GREEN GEOTECHNICS

GEOTECHNICAL ASSESSMENT

FOR

MR ALEX HUBBARD C/- 4 PILLARS ENVIRONMENTAL CONSULTING

31-33 CALABASH ROAD, ARCADIA

REPORT GG10636.001

14th JUNE 2022

Geotechnical Assessment of an existing fill batter at 31-33 Calabash Road, Arcadia.

Prepared for

Mr Alex Hubbard
C/- 4 Pillars Environmental Consulting
Level 1, 5 George Street
North Strathfield NSW 2137

Prepared by

Green Geotechnics Pty Limited
PO Box 3244
Rouse Hill, NSW, 2155
ABN: 786 438 493 89
www.greengeo.com.au
matt@greengeo.com.au

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For and on behalf of Green Geotechnics

Matthew Green
Principal Engineering Geologist
RPGeo (Geotechnical & Engineering) - 10276

Document Control

Revision	Description	Format	Date	Author	Distributed to
-	Final	PDF	14/6/2022	MG	Mr Alex Hubbard C/- 4 Pillars Environmental (Client)

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1. INTRODUCTION

This report presents the results of a geotechnical assessment undertaken by Green Geotechnics Pty Limited for the analysis of an existing fill batter at 31-33 Calabash Road, Arcadia. The assessment was commissioned by 4 Pillars Environmental Consulting on behalf of Mr Alex Hubbard.

We understand that a fill batter was constructed over the northern portion of the site between 2015 and 2016. We understand that a stability assessment of the batter is required, together with a Landslip Risk Assessment (LRA) of the batter to understand the likelihood and consequences of any potential batter instability. The LRA is to be undertaken in accordance with AGS 2007 Guidelines.

The purpose of the investigation was to

- assess the surface and subsurface conditions over the batter area,
- assess the stability of the slope and determine its current Factor of Safety (FOS),
- undertake a slope risk assessment in accordance with AGS2007 Guidelines, assigning both the risk to life and to property,
- provide recommendations to address the outcomes of the stability and slope risk assessment.

2. FIELDWORK DETAILS

The fieldwork was carried out on the 4th June 2022 and comprised a detailed site walkover together with the drilling of four (4) boreholes numbered BH1 to BH4. The boreholes were drilled using rotary solid flight augers attached to a utility mounted Christie Engineering drilling rig owned and operated by Green Geotechnics.

The site location is shown in the attached Figure A. The borehole locations, as shown on Figure B, are based on aerial drone imagery recorded during the fieldworks. Surface elevations for the boreholes have been interpolated by overlaying aerial imagery onto the provided site survey by Total Surveying Solutions (Reference 211147 dated 17/6/2021). Photographs of the site are shown on Figure C.

The strength of the soils and estimated compaction of fill materials encountered in the boreholes was assessed by undertaking Dynamic Cone Penetrometer (DCP) tests adjacent to each borehole. The strength of the weathered bedrock was assessed by observation of the auger penetration resistance together with examination of the recovered rock cuttings and exposed rock cuts on the site.

Groundwater observations were made in all boreholes during the fieldwork. No longer term monitoring of groundwater was carried out.

The fieldwork was completed in the full-time presence of our principal engineering geologist who set out the boreholes, nominated the sampling and testing, and prepared the field logs. The logs are attached to this report, together with a glossary of the terms and symbols used in the logs.

For further details of the investigation techniques adopted, reference should be made to the attached explanation notes.

Environmental and contamination testing of the soils was beyond the agreed scope of the works.

3. RESULTS OF INVESTIGATION

3.1 Site Description

The site is identified as Lot 1 in DP513823 and is roughly rectangular in shape with an area of approximately 10.1 hectares.

At the time of the fieldwork the site was occupied by a two storey residence with tile roof. The dwelling includes an in-ground swimming pool and separate shed. The existing residence is located towards the centre of the site and towards the southern boundary. The dwelling is positioned towards the crest of a sandstone ridgeline which is accessed via a gravel driveway from the east. To the north of the dwelling is a moderately steep grassed slope which leads down to a level grassed area, which is the subject of this assessment.

The assessment area and fill platform has a length of approximately 150 metres and a width of between 30 and 40 metres. The assessment area is demarked by a batter slope on its northern side, natural sandstone escarpments and rock faces on the southern side, bushland to the west, and a sandstone quarry and further batter to the east.

The ground surface in the assessment area has a gentle slope to the west of around 2°. The batter slopes which form the northern extent have been formed at angles of 20° to 33°, being shallowest at the western end and steepest over the central and eastern portion. The batter slopes are covered by grass, sapling trees and shrubs.

Some evidence of localised slumping was noted in the vicinity of BH2 and BH3, however there was no evidence of large scale instability in the embankment.

At the toe of the embankment (northern side) is native bushland.

The platform area is vacant with some disused equipment being stored on the southern side of the platform.

At the time of the fieldwork there were several large excavations positioned in a north south alignment towards the western end of the platform area. The excavations extend to a depth of 2.0 to 2.5 metres. The northern most excavation is positioned at the crest of the batter. Materials excavated from the pits appears to have been stockpiled at the western end of the site and are covered with plastic sheeting.

At the eastern end of the platform is a sandstone quarry which appears to have been excavated around 2016, roughly at the time the platform was constructed. The faces of the quarry are near vertical and comprise sandstone bedrock belonging to the Hawkesbury Sandstone formation. The materials exposed in the floor of the quarry comprise mostly sandstone bedrock, transitioning into residual clayey soils over the central and northern portion.

3.2 Regional Geology & Subsurface Conditions

The 1:100,000 series geological map of Wollongong – Port Hacking (Geological Survey of NSW, Geological Series Sheet 9029-9129) indicates that the site is underlain by Triassic Age bedrock belonging to the Hawkesbury Sandstone Formation. Bedrock within this formation comprises fine to medium grained quartz sandstone. There are outcrops of bedrock on the site which are consistent with this geological setting.

A summary of the subsurface conditions encountered at each borehole location is provided below:

BH1:

Fill materials were encountered to a depth of 1.6 metres overlying natural clayey silty sands to a depth of 2.2 metres, overlying natural silty sandy clays to a depth of 2.8 metres, overlying sandstone bedrock. The sandstone bedrock could not be penetrated below a depth of 3.0 metres. The fill comprises a silty clay with some gravel and appears poorly compacted in the upper 0.4 metres, becoming moderately compacted below this depth.

The natural clayey silty sands were assessed to be loose to medium dense, and the underyling clays stiff to very stiff. The fill materials were noted as being moist and the natural sands below moist to wet.

BH2:

Fill materials were encountered to a depth of 3.2 metres overlying natural sandy clays to a depth of 3.85 metres, overlying sandstone bedrock. The sandstone bedrock could not be penetrated below a depth of 3.9 metres. The fill comprises a layer of gravelly clayey sand to a depth of 0.8 metres overlying a silty clay fill with some gravel. The fill appears moderately compacted.

The natural sandy clays below the fill were assessed to be very stiff. The fill materials were noted as being moist becoming moist to wet with depth.

BH3:

Fill materials were encountered to a depth of 3.5 metres overlying natural gravelly silty clays to a depth of 4.3 metres, overlying sandstone bedrock. The sandstone bedrock could not be penetrated below a depth of 4.5 metres. The fill comprises a mixture of gravelly sandy clays and silty sandy clays. The fill appears moderately compacted in the upper 0.7 meters and poorly compacted between depths of 0.7 and 2.4 metres.

The natural gravelly silty clays below the fill were assessed to be very stiff. The fill materials were noted as being moist becoming moist to wet with depth.

BH4:

Fill materials were encountered to a depth of 1.4 metres overlying natural clayey sands to a depth of 2.0 metres, overlying natural sandy clays to a depth of 3.0 metres, overlying sandstone bedrock. The sandstone bedrock could not be penetrated below a depth of 3.1 metres. The fill comprises a silty clay and silty sandy clay with some gravel, and appears moderately compacted in the upper 1.0 metre, becoming poorly compacted below this depth.

The natural clayey sands were assessed to be loose to medium dense and the underyling clays stiff to very stiff. The fill materials and underlying natural were noted as being moist.

Groundwater seepage was not observed during auger drilling of the boreholes.

4. SLOPE STABILITY ASSESSMENT

A slope stability assessment has been carried out for the site using the program SlopeW. Embankment cross sections have been assessed for BH2 and BH3, as these locations are considered the most critical based on embankment geometry and fill depth/composition.

The ground models, material parameters and surface geometry for each section are summarised in Tables 4.1 and 4.2 below:

TABLE 4.1 – BH2 Section

Top of Batter RL	189.6			
Toe of Batter RL	185.5			
Batter Height	4.1			
Batter Angle	30°			
Depth	Material Type	Cohesion (C’)	Unit Weight (kN/m^3)	Friction Angle (Phi)
0.0 – 0.8	Loose to medium dense sand fill	0	18	28
0.8 – 3.2	Stiff clay fill	0	18	26
3.2 – 3.8	Very stiff natural clay	5	19	28
>3.8m	Sandstone Bedrock	100	23	33

TABLE 4.2 – BH3 Section

Top of Batter RL	190			
Toe of Batter RL	185.4			
Batter Height	4.6			
Batter Angle	32°			
Depth	Material Type	Cohesion (C’)	Unit Weight (kN/m^3)	Friction Angle (Phi)
0.0 – 0.7	Stiff Clay fill	0	18	26
0.7 – 2.5	Soft Clay Fill	0	17	23
2.5 – 3.5	Stiff Clay Fill	0	18	26
3.5 – 4.3	Very stiff natural clay	5	19	28
>4.3m	Sandstone Bedrock	100	23	33

The slope stability analysis has assumed no surcharge loads and no design groundwater level. The calculated FOS values for the various cases are provided below in Table 4.3

TABLE 4.3 – Slope Stability Results

BHID	Type	Factor of Safety (FOS)
BH2	Global Failure	1.47
	Batter Slump	0.86
BH3	Global Failure	1.33
	Batter Slump	0.86

Typically, a FOS above 1.5 would be targeted when assessing embankment stability. Based on the results presented in Table 4.3, the embankments have generally achieved values of 1.3 to 1.5 for global stability, however the FOS for batter slumping is less than 1.0.

The results of the slope stability assessment have been incorporated into the LRA presented in Section 5.

5. LANDSLIDE RISK ASSESSMENT

5.1 Introduction

A landslide risk assessment has been undertaken for the northern fill batter located at 31-33 Calabash Road, Arcadia. It is not technically feasible to assess the stability of a particular site in absolute terms such as stable or unstable, and it must be recognised by the reader that all sites have a risk of land sliding, however small. However, a risk assessment can be undertaken by the recognition of surface features supplemented by limited information on the regional and local subsurface profile, and with the benefit of experience gained in similar geological environments.

Hill slopes are formed by processes that reflect the site geology, environment and climate. These processes include down slope movement of the near surface soil and rock. In geological time all slopes are 'unstable'. The area of influence of these down slope movements may range from local to regional and are rarely related to property boundaries. The natural processes may be affected by human intervention in the form of construction, drainage, fill placement and other activities.

5.2 Purpose of the Assessment

The purpose of this assessment is to enable the owner, potential owner or other parties interested in the site in question, to be aware of the level of risk associated with potential slope movements within the property, and within the area immediately surrounding the property. The risk is assessed considering the existing development of the property and proposed developments of which we have been informed of and which are summarised in this report. The onus is on the owner, potential owner or other party to decide whether the level of risk presented in this report is acceptable in the light of the possible economic consequence of such risk.

5.3 Risk Assessment Methodology

The risk assessment in this report is based on the guidelines on Landslide Risk Management (LRM) as presented in the Australian Geomechanics publication, Volume 42, Number 1, dated March 2007. This issue presents a series of LRM guidelines and further understanding on the application of the risk assessments for the recommended use by all practitioners nationwide.

Definition of the terms used in this report with respect to the slope risk assessment and management are given in Appendix B.

It must be accepted that the risks associated with hillside construction are greater than construction on level ground in the same geological environment. The impact of development may be adverse, and imprudent construction techniques can increase the potential for movement. Areas of instability rarely respect property boundaries and poor practices on one property can trigger instability in the surrounding area.

5.4 Hazard Identification

A landslide is defined as “the movement of a mass of rock, debris or earth down a slope”. Apart from ground subsidence and collapse, this definition is open to the movement of material types including rock, earth and debris down slope. The causes of landslides can be complex. However, two common factors include the occurrence of a failure of part of the soil or rock material on a slope and the resulting movement is driven by gravity. The actual motion of a landslide is subdivided into the five kinematically distinctive types of material movement including fall, topple, slide, spread, and flow. For further information regarding types of landslides please refer to Appendix B – Landslide Terminology from Australian Geomechanics Practice Note Guidelines For Landslide Risk Management 2007.

The frequency of landslides are difficult to quantify and typically dependant on the inter-relationship between the factors influencing the stability of the slope. Some of the common factors affecting the stability of slopes include the weather (prolonged rainfall with water percolating into rock mass defects can cause washout of fines and reduction of rock mass strength), land development, vegetation removal, changes in drainage and earthquakes. One or a combination of these conditions could result in a landslide failure event.

For the fill batter at 31-33 Calabash Road, Arcadia the following landslide hazards have been considered in the risk assessment.

TABLE 5.1 – Landslide Hazard Identification

Hazard Description	Estimated Volume (m^3)
Global (Large Scale) Embankment Failure	60-80
Localised Slumping	5-10

5.5 Risk Assessment to Property

The Risk to property has been estimated by assessing the likelihood of an event and the consequences if such an event takes place. The relationship between likelihood, consequence and risk is determined by a risk matrix. The risk categories and implications are shown in Attachment 3 of Appendix B (taken from Practice Note Guidelines for Landslide Risk Management 2007, Appendix C).

The assessment process involved the following:

- Risk estimation (comparative analysis of likelihood of a slope failure versus consequence of the failure).
- Evaluation of the estimated (assessed) risk by comparing against acceptance criteria.

The following factors observed during the site walkover were taken into consideration when undertaking the slope risk assessment:

- Topography: The fill platform is near level with the northern batter formed at angles of 20° to 33°. At the toe of the batter is an area of gently sloping bushland.
- Geology: The surface soils comprise variably compacted granular and cohesive fill overlying natural sands and clays, overlying sandstone bedrock. There may also be included boulders of high strength sandstone bedrock.
- Drainage: The site in general is reasonably drained. Groundwater seepage was not observed on the site and the surface was firm under foot and vehicle traffic. No seepage was noted on the batter slope, however some surface seepage was noted in the quarry to the south east.
- Slope stability: There were no signs of active slope instability noted during the site walkover. Some evidence of localised slumping was noted in the vicinity of BH2 and BH3, however there was no evidence of large scale instability in the embankment.

Based on the above factors and site observations, an assessment of risk to property have been carried out as shown in Table 5.2 below.

TABLE 5.2 – Risk to Property

Hazard		Large Scale Global Embankment Failure	Localised Slumping
Likelihood	Descriptor	Unlikely	Likely
	Approximate Annual Probability	1×10^{-4}	1×10^{-2}
Consequence		Minor*	Insignificant*
Risk Category		Low	Low

* There are no structures within 50 metres of the batter edge and therefore the consequence of instability relates only to the reinstatement of the batter.

The assessed risk to property is assessed to be low risk. Based on the information provided by the AGS and presented in Attachment 1, Appendix C, the implications for a risk level of low is it is usually acceptable to regulators.

5.6 Risk Assessment to Loss of Life

A risk assessment for the loss of life was undertaken for the identified geotechnical hazards for the site. The risk assessment and management process adopted for this study was carried out in general accordance with AGS (2007a).

In accordance with the AGS 2007c Landslide Risk Management Guidelines for loss of life, the individual risk for loss of life can be calculated from:

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

Where

- $R_{(LoL)}$ is the risk - annual probability of loss of life (death) - of an individual.
- $P_{(H)}$ is the annual probability of the landslide.
- $P_{(S:H)}$ is the probability of spatial impact of the landslide impacting on a location potentially occupied by a person.
- $P_{(T:S)}$ is the temporal spatial probability (e.g. of the location being occupied by the individual) given the spatial impact and allowing for the possibility of evacuation given there is warning of the landslide occurrence.
- $V_{(D:T)}$ is the vulnerability of the individual (probability of loss of life of the individual given the impact).

In accordance with AGS 2007, the regulator should set risk acceptance criteria. In this case, The Council of Hornsby Shire is the regulator, however The Council of Hornsby Shire does not provide published guidance in this matter. We have therefore adopted an “Acceptable” risk criteria for existing areas of residential occupancy.

The risk acceptance criteria considers the occurrence of the potential geotechnical hazards identified for the site and evaluate the risk against an Acceptable Risk Criteria for loss of life. In this instance, the individual risk is accepted due to being Acceptable or risk mitigation measures are undertaken to reduce the risk to more acceptable levels.

The AGS 2007 guidelines indicate that the regulator, with assistance from the practitioner where required, is the appropriate authority to set the standards for risk relating to perceived safety in relation to other risks and government policy. The importance of the implementation of levels of the acceptable risk should not be understated due to the wide ranging implications, both in terms of the relative risks or safety to the community and the potential economic impact to the community. The AGS provide recommendations in relation to acceptable risk for loss of life as shown below in Table 5.3.

TABLE 5.3 – AGS Recommendations – Risk to Life

Situation	Suggested Acceptable Loss of Life Risk for Person Most at Risk
Existing Slope(1) / Existing Development(2)	10^{-5}/annum
New Constructed Slope(3) / New Development(4) / Existing Landslide	10^{-6}/annum

Notes:

1. “Existing Slopes” in this context are slopes that are not part of a recognisable landslide and have demonstrated non-failure performance over at least several seasons or events of extended adverse weather, usually being a period of at least 10 to 20 years.

2. “Existing Development” includes existing structures, and slopes that have been modified by cut and fill, that are not located on or part of a recognisable landslide and have demonstrated non-failure performance over at least several seasons or events of extended adverse weather, usually being a period of at least 10 to 20 years.

3. “New Constructed Slope” includes any change to existing slopes by cut or fill or changes to existing slopes by new stabilisation works (including replacement of existing retaining walls or replacement of existing stabilisation measures, such as rock bolts or catch fences).

4. “New Development” includes any new structure or change to an existing slope or structure. Where changes to an existing structure or slope result in any cut or fill of less than 1.0m vertical height from the toe to the crest and this change does not increase the risk, then the Existing Slope/Existing Structure criterion may be adopted. Where changes to an existing structure do not increase the building footprint or do not result in an overall change in footing loads, then the Existing Development criterion may be adopted.

5. “Existing Landslides” have been considered likely to require remedial works and hence would become a New Constructed Slope and require the lower risk. Even where remedial works are not required per se, it would be reasonable expectation of the public for a known landslide to be assessed to the lower risk category as a matter of “public safety”.

Due to the extent of filling the batter slope on the subject site at 31-33 Calabash Road, Arcadia must be considered a New Development. The AGS risk threshold provided in Table 5.3 for new developments suggests the ‘Acceptable Loss of Life for the person most at risk’ is 10^{-6} per annum.

The risk assessment has been based on observations made during the site visit by an experienced engineering geologist, and by reviewing available geotechnical data and the future geotechnical requirements for development as outlined elsewhere in this report. Departures from the recommendations in this report may change the quantification of the hazard risk. A risk assessment has been carried out for the identified geotechnical hazards and is presented in Section 5.4 of this report.

The annual probability of a failure occurring has been calculated based on engineering judgement and observations made during the site visit. The probability of spatial impact is calculated by dividing the size of the estimated landslide by the size of the platform area, 5,000m^2.

The temporal spatial probability has been calculated based on the assumption that someone will be present on the platform for around 1 hour a day, potentially for exercise or maintenance such as grass mowing. This is then divided by the number of hours in a day. The vulnerability of an individual is based on values from Australian Geomechanics Vol. 42. If visitor numbers to the platform were to increase, then this would change the risk to loss of life. This could affect whether the risk is considered acceptable or otherwise.

Any changes to the site will affect the risk assessment outcome, making it necessary to carry out the risk assessment again.

From our quantitative risk to life assessment we have estimated the annual probability of risk to life to be in the range of 4.9×10^{-7} to 3.2×10^{-8}. These values are considered acceptable using the AGS risk acceptance criteria.

6. CONCLUSIONS

Based on the results of our assessment we have concluded that the batter slope has a “Low” risk to property and an “Acceptable” risk to life. The FOS of the batter for large scale instability is around 1.5, which is considered acceptable, and the risks associated with small scale localised slumping have been quantified as part of the LRA.

The LRA has been carried out based on the understanding that the platform area and batter slope are vacant land and not subject to a proposed development or future occupation. Should the land usage change, or should future development be proposed then the outcomes of the LRA should be re-assessed.

We note that the large open excavations towards the western end of the platform have started to fill with water from rains, and that the largest of the excavations is immediately adjacent to the crest of the batter. Open excavations are likely to saturate the embankment materials and may potentially form a pathway for water to enter the slope. If the embankment materials become saturated, then the risk likelihood of instability would increase. We therefore recommend that the open excavations be de-watered and backfilled as soon as practical. The backfill materials should be placed in layers and compacted.

7. GENERAL RECOMMENDATIONS

Based on the observations made during the site walkover and the risk assessment undertaken, it has been determined that the site has a low risk of slope instability.

Occasionally, the subsurface conditions may be found to be different (or may be interpreted to be different) from those expected. Variation can also occur with groundwater conditions, especially after climatic changes. If such differences appear to exist, we recommend that you immediately contact this office.

This report has been prepared for the particular project described and no responsibility is accepted for the use of any part of this report in any other context or for any other purpose. If there is any change in the proposed development described in this report then all recommendations should be reviewed.

Copyright in this report is the property of Green Geotechnics. We have used a degree of care, skill and diligence normally exercised by consulting engineers in similar circumstances and locality. No other warranty expressed or implied is made or intended. Subject to payment of all fees due for the investigation, the client alone shall have a licence to use this report. The report shall not be reproduced except in full.

REPORT INFORMATION

Introduction

These notes have been provided to amplify Green Geotechnics report in regard to classification methods, field procedures and the comments section. Not all are necessarily relevant to all reports.

Green Geotechnics reports are based on information gained from limited subsurface excavations and sampling, supplemented by knowledge of local geology and experience. For this reason, they must be regarded as interpretive rather than factual documents, limited to some extent by the scope of information on which they rely.

Borehole and Test Pit Logs

The borehole and test pit logs presented in this report are an engineering and/or geological interpretation of the subsurface conditions, and their reliability will depend to some extent on frequency of sampling and the method of drilling or excavation.

Interpretation of the information and its application to design and construction should therefore take into account the spacing of boreholes or pits, the frequency of sampling, and the possibility of other than 'straight line' variations between the test locations.

Groundwater

Where groundwater levels are measured in boreholes there are several limitations, namely:

- In low permeability soils groundwater may enter the hole very slowly or perhaps not at all during the time the hole is left open;
- A localised, perched water table may lead to an erroneous indication of the true water table;
- Water table levels will vary from time to time with seasons or recent weather changes. They may not be the same at the time of construction as are indicated in the report; and
- The use of water or mud as a drilling fluid will mask any groundwater inflow. The borehole must be flushed, and any water must be extracted from the hole if further water measurements are to be made.

More reliable measurements can be made by installing standpipes which are read at intervals over several days, or perhaps weeks for low permeability soils. Piezometers, sealed in a particular stratum, may be advisable in low permeability soils or where there may be interference from a perched water table.

Reports

The report has been prepared by qualified personnel, is based on the information obtained from field and laboratory testing, and has been undertaken to current engineering standards of interpretation and analysis. Where the report has been prepared for a specific design proposal, the information and interpretation may not be relevant if the design proposal is changed. If this happens, GG will be pleased to review the report and the sufficiency of the investigation work.

Every care is taken with the report as it relates to interpretation of subsurface conditions, discussion of geotechnical and environmental aspects, and recommendations or suggestions for design and construction. However, GG cannot always anticipate or assume responsibility for:

- Unexpected variations in ground conditions. The potential for this will depend partly on borehole or pit spacing and sampling frequency;
- Changes in policy or interpretations of policy by statutory authorities; or
- The actions of contractors responding to commercial pressures.

If these occur, Green Geotechnics will be pleased to assist with investigations or advice to resolve the matter.

Site Anomalies

In the event that conditions encountered on site during construction appear to vary from those which were expected from the information contained in the report, GG requests that it be immediately notified. Most problems are much more readily resolved when conditions are exposed rather than at some later stage, well after the event.

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FIGURES

Subject Site

GREEN GEOTECHNICS	Project No: GG10636.001	Geotechnical Investigation 31-33 Calabash Road, Arcadia **SITE LOCATION PLAN**	Figure No: GG10636.001A
	Client: 4Pillars Environmental Consulting		Drawn By: MG
	Date: 12 June 2022		Scale: Unknown

Legend:

= Borehole

= DCP

= Test Pit

GREEN GEOTECHNICS

Project No: GG10636.001	Geotechnical Investigation 31-33 Calabash Road, Arcadia
Client: 4Pillars Environmental Consulting	**TEST LOCATION PLAN**
Date: 12th June	

Figure No: GG10636.001B
Drawn By: MG
Scale: Unknown

Aerial View of Assessment Area Indicating Surface Features

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Aerial View of Embankment Looking East

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Aerial View of Embankment Looking West

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Typical Embankment Face

Minor Slumping Noted in Batter

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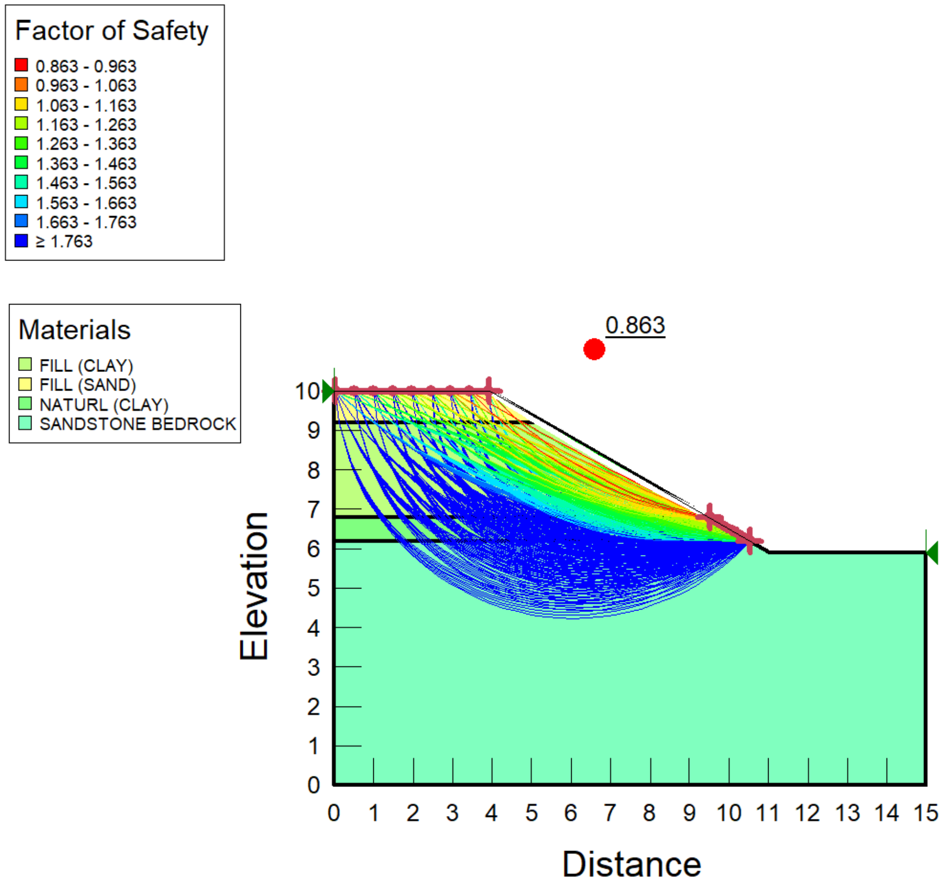
Shallow batter toe into bushland

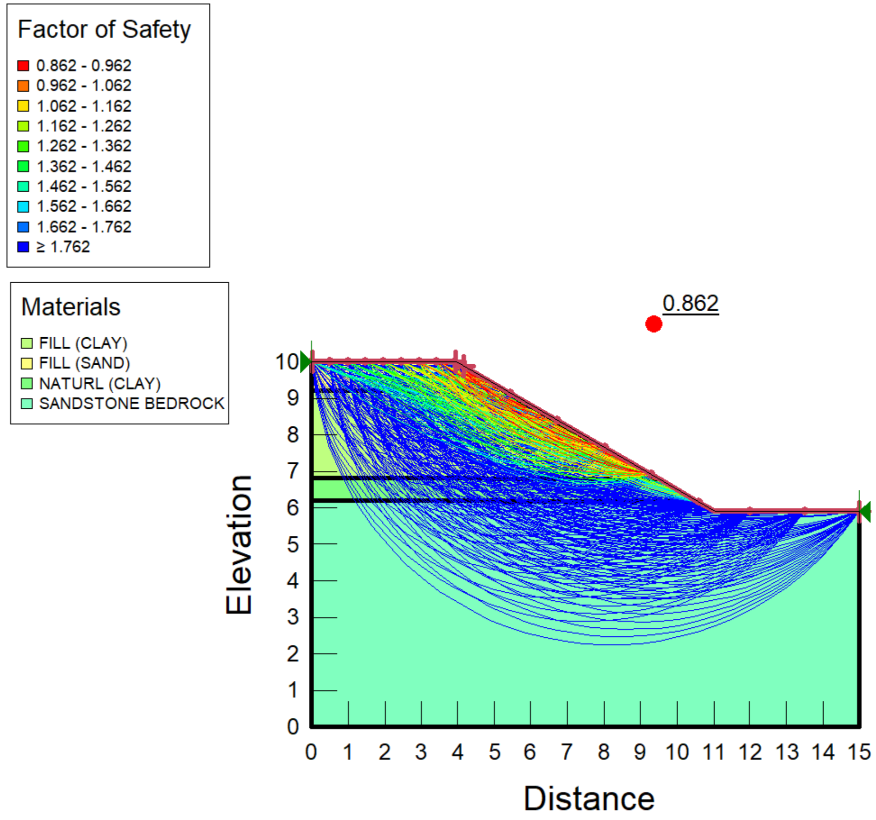
Batter Crest Looking West

Location of excavation pits and stockpile in relation to batter face


Large excavation immediately adjacent to batter with water in base

Quarried Area with Sandstone exposed in south east corner





OUTPUTS FOR BH2

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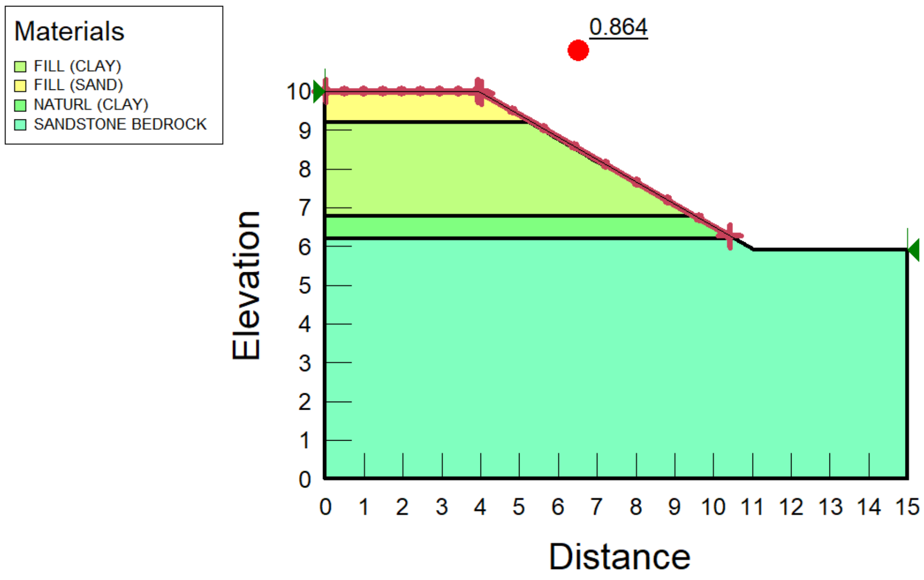

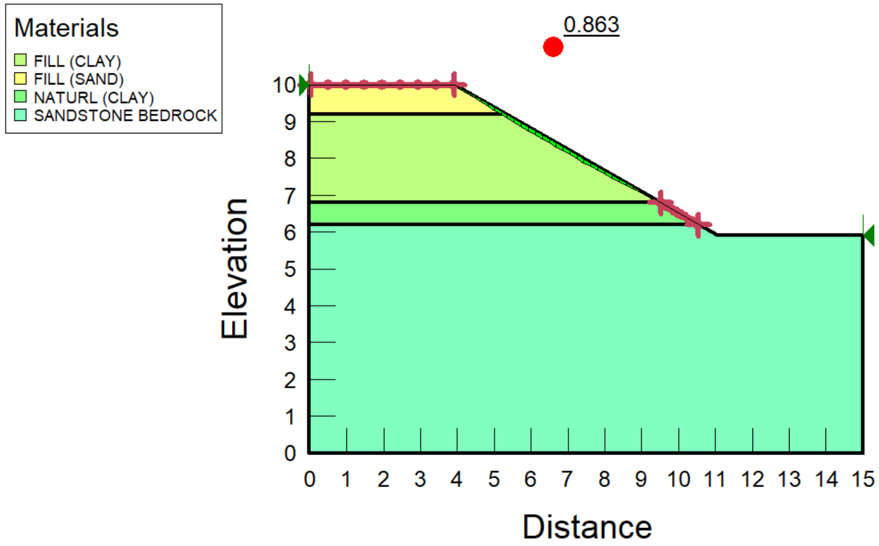

OUTPUTS FOR BH2

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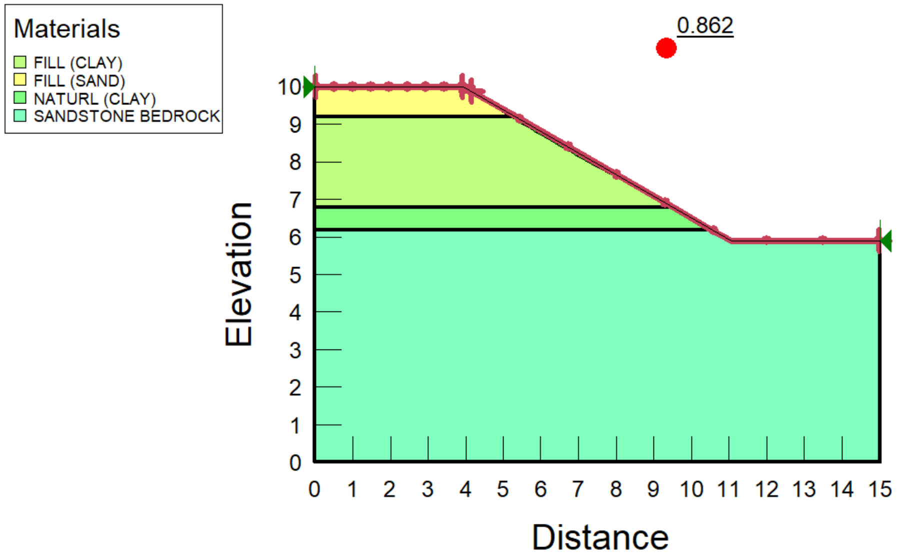
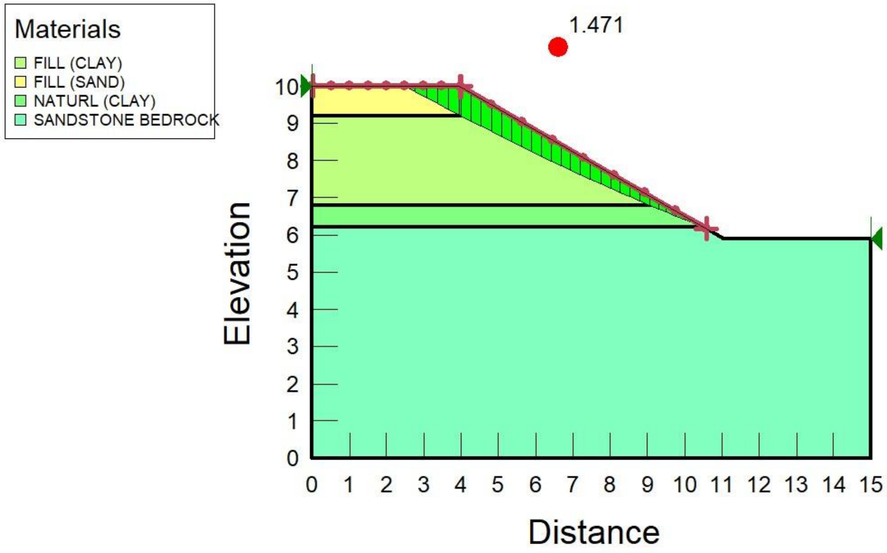
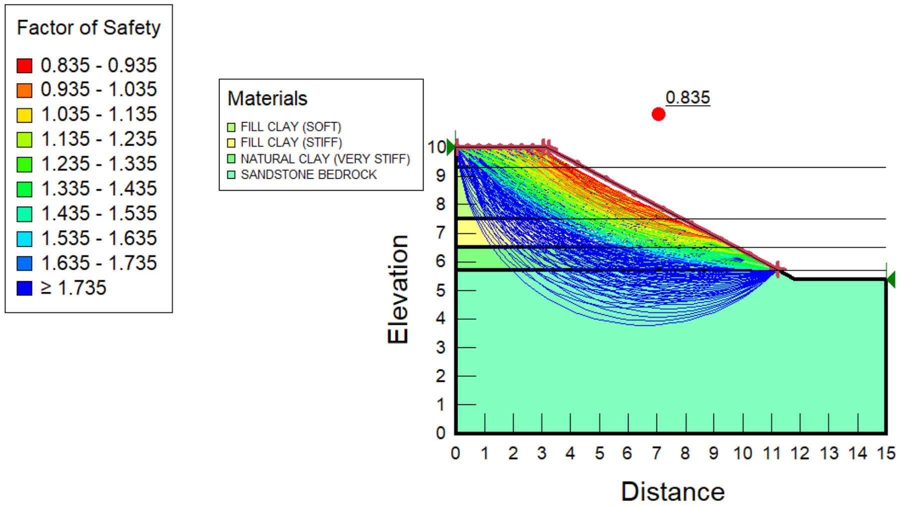
	Client: 4Pillars Environmental Consulting		
	Date: 14th June 2022	**SLOPE STABILITY ANALYSIS OUTPUTS**	

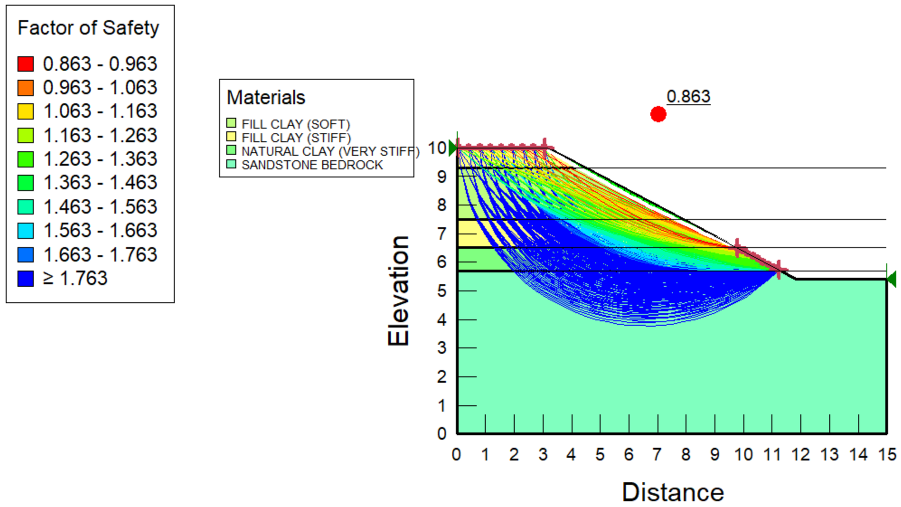




OUTPUTS FOR BH2

GREEN GEOTECHNICS	Project No: GG10636.001	Geotechnical Investigation 31-33 Calabash Road, Arcadia	Page: 3 of 7
	Client: 4Pillars Environmental Consulting		
	Date: 14th June 2022	**SLOPE STABILITY ANALYSIS OUTPUTS**	





OUTPUTS FOR BH3

GREEN GEOTECHNICS	Project No: GG10636.001	Geotechnical Investigation 31-33 Calabash Road, Arcadia	Page: 4 of 7
	Client: 4Pillars Environmental Consulting		
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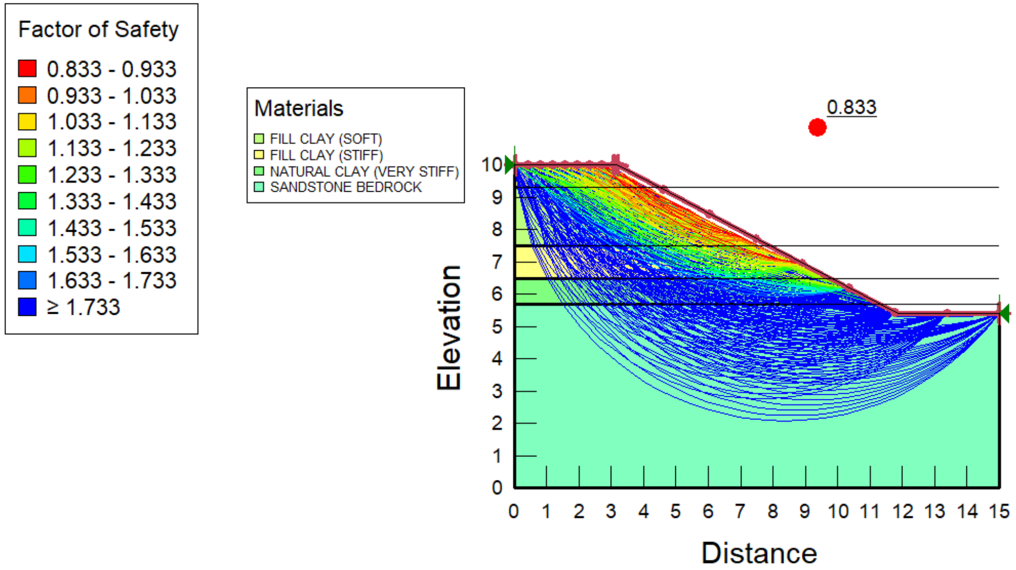
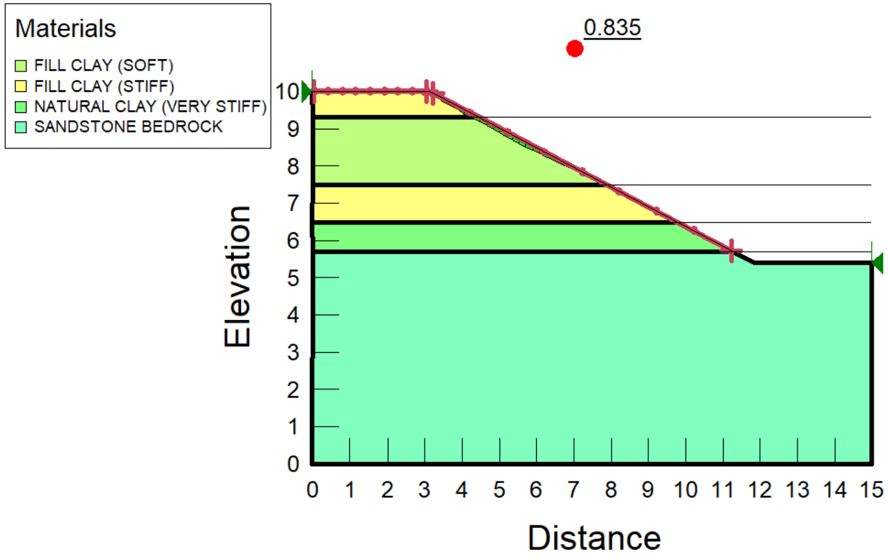
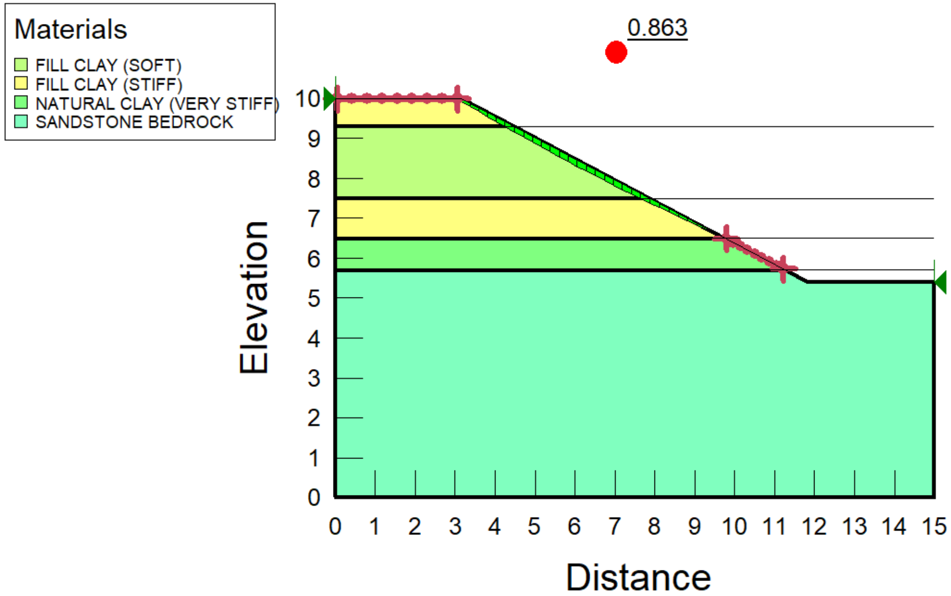
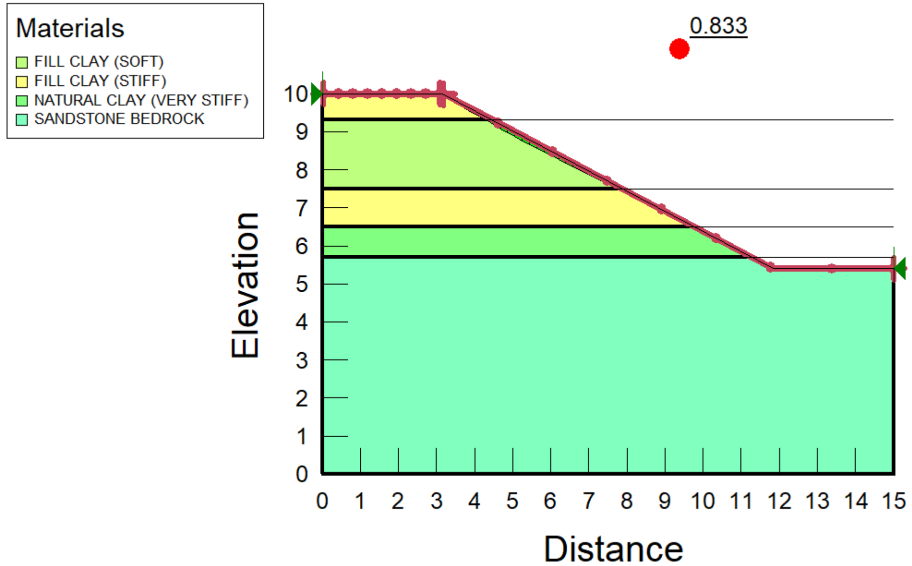




OUTPUTS FOR BH3

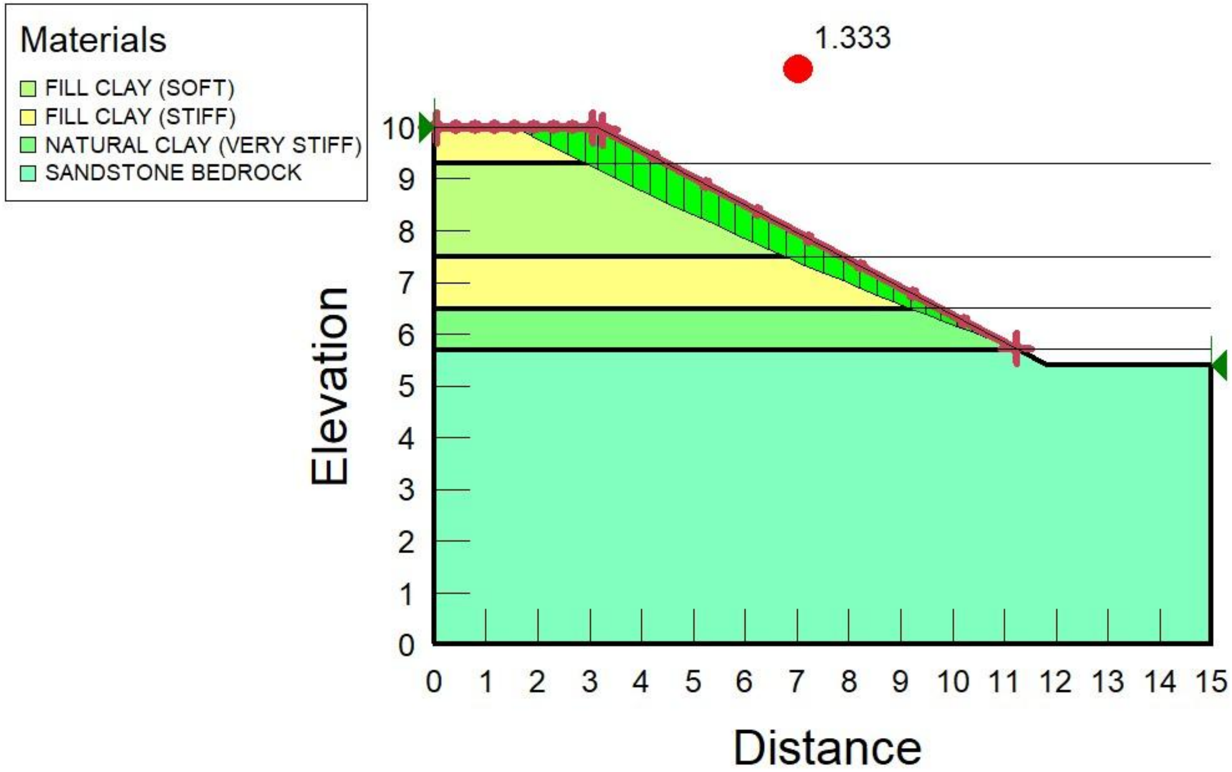
GREEN GEOTECHNICS	Project No: GG10636.001	Geotechnical Investigation 31-33 Calabash Road, Arcadia	Page: 5 of 7
	Client: 4Pillars Environmental Consulting		
	Date: 14th June 2022	**SLOPE STABILITY ANALYSIS OUTPUTS**	





OUTPUTS FOR BH3

GREEN GEOTECHNICS	Project No: GG10636.001	Geotechnical Investigation 31-33 Calabash Road, Arcadia	Page: 6 of 7
	Client: 4Pillars Environmental Consulting		
	Date: 14th June 2022	**SLOPE STABILITY ANALYSIS OUTPUTS**	



OUTPUTS FOR BH3

GREEN GEOTECHNICS	Project No: GG10636.001	Geotechnical Investigation 31-33 Calabash Road, Arcadia	Page: 7 of 7
	Client: 4Pillars Environmental Consulting		
	Date: 14th June 2022	**SLOPE STABILITY ANALYSIS OUTPUTS**	

APPENDIX A – BOREHOLE LOGS

GEOTECHNICAL LOG - NON CORED BOREHOLE

GREEN GEOTECHNICS

Project No: GG10636 | Surface RL: 188.3m AHD | Date Logged : 04/06/2022
Address: 31-33 Calabash Road, Arcadia | Logged By: JK
Client: 4Pillars Environmental Consulting | Checked By: MG

BOREHOLE NO.: BH 1
Sheet 1 of 1

WATER TABLE	SAMPLES	DEPTH (M)	DESCRIPTION (Soil type, colour, grain size, plasticity, minor components, observations)	USC SYMBOL	CONSISTENCY (cohesive soils) or RELATIVE DENSITY (sands and gravels)	MOISTURE
			FILL: Silty CLAY: Dark brown with orange brown and dark grey, medium to high plasticity, trace of gravel.	CI-CH	APPEARS POORLY COMPACTED APPEARS MODERATELY COMPACTED	M
		1.0				
			Clayey Silty SAND: Light grey with dark grey, fine to medium grained.	SM	LOOSE TO MEDIUM DENSE	M-W
		2.0				
			Silty Sandy CLAY: Orange brown, medium plasticity, fine grained sand.	CL	STIFF VERY STIFF	M
			SANDSTONE: Red brown with light grey, fine to medium grained.			M-D
		3.0				D
			AUGER REFUSAL AT 3.0m ON WEATHERED SANDSTONE.			
		4.0				
		5.0				

D - Disturbed sample | U - Undisturbed tube sample | B - Bulk sample
S - Chemical Sample | SPT - Standard Penetration Test
WT - Standing Water Table | SP - Water Seepage Level

NOTES: See explanation sheets for meaning of all descriptive terms and symbols

Contractor: Green Geotechnics
Equipment: CHRISTIE
Hole Diameter (mm): 105mm
Angle from Vertical (^{o}): 0°
Drill Bit: Spiral TC

GEOTECHNICAL LOG - NON CORED BOREHOLE

GREEN GEOTECHNICS

Project No: GG10636 | Surface RL: 189.6m AHD | Date Logged : 04/06/2022

Address: 31-33 Calabash Road, Arcadia | Logged By: JK

Client: 4 Pillars | Checked By: MG

BOREHOLE NO.: BH 2

Sheet 1 of 1

WATER TABLE	SAMPLES	DEPTH (M)	DESCRIPTION (Soil type, colour, grain size, plasticity, minor components, observations)	USC SYMBOL	CONSISTENCY (cohesive soils) or RELATIVE DENSITY (sands and gravels)	MOISTURE
			FILL: Gravelly Clayey SAND: Orange brown, fine to coarse grained sand, some gravel.	SC	APPEARS MODERATELY COMPACTED	M
		1.0	FILL: Sandy Silty CLAY: Dark brown with dark grey and orange brown, medium plasticity, fine to medium grained, trace of shale gravel.	CI	APPEARS MODERATELY COMPACTED	M
		2.0 3.0	FILL: Silty Sandy CLAY: Dark grey with dark brown, low plasticity, fine to medium grained, trace of organics / organic odour, trace of gravel.	CI	APPEARS MODERATELY COMPACTED	M-W
			Sandy CLAY: Orange brown with red brown, medium plasticity, fine to medium grained, trace of ironstone / sandstone gravel.		VERY STIFF	
			SANDSTONE: Red brown, fine to medium grained.			
		4.0 5.0	AUGER REFUSAL AT 3.9m ON WEATHERED SANDSTONE.			

D - Disturbed sample | U - Undisturbed tube sample | B - Bulk sample

S - Chemical Sample | SPT - Standard Penetration Test

WT - Standing Water Table | SP - Water Seepage Level

NOTES: See explanation sheets for meaning of all descriptive terms and symbols

Contractor: Green Geotechnics

Equipment: CHRISTIE

Hole Diameter (mm): 105mm

Angle from Vertical (^{o}): 0°

Drill Bit: Spiral TC

GEOTECHNICAL LOG - NON CORED BOREHOLE

GREEN GEOTECHNICS

Project No: GG10636	Surface RL: 190m AHD	Date Logged : 04/06/2022	BOREHOLE NO.: BH 3
Address: 31-33 Calabash Road, Arcadia		Logged By: JK	
Client: 4Pillars Environmental Consulting		Checked By: MG	Sheet 1 of 1

WATER TABLE	SAMPLES	DEPTH (M)	DESCRIPTION (Soil type, colour, grain size, plasticity, minor components, observations)	USC SYMBOL	CONSISTENCY (cohesive soils) or RELATIVE DENSITY (sands and gravels)	MOISTURE
			FILL: Gravelly Sandy CLAY: Orange brown with light grey and dark grey, medium plasticity, fine to medium sandstone gravel.	CI	APPEARS MODERATELY COMPACTED	M
					APPEARS POORLY COMPACTED	
		1.0	FILL: Silty Sandy CLAY: Light brown and grey with dark grey, medium plasticity, fine to medium grained, trace of gravel.	CI	APPEARS POORLY COMPACTED	M-W
		2.0				
					APPEARS MODERATELY COMPACTED	
		3.0				
			Gravelly Silty CLAY: Red to orange and grey brown, medium plasticity with a trace of ironstone gravel	CI	VERY STIFF	M
		4.0				
			SANDSTONE: Red grey to orange grey, fine to medium grained			D
			AUGER REFUSAL AT 4.5M ON WEATHERED SANDSTONE.			
		5.0				

D - Disturbed sample	U - Undisturbed tube sample	B - Bulk sample	Contractor: Green Geotechnics
S - Chemical Sample	SPT - Standard Penetration Test		Equipment: CHRISTIE
WT - Standing Water Table	SP - Water Seepage Level		Hole Diameter (mm): 105mm
NOTES:	See explanation sheets for meaning of all descriptive terms and symbols		Angle from Vertical (^{o}): 0°
			Drill Bit: Spiral TC

GEOTECHNICAL LOG - NON CORED BOREHOLE

GREEN GEOTECHNICS

Project No: GG10636 | Surface RL: 191.1m AHD | Date Logged : 04/06/2022

Address: 31-33 Calabash Road, Arcadia | Logged By: JK

Client: 4Pillars Environmental Consulting | Checked By: MG

BOREHOLE NO.: BH 4

Sheet 1 of 1

WATER TABLE	SAMPLES	DEPTH (M)	DESCRIPTION (Soil type, colour, grain size, plasticity, minor components, observations)	USC SYMBOL	CONSISTENCY (cohesive soils) or RELATIVE DENSITY (sands and gravels)	MOISTURE
			FILL: Silty CLAY: Dark brown with orange brown, medium plasticity, trace of fine grained sand, trace of gravel.	CI	APPEARS MODERATELY COMPACTED	M
		1.0	FILL: Silty Sandy CLAY: Dark grey with orange brown, medium plasticity, fine to medium grained, trace of gravel.	CI	APPEARS POORLY COMPACTED	M
			Clayey SAND: Light grey with orange brown and dark grey, fine to medium grained.	SC	LOOSE TO MEDIUM DENSE	M
		2.0	Sandy CLAY: Orange brown with light grey, low plasticity, fine to medium grained, trace of sandstone gravel.	CL	STIFF	M
					VERY STIFF	
		3.0	SANDSTONE: Red brown and light grey, fine to medium grained.			D
			AUGER REFUSAL AT 3.1m ON WEATHERED SANDSTONE.			
		4.0				
		5.0				

D - Disturbed sample | U - Undisturbed tube sample | B - Bulk sample

S - Chemical Sample | SPT - Standard Penetration Test

WT - Standing Water Table | SP - Water Seepage Level

NOTES: See explanation sheets for meaning of all descriptive terms and symbols

Contractor: Green Geotechnics

Equipment: CHRISTIE

Hole Diameter (mm): 105mm

Angle from Vertical (^{o}): 0°

Drill Bit: Spiral TC

Dynamic Cone Penetrometer Test Report

Project Number: GG10636
Site Address: 31-33 Calabash Road, Arcadia
Test Date: 04/06/2022

Page: 1 of 2

Test Method: **AS 1289.6.3.2**

Technician: JK

Test No	BH1	BH2	BH3	Test No	BH1	BH2	BH3
Starting Level	Surface	Surface	Suface	Starting Level	n/a	3.00m	3.00m
Depth (m)	Penetration Resistance (blows / 150mm)			Depth (m)	Penetration Resistance (blows / 150mm)		
0.00 - 0.15	2	2	*	3.00 - 3.15		12	6
0.15 - 0.30	2	5	6	3.15 - 3.30		13	8
0.30 - 0.45	3	9	10	3.30 - 3.45		10	16
0.45 - 0.60	5	7	10	3.45 - 3.60		12	Bounce at 3.5m
0.60 - 0.75	11	5	8	3.60 - 3.75		13	
0.75 - 0.90	9	3	2	3.75 - 3.90		22	
0.90 - 1.05	6	5	1	3.90 - 4.05		Refusal	
1.05 - 1.20	7	5	1	4.05 - 4.20			
1.20 - 1.35	8	7	1	4.20 - 4.35			
1.35 - 1.50	11	5	1	4.35 - 4.50			
1.50 - 1.65	6	5	1	4.50 - 4.65			
1.65 - 1.80	4	5	1	4.65 - 4.80			
1.80 - 1.95	3	4	1	4.80 - 4.95			
1.95 - 2.10	4	5	3	4.95 - 5.10			
2.10 - 2.25	5	6	2	5.10 - 5.25			
2.25 - 2.40	11	8	4	5.25 - 5.40			
2.40 - 2.55	Bounce at 2.5m	14	4	5.40 - 5.55			
2.55 - 2.70		17	5	5.55 - 5.70			
2.70 - 2.85		10	6	5.70 - 5.85			
2.85 - 3.00		8	5	5.85 - 6.00			

Remarks: * Pre drilled prior to testing

Dynamic Cone Penetrometer Test Report

GREEN GEOTECHNICS

Project Number: GG10636
Site Address: 31-33 Calabash Road, Arcadia
Test Date: 04/06/2022

Test Method: **AS 1289.6.3.2**

Technician: JK

Test No	BH4			Test No	BH4		
Starting Level	Surface			Starting Level	3.00m		
Depth (m)	Penetration Resistance (blows / 150mm)			Depth (m)	Penetration Resistance (blows / 150mm)		
0.00 - 0.15	*			3.00 - 3.15	n/a		
0.15 - 0.30	6			3.15 - 3.30			
0.30 - 0.45	5			3.30 - 3.45			
0.45 - 0.60	4			3.45 - 3.60			
0.60 - 0.75	3			3.60 - 3.75			
0.75 - 0.90	2			3.75 - 3.90			
0.90 - 1.05	2			3.90 - 4.05			
1.05 - 1.20	4			4.05 - 4.20			
1.20 - 1.35	2			4.20 - 4.35			
1.35 - 1.50	3			4.35 - 4.50			
1.50 - 1.65	3			4.50 - 4.65			
1.65 - 1.80	4			4.65 - 4.80			
1.80 - 1.95	5			4.80 - 4.95			
1.95 - 2.10	4			4.95 - 5.10			
2.10 - 2.25	8			5.10 - 5.25			
2.25 - 2.40	8			5.25 - 5.40			
2.40 - 2.55	12			5.40 - 5.55			
2.55 - 2.70	25			5.55 - 5.70			
2.70 - 2.85	16			5.70 - 5.85			
2.85 - 3.00	24			5.85 - 6.00			

Remarks: * Pre drilled prior to testing

SAMPLING & IN-SITU TESTING

Sampling

Sampling is carried out during drilling or test pitting to allow engineering examination (and laboratory testing where required) of the soil or rock. Disturbed samples taken during drilling provide information on colour, type, inclusions and, depending upon the degree of disturbance, some information on strength and structure. Undisturbed samples are taken by pushing a thin walled sample tube into the soil and withdrawing it to obtain a sample of the soil in a relatively undisturbed state. Such samples yield information on structure and strength and are necessary for laboratory determination of shear strength and compressibility.

Test Pits

Test pits are usually excavated with a backhoe or an excavator, allowing close examination of the in-situ soil if it is safe to enter into the pit. The depth of excavation is limited to about 3 m for a backhoe and up to 6 m for a large excavator.

Large Diameter Augers

Boreholes can be drilled using a large diameter auger, typically up to 300 mm or larger in diameter mounted on a standard drilling rig. The cuttings are returned to the surface at intervals (generally not more than 0.5 m) and are disturbed but usually unchanged in moisture content.

Continuous Spiral Flight Augers

The borehole is advanced using 90-115 mm diameter continuous spiral flight augers which are withdrawn at intervals to allow sampling or in-situ testing. This is a relatively economical means of drilling in clays and sands above the water table. Samples are returned to the surface, or may be collected after withdrawal of the auger flights, but they are disturbed and may be mixed with soils from the sides of the hole.

Non-core Rotary Drilling

The borehole is advanced using a rotary bit, with water or drilling mud being pumped down the drill rods and returned up the annulus, carrying the drill cuttings. Only major changes in stratification can be determined from the cuttings, together with some information from the rate of penetration.

Diamond Core Rock Drilling

A continuous core sample of can be obtained using a diamond tipped core barrel, usually with a 50 mm internal diameter (NMLC). The borehole is advanced using a water or mud flush to lubricate the bit and removed cuttings.

Standard Penetration Tests

Standard penetration tests (SPT) are used as a means of estimating the density or strength of soils and of obtaining a relatively undisturbed sample. The test procedure is described in Australian Standard 1289, Methods of Testing Soils for Engineering Purposes - Test 6.3.1. The test is carried out in a borehole by driving a 50 mm diameter split sample tube under the impact of a 63 kg hammer with a free fall of 760 mm. It is normal for the tube to be driven in three successive 150 mm increments and the 'N' value is taken as the number of blows for the last 300 mm. In dense sands, very hard clays or weak rock, the full 450 mm penetration may not be practicable, and the test is discontinued.

The test results are reported in the following form.

- In the case where full penetration is obtained with successive blow counts for each 150 mm of, say, 4, 6 and 7 as:

  4,6,7
  N=13

- In the case where the test is discontinued before the full penetration depth, say after 15 blows for the first 150 mm and 30 blows for the next 40 mm as: 15, 30/40 mm.

The results of the SPT tests can be related empirically to the engineering properties of the soils.

Dynamic Cone Penetrometer Tests / Perth Sand Penetrometer Tests

Dynamic penetrometer tests (DCP or PSP) are carried out by driving a steel rod into the ground using a standard weight of hammer falling a specified distance. As the rod penetrates the soil the number of blows required to penetrate each successive 150 mm depth are recorded. Two types of penetrometer are commonly used.

- Perth sand penetrometer - a 16 mm diameter flat ended rod is driven using a 9 kg hammer dropping 600 mm (AS 1289, Test 6.3.3). This test was developed for testing the density of sands and is mainly used in granular soils and filling.

- Cone penetrometer - a 16 mm diameter rod with a 20 mm diameter cone end is driven using a 9 kg hammer dropping 510 mm (AS 1289, Test 6.3.2). This test was developed initially for pavement subgrade investigations, and correlations of the test results with California Bearing Ratio have been published by various road authorities.

SOIL DESCRIPTIONS

GREEN
GEOTECHNICS

Description and Classification Methods

The methods of description and classification of soils and rocks used in this report are based on Australian Standard AS 1726, Geotechnical Site Investigations Code. In general, the descriptions include strength or density, colour, structure, soil or rock type and inclusions.

Soil Types

Soil types are described according to the predominant particle size, qualified by the grading of other particles present:

Type	Particle Size (mm)
Boulder >200	Boulder >200
Cobble 63 - 200	Cobble 63 - 200
Gravel 2.36 - 63	Gravel 2.36 - 63
Sand 0.075 - 2.36	Sand 0.075 - 2.36
Silt 0.002 - 0.075	Silt 0.002 - 0.075
Clay <0.002	Clay <0.002

The sand and gravel sizes can be further subdivided as follows:

Type	Particle Size (mm)
Coarse Gravel	20 – 63
Medium Gravel	6 – 20
Fine Sand	2.36 – 6
Coarse Sand	0.6 – 2.36
Medium Sand	0.2 – 0.6
Fine Sand	0.075 – 0.2

The proportions of secondary constituents of soils are described as:

Term	Proportion
And	Specify
Adjective	20 - 35%
Slightly	12 - 20%
With some	5 - 12%
With a trace of	0 - 5%

Definitions of grading terms used are:

- Well graded - a good representation of all particle sizes
- Poorly graded - an excess or deficiency of particular sizes within the specified range
- Uniformly graded - an excess of a particular particle size
- Gap graded - a deficiency of a particular particle size with the range

Cohesive Soils

Cohesive soils, such as clays, are classified on the basis of undrained shear strength. The strength may be measured by laboratory testing, or estimated by field tests or engineering examination. The strength terms are defined as follows:

Description	Abbreviation	Undrained Shear Strength (kPa)
Very soft	VS	<12
Soft	S	12 - 25
Firm	F	25 - 50
Stiff	ST	50 - 100
Very stiff	VST	100 - 200
Hard	H	200

Cohesionless Soils

Cohesionless soils, such as clean sands, are classified on the basis of relative density, generally from the results of standard penetration tests (SPT), cone penetration tests (CPT) or dynamic penetrometers (DCP). The relative density terms are given below:

Relative Density	Abbreviation	SPT N Value	CPT qc value (MPa)
Very loose	VL	<4	<2
Loose	L	4 - 10	2 -5
Medium Dense	MD	10-30	5-15
Dense	D	30-50	15-25
Very Dense	VD	>50	>25

Soil Origin

It is often difficult to accurately determine the origin of a soil. Soils can generally be classified as:

- Residual soil - derived from in-situ weathering of the underlying rock;
- Transported soils - formed somewhere else and transported by nature to the site; or
- Filling - moved by man.

Transported soils may be further subdivided into:

- Alluvium - river deposits
- Lacustrine - lake deposits
- Aeolian - wind deposits
- Littoral - beach deposits
- Estuarine - tidal river deposits
- Talus - scree or coarse colluvium
- Slopewash or Colluvium - transported downslope by gravity assisted by water. Often includes angular rock fragments and boulders.

ROCK DESCRIPTIONS

GREEN GEOTECHNICS

Rock Strength

The Rock strength is defined by the Point Load Strength Index ($Is_{(50)}$) and refers to the strength of the rock substance and not the strength of the overall rock mass, which may be considerably weaker due to defects. The test procedure is described by Australian Standard 4133.4.1 - 1993. The terms used to describe rock strength are as follows:

Term	Abbreviation	Point Load Index $IS_{(50)}$ MPa	Approximate Unconfined Compressive Strength MPa*
Extremely low	EL	<0.03	<0.6
Very low	VL	0.03 - 0.1	0.6 - 2
Low	L	0.1 - 0.3	2 - 6
Medium	M	0.3 - 1.0	6 - 20
High	H	1 - 3	20 - 60
Very high	VH	3 - 10	60 - 200

* Assumes a ration of 20:1 for UCS to $IS_{(50)}$

Degree of Weathering

The degree of weathering of rock is classified as follows:

Term	Abbreviation	Description
Extremely weathered	EW	Rock substance has soil properties, i.e. it can be remoulded and classified as a soil but the texture of the original rock is still evident.
Highly weathered	HW	Limonite staining or bleaching affects whole of rock substance and other signs of decomposition are evident. Porosity and strength may be altered as a result of iron leaching or deposition. Colour and strength of original fresh rock is not recognisable.
Moderately weathered	MW	Staining and discolouration of rock substance has taken Place.
Slightly weathered	SW	Rock substance is slightly discoloured but shows little or no change of strength from fresh rock.
Fresh stained	FS	Rock substance unaffected by weathering but staining visible along defects.
Fresh	FR	No signs of decomposition or staining.

Degree of Fracturing

The following classification applies to the spacing of natural fractures in core samples (bedding plane partings, joints and other defects, excluding drilling breaks

Term	Description
Fragmented	Fragments of <20 mm
Highly Fractured	Core lengths of 20-40 mm with some fragments
Fractured Core	Core lengths of 40-200 mm with some shorter and longer sections
Slightly Fractured	Core lengths of 200-1000 mm with some shorter and loner sections
Unbroken	Unbroken Core lengths mostly > 1000 mm

Stratification Spacing

For sedimentary rocks the following terms may be used to describe the spacing of bedding partings:

Term	Separation of Stratification Planes
Thinly laminated	6 mm
Laminated	6 mm to 20 mm
Very thinly bedded	20 mm to 60 mm
Thinly bedded	60 mm to 0.2 m
Medium bedded	0.2 m to 0.6 m
Thickly bedded	0.6 m to 2 m
Very thickly bedded	2 m

Rock Quality Designation

The quality of the cored rock can be measured using the Rock Quality Designation (RQD) index, defined as:

$$RQD\ \% = \frac{\text{cumulative length of 'sound' core sections} \geq 100 \text{ mm long}}{\text{total drilled length of section being assessed}}$$

'sound' rock is assessed to be rock of low strength or better. The RQD applies only to natural fractures. If the core is broken by drilling/handling, then the broken pieces are fitted back together and are not included in the calculation of RQD.

ABBREVIATIONS

GREEN GEOTECHNICS

Introduction

These notes summarise abbreviations commonly used on borehole logs and test pit reports.

Drilling or Excavation Methods

C	Core Drilling
R	Rotary drilling
SFA	Spiral flight augers
NMLC	Diamond core - 52 mm dia
NQ	Diamond core - 47 mm dia
HQ	Diamond core - 63 mm dia
PQ	Diamond core - 81 mm dia

Water

Z	Water seep
V	Water level

Sampling and Testing

A	Auger sample
B	Bulk sample
D	Disturbed sample
S	Chemical sample
U50	Undisturbed tube sample (50mm)
W	Water sample
PP	Pocket Penetrometer (kPa)
PL	Point load strength Is(50) MPa
S	Standard Penetration Test
V	Shear vane (kPa)

Description of Defects in Rock

The abbreviated descriptions of the defects should be in the following order: Depth, Type, Orientation, Coating, Shape, Roughness and Other. Drilling and handling breaks are not usually included on the logs.

Defect Type

B	Bedding plane
Cs	Clay seam
Cv	Cleavage
Cz	Crushed zone
Ds	Decomposed seam
F	Fault
J	Joint
Lam	lamination
Pt	Parting
Sz	Sheared Zone
V	Vein

Orientation

The inclination of defects is always measured from the perpendicular to the core axis.

h	horizontal
v	vertical
sh	sub-horizontal
sv	sub-vertical

Coating or Infilling Term

cln	clean
co	coating
he	healed
inf	infilled
stn	stained
ti	tight
vn	veneer

Coating Descriptor

ca	calcite
cbs	carbonaceous
cly	clay
fe	iron oxide
mn	manganese
slt	silty

Shape

cu	curved
ir	irregular
pl	planar
st	stepped
un	undulating

Roughness

po	polished
ro	rough
sl	slickensided
sm	smooth
vr	very rough

Other

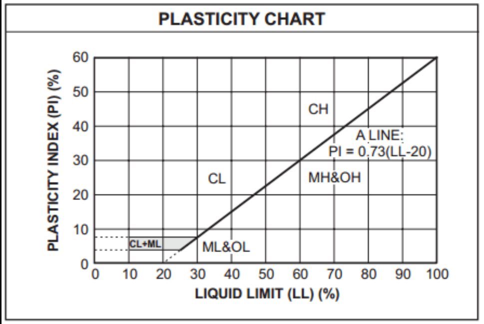
fg	fragmented
bnd	band
qtz	quartz

UNIFIED SOIL CLASSIFICATION TABLE

Field Identification Procedures (Excluding particles larger than 75um and basing fractions on estimated weights)				Group Symbols	Typical Names	Information Required for Describing Soils	Laboratory Classification Criteria
Coarse-grained soils More than half of the material is large that 75um sieve size[b] (The 75um sieve size is about the particle visible to the naked eye)	Gravels More than half of the coarse fraction is larger than a 4mm sieve	Clean gravels (little or no fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes	*GW*	Well graded gravels, gravel-sand mixtures, little or no fines	Give typical name: indicative approximate percentages of sand and gravel; maximum size; angularity; surface condition, and hardness of the coarse grains; local of geologic name and other pertinent descriptive information; and symbols in parentheses	$C_u = \frac{D_{60}}{D_{10}}$ Greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3
			Predominantly one size or range of sizes with some intermediate sizes missing	*GP*	Poorly graded gravels, grave-sand mixtures, little or no fines	For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions and drainage characteristics	Not meeting all graduation requirements for *GW*
		Gravels with fines (appreciable amount of fines)	Nonplastic fines (for identification procedures see *ML* below)	*GM*	Silty gravels, poorly graded gravel-sand-silt mixtures	Example:	Atterberg limits below "A" line or *PI* less than 4 — Above "A" line with *PI* between 4 and 7 are borderline cases of requiring use of dual symbols
			Plastic fines (for identification procedures see *CL* below)	*GC*	Clayey gravels, poorly graded gravel-sand-clay mixtures	*Silty Sand*, gravelly; about 20% hard, angular gravel particles 12mm maximum size; rounded and subangular sand grains, coarse to fine, about 15% non-plastic fines low dry strength; well compacted and moist in place; alluvial sand; *(SM)*	Atterberg limits above "A" line with *PI* greater than 7
	Sands More than half of the coarse fraction is smaller than a 4mm sieve	Clean sands (little or no fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes	*SW*	Well graded sands, gravelly sands, little or no fines		$C_u = \frac{D_{60}}{D_{10}}$ Greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3
			Predominantly one size or range of sizes with some intermediate sizes missing	*SP*	Poorly graded sands, gravelly sands, little or no fines		Not meeting all graduation requirements for *SW*
		Sands with fines (appreciable amount of fines)	Nonplastic fines (for identification procedures see *ML* below)	*SM*	Silty sands, poorly graded sand-silt mixtures		Atterberg limits below "A" line or *PI* less than 5 — Above "A" line with *PI* between 4 and 7 are borderline cases of requiring use of dual symbols
			Plastic fines (for identification procedures see *CL* below)	*SC*	Clayey sands, poorly graded sand-clay mixtures		Atterberg limits above "A" line with *PI* greater than 7

Laboratory Classification Criteria (coarse-grained soils): Use grain size curve in identifying the fractions as given under field identification. Determine percentages of gravel and sand from grain size curve. Depending on percentage of fines (fraction smaller than 75um sieve size) coarse grained soils are classified as follows: Less than 5% — GW, GP, SW, SP; More than 12% — GM, GC, SM, SC; 5 to 12% — Borderline cases requiring use of dual symbol

Find-grained soils More than half of the material is smaller than 75um sieve size	Identification Procedures of Fractions Smaller than 380 um Sieve Size: Dry Strength (crushing characteristics)	Dilatancy (reaction to shaking)	Toughness (consistency near plastic limit)	Group Symbols	Typical Names	Information Required for Describing Soils
Silts and clays liquid limit less than 50	None to slight	Quick to slow	None	*ML*	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slit plasticity	Give typical name: indicative degree and character of plasticity, amount and maximum size of coarse grains; colour in wet condition, odour if any, local or geologic name, and other pertinent descriptive information, and symbol in parentheses
	Medium to high	None to very slow	Medium	*CL*	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	
	Slight to medium	Slow	Slight	*OL*	Organic silts and organic silt-clays of low plasticity	
Silts and clays liquid limit greater than 50	Slight to medium	Slow to none	Slight to medium	*MH*	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, clastic silts	For undisturbed soils add information on structure, stratification, consistency in undisturbed and remoulded states, moisture and drainage conditions
	High to very high	None	High	*CH*	Inorganic clays of high plasticity, fat clays	Example:
	Medium to high	None to very slow	Slight to medium	*OH*	Organic clays of medium to high plasticity	*Clayey Silt*, brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; *(ML)*
Highly Organic Soils	Readily identified by colour, odour, spongy feel and frequently by fibrous texture			*Pt*	Peat and other highly organic soils	



Plasticity Chart
For laboratory classification of fine-grained soils

Note: 1 Soils possessing characteristics of two groups are designated by combinations of group symbols (eg. GW-GC, well graded gravel-sand mixture with clay fines

2 Soils with liquid limits of the order of 35 to 50 may be visually classified as being of medium plasticity

APPENDIX B – AGS 2007 GUIDELINES

ATTACHMENT 1: 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 1: – 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 2 - DEFINITION OF TERMS AND LANDSLIDE RISK

(Australian Geomechanics Vol 42 No 1 March 2007)

Acceptable Risk – A risk for which, for the purposes of life or work, we are prepared to accept as it is with no regard to its management. Society does not generally consider expenditure in further reducing such risks justifiable.

Annual Exceedance Probability (AEP) – The estimated probability that an event of specified magnitude will be exceeded in any year.

Consequence – The outcomes or potential outcomes arising from the occurrence of a landslide expressed qualitatively or quantitatively, in terms of loss, disadvantage or gain, damage, injury or loss of life.

Elements at Risk – The population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by landslides.

Frequency – A measure of likelihood expressed as the number of occurrences of an event in a given time. See also Likelihood and Probability.

Hazard – A condition with the potential for causing an undesirable consequence (the landslide). The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material, and the likelihood of their occurrence within a given period of time.

Individual Risk to Life – The risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the landslide; or who follows a particular pattern of life that might subject him or her to the consequences of the landslide.

Landslide Activity – The stage of development of a landslide; pre failure when the slope is strained throughout but is essentially intact; failure characterised by the formation of a continuous surface of rupture; post failure which includes movement from just after failure to when it essentially stops; and reactivation when the slope slides along one or several pre-existing surfaces of rupture. Reactivation may be occasional (e.g. seasonal) or continuous (in which case the slide is “active”).

Landslide Intensity – A set of spatially distributed parameters related to the destructive power of a landslide. The parameters may be described quantitatively or qualitatively and may include maximum movement velocity, total displacement, differential displacement, depth of the moving mass, peak discharge per unit width, kinetic energy per unit area.

Landslide Risk – The AGS Australian GeoGuide LR7 (AGS, 2007e) should be referred to for an explanation of Landslide Risk.

Landslide Susceptibility – The classification, and volume (or area) of landslides which exist or potentially may occur in an area or may travel or retrogress onto it. Susceptibility may also include a description of the velocity and intensity of the existing or potential landsliding.

Likelihood – Used as a qualitative description of probability or frequency.

Probability – A measure of the degree of certainty. This measure has a value between zero (impossibility) and 1.0 (certainty). It is an estimate of the likelihood of the magnitude of the uncertain quantity, or the likelihood of the occurrence of the uncertain future event.

There are two main interpretations:

(i) Statistical – frequency or fraction – The outcome of a repetitive experiment of some kind like flipping coins. It includes also the idea of population variability. Such a number is called an “objective” or relative frequentist probability because it exists in the real world and is in principle measurable by doing the experiment.

(ii) Subjective probability (degree of belief) – Quantified measure of belief, judgment, or confidence in the likelihood of an outcome, obtained by considering all available information honestly, fairly, and with a minimum of bias. Subjective probability is affected by the state of understanding of a process, judgment regarding an evaluation, or the quality and quantity of information. It may change over time as the state of knowledge changes.

Qualitative Risk Analysis – An analysis which uses word form, descriptive or numeric rating scales to describe the magnitude of potential consequences and the likelihood that those consequences will occur.

Quantitative Risk Analysis – An analysis based on numerical values of the probability, vulnerability and consequences and resulting in a numerical value of the risk.

Risk – A measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability x consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form.

Risk Analysis – The use of available information to estimate the risk to individual, population, property, or the environment, from hazards. Risk analyses generally contain the following steps: Scope definition, hazard identification and risk estimation.

Risk Assessment – The process of risk analysis and risk evaluation.

Risk Control or Risk Treatment – The process of decision making for managing risk and the implementation or enforcement of risk mitigation measures and the re-evaluation of its effectiveness from time to time, using the results of risk assessment as one input.

Risk Estimation – The process used to produce a measure of the level of health, property or environmental risks being analysed. Risk estimation contains the following steps: frequency analysis, consequence analysis and their integration.

Risk Evaluation – The stage at which values and judgments enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental and economic consequences, in order to identify a range of alternatives for managing the risks.

Risk Management – The complete process of risk assessment and risk control (or risk treatment).

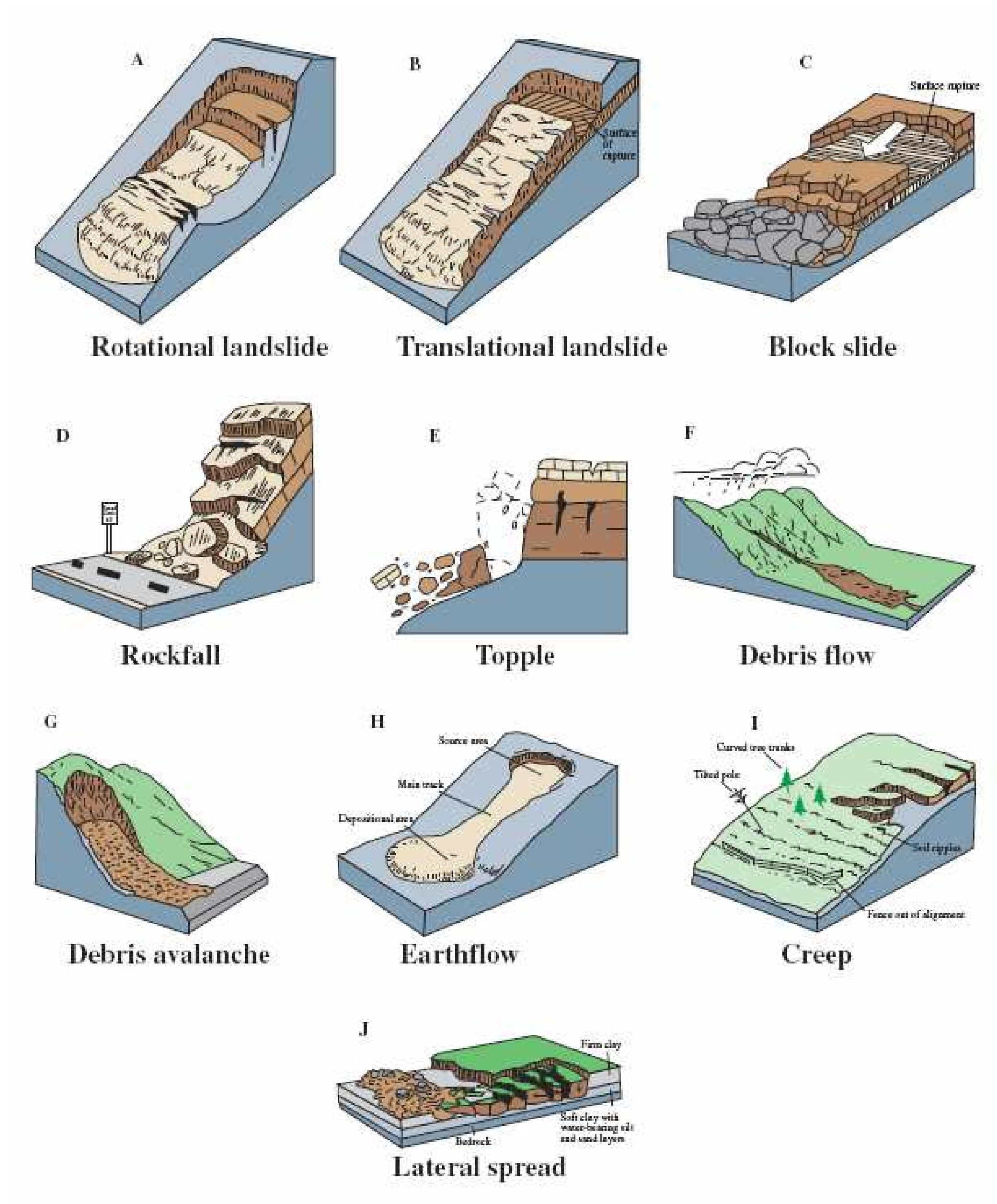
Societal Risk – The risk of multiple fatalities or injuries in society as a whole: one where society would have to carry the burden of a landslide causing a number of deaths, injuries, financial, environmental and other losses.

Susceptibility – see Landslide Susceptibility

Temporal Spatial Probability – The probability that the element at risk is in the area affected by the landsliding, at the time of the landslide.

Tolerable Risk – A risk within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible.

Vulnerability – The degree of loss to a given element or set of elements within the area affected by the landslide hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is affected by the landslide.



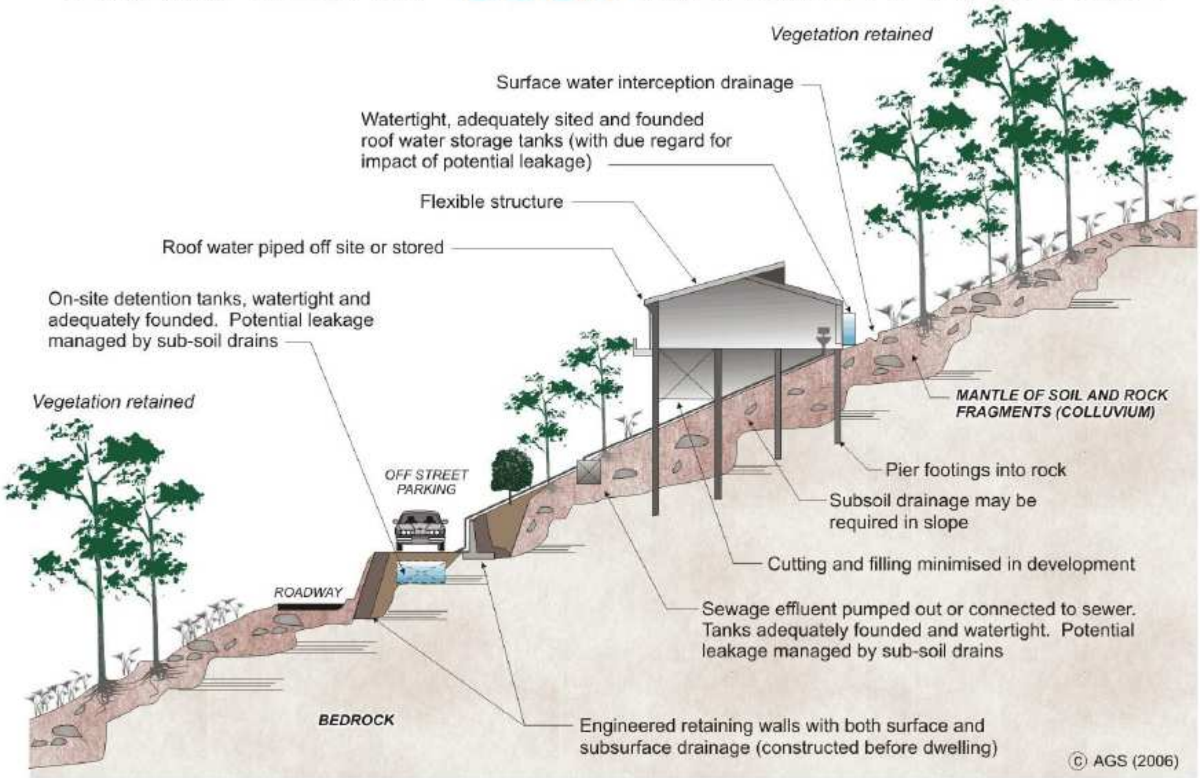
ATTACHMENT 3 MAJOR TYPES OF LANDSLIDES

ATTACHMENT 4

SOME GUIDELINES FOR HILLSIDE CONSTRUCTION

	GOOD ENGINEERING PRACTICE	*POOR ENGINEERING PRACTICE*
ADVICE		
GEOTECHNICAL ASSESSMENT	Obtain advice from a qualified, experienced geotechnical consultant at early stage of planning and before site works.	Prepare detailed plan and start site works before geotechnical advice.
PLANNING		
SITE PLANNING	Having obtained geotechnical advice, plan the development with the risk arising from the identified hazards and consequences in mind.	Plan development without regard for the Risk.
DESIGN AND CONSTRUCTION		
HOUSE DESIGN	Use flexible structures which incorporate properly designed brickwork, timber or steel frames, timber or panel cladding. Consider use of split levels. Use decks for recreational areas where appropriate.	Floor plans which require extensive cutting and filling. Movement intolerant structures.
SITE CLEARING	Retain natural vegetation wherever practicable.	Indiscriminately clear the site.
ACCESS & DRIVEWAYS	Satisfy requirements below for cuts, fills, retaining walls and drainage. Council specifications for grades may need to be modified. Driveways and parking areas may need to be fully supported on piers.	Excavate and fill for site access before geotechnical advice.
EARTHWORKS	Retain natural contours wherever possible.	Indiscriminant bulk earthworks.
CUTS	Minimise depth. Support with engineered retaining walls or batter to appropriate slope. Provide drainage measures and erosion control.	Large scale cuts and benching. Unsupported cuts. Ignore drainage requirements
FILLS	Minimise height. Strip vegetation and topsoil and key into natural slopes prior to filling. Use clean fill materials and compact to engineering standards. Batter to appropriate slope or support with engineered retaining wall. Provide surface drainage and appropriate subsurface drainage.	Loose or poorly compacted fill, which if it fails, may flow a considerable distance including onto property below. Block natural drainage lines. Fill over existing vegetation and topsoil. Include stumps, trees, vegetation, topsoil, boulders, building rubble etc in fill.
ROCK OUTCROPS & BOULDERS	Remove or stabilise boulders which may have unacceptable risk. Support rock faces where necessary.	Disturb or undercut detached blocks or boulders.
RETAINING WALLS	Engineer design to resist applied soil and water forces. Found on rock where practicable. Provide subsurface drainage within wall backfill and surface drainage on slope above. Construct wall as soon as possible after cut/fill operation.	Construct a structurally inadequate wall such as sandstone flagging, brick or unreinforced blockwork. Lack of subsurface drains and weepholes.
FOOTINGS	Found within rock where practicable. Use rows of piers or strip footings oriented up and down slope. Design for lateral creep pressures if necessary. Backfill footing excavations to exclude ingress of surface water.	Found on topsoil, loose fill, detached boulders or undercut cliffs.
SWIMMING POOLS	Engineer designed. Support on piers to rock where practicable. Provide with under-drainage and gravity drain outlet where practicable. Design for high soil pressures which may develop on uphill side whilst there may be little or no lateral support on downhill side.	
DRAINAGE		
SURFACE	Provide at tops of cut and fill slopes. Discharge to street drainage or natural water courses. Provide general falls to prevent blockage by siltation and incorporate silt traps. Line to minimise infiltration and make flexible where possible. Special structures to dissipate energy at changes of slope and/or direction.	Discharge at top of fills and cuts. Allow water to pond on bench areas.
SUBSURFACE	Provide filter around subsurface drain. Provide drain behind retaining walls. Use flexible pipelines with access for maintenance. Prevent inflow of surface water.	Discharge roof runoff into absorption trenches.
SEPTIC & SULLAGE	Usually requires pump-out or mains sewer systems; absorption trenches may be possible in some areas if risk is acceptable. Storage tanks should be water-tight and adequately founded.	Discharge sullage directly onto and into slopes. Use absorption trenches without consideration of landslide risk.
EROSION CONTROL & LANDSCAPING	Control erosion as this may lead to instability. Revegetate cleared area.	Failure to observe earthworks and drainage recommendations when landscaping.
DRAWINGS AND SITE VISITS DURING CONSTRUCTION		
DRAWINGS	Building Application drawings should be viewed by geotechnical consultant	
SITE VISITS	Site Visits by consultant may be appropriate during construction/	
INSPECTION AND MAINTENANCE BY OWNER		
OWNER'S RESPONSIBILITY	Clean drainage systems; repair broken joints in drains and leaks in supply pipes. Where structural distress is evident see advice. If seepage observed, determine causes or seek advice on consequences.	

EXAMPLES OF **GOOD** HILLSIDE PRACTICE



EXAMPLES OF **POOR** HILLSIDE PRACTICE