ATTACHMENT A

REPORT

Western Bay of Plenty District Council

Bramley Drive Landslip Hazard Assessment

Report prepared for:

WESTERN BAY OF PLENTY DISTRICT COUNCIL

Report prepared by:

Tonkin & Taylor Ltd

Distribution:

WESTERN BAY OF PLENTY DISTRICT COUNCIL	2 copies
TONKIN & TAYLOR LTD (FILE)	1 copy

June 2011

T&T Ref: 851378.150

ATTACHMENT A

Table of contents

1 Introduction

A large landslip occurred below Bramley Drive in March 1979 following a prolonged period of heavy rainfall. Recent heavy rainfall has triggered a reactivation of this landslip with significant regression of the headscarp occurring on 11th May 2011. The landslip is likely to regress as the slope angle of the headscarp reduces. In this regard Western Bay of Plenty District Council (Council) has engaged Tonkin & Taylor to:

- Undertake a visual assessment of the landslip
- Assess the likely future activity of the landslip and the risk posed to the public and to Council services
- Provide concept designs of potential remedial options for the landslip

Information supplied in this report only applies to the landslip below Bramley Drive and should not be utilised for the remainder of the peninsula.

2 Site Description and history

The landslip is located on the western margin of Omokoroa Peninsula on steep coastal cliffs. The northern and southernmost extents of the landslip are bounded by numbers 17 and 5 Bramley Drive respectively.

The original landslip has been described in a Tonkin & Taylor report dated May 1980[1] and in an unpublished Master's thesis[2]. The landslip measured roughly 60m in width and had a run out distance exceeding 150m from the base of the slope. It caused the cliff edge to recede by more than 20m. The landslip forced the evacuation and eventual removal of five houses due to their close proximity to the main headscarp. It occurred as a large block slide which failed along a highly sensitive ash layer approximately 20 m below the headscarp. The location and extent of the 1979 landslip is shown on Figures 1 and 2 in Appendix A. Following the 1979 landslip dwellings on the affected properties were demolished. A fence was also erected around the headscarp to prevent public access to the area.

The slope failure of 11th May 2011 involved the reactivation of the 1979 landslip and has resulted in regression of the head scarp and re-inundation of the original failure deposit. The recent failure appears to have occurred as a second block slide mainly affecting the upper 20 m of the slope. A pronounced bench is present approximately 20 m below the headscarp that coincides with the location of the sensitive ash layer. The size and extent of the recent landslip is shown on Figures 3 and 4 and in Photographs 1 to 4, Appendix A.

---

[1] Tonkin & Taylor (May 1980) Omokoroa Point Land Stability Investigation. Report to Tauranga County Council

[2] Keam, M. (2008) Engineering Geology and Mass Movement on the Omokoroa Peninsula, Bay of Plenty, New Zealand

3 Investigations undertaken

Our investigations comprised:

- A walkover by two engineering geologists
- Production of basic geomorphological maps and cross sections
- Comparison of new information with the pre-existing site data
- Assessment of the risk to life and property/assets posed by the landslip in accordance with Australian Geomechanics Society Guidelines[3]

It should be noted that inspections were only undertaken where access or visual inspection was possible.

4 Geology and subsurface conditions

4.1 Soils and behavioural properties

The soil materials involved in the landslip consist of a typical stratigraphic sequence of un-welded ignimbrites overlain by airfall tephra. Some of these volcanic units are intercalated with sediments that were formed in response to fluvial, lacustrine and estuarine processes of erosion, transportation and redeposition of unconsolidated volcanic debris[4]. The whole sequence is grouped together and has been named Matua Subgroup.

The sequence of material located in the landslip consists of Younger Ashes and Hamilton Ash, a number of unidentified ash units with interbedded paleosols, a highly sensitive silt unit, and Kidnappers Ignimbrite overlying interbedded sediments and volcanic deposits (see Figure 2 after Keam 2008). This geology constitutes an over thickened sequence of soil which is considered to coincide with the presence of an ancient channel below the end of Bramley Drive[1]. The location of the landslip was ultimately determined by the presence of the infilled channel.

Of particular note is the highly sensitive silt unit which is a large contributor to slope instability right along the western margin of Omokoroa Peninsula. This material has a very high porosity but low permeability. It inhibits the downward percolation of water and causes a perched water table. The material is weak in compression with a high natural moisture content that often exceeds its liquid limit. The silt exhibits very low values of cohesion but relatively high angles of internal friction. It is able to support relatively steep slopes until saturated. Upon saturation the pore pressure forces the grains to separate and the structure of the material to collapse. Once disturbed the material looses all integral strength and becomes highly fluid and mobile. This contributes to the extensive run out distance of the displaced material[2].

4.2 Overland water flow and seepage

During visual inspection it was noted that overland flow was still evident from near the headscarp of the landslip. Seepage was also occurring over much of the headscarp, but particularly from a point midway up the headscarp. This indicates the existence of a perched water table with groundwater flowing above a relatively impermeable unit. This groundwater flow is now channelled due to the effects of paleotopography.

---

[3] Australian Geomechanics Society (2007) Landslide Risk Management

[4] Briggs et al. (1996) Geology of the Tauranga area, Occasional Report No. 22, University of Waikato, Department of Earth Sciences

Tonkin & Taylor (1980)[1] also noted considerable seepage from midway up the main scarp that occurred for a month following the initial landslip in 1979. This produced small mobile slurries of debris from the mud deposit in the zone of depletion. These slurries were also evident following the events of 11th May 2011.

5 Landslip morphology and activity

5.1 Existing profile

The recent landslip activity occurred over a 60 m width and is fully contained within the 1979 landslip. The main regression has occurred at the southern end of the headscarp. The main slip surface appears to coincide with the sensitive ash layer located on a bench in the slope approximately 20 m below the crest of the headscarp. The failure has resulted in an oversteep headscarp and considerable inundation at the base of the slope.

In comparison to the landslip profile before the events of 11th May 2011, the main scarp is much steeper, and the bench is more pronounced. The landslip has not increased in width or in length although the headscarp has regressed by up to 6 m. The debris has re-inundated approximately the same area that was affected in 1979. At its southern end, the landslip has undermined the barrier fence (see Figure 3).

The soils within the landslip are likely to have weakened over time as they have weathered and as the slope has relaxed following the 1979 event. The recent landslip event is considered to have been finally triggered by heavy rainfall following a prolonged period of wet weather.

5.2 Future activity

The landslip headscarp will undergo post-failure relaxation and regression in order to achieve a sustainable slope angle. This occurred following the 1979 landslip where repeated movements of the same type occurred in the days following the initial failure. The majority of the landslip regression is likely to occur in the southern and central areas of the headscarp which have been oversteepened. The likely headscarp regression in the short and medium terms is shown on Figures 3 and 4. For the purposes of this report short term is taken to mean within the next 6 months and medium term the next 1 to 10 years. Long term is taken as 10 to 50 years.

The portion of the fence behind the centre of the headscarp is expected to remain in its current position in the short term. In the medium term it is at risk of collapse due to undermining. A Council water supply main is situated in the grass verge between the footpath and the road and may also be at risk of damage resulting from regression of the headscarp in the medium term. The portion of the headscarp at the southern end has undermined part of the fence around the landslip. Further portions of the fence are likely to be undermined in the short term.

The closest corner of the dwelling located on No. 5 Bramley Drive is currently 20m from the nearest point of the landslip headscarp. It is unlikely that this dwelling will be in danger, within the medium term, as a result of the recent landslip.

6 Risk analysis

The risk of further instability affecting Bramley Drive and the property and dwelling of No. 5 Bramley Drive has been assessed according to Australian Geomechanics Society Guidelines (2007)[3]. Risk matrices taken from the AGS Guideline are provided in Appendix B. This approach provides a methodology for determining the actual level of risk associated with future instability.

6.1 Risk to existing Council infrastructure and private property

Note that landslide risk analysis for Bramley Drive has been divided into both short to medium term risk and long term risk and assumes existing conditions without implementation of remedial measures. Short to medium term denotes a period of less than 10 years and long term represents a period of 10 to 50 years.

6.1.1 Short to medium term risk

Based on historic slope movements of the landslip below Bramley Drive it may be assumed that the landslip will seek to establish a more sustainable slope angle (approximately 40° to 50° based on past activity). This suggests that within the next six months the landslip headscarp may recede by up to approximately 5m. Within the next 5-10 years the headscarp may recede by up to approximately 10m.

6.1.1.1 Risk to Council Infrastructure

Council services located within the area include sewer, stormwater and water mains. There is no existing Council infrastructure within 10m of the headscarp and Council infrastructure is therefore **"Unlikely"** to be at risk of damage resulting from short to medium term landslip activity. The closest service to the landslip is a water main that runs along the grass verge between the road and the footpath. The damage to the water main resulting from a large landslip would be **"Major".** A section of the water main would be destroyed by a landslip that reached it and this would affect all neighbouring properties.

The overall short to medium term risk rating for an unlikely impact with major consequences to existing Council infrastructure is classified as **"Moderate"** under AGS guidelines. Moderate risk 'may be tolerated in certain circumstances (subject to regulator's approval) but requires investigation, planning and implementation of treatment options to reduce the risk to Low. Treatment options to reduce to Low risk should be implemented as soon as practicable'[3].

6.1.1.2 Risk to the property and dwelling of No. 5 Bramley Drive

The property boundary of No. 5 Bramley Drive is situated within 10m from the closest point of the headscarp. It is **"Possible"** that the property will be affected by short to medium term landslip activity. The dwelling is set back approximately 20m from the headscarp and is considered a **"Rare"** possibility of being damaged by short to medium term landslip activity.

The impact of a landslip on the property of No. 5 Bramley Drive would be **"Minor"** and require reinstatement stabilisation works to only part of the property, though this would be difficult. If the landslip were to recede back to the dwelling on this property the impact could be **"Catastrophic"** causing complete destruction of the building or, at the very least, rendering it uninhabitable.

The overall short to medium term risk rating for a possible impact with minor consequences to the property of No. 5 Bramley Drive is classified as **"Moderate"**. The short to medium term risk rating for a rare impact with catastrophic consequences to the dwelling on No. 5 Bramley Drive is also classified as **"Moderate"**. As mentioned in 6.1.1.1, moderate risk is tolerable but requires treatment options to reduce the risk to Low.

6.1.2 Long term risk

Long term risk is difficult to predict, even with the aid of geotechnical investigation. However, the landslip has reactivated after a period of approximately 32 years following the initial failure. It is

"Likely" that the landslip will eventually recede back to Bramley Drive and maybe beyond. To reach Bramley Drive another large landslip event would be required. This may occur within the next 10 to 50 years. It is impossible to rule out two landslip events within this period which would involve regression of the headscarp beyond Bramley Drive and into the existing properties behind. It is also worth noting that the remaining design life of the existing Council services is 50 years and the majority of local dwellings is likely to be 20 to 30 years.

The damage and impact to Bramley Drive, local Council services and neighbouring properties would be **"Catastrophic"**. All eight dwellings north of the landslip on Bramley Drive would be cut off and therefore inaccessible.

The overall long term risk rating for a likely impact with major consequences to Bramley Drive and its properties is classified as **"Very High"**.

6.2 Risk to People

Risk to people has been analysed on a short to medium term basis and therefore concerns the area within 10m of the existing headscarp and within the zone of existing debris only.

Annualised Loss of Life Risk ($R_{(LOL)}$) is defined by AGS (2007) as:

$$R_{(LOL)} = P_{(H)} \times P_{(S:H)} \times P_{(T:S)} \times V_{(D:T)}$$

Where:

$P_{(H)}$ = Total annual probability of a landslide occurring - 10^{-1} (Almost certain) for the area between the headscarp and 10m out from the headscarp

$P_{(S:H)}$ = Probability of spatial impact (i.e. the probability that the landslide headscarp and debris will reach the areas of interest) – 0.3

$P_{(T:S)}$ = Temporal Spatial Probability (i.e. the probability that persons at risk will be present when the landslide occurs) – 0.01 for the area near the existing fence or within the zone of existing debris

$V_{(D:T)}$ = Vulnerability of person to impact (i.e. the probability that death will result as a consequence of the evacuation and inundation of land) – 0.8 for a person standing in the area near the fence or in the zone of existing debris i.e. the probability that death will occur if a person is carried away or buried by the landslide is considered to be high

Based on the above, the risk to loss of life ($R_{(LOL))}$) is then 2.4×10^{-4} for a person standing near the fence surrounding the headscarp of the slope or within the zone of existing debris(see Table 1). This equates to **"Moderate to High"** risk in accordance with the AGS guidelines. However, there are mitigating circumstances that would reduce this risk. The landslip would have to be large and would most likely occur during heavy rainfall. The likelihood of someone standing near the fence or in the area of existing debris in the rain is low. Given these mitigating factors we consider that the appropriate risk rating to persons outside the fence bounding the landslip headscarp or within the existing debris is **"Moderate"**.

Table 1 Life Loss Criteria Descriptors (AGS, 2007)

Annual Probability of Death of the Person Most at Risk in the Zone	Risk Zoning Descriptors
$>10^{-3}$/annum	Very High
10^{-4} to 10^{-3}/annum	High
10^{-5} to 10^{-4}/annum	Moderate
10^{-6} to 10^{-5}/annum	Low
10^{-6}/annum	Very Low

A moderate risk for an existing slope is usually tolerable, but treatment options need to be undertaken to reduce the risk to low. Implementation of such measures is generally required as soon as practicable. Concept remedial options are described in the following section.

7 Concept Remedial Options

A number of options are available to mitigate the effects of further landslipping and regression of the existing headscarp. The options are detailed in the following sections.

7.1 Earthworks

We have considered earthworks as an option to stabilise the landslip. To achieve a slope that is not prone to land slippage would require a batter of less than 1V:2H. Such a batter would extend under the road and into properties on the opposite side. As this is the case, this option is not considered further.

7.2 Palisade Wall

A possible remedial solution that would remove the imminent risk to dwellings, properties, council infrastructure and the public would involve the construction of a large palisade wall with a capping beam and two rows of anchors. This palisade wall would likely comprise 600-750mm diameter reinforced concrete piles at 1.5-2m spacings, approximately 20-25m long with a capping beam. The palisade wall would be tied back using 25 to 30 m long anchors from the capping beam into the soil below the existing road.

Slope stability is usually expressed in terms of a Factor of Safety (FOS). A slope with a FOS above 1.0 is stable whereas a slope with a FOS of less than 1.0 is failing. Slope mitigation measures are usually designed to achieve a minimum FOS of 1.5 with respect to the stability of a slope under static conditions.

At least two rows of ground anchors would likely be required for the palisade wall to achieve a FOS of 1.5 for the Bramley Drive landslip. A single row of anchors would increase the Factor of Safety from its current level, but the wall would likely fail under earthquake loading. Council may consider a reduced FOS acceptable under the current circumstances but would have to accept the risk that landsliding may occur during seismic activity.

A concept drawing of this remedial solution is shown in Sketch 1, Appendix A. It would likely be a costly option.

7.3 Rockfill Buttress

Construction of a rockfill buttress would stabilise the slope and more than reinstate the evacuated land resulting from the 11th May 2011 landslip. This would involve the placement of approximately 35,000 m^3 of free draining material such as quarry rock within the existing landslip footprint. The rock fill would need to be benched into the slope and battered to an angle no steeper than 1V:1.5H. Horizontal drains into the main scarp and bench drains with a central collector would also need to be constructed to control the groundwater beneath the buttress. This solution would effectively remove the imminent risk and may be slightly cheaper than an anchored palisade wall. It may also provide the potential for reinstatement and resale of the properties that were removed as a result of the initial 1979 landslip.

A concept drawing of this remedial solution is shown in Sketch 2, Appendix A.

7.4 Do nothing to the slope, prevent access close to the landslip headscarp and relocate the Council water main

If left to recede back to a sustainable slope angle the landslip would require further barriers to restrict access by the public. This would involve extension of the existing fence to join the boundary fence on No. 5 Bramley Drive. The fence line would also need to be set back from the headscarp to a point close to the footpath and adjusted according to future landslip activity. Regression of the landslip would need to be monitored, initially on a weekly basis and on a monthly basis for the next six months (until the end of winter). Regular visits should be maintained following this period.

With this option Council should consider relocating the water supply to the south eastern side of Bramley Drive. The relocation of the water supply would reduce the likelihood that it will be undermined by future landslippage.

7.5 Drainage

Installation of drainage will be required whichever option is chosen. This would involve the drilling of two rows of horizontal drains into the main scarp on the upper and lower surfaces of the sensitive silt. This solution would lessen pore pressures in the sensitive silt and reduce the regression rate of the headscarp. It would not prevent future landslip activity but would likely decrease the frequency and magnitude of events. The drains would be installed at approximately 5m centres horizontally within the main scarp. Water from these drains would need to be collected by a non-perforated pipe before ultimately discharging to the base of the slope. The drains would need to be maintained and checked periodically to ensure that they remain free of blockages.

A concept drawing of this remedial solution is shown in Sketch 3, Appendix A.

7.6 Vegetation Management

Several large trees exist adjacent the southern end of the headscarp. These trees surcharge the top of the slope and provide little support in terms of slope stability. The western margin of Omokoroa Peninsula is prone to high winds which place pressure on these trees and the soils in which they are rooted. It is recommended that these large trees be removed and deposited at the base of the slope. Care must be taken in the execution of this task as dragging the trees over the headscarp may cause further destabilisation of the slope.

The establishment of small shrubs with deep root systems would be beneficial to slope stability. It is recommended that removed vegetation be replaced with such shrubs.

ATTACHMENT A

8 Discussion and Conclusions

The landslip below Bramley Drive is a result of a number of factors including:

- A prolonged period of heavy rainfall
- The presence of highly sensitive silt that is prone to collapse upon loading and saturation
- The existence of a perched groundwater table

The material involved in the landslip is highly mobile once disturbed. This mobility results in the extensive run out distance of the failure deposits.

The landslip headscarp is vulnerable to post failure regression and relaxation. Based on previous landslip activity, this may cause the landslip to recede by up to 10m over the next 10 years. Landslip activity beyond a 10 year period is difficult to predict but may involve several landslip events that cause recession of the headscarp back to and beyond Bramley Drive.

The short to medium term risk to Council infrastructure, local properties and dwellings caused by further landslipping and recession of the existing headscarp is considered to be "moderate" in accordance with AGS guidelines. In order to reduce this risk to "low", one of several remedial options is required.

The risk of loss of life caused by reactivation of the existing landslip is considered "Moderate" in accordance with the AGS guideline. This risk increases with proximity to the existing headscarp and failure deposit. Moderate risk ratings are generally considered tolerable as long as mitigation options are put in place to reduce the risk to low as soon as possible (such as moving the existing fence back from its current position).

Installation of horizontal drains within the scarp of the landslip would likely decrease the frequency and magnitude of future landslip activity. This option should be used in conjunction with adjustment of existing barriers and ongoing monitoring of the landslip. We recommend that the fence situated behind the headscarp be relocated close to the footpath and a minimum of 10m back from its existing location along the southern portion of the headscarp. The fence should be joined to the boundary fence of No. 5 Bramley Drive. We also recommend the immediate placement of hazard tape or temporary fencing to bound off the southern portion of the headscarp and keep the public from danger. This may be removed following adjustments to the existing fence. The large trees situated adjacent the southern end of the headscarp should be carefully removed and replaced with more appropriate vegetation.

The relocation of Council water supply to the south eastern side of Bramley Drive would reduce the likelihood that it will be undermined by future landslips.

Other options to mitigate the risk of future landslipping (in addition to the installation of drainage) would include the construction of a large palisade wall behind the existing headscarp or placement of a rockfill buttress within the landslip footprint. A rockfill buttress is likely to be more cost effective than a palisade wall and may also provide the potential for reinstatement and resale of the properties removed as a result of the initial 1979 landslip.

ATTACHMENT A

9 Applicability

This report has been prepared for the benefit of Western Bay of Plenty District Council with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

This opinion is not intended to be advice that is covered by the Financial Advisers Act 2010.

Tonkin & Taylor Ltd

Environmental and Engineering Consultants

Report prepared by:	Reviewed by:
....	....
Matthew Keam Engineering Geologist	David Milner Senior Engineering Geologist

Authorised for Tonkin & Taylor Ltd by:

....

Dave Taylor
Senior Civil Engineer

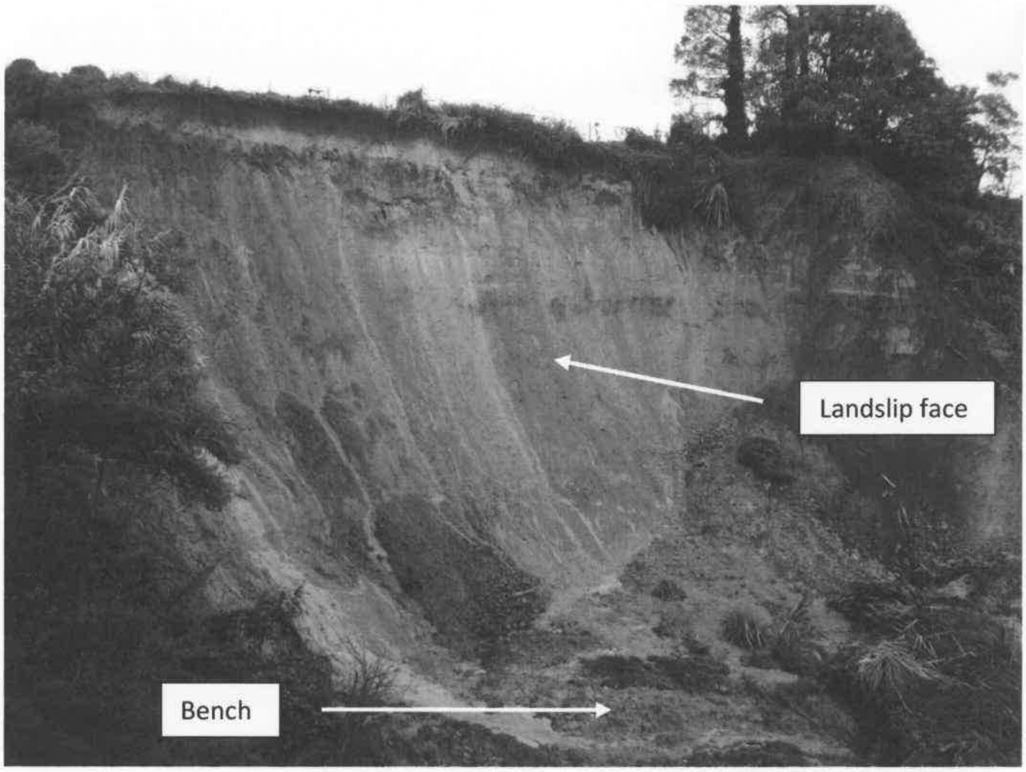
MJK

P:\851378\851378.150\IssuedDocuments\110607.mjk.rep.bramleydrive.firstissue.docx

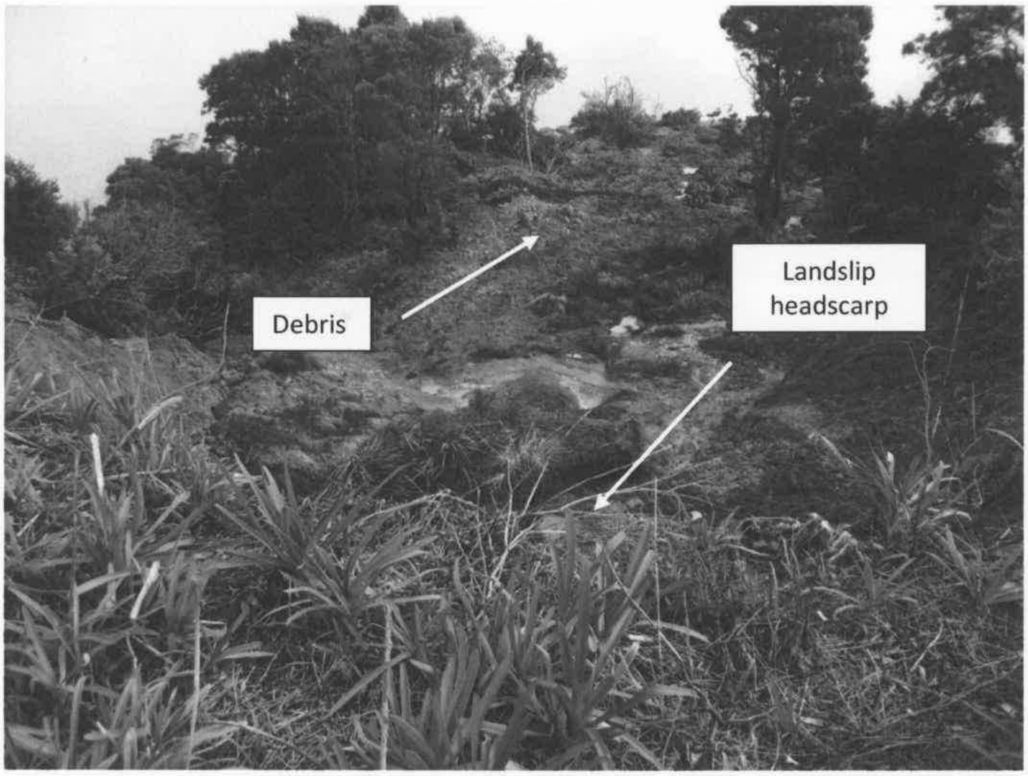
ATTACHMENT A

Appendix A: Photographs, Figures and Sketches

ATTACHMENT A

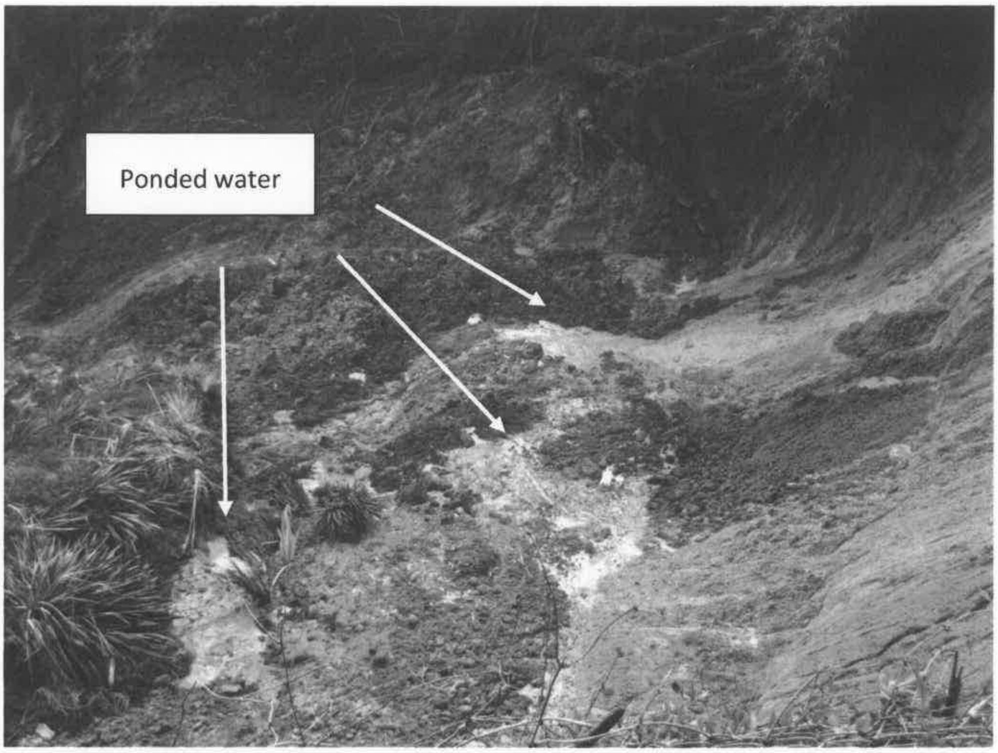


Photograph 1- Photograph of landslip main scarp and pronounced bench.

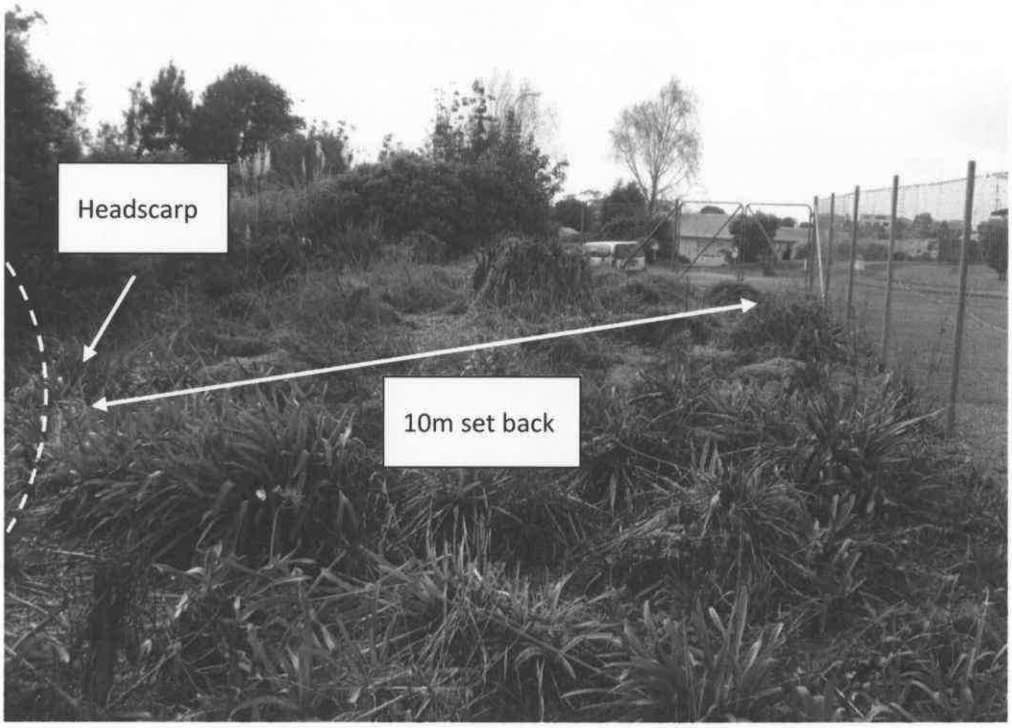


Photograph 2- Showing the extent of the failure deposit.

ATTACHMENT A



Photograph 3- Ponded water situated on the bench below the main scarp.



Photograph 4- Showing the 10m set back from the centre of the headscarp to the fence.

ATTACHMENT A

Appendix B: **Extracts from the Australian Geomechanics Society Guideline "*Landslide Risk Management*"**

ATTACHMENT A

APPENDIX C: LANDSLIDE RISK ASSESSMENT

QUALITATIVE TERMINOLOGY FOR USE IN ASSESSING RISK TO PROPERTY

QUALITATIVE MEASURES OF LIKELIHOOD

Approximate Annual Probability		Implied Indicative Landslide Recurrence Interval		Description	Descriptor	Level
Indicative Value	Notional Boundary					
10^{-1}	$5x10^{-2}$	10 years	20 years	The event is expected to occur over the design life.	ALMOST CERTAIN	A
10^{-2}	$5x10^{-3}$	100 years	200 years	The event will probably occur under adverse conditions over the design life.	LIKELY	B
10^{-3}	$5x10^{-4}$	1000 years	2000 years	The event could occur under adverse conditions over the design life.	POSSIBLE	C
10^{-4}	$5x10^{-5}$	10,000 years	20,000 years	The event might occur under very adverse circumstances over the design life.	UNLIKELY	D
10^{-5}	$5x10^{-6}$	100,000 years	200,000 years	The event is conceivable but only under exceptional circumstances over the design life.	RARE	E
10^{-6}		1,000,000 years		The event is inconceivable or fanciful over the design life.	BARELY CREDIBLE	F

Note: (1) The table should be used from left to right; use Approximate Annual Probability or Description to assign Descriptor, not *vice versa*.

QUALITATIVE MEASURES OF CONSEQUENCES TO PROPERTY

Approximate Cost of Damage		Description	Descriptor	Level
Indicative Value	Notional Boundary			
200%	100%	Structure(s) completely destroyed and/or large scale damage requiring major engineering works for stabilisation. Could cause at least one adjacent property major consequence damage.	CATASTROPHIC	1
60%	40%	Extensive damage to most of structure, and/or extending beyond site boundaries requiring significant stabilisation works. Could cause at least one adjacent property medium consequence damage.	MAJOR	2
20%	10%	Moderate damage to some of structure, and/or significant part of site requiring large stabilisation works. Could cause at least one adjacent property minor consequence damage.	MEDIUM	3
5%	1%	Limited damage to part of structure, and/or part of site requiring some reinstatement stabilisation works.	MINOR	4
0.5%		Little damage. (Note for high probability event (Almost Certain), this category may be subdivided at a notional boundary of 0.1%. See Risk Matrix.)	INSIGNIFICANT	5

Notes: (2) The Approximate Cost of Damage is expressed as a percentage of market value, being the cost of the improved value of the unaffected property which includes the land plus the unaffected structures.

(3) The Approximate Cost is to be an estimate of the direct cost of the damage, such as the cost of reinstatement of the damaged portion of the property (land plus structures), stabilisation works required to render the site to tolerable risk level for the landslide which has occurred and professional design fees, and consequential costs such as legal fees, temporary accommodation. It does not include additional stabilisation works to address other landslides which may affect the property.

(4) The table should be used from left to right; use Approximate Cost of Damage or Description to assign Descriptor, not vice versa

ATTACHMENT A

 ATTACHMENT A

APPENDIX C: – QUALITATIVE TERMINOLOGY FOR USE IN ASSESSING RISK TO PROPERTY (CONTINUED)

QUALITATIVE RISK ANALYSIS MATRIX – LEVEL OF RISK TO PROPERTY

LIKELIHOOD		CONSEQUENCES TO PROPERTY (With Indicative Approximate Cost of Damage)				
	Indicative Value of Approximate Annual Probability	1: CATASTROPHIC 200%	2: MAJOR 60%	3: MEDIUM 20%	4: MINOR 5%	5: INSIGNIFICANT 0.5%
A – ALMOST CERTAIN	10^{-1}	VH	VH	VH	H	M or L (5)
B - LIKELY	10^{-2}	VH	VH	H	M	L
C - POSSIBLE	10^{-3}	VH	H	M	M	VL
D - UNLIKELY	10^{-4}	H	M	L	L	VL
E - RARE	10^{-5}	M	L	L	VL	VL
F - BARELY CREDIBLE	10^{-6}	L	VL	VL	VL	VL

Notes: (5) For Cell A5, may be subdivided such that a consequence of less than 0.1% is Low Risk.
(6) When considering a risk assessment it must be clearly stated whether it is for existing conditions or with risk control measures which may not be implemented at the current time.

RISK LEVEL IMPLICATIONS

Risk Level		Example Implications (7)
VH	VERY HIGH RISK	Unacceptable without treatment. Extensive detailed investigation and research, planning and implementation of treatment options essential to reduce risk to Low; may be too expensive and not practical. Work likely to cost more than value of the property.
H	HIGH RISK	Unacceptable without treatment. Detailed investigation, planning and implementation of treatment options required to reduce risk to Low. Work would cost a substantial sum in relation to the value of the property.
M	MODERATE RISK	May be tolerated in certain circumstances (subject to regulator's approval) but requires investigation, planning and implementation of treatment options to reduce the risk to Low. Treatment options to reduce to Low risk should be implemented as soon as practicable.
L	LOW RISK	Usually acceptable to regulators. Where treatment has been required to reduce the risk to this level, ongoing maintenance is required.
VL	VERY LOW RISK	Acceptable. Manage by normal slope maintenance procedures.

Note: (7) The implications for a particular situation are to be determined by all parties to the risk assessment and may depend on the nature of the property at risk; these are only given as a general guide.

ATTACHMENT A

APPENDIX F- EXAMPLE OF VULNERABILITY VALUES

SUMMARY OF HONG KONG VULNERABILITY RANGES FOR PERSONS, AND RECOMMENDED VALUES FOR LOSS OF LIFE FOR LANDSLIDING IN SIMILAR SITUATIONS

The following table is adapted from P J Finlay, G R Mostyn & R Fell (1999). *Landslides: Prediction of Travel Distance and Guidelines for Vulnerability of Persons*. Proc 8th. Australia New Zealand Conference on Geomechanics, Hobart. Australian Geomechanics Society, ISBN 1 86445 0029, Vol 1, pp.105-113.

Case	Range in Data	Recommended Value	Comments
Person in Open Space			
If struck by a rockfall	0.1 – 0.7	0.5	May be injured but unlikely to cause death
If buried by debris	0.8 – 1.0	1.0	Death by asphyxia almost certain
If not buried	0.1 – 0.5	0.1	High chance of survival
Persons in a Vehicle			
If the vehicle is buried/crushed	0.9 – 1.0	1.0	Death is almost certain
If the vehicle is damaged only	0 – 0.3	0.3	High chance of survival
Person in a Building			
If the building collapses	0.9 – 1.0	1.0	Death is almost certain
If the building is inundated with debris and the person buried	0.8 – 1.0	1.0	Death is highly likely
If the debris strikes the building only	0 – 0.1	0.05	Very high chance of survival

EXAMPLE OF VULNERABILITY VALUES FOR DESTRUCTION OF PEOPLE, BUILDINGS AND ROADS

The following table is adapted from Marion Michael-Leiba, Fred Baynes, Greg Scott & Ken Granger (2002). *Quantitative Landslide Risk Assessment of Cairns*. Australian Geomechanics, June 2002.

Geomorphic Unit	Vulnerability Values		
	People	Buildings	Roads
Hill slopes	0.05	0.25	0.3
Proximal debris fan	0.5	1.0	1.0
Distal debris fan	0.05	0.1	0.3

EXAMPLE OF VULNERABILITY VALUES FOR LIFE FOR ROCKFALLS AND DEBRIS FLOWS FOR LAWRENCE HARGRAVE DRIVE PROJECT, COALCLIFF TO CLIFTON AREA, AUSTRALIA

The following table is adapted from R A Wilson, A T Moon, M Hendricks & I E Stewart (2005). *Application of quantitative risk assessment to the Lawrence Hargrave Drive Project, New South Wales,Australia.* Landslide Risk Management - Hungr, Fell, Couture & Eberhardt (eds) 2005. Taylor & Francis Group, London, ISBN 04 1538 043X.

Order of magnitude of landslide crossing road (m^3)	**Rockfalls from Scarborough Cliff**		**Debris flow from Northern Amphitheatre**	
	Landslide hits car	**Car hits landslide**	**Landslide hits car**	**Car hits landslide**
0.03	0.05	0.006	–	–
0.3	0.1	0.002	–	–
3	0.3	0.03	0.001	–
30	0.7	0.03	0.01	0.001
300	1	0.03	0.1	0.003
3,000	1	0.03	1	0.003

NOTE: The above data should be applied with common sense, taking into account the circumstances of the landslide being studied. Judgment may indicate values other than the recommended value are appropriate for a particular case.