GREEN
GEOTECHNICS

GEOTECHNICAL INVESTIGATION

FOR

BRICKWOOD HOMES PTY LIMITED

8 COUSINS ROAD, BEACON HILL

REPORT GG10842.001
16 NOVEMBER 2022

Geotechnical Investigation for proposed alterations and additions to an existing residential dwelling to be constructed at 8 Cousins Road, Beacon Hill

Prepared for

Brickwood Homes (Aust) Pty Limited
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16 November 2022

Document Authorisation

Our Ref: GG10842.001

For and on behalf of Green Geotechnics

Matthew Green
Principal Engineering Geologist

Document Control

Revision	Description	Format	Date	Author	Distributed to
-	Final	PDF	16/11/2022	MG	Brickwood Homes (Client)

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1. INTRODUCTION

This report presents the results of a geotechnical investigation undertaken by Green Geotechnics Pty Limited for proposed alterations and additions to an existing residential dwelling at 8 Cousins Road, Beacon Hill, NSW. The investigation was commissioned by Brickwood Homes (Aust) Pty Limited by return acceptance of Proposal PROP-2022-0461, dated 3 November 2022.

We understand that the development comprises the construction of a secondary dwelling, which is to be constructed to the west of the existing primary dwelling. The secondary dwelling will be constructed on a lower terrace area adjacent to a retaining wall, which we understand will be demolished and reconstructed.

Further, we understand that the site is located within a Zone B Landslip Area as mapped by Northern Beaches Council, and therefore a preliminary landslip assessment will be required.

The purpose of the investigation was to:

- assess the subsurface conditions over the site,
- comment on groundwater levels and their implications to the development,
- provide a Site Classification to AS2870,
- provide recommendations regarding appropriate foundation systems for the site including foundation design parameters,
- comment on excavation conditions and provide design parameters for the reconstruction of retaining walls,
- undertake a preliminary landslip assessment in accordance with councils' guidelines, and
- provide recommendations to address the outcomes of the preliminary landslip assessment.

2. FIELDWORK DETAILS

The fieldwork was carried out on 14 November 2022 and comprised a detailed site walkover together with the drilling of two (2) boreholes numbered BH1 and BH2. Due to restricted site access the boreholes were drilled using hand auger equipment.

The site location is shown in the attached Figure A. The borehole locations, as shown on Figure B, were determined by taped measurements from existing surface features overlain on available architectural drawings of the site. Photographs of the site indicating the borehole and locations are shown on Figure C.

The strength of the soils encountered in the boreholes was assessed by undertaking a Dynamic Cone Penetrometer (DCP) test 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 inspections of nearby rock outcrops.

Groundwater observations were made in all boreholes during drilling, on completion of drilling and a short time after completion of drilling. No longer term monitoring of groundwater was carried out.

The fieldwork was completed in the full-time presence of our senior field geologist who set out the boreholes, nominated the sampling and testing, and prepared the borehole 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 9 in DP 201290, and is roughly rectangular in shape with an area of approximately 554m^2. At the time of the fieldwork the site was occupied by a double storey brick rendered residential dwelling with metal roof and internal garage space. The dwelling includes a concrete driveway fronting Lanai Place.

The rear garden area of the dwelling comprises a series of terraces. An above ground swimming pool was previously located on the upper terrace at the rear of the dwelling, however, has now been removed. The terraces are formed by a series of sandstone boulder and timber post and panel walls with maximum wall heights of between 1 and 1.2 metres.

At the toe of the lower wall is a grassed lawn area with a small metal shed, in front of which is a sewer manhole.

The ground surface on the site falls approximately 6 metres to the west from Reduced Level (RL) 52 metres Australian Height Datum (AHD) on the eastern boundary to RL 46 metres AHD on the eastern boundary.

To the north of the site is Lanai Place and to the west is Cousins Road. To the south and east are double storey residential dwellings similar to that on the subject site. Sandstone bedrock can be observed outcropping on the northern side of Lanai Place and immediately to the west of the site in the nature strip of Cousins Road. The exposed bedrock comprises fine to medium grained medium strength Hawkesbury Sandstone.

3.2 Regional Geology & Subsurface Conditions

The 1:100,000 series geological map of Sydney (Geological Survey of NSW, Geological Series Sheet 9130) 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 in the immediate vicinity of the site that are consistent with this geological setting.

For the development of a site-specific geotechnical model, the observed subsurface conditions from the borehole have been grouped into three (3) geotechnical units which are summarised as follows:

Unit 1 – Fill:

Fill materials were encountered in both boreholes to depths of 0.1 to 0.55 metres, being deepest in BH2. The fill comprises a gravelly sandy clay and silty sandy clay. In BH2 the fill directly overlies sandstone bedrock and was likely placed during construction of the above ground swimming pool.

Unit 2 – Soft becoming stiff and very stiff Sandy Clays and Silty Clays (Residual Soil):

Natural soft becoming stiff and very stiff sandy clays and silty clays were encountered below the fill in BH1 and extended to a depth of 0.4 metres. The clays were assessed to be moist and are of residual origin.

Unit 3 – Sandstone bedrock:

Weathered sandstone bedrock was encountered in BH1 at a depth of 0.4 metres, and could not be penetrated with a hand auger below a depth of 0.41 metres. Bedrock was encountered was encountered in BH2 at a depth of 0.5 metres, and could not be penetrated with a hand auger below a depth of 0.58 metres. The bedrock was assessed to be at least low strength (Class V), however is likely to increase to medium and possibly high strength with depth.

Groundwater seepage was not observed during hand auger drilling.

4. GEOTECHNICAL RECOMMENDATIONS

4.1 Site Classification to AS2870

The classification has been prepared in accordance with the guidelines set out in the "Residential Slabs and Footings" Code, AS2870 – 2011.

Due to the presence of greater than 400mm of fill the site is classified as a ***Problem Site (P).*** However, provided the recommendations given below in Section 4.4 are adopted and footings are founded in sandstone bedrock, the site may be re-classified as a ***Stable Site (A).***

4.2 Excavation Conditions & Vibration Control

From the outcomes of the fieldwork and site inspection, excavations on the subject site undertaken during the removal and relocation of the retaining walls are expected to encounter fill materials overlying a limited depth of natural residual soils, overlying shallow sandstone bedrock.

Excavation of the overlying natural soils and fill materials is expected to be achievable using conventional earthmoving equipment such as a small tracked excavator fitted with a toothed bucket attachment. Removal of in-situ sandstone bedrock is however likely to require the use of jack hammers or hydraulic rock hammers fitted to a small excavator.

During the use of hydraulic impact hammers, precautions must be made to reduce the risk of vibrational damage to adjoining structures. At the commencement of the use of hydraulic impact hammers we recommend that full time quantitative vibration monitoring be carried out on the adjoining structures/footings or at the site boundaries by an experienced vibration consultant or geotechnical engineer to check that vibrations are within acceptable limits.

Australian Standard AS 2187: Part 2-2006 recommends the frequency dependent guideline values and assessment methods given in BS 7385 Part 2-1993 "Evaluation and measurement for vibration in buildings Part 2" as they "are applicable to Australian conditions". The standard sets guide values for building vibration based on the lowest vibration levels above which damage has been credibly demonstrated. These levels are judged to give a minimum risk of vibration-induced damage, where the minimal risk for a named effect is usually taken as a 95% probability of no effect.

Sources of vibration that are considered in the standard include demolition, blasting (carried out during mineral extraction or construction excavation), piling, ground treatments (e.g. compaction), construction equipment, tunnelling, road and rail traffic and industrial machinery.

For residential structures, BS 7385 recommends vibration criteria of 7.5 mm/s to 10 mm/s for frequencies between 4 Hz and 15 Hz, and 10 mm/s to 25 mm/s for frequencies between 15 Hz to 40 Hz and above. These values would normally be applicable for new residential structures or residential structures in good condition. Higher values would normally apply to commercial structures, and more conservative criteria would normally apply to heritage structures. However, structures can withstand vibration levels significantly higher than those required to maintain comfort for their occupants. Human comfort is therefore likely to be the critical factor in vibration management.

Excavation methods should be adopted which limit ground vibrations at the adjoining structures to not more than 5mm/sec. Vibration monitoring is recommended to verify that this is achieved.

Table 4.1 – Recommendations for rock breaking equipment

Distance from adjoining structure (m)	Maximum Peak Particle Velocity 5mm/sec	
	Equipment	Operating Limit (% of maximum capacity)
1.5 to 2.5	Hand operated hack hammer only	100
2.5 to 5.0	300 kg rock hammer	50

At all times, the excavation equipment must be operated by experienced personnel, per the manufacturer's instructions, and in a manner, consistent with minimising vibration effects.

If during excavation with the hydraulic impact hammers, vibrations are found to be excessive or there is concern, then alternative lower vibration emitting equipment, such as rock saws, rock grinders or smaller hammers may need to be used. The use of a rotary grinder or rock sawing in conjunction with ripping presents an alternative low vibration excavation technique, however, productivity is likely to be slower. When using a rock saw or rotary grinder, the resulting dust must be suppressed by spraying with water.

It should be noted that vibrations that are below threshold levels for building damage may be experienced at adjoining developments. Rock excavation methodology should also consider acceptable noise limits as per the “Interim Construction Noise Guideline” (NSW EPA).

4.3 Retaining Wall Design

Given the limited depth of excavation, we expect the exposed cut faces formed during construction of the retaining walls to remain stable without the need for temporary support. In the long term the exposed faces must be supported by engineer designed retaining walls.

When considering the design of the reconstructed retaining walls, it will be necessary to allow for the loading from adjoining structures, any ground surface slope and the water table present.

A triangular stress distribution should be adopted for the design of a cantilevered retaining wall. The lateral earth pressure for a cantilevered wall should be determined as a proportion of the vertical stress, as given in the following formula:

$\sigma z = K z \gamma$, where σz = Horizontal pressure at depth z (kPa)

K = Earth pressure coefficient

z = Depth (m)

γ = Unit weight of soil or rock (kN/m^3)

Retaining walls may be designed using the parameters provided below in Table 4.2.

TABLE 4.2 – Retaining Wall Design Parameters

Material Type	Unit Weight (kN/m^3)	Earth Pressure Coefficient		
		Active (K_a)[1]	At Rest (K_O) [1]	Passive (K_p)[2,3]
Fill	18	0.4	0.6	-
Natural Soil	18	0.4	0.6	-
Sandstone Bedrock	22	0.1	-	4.5

1. These values assume that some wall movement and relaxation of horizontal stress will occur due to the excavation. Actual in-situ K_0 values may be higher, particularly in the rock units.

2. Includes a reduction factor to the ultimate value of K_p to consider strain incompatibility between active and passive pressure conditions. Parameters assume horizontal backfill and no back of wall friction.

3. The values for rock assume no adversely dipping joints or other defects are present in the bedrock.

The embedment of retaining walls can be used to achieve passive support. A triangular passive earth pressure distribution (increasing linearly with depth) may be assumed, starting from 0.5 m below excavation toe/base level.

Adequate drainage must be installed behind any retaining or below ground structures to prevent the build-up of hydrostatic forces.

4.4 Foundation Design

The allowable bearing pressures provided below have been determined using the procedures given by Pells et al, in their paper titled "Design Loadings for Foundations on Shale and Sandstone in the Sydney Region," published in the Australian Geomechanics Journal, 1998.

The sandstone bedrock encountered on the site is expected to comprise at least Class IV Sandstone or better. Pad/strip footings or piles founded on Class IV bedrock may be proportioned using an allowable bearing pressure of 1,000 kPa. For pile foundations an allowable adhesion of 100 kPa may be adopted for the portion of the pile shaft socketed into the weathered sandstone.

Due to their variable nature and distribution across the site, any natural soils are not considered suitable for foundation support.

Settlements for pad footings and piled foundations in sandstone bedrock are anticipated to be about 1% of the minimum footing dimension, based on serviceability parameters provided above.

All shallow footings should be poured with minimal delay (i.e. preferably on the same day of excavation) or the base of the footing should be protected by a concrete blinding layer after cleaning of loose spoil and inspection.

The site is considered suitable for the use of conventional bored cast in-situ piles. Socketing of piles into the sandstone bedrock will however require the use of large excavators fitted with rock drilling augers, or purpose built piling rigs.

Based on the observations made during auger drilling, the sidewalls of bored piles are expected to remain stable during drilling. However, pile excavations should not be left open overnight. The possibility of some minor seepage needs to be considered when drilling bored piles and pouring concrete.

Bored pile footings should be drilled, cleaned, inspected and poured with minimal delay, on the same day. Water should be prevented from ponding in the base of footings as this will tend to soften the foundation material, resulting in further excavation and cleaning being required.

The initial stages of footing excavation/drilling, particularly if bored piles are adopted, should be inspected by a geotechnical engineer/engineering geologist to ascertain that the recommended foundation material has been reached and to check initial assumptions about foundation conditions and possible variations that may occur between borehole locations. The need for further inspections can be assessed following the initial visit.

4.5 Preliminary Landslide Risk Assessment

The development will comprise the construction of secondary dwelling. The dwelling will be supported by pile foundations. Construction of the dwelling will however require the removal and reconstruction of an existing retaining wall, which will require excavating around 1.2 metres below the existing ground surface. Northern Beaches Council's landslip hazard mapping indicates that the site is located within a Class B area.

The preliminary landslip carried out is based on Council's check list. The assessment follows:

- Does the site or adjacent properties have a history of slope instability – No.
- Are excavations or fills greater than 2 metres proposed – No.
- Is the site developed – Yes.
- Is fill greater than 1m depth present: No
- Are cuts/excavations greater than 2m high present – No.

Based on our observations and Council's check list a detailed landslip assessment **will not** be required.

5. GENERAL RECOMMENDATIONS

Any development on the site should follow good hillside building practices (refer to Attachment 4 in Appendix B for some examples).

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. The site is suitable for residential development provided good hillside building practices are followed. There are no geotechnical constraints for the proposed development of the site; however, Section 4 of this report provides advice and recommendations that should be taken into consideration and applied to any future development.

The recommendations presented in this report include specific issues to be addressed during the construction phase of the project. In the event that any of the construction phase recommendations presented in this report are not implemented, the general recommendations may become inapplicable and Green Geotechnics accept no responsibility whatsoever for the performance of the structure where recommendations are not implemented in full and properly tested, inspected and documented.

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 provides advice on geotechnical aspects for the proposed civil and structural design. As part of the documentation stage of this project, Contract Documents and Specifications may be prepared based on our report. However, there may be design features we are not aware of or have not commented on for a variety of reasons. The designers should satisfy themselves that all the necessary advice has been obtained. If required, we could be commissioned to review the geotechnical aspects of contract documents to confirm the intent of our recommendations has been correctly implemented.

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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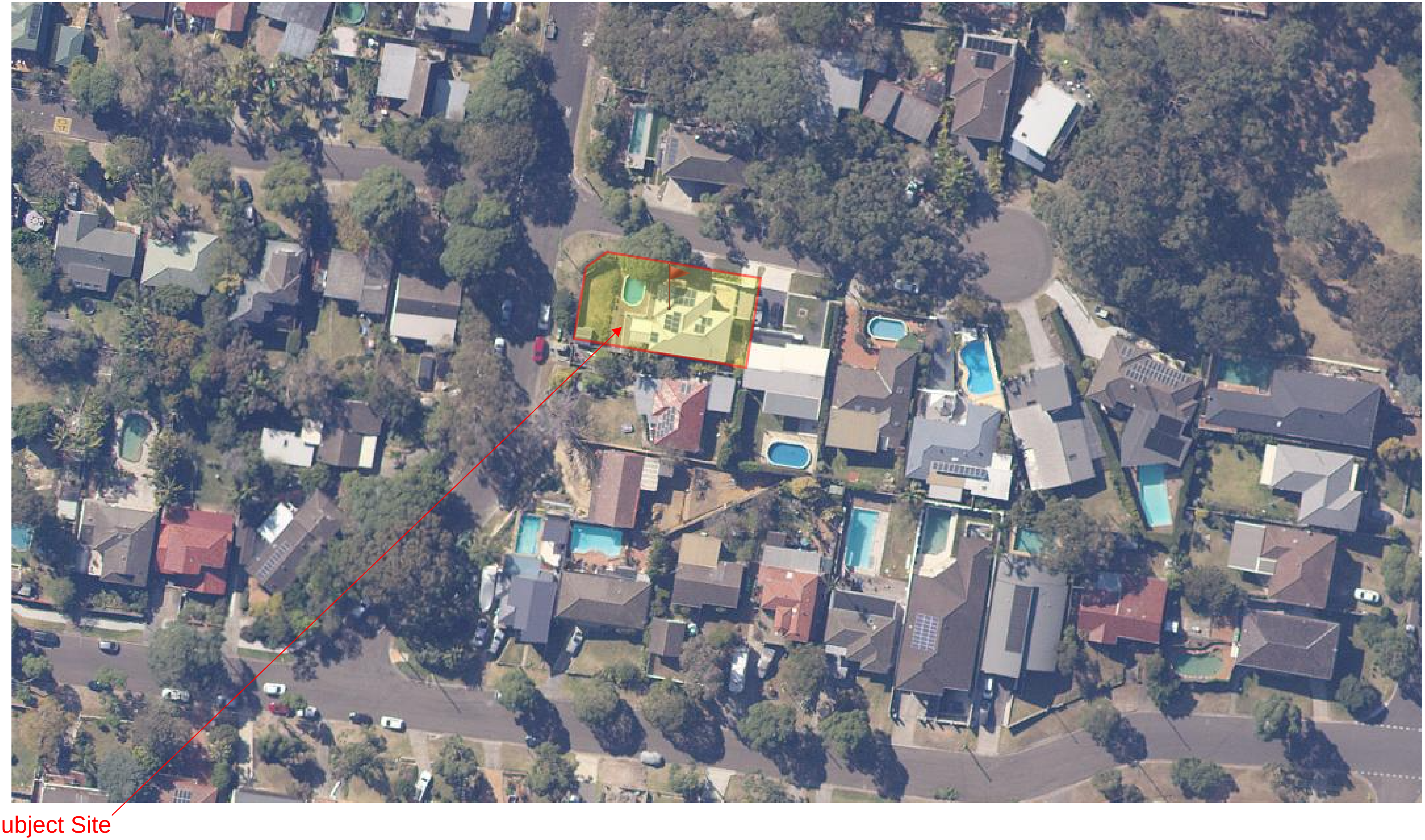
FIGURES



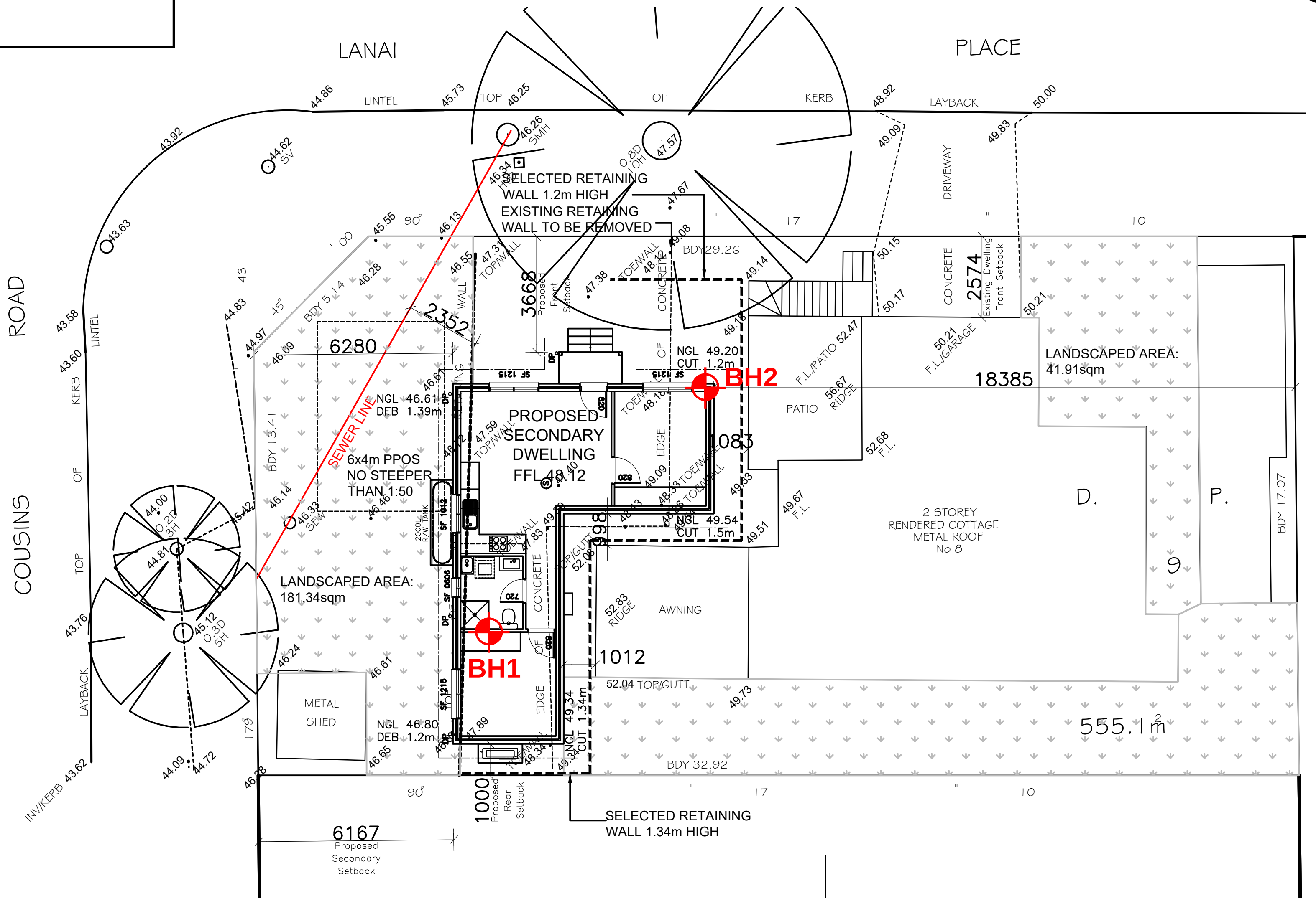
GREEN GEOTECHNICS	Project No: GG10842.001	Geotechnical Investigation 8 Cousins Road, Beacon Hill	Figure No: GG10842.001A
	Client: Brickwood Homes PTY Limited		Drawn By: MG
	Date: 16 November 2022	**SITE LOCATION PLAN**	Scale: Unknown

Legend:

⊕ = Borehole

◎ = DCP

⊞ = Test Pit



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	Date: 16 November 2022

Geotechnical Investigation
8 Cousins Road, Beacon Hill

TEST LOCATION PLAN

Figure No: GG10842.001B
Drawn By: MG
Scale: Unknown

Position of BH1

Position of BH2

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Client: Brickwood Homes PTY Limited			
Date: 16 November 2022	**SITE PHOTOGRAPHS**		

APPENDIX A – BOREHOLE LOGS

GEOTECHNICAL LOG - NON CORED BOREHOLE

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Project No: GG10842	Surface RL: 46.8m AHD	Date Logged : 14/11/2022	**BOREHOLE NO.: BH 1**
Address: 8 Cousins Road, Beacon Hill		Logged By: JK	
Client: Brickwood Homes PTY Limited		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: Silty Sandy CLAY: Dark brown low plasticity, fine grained sand.	CL		M
			Silty Sandy CLAY: Orange brown with light grey and dark brown, medium plasticity, fine grained sand.	CI	SOFT TO FIRM	M
			Silty CLAY: Orange brown with light grey, medium plasticity, trace of fine grained sand.	CI	STIFF TO VERY STIFF	M
			SANDSTONE: Orange brown, fine to medium grained.			D
		0.5	HAND AUGER REFUSAL AT 0.41m ON WEATHERED SANDSTONE.			
		1.0				
		1.5				
		2.0				
		2.5				

D - Disturbed sample	U - Undisturbed tube sample	B - Bulk sample	Contractor: Green Geotechnics
S - Chemical Sample	SPT - Standard Penetration Test		Equipment: Hand Auger
WT - Standing Water Table	SP - Water Seepage Level		Hole Diameter (mm): 65mm
NOTES:	See explanation sheets for meaning of all descriptive terms and symbols		Angle from Vertical (^{o}): 0°
			Drill Bit: Mild Steel

GEOTECHNICAL LOG - NON CORED BOREHOLE

Project No: GG10842 Surface RL: 48.1m AHD Date Logged : 14/11/2022

Address: 8 Cousins Road, Beacon Hill Logged By: JK

Client: Brickwood Homes PTY Limited Checked By: MG

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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 Sandy CLAY: Orange brown with dark brown and light grey, low plasticity, fine to medium grained, some gravel.	CL		D
		0.5				M
			SANDSTONE: Orange brown with light grey, fine to medium grained.			M-D
			HAND AUGER REFUSAL AT 0.58m ON WEATHERED SANDSTONE.			
		1.0				
		1.5				
		2.0				
		2.5				

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: Hand Auger

Hole Diameter (mm): 65mm

Angle from Vertical (^{o}): 0°

Drill Bit: Mild Steel

Dynamic Cone Penetrometer Test Report

Project Number: GG10842
Site Address: 8 Cousins Road, Beacon Hill
Test Date: 14/11/2022

Page: 1 of 1

Test Method: **AS1289.6.3.2**

Technician: JK

Test No	BH1	BH2				
Starting Level	Surface Level	Surface Level				
Depth (m)	Penetration Resistance (blows / 150mm)					
0.00 - 0.15	1	1				
0.15 - 0.30	1	3				
0.30 - 0.45	22	4				
0.45 - 0.60	Refusal	22				
0.60 - 0.75		Refusal				
0.75 - 0.90						
0.90 - 1.05						
1.05 - 1.20						
1.20 - 1.35						
1.35 - 1.50						
1.50 - 1.65						
1.65 - 1.80						
1.80 - 1.95						
1.95 - 2.10						
2.10 - 2.25						
2.25 - 2.40						
2.40 - 2.55						
2.55 - 2.70						
2.70 - 2.85						
2.85 - 3.00						

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

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

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:

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

'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

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

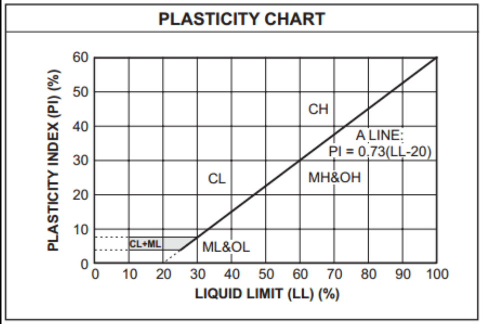
Roughness

po	polished
ro	rough
sl	slickensided
sm	smooth
vr	very rough

Other

fg	fragmented
bnd	band
qtz	quartz

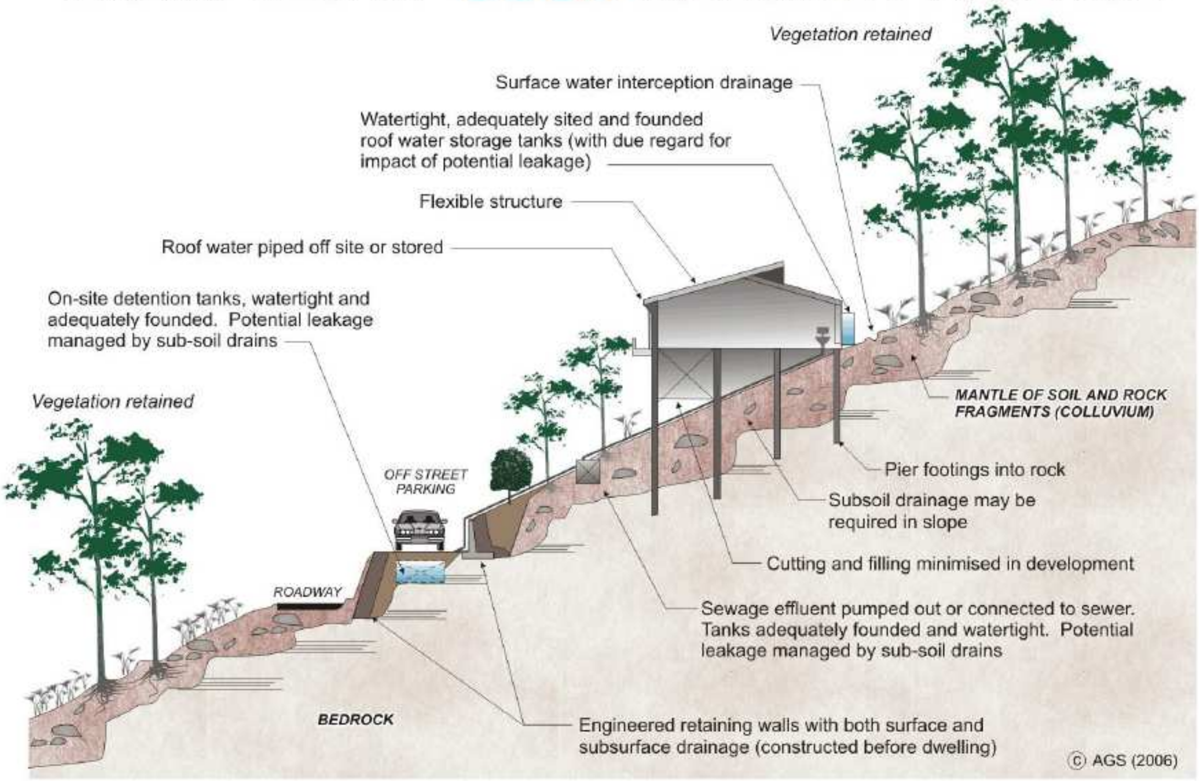
UNIFIED SOIL CLASSIFICATION TABLE

<table>
<tr><td colspan="7">Field Identification Procedures
(Excluding particles larger than 75um and basing fractions on estimated weights)</td><td>Group Symbols</td><td>Typical Names</td><td>Information Required for Describing Soils</td><td colspan="4">Laboratory Classification Criteria</td></tr>
<tr><td rowspan="8">Coarse-grained soils
More than half of the material is large that 75um sieve size[b]</td><td rowspan="16">The 75um sieve size is about the particle visible to the naked eye</td><td rowspan="4">Gravels
More than half of the coarse fraction is larger than a 4mm sieve</td><td rowspan="2">Clean gravels (little or no fines)</td><td colspan="3">Wide range in grain size and substantial amounts of all intermediate particle sizes</td><td>*GW*</td><td>Well graded gravels, gravel-sand mixtures, little or no fines</td><td rowspan="8">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
For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions and drainage characteristics
Example:
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)*</td><td rowspan="17">Use grain size curve in identifying the fractions as given under field identification</td><td rowspan="8">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</td><td>$C_u = \frac{D_{60}}{D_{10}}$
$C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$</td><td>Greater than 4
Between 1 and 3</td></tr>
<tr><td colspan="3">Predominantly one size or range of sizes with some intermediate sizes missing</td><td>*GP*</td><td>Poorly graded gravels, grave-sand mixtures, little or no fines</td><td colspan="2">Not meeting all graduation requirements for *GW*</td></tr>
<tr><td rowspan="2">Gravels with fines (appreciable amount of fines)</td><td colspan="3">Nonplastic fines (for identification procedures see *ML* below)</td><td>*GM*</td><td>Silty gravels, poorly graded gravel-sand-silt mixtures</td><td>Atterberg limits below “A” line or *PI* less than 4</td><td rowspan="2">Above “A” line with *PI* between 4 and 7 are borderline cases of requiring use of dual symbols</td></tr>
<tr><td colspan="3">Plastic fines (for identification procedures see *CL* below)</td><td>*GC*</td><td>Clayey gravels, poorly graded gravel-sand-clay mixtures</td><td>Atterberg limits above “A” line with *PI* greater than 7</td></tr>
<tr><td rowspan="4">Sands
More than half of the coarse fraction is smaller than a 4mm sieve</td><td rowspan="2">Clean sands (little or no fines)</td><td colspan="3">Wide range in grain size and substantial amounts of all intermediate particle sizes</td><td>*SW*</td><td>Well graded sands, gravelly sands, little or no fines</td><td>$C_u = \frac{D_{60}}{D_{10}}$
$C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$</td><td>Greater than 6
Between 1 and 3</td></tr>
<tr><td colspan="3">Predominantly one size or range of sizes with some intermediate sizes missing</td><td>*SP*</td><td>Poorly graded sands, gravelly sands, little or no fines</td><td colspan="2">Not meeting all graduation requirements for *SW*</td></tr>
<tr><td rowspan="2">Sands with fines (appreciable amount of fines)</td><td colspan="3">Nonplastic fines (for identification procedures see *ML* below)</td><td>*SM*</td><td>Silty sands, poorly graded sand-silt mixtures</td><td>Atterberg limits below “A” line or *PI* less than 5</td><td rowspan="2">Above “A” line with *PI* between 4 and 7 are borderline cases of requiring use of dual symbols</td></tr>
<tr><td colspan="3">Plastic fines (for identification procedures see *CL* below)</td><td>*SC*</td><td>Clayey sands, poorly graded sand-clay mixtures</td><td>Atterberg limits above “A” line with *PI* greater than 7</td></tr>
<tr><td rowspan="8">Find-grained soils
More than half of the material is smaller than 75um sieve size</td><td colspan="5">Identification Procedures of Fractions Smaller than 380 um Sieve Size</td><td colspan="3" rowspan="2"></td><td colspan="3" rowspan="9">

Plasticity Chart
For laboratory classification of fine-grained soils</td></tr>
<tr><td colspan="2" rowspan="4">Silts and clays liquid limit less than 50</td><td>Dry Strength (crushing characteristics)</td><td>Dilatancy (reaction to shaking)</td><td>Toughness (consistency near plastic limit)</td></tr>
<tr><td>None to slight</td><td>Quick to slow</td><td>None</td><td>*ML*</td><td>Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slit plasticity</td><td rowspan="7">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
For undisturbed soils add information on structure, stratification, consistency in undisturbed and remoulded states, moisture and drainage conditions
Example:
Clayey Silt, brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; *(ML)*</td></tr>
<tr><td>Medium to high</td><td>None to very slow</td><td>Medium</td><td>*CL*</td><td>Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays</td></tr>
<tr><td>Slight to medium</td><td>Slow</td><td>Slight</td><td>*OL*</td><td>Organic silts and organic silt-clays of low plasticity</td></tr>
<tr><td colspan="2" rowspan="3">Silts and clays liquid limit greater than 50</td><td>Slight to medium</td><td>Slow to none</td><td>Slight to medium</td><td>*MH*</td><td>Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, clastic silts</td></tr>
<tr><td>High to very high</td><td>None</td><td>High</td><td>*CH*</td><td>Inorganic clays of high plasticity, fat clays</td></tr>
<tr><td>Medium to high</td><td>None to very slow</td><td>Slight to medium</td><td>*OH*</td><td>Organic clays of medium to high plasticity</td></tr>
<tr><td colspan="4">Highly Organic Soils</td><td colspan="3">Readily identified by colour, odour, spongy feel and frequently by fibrous texture</td><td>*Pt*</td><td>Peat and other highly organic soils</td></tr>
</table>

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

EXAMPLES OF GOOD HILLSIDE PRACTICE



EXAMPLES OF POOR HILLSIDE PRACTICE