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INVESTIGATION OF SOME SELECTED LANDSLIDE INCIDENTS IN 1997 (VOLUME 5)

GEO REPORT No. 91

Halcrow Asia Partnership Ltd.
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. A charge is made to cover the cost of printing.

The Geotechnical Engineering Office also publishes guidance documents as GEO Publications. These publications and the GEO Reports may be obtained from the Government's Information Services Department. Information on how to purchase these documents is given on the last page of this report.

R.K.S. Chan
Head, Geotechnical Engineering Office
June 1999
EXPLANATORY NOTE

This GEO Report consists of four Landslide Study Reports on the investigation of selected slope failures that occurred in 1997. The investigations were carried out by Halcrow Asia Partnership Ltd (HAP) for the Geotechnical Engineering Office as part of the 1997 Landslip Investigation Consultancy.

The LI Consultancies aim to achieve the following objectives through the review and study of landslides:

(a) establishment of an improved slope assessment methodology,

(b) identification of slopes requiring follow-up action, and

(c) recommendation of improvement to the Government’s slope safety system and current geotechnical engineering practice in Hong Kong.

The Landslide Study Reports prepared by HAP are presented in four sections in this Report. Their titles are as follows:

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The Landslip Investigation Division of the Geotechnical Engineering Office worked closely with the LI Consultants and provided technical input and assistance to the landslide studies.
SECTION 1:
DETAILED STUDY OF THE LANDSLIDE AT HONG TSUEN ROAD, SAI KUNG ON 3 JULY 1997

Halcrow Asia Partnership Ltd

This report was originally produced in December 1998 as GEO Landslide Study Report No. LSR 21/98
FOREWORD

This report presents the findings of a detailed study of a landslide (GEO Incident No. ME 97/7/6) that occurred in the early hours of 3 July 1997 on a soil cut slope adjacent to Hong Tsuen Road, Sai Kung. Landslide debris blocked a two-lane highway. No fatalities or injuries were reported.

The key objectives of the detailed study were to document the facts about the landslide, present relevant background information and establish the probable causes of the landslide. The scope of the study was generally limited to site reconnaissance, desk study and analysis. Recommendations for follow-up actions are reported separately.

The report was prepared as part of the 1997 Landslip Investigation Consultancy (LIC), for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 68/96. This is one of a series of reports produced during the consultancy by Halcrow Asia Partnership Ltd (HAP). The report was written by Dr Mark Swales and reviewed by Dr S Hencher and Dr R Moore. The assistance of the GEO in the preparation of the report is gratefully acknowledged.

G. Daughton
Project Director/Halcrow Asia Partnership Ltd.
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1. INTRODUCTION

In the early hours of 3 July 1997, a landslide (GEO Incident No. ME 97/7/6) occurred on a cut slope (No. 8SW-C/C3) adjacent to Hong Tsuen Road, Sai Kung (Figure 1). The landslide blocked a two-lane highway, but no fatalities or injuries were reported.

Following the landslide, Halcrow Asia Partnership Ltd (the 1997 Landslip Investigation Consultants) carried out a detailed study of the failure for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 68/96. This is one of a series of reports produced during the consultancy by Halcrow Asia Partnership Ltd (HAP).

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

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

(a) a review of relevant documents relating to the history of the site,
(b) analysis of rainfall records,
(c) interviews with witnesses,
(d) detailed observations and measurements of the landslide site, and
(e) diagnosis of the probable causes of the landslide.

2. THE SITE

2.1 Site Description

The landslide occurred on a registered soil cut slope on the southeast side of Hong Tsuen Road (Figure 1 and Plate 1). The cut slope is 185 m long, 17 m high in its central part and consists of three batters with two 1.5 m- to 2 m-wide berms. The lower, middle and upper batters are inclined at about 42°, 35° and 24°, respectively. Above its crest, a narrow strip of natural terrain separates the cut slope from a platform occupied by the Sai Kung Outdoor Recreation Centre. The cut slope and surrounding natural terrain are vegetated by shrubs, trees, bamboo, grass and ferns.

The two berms are drained by 250 mm diameter U-channels that discharge into a culvert at the northeastern end of the slope (Figure 2). In the centre of the cut slope, there is a catchpit on each berm. These are connected by a stepped channel leading to a covered drain at the toe of the slope. There is also a U-channel in the natural terrain above the crest of the cut slope.
During inspections by HAP on 3 July 1997 and 23 March 1998, the U-channels in the vicinity of the 1997 landslide were partly blocked with vegetation debris (Plates 2 and 3).

According to the SIMAR (Systematic Identification of Maintenance Responsibility of Slopes in the Territory) consultancy, the Highways Department (HyD) is responsible for the maintenance of the slope.

2.2 Site History

2.2.1 General

The history of the site was determined from a review of aerial photographs and available documentary information. Key events in the history of the site are described below and the pertinent observations are summarised in Figure 3.

2.2.2 History of Development

In 1975, the lower part of the northwest-facing hillside was undeveloped and overlooked a shallow, vegetated, northeast-trending valley leading to Sai Kung Hoi. An army base was present on the upper part of the slope at the current site of the Sai Kung Outdoor Recreation Centre.

Construction of the slope and installation of the drainage system on the cut slope was completed in 1978 (WSA, 1981). Corestones and exposures of rock were evident in the centre and at the southwestern end of the cut slope on the 1978 aerial photographs.

By 1979, Hong Tsuen Road had been completed and construction of a large building was nearing completion above the crest of the cut slope, within the army base. The stepped-channel in the centre of the cut slope had also been installed. Redevelopment of the army base commenced in 1988.

No further significant development is apparent at the site after 1988 and the density of vegetation covering the cut slope increased during this period. By 1990, the entire cut slope was covered by vegetation (Figure 2).

2.2.3 Previous Landslides

An area of surface erosion of about 50 m² in the centre of the cut slope is visible on aerial photographs taken in 1982 (Figure 3). The location of this erosion corresponds approximately to the toe on the southwestern side of the main scarp of the recent failure. Observations from aerial photographs also show that further erosion occurred at the same place on the slope in 1989. A smaller area of erosion on the upper batter is apparent in the 1984 photographs.

According to GEO's landslide database, no previous landslide incidents have been
reported on the cut slope.

2.3 Previous Studies and Assessments

The cut slope was inspected on 6 April 1978, whilst under construction, by consultants engaged by the Government to prepare the 1977/78 Catalogue of Slopes (Binnie & Partners, 1978). The feature was registered as Slope No. 8SW-C/C3. The inspection noted no signs of seepage or signs of distress.

The cut slope was assessed by Wilbur Smith & Associates (WSA) in the late 1970's (WSA, 1979) as part of their design responsibilities for the Sai Kung Development Phase 3. In early 1979, WSA made a preliminary geotechnical submission, which included cut slope No. 8SW-C/C3. In their calculations, WSA assumed that groundwater would not influence slope stability but Binnie & Partners (B & P) in their review stated that “there is evidence to indicate that groundwater cannot be ignored” (B & P, 1979). Following a ground investigation, WSA (1980) made another submission in December 1980. Details of the stability analyses of Section Q-Q taken through cut Slope No. 8SW-C/C3 in the area of the 1997 landslide are given in Appendix A. WSA’s Report states that “for the purpose of the stability analysis, 1 metre and 3 metres rise in water levels are assumed for a 1 in 10 year and 1 in 1000 year storm respectively. These water levels have been superimposed on the maximum water level recorded or on the bedrock surface” (WSA, 1980).

On 14 January 1981, WSA, B & P and GCO carried out a joint site inspection of the slopes and a retaining wall on the Sai Kung Development. According to the caption to one of the site record photographs, “there is a perennial discharge into cracked surface water drains” (Plate 4). The precise location of this discharge is not known but it is believed to be close to the 1997 landslide site.

In their comments on the WSA submission, B & P (1981a) stated that “there may be colluvium exposed in the top of the cutting. If a perched water table were to form in this material the factor of safety could fall dangerously.” WSA (1981) responded by stating “The possibility of perched water tables occurring on this slope was based on the possibility of the upper layer of material being colluvium. Further inspection does not reveal this to be the case. The upper layer is more highly weathered and has a greater proportion of clay than the lower layer. It would therefore be expected to be less permeable and this is confirmed by the permeability results from the consolidation stage of the triaxial test.... Thus, a perched water level is not possible at the interface of the two layers and additional investigation is considered unnecessary.” In reply to this, B & P (1981b) stated “The laboratory test results indicate that the permeability increases with depth through the volcanics which would indicate that a perched water table is unlikely. However, no measurements were made in the top 3 m and the highest permeability was recorded between 3 and 6 m at the top of this layer so it is still possible that water could perch at about 3 m below original ground level.” They went on to say “The effect of this perched table on the overall stability is small and local slips involving only the top of the slope have factors of safety close to 1.2 with the shear strength parameters $c' = 0$, $\phi' = 37^\circ$. A very small cohesion intercept of 1 to 2 kPa which could be justified from the test results is all that is necessary to maintain a satisfactory factor of safety.” In their final letter on the subject of the perched water table, B & P (1982) stated “A perched
water table is therefore still possible and we have considered this in our analyses. A satisfactory factor of safety was obtained allowing a small cohesion intercept of 1 to 2 kPa. Further site investigation, which is probably not justified in the circumstances, would be required to prove or disprove a perched water table.

Monitoring of piezometers continued and in June 1982 WSA “re-examined the stability of Section Q1-Q1” through Slope No. 8SW-C/C3, following a recorded rise of about 4 m in a piezometer installed in a borehole on Slope No. 8SW-C/C86, about 250 m to the southeast of the 1997 landslide site (Figure 1). They concluded, “there is some doubt as to the stability of the slope”. An existing piezometer in borehole S2 had been damaged and WSA recommended to the Junk Bay Development Office (JBDO) that “it would be advisable to install a new piezometer”. In September 1982 a piezometer was installed at a depth of 11.2 m (one metre above rockhead) in borehole S8 on the first berm (Figures 3 and 4).

In October 1982, GCO noted the need for WSA to submit piezometer readings and their interpretation of groundwater conditions (GCO, 1982). Piezometer readings covering the periods up to October 1982 and February 1983 were submitted to the GCO in November 1982 and February 1983, respectively. These show that the water level in the new piezometer varied between about 8.3 m and 9.6 m below ground level. In January 1983, JBDO requested GCO to “confirm that you now have sufficient calculations and information to establish the water regimes in the various slopes and that further monitoring ... is not required”. They also stated that “if you cannot confirm that further monitoring is not required will you please supply in details what further work is required and also your reasons for requiring this work” (JBDO, 1983). The GCO responded that there was “no further requirement on piezometer monitoring” (GCO, 1983).

In 1992, the GEO initiated a consultancy agreement entitled “Systematic Inspection of Features in the Territory” (SIFT), which, inter alia, aims to identify features not registered in the 1977/78 Catalogue of Slopes and to update information on registered slopes based on studies of aerial photographs and limited site inspections. In August 1996, SIFT assigned the cut slope (No. 8SW-C/C3) to Class “C1”, i.e. a slope “formed or substantially modified before 30.6.78”.

In July 1994, the GEO initiated a consultancy agreement entitled “Systematic Identification and Registration of Slopes in the Territory” (SIRST) to update the 1977/78 Catalogue of Slopes and to prepare the New Catalogue of Slopes. The SIRST consultants inspected the cut slope on 11 November 1994. No signs of seepage or distress were recorded and no emergency action was considered necessary.

In July 1995, a Stage 1 Study was carried out on the slope by GEO (1995) under SIRST. It was considered probable that works would “be required to bring the feature up to current engineering standards”.

In January 1996, the slope was inspected by consultants appointed by HyD to undertake the “Roadside Slope Inventory and Inspections” of their slopes (HyD, 1996). The Engineer Inspection Record states that “routine maintenance (has not been) carried out satisfactorily because surface drainage systems (are) not clear (and) because drainage channels (are) cracked/damaged”. The vegetated surface of the slope was found to be in good condition and no seepage was reported. The Inspection Record made recommendations to
clear drainage channels in vicinity of feature, repair cracked/damaged channels (and) improve the protection against infiltration above the crest. HAP has found no information to confirm that these works have subsequently been carried out. The Inspection Record further noted that "geotechnical conditions (are) not known (and) stability assessment (is) considered to be required".

2.4 Subsurface Conditions

According to Map Sheet No. 8 produced by the Hong Kong Geological Survey (GCO, 1989), the site is underlain by coarse-grained, ash crystal tuff of the Tai Mo Shan Formation. This is characterised by a "lack of intraformational boundaries or segregations" (Strange et al, 1990) and typically weathers to "an orange to reddish brown saprolitic soil with large corestones" (Addison, 1986).

The structural geology of Sai Kung is dominated by northeast- and northwest-striking faults. In the vicinity of the site, a northeasterly-striking minor fault is present in the valley floor beyond the cut slope.

There have been four ground investigations in the vicinity of the slope (Gammon, 1979; WSA, 1980; Gammon, 1981 and Gammon, 1987). Four boreholes and one trial pit are of relevance (Figure 3). HAP has used information from these investigations and site observations to prepare a geological section (Figure 4).

In the area of the landslide, borehole information indicates that the slope is composed of PW 0/30 volcanic rock consisting of completely decomposed volcanics (CDV) with highly and moderately decomposed volcanics (HDV/MDV) that are probably corestones. This overlies less weathered rock, predominantly consisting of MDV. The PW 0/30 zone can be differentiated into two layers. The upper layer, interpreted to be up to about 7 m thick, comprises soft to firm sandy silt and clay (i.e. predominantly silt and clay in approximately equal proportions - subsequently referred to as clay-rich CDV), with SPT values of 3 or less. At depth, this becomes stiff to very stiff with SPT values in excess of 20. The lower layer consists of up to about 6 m of medium to very dense silty sand (CDV).

The results of Atterberg limit tests (WSA, 1980) on samples from the upper layer are plotted on the standard plasticity chart given in Geoguide 3 (GCO, 1988) in Figure 5. The failure occurred entirely within this upper layer of clay-rich CDV.

An extensive area of rock, exposed at the southwestern end of the slope, indicates that the rockhead probably rises in elevation towards the southwest. However, small rock exposures in the lower and middle batters in the central part of the cut slope are probably corestones as they are above the rockhead, based on information derived from boreholes.

The closest piezometers to the 1997 landslide were installed in boreholes S2 and S8, which were first monitored on 30 April 1981 and 22 October 1982 respectively (Figure 3). The response zone in piezometer S2 (23.7 mPD to 25.2 mPD) was just below rockhead (25.3 mPD). Piezometer S8 was installed at a depth of 11.2 m, one metre above rockhead (16.9 mPD) and the response zone was not recorded. The maximum water levels recorded in
these piezometers were 30.8 mPD (S2) and 20.7 mPD (S8), respectively (Figure 4). Piezometer S2 was monitored between 30 April 1981 and 11 August 1981. Piezometer S8, however, was monitored mainly in the dry season between 22 October 1982 and 9 February 1983.

3. THE LANDSLIDE

3.1 Time of the Failure

According to the Senior Officer at the fire station located immediately across the road from the cut slope, the landslide occurred at 00:23 hours on 3 July 1997.

3.2 Description of the Landslide

A plan of the landslide is shown in Figure 6 and Plate 5 shows a general view of the landslide on the day of the incident.

The landslide occurred in the centre of the middle batter and locally undercut the second berm and its associated U-channel. The toe of the rupture surface, which was exposed following the clearance of landslide debris (Plate 5), was observed to daylight at the first berm. The rupture surface of the landslide was about 25 m wide, 12 m long and was up to 2.4 m below the original surface of the cut slope. The angle of the rupture surface, measured relative to the horizontal, increased from 18° near the base of the landslide to near-vertical towards the crest. The angle between the toe of the landslide rupture surface and the crest, which extended to the back of the second berm, was about 28° to the horizontal.

The volume of landslide debris was estimated to be about 250 m$^3$, about 75% of which was deposited on the road. The remaining debris came to rest on the first berm and as a thin cover on the lower batter. At the toe of the slope, the wet debris spread across both lanes of the highway and pedestrian footpaths to a depth of between about 2 m and 0.5 m. Silty and sandy material was washed down the road in a northeasterly direction. The travel angle of the landslide debris, measured from the crest of the main scarp to the distal end of the debris, was about 25°. This indicates greater mobility of debris than is typical for rain-induced landslides of comparable volume in Hong Kong (Wong & Ho, 1996).

The weathering grade of material exposed in the main scarp decreased from northeast to southwest (Figure 6 and Plate 5). In the northeastern part of the main scarp residual soil, comprising mostly homogeneous, soft to firm, moist to wet, orange red, sandy silt to sandy clay, was exposed. This material is also locally exposed to the northeast of the landslide (Plate 6). In the centre of the main scarp, there was CDV of mass weathering grade PW 0/30, comprising completely decomposed, coarse ash crystal tuff described as fissured to intact, firm to stiff, moist to wet, orange yellow, slightly gravelly, sandy silt to sandy clay. Similar material was exposed in a shallow trial trench excavated along the second batter to the southwest of the failure (Figure 6 and Plate 7). The southwestern part of the main scarp revealed a large corestone of pale orange yellow, highly and moderately decomposed, coarse ash crystal tuff, with medium- to closely-spaced discontinuities. This tuff was intersected by
both near vertical and sub-horizontal, but not adverse, planar discontinuities. Some discontinuities had apertures up to about 30 mm wide and were stained with iron and manganese oxides (Plates 8 and 9). The width of the discontinuity may have been a result of the landslide.

During an inspection at about 16:00 hours on 3 July 1997 HAP observed water issuing approximately 1.5 m below the ground surface from the large corestone in the southwestern side of the main scarp (Plate 9). When the site was inspected 6 days later this flow of water had ceased. HAP also observed that the U-channels in the vicinity of the main scarp were partially blocked with vegetation (Figure 6).

Following the landslide, HyD carried out urgent repair works comprising removal of debris, shotcreting of the affected area of the slope and re-instatement of the surface drainage system (Plate 10).

4. RAINFALL

Raingauge No. N15, located at Sung Tsun Primary School, Yau Ma Po, some 750 m to the northeast of the landslide, is the nearest GEO automatic raingauge. This raingauge began operation in June 1990. Between 1984 and 1990, the raingauge had been located at the Management Centre of Pak Kong Country Park, about 1 km to the northwest of the landslide.

The daily rainfall recorded in June and early July 1997, together with the hourly rainfall from 29 June to 4 July 1997, is shown in Figure 7. The daily record shows that in the 31 days and 15 days prior to midnight on 2 July 1997 (i.e. shortly before the landslide at 00:23 hours on 3 July 1997), the rainfall totals were 1 193 mm and 683 mm respectively. The rainfall totals in the 24-hour and 12-hour periods before midnight on 2 July were 341 mm and 225 mm respectively.

The 5-minute rainfall record (Figure 8) shows that heavy pulses of intense rainfall occurred on the day before the landslide, with the heaviest being around 06:00 hours on 2 July 1997. The last pulse of heavy rainfall reached peak intensity at 23:35 hours on 2 July 1997, about 50 minutes before the landslide occurred.

Isohyets of rainfall over Hong Kong for the period between 00:00 hours on 2 July to 00:25 hours on 3 July are given in Figure 9.

The estimated return periods of the maximum rolling rainfall for selected durations prior to the landslide, based on historical rainfall data at the Hong Kong Observatory, are given in Table 1. The rolling rainfall totals for durations up to 15 days ranged from 1 to 9 years and were not particularly unusual. However, the 31-day rolling rainfall was more severe, having an estimated return period of over 40 years.

The daily rainfall on 2 July 1997 was the highest since raingauge No. N15 was installed in 1984 (Figure 10).
5. **THEORETICAL STABILITY ANALYSIS**

Stability analyses were carried out to assess the possible range of shear strengths and groundwater pressures that may have been operational at the time of failure. The cross-section through the landslide, on which stability analyses were carried out using the rigorous method of Morgenstern and Price (1965), is presented in Figure 11. The pre-failure profile was established from topographical survey plans and the geometry of the failure surface was based on site measurements made by HAP (Figure 4).

The presence of clay-rich material would suggest that the shear strength parameters for the upper layer were probably lower than those assumed in design (\(c' = 0\) and \(\phi' = 37^\circ\)). Accordingly, for the purpose of the analyses, a range of shear strengths for clay-rich CDV of \(c' = 0\) to 6 kPa and \(\phi' = 24^\circ\) to \(34^\circ\) was considered, together with various perched water tables. The development of high groundwater pressure is consistent with the observation of a groundwater issue from the main scarp on the day of the failure.

The results of the stability analyses, which support the idea that the failure was likely to have been the result of a combination of low shear strength material and high groundwater, are summarised in Figure 12.

6. **PROBABLE CAUSES OF FAILURE**

The correlation between the rainfall and the time of failure indicates that the landslide was probably triggered by rainfall. A number of contributory factors probably combined to cause the landslide, including:

- (a) infiltration and subsurface groundwater flow,
- (b) the presence of clay-rich CDV in the upper part of the cut slope, and
- (c) the development of transient positive water pressure within the clay-rich CDV in the upper part of the cut slope.

It is postulated that the upper layer of CDV was probably heterogeneous with bands of low permeability clay-rich material, which could lead to downslope seepage flow (i.e. non-vertical) and hence development of seepage pressure, which is effectively equivalent to perching within the layer. The most likely sources of water were by direct infiltration and groundwater ingress through more permeable layers and zones within the heterogeneous upper CDV layer.

7. **DISCUSSION**

The landslide occurred at a soil cut slope that had previously been subjected to a detailed stability assessment based on site-specific ground investigation and laboratory testing.
The landslide is of technical interest in that it occurred on a slope where the gradient over the failed section was only about 28 degrees. The upper layer of CDV in which failure took place is also of interest in that it has a high fines (i.e. silt and clay) content. The composition of this material probably resulted in a lower shear strength than that adopted in the design of the cut slope (viz. $c' = 0$ kPa, $\phi' = 37^\circ$).

Infiltration and the presence of low permeability bands within the upper layer of CDV probably led to the development of adversely high groundwater conditions. It is noteworthy that the possibility of perched water within the slope was recognised by the consultant checking the assessment of the slope in the early 1980s on behalf of GCO. The theoretical stability analyses support the proposition that the failure on such moderately sloping ground probably involved relatively high groundwater conditions coupled with low shear strength material. However, without ground investigation, groundwater monitoring and laboratory testing it is not possible to identify the relative contributions of these to the failure.

There is evidence of inadequate slope maintenance in that the U-channel near the crest of the landslide was observed to be partially blocked after the failure. However, the contribution of this to the landslide was unlikely to be significant given the scale and mode of failure.

Past erosion at the portion of the slope that failed in 1997 was observed in aerial photographs but there is no documentary information on the incidents. It is not possible to establish whether these were maintenance-related problems or if they were indications of slope instability.

8. CONCLUSIONS

It is concluded that the landslide was triggered by rainfall. The failure occurred at a slope that had previously been subjected to a detailed stability assessment based on site-specific ground investigation and laboratory testing.

The landslide is of technical interest in that a large-scale failure occurred at a moderately-inclined soil cut slope and that the landslide debris was relatively mobile.

The failure involved CDV with a relatively high fines content. The low shear strength of this material and the development of high groundwater pressure within the upper clay-rich layer were probably significant contributory factors to the failure.

9. REFERENCES


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Table 1 – Maximum Rolling Rainfall at GEO Raingauge No. N15 for Selected Durations Preceding the 3 July 1997 Landslide and The Corresponding Estimated Return Periods

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<td>15 minutes</td>
<td>19.5</td>
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<td>1 hour</td>
<td>52.5</td>
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Notes: (1) Return periods were derived from the Gumbel equation and data published in Table 3 of Lam & Leung (1994).

(2) Maximum rolling rainfall was calculated from 5-minute data for durations up to one hour and from hourly data for longer durations.
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Note Base map is extracted from Survey Sheet Nos 8-SE-11C and 8-SW-16A dated October 1992

Figure 1 - Site Location Plan
Figure 2 - General Plan of the Site and the Landslide

Legend

- Drainage channel with catchpit
  (arrow shown direction of flow)

- Predominantly
  Debris
  Thin covering
  of debris

- Predominantly
  Main scarp
  shrubs and trees
  on the cut slope

- Predominantly
  grasses and ferns
  on the cut slope

Note
Base map is extracted from Survey Sheet Nos 8SW-11C & 8SW-16A
dated October 1992
Car park with cut slope constructed in 1976

Former inlet of the Sai Kung inner port shelter prior to 1976

Slope formation commenced in 1977

Superficial erosion in 1982 and 1989

Fire Station built in 1984

Rilling and erosion in 1984

Reclamation fill in place with deep drainage channel in 1977

Unallocated Government land

Stepped-channel present downslope in 1979

Army base present up to 1988 when redevelopment of the site commenced under RSD

Legend:
- Rock exposed during formation of slope in 1977 (from API)
- Extent of vegetation cover by 1983
- Lot boundary
- Borehole
- Trial Pit

Notes:
1. Land status is only shown for area on southeast side of Hong Tsuen Road.
2. Maintenance responsibility according to SIMAR.
3. Abbreviations: HyD (Highways Department); RSD (Regional Services Department).

Figure 3 - Land Status, Site History and Previous Ground Investigations
Figure 4 - Geological Cross-section through the Landslide
Figure 5 - Results of Soil Classification Tests in Accordance with the Standard Plasticity Chart of Geoguide 3 (GCO, 1988)
Sai Kung Tuk
Reclamation Area

Stepped channel
Second berm
Orangish red
residual soil
Section of failed U-channel
from second berm

Vegetation stripped from first batter
Densely vegetated natural slope above crest of main scarp
Orangish yellow completely decomposed volcanics
Trial trench excavated following the landslide

Channels blocked by vegetation
Groundwater issue observed from joints within highly decomposed tuff, 1.5 m below crest of main scarp, at 16.00 hours on 3 July 1997

Legend:
- Residual soil (RS)
- PW 0/30
- PW 30/50
- Thin debris cover
- Debris
- Catchpit

Section line
(see Figure 4)

Note: Base map is extracted from Survey Sheet Nos. 8SW-11C and 8SW-16A dated October 1992.

Figure 6 - Site Plan and Details of the Landslide
193 mm of rainfall recorded in the 31 days before the landslide

683 mm of rainfall recorded in the 15 days before the landslide

Date of landslide on 3 July 1997

(a) Daily Rainfall Recorded between 1 June and 5 July 1997

341 mm of rainfall recorded in the 24 hours before the landslide

225 mm of rainfall recorded in the 12 hours before the landslide

Time of the landslide at 00:23 hours on 3 July 1997

(b) Hourly Rainfall Recorded between 29 June and 4 July 1997

Figure 7 - Rainfall Records at GEO Raingauge No. N15
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Note: Isohyets prepared by the Hong Kong Observatory.

Figure 9 - Isohyets of Rainfall between 00:00 Hours on 2 July 1997 and 00:25 Hours on 3 July 1997
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Notes:  
(1) See Figure 2 for location of section.  
(2) Information shown in this figure is based on topographic survey, field observations and documentary records.  
(3) Geological boundary is approximate only.  
(4) Levels A to E refer to the assumed piezometric levels, used in the stability analyses (see Figure 12).  

Figure 11 - Cross-section of the Landslide Used for Theoretical Stability Analyses
Figure 12 - Summary of Theoretical Stability Analyses
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SECTION 2:
DETAILED STUDY OF THE LANDSLIDES AT NOS. 1 TO 5 CHUNG SHAN TERRACE LAI CHI KOK ON 4 JUNE 1997

Halcrow Asia Partnership Ltd

This report was originally produced in December 1998 as GEO Landslide Study Report No. LSR 22/98
FOREWORD

This report presents the findings of a detailed study of four landslides (reported in GEO Incident Report Nos. MW97/6/20 and MW97/6/30) which occurred on 4 June 1997 on cut slopes behind Nos. 1 to 5 Chung Shan Terrace, Lai Chi Kok. Debris from the landslides affected residential properties below the slopes. No fatalities or injuries were reported.

The key objectives of the detailed study were to document the facts about the landslides, present relevant background information and establish the probable causes of the landslides. The scope of the study was generally limited to site reconnaissance, desk study and analysis. Recommendations for follow-up actions are reported separately.

The report was prepared as part of the 1997 Landslip Investigation Consultancy (LIC), for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 68/96. This is one of a series of reports produced during the consultancy by Halcrow Asia Partnership Ltd (HAP). The report was written by Mr P Smith and reviewed by Dr R Moore and Dr X D Pan. The assistance of the GEO in the preparation of the report is gratefully acknowledged.

G. Daughton
Project Director/Halcrow Asia Partnership Ltd.
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1. INTRODUCTION

On the morning of 4 June 1997, four landslides occurred on the cut slopes immediately northeast of Chung Shan Terrace, Lai Chi Kok, New Territories (Figure 1). Three of the landslides (A1 to A3 in Figure 1) affected an unregistered cut slope behind Nos. 2 and 3 Chung Shan Terrace. The fourth landslide (B in Figure 1) affected the cut slope, registered as Slope No. 11NW-A/CR261, behind Nos. 4 and 5 Chung Shan Terrace (Figure 1). Debris from the landslides came to rest in the open space between the toe of the slopes and the buildings of Chung Shan Terrace. No fatalities or injuries were reported.

Following the landslides, Halcrow Asia Partnership Ltd (the 1997 Landslip Investigation Consultants) carried out a detailed study of the failures for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 68/96. This is one of a series of reports produced during the consultancy by Halcrow Asia Partnership Ltd (HAP).

The key objectives of the detailed study were to document the facts about the landslides, present relevant background information and establish the probable causes of the landslides. The scope of the detailed study was limited to site reconnaissance, desk study and analysis. Recommendations for follow-up actions are reported separately.

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

(a) a review of relevant documents relating to the history of the site,

(b) analysis of rainfall records,

(c) interviews with witnesses and persons affected by the landslides,

(d) detailed site observations and measurements at the landslides, and

(e) diagnosis of the probable causes of the landslides.

2. THE SITE

2.1 Site Description

The locations of the landslides are shown in Figure 2.

At the location of landslides A1 to A3, the cut slope is about 5 m high and inclined at about 70° to the horizontal. The slope is unsealed and essentially bare and there is no surface drainage provision at its crest.
At the location of landslide B, the cut slope is about 12 m high and inclined at about 50° to the horizontal. Its surface was predominantly covered with small shrubs and grass prior to the landslides. U-channels were present at its crest and toe. Prior to the landslide, the slope was crossed at about mid-height by a water-carrying pipe and further upslope by a group of pipes. All the pipes were above the slope surface (Figure 2, Plate 1).

The ground upslope of the cut slopes is lightly vegetated with trees and shrubs and inclined typically between 30° and 40° to the horizontal. It extends upslope towards an area of level ground used as a sitting-out area (Figure 2). The sitting-out area is covered with grass and provides a sizeable area through which infiltration of surface water may occur. Castle Peak Road is located beyond the sitting-out area, some 25 m from the crest of the cut slope.

A concrete retaining wall, about 1 m to 2 m high, is present along the toe of the cut slopes. There is a U-channel at the crest of the retaining wall along most of its length and a fence is present on the retaining wall behind Nos. 4 and 5 Chung Shan Terrace. The buildings of Nos. 1 to 5 Chung Shan Terrace are located typically between about 1.5 m and 4 m from the retaining wall.

Landslides A1 to A3 affected Private Lot Nos. KCTL 449 and 3326RP and adjacent Government land (Figure 3). Landslide B predominantly affected Private Lot Nos. 3326RP and KCTL 425RP but the main scarp extended upslope into Government land (Figure 3). At the time of preparing this report, the party responsible for maintenance of the Government Land affected by the failures was still being determined by the Lands Department.

2.2 Site History and Past Landslides

The history of the site was established from a review of aerial photographs (Table 1) and available documentary information. Information sources consulted during the detailed study are summarised in Table 2.

Photographs taken in 1949 show that the platform now occupied by Nos. 2 to 5 Chung Shan Terrace had been formed by cutting and filling of a natural hillside. Castle Peak Road had been constructed and at the time carried two lanes of traffic. The cut slopes, retaining walls and earlier buildings (subsequently demolished) were completed by 1954 (GCO, 1988a). Re-alignment and widening of the Castle Peak Road to its present four lanes were completed by 1963. Some filling above the crest of the cut slopes took place during these works to form the sitting-out area at the crest. No significant modifications to the slopes or the buildings are apparent on aerial photographs taken between 1963 and 1973.

Aerial photographs taken in 1973 show a small failure on the cut slope behind No. 5 Chung Shan Terrace, about 10 m north of the location of 1997 landslide B (Figure 3). The photographs indicate that surface protection was applied to the 1973 failure scar after the incident, along with improvement to the surface drainage system.

Between 1978 and 1984, the earlier buildings at the location of Nos. 4 and 5 Chung Shan Terrace were demolished. The platform remained vacant until sometime between 1988 and 1991 when the present buildings were constructed. Localised surfacing works to the
slope behind No. 4 Chung Shan Terrace, associated with the occurrence of a minor landslide (see below), were carried out in about 1992. The earlier buildings at Nos. 2 and 3 Chung Shan Terrace were demolished in 1992 and the subsequent construction of buildings that currently occupy the platform was completed by 1995.

According to GEO's landslide database, a landslide (GEO Incident Report No. MW92/5/63) occurred on the cut slope behind No. 4 Chung Shan Terrace on 8 May 1992. In the Incident Report prepared by the GEO, it is noted that approximately 3 m$^3$ of material failed from the middle part of the cut slope and came to rest behind the fence at the crest of the retaining wall. Infiltration was reported as the cause of failure. The 1992 minor landslide occurred at the same location as landslide B in 1997 (Figure 3).

Following the landslide incident in 1992, the GEO advised the Buildings Department (BD) that repair and maintenance works would be needed. On 14 September 1992, the BD issued an Advisory Letter to Sinotrade Development Ltd (SDL), who manage Nos. 4 and 5 Chung Shan Terrace, suggesting that they provide "surface protection to the slip surface" and relocate "the 50 mm water pipe away from the slope" (Figure 2). The slope protection works had been completed by November 1995. Reminders of the need to relocate the water pipe were sent to the owners by the BD on 11 December 1995 and 14 May 1996 respectively, but the relocation of the pipe had not been carried out prior to the 1997 failures.

2.3 Previous Studies and Assessments

In April 1978 Binnie & Partners (B & P), the consultants appointed by Government to prepare the 1977/78 Catalogue of Slopes, inspected the retaining wall at the toe of the cut slope behind Nos. 3 and 4 Chung Shan Terrace. The slope was registered as No. 11NW-A/R6 in the 1977/78 Catalogue of Slopes (Figure 3). In the field sheet prepared for the feature following the inspection (B & P, 1978a), it is recorded that there were no signs of seepage or distress associated with either the retaining wall or the cut slope above.

The retaining wall at the toe of the cut slope behind No. 5 Chung Shan Terrace was registered as No. 11NW-A/R7 in the 1977/78 Catalogue of Slopes (Figure 3). It is noted in the field sheet for the feature (B & P, 1978b), that there were no signs of distress and that weepholes positioned 1.5 m above the toe of the wall were wet. For the cut slope above the wall, no signs of seepage or distress were reported.

In the late 1980s, retaining wall No. 11NW-A/R7 and part of retaining wall No. 11NW-A/R6 and the associated cut slope, were upgraded as part of the site formation for the redevelopment of Nos. 4 and 5 Chung Shan Terrace. The 1997 landslide B affected this part of the cut slope. Fugro (Hong Kong) Ltd (FHKL) completed the design of the site formation works in 1988. The design included provision for constructing a retaining wall in front of the existing concrete retaining wall and cutting back the cut slope above to 50°. The geological model, the assumptions and the results of the stability assessment for the design at the location of landslide B are summarised in Figure A1 of Appendix A. The site formation submission was checked by the Geotechnical Control Office (GCO, renamed GEO in 1991) in 1988 (GCO, 1988a) and was approved by the Buildings and Lands Department (BLD, subsequently renamed BD) in August 1988.
In July 1988 the Planning Division of the GCO completed a detailed Stage 1 Study of the southern part of retaining wall No. 11NW-A/R6 (behind No. 3 Chung Shan Terrace) and the wall behind No. 2 Chung Shan Terrace (which was unregistered at the time) together with the cut slope above the walls (GCO, 1988a). The northern part of wall No. 11NW-A/R6 was excluded from the study because of the earlier assessment and upgrading works at Nos. 4 and 5 Chung Shan Terrace. The Stage 1 Study report indicated that the cut slope had an adequate factor of safety but that the stability of the walls was inadequate. In the study it was recommended that wall No. 11NW-A/R6 and the wall behind No. 2 Chung Shan Terrace should be registered as “CR-feature(s)”, and that a Stage 2 Study be carried out. The retaining wall behind No. 2 Chung Shan Terrace was subsequently registered as No. 11NW-A/R12 in October 1988 (Figure 3).

The Stage 2 Study of the southern part of wall No. 11NW-A/R6, wall No. 11NW-A/R12 and the cut slope above included a stability assessment of a section about 5 m northwest of landslide A1, based on site-specific ground investigation that included boreholes (GCO, 1991). The location of the section together with the adopted geological model, assumptions and results of the assessment are summarised in Figure A2 of Appendix A.

The factor of safety of the potential failure surface, which most closely represents the rupture surface of landslide, A1 was about 1.5. It was also noted that “local slips in the residual soil” had a “marginally inadequate” factor of safety of 1.18. It was considered, however, that “the critical slip is quite small and shallow and (that) its failure would not affect the houses below”. It was further noted that the stability of this part of the slope could “be maintained if adequate drainage is provided to minimise surface erosion and infiltration.” The retaining walls were considered to have adequate factors of safety.

Following the Stage 2 Study, the BLD advised the owners of Nos. 2 and 3 Chung Shan Terrace in June 1992 to “provide (a) surface channel along (the) slope crest and behind the wall .... clear vegetation from the slope (and) .... protect the cleared slope surface with chunam plaster”. The absence of surface protection and drainage on the slope, noted by HAP during the investigation of the landslides, suggests these works were not carried out before the 1997 failures occurred.

In 1992 John Connell & Associates Ltd (JCAL) were engaged as the consultants for the redevelopment of Nos. 2 and 3 Chung Shan Terrace. JCAL prepared a geotechnical report for the site formation works and assessed the stability of the existing cut slope. They reported that the cut slope had “a minimum factor of safety of 1.48” and was considered to be “adequately safe” (JCAL, 1992). The geological model, assumptions and results of the assessment are summarised in Figure A3. The geotechnical report and associated site formation drawings were submitted to the BLD in November 1992. The submission was checked by the GEO in December 1992 (GEO, 1992) and was approved by BLD in January 1993.

In 1992, the GEO initiated the consultancy agreement entitled “Systematic Inspection of Features in the Territory” (SIFT,) which, inter alia, aims to systematically search for features not registered in the 1977/78 Catalogue of Slopes and to update information on previously registered features, based on studies of aerial photographs and limited site
inspections. The part of the feature behind Nos. 1 to 3 Chung Shan Terrace was assigned a “Work in Progress” status in 1995, as at that time the area was being redeveloped. The part of the feature behind Nos. 4 and 5 Chung Shan Terrace was assigned to SIFT Class “C1”, which is for slopes “assumed (to have been) formed pre-1978”.

In July 1994, the GEO initiated the consultancy agreement entitled “Systematic Identification and Registration of Slopes in the Territory” (SIRST) to update the 1977/78 Catalogue of Slopes and to prepare the New Catalogue of Slopes. The wall behind Nos. 4 and 5 Chung Shan Terrace (i.e. previously wall No. 11NW-A/R7 and the northern part of wall No. 11NW-A/R6) and the cut slope above were re-registered as Slope No. 11NW-A/CR261 (Figure 3). In the SIRST field sheet prepared in August 1995, it was noted that there were no signs of seepage or distress. The feature was not recommended for further study as it was considered to have been “checked by GEO” during the earlier redevelopment of Nos. 4 and 5 Chung Shan Terrace.

2.4 Subsurface Conditions

Sheet 11 of the Hong Kong Geological Survey 1:20 000-scale map series (GCO, 1986) and the Engineering Geology Map of the Geotechnical Area Studies Programme (GASP) for the Central New Territories (GCO, 1987) indicate that the site is underlain by coarse-grained granite.

Ground investigations for the Stage 2 Study of the retaining wall and cut slope behind Nos. 1 to 3 Chung Shan Terrace were carried out by Geotechnics & Concrete Engineering (GCE) in September 1990. The investigation included two vertical boreholes, two trial pits and two surface strips on the cut slope and six coreholes through the retaining wall. The locations of the exploratory holes are shown in Figure 3.

A geological section showing the ground conditions near the location of landslide A1, interpreted from GCE’s borehole information (GCE, 1990), is presented in Figure 4. The information suggests that the crest of the slope has a cover of about 2 m of fill, overlying about 2 m of residual soil that comprised medium-dense to dense clayey sand. The residual soil overlies about 7 m of completely decomposed granite and below that, highly decomposed granite. The highest observed water level, based on monitoring of piezometers installed in boreholes at the site between July and October 1990, was well below the base of landslide A1 (Figure 4).

The ground investigations for the redevelopment of Nos. 4 and 5 Chung Shan Terrace (see Section 2.3 above) were carried out by Oriental Boring & Engineering Company Ltd (OBECL) in 1988. The investigation included four vertical boreholes, three horizontal boreholes and two trial pits (Figure 3).

A geological section showing the ground conditions near the location of landslide B, interpreted from the OBECL ground investigation data (1988), is presented in Figure 5. Borehole BH2 proved “completely weathered” granite to a depth of about 8 m, overlying about 7 m of “highly weathered” granite and below that, slightly “weathered” granite. According to the geotechnical report on the site formation aspects of the redevelopment of
Nos. 4 and 5 Chung Shan Terrace (FHKL, 1988), records of piezometers made between May 1988 and June 1988 "indicate that there is generally no groundwater table above rockhead in the hillside".

3. THE LANDSLIDES

3.1 Time of Failure

The time of failure of landslides A1 to A3 (GEO Incident Report No. MW97/6/30) behind Nos. 1 and 3 Chung Shan Terrace was reported to GEO to be at 07:00 hours on 4 June 1997. A resident of No. 4 Chung Shan Terrace witnessed landslide B (GEO Incident Report No. MW97/6/20) and reported the time of failure as 08:30 hours on 4 June 1997. A Landslip Warning was issued at 07:45 hours on 4 June 1997.

3.2 Description of the Landslides

A cross-section through landslide A1, the largest of the landslides affecting the cut slope behind Nos. 1 to 3 Chung Shan Terrace, is shown in Figure 4 and a photograph of the landslide taken after completion of urgent repair works is shown in Plate 2.

The rupture surface of landslide A1 was estimated to be about 8 m wide, 6 m long and 0.5 m deep. The volume of the displaced debris was estimated to be about 10 m$^3$. Landslide debris overtopped the retaining wall at the toe of the slope and accumulated behind Nos. 2 and 3 Chung Shan Terrace.

Landslides A2 and A3 were smaller (Plates 3 and 4). Landslide A2 was about 4 m wide, 2 m long and 0.5 m deep, and landslide A3 was about 2 m wide, 2 m long and 0.4 m deep (Plates 3 and 4). The total volume of these two landslides was about 4 m$^3$. According to GEO's Incident Report prepared following an inspection on 4 June 1997, the debris was deposited at the toe of the retaining wall behind Nos. 2 and 3 Chung Shan Terrace. There is no record of groundwater seepage in the main scars on the incident report. Application of shotcrete to the landslide scars as part of the urgent repair works prevented HAP preparing detailed descriptions of materials involved in the failures. The geology of the site, established from previous ground investigations (Figure 4) and observation of nearby exposures on the cut slope, suggests that the failures would have involved predominantly completely decomposed granite.

The morphology of the landslide scars and debris suggests that the failures occurred principally by shallow sliding. There is insufficient reliable information on debris deposition to enable their mobility to be assessed.

HAP noted that there was no surface protection or drainage provision on the slope, during inspections carried out as part of the investigation. This suggests that the recommendation of the 1992 Advisory Letter (see Section 2.3 above) had not been carried out before the 1997 landslides.
A cross-section through landslide B is shown in Figure 5 and photographs taken soon after the failure are presented in Plates 5 and 6.

The rupture surface of the landslide was about 16 m wide, 7 m long and up to 1.5 m deep. The estimated volume of the landslide was about 85 m$^3$. The material exposed in the main scarp was completely decomposed granite consisting of predominantly medium-dense brown mottled light yellow silty fine- to coarse-grained sand. There was no evidence of adversely oriented discontinuities or groundwater seepage from the main scarp. Inspection of intact and broken sections of the U-channel near the crest of the main scarp found no evidence of blockage that may have caused overflow of surface water onto the slope before failure.

Landslide debris destroyed the fence on the retaining wall and piled up behind No. 4 Chung Shan Terrace. The landslide engulfed the slope protection put in place after the 1992 incident, destroyed a U-channel on the slope and displaced a catchpit associated with the U-channel (Plate 6). The landslide also severed the water pipes on the surface of the slope that caused water leakage and erosion of a channel through the landslide debris before the water flow was brought under control by installation of a stopcock on the pipe. Vegetation on debris rafts in the upper part of the landslide debris remained upright while vegetation on rafts at the toe toppled forward. The presence of the rafts suggests that this failure also occurred principally by shallow sliding. The travel angle of landslide B cannot be established because the run-out of the debris was constrained by a wall behind No. 4 Chung Shan Terrace.

Following the landslides, BD implemented urgent repair works including removal of landslide debris, reinstatement of the slope drainage and protection of the landslide scars, at the recommendation of GEO. BD served a DH Order on the owners of Nos. 4 and 5 Chung Shan Terrace on 3 November 1997 at the recommendation of GEO.

4. RAINFALL

The nearest GEO automatic raingauge No. N04 is located about 870 m northwest of the site at Kai Kwong Lau, Cho Yiu Estate, Lai King (Figures 1 and 7). The daily rainfall between 1 May and 10 June 1997 is shown in Figure 6a. A total of 296.5 mm of rainfall was recorded in the 15 days before 07:00 hours on 4 June 1997.

Hourly rainfall between 2 June 1997 and 5 June 1997 is presented in Figure 6b. Rainfall was continuous between 01:30 hours and 06:00 hours on 4 June 1997 and intensified between 06:00 hours and 07:00 hours immediately before the reported time of landslides A1 to A3. The isohyets of rainfall between 01:30 hours and 08:30 hours on 4 June 1997 are shown on Figure 7.

Tables 3 and 4 present the estimated return periods of maximum rolling rainfall recorded before landslides A1 to A3 and B1 respectively for selected durations, based on historical rainfall data at the Hong Kong Observatory (Lam & Leung, 1994). The analysis for Incident No. MW97/6/30 includes rainfall recorded before 7:00 hours, the time that the failure was reported to GEO. The analysis for Incident No. MW97/6/20, includes rainfall recorded before 08:30 hours, the time that the landslide was reported to have occurred. The 1-hour rainfall for Incident No. MW97/6/30, and the 4-hour rainfall for Incident No. MW97/6/20,
were the most severe, with corresponding estimated return periods of about 40 years and 50 years respectively.

Figure 8 shows the maximum rolling rainfall at raingauge No. N04 for selected major rainstorms. The rainfall was the highest recorded for durations of between 15 minutes and 9 hours for landslides A1 to A3 and between 15 minutes and about 15 hours for landslide B.

5. **PROBABLE CAUSES OF FAILURE**

5.1 **Landslides A1, A2 and A3**

The morphology and geology of the three landslide scars suggest that they were shallow sliding failures predominantly within completely decomposed granite. The close correlation of the severe rainstorm on 4 June 1997 and the reported time of the failures indicate that they were probably triggered by rainfall.

Based on the field observations, there was no evidence of unusually weak materials, discontinuities or other adverse geological features. The failures were not typical of major washout incidents resulting from concentrated surface water flow nor was there any evidence of a general rise in the base groundwater table. Rainfall on 4 June 1997 was particularly severe and rainfall falling on the cut slope and surface run-off from the upslope area (as there was no surface drainage provision at the slope crest) were probably the principal sources of water. It is postulated that the most likely cause of failure was infiltration into the vegetated slope followed by downslope seepage flow (i.e. non-vertical) along preferential flowpaths resulting in the development of local seepage pressures in the near-surface soils.

5.2 **Landslide B**

The morphology and geology of the landslide scar and debris suggest that the failure probably involved shallow sliding predominantly within completely decomposed granite. Landslide B occurred about 90 minutes after landslides A1 to A3, and was probably triggered by severe rainfall.

As with landslides A1 to A3, there is no evidence of unusually weak materials, discontinuities or other adverse geological features. The landslide was not typical of a major washout incident resulting from concentrated surface water flow nor was there any evidence of a general rise in the base groundwater table. Inspections of the broken and remaining sections of the crest U-channel by HAP immediately following the landslide did not reveal any evidence of blockage that may have resulted in overtopping of the U-channel.

There is no known observation or record of water pipe leakage prior to the failure. The coincidence of the time of the landslide occurrence and severe rainfall suggests that the failure was probably triggered by rain.
It is considered that the landslide was most probably caused by direct infiltration of rainwater into the predominantly unprotected cut slope followed by downslope seepage flow and the development of local seepage pressures in the near-surface soils.

6. DISCUSSION

Landslides A1 to A3, behind Nos. 2 and 3 Chung Shan Terrace, occurred on a cut slope which had been subjected to a detailed stability assessment in 1991, and the calculated safety margin against shallow failures in the upper part of the slope were only just below the required standard. However, slope works recommended in the Advisory Letter following the assessment were not carried out by the owners prior to the 1997 landslides.

The same cut slope behind Nos. 2 and 3 Chung Shan Terrace was assessed as being up to standard, as part of the site formation design for the redevelopment in 1992. The maximum slope angle considered in this assessment, however, appears to be lower than that considered in the 1991 study and observed on site. The reasons for this discrepancy are not known.

Landslide B occurred on a cut slope which was upgraded during the private redevelopment of Nos. 4 and 5 Chung Shan Terrace in 1990. This slope had a history of minor failures both before and after the upgrading works.

Monitoring of piezometers installed in the cut slopes, carried out for the above assessments and site formation design, indicated that the base groundwater table was well below the observed failure surfaces. The possible development of local seepage pressures in the near-surface soils resulting from surface infiltration was not considered in the assessments.

The previous assessments were based on the assumption of saturated shear strengths (determined from site-specific ground investigation and laboratory tests) and zero pore water pressure. The assumed shear strengths (Appendix A) seem reasonable in that they are consistent with parameters typically taken for similar materials and that no evidence of unusually weak materials, discontinuities or other adverse geological features was found. Hence, the shallow failures were likely to be due to the build-up of local positive pore water pressures. It is probable that these resulted from development of seepage pressure following direct infiltration or concentrated water ingress after localised erosion by surface water flow down the slope face.

7. CONCLUSIONS

It is concluded that the landslides that affected the cut slopes behind Nos. 1 to 5 Chung Shan Terrace were triggered by severe rainfall.

The failures were probably caused by direct infiltration of rainfall leading to downslope seepage flow and consequential development of seepage pressure in the near-surface soils. The lack of surface protection at the concerned slopes, together with the
absence of surface drainage at the crest of the cut slope at the location of landslides A1 to A3, were probably contributory factors to the failures.

The failures occurred at slopes that were previously subjected to detailed stability assessments.

8. **REFERENCES**


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<td>Year</td>
<td>Observation</td>
<td></td>
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<tr>
<td>------</td>
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<tr>
<td>1949</td>
<td>Chung Shan Terrace under construction. Platforms created for the development, by cutting and filling. Cut slope formed to the rear of the platforms where Nos. 2 to 4 Chung Shan Terrace are to be constructed. Access road to properties is present and supported in sections by large fill bodies. The foundations for Nos. 2 to 4 Chung Shan Terrace are in place. Castle Peak Road (2-lane) constructed with vegetated slopes adjacent to the road. A verge is present above 1997 failure sites.</td>
<td></td>
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<tr>
<td>1963</td>
<td>Castle Peak Road widened to 4 lanes. The sitting-out area directly above the 1997 failures has been widened by the addition of fill. Nos. 1 to 5 Chung Shan Terrace have been constructed. A retaining wall can be seen at the rear of Nos. 4 and 5, and there is a lineament to the rear of Nos. 2 and 3 suggesting that a retaining structure has been built there also.</td>
<td></td>
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<td>1973</td>
<td>Cut slope behind No. 5 Chung Shan Terrace has recently been re-surfaced. The configuration of the re-surfaced section indicates a minor failure may have previously occurred.</td>
<td></td>
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<tr>
<td>1978</td>
<td>The section of the slope previously re-surfaced appears more clearly in these photographs. A vertical lineament on the face of the failure suggests that surface drainage channels have been constructed. Additionally, a newly surfaced area is present just below the crest of the same slope (directly above the relict scar and below the verge).</td>
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<tr>
<td>1984</td>
<td>Nos. 4 and 5 Chung Shan Terrace have been demolished. The platforms upon which the buildings had been previously located remain unchanged.</td>
<td></td>
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<tr>
<td>1986</td>
<td>Site for building Nos. 4 and 5 remain vacant.</td>
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<tr>
<td>1991</td>
<td>Nos. 4 and 5 Chung Shan Terrace recently constructed. Dense vegetation on slope to rear of Nos. 1 to 5 Chung Shan Terrace.</td>
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<tr>
<td>1992</td>
<td>Slope to the rear of No. 4 Chung Shan Terrace locally re-surfaced. Nos. 2 and 3 Chung Shan Terrace demolished.</td>
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<tr>
<td>1994</td>
<td>Building Nos. 2 and 3 Chung Shan Terrace under construction.</td>
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<td>1995</td>
<td>Construction of Nos. 2 and 3 completed.</td>
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<table>
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<th>End of Period</th>
<th>Estimated Return Period (Years)</th>
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<td>14</td>
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<td>3</td>
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<td>07:00 hours on 4 June 1997</td>
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<td>128.5</td>
<td>07:00 hours on 4 June 1997</td>
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<td>07:00 hours on 4 June 1997</td>
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<td>07:00 hours on 4 June 1997</td>
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Notes:  
(1) Return periods were derived from the Gumbel equation and data published in Table 3 of Lam and Leung (1994).  
(2) Maximum rolling rainfall was calculated from 5-minute data for durations up to one hour and from hourly data for longer rainfall durations.
Table 4 – Maximum Rolling Rainfall Recorded at GEO Raingauge No. N04 for Selected Durations Preceding 08:30 Hours on 4 June 1997 and The Corresponding Estimated Return Periods (Landslide B)

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<th>Estimated Return Period (Years)</th>
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<td>4 hours</td>
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<td>12 hours</td>
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<td>4 days</td>
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<td>15 days</td>
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<td>31 days</td>
<td>846.5</td>
<td>08:00 hours on 4 June 1997</td>
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Notes:  
(1) Return periods were derived from the Gumbel equation and data published in Table 3 of Lam and Leung (1994).  
(2) Maximum rolling rainfall was calculated from 5-minute data for durations up to one hour and from hourly data for longer rainfall durations.
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Figure 1 - Site Location Plan
Castle Peak Road

Group of pipes on surface of slope

Area of chunam surfacing beyond crest of cut slope

Displaced catchpit

Severed U-channel

Location of landslide B on 4 June 1997

Broken U-channel 200 mm wide

Sitting-out area

Opening to basement car park

Location of landslide A1, A2 and A3 on 4 June 1997

Chung Shan Terrace

Legend:
- Landslide scar
- Landslide debris
- Cut slope boundary based on FHKL (1988)
- Approximate cut slope boundary from site observation
- Pipe(s)
- U-channel
- Concrete retaining wall

Note: Refer to Figures 4 and 5 for cross-sections A-A and B-B.

Figure 2 - Plan of the Landslide Sites
Area of chunam surfacing associated with repairs to a landslide evident on 1973 aerial photographs.

Extent of Slope No. 11NW-A/CR261

Government land

Government land

Location of landslide on 8 May 1992

Location of landslide B on 4 June 1997

Location of landslide A1, A2 and A3 on 4 June 1997

Exposures of completely decomposed granite

Figure 3 - Land Status and Site History
Figure 4 - Cross-section A-A through Landslide A1

Notes:
1. For location of section see Figure 2
2. Topographic section based on site observation
3. Borcholes were formed for the ground investigation carried out for the 1990 Stage 2 Study (GCE, 1990)

Legend:
- Piezometer tip and response zone
- Highest water level observed during monitoring between July and October 1990 (GCO, 1991)
Figure 5 - Cross-section B-B through Landslide B

Legend:
- Piezometer tip and response zone

Notes:
1. For location of section see Figure 2.
2. Exploratory holes were formed for the site formation works design of the redevelopment of Nos. 4 and 5 Chung Shan Terrace (OBECL, 1988).
3. For location of horizontal borehole HB1 and vertical borehole BH2 see Figure 3.
4. Topographic section based on site observation.
787.5 mm of rainfall recorded in the 31 days before 07:00 hours on 4 June 1997
256.5 mm of rainfall recorded in the 15 days before 07:00 hours on 4 June 1997

Date of the Landslides (4 June 1997)

(a) Daily Rainfall recorded between 1 May and 10 June 1997

263 mm of rainfall recorded in the 24-hours before landslides A1, A2 & A3
252.5 mm of rain recorded in the 12-hours before landslides A1, A2 & A3

314.5 mm of rainfall recorded in the 24-hours before landslide B
304 mm of rainfall recorded in the 12-hours before landslide B

(b) Hourly Rainfall Recorded between 08:00 hours on 2 June and 06:00 hours 5 June 1997

Reported time of landslides A1, A2 & A3 (07:00 hour on 4 June 1997)

Reported time of landslide B (08:30 hours on 4 June 1997)

Figure 6 - Rainfall Records at GEO Raingauge No. N04
Note: Isohyets prepared by the Hong Kong Observatory.

Figure 7 - Isohyets of Rainfall between 01:30 Hours and 08:30 Hours on 4 June 1997
June 1997  
(Rainfall preceding 08:30 hours on 4 June 1997 - landslide B)

June 1997  
(Rainfall preceding 07:00 hours on 4 June 1997 - landslides A1, A2 & A3)

August 1995

July 1994

July 1992

May 1992

May 1990

Figure 8 - Maximum Rolling Rainfall at GEO Raingauge No. N04 for Selected Major Rainstorms
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(Photograph Taken on 5 June 1997)
APPENDIX A

PREVIOUS STABILITY ASSESSMENTS
Notes:
(1) See insert for location of section.
(2) Details of the stability assessment are extracted from FHKL (1988).
(3) The piezometer installed in BH2 was dry during monitoring in May 1988 and June 1988.
(4) Adopted shear strength parameters are based on site specific laboratory testing.

Figure A1 - Stability Assessment for Site Formation Works Design of the Redevelopment of Nos. 4 and 5 Chung Shan Terrace
Notes:
(1) See insert for location of section
(2) Details of the stability assessment are extracted from GCO (1991)
(3) Adopted shear strength parameters are based on site specific laboratory testing
(4) The assumed 1-in-10 year groundwater table was derived from the height observed water levels (Figure 4) with "1 m rise allowed for any transient rainstorm effects" (GCO, 1991)

Figure A2 - Stability Assessment for the 1991 Stage 2 Study
Notes:
(1) Details of the assessment are extracted from JCAL (1992).
(2) The "recorded water level" appears to have been taken from monitoring of a piezometer installed at +37.97mPD (with a response zone between 39.97mPD and 39.07mPD) in borehole D1 (Figure 3) which was carried out between 10 August 1992 and 17 August 1992.

Figure A3 - Stability Assessment for Site Formation Works Design for the Redevelopment of Nos. 2 and 3 Chung Shan Terrace
SECTION 3:
DETAILED STUDY OF
THE LANDSLIDES
AT KA TIN COURT,
SHATIN
ON 2 JULY 1997

Halcrow Asia Partnership Ltd

This report was originally produced in December 1998
as GEO Landslide Study Report No. LSR 24/98
FOREWORD

This report presents the findings of a study of a landslide and a washout (GEO Incident Report No. MW97/7/24) that occurred above Ka Tin Court, Shatin on 2 July 1997. The landslide occurred on a partly-modified natural valley-side slope, that has a fill platform at the crest and a cut slope at the toe. The landslide debris partially blocked a minor river course in the valley. The washout occurred further down the river course, adjacent to the entrance of a drainage cascade that had become blocked with landslide debris transported by the river. The blockage caused debris and silty water to overspill onto an adjacent cut slope and the resulting washout into Ka Tin Court. The washout affected walkways adjacent to Ka Wing House, Ka Tin Court. No injuries or fatalities were reported.

The key objectives of the detailed study were to document the facts about the failures, present relevant background information and establish the probable causes of the failures. The scope of the study was generally limited to site reconnaissance, desk study and analysis. Recommendations for follow-up actions are reported separately.

The report was prepared as part of the 1997 Landslip Investigation Consultancy (LIC), for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 68/96. This is one of a series of reports produced during the consultancy by Halcrow Asia Partnership Ltd (HAP). The report was written by Dr Mark Swales and reviewed by Dr R Moore. The assistance of the GEO in the preparation of the report is gratefully acknowledged.

G. Daughton
Project Director/Halcrow Asia Partnership Ltd.
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1. **INTRODUCTION**

On the morning of 2 July 1997, a landslide (GEO Incident Report No. MW97/7/24) affected a partly-modified natural valley-side slope and a cut slope (No. 7SW-D/C551) overlooking a minor river valley above Ka Tin Court (Figures 1 and 2; Plate 1). The landslide partly obstructed the minor river and resulted in blockage of the entrance to a drainage cascade downstream of the landslide. Blockage of the drainage cascade caused the minor river to overtop its banks, resulting in a washout (Plate 2) on an adjacent cut slope (No. 7SW-D/C525) bordering the residential development known as Ka Tin Court. The washout affected walkways adjacent to Ka Wing House, Ka Tin Court. No fatalities or injuries were reported.

Following the landslide, Halcrow Asia Partnership Ltd (the 1997 Landslip Investigation Consultants) carried out a detailed study of the failures for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 68/96. This is one of a series of reports produced during the consultancy by Halcrow Asia Partnership Ltd (HAP).

The key objectives of the detailed study were to document the facts about the failures, present relevant background information and establish the probable causes of the failures. The scope of the study was limited to site reconnaissance, desk study and analysis. Recommendations for follow-up actions are reported separately.

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

(a) a review of relevant documents relating to the history of the site,

(b) analysis of rainfall records,

(c) interviews with witnesses and persons affected by the failures,

(d) detailed site observations and measurements, and

(e) diagnosis of the probable causes of the failures.

2. **THE SITE**

2.1 **Site Description**

The landslide and washout affected an unregistered partly-modified natural valley-side slope and a registered man-made cut slope adjacent to a minor river course above the Ka Tin Court housing development in Shatin (Figure 2). The river valley passes below a level fill platform constructed for the Union Hospital building, and between Slope No. 7SW-D/C551 on the east side and Slope No. 7SW-D/C525 on the west side of the river. At the boundary of Ka Tin Court, the river is controlled by a drainage cascade above a culvert (Figure 2).
The crown of the landslide was located, at about 60 mPD, on partly-modified natural terrain within a topographic depression on the valley-side slope (Figure 2). The landslide debris stripped material from downslope parts of the valley-side slope and the 8 m-high cut slope (No. 7SW-D/C551) at the toe. The valley-side slope and cut slope were inclined at angles between about 45° and 50° (Plate 3). The cut slope was covered in dense vegetation. No drainage provision was found on the cut slope, valley-side slope or fill platform above.

The washout occurred on the eastern end of an unsealed cut slope (No. 7SW-D/C525) which is situated on the west-side of the drainage cascade (Figure 2). The part of the cut slope affected by the washout was about 6 m high and inclined at about 30° to the horizontal.

A U-channel with a concrete apron was present around the perimeter of Ka Tin Court and a system of U-channels drain cut slope Nos. 7SW-D/C525 and 7SW-D/C401 (Figures 2 and 4).

According to the District Lands Office (1997), the landslide occurred on unallocated Government land. According to the SIMAR (Systematic Identification of Maintenance Responsibility of Slopes in the Territory) consultancy, the co-owners of Lot S.T.T.L. 290 are responsible for the maintenance of Slope No. 7SW-D/C525, which was affected by the washout.

2.2 Site History

The history of the site was determined from a review of aerial photographs and available documentary information. Key developments in the history of the site are given in Table 1 and Figure 3 and the key observations are summarised below.

Aerial photographs taken in 1963 show the site of the 1997 incidents to be located on the eastern side slope of a deeply incised valley, trending approximately northwest- to southeast.

The fill platform now occupied by Union Hospital was constructed between 1963 and 1976, and extended towards the site of the 1997 landslide between 1978 and 1980. A superficial body of fill was deposited on the valley-side slope below the platform, at the location of the 1997 landslide, at sometime between 1978 and 1980. The appearance of the fill on the aerial photographs suggests that it was end-tipped and may therefore be expected to be in a relatively loose state.

The cut slope (No. 7SW-D/C551) at the toe of the valley-side slope was formed as an agricultural terraced area between 1976 and 1978 and a few village huts were located at the toe of the slope at that time. The huts had been cleared and the terracing was abandoned by 1980.

Slope Nos. 7SW-D/C525 and 7SW-D/C401 were formed by cutting of the lower part of the hillside at sometime between 1980 and 1984.

Construction of Ka Tin Court began in 1985 and was complete by 1990. The fill
platform upslope of the 1997 landslide site was cleared of vegetation in 1990 prior to
collection of the buildings of Union Hospital which were completed by 1993. No significant
changes were apparent at the site since then.

There are no records of previous landslides in the near vicinity of the 1997 incident.

2.3 Previous Studies

As part of the site formation design submission for the construction of Union Hospital,
the consultants appointed by the developers carried out an “assessment of the conditions of the
slopes within and surrounding the site” with the intention of carrying out “slope upgrading
works if found necessary” (C.M. Wong & Associates, 1992). The area considered by
the assessment, however, did not include the valley-side slope involved in the 1997 landslide.

In 1992, GEO initiated the consultancy agreement entitled “Systematic Inspection of
Features in the Territory” (SIFT) which, inter alia, aims to update information on existing
registered slopes in the 1977/78 Catalogues of Slopes based on studies of aerial photographs
and limited site inspections. The landslide occurred on partly-modified natural terrain which
according to SIFT was not registerable.

The cut slope at the toe of the valley-side slope affected by the landslide was not
report prepared in 1995 for the cut slope indicated that it had been assigned Class “C1”, i.e. a
cut slope formed or substantially modified before June 1978. The fill platform occupied by
Union Hospital was also identified during the SIFT consultancy (Figure 3) but the fill body was
considered not to meet GEO’s criteria for slope registration.

The cut slope was subsequently registered as No. 7SW-D/C551 in the New Catalogue of
Slopes by consultants engaged in the “Systematic Identification and Registration of Slopes in
the Territory” consultancy for the GEO.

2.4 Subsurface Conditions

The Hong Kong Geological Survey map sheet No. 7 (GCO, 1986) and memoir for the
area (Addison, 1986) indicate that the river channel follows the line of a northwest-trending
fault and that the narrow valley floor and most of Ka Tin Court are underlain by debris flow
deposits. The area around the main landslide and the platform on which the Union Hospital is
located is underlain by coarse-grained granite which is cut by a northeast-trending intrusion of
quartz monzonite.

In 1982 a ground investigation was carried out in the area (Lam Construction, 1982).
Borehole ST 31/23, drilled from 39 mPD in the river bed below the landslide (Figure 2)
identified predominantly boulders of moderately decomposed granite to about 34 mPD, below
which alluvial sands and silts were logged to a depth of 28 mPD. The alluvial sands and silts
overlay a sequence of moderately and slightly decomposed granite (Figure 4).
In 1996, a ground investigation was carried out by Geotechnics & Concrete Engineering Ltd (GCE) to provide information for a geotechnical assessment of Slope No. 7SW-D/C401 by the HD (GCE, 1997). Borehole KT/B1 was formed from about 55 mPD (Figures 2 and 5) and proved completely decomposed granite to about 39 mPD, which overlay a sequence of highly and moderately decomposed granite that extended to the base of the borehole at about 28 mPD. Borehole KT/B2 was formed from about 47 mPD (Figures 2 and 5) and proved completely decomposed granite to 42 mPD, overlying moderately to slightly decomposed granite that extended to the base of the borehole at about 37 mPD.

A piezometer was installed in borehole KT/B1 within the highly to moderately decomposed granite at about 33.5 mPD and a standpipe was installed in borehole KT/B2 in moderately to slightly decomposed granite near the base of the borehole (Figure 5). Water levels were recorded in the piezometer and standpipe at about 41 mPD and 38.5 mPD respectively during November 1996.

Borehole logs from the ground investigation on the fill platform were unavailable, but the consultant’s report states that “the subsoil profile consists of a relatively thin layer of fill up to 3.5 m thick overlying the decomposed granite” (C.M. Wong & Associates, 1989). The report also states that “rockhead in the form of moderately to slightly decomposed granite varies in level from about +60 mPD to about +30 mPD towards both north and west”. The report indicates the groundwater level was located at about 33 mPD.

3. THE LANDSLIDE

3.1 Time of the Failures

Residents of Ka Tin Court reported to the Housing Department that the time of the failure was 09:30 hours on 2 July 1997. The reported time of failure probably corresponded to the occurrence of the washout on cut slope No. 7SW-D/C525, with the landslide occurring upstream sometime before this. A Landslip Warning was issued by GEO at 06:25 hours on 2 July 1997 until 08:40 hours on 5 July 1997.

3.2 Description of the Landslide and Washout

A plan and cross-section of the landslide and washout are shown in Figures 4 and 5 respectively.

The landslide principally involved the failure of the partly-modified natural valley-side slope below the fill platform. The main scarp of the landslide was up to 10 m wide, 15 m in length and 2 m deep. The estimated volume of displaced material was 150 m$^3$, excluding the material stripped from the valley-side slope (Section 2.1). The Incident Report prepared by the GEO following an inspection of the landslide on 5 July 1997 indicated that the failure occurred on “natural terrain” and involved “partially weathered rock”. There was no record of groundwater seepage in the main scarp. HAP carried out a preliminary inspection of the landslide on 6 August 1997. During the inspection observations confirmed the presence of completely decomposed granite. No seepage of groundwater in the main scarp was observed at
the time. Application of shotcrete subsequent to this inspection as part of the urgent repair works to the landslide scar prevented more detailed description of the materials involved in the failure.

Field reconnaissance of the area surrounding the landslide scar carried out by HAP during the investigation, however, identified highly to completely decomposed, coarse-grained granite with some sub-angular to rounded boulders up to 1.5 m in diameter on the north side of the landslide (Plate 5). On the south side of the landslide, the geology comprised completely decomposed granite with some rounded, similarly sized boulders. The landslide scar was also observed to have occurred within a topographic depression on the valley-side slope, that would have directed surface water towards the landslide site.

The morphology and observations made in and around the landslide scar suggest that the landslide probably involved sliding failure of the completely decomposed granite as well as the fill that had been placed on that part of the slope between 1978 and 1980 (Figure 3).

HAP also observed that the fill platform above the crest of the landslide was overgrown and contained a hollow, about 17 m wide, 7 m long and up to 0.5 m deep (Figure 4). A bund of fill, about 0.3 m high, was also present beyond the crest of the valley-side slope, which was probably formed during the site formation work for the hospital platform (Figure 4). The hollow and bund together would have acted as a sink for water collection.

Debris from the landslide stripped material from the area lower down the valley-side slope and cut slope No. 7SW-D/C551 (Figure 4) and was deposited in the river bed at the toe. The river bed was found to be strewn with stream deposits including rounded boulders, typically between about 0.5 m and 1 m in diameter, that would have been present before the 2 July 1997 incident. The travel angle of the landslide debris was estimated to be about 30°, which is typical for rain-induced landslides in Hong Kong (Wong & Ho, 1996).

A steel grill gate across the entrance to the cascade was observed to be partly obstructed by landslide debris that included a significant proportion of vegetation. This material appeared to have been transported by water flow within the river course, that would have been relatively high in response to heavy rainfall in the area on 2 July 1997 (see Section 4).

Localised erosion, stripping of vegetation and deposition of fines immediately upstream of the steel grill gate indicated that the river overtopped the concrete wing wall on the west side of the drainage cascade (Figure 4). There is also evidence that large areas of the west bank of the river have been affected by overtopping in the past (Figure 4).

A 1 m-deep channel was observed to have been eroded on the unsealed cut slope (No. 7SW-D/C525) adjacent to the drainage cascade. This was caused by water that had overtopped the river course and flowed over the concrete wing wall of the drainage cascade and onto the cut slope, resulting in the washout into Ka Tin Court (Plate 6).
4. **RAINFALL**

Rainfall data was obtained from the nearest GEO automatic raingauge No. N01 which is located about 650 m northwest of the site.

The cumulative 31-day rainfall before the landslide was 1108 mm and the 12-hour rainfall was 255.5 mm (Figure 6). Isohyets of rainfall between 02:55 hours and 09:30 hours on 2 July 1997 are shown in Figure 7.

Figure 8 presents the 5-minute rainfall data prior to the reported time of the incident. It is apparent that the reported time of the failures at 09:30 hours occurred around 3.5 hours after the most intense period of the rainstorm. This may be attributed to the lag-time response of increased discharge within the river valley and the likely occurrence of the landslide and subsequent blockage of the entrance to the drainage cascade sometime before the washout.

The estimated return periods for the maximum rolling rainfall up to 09:00 hours on 2 July 1997, for selected durations based on historical rainfall data at the Hong Kong Observatory (Lam & Leung, 1994) are given in Table 2. The most severe durations were between 1 and 4 hours, with estimated return periods of between about 20 and 45 years. The 31-day duration rainfall was also relatively severe, with an estimated return period of about 27 years.

5. **PROBABLE CAUSES OF FAILURE**

The close correlation between the rainstorm and the likely time of the landslide on 2 July 1997 indicates that the failure was probably triggered by rainfall.

The incident involved the failure of a substandard valley-side slope in completely decomposed granite with a superficial layer of fill which was probably loose.

The fill platform above the crest of the landslide was unsealed with no surface drainage provisions in that locality thus allowing direct infiltration over a large area. The hollow present on the fill platform (Sub-section 3.2) above the crest of the landslide may have resulted in ponding and concentrated infiltration during heavy rainfall. The setting of the landslide site in a natural depression on the valley-side slope would have directed surface water flow to the landslide site and the loose fill present on the slope may have locally promoted infiltration. Infiltration of water would have locally saturated the soil mass in the partly-modified natural terrain and reduced its shear strength, leading to failure.

Debris from the landslide partly blocked the river, and was eroded and transported downstream by stormflow within the river course causing blockage of the entrance to the drainage cascade. Blockage of the cascade led to overtopping of the west river bank, with water and debris causing washout of the unsealed slope adjacent to Ka Tin Court.
6. CONCLUSIONS

The landslide occurred on a slope which had not been subjected to detailed stability assessment and was probably triggered by severe rainfall.

The main scarp of the landslide approximately coincided with a topographic depression on the natural terrain. This, together with the presence of a hollow on the fill platform above the landslide and a thin veneer of fill on the valley-side slope, may have concentrated surface infiltration into the unprotected ground. Water ingress into the slope led to the failure.

7. REFERENCES


Housing Department (1997). Correspondence to the Director of Civil Engineering, reference (na) in HD(H)H/KAT 11/24/42/1 dated 2 July 1997.


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Table 1 – Summary of Aerial Photograph Interpretation

<table>
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<tr>
<th>Year</th>
<th>Photograph Reference No.</th>
<th>Observation</th>
</tr>
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<tbody>
<tr>
<td>1963</td>
<td>Y08740-1</td>
<td>The site of the landslides is situated on the eastern side slope of a roughly northwest-southeast trending a deeply-incised valley, densely vegetated with trees and shrubs. No developments evident in the area other than a few village huts/platforms at the base of the valley.</td>
</tr>
<tr>
<td>1976</td>
<td>13166-67</td>
<td>The fill platform for the Union Hospital has been constructed requiring cutting and filling of existing terrain. No spoil fill evident on the natural slope involved in the 1997 landslide.</td>
</tr>
<tr>
<td>1978</td>
<td>23486-87</td>
<td>The lower part of the slope affected by the 1997 landslide has been modified by the construction of agricultural terraces. The terraced area does not extend upslope as far as the main scarp of the 1997 landslide.</td>
</tr>
<tr>
<td>1980</td>
<td>30795-96</td>
<td>The platform for Union Hospital has been extended towards the site of the 1997 landslide by placement of fill. A ‘teardrop’ shaped lobe of spoil fill has been deposited on the natural slope at the location of the 1997 landslide. The fill body appear to be between 1 m and 1.5 m thick and extended over most of the height of the slope. The agricultural terraces at the base of the valley are now derelict.</td>
</tr>
<tr>
<td>1984</td>
<td>56838-9</td>
<td>Village houses and associated terraces at the base of the valley have been cleared and the area infilled to form a level platform for construction of Ka Tin Court. Slope Nos. 7SW-D/C551 and 7SW-D/C401 have been formed by cutting into the natural hillside either side of the lower part of the valley. Surface drainage channels and the drainage cascade are evident, associated with the cut slope.</td>
</tr>
<tr>
<td>1985</td>
<td>A2403-4</td>
<td>Construction of foundations for Ka Tin Court has commenced. Recently formed cut slopes re-vegetating.</td>
</tr>
<tr>
<td>1990</td>
<td>A23459-60</td>
<td>Buildings of Ka Tin Court have been completed.</td>
</tr>
<tr>
<td>1992</td>
<td>A30168-69</td>
<td>The fill platform upslope of the 1997 landslide site has been cleared of vegetation in preparation for construction of Union Hospital.</td>
</tr>
<tr>
<td>1993</td>
<td>A34688-89</td>
<td>Buildings associated with Union Hospital have now been completed.</td>
</tr>
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Table 2 - Maximum Rolling Rainfall at GEO Raingauge No. N01 for Selected Durations Preceding the 2 July 1997 Failures and The Corresponding Estimated Return Periods

<table>
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<th>Duration</th>
<th>Maximum Rolling Rainfall (mm)</th>
<th>End of Period</th>
<th>Estimated Return Period (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 minutes</td>
<td>12.5</td>
<td>06:10 hours on 2 July 1997</td>
<td>2</td>
</tr>
<tr>
<td>15 minutes</td>
<td>36.5</td>
<td>06:20 hours on 2 July 1997</td>
<td>8</td>
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<tr>
<td>1 hour</td>
<td>125</td>
<td>06:30 hours on 2 July 1997</td>
<td>34</td>
</tr>
<tr>
<td>2 hour</td>
<td>188.5</td>
<td>06:40 hours on 2 July 1997</td>
<td>45</td>
</tr>
<tr>
<td>4 hours</td>
<td>224</td>
<td>07:00 hours on 2 July 1997</td>
<td>21</td>
</tr>
<tr>
<td>12 hours</td>
<td>255.5</td>
<td>09:00 hours on 2 July 1997</td>
<td>6</td>
</tr>
<tr>
<td>24 hours</td>
<td>270</td>
<td>09:00 hours on 2 July 1997</td>
<td>3</td>
</tr>
<tr>
<td>2 days</td>
<td>315</td>
<td>09:00 hours on 2 July 1997</td>
<td>3</td>
</tr>
<tr>
<td>4 days</td>
<td>321</td>
<td>09:00 hours on 2 July 1997</td>
<td>2</td>
</tr>
<tr>
<td>7 days</td>
<td>329</td>
<td>09:00 hours on 2 July 1997</td>
<td>2</td>
</tr>
<tr>
<td>15 days</td>
<td>463</td>
<td>09:00 hours on 2 July 1997</td>
<td>2</td>
</tr>
<tr>
<td>31 days</td>
<td>1108</td>
<td>09:00 hours on 2 July 1997</td>
<td>27</td>
</tr>
</tbody>
</table>

Notes:  
1) Return periods were derived from the Gumbel equation and data published in Table 3 of Lam & Leung (1994).
2) Maximum Rolling rainfall was calculated from 5-minute data for duration up to two hours and from hourly data for longer rainfall durations.
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Figure 1 - Site Location Plan

Legend: □ Minor river course

Note: Base map is extracted from Survey Sheet Nos. 7SW-24B, 7SW-24D, 7SW-25A & 7SW-25C dated October 1992 (Original scale 1:1 000).
Figure 2 - Plan of the Failures and Previous Ground Investigations
Figure 3 - Land Status and Site History
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Figure 5 - Cross-section A - A through the Landslide
Figure 6 - Rainfall Records at GEO Raingauge No. N01
Note: Isohyets prepared by the Hong Kong Observatory.

Figure 7 - Isohyets of Rainfall between 02:55 Hours and 09:30 Hours on 2 July 1997
Figure 8 - Rainfall Recorded at GEO Raingauge No. N01 at 5-minute Intervals on 1 July and 2 July 1997

Time of failure reported at 09:30 hours on 2 July 1997
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Plate 6 - Erosion Channel and Washout Scarp
(Photograph Taken on 3 July 1997)
SECTION 4
DETAILED STUDY OF
TWO FAILURES
AT LI PO CHUN
UNITED WORLD COLLEGE,
WU KAI SHA
ON 2 JULY 1997

Halcrow Asia Partnership Ltd

This report was originally produced in December 1998
as GEO Landslide Study Report No. LSR 25/98
FOREWORD

This report presents the findings of a study of two failures (GEO Incident Report No. ME97/8/16), one on a cut slope and the other on a fill slope, at Li Po Chun United World College, Wu Kai Sha. The failures occurred sometime between 1 and 2 July 1997. Both failures were minor and deposited debris on open space, with no significant consequence.

The key objectives of the detailed study were to document the facts about the failures, present relevant background information and establish the probable causes of the failures. The scope of the study was limited to site reconnaissance, desk study and analysis. Recommendations for follow-up actions are reported separately.

The report was prepared as part of the 1997 Landslip Investigation Consultancy (LIC), for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 68/96. This is one of a series of reports produced during the consultancy by Halcrow Asia Partnership Ltd (HAP). The report was written by Mr R J Simonds and reviewed by Dr R Moore. The assistance of the GEO in the preparation of the report is gratefully acknowledged.

G. Daughton
Project Director/Halcrow Asia Partnership Ltd.
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1. **INTRODUCTION**

Sometime between 18:00 hours on 1 July 1997 and 08:00 hours on 2 July 1997 two failures occurred, one on a cut slope and the other on a fill slope, at Li Po Chun United World College (Figure 1 and Plates 1 and 2). In both cases debris was deposited on open space. No fatalities or injuries were reported.

Following the incidents, Halcrow Asia Partnership Ltd (the 1997 Landslip Investigation Consultants), carried out a detailed study of the failures for the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), under Agreement No. CE 68/96. This is one of a series of reports produced during the consultancy by Halcrow Asia Partnership Ltd (HAP).

The key objectives of the study were to document the facts about the failures, present relevant background information and establish the probable causes of the failures. The scope of the study was limited to site reconnaissance, desk study and analysis. Recommendations for follow-up actions are reported separately.

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

(a) a review of relevant documents relating to the history of the site,

(b) analysis of rainfall records,

(c) detailed site observations and measurements, and

(d) diagnosis of the probable causes of the failures.

2. **THE SITE**

2.1 **Site Description**

The locations of the failures are shown in Figure 1. One of the failures (denoted ‘A’ in Figure 2), located 20 m north of Lok Wo Sha Lane, occurred on a 7 m-high old cut slope (No. 7NE-D/C44), which is inclined at about 60° to the horizontal. Prior to the failure the cut slope was unprotected and sparsely covered with vegetation (Plate 2). A trapezoidal drainage channel is located about 2 m beyond the crest of the cut slope.

The second failure (denoted ‘B’ in Figure 2), located to the east of an access road to Li Po Chun World College, occurred an 8 m-high fill slope, which is inclined at about 30° to the horizontal and was constructed against an old cut slope in 1996. A basketball court and tennis courts are present at the toe of the fill slope.

Prior to the failure, the fill slope and the area beyond the slope crest were covered with grass and a few isolated young trees. The drainage on the fill slope comprised 300 mm
U-channels along the toe of the slope and 4 m beyond the crest of the slope respectively (Figure 2).

According to District Lands Office, failure A occurred on unallocated Government land and failure B occurred within Sha Tin Town Lot (STTL) No. 367 (Figure 3). According to the SIMAR (Systematic Identification of Maintenance Responsibility of Slopes in the Territory) consultancy, the Lands Department is responsible for the maintenance of the section of Slope No. 7NE-D/C44 on which failure A occurred. The owners of Li Po Chun United World College are responsible for the maintenance of the portion of slope No. 7NE-D/C44, within Lot (STTL) No. 367.

2.2 Site History

The site history has been established from aerial photographs of the site spanning the period 1949 to 1997 and a review of documentary information (Tables 1 and 2).

Aerial photographs taken in 1969 show that a large quarry was located at the site which modified the existing natural terrain and created the cut slope (Figure 3). At this time there was a trapezoidal drainage channel along the crest of the cut slope. This channel appears to have been either removed or infilled sometime before 1996. A fill slope was subsequently constructed against the cut slope, between January and May 1996, except for the southern-most 25 m-long section.

The development of the college was carried out in two phases. The works under Phase I commenced in early 1991 and consisted of site formation, slope drainage provisions and construction of the main college buildings. Phase I was completed in mid-1994. Works under Phase II, which commenced in January 1996, comprised a 160 m-long and 8 m-high fill slope formed against the existing cut slope (Figure 2). Phase II was completed in May 1996.

The owners of the college appointed consultants Wong & Ouyang (HK) Ltd (W & O) to undertake design and supervision of the construction works. As part of the Phase I design, a drainage layout plan was submitted to the Buildings Department (BD) and was approved in February 1992. This plan gave the proposed drainage detail along the crest of the slope, which consisted of a 300 mm U-channel connected to an existing trapezoidal channel.

A site formation plan for the Phase II works was submitted to the GEO via BD, who commented that there was “no geotechnical objection” to the proposed site formation works “subject to Qualified Supervision” (GEO, 1995). The site formation plan was subsequently approved by BD in November 1995.

Aerial photographs taken in July 1995 show white staining on the access road above the location of failure B on the fill slope (Figure 3). It is considered likely that the staining resulted from surface water run-off down the access road.

During construction of the fill slope, movement monitoring points installed at the slope crest were checked weekly (W & O, 1996a). The monitoring records showed that there was no significant movement of the fill slope during this period.
The specification for the new fill slope, as detailed on the site formation plan, required, inter alia, that the existing cut slope be benched prior to filling and that the in-situ density of compacted fill should not be less than 95% of the maximum dry density. It would appear from weekly site records (W & O, 1996a) that a notable amount of fill was placed prior to in-situ density testing. It is also unclear from the records as to the extent of testing during fill placement. Following completion of the slope works, in-situ testing was undertaken from trial pits to an estimated depth of up to 2 m. Results show the degree of compaction ranged between 95% and 104% (W & O, 1996b).

In August 1996, W & O submitted the as-built drawings and a slope record sheet certifying that the fill slope had been completed and was “structurally safe”. A copy of these documents was forwarded to the GEO who advised BD that “there is no geotechnical objection to the site formation works provided that the works have been completed in accordance with the approved plans” (GEO, 1996a).

2.3 Previous Studies

The old cut slope, against which the new fill slope was constructed, was not registered in the 1977/78 Catalogue of Slopes.

In 1992, the GEO initiated the consultancy agreement entitled “Systematic Inspection of Features in the Territory” (SIFT) which, inter alia, aims to identify and update information on slopes based on studies of aerial photographs and limited site inspection. In 1996, the SIFT study noted that “construction (was) visible” and identified the slope as a SIFT Class “C2” indicating that it was a cut slope that had been “formed or substantially modified after 30.6.78” (GEO, 1996b).

In 1994, the GEO commenced the consultancy agreement entitled “Systematic Identification and Registration of Slopes in the Territory” (SIRST) to update the 1977/78 Catalogue of Slopes and to prepare the New Catalogue of Slopes. The fill slope was inspected by the SIRST consultant in July 1997 following the landslide. The consultant reported no signs of seepage or distress but noted a partially blocked crest drain. The fill slope and the cut slope were considered as one feature and registered as cut slope No. 7NE-D/C44 in the New Catalogue of Slopes. The consultant also reported no “Inferred Past Instability” and confirmed that the slope, referred to as a cut slope with a SIFT classification of “C2”, was “formed or modified post mid 78”. Most of the feature is, however, a newly-formed fill slope.

W & O (1996c), the consultants appointed to design sport facilities at the site, completed a stability assessment of slope No. 7NE-D/C44 including the design of upgrading works within Lot (STTL) No. 367. There was no assessment or upgrading works on the southern most 25 m-long section of the cut slope, on which failure A occurred, as this section of slope was outside the lot boundary.
2.4 Previous Landslides

There are no records of past landslides in the vicinity of the 1997 failures in GEO's landslide database.

A landslide was identified on the 1969 aerial photographs (Table 1) on the northern part of the original cut slope (Figure 3). The landslide scar was subsequently regraded and covered by the fill slope formed in 1996.

Minor erosion was observed near the northern part of the fill slope according to aerial photographs taken in May 1997 (Figure 3).

2.5 Subsurface Conditions

The geological memoir (Addison, 1986) and Sheet 7 of the Hong Kong Geological Survey 1:20 000-scale Map Series (Geotechnical Control Office, 1986) indicate that the site is underlain by medium-grained granite. Geological sections through the cut slope and fill slope are shown in Figures 4 and 5 respectively.

At the location of failure A, adjacent surface exposures indicate that the cut slope comprised completely decomposed granite of mass weathering grade PW 0/30 (Figure 4).

A site investigation report by Lam Geotechnics Ltd (1990) included records of twelve boreholes drilled over the site of the proposed college development. Borehole No. BH10 was located about 20 m to the north of failure B (Figures 2 and 5). Groundwater assumed by W & O (1990) for the design was at a depth of about 4 m below the base of the newly-formed fill slope (Figure 5).

3. THE INCIDENTS

3.1 Time of the Failures

No eye-witnesses to the failures were identified. The caretaker at Li Po Chun United World College reported that the incidents had not occurred prior to 18:00 hours on 1 July 1997 but he observed the debris at about 08:00 hours on 2 July 1997. The precise timing of the failures is therefore unknown, although it is considered possible that they occurred sometime between 04:00 hours and 08:00 hours on 2 July 1997, during which time there was a severe rainstorm (see Section 4). A Landslip Warning was issued at 06:25 hours on 2 July 1997.

3.2 Description of the Failures

The description of the failures is based on the GEO Incident Report (No. ME97/8/6) and information provided by the college. HAP was unable to examine the failure scars or debris prior to completion of the remedial works.
The scar of failure A was reported as 3 m wide, 5 m high and about 0.5 m deep, with an estimated failure volume of about 8 m$^3$. The failure occurred on a 7 m-high cut slope inclined at about 60° to the horizontal. Examination of exposures in the cut slope on either side of the scarp by HAP confirmed the material to be completely decomposed granite with a mass weathering zone of PW 0/30. The failed section had no surface protection or slope drainage. The debris from the failure was deposited at the base of the slope where it blocked a catchpit and a U-channel. The geometry of the failure and the mode of debris deposition indicate that the failure was a shallow debris slide.

The GEO Incident Report noted that the scarp for failure B was 6 m-long but according to information provided by the college, failure B consisted of a 35 m-long scarp at the crest of the fill slope near to its interface with the cut slope (Figure 2). The scarp was an approximately linear feature that ran parallel to the slope crest with a height of up to about 1 m. The face of the scarp was inclined at between about 45° and sub-vertical. Some time after the failure, it appears that secondary washout of the exposed fill occurred locally below the scarp, probably as a result of surface run-off. A narrow (less than 2 m wide), thin washout trail formed down the fill slope. The debris from the washout blocked the U-channel at the toe of the slope and a thin layer of debris accumulated on the adjacent open space (Plate 1). Based on the dimensions of the scarp, the estimated failure volume was about 25 m$^3$.

Shortly after the incident, from information provided by the college, seepage was observed from a number of locations at the toe of the slope, but no seepage was observed on the scarp surface. It was noted during inspection by HAP on 24 February 1998 that the existing U-channel at the crest of the fill slope was partially blocked.

The general drainage layout plan for the college approved by BD in February 1992 shows a 300 mm U-channel connecting with the trapezoidal channel along the crest of the fill slope. At the time of inspection, the college caretaker informed HAP that this connecting U-channel was not present prior to the failure and had been constructed during the remedial works which were designed by W&O (Plate 5). The absence of the connecting U-channel could have promoted blockage and ponding of the crest U-channel.

The GEO Incident Report states "poor compaction" as a possible contributing cause of failure. Information provided by the college also suggested that the fill near the slope surface may not have been adequately compacted.

3.3 Follow-up Action

Following the incident, the GEO recommended a Dangerous Hillside Order be served on the owners of Lot (STTL) No. 367 (GEO, 1997) in respect of slope No. 7NE-D/C44 in November 1997.
4. **RAINFALL**

The nearest GEO automatic rain gauge No. N09 is located at the Meteorology Laboratory at Chinese University, Sha Tin, about 4 km west of the site (Figure 7). The daily rainfall recorded between 1 June and 5 July 1997 is shown in Figure 6a. There was 1005.5 mm and 617 mm of rainfall in the 31 days and 15 days before the incidents respectively. The hourly rainfall between 29 June and 2 July 1997 is shown in Figure 6b. There was little rainfall between 18:00 hours on 1 July 1997 and 04:00 hours on 2 July 1997 which was followed by a severe rainstorm between about 04:00 hours and about 12:00 hours on 2 July 1997.

An isohyet plot of rainfall recorded during the rainstorm between 00:00 hours and 08:00 hours on 2 July 1997 is given in Figure 7.

The estimated return periods for maximum rolling rainfall for selected durations based on historical rainfall at the Hong Kong Observatory (Lam & Leung, 1994) are presented in Table 3. The maximum rolling 4-hour rainfall between 04:00 hours and 08:00 hours on 2 July 1997 was the most severe, with a corresponding return period of about 30 years.

5. **PROBABLE CAUSES OF THE FAILURES**

Given that HAP’s study was initiated after completion of the slope repair works and that no ground investigation was carried out, the following diagnosis of the probable causes of the failures is based essentially on the findings of the desk study.

The close temporal correlation between the severe rainstorm in the morning of 2 July 1997 and the likely time of the failures indicates that intense rainfall probably triggered the landslides.

Failure A occurred on an oversteep (60°) old cut slope, which was formed in completely decomposed granite and was substandard. The failure was probably caused by infiltration of rainwater into the unprotected slope. Infiltration probably caused an increase in the degree of saturation of the near-surface soil, which resulted in loss of soil suction and reduction in shear strength leading to failure.

Failure B appears to have involved deformation near the crest of the fill slope and the development of 35 m-long scarp as a result of water ingress. The likely sources of water in the slope are:

(a) stormwater run-off from the access road above the fill slope overflowing the crest U-channel, and

(b) direct infiltration of rainfall into the slope.

Probable contributory factors to the failure could have been the presence of poorly compacted fill and inadequate surface drainage provision.
6. CONCLUSIONS

The two failures reported at Li Po Chun United World College affected an old substandard cut slope and a compacted fill slope recently formed in 1996. The failures were probably triggered by rainfall.

The cause of the minor cut slope failure is likely to have been infiltration into the unprotected oversteep soil cut formed in completely decomposed granite.

The failure on the fill slope involved deformation near the crest of the slope and secondary washout. Concentrated water ingress into the fill slope as a result of overflow from the crest U-channel was possible. The presence of poorly compacted fill could be a possible contributory factor in the failure.

7. REFERENCES


Lam Geotechnics Ltd. (1990). Site Investigation Report. Li Po Chun, United World College, Sai Sha Road / Lo Wo Sha Lane.


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Table 1 – Summary of Site Development from Aerial Photograph Interpretation

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<th>Year</th>
<th>Photograph Reference No.</th>
<th>Altitude</th>
<th>Observations</th>
</tr>
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<tbody>
<tr>
<td>1949</td>
<td>Y020212/3</td>
<td>5800 ft</td>
<td>The site was heavily vegetated natural hillside with low-lying agricultural terraces to the east and a small sea inlet from Tolo Harbour to the west.</td>
</tr>
<tr>
<td>1963</td>
<td>Y08730/1</td>
<td>3900 ft</td>
<td>Several depressions possibly minor excavations evident along the crest-line of the natural terrain.</td>
</tr>
<tr>
<td>1969</td>
<td>Y15703/4/5</td>
<td>-</td>
<td>A large quarry had developed over the site. The natural terrain had been significantly modified and a cut slope had been formed with an access road along the crest. The quarry was apparently not active and rows of young trees had been planted as part of a restoration scheme. A landslide was present in the cut slope, however no debris was evident at the toe of the slope. A drainage channel was visible running along the crest of the slope as far as the landslide scarp.</td>
</tr>
<tr>
<td>1973</td>
<td>07243/4/5</td>
<td>2000 ft</td>
<td>No changes were apparent other than the increase in the tree canopy over the site.</td>
</tr>
<tr>
<td>1982</td>
<td>40735/6</td>
<td>4000 ft</td>
<td>Construction of Sai Sha Road to the southwest of the site was on-going. The cut slope was visible and re-vegetation of the slopes above was apparent.</td>
</tr>
<tr>
<td>1984</td>
<td>56808/9</td>
<td>4000 ft</td>
<td>No changes were apparent other than the reduction of the tree canopy over the site.</td>
</tr>
<tr>
<td>1989</td>
<td>A19549/50/51</td>
<td>4000 ft</td>
<td>Sai Sha Road and Lok Wo Sha Lane had been constructed otherwise there were no apparent changes to the site.</td>
</tr>
<tr>
<td>1991</td>
<td>A27096/7</td>
<td>4000 ft</td>
<td>Li Po Chun United World College was under construction. The scarp of the landslide on the 1969 photographs had been trimmed back.</td>
</tr>
<tr>
<td>1994</td>
<td>A39104/5</td>
<td>6000 ft</td>
<td>The construction of Li Po Chun United World College was complete. The area directly upslope of the southern end of the cut slope and the flat-lying area at the toe of the cut slope had become heavily vegetated.</td>
</tr>
<tr>
<td>1995</td>
<td>CN10331/2/3</td>
<td>3200 ft</td>
<td>Surface water flow-lines were visible down the access road from the college to the crest of the slope.</td>
</tr>
<tr>
<td>1996</td>
<td>CN13355/6</td>
<td>4000 ft</td>
<td>The cut slope had been modified by the addition of a fill slope along the toe. A 25 m-long section of the cut slope remained unmodified at the southern end. A stockpile of fill material was observed at the edge of the access road with a possible washout trail down the edge of the road in the direction of the fill slope.</td>
</tr>
<tr>
<td>1997</td>
<td>CN17765/6</td>
<td>4000 ft</td>
<td>A basketball court and two tennis courts had been constructed adjacent to the toe of the fill slope. There was evidence of minor erosion of the fill slope near the northern staircase.</td>
</tr>
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Table 2 – Summary of Information Sources

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<tr>
<th>Source</th>
<th>Information Obtained</th>
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<tr>
<td>Geotechnical Information Unit (GIU).</td>
<td>There were no relevant borehole records.</td>
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<td>Mainland East Division and Design Division of GEO.</td>
<td>(a) Correspondence indicating land status from District Lands Office.</td>
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<td>(b) Correspondence to and from BD in connection with GEO checking of fill slope.</td>
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<td></td>
<td>(c) Correspondence to BD from GEO recommending Dangerous Hillside Order.</td>
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<tr>
<td></td>
<td>(d) A geological cross-section within geotechnical report by Wong &amp; Ouyang (1990).</td>
</tr>
<tr>
<td>GEO Publications, Reports, Maps and Memoirs.</td>
<td>(a) Sha Tin: Solid and superficial geology, Hong Kong Geological Survey Map Series HGM20 Sheet 7, 1:20 000 scale.</td>
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<td>(b) Geology of Sha Tin, Hong Kong Geological Survey Memoir No. 1.</td>
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<tr>
<td>GEO Landslide Incident Report database.</td>
<td>There was no relevant information.</td>
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<td>GEO Planning Division.</td>
<td>(a) Phase 2 SIFT Study Map Sheet Report 1:1 000 Map Sheet 7NE-15C&amp;D.</td>
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<td>(b) Natural Terrain Landslide Inventory.</td>
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<td>GEO Slope Safety Division.</td>
<td>SIRST report for Slope No. 7NE-D/C44.</td>
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<td>Water Supplies Department (WSD).</td>
<td>Existing Utility Information.</td>
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<tr>
<td>Drainage Services Department (DSD).</td>
<td>Existing Utility Information.</td>
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<tr>
<td>LPM / SIRST / SIFT Databases.</td>
<td>Registration status of Slope No. 7NE-D/C44.</td>
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<td>(b) Approved Site Formation Plans: Phase II Works dated 5 November 1995.</td>
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<tr>
<td>Hong Kong Observatory (HKO).</td>
<td>(a) Daily rainfall data from January 1983 to July 1997.</td>
</tr>
<tr>
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<td>(b) Hourly rainfall data from January 1984 to July 1997.</td>
</tr>
<tr>
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<td>(c) Isohyets of rainfall between 00:00 hours and 08:00 hours on 2 July 1997.</td>
</tr>
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Table 3 - Maximum Rolling Rainfall at GEO Raingauge No. N09 for Selected Durations Preceding the 2 July 1997 Incident and the Corresponding Estimated Return Periods

<table>
<thead>
<tr>
<th>Duration</th>
<th>Maximum Rolling Rainfall (mm)</th>
<th>End of Period</th>
<th>Estimated Return Period (Years)</th>
</tr>
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<tr>
<td>5 minutes</td>
<td>15</td>
<td>06:20 hours on 2 July 1997</td>
<td>4</td>
</tr>
<tr>
<td>15 minutes</td>
<td>41</td>
<td>06:25 hours on 2 July 1997</td>
<td>18</td>
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<tr>
<td>1 hour</td>
<td>100</td>
<td>06:30 hours on 2 July 1997</td>
<td>8</td>
</tr>
<tr>
<td>2 hours</td>
<td>168</td>
<td>07:50 hours on 2 July 1997</td>
<td>21</td>
</tr>
<tr>
<td>4 hours</td>
<td>239.5</td>
<td>08:00 hours on 2 July 1997</td>
<td>30</td>
</tr>
<tr>
<td>12 hours</td>
<td>271.5</td>
<td>08:00 hours on 2 July 1997</td>
<td>8</td>
</tr>
<tr>
<td>24 hours</td>
<td>283.5</td>
<td>08:00 hours on 2 July 1997</td>
<td>4</td>
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<tr>
<td>2 days</td>
<td>356.5</td>
<td>08:00 hours on 2 July 1997</td>
<td>5</td>
</tr>
<tr>
<td>4 days</td>
<td>384</td>
<td>08:00 hours on 2 July 1997</td>
<td>3</td>
</tr>
<tr>
<td>7 days</td>
<td>459.5</td>
<td>08:00 hours on 2 July 1997</td>
<td>4</td>
</tr>
<tr>
<td>15 days</td>
<td>617</td>
<td>08:00 hours on 2 July 1997</td>
<td>5</td>
</tr>
<tr>
<td>31 days</td>
<td>1005.5</td>
<td>08:00 hours on 2 July 1997</td>
<td>14</td>
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Notes:
1. Return periods were derived from the Gumbel equation and data published in Table 3 of Lam & Leung (1994).
2. Maximum rolling rainfall was calculated from 5-minute data for durations up to one hour and from hourly data for longer rainfall durations.
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<td>Isohyets of Rainfall between 00:00 Hours and 08:00 Hours on 2 July 1997</td>
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Figure 1 - Site Location Plan

Note: Base map is extracted from Survey Sheet Nos. 7NE-20A, 7NE-15C, 7NE-14D and 7NE-19B dated November 1996 (Original scale 1:1000).
Figure 2 - Plan of the Failure Sites
Li Po Chun United World College constructed between 1990 and 1994

White staining on access road probably evidence of surface water run-off, between 1995 and 1997

Stockpile of fill material with possible washout trail indicating surface water run-off towards fill slope, 1996

Existing cut slope formed during quarry operations between 1963 and 1969

Trapezoidal drainage channel infilled or removed by 1996

Landslide scar visible on 1969 aerial photographs

Minor erosion of fill slope near staircase visible on May 1997 aerial photographs

Fill slope constructed against existing cut slope between January 1996 and May 1996

Note: The site history has been established from a review of aerial photographs taken between 1949 and 1997.

Figure 3 - Site History and Land Status
Slope No. TNE-D/C44
Trapezoidal channel
Pre-failure cut slope profile
Post-failure cut slope profile
Completely decomposed granite (PW 0/30)
Approximate extent of failure debris which accumulated on open space

Elevation (mPD)

Note: Refer to Figure 2 for location of cross-section.

Figure 4 - Geological Cross-section A - A
Access road to Li Po Chun College

Stromwater run-off from overflowing U-channel

Scarp (up to about 1m high)

Narrow (<2 m wide) washout trail down the fill slope

Fill slope

Approximate extent of washout debris which accumulated on open space

300 mm U-channel blocked with washout debris

300 mm U-channel

Trapezoidal drainage channel infilled or removed

Original cut slope profile

Completely to highly decomposed medium-grained granite

Moderately to slightly decomposed medium-grained granite

BH10

Legend:

Legend: 

Groundwater table as shown on cross-section in W & O (1990)

Note:

Refer to Figure 2 for location of cross-section.

Figure 5 - Geological Cross-section B - B
S005.5 mm of rainfall recorded in the 31 days before the failures
617 mm of rainfall recorded in the 15 days before the failures

Probable date of the failures

1005.5 mm of rainfall recorded in the 31 days before the failures
617 mm of rainfall recorded in the 15 days before the failures

(a) Daily Rainfall Recorded between 1 June and 5 July 1997

(b) Hourly Rainfall Recorded between 29 June and 2 July 1997

Figure 6 - Rainfall Recorded at GEO Raingauge No. N09
Note: Isohyets prepared by the Hong Kong Observatory.

Figure 7 - Isohyets of Rainfall between 00:00 Hours and 08:00 Hours on 2 July 1997
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Plate 3 - Remedial Works at the Cut Slope  
(Photograph Taken on 24 February 1998)

Plate 4 - Remedial Works at the Fill Slope  
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Plate 5 - U-channel Constructed between the Existing Drainage Channels at the Crest of the Fill Slope During Remedial Works (Photograph Taken on 24 February 1998)
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