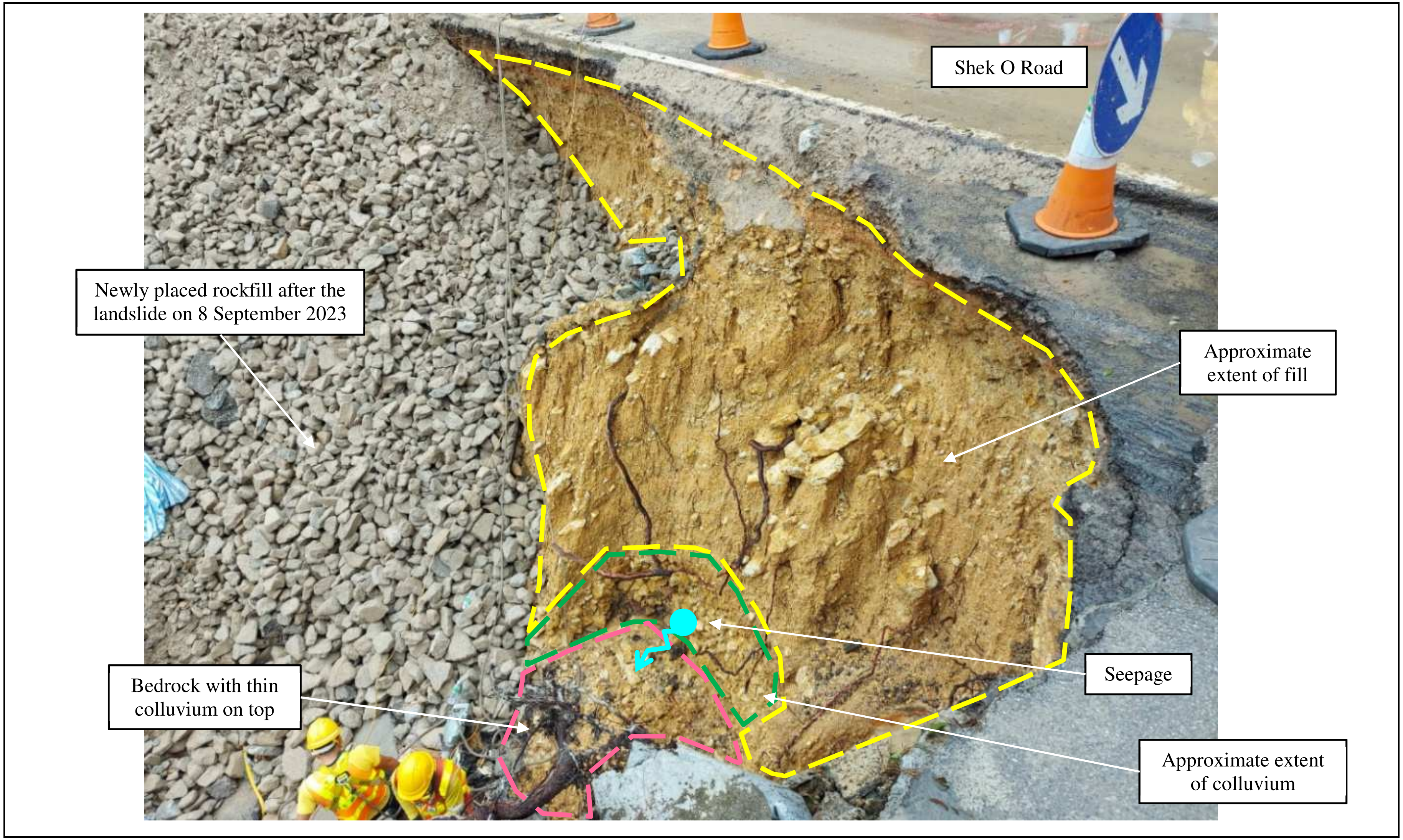


Figure 5.13 General View of the Landslide Scar (Photograph Taken on 14 September 2023)

Figure 5.14 Ponding on the Catchpit of the Upslope Rocky Natural Stream Course (Photograph Taken on 14 September 2023)

Figure 5.15 Significant Overland Flow from Shek O Road towards the Fill Slope (Photograph Taken on 14 September 2023)

**Figure 5.16 Blocked Roadside Gully on Shek O Road
(Photograph Taken on 14 September 2023)**

**Figure 5.17 Blocked Roadside Gully on Lay-by Area
(Photograph Taken on 14 September 2023)**

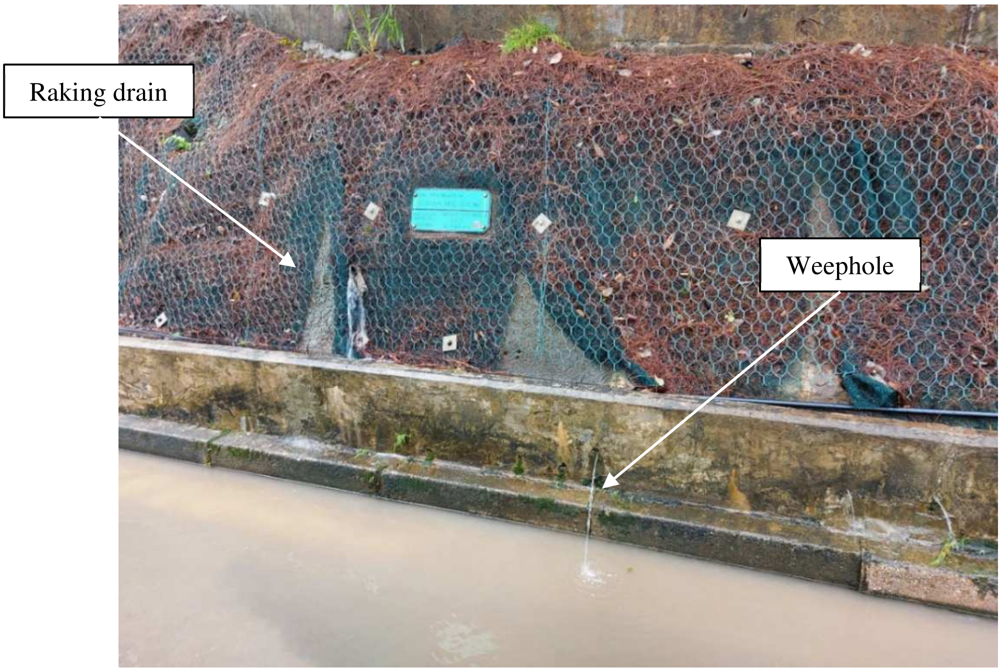


Figure 5.18 Persistent Water Flow on Nearby Cut Slopes (Photograph Taken on 14 September 2023)

5.3 Groundwater Conditions

Two piezometers were installed in each of the two drillholes BH1 and BH2 to capture groundwater levels below the fill slope for the LPM Study. Groundwater in these piezometers was monitored from November 1996 to February 1997, and additional groundwater monitoring was conducted in August 1997. The upper piezometers of BH1 and BH2, i.e. BH1U and BH2U, were installed in the colluvium layer, while the lower piezometers, i.e. BH1L and BH2L, were installed in the bedrock of M/SDT.

Table 5.1 provides details of the piezometers and the highest groundwater levels measured during the monitoring period.

Throughout the monitoring period, the two upper piezometers BH1U and BH2U did not record any groundwater table in the colluvium layer. This suggests that the perched groundwater table was unlikely to have been presented in the fill layer. On the other hand, the lower piezometer BH1L recorded its highest groundwater level at +135.80 mPD, which was at the interface between colluvium and bedrock.

Seepage was observed on the source floor at the interface between colluvium and bedrock during the post-landslide field mapping, as discussed in Section 5.1. Both groundwater monitoring results and seepage observed after the landslides suggest the presence of a persistent groundwater flow along the interface between colluvium and bedrock.

In addition, persistent water flow was observed on nearby cut slopes after the landslide, as discussed in Section 5.1.2.

Table 5.1 Summary of Groundwater Monitoring Results between November 1996 and February 1997 and in August 1997

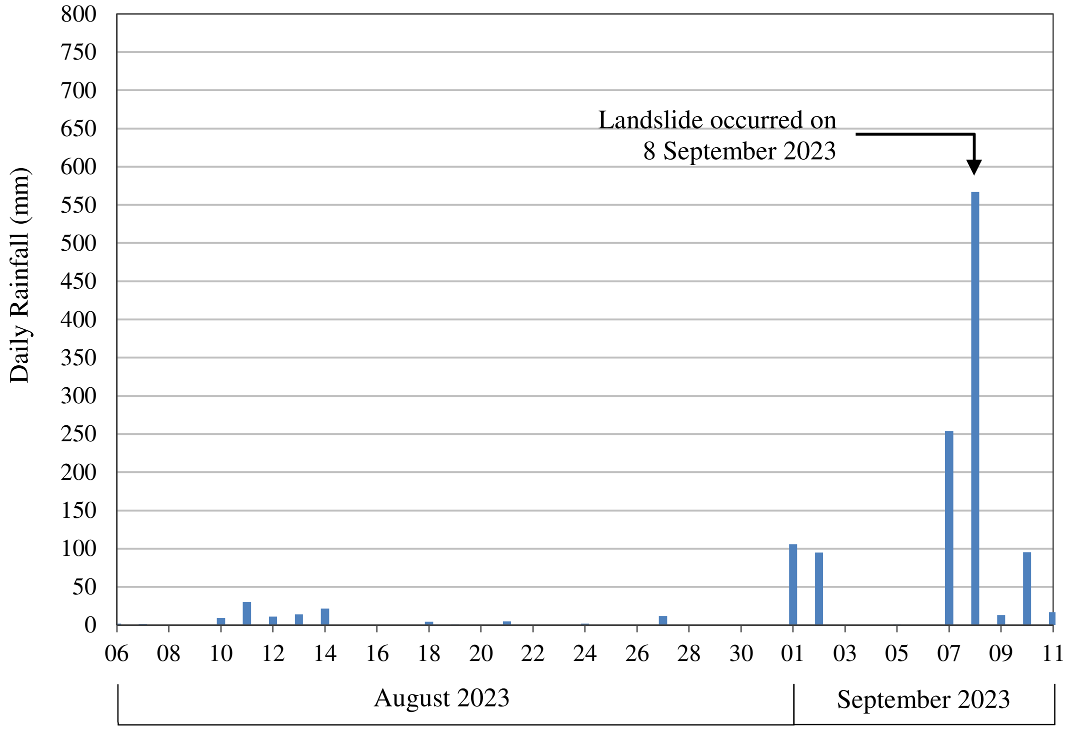
Piezometer	Ground Level (mPD)	Tip Level (mPD)	Response Zone (mPD)	Response Zone	Highest Measured Groundwater Level (mPD)
BH1U	+142.30	+137.30	+136.80 to +138.10	Colluvium	Dry
BH1L		+133.80	+133.30 to +134.60	Bedrock	+135.80 (at the interface between colluvium and bedrock)
BH2U	+134.65	+130.65	+130.45 to +131.45	Colluvium	Dry
BH2L		+129.15	+126.65 to +129.95	Bedrock	+130.15 (below rockhead)

6 Analysis of Rainfall Records

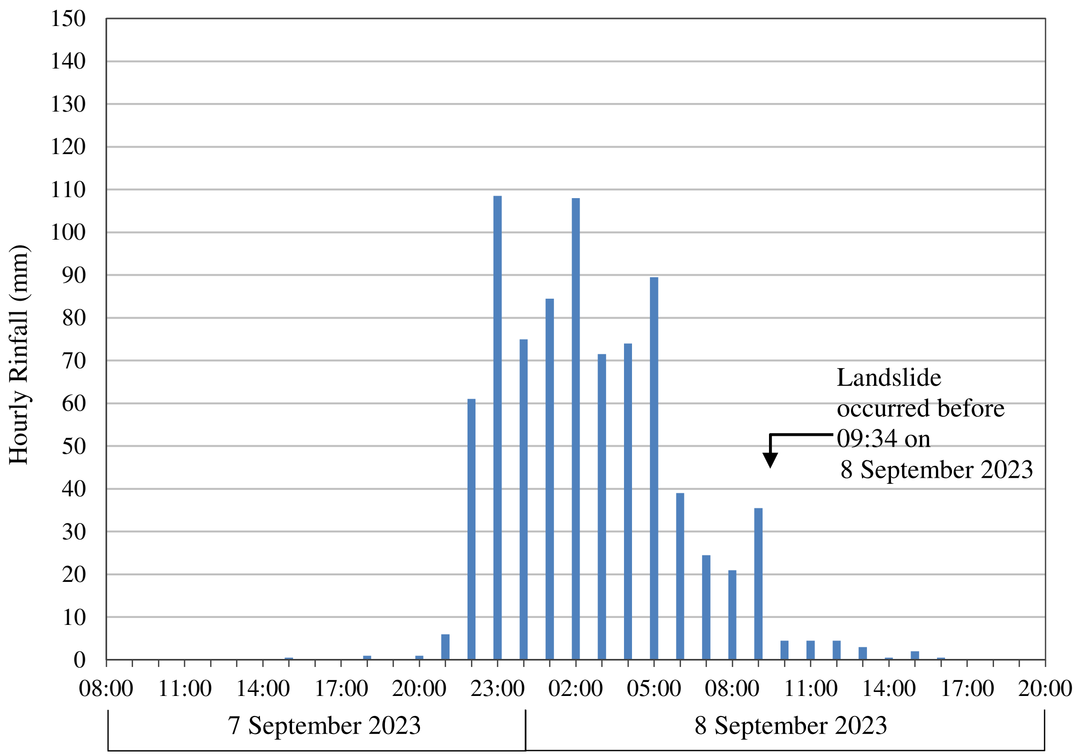
Rainfall data was obtained from the nearest GEO raingauge No. H26, which is located about 1.2 km west of the landslide site (Figure 1.1). This raingauge records rainfall data at 5-minute intervals. Figure 6.1 shows the daily rainfall recorded by the raingauge between 6 August 2023 and 11 September 2023, and the hourly rainfall recorded between 8:00 a.m. on 7 September 2023 and 8:00 p.m. on 8 September 2023. On the other hand, Figure 6.2 presents the daily rainfall recorded between 12 August 2023 and 17 September 2023, and the hourly rainfall recorded between 0:00 a.m. on 13 September 2023 and 4:00 p.m. on 14 September 2023.

Tables 6.1 and 6.2 and Figure 6.3 presents the maximum rolling rainfall for various durations and the comparison of the 8 to 14 September 2023 rainstorms with previous major rainstorms recorded at raingauge No. H26. It can be seen that the 2- to 24-hour rolling rainfall preceding the landslide on 8 September 2023 hit record highs, with the estimated return periods falling between 176 years and over 1,000 years. In contrast, the rainfall preceding the landslide on 14 September 2023 was not particularly intense.

The Gumbel parameters of the raingauge were derived based on the frequency analysis of extreme rainfall using 22 years of rainfall data (Chu, 2023). The large extrapolation of these available data inevitably resulted in considerable uncertainties in determining the return periods of the record-breaking rainstorm events (Wong & Ho, 1996b). Nevertheless, the analysis results indicate that the intensities of 2- to 24-hour rolling rainfall of the 7 to 8 September 2023 rainstorm were the severest ever recorded by raingauge No. H26 since it came into operation in 1999.

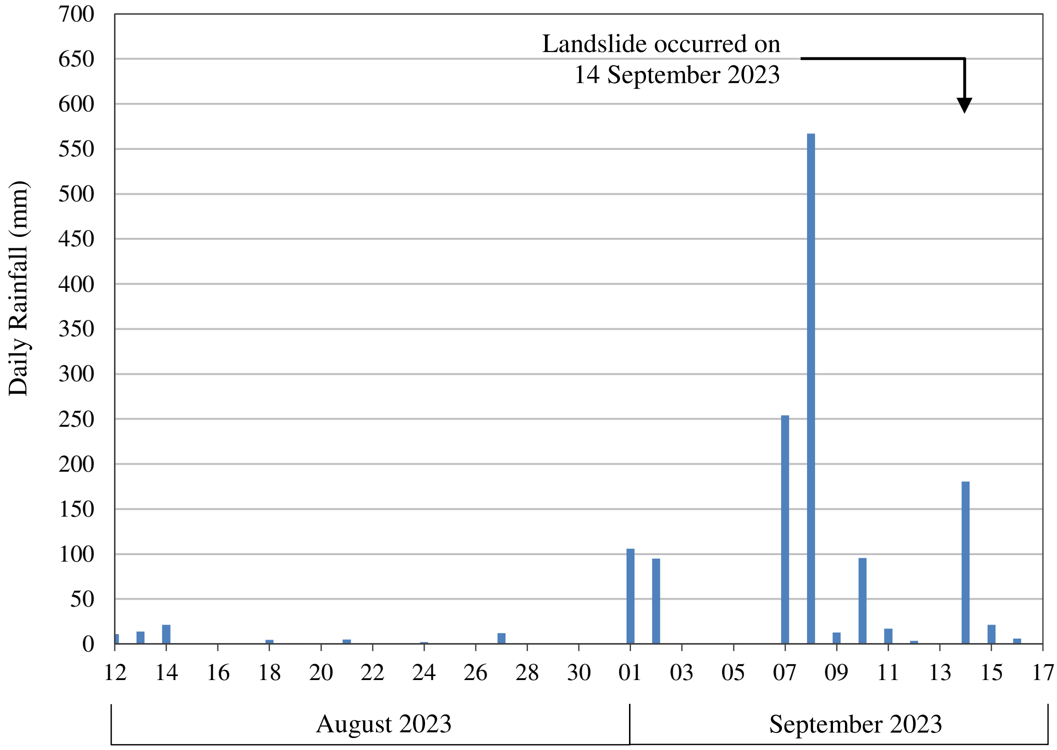


(a) Daily rainfall recorded between 6 August 2023 and 11 September 2023 based on clock-hour rainfall data

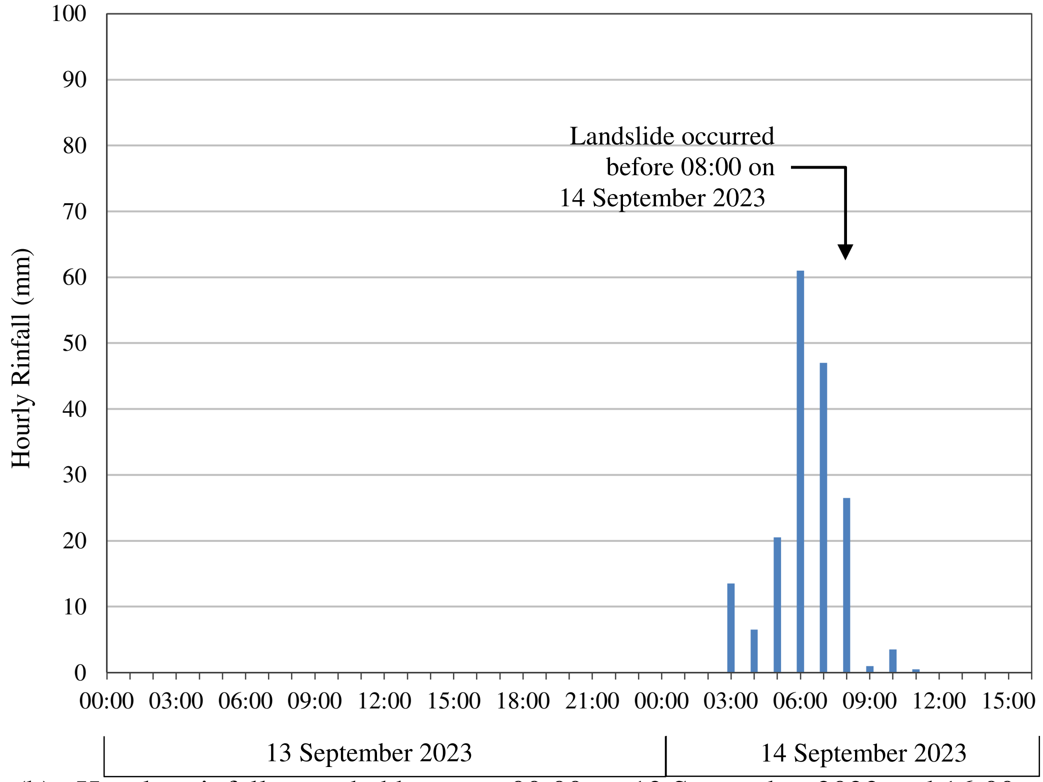


(b) Hourly rainfall recorded between 08:00 on 7 September 2023 and 20:00 on 8 September 2023 based on clock-hour rainfall data

Figure 6.1 Daily and Hourly Rainfall Recorded at GEO Raingauge No. H26 for the Landslide on 8 September 2023



(a) Daily rainfall recorded between 12 August 2023 and 17 September 2023 based on clock-hour rainfall data



(b) Hourly rainfall recorded between 00:00 on 13 September 2023 and 16:00 on 14 September 2023 based on clock-hour rainfall data

Figure 6.2 Daily and Hourly Rainfall Recorded at GEO Raingauge No. H26 for the Landslide on 14 September 2023

Table 6.1 Maximum Rolling Rainfall at GEO Raingauge No. H26 for Selected Durations Preceding the 8 September Landslide and the Estimated Return Periods

Duration	Maximum Rolling Rainfall (mm) (1)(2)	End of Period (3)	Estimated Return Period (years) (4)
5 Minutes	17.5	11:50 p.m. on 7 September 2023	16
15 Minutes	44.5	0:00 a.m. on 8 September 2023	12
30 Minutes	71	1:30 a.m. on 8 September 2023	12
1 Hour	119	1:45 a.m. on 8 September 2023	15
2 Hours	229	1:40 a.m. on 8 September 2023	176
4 Hours	389.5	1:45 a.m. on 8 September 2023	> 1000
12 Hours	792	9:00 a.m. on 8 September 2023	> 1000
24 Hours	803.5	9:34 a.m. on 8 September 2023	> 1000
48 Hours	804.5	9:34 a.m. on 8 September 2023	> 1000
4 Days	805.5	9:34 a.m. on 8 September 2023	150
7 Days	1005.5	9:34 a.m. on 8 September 2023	429
15 Days	1019	9:34 a.m. on 8 September 2023	95
31 Days	1118.5	9:34 a.m. on 8 September 2023	24

Notes:
(1) Maximum rolling rainfall was calculated from 5-minute interval rainfall data.
(2) The nearest GEO raingauge is raingauge No. H26 located about 1.2 km west of the landslide site. The raingauge came into operation on 1 November 1999.
(3) For the purpose of rainfall analysis, the landslide occurred before 9:34 a.m. on 8 September 2023.
(4) Return periods were estimated based on the method described by Chu (2023).

Table 6.2 Maximum Rolling Rainfall at GEO Raingauge No. H26 for Selected Durations Preceding the 14 September Landslide and the Estimated Return Periods

Duration [1]	Maximum Rolling Rainfall (mm) [2][3]	End of Period [4]	Estimated Return Period (years) [5]
5 Minutes	11	5:45 a.m. on 14 September 2023	< 2
15 Minutes	29	5:45 a.m. on 14 September 2023	< 2
30 Minutes	50	5:45 a.m. on 14 September 2023	< 2
1 Hour	70	6:10 a.m. on 14 September 2023	< 2
2 Hours	115	7:15 a.m. on 14 September 2023	3
4 Hours	157	7:40 a.m. on 14 September 2023	3
12 Hours	175	7:40 a.m. on 14 September 2023	2
24 Hours	175	7:40 a.m. on 14 September 2023	< 2
48 Hours	178.5	7:40 a.m. on 14 September 2023	< 2
4 Days	246	6:40 p.m. on 14 September 2023	< 2
7 Days	1124	7:40 a.m. on 14 September 2023	> 1000
15 Days	1327	7:40 a.m. on 14 September 2023	> 1000
31 Days	1363.5	7:40 a.m. on 14 September 2023	125

Notes:

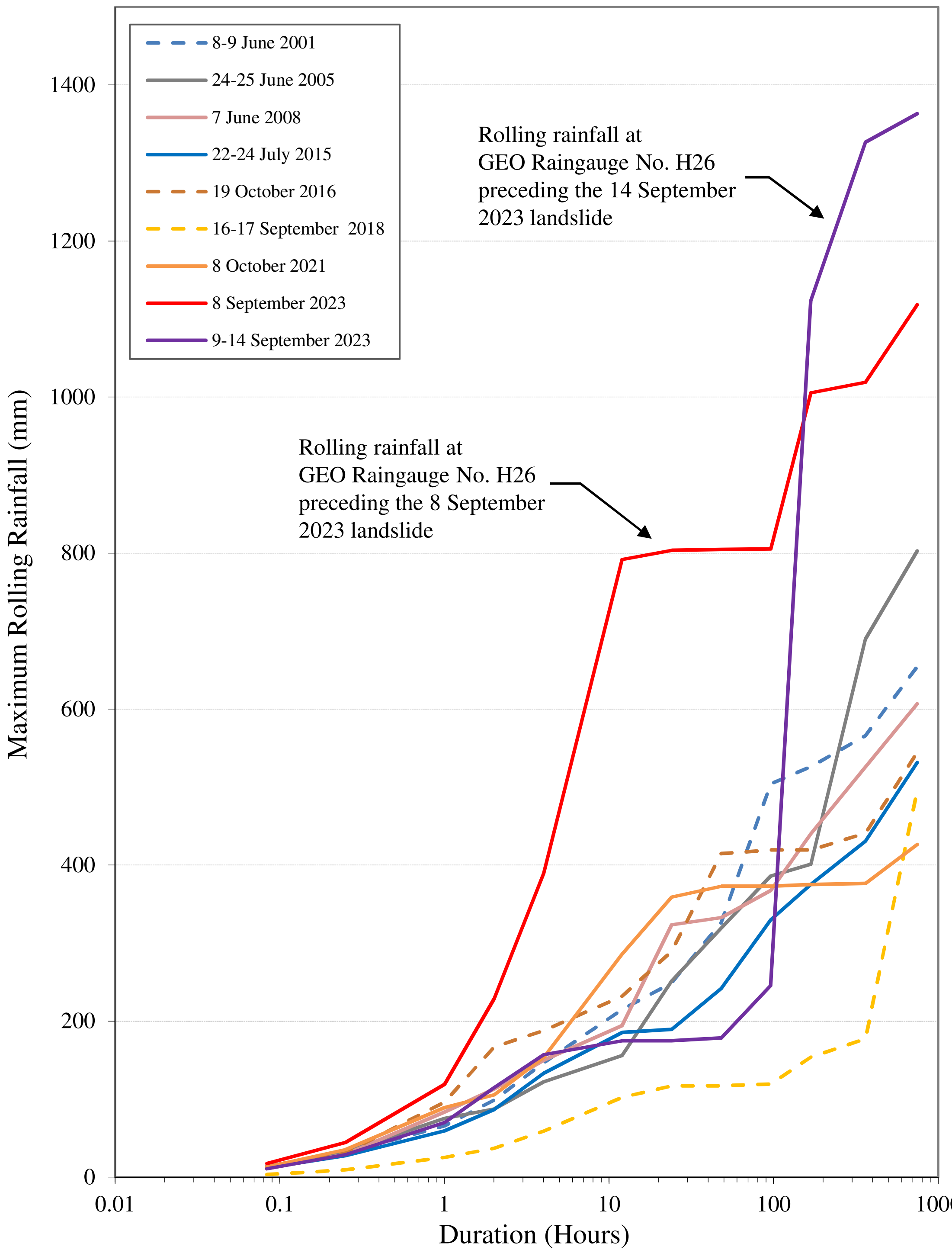
(1) The durations of 5 minutes to 4 days refer to the period between 9 September and 14 September 2024 and durations of 7 days to 31 days refer to the period between 13 August and 14 September 2024.

(2) Maximum rolling rainfall was calculated from 5-minute interval rainfall data.

(3) The nearest GEO raingauge is raingauge No. H26 located about 1.2 km west of the landslide site. The raingauge came into operation on 1 November 1999.

(4) For the purpose of rainfall analysis, the landslide occurred before 8:00 a.m. on 14 September 2023.

(5) Return periods were estimated based on the method described by Chu (2023).



Notes: (1) Maximum rolling rainfall was evaluate from 5-minute interval rainfall data recorded at GEO raingauge No. H26, located at about 1.2 km west of the landslide site.

(2) The GEO Raingauge No. H26 started its operations since 1999.

Figure 6.3 Maximum Rolling Rainfall Preceding the Landslides and Previous Major Rainstorms at GEO Raingauge No. H26

7 Slope Stability Back-analyses

Slope stability back-analyses were conducted to determine the probable extent of a rise in the groundwater table, in response to the rainfall that triggered the sliding failure on 8 September 2023. The analyses were carried out using the computer program SLOPE/W, which employed the limit equilibrium method to compute theoretical factors of safety at different levels of the groundwater table. The pre- and post-landslide ground profiles of the landslide site were established using the 2020 LiDAR data, post-landslide topographic information collected by the UAVs, and field observations.

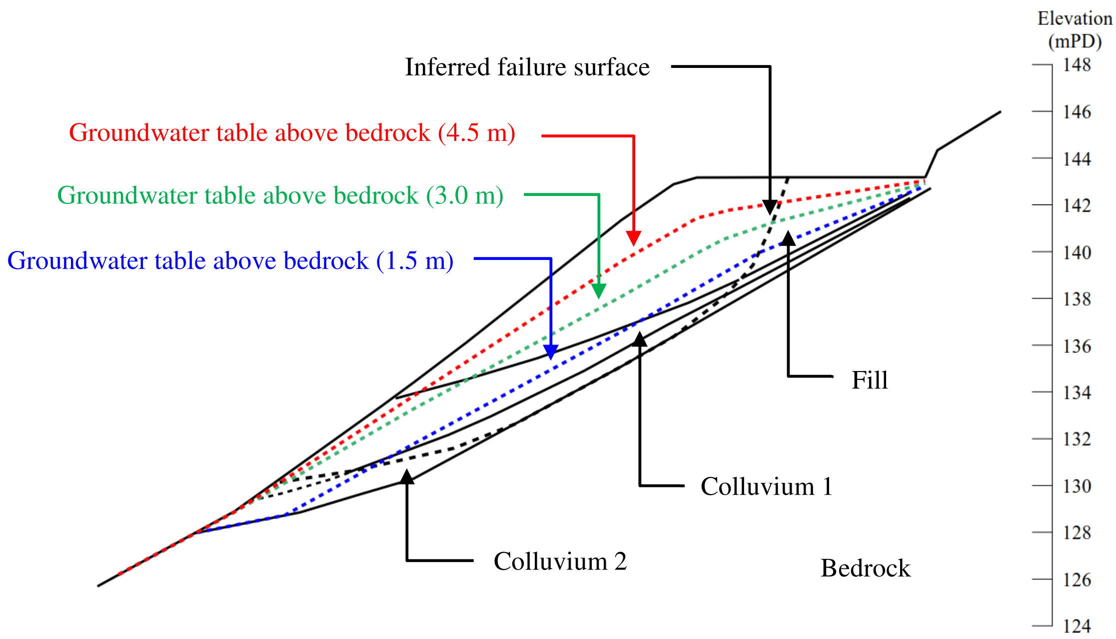
Table 7.1 summarises the shear strength parameters adopted in the analyses, based primarily on the derived parameters in the previous LPM Study (Section 3.3.2). Figure 7.1 illustrates the representative cross-section of the landslide site along with the results of the analyses.

Table 7.1 Soil Parameters Adopted in Slope Stability Back-analyses

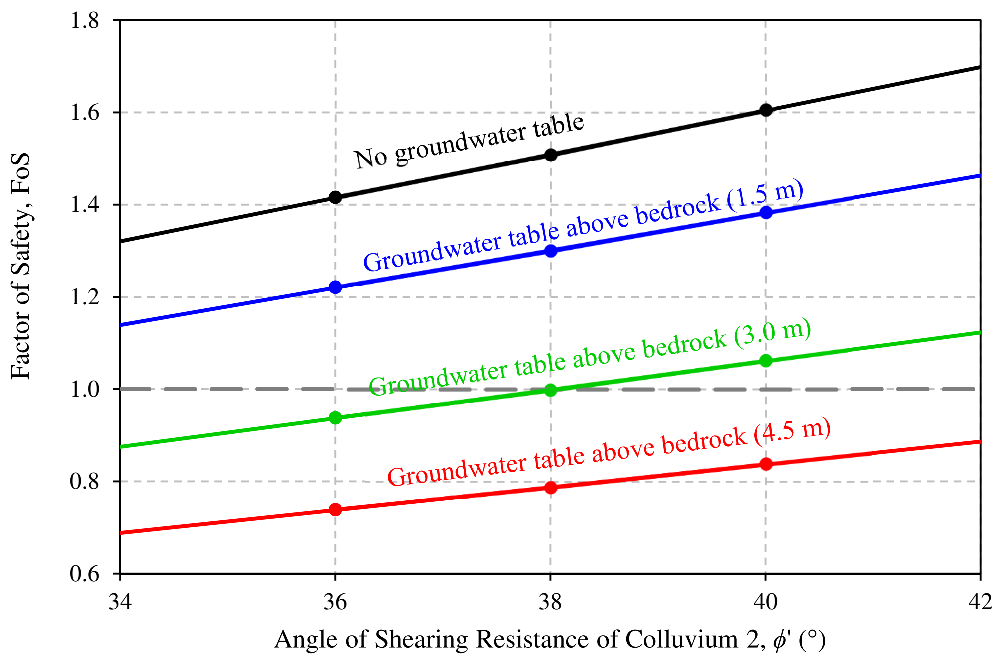
Soil Type	Bulk Unit Weight γ (kN/m³)	Cohesion c' (kPa)	Angle of Shearing Resistance ϕ' (°)
Fill	19	0	40 (1)
Colluvium 1	19	2	36 (2)
Colluvium 2	19	0	Varies from 38 to 40 (3)

Notes:
(1) The angle of shearing resistance is based on the assumed parameter in the previous LPM Study (Binnie, 1997).
(2) The angle of shearing resistance is based on the derived lower-bound parameter from site-specific laboratory tests (Binnie, 1997).
(3) The angle of shearing resistance is based on the derived upper-bound and lower-bound parameters from site-specific laboratory tests (Binnie, 1997).

The analyses considered various slip surfaces of shallow and deep-seated sliding failure modes to assess the groundwater conditions during the incident on 8 September 2023. The results indicate that the build-up of the perched groundwater table within the fill layer would result in a shallow failure. On the other hand, the deep-seated sliding failure would correspond to an approximately 3 m rise of the groundwater table above the bedrock, given the ranges of shear strength parameters of the colluvium 2. The results of the rise in the groundwater table above the bedrock rather than the development of the perched water pressure within the fill layer are consistent with the previous groundwater monitoring records (Section 5.3) and field observations that the rupture surface encroached deeply onto the interface of colluvium and bedrock, and seepage was evident on the source floor at this interface (Section 5.1).



(a) Representative cross-section



(b) Results of slope stability back-analyses

Figure 7.1 Summary of Slope Stability Back-analyses

It is important to note that the landslide that occurred on 14 September 2023 was primarily caused by surface erosion on the newly placed rockfill without a distinct slip surface, but an eroded source floor. Therefore, the failure mechanism of the landslide was supported by field observations (Section 5.1.2) instead of slope stability back-analyses using the limit equilibrium method.

8 Diagnosis of the Landslides

The close correlation between the timing of the incidents and the rainstorms suggests that the landslides on 8 and 14 September 2023 were rain-induced.

The fill slope was formed before 1924 during the construction of Shek O Road (Section 3.1). The construction practice at that time likely involved cutting the hillside to form the road and end-tipping the excavated materials on the downslope side. The fill material was not properly compacted with the relative compaction varying between 88% and 92% (Section 3.3.3). The loose nature of the fill facilitated water ingress and rapid saturation of the underlying materials. The landslides in 1995 and 2016 further indicated that the fill slope downhill in this road section is prone to landsliding (Section 3.2.3).

Slope stability back-analyses suggest that the rise in the groundwater table above the bedrock could have contributed to the landslide. Probable sources of water, either separately or in combination, that could have led to the rise in the groundwater table in the slope body include:

(a) Direct infiltration: Rainwater infiltrated into the underlying soils through the cracked shotcrete cover on the fill slope and the porous rockfill placed after emergency repair works (Sections 3.3.4, 5.1.1 and 5.1.2).

(b) Subsurface flow: Surface water from the uphill rocky natural stream course had probably flowed and seeped along a preferential path at the interface between colluvium and bedrock. This is evident by the pre-landslide groundwater monitoring results (Section 5.3), seepage observed on the landslide scar (Sections 5.1.1 and 5.1.2), and the persistent water flow on the nearby cut slopes (Section 5.1.2) during the post-landslide field mapping.

(c) Uncontrolled surface runoff: The capacity of the cross-road drain was probably inadequate when it was substantially blocked by foliage and debris (Sections 5.1.1 and 5.1.2). The water ponding at the upslope inlet caused significant overflow to Shek O Road, where most roadside gullies were blocked. Without the roadside upstand, the surface water overflowed directly onto the fill slope at the topographical low point.

The blockage of road drains and catchpits along Shek O Road failed to drain the surface runoff. The road formed in the 1920s with minor modifications since then (Section 3.1). It descends from the north to the south, slightly curved on-plan, and served as a natural conduit to divert surface water from other catchments to the fill slope. The absence of slope surface channels and roadside upstand (Section 2.1), other than the 300 mm and 600 mm U-channels, eventually led to the concentrated water flow onto the fill slope.

The effectiveness of the drainage system plays a vital role in preventing landslides. The rocky natural stream course overseeing Shek O Road is supposed to be intercepted by the 600 mm diameter cross-road drain, diverting surface water to the 600 mm U-channel on the fill slope. Tables 8.1 and 8.2 estimate the surface runoff carried down from the rocky natural stream course through the cross-road drain. By comparison, the theoretical capacity of the cross-road drain appears sufficient to convey the flow from the upslope catchment. Nevertheless, the blockage of the cross-road drain diminished its intended function and led to overflow to Shek O Road.

Table 8.1 Surface Runoff from the Upslope Catchment

Runoff coefficient	Area of catchment (m^2)	Surface runoff (m^3/min)
0.9	25,733	27 to 46

Note: Surface runoff was calculated using rainfall intensities of 70 mm/hr (5:10 a.m. – 6:10 a.m. on 14 September 2023) and 119 mm/hr (00:45 a.m. – 1:45 a.m. on 8 September 2023) recorded at GEO raingauge No. H26.

Table 8.2 Flow Capacity of the Cross-road Drain

Diameter (mm)	Gradient (m/m)	Flow capacity (m^3/min)
600	0.103	186

The landslide on 8 September 2023 involved a sliding failure with a well-defined main scarp encroaching onto Shek O Road and a sliding surface between colluvium and bedrock. The blocked drainage measures on Shek O Road, the cracked slope surface cover, and the lack of subsurface drainage provisions inevitably led to the rise in the main groundwater table above the bedrock in the slope body. The failure was not particularly mobile as most detached materials were deposited below the fill slope with a debris travel angle of about 30°. The observations of limited debris mobility and the deep sliding surface to the interface between colluvium and bedrock rather than solely in fill preclude the potential of liquefaction failure.

After the landslide, emergency repair works were carried out to reinstate the failed area by placing rockfill. However, on 14 September 2023, another landslide resulted in a washout failure of the rockfill and the underlying fill and colluvium. Once again, the blockage of the cross-road drain and roadside gullies caused flooding on Shek O Road and uncontrolled surface runoff to the repaired main scarp of the fill slope.

Figures 8.1 to 8.4 illustrate the reconstructed sequence of the events which led to the landslides on 8 and 14 September 2023.

Local geotechnical practitioners have long discussed environmental factors and road drainage causing roadside slope failures (Au & Suen, 1991 & 1996). One of the lessons learnt from the Shum Wan Road Landslide of 13 August 1995 was that "the discharge of water into the top of a slope can be an important factor in triggering a landslide. Continued discharge into a slope following a failure will weaken and soften materials within a slope and can prolong the downhill movement of debris. There should be awareness as to the role of roads in acting as catchments for collecting and channelling water into the upper part of slopes" (GEO & Knill, 1996). It is sometimes observed that the capacities of catchpits and cross-road drains could not cope with the water flow, causing roadway flooding and overflowing onto nearby downslopes. As extreme rainstorms brought by climate change happen more and more frequently, this scenario will likely happen more often.

In light of the environmental setting at the landslide site, the existing blocked cross-road drain could not cope with the high intensity of rainwater and surface water from the rocky natural stream course. This caused flooding on Shek O Road and overflow onto the fill slope. The overflow from Shek O Road, along with the subsurface flow and direct infiltration through the cracked slope surface, would have resulted in the rise in the groundwater table in the slope body, leading to the failure.

The landslide highlighted the importance of proper and regular maintenance on slopes and roadside drainage provisions. Suitable precautionary measures at drainage inlets, such as trash grilles or debris screens at inlets, are warranted if materials carried down by the flow would block the downstream drainage system. Subsurface drainage measures, such as drainage blankets and prescriptive raking drains, might be necessary to control the possible build-up of groundwater pressures at depth during intense rainfall.

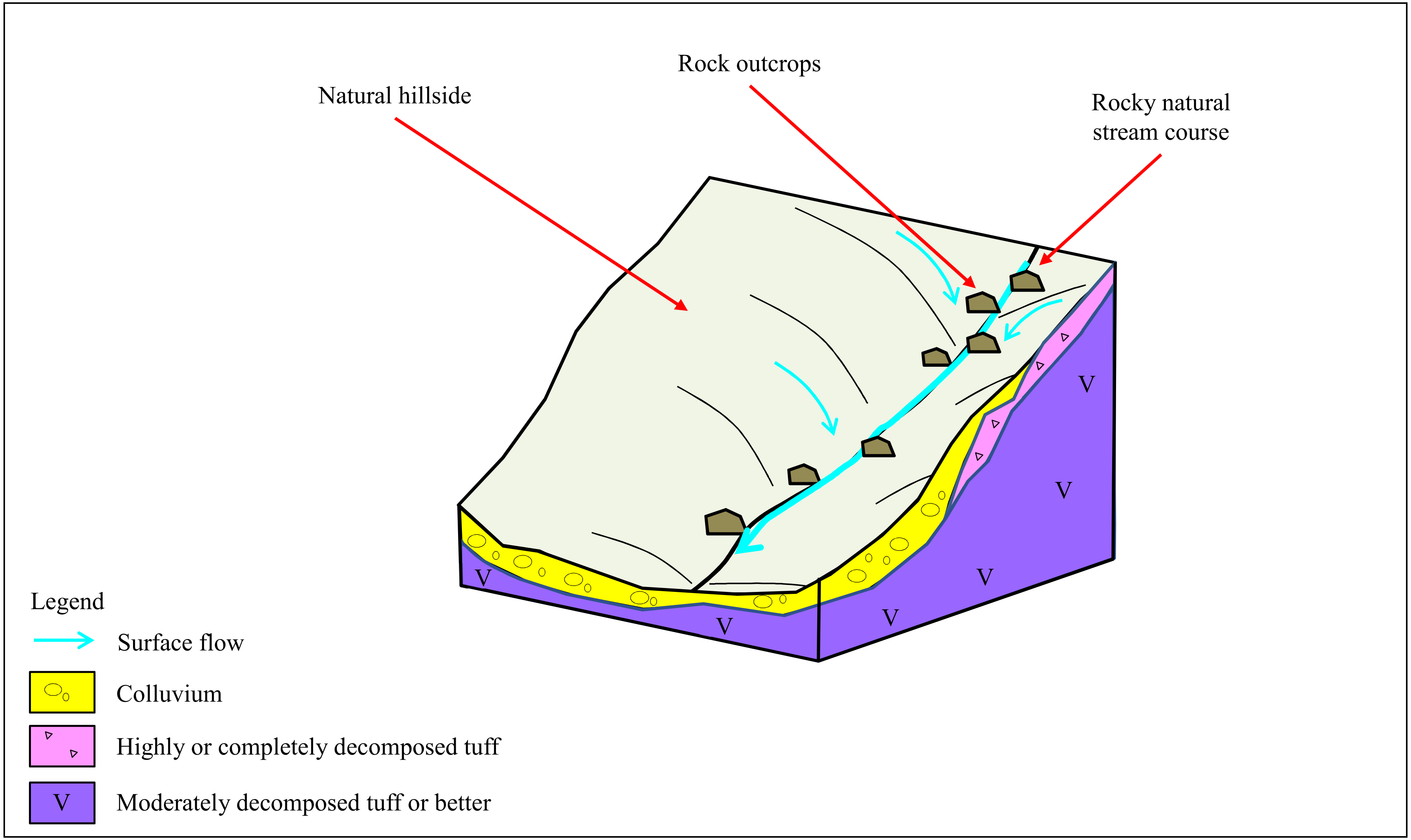


Figure 8.1 Ground Model – Before Formation of Shek O Road

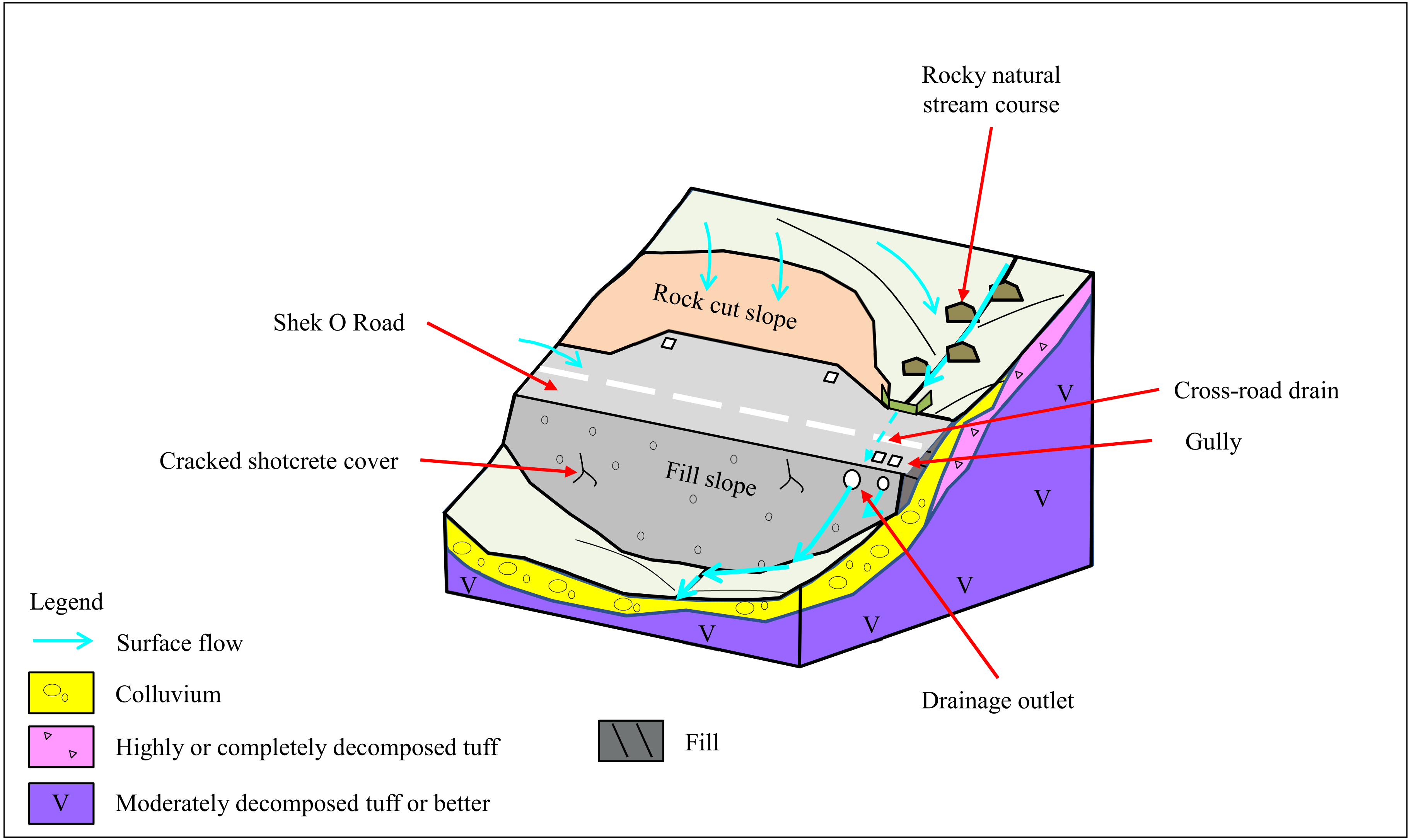


Figure 8.2 Ground Model – After Formation of Shek O Road

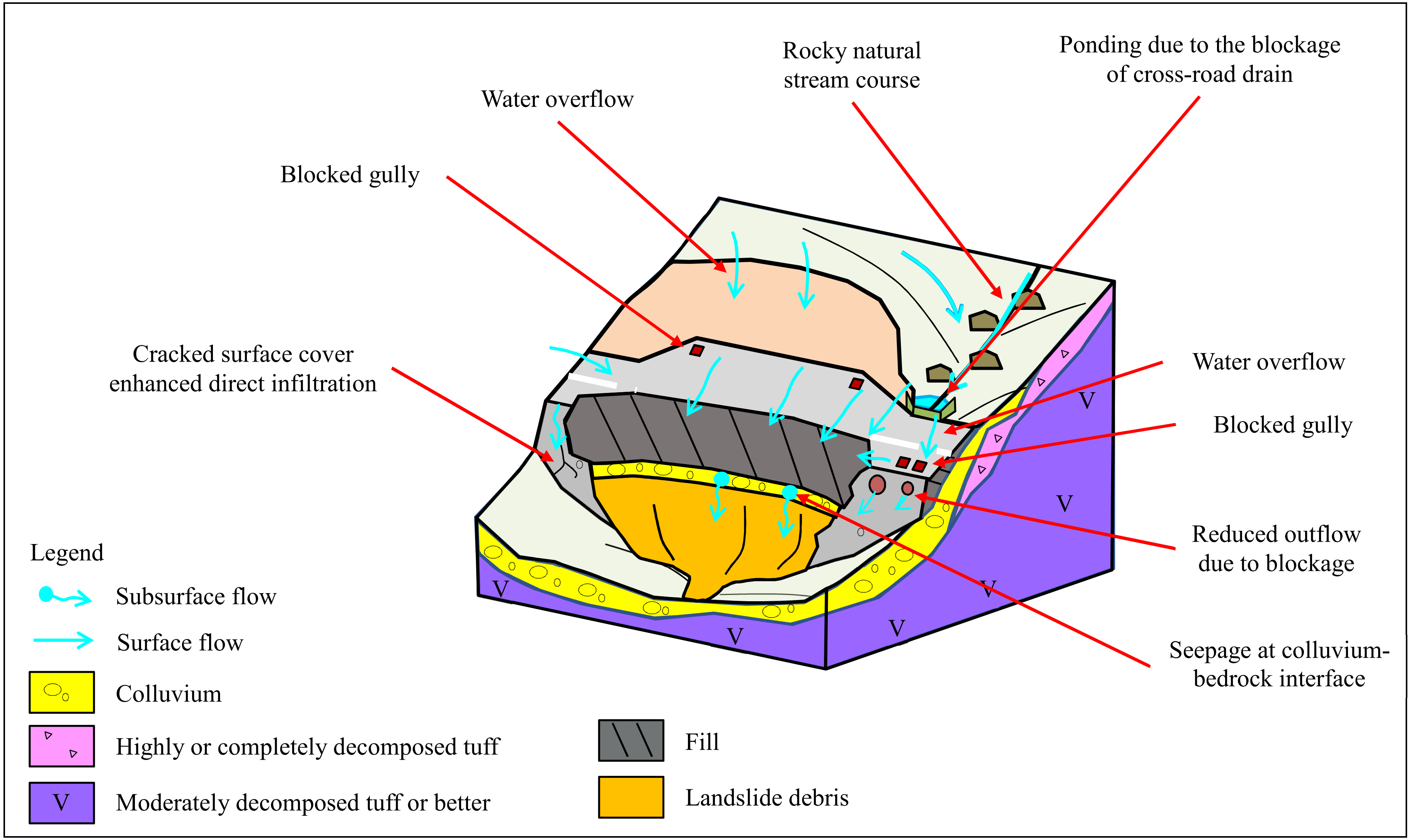


Figure 8.3 Ground Model – Landslide on 8 September 2023

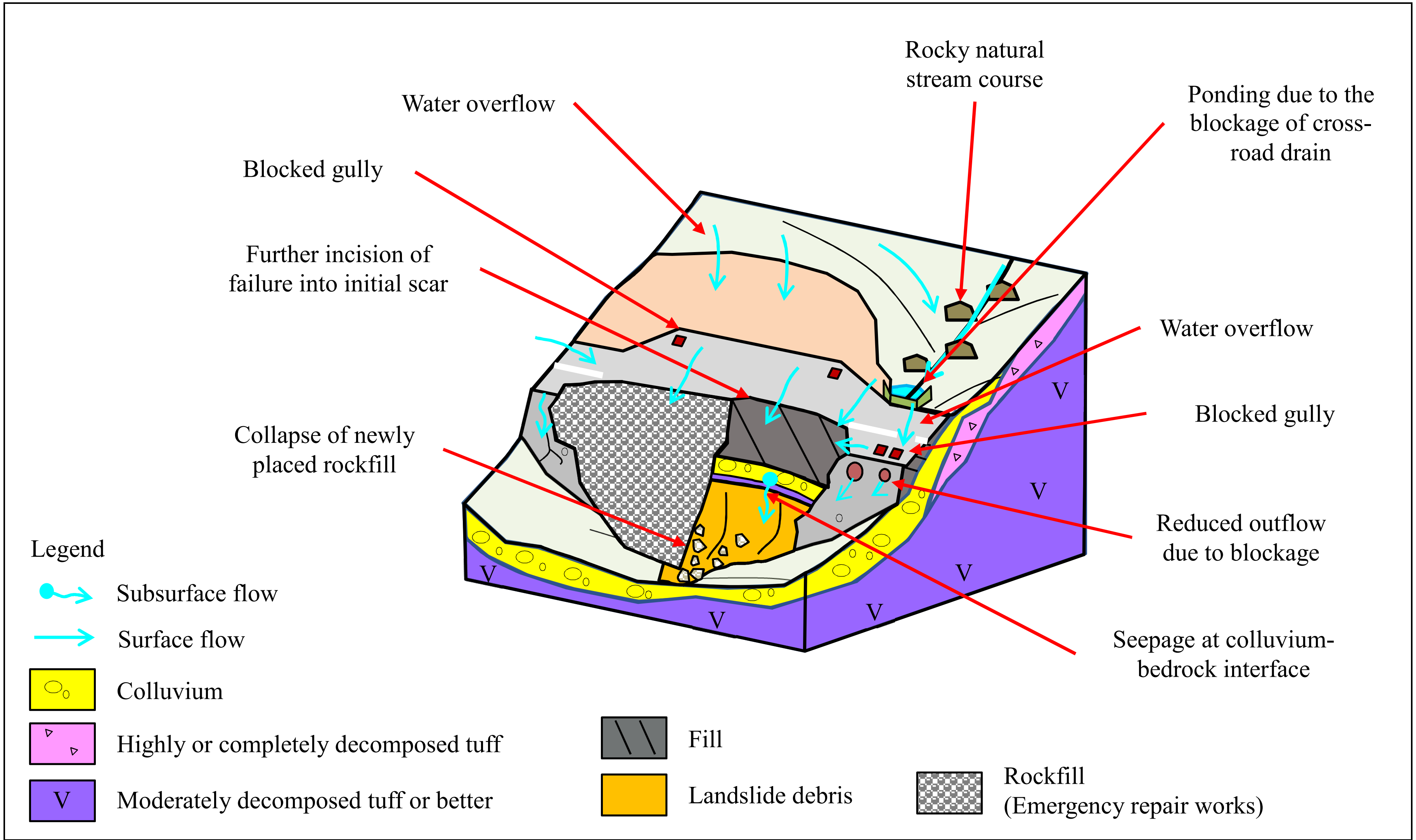


Figure 8.4 Ground Model – Landslide on 14 September 2023

9 Conclusions

The rainfall preceding the failures on 8 and 14 September 2023 triggered the landslides. The exact time and duration of the incidents are not known.

The landslide on 8 September 2023 involved a sliding failure at the interface between colluvium and bedrock. The blockage of the catchpit, cross-road drain, and gullies caused significant overflow to the fill slope and enhanced infiltration through the cracked shotcrete cover. Coupled with the subsurface flow, the rise in the groundwater table would have eventually triggered the failure.

On the other hand, the landslide on 14 September 2023 involved a washout failure of the newly placed rockfill and the underlying fill and colluvium. Direct infiltration into the rockfill and overflow from Shek O Road would have resulted in surface erosion.

This incident served as a vivid example to highlight the importance of proper and regular maintenance on slopes and roadside drainage provisions, as well as providing surface and subsurface drainage measures for slopes.

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Appendix A

Aerial Photograph Interpretation

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A.1 Introduction

This appendix presents an aerial photograph interpretation (API) of the landslide site and its vicinity to identify a detailed site history, including geomorphological characteristics and past instabilities. About 60 pairs of aerial photographs have been reviewed covering the period from 1924 to 2022.

A.2 Summary

The earlier available aerial photographs in 1924 show that slope No. 11SE-D/F47 was formed as part of the construction of Shek O Road. The fill slope is located on the middle portion of a south-facing planar hillside. The region was largely undeveloped and covered with moderately dense vegetation.

The hillside was characterised by a concave terrain with several well-defined drainage lines trending to the southwest with dendritic pattern. The slope located in a valley bounded by steep south to south-west sloping, rounded spurlines. A rocky natural stream course descends from the natural hillside to the slope.

Minor improvement works to Shek O Road, such as construction of the lay-by area in 1961, were observed occasionally from the available aerial photographs. Slope repair works were carried out in 1995 and 2016 to 2017, respectively, following the landslides (Incident Nos. HK95/8/31 and 2016/11/1997). No significant changes were observed after 2017.

A.3 Detailed Observations

Year	Observations
1924	High level (12500 ft) single aerial photograph of moderate quality. The fill slope was formed in association with the construction of Shek O Road. The catchment above the fill slope was masked by moderately dense shrub or grassy vegetation. Well-defined drainage lines are discerned.
1945	High level (20000 ft) stereopair of good quality. A footpath is discerned at about 140 m upslope, traversing across the hillside. A firebreak is observed about 10 m upslope of Shek O Road. A catchwater was formed at about 220 m downslope, toward Tai Tam Tuk Reservoir.
1949	High level (8000 & 8600 ft) stereopairs of good quality. A recent ENTLI feature (ENTLI No. 11SED0384E) is observed at the downslope catchment (RC4).
1961	High level (30000 ft) stereopair of good quality. A lay-by area was formed at the northbound lane of Shek O Road opposite to the fill slope.
1963	Low level (2700 ft) stereopair of excellent quality. Three ENTLI features (ENTLI Nos. 11SED0067E, 11SED0068E and 11SED0069E) are observed at the upslope catchment (RC1 to RC3).
1964	High level (12500 ft) stereopair of moderate quality. No significant changes are apparent.
1967	Medium level (6250 ft) stereopair of good quality. No significant changes are apparent.
1972	High level (13000 ft) single aerial photograph of good quality. No significant changes are apparent.
1973	High level (12500 ft) single aerial photograph of good quality. No significant changes are apparent.
1974	High level (12500 ft) stereopair of good quality. No significant changes are apparent.
1975	High level (12500 ft) stereopair of good quality. No significant changes are apparent.
1976	Low level (4000 ft) stereopair of good quality. No significant changes are apparent.
1978	Low level (4000 ft) stereopair of moderate quality. No significant changes are apparent.
1979	High level (10000 ft) stereopair of good quality. Tai Tam Gap correctional Institution to the north of the fill slope was constructed.

Year	Observations
1980	High level (10000 ft) stereopair of good quality. No significant changes are apparent.
1981	Low and high level (4000 & 10000 ft) stereopairs of good quality. No significant changes are apparent.
1982	High level (10000 ft) stereopair of good quality. No significant changes are apparent.
1983	High level (10000 ft) stereopair of good quality. No significant changes are apparent.
1984	Low level (4000 ft) stereopair of good quality. The area to the west of Shek O Road between slope Nos. 11SE-D/F157 and 11SE-D/FR94 appeared to be under construction.
1985	High level (10000 ft) stereopair of good quality. No significant changes are apparent.
1986	Low level (4000 ft) stereopair of good quality. No significant changes are apparent.
1987	Low level (4000 ft) stereopair of good quality. No significant changes are apparent.
1988	Low level (4000 ft) stereopair of good quality. No significant changes are apparent.
1989	Low level (4000 ft) stereopair of good quality. No significant changes are apparent.
1990	Low level (4000 ft) stereopair of good quality. No significant changes are apparent.
1991	Low level (4000 ft) stereopair of good quality. No significant changes are apparent.
1992	Low level (4000 ft) stereopair of good quality. No significant changes are apparent.
1993	Low level (4000 ft) stereopair of good quality. No significant changes are apparent.
1994	Low level (4000 ft) stereopair of good quality. No significant changes are apparent.
1995	Low level (4000 ft) stereopair of good quality. The fill slope was repaired following the landslide (Incident No. HK95/8/3). Formation works of slope No. 11SE-D/F174 was completed.
1996	Low level (4000 ft) stereopair of good quality. No significant changes are apparent.
1997	Low level (4000 ft) stereopair of good quality. No significant changes are apparent.
1998	Low level (4000 ft) stereopair of good quality. No significant changes are apparent.
1999	Low level (2500 ft) stereopair of good quality. No significant changes are apparent.
2000	Low level (4000 ft) stereopair of good quality. No significant changes are apparent.

Year	Observations
2001	Low level (4000 ft) stereopair of good quality. No significant changes are apparent.
2002	Low level (3500 ft) stereopair of good quality. No significant changes are apparent.
2003	Low level (4000 ft) stereopair of good quality. No significant changes are apparent.
2004	Low level (4000 ft) stereopair of good quality. No significant changes are apparent.
2005	Low level (4000 ft) stereopair of good quality. No significant changes are apparent.
2006	Medium level (6000 ft) stereopair of good quality. No significant changes are apparent.
2007	Low level (3000 ft) stereopair of good quality. No significant changes are apparent.
2008	Medium level (6000 ft) stereopair of good quality. No significant changes are apparent.
2009	Low level (3000 ft) stereopair of good quality. No significant changes are apparent.
2010	Medium level (6000 ft) stereopair of good quality. No significant changes are apparent.
2011	Medium level (6000 ft) stereopair of good quality. No significant changes are apparent.
2012	Medium level (6000 ft) stereopair of good quality. No significant changes are apparent.
2013	Low level (3000 ft) stereopair of good quality. No significant changes are apparent.
2014	Medium level (6000 ft) stereopair of good quality. No significant changes are apparent.
2015	Medium level (6000 ft) stereopair of good quality. No significant changes are apparent.
2016	Medium level (6000 ft) stereopair of good quality. No significant changes are apparent.
2017	Medium level (6000 ft) stereopair of good quality. The failure scar of landslide in 2016 (Incident No. 2016/11/1997) probably repaired as indicated by an area of relatively high reflectance.
2018	Medium level (6900 ft) stereopair of good quality. No significant changes are apparent.

Year	Observations
2019	Medium level (6900 ft) stereopair of good quality. No significant changes are apparent.
2020	Medium Level (6900 ft) stereopair of fair quality. No significant changes are apparent.
2021	Medium Level (6900 ft) stereopair of good quality. No significant changes are apparent.
2022	Medium Level (6900 ft) stereopair of good quality. No significant changes are apparent.

Table A1 List of Aerial Photographs (Sheet 1 of 3)

Date of Photographs	Photograph Number	Altitude (ft)
1924	Y00039	12500
11/11/1945	Y00384 &Y00385	20000
29/04/1949	Y01248 to Y01250	8000
25/05/1949	Y01184 & Y01185	8600
17/01/1961	Y04731 & Y04732	30000
01/02/1963	Y06998 & Y06999	2700
1964	Y12802 & Y12803	12500
16/05/1967	Y13244 & Y13245	6250
03/10/1972	2289	13000
20/12/1973	8054	12500
21/11/1974	9664 & 9665	12500
14/12/1975	12074 & 12075	12500
19/12/1975	11701 & 11702	12500
04/11/1976	15861 & 15862	12500
30/11/1978	23727 & 23728	4000
28/11/1979	27957 & 27958	10000
28/11/1980	33376 & 33377	10000
18/05/1981	37494	4000
26/10/1981	38967 & 38968	10000
10/10/1982	44448 & 44449	10000
30/11/1983	51265 & 51266	10000
02/03/1984	53762 & 53763	4000
07/07/1985	A01677 & A01678	10000
20/09/1986	A06093 & A06094	4000
09/09/1987	A10392 to A10394	4000
27/09/1988	A14534 & A14535	4000
15/08/1989	A17737 & A17738	4000
14/11/1990	A23874 & A23875	4000
04/10/1991	A27927 & A 27973	4000

Note: Photographs numbered with CN, CW, CS, E or RS are in colour. All others are in black and white.

Table A1 List of Aerial Photographs (Sheet 2 of 3)

Date of Photographs	Photograph Number	Altitude (ft)
12/05/1992	A31034 & A31035	4000
05/12/1993	A37053 & A37054	4000
17/11/1994	CN8018 to CN8020	4000
31/10/1995	CN11703 & CN11704	4000
23/10/1996	CN15492 & CN15943	4000
23/07/1997	CN17785 to CN17787	4000
23/10/1998	CN21046 & CN21047	4000
04/06/1999	CN22942 & CN22943	2500
09/08/2000	CN27621 & CN27622	4000
27/09/2001	CW34402 & CW34403	4000
17/04/2002	CW39963 & CW 39964	3500
25/11/2003	CW53130 to CW53132	4000
05/10/2004	CW60486 & CW60487	4000
24/10/2005	CW65600 & CW65601	4000
21/12/2006	CS02614 & CS02615	6000
12/07/2007	CW77211 & CW 77212	3000
20/11/2008	CS19336 & CS 19337	6000
08/07/2009	CW83347 & CW83348	3000
15/01/2010	RS00692 & RS00693	6000
04/07/2011	CS32887 & CS32888	6000
07/06/2012	CS36624 & CS36625	6000
02/01/2013	CW99489 & CW99490	3000
01/01/2014	CS47680 & CS47681	6000
01/01/2015	CS54696 & CS54697	6000
01/01/2016	CS62639 & CS62640	6000
06/01/2017	E012072C to E012074C	6000
05/10/2018	E046848C, E046849C	6900
04/12/2019	E083191C & E083192C	6900
27/10/2020	E103455C & E103456C	6900

Note: Photographs numbered with CN, CW, CS, E or RS are in colour. All others are in black and white.

Table A1 List of Aerial Photographs (Sheet 3 of 3)

Date of Photographs	Photograph Number	Altitude (ft)
13/01/2021	E122779C & E122780C	6900
11/01/2022	E146018C & E146018C	6900

Note: Photographs numbered with CN, CW, CS, E or RS are in colour. All others are in black and white.

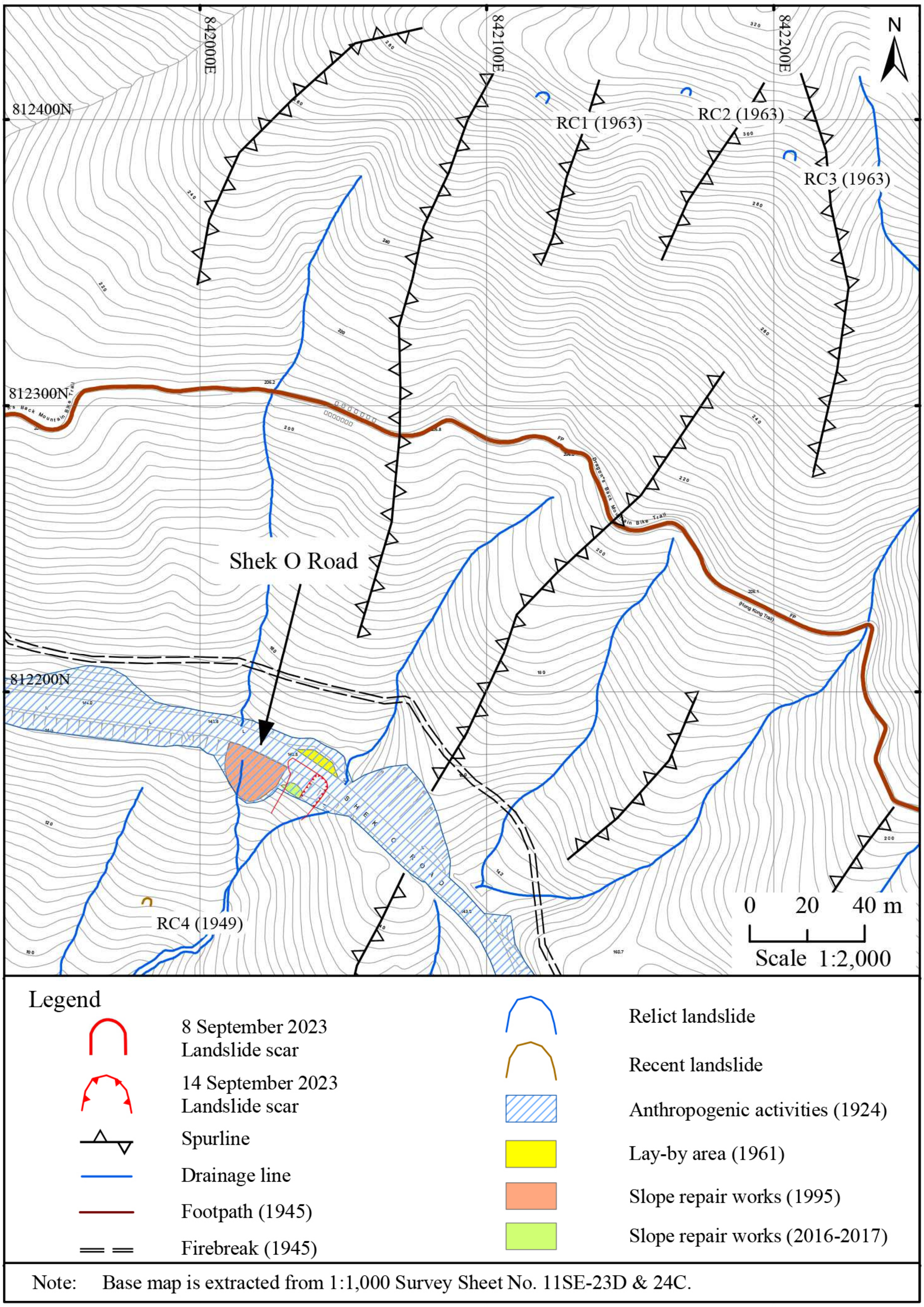

Figure A1 Summary of API Observations

Appendix B

Video Clip Showing Overland Flow

Contents

List of Video

Video B1 Video Clip showing Overland Flow from Shek O Road towards the Fill Slope (Video recorded on 14 September 2023)

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或

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