GEOTECHNICAL INVESTIGATION REPORT

FORTIFY GEOTECH

Proposed Car Storage Facility – Brookvale

CLIENT

Arcadis

ADDRESS

8 Grosvenor Place, Brookvale, NSW

DATE

June 2021

2/538 Gardeners Road, Alexandria NSW 2015
PO Box 9225, Deakin ACT 2600

Consulting Engineers

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9 July 2021
Our ref: JS/S1294

Arcadis
Level 16 580 George St
Sydney NSW 2000

Attention: Leila Bowe

Proposed Car Storage Facility – 8 Grosvenor Place, Brookvale, NSW
Geotechnical Investigation Report

Dear Madam

We are pleased to present our geotechnical investigation report for the proposed car storage facility at 8 Grosvenor Place, in Brookvale, NSW.

The report outlines the methods and results of exploration, describes site subsurface conditions, and provides recommendations for building footing design, excavation conditions, preparation of subgrades, stability of cut and fill batters, provides laboratory test results, provides design CBR values, and site drainage advice.

Should you require any further information regarding this report, please do not hesitate to contact our office.

Yours faithfully
Fortify Geotech

Jeremy Murray
Director
Senior Geotechnical Engineer

About us

We work with our clients to provide practical advice and solutions tailored to each project. Our professional services are reliable, responsive and efficient.

Our highly capable Geotechnical Engineers and Geologists have a comprehensive understanding of the industry. We provide the best engineering solution for complicated geotechnical engineering issues. This has earned us a solid reputation with our Construction Industry, Municipal and Government clients

- Residential
- Commercial
- Transport Infrastructure
- Industrial Developments of all sizes.

- Geotechnical Site Investigations and Reporting;
- Engineering Geology;
- Mining/Rock Geotechnics;
- Foundation Engineering;
- Dam Engineering; Embankment Design and Specification;
- Geotechnical Design Recommendations;
- Pavement Engineering and Design;
- Pavement Condition Surveys;
- Slope Stability and Risk Assessments;

- Geotechnical and Hydrological Instrumentation and Monitoring;
- Footing and Excavation Supervision and Certifications;
- Excavated soil/rock assessments and VENM assessments;
- Supervision and Certification of Earthworks and Controlled Fill, including Level 1 supervision;
- Geotechnical Construction Specifications;
- Deep Excavation Support; and
- Slope/Retaining Structure Analysis and Design

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Proposed Car Storage Facility – 8 Grosvenor Place, Brookvale
Geotechnical Investigation Report

1 INTRODUCTION

At the request of Arcadis, Fortify Geotech carried out a geotechnical investigation for the proposed car storage facility at 8 Grosvenor Place, in Brookvale, NSW.

The project involves the construction of multi-storey above ground carpark. The aim of the investigation was to:

(i) Identify subsurface conditions including the extent and nature of any fill materials, soil strata, bedrock type and depth, and groundwater presence.

(ii) Advise on excavation conditions and suitability of excavated material for use as structural fill.

(iii) Provide site classification to AS2870 “Residential Slabs & Footings”.

(iv) Advise on suitable footings systems, founding depths, allowable bearing pressures and design parameters for ground slabs.

(v) Provide guidelines for construction of controlled fill platforms.

(vi) Advise on stable batter slopes and retaining wall design parameters.

(vii) Provide subgrade CBR value(s) for pavement design.

(viii) Drainage and other geotechnical advice.

2 SITE DESCRIPTION & GEOLOGY

The site is located at 8 Grosvenor Place, in Brookvale, NSW. The site is currently occupied by a concrete manufacturing plant which will be demolished prior to the proposed development. The groundsurface is relatively flat and concrete covered. Figure 1 shows the site locality, while Figure 2 is a recent aerial photograph showing the approximate borehole locations. The 1:100,000 Sydney Geology map (Reference 1) documents the site to be covered by Quaternary age silty to peaty quartz sand, silt and clay, ferruginous and humic cementation in places, common shell layers.

3 INVESTIGATION METHODS

The site investigation was conducted on 7th June 2021, comprising four boreholes, designated BH1 to BH4, drilled using a Geoprobe 6625 CPT with a 55mm diameter auger. The boreholes were drilled to the target depth of 5m for borehole BH1, BH2 & BH4, and a target depth of 7.4m for borehole BH3. The locations of the boreholes are shown on Figure 2, and the detailed borehole logs are included in Appendix A.

The borehole profiles were visually logged in accordance with the Unified Soil Classification System (USCS). Definitions of geotechnical engineering terms used in the report on the borehole logs, including a copy of the USCS chart, are provided in Appendix C.

4 INVESTIGATION RESULTS

4.1 SUBSURFACE CONDITIONS

The subsurface conditions of the proposed development were investigated by four boreholes designated BH1 to BH4. The borehole logs in Appendix A can be referred to for more detail. Investigation boreholes found the subsurface profile to comprise:

Geological Profile	Typical Depth Interval	Description
FILL	0m to 1.4m/2.6m	CONCRETE, SILTY GRAVEL, SILTY SANDY GRAVEL, SILTY CLAY, SANDSTONE, CLAYEY SAND, SANDY GRAVEL, SANDY CLAY, CLAYEY GRAVEL, GRAVELLY CLAYEY SAND, GRAVELLY SAND; low plasticity clay, low to medium plasticity clay, medium plasticity clay, medium to high plasticity clay, medium to coarse grained sand, fine to coarse grained sand, angular gravels to 20mm size, sub angular gravels to 20mm size, orange to brown, yellow to brown, brown to grey, black, red, brown, trace orange, some grey, some sandstone gravels to 10mm size, some angular gravels to 30mm size, some anthropogenic material (brick), dry, dry to moist, loose to medium dense, medium dense, medium dense to dense, dense, stiff, stiff to very stiff.
PEAT	1.4m/2.6m to 5.0m/>5.0m	CLAYEY SILT; low plasticity clay, medium plasticity clay, black, some plant roots, dry to moist, moist, wet, soft, soft to firm.
ALLUVIUM	5.0m to >7.4m	SILTY CLAY, SAND/CLAYEY SAND; fine to coarse grained sand, medium plasticity clay, black, pale grey, moist, wet, firm, medium dense to dense. This material was only encountered in borehole BH3.

4.2 GROUNDWATER

Permanent groundwater was only encountered in borehole BH4 at a depth of ~5m. Most of the soils within the investigation depth and the soils were dry to moist and moist. Temporary, perched seepages could be encountered following rainfall within the more pervious soils.

5 DISCUSSION & RECOMMENDATIONS

5.1 SITE CLASSIFICATION

Due to the presence of uncontrolled fill and low bearing capacity of the material to at least 2.6m depth, the site is designated as Class “P” (problem) site in accordance with AS2870 “Residential Slabs & Footings”. If the fill is removed, and replaced with controlled fill, or if footings are founded in the stiff alluvial soils below the fill or if the remediation recommendations in section 5.3 are followed, a Class “M” (moderately reactive) category can be used in design of new footings (Y_s is estimated to be between 20mm and 40mm).

Deemed-to-comply footing designs provided by AS2870 are applicable specifically to residential-style one and two-storey structures, or buildings with similar loads and superstructure stiffness.

5.2 BUILDING FOOTINGS

AS2870 provides “deemed-to-comply” footing/slab designs, which for a class “M” site includes stiffened rafts, stiffened footing slabs, waffle rafts, and strip and/or pad footings with above ground floors. Footings and slabs should be in accordance with the principles of AS2870 (Reference 2).

For structures founded at existing grade, footings, including thickened sections of slabs forming footings should be founded below any uncontrolled fill and moisture softened soils. A depth of up to >5m from existing levels may be required to reach a suitable founding stratum. Shallow footings could be founded in remediated fill (Section 5.3) or in newly placed controlled fill following removal of any uncontrolled fill material (see Section 5.8). It is recommended that screw piles founded in weathered bedrock be used, however, bedrock was not encountered within the 7.4m investigation depth.

Recommended allowable end-bearing pressures and shaft adhesion values for various footing systems and likely foundation materials are provided in Table 2.

Table 2 – Recommended Allowable End-Bearing Pressures for Footings

Foundation Material Type	Depth Below Existing Surface Level	Allowable End-Bearing Pressure			Allowable Shaft Adhesion on Bored Piers and Anchors	
		Strips	Pads	Bored Piers	Downward Loading	Uplift
Newly Placed Controlled Fill (Constructed as per Section 5.3 or 5.8)	-	100kPa	125kPa	N.A	N.A	N.A
Medium Dense to Dense Alluvial Soils	~5.6m (Borehole BH3)	N.A	N.A	100kPa	10kPa	5kPa
Screw Piles/Driven Piles	Unknown (>7.4m depth)	N.A	N.A	700kPA	70kPa	35kPa

All footings should be inspected and approved by an experienced geotechnical engineer to confirm the foundation material and design values, and to ensure the excavations are clean and stable.

Groundslabs can be constructed on the natural soils or newly placed controlled fill, following the removal of any topsoil, and fill material. Following excavation to required level, slab areas on soil should be proof-rolled by a pad foot roller to check for any weak, wet or deforming soils that may require replacement. Suitable replacement fill should be compacted in not thicker than 150mm layers to not less than 98%StdMDD.

If required for design of ground slabs, a modulus of subgrade reaction of 30kPa/mm can be assumed for a natural soil or controlled fill foundation.

5.3 FOUNDATION REMEDIATION ADVICE

The uncontrolled fill is unsuitable as a foundation for the proposed car storage facility. Therefore, as an alternative to using bored piers to bedrock as a footing system, the foundation could be remediated, with shallow footing system (strip footings, raft slab, etc) used.

The recommended foundation remediation work procedure is outlined below. Where a geotechnical inspection is called up or direction required, this is to be treated as a hold point. Work is not to proceed to the next step without consent from the Geotechnical Engineer.

1. Strip off the existing uncontrolled fill to at least 1m below the proposed footing level or to at least 1m below existing ground level, whichever is deeper. The Geotechnical Engineer should supervise this process to assess the material and ensure no unsuitable material is included in the stockpile.

2. The exposed foundation should be cleaned of all loose soil, and heavily proof-rolled using a vibratory pad foot roller of not less than 12 tonnes. The Geotechnical Engineer should inspect the foundation and view the proof-rolling. If soft or weak spots are exposed, the Geotechnical Engineer may instruct for local soft spots to be stripped further.

3. A geofabric (minimum Bidum A14) should be placed over the foundation area, with a biaxial geogrid (such as Tensar TX150) placed on top of the geofabric.

4. A well-graded gravelly select fill (such as DGS20/DGS40, or similar well-graded gravel) can then be placed directly on top of the fabric to a thickness of at least 300mm. The Geotechnical Engineer should inspect and approve this material prior to use.

5. A geofabric (minimum Bidum A14) should be placed over the select fill to act as a filter to prevent migration of fines.

6. The stockpiled fill can then be placed as controlled fill to design levels. The controlled fill should be placed in not thicker than 200mm layers and compacted to not less than 95%ModMDD. The fill placement should be supervised on a part-time basis by the Geotechnical Engineer, and then the fill will be certified as controlled fill at Level 2 as defined in AS3798 – 2007 “Guidelines on Earthworks for Commercial and Residential Developments”

7. If there is insufficient volume of suitable stockpiled fill material, fill will need to be imported to the site.

8. Shallow footings can then be founded in the remediated fill and proportioned using an allowable bearing pressure of 100kPa. Provided only low reactive clayey/sandy fill is used (no high plasticity clay), the footings can be designed for a class “M” (moderately reactive) site.

5.4 EXCAVATION CONDITIONS & USE OF EXCAVATED MATERIAL

It is understood that only shallow excavations will be required. The excavations will be through existing fill, peat and alluvial soils. The fill and alluvial soils are readily diggable by backhoe and medium sized excavator to at least 5m/7.4m depth.

The low/medium plasticity alluvial soils can be used in controlled fill construction of building platforms. Medium to high plasticity soils should not be used in controlled fill construction, however, it can be used for landscaping. Existing fill material may be used in controlled fill, provided any deleterious matter is removed.

If imported fill is required, a suitable select fill material would include a low or medium plasticity soil such as clayey sand or gravelly clayey sand, containing between 25% and 50% fines less than 0.075mm size (silt and clay), and no particles greater than 75mm size.

5.5 STABLE EXCAVATION BATTERS

Temporary site excavations to 1.5m depth can be formed near vertical, although loose fill should be cut back at 1(H):1(V). If required and space allows, deeper temporary cuts can be formed at 1(H):1(V) or benched at 1.5m intervals in soils. Excavations encountering groundwater are expected to be unstable. A geotechnical engineer should inspect all cut batters during construction to confirm stability. Exposed temporary batters should be protected from the weather by black plastic pinned to the face with link-wire mesh, or similar.

Permanent cut & fill batter slopes should be formed at no steeper than 2(H):1(V) in soil and be protected against erosion by shotcreting, stone pitching or other suitable methods. Alternatively, permanent excavations can be supported by structural retaining walls.

5.6 LOW RETAINING WALLS

Retaining walls constructed in open excavation, with the gap between the excavation face and the wall backfilled later, can be designed for an earth pressure distribution given by:

$$\sigma_h = (K\gamma' h) + Kq$$

where,

σ_h	is the horizontal earth pressure acting on the back of the wall, in kPa
K	is the dimensionless coefficient of earth pressure; this can be assumed to be 0.4 when the top of the wall is unrestrained horizontally, and 0.6 when the top of the wall is restrained (i.e. by building slabs etc.)
γ'	is the effective unit weight of the backfill, and can be assumed to be 20kN/m^3 for a lightly compacted soil backfill
h	is the height of the backfill, in metres
q	is any uniform distributed vertical surcharge acting on the top of the backfill, in kPa

Apart from structural restraints such as floor slabs, resistance to overturning and sliding of retaining walls is provided by frictional and adhesive resistance on the base, and by passive resistance at the toe of the wall. For a natural soil or controlled fill foundation, an ultimate base friction factor (tanδ) of 0.4, base adhesion (c) of 30kPa, and allowable passive earth pressure coefficient Kp=2.5 can be used for calculation of sliding resistance.

Free-draining granular backfill or synthetic fabric drains should be installed behind all walls. These should connect to weep holes and/or a collector drain, and ultimately to the stormwater system. Granular backfill should be wrapped in a suitable filter fabric to minimise infiltration of silt/clay fines

5.7 CONTROLLED FILL CONSTRUCTION

For construction of any new fill foundation platforms and road subgrades, it is recommended that:

- Areas be fully stripped of all uncontrolled fill. A general stripping depth of 1.4m/2.6m may be required. Stripped foundations should be proof-rolled by a vibratory pad-foot roller of not less than 9 tonne static mass to check for any weak or wet areas that would require replacement. If soft/wet Conditions are exposed, a bridging layer may be required. No fill should be placed until a geotechnical engineer has confirmed the suitability of the foundation. To reduce the amount of fill required to be removed, additional advice on foundation remediation has been provided in Section 5.3.

- Controlled fill comprising suitable site excavated or imported materials of not greater than 75mm maximum particle size, be compacted in not greater than 150mm layers to not less than 95%ModMDD at about OMC.

- Fill placement and control testing be overviewed and certified by a geotechnical engineer at Level 1 or 2 involvement of AS3798 – 2007 "Guidelines on Earthworks for Commercial & Residential Developments" (Reference 3).

5.8 PAVEMENT SUBGRADES

Pavement subgrades should be prepared as outlined in Section 5.7. controlled fill subgrades can be designed using a CBR value of 3%. Exposed subgrades should be inspected by a geotechnical engineer to check the recommended design CBR value.

5.9 EARTHQUAKE SITE FACTOR

The Geosciences website (Reference 4) lists the earthquake acceleration coefficients for major centres to be considered in structural design. The Brookvale area has an acceleration coefficient of 0.08 (minimum value permitted by AS1170.4).

Section 4.2 of AS1170.4 "Minimum Design Loads on Structures – Part 4: Earthquake Loads" Reference 5) lists the site sub-soil classes to be considered in structural design. The site is classified as a "Class C_e – Shallow Soil Site".

5.10 SITE DRAINAGE

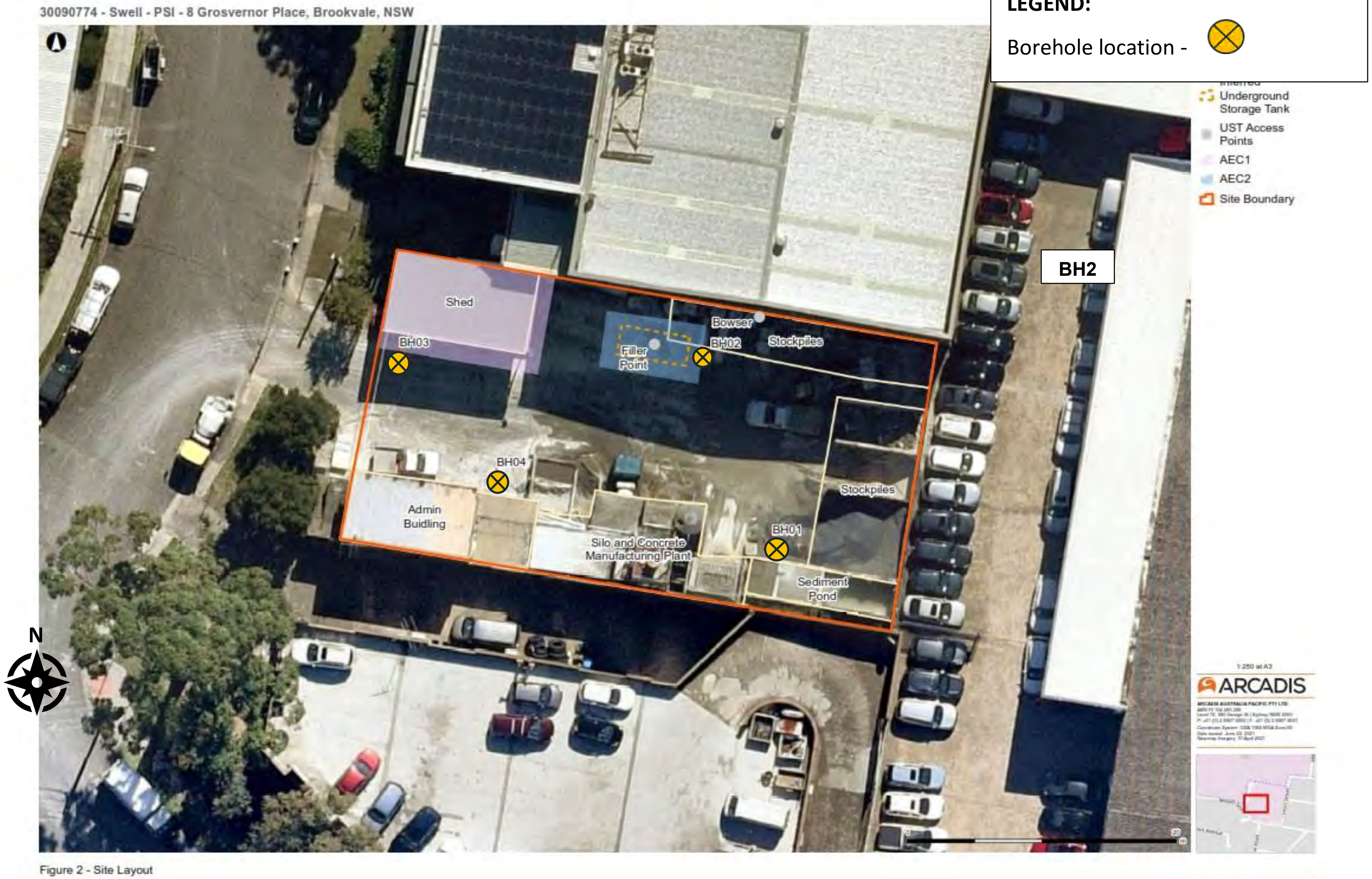
Groundwater was encountered during the investigation in borehole BH4 at ~5m depth. It is understood that only shallow excavations are expected, and therefore, groundwater inflow is not anticipated during excavations. Temporary, perched seepages could also be present at shallower depth following rain, but should be readily controllable through the use of pumps during construction.

Suitable surface drainage should be provided to ensure rainfall run-off or other surface water cannot pond against buildings or pavements. Drainage should be provided behind all retaining walls, and subsoil drains should be installed along the upslope sides of access roads and carparks.

REFERENCES

Reference 1	Herbert C., 1983, Sydney 1:100 000 Geological Sheet 9130, 1st edition. Geological Survey of New South Wales, Sydney
Reference 2	Standards Australia, "AS2870 – Residential Slabs & Footings", 2011.
Reference 3	AS3798, "Guidelines on earthworks for commercial and residential developments".
Reference 4	Geosciences Website: http://www.ga.gov.au/darwin-view/hazards.xhtml# - Accessed on 17/6/2021
Reference 5	Standards Australia, "AS1170.4 – 2007 – Minimum Design Loads on Structures – Part 4 Earthquake Loads".

SITE LOCALITY	S1294	FIGURE 1



Aerial Photograph & Borehole locations	S1294	FIGURE 2

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Appendix A

Borehole logs BH1 – BH4

Borehole Log

Borehole No.	BH1
Sheet	1 of 1
Job No.	S1294

CLIENT: Arcadis

PROJECT: Proposed Development
8 Grosvenor Place, Brookvale, NSW

Equipment Type : Geoprobe 6625 CPT
Hole Diameter : 55mm

Location :

Collar Level : Not Known
Angle From Vertical : 0°
Bearing : N.A.

Samples	Water	Casing	Depth Metres	U.S.C.S.	Material Description, Structure (Soil Type: Plasticity or Particle Characteristics, Colour, Secondary and Minor Components, Moisture, Structure)	Consistency or Relative Density	Field Test Results	Geological Profile
	None Encountered		0.12		CONCRETE			FILL
			0.15	GM	SILTY GRAVEL; ROADBASE, angular gravels to 20mm size, grey, dry	Medium Dense		
			0.45	GWS	SILTY SANDY GRAVEL; angular gravels to 20mm size, fine to coarse grained sand, grey to brown, dry	Medium Dense to Dense		
			0.5	CL	SILTY CLAY; medium plasticity clay, brown, trace orange, some angular gravels to 5mm size, dry to moist	Stiff		
			0.7	SC	SANDSTONE; sub angular gravels to 20mm size, fine to coarse grained, red, pale grey, dry to moist	Dense		
			0.8	GWS	CLAYEY SAND; fine to coarse grained sand, low plasticity clay, brown to grey, some grey, some sub angular sandstone gravels to 10mm size, dry to moist	Medium Dense		
			1.0	CH	SANDY GRAVEL; sub angular gravels to 8mm size	Medium Dense		
					SANDY CLAY; medium to high plasticity clay, fine to coarse grained sand, black, some grey, some sandstone gravels to 10mm size, dry to moist	Stiff to Very Stiff		
			1.3	GW	CLAYEY GRAVEL; angular gravels to 20mm size, medium plasticity clay, brown to grey, some anthropogenic material (brick), dry to moist	Dense		
			2.0	ML	CLAYEY SILT; medium plasticity clay, black, some plant roots, moist	Soft to Firm		PEAT
					Wet			
			3.0			Soft		
			4.0					
			5.0		BOREHOLE TERMINATED AT 5m At Target			
			6.0					
			7.0					
			7.7					

Logged By : AB Date : 7/6/21 Checked By : Date :

BOREHOLE/EXCAVATION LOG S1294.GPJ ACT GEO.GDT 15/6/21

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Borehole Log

Borehole No.	BH2
Sheet	1 of 1
Job No.	S1294

CLIENT: Arcadis

PROJECT Proposed Development
8 Grosvenor Place, Brookvale, NSW

Equipment Type : Geoprobe 6625 CPT
Hole Diameter : 55mm

Location :

Collar Level : Not Known
Angle From Vertical : 0°
Bearing : N.A.

Samples	Water	Casing	Depth Metres	Graphic Log	U.S.C.S.	Material Description, Structure Soil Type: Plasticity or Particle Characteristics, Colour, Secondary and Minor Components, Moisture, Structure	Consistency or Relative Density	Field Test Results	Geological Profile
	None Encountered		0.15			CONCRETE			FILL
			0.5		GM	SILTY GRAVEL; ROADBASE, angular gravels to 20mm size, grey, dry	Medium Dense		
			1.0 1.5		SC	CLAYEY SAND; fine to coarse grained sand, medium plasticity clay, grey, some angular gravels to 30mm size, dry to moist some silt	Medium Dense to Dense		
			1.8			SANDSTONE; fine to coarse grained, yellow to brown, dry	Dense		
			2.0 2.6		SC	GRAVELLY CLAYEY SAND; fine to coarse grained sand, low to medium plasticity clay, angular gravels to 15mm size, grey to brown, trace anthropogenic material (brick), moist	Dense		
			3.0 4.0 5.0		ML	CLAYEY SILT; low plasticity clay, black, some plant roots, dry to moist	Soft to Firm		PEAT
			6.0 7.0 7.7			BOREHOLE TERMINATED AT 5m At Target			

Logged By : AB Date : 7/6/21 Checked By : Date :

BOREHOLE/EXCAVATION LOG S1294.GPJ ACT GEO.GDT 15/6/21

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Borehole Log

Borehole No.	BH3
Sheet	1 of 1
Job No.	S1294

CLIENT: Arcadis

PROJECT: Proposed Development
8 Grosvenor Place, Brookvale, NSW

Equipment Type : Geoprobe 6625 CPT
Hole Diameter : 55mm

Location :

Collar Level : Not Known
Angle From Vertical : 0°
Bearing : N.A.

Samples	Water	Casing	Depth Metres	Graphic Log	U.S.C.S.	Material Description, Structure (Soil Type: Plasticity or Particle Characteristics, Colour, Secondary and Minor Components, Moisture, Structure)	Consistency or Relative Density	Field Test Results	Geological Profile
	None Encountered		0.18			CONCRETE			FILL
			0.5		GM	SILTY GRAVEL; ROADBASE, angular gravels to 20mm size, grey, dry	Medium Dense		
			1.65		SWG	GRAVELLY SAND; medium to coarse grained sand, angular gravels to 10mm size, grey to brown, dry Orange to brown	Loose to Medium Dense		
			5		ML	CLAYEY SILT; low plasticity clay, black, some plant roots, dry to moist	Soft to Firm		PEAT
			5.6		CL	SILTY CLAY; medium plasticity clay, black, wet	Firm		ALLUVIUM
			7.4		SC	SAND/CLAYEY SAND; fine to coarse grained sand, medium plasticity clay, pale grey, moist	Medium Dense to Dense		
			7.7			BOREHOLE TERMINATED AT 7.4m At Target			

Logged By : AB Date : 7/6/21 Checked By : Date :

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Borehole Log

Borehole No.	BH4
Sheet	1 of 1
Job No.	S1294

CLIENT: Arcadis

PROJECT: Proposed Development
8 Grosvenor Place, Brookvale, NSW

Equipment Type : Geoprobe 6625 CPT
Hole Diameter : 55mm

Location :

Collar Level : Not Known
Angle From Vertical : 0°
Bearing : N.A.

Samples	Water	Casing	Depth Metres	Graphic Log	U.S.C.S.	Material Description, Structure (Soil Type: Plasticity or Particle Characteristics, Colour, Secondary and Minor Components, Moisture, Structure)	Consistency or Relative Density	Field Test Results	Geological Profile
			0.1			CONCRETE			FILL
			0.15		GM	SILTY GRAVEL; ROADBASE, angular gravels to 20mm size, grey, dry	Medium Dense to Dense		
					SC	GRAVELLY CLAYEY SAND; fine to coarse grained sand, low plasticity clay, angular gravels to 20mm size, grey to brown, some red and grey, dry	Medium Dense		
			1.0		SC	SAND/CLAYEY SAND; medium to coarse grained sand, pale brown, low plasticity clay, dry to moist	Medium Dense		
			1.4		ML	CLAYEY SILT; medium plasticity clay, black, some plant roots, moist	Soft to Firm		PEAT
						Wet	Soft		
	Groundwater Level ▽		5.0			BOREHOLE TERMINATED AT 5m At Target			
			6.0						
			7.0						
			7.7						

Logged By : AB Date : 7/6/21 Checked By : Date :

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Appendix B

Engineering Terms and Definitions

DESCRIPTION AND CLASSIFICATION OF SOILS

The methods of description and classification of soils used in this report are based on the Australian Standard 1726 – 1993, Geotechnical site investigations. In general, descriptions cover the following properties – soil type, colour, secondary grain size, structure, inclusions, strength or density and geological description.

Soil types are described according to the predominating particle size, qualified by the grading of other particles present (e.g. sandy clay) on the following basis:

Classification	Particle Size
Clay	Less than 0.002mm
Silt	0.002mm to 0.06mm
Sand	0.06mm to 2.00mm
Gravel	2.00mm to 60.00mm
Cobbles	60mm (63mm) to 200mm
Boulders	>200mm

Soils are also classified according to the Unified Soil Classifications System which is included in this Appendix. Rock types are classified by their geological names.

Cohesive soils are classified on the basis of strength either by laboratory testing or engineering examination. The terms are defined as follows:

Consistency	Shear Strength su(kPa) (Representative Undrained Shear)	
Very soft	< 12	<2 (~SPT "N")
Soft	12 - 25	2-4
Firm	25 - 50	4-8
Stiff	50 – 100	8-15
Very Stiff	100 – 200	15-30
Hard	> 200	>30

Non-cohesive soils are classified on the basis of relative density, generally from the results of in-situ standard penetration tests as below:

Term	Relative Density (%)	SPT Blows/300mm 'N'
Very loose	< 15	<4
Loose	15-35	4-10
Medium dense	35-65	10-30
Dense	65-85	30-50
Very Dense	>85	>50

SAMPLING

Sampling is carried out during drilling to allow engineering examination (and laboratory testing where required) of 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 generally taken by one of two methods:

1. Driving or pushing a thin walled sample tube into the soil and withdrawing with a sample of soil in a relatively undisturbed state.

2. Core drilling using a retractable inner tube (R.I.T.) core barrel.

Such samples yield information on structure and strength in additions to that obtained from disturbed samples and are necessary for laboratory determination of shear strength and compressibility. Undisturbed sampling is generally effective only in cohesive soils.

Details of the type and method of sampling are given in the report.

PENETRATION TESTING

The relative density of non-cohesive soils is generally assessed by in-situ penetration tests, the most common of which is the standard penetration test. The test procedure is described in Australian Standard 1289 “Testing Soils for Engineering Purposes” Testing Soils for Engineering Purposes” – Test No. F3.1.

The standard penetration test is carried out by driving a 50mm diameter split tube penetrometer of standard dimensions under the impact of a 63 kg hammer having a free fall of 750mm.

The “N” value is determined as the number of blows to achieve 300mm of penetration (generally after disregarding the first 150mm penetration through possibly disturbed material). The results of these tests can be related empirically to the engineering properties of the soil.

The test is also used to provide useful information in cohesive soils under certain conditions, a good quality disturbed sample being recovered with each test. Other forms of in situ testing are used under certain conditions and where this occurs, details are given in the report.

DEFINITIONS OF ROCK, SOIL, AND DEGREES OF CHEMICAL WEATHERING

GENERAL DEFINITIONS – ROCK AND SOIL

ROCK In engineering usage, rock is a natural aggregate of minerals connected by strong and permanent cohesive forces.

Note: Since “strong” and “permanent” are subject to different interpretations, the boundary between rock and soil is necessarily an arbitrary one.

SOIL In engineering usage, soil is a natural aggregate of mineral grains which can be separated by such gentle mechanical means as agitation in water, can be remoulded and can be classified according to the Unified Soil Classification System. Three principal classes of soil recognized are:

Residual soils: soils which have been formed in-situ by the chemical weathering of parent rock. Residual soil may retain evidence of the original rock texture or fabric or, when mature, the original rock texture may be destroyed.

Transported soils: soils which have been moved from their places of origin and deposited elsewhere. The principal agents of erosion, transport and deposition are water, wind and gravity. Two important types of transported soil in engineering geology and materials investigations are:

Colluvium – a soil, often including angular rock fragments and boulders, which has been transported downslope predominantly under the action of gravity assisted by water. The principle forming process is that of soil creep in which the soil moves after it has been weakened by saturation. It may be water borne for short distances.

Alluvium – a soil which has been transported and deposited by running water. The larger particles (sand and gravel size) are water worn.

Lateritic soils: soils which have formed in situ under the effects of tropical weathering include all reddish residual and non residual soils which genetically form a chain of material ranging from decomposed rock through clay to sesqui-oxide rich crusts. The term does not necessarily imply any compositional, textural or morphological definition; all distinctions useful for engineering purposes are based on the differences in geotechnical characteristics.

ROCK WEATHERING DEFINITIONS

Extremely Weathered (EW)	Rock substance affected by weathering to the extent that the rock exhibits soil properties, i.e. it can be remoulded and can be classified according to the Unified Classification System, but the texture of the original rock is still evident.
Highly Weathered (HW)	Rock substance affected by weathering to the extent that limonite staining or bleaching affects the whole of the rock substance and other signs of the chemical or physical decomposition are evident. Porosity and strength may be increased or decreased compared to the fresh rock usually as a result of iron leaching or deposition. The colour and strength of the original fresh rock substance is no longer recognisable.
Moderately Weathered (MW)	Rock substance affected by weathering to the extent that staining extends throughout the whole of the rock substance and the original colour of the fresh rock is no longer recognisable.
Slightly Weathered (SW)	Rock substance affected by weathering to the extent that partial staining or discolouration of the rock substance, usually by limonite, has taken place. The colour and texture of the fresh rock is recognisable.
Fresh (Fr)	Rock substance unaffected by weathering.

The degrees of rock weathering may be gradational. Intermediate stages are described by dual symbols with the prominent degree of weathering first (e.g. EW-HW).

The various degrees of weathering do not necessarily define strength parameters as some rocks are weak, even when fresh, to the extent that they can be broken by hand across the fabric, and some rocks may increase in strength during the weathering process.

Fresh drill cores of some rock types, such as basalt and shale may disintegrate after exposure to the atmosphere due to slaking, desiccation, expansion or contraction, stress relief or a combination of any of these factors.

AN ENGINEERING CLASSIFICATION OF SEDIMENTARY ROCKS

This classification system provides a standardised terminology for the engineering description of the sandstone and shales in the Sydney area, but the terms and definitions may be used elsewhere when applicable. Where other rock types are encountered, such as in dykes, standard geological descriptions are used for rock types and the same descriptions as below are used for strength, fracturing and weathering.

Under this system rocks are classified by Rock Type, Strength, Stratification Spacing, Degree of Fracturing and Degree of Weathering. These terms do not cover the full range of engineering properties. Descriptions of rock may also need to refer to other properties (e.g. durability, abrasiveness, etc) where these are relevant.

ROCK TYPE DEFINITIONS

ROCK TYPE	DEFINITION
Conglomerate:	More than 50% of the rock consists of gravel sized (greater than 2mm) fragments.
Sandstone:	More than 50% of the rock consists of sand sized (0.06 to 2mm) grains.
Siltstone:	More than 50% of the rock consists of silt-sized (less than 0.06mm) granular particles and the rock is not laminated.
Claystone:	More than 50% of the rock consists of silt or clay sized particles and the rock is not laminated.
Shale:	More than 50% of the rock consists of silt or clay sized particles and the rock is laminated.

Rocks possessing characteristics of two groups are described by their predominant particle size with reference also to the minor constituents, e.g. clayey sandstone, sandy shale.

STRATIFICATION SPACING

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

DEGREE OF FRACTURING

This classification applies to diamond drill cores and refers to the spacing of all types of natural fractures along which the core is discontinuous. These include bedding plane partings, joints and other rock defects, but exclude known artificial fractures such as drilling breaks.

Term	Description
Fragmented:	The core is comprised primarily of fragments of length less than 20mm, and mostly of width less than the core diameter
Highly Fractured:	Core lengths are generally less than 20mm – 40mm with occasional fragments.
Fractured:	Core lengths are mainly 30mm – 100mm with occasional shorter and longer section.
Slightly Fractured:	Core lengths are generally 300mm – 1000mm with occasional longer sections and occasional sections of 100mm – 300mm.
Unbroken:	The core does not contain any fracture.

ROCK STRENGTH

Rock strength is defined by the Point Load Strength Index (Is 50) and refers to the strength of the rock substance in the direction normal to the bedding. The test procedure is described by the International Society of Rock Mechanics.

Term	**Point Load Index Is(50) MPa**	**Field Guide**	**Approx qu MPa***
Extremely Weak:	0.03	Easily remoulded by hand to a material with soil properties.	0.7
Very Weak:	0.1	May be crumbled in the hand. Sandstone is “sugary” and friable.	2.4
Weak:	0.3	A piece of core 150mm long x 50mm dia. May be broken by hand and easily scored with a knife. Sharp edges of core may be friable and break during handling.	7
Medium Strong:	1	A piece of core 150mm long x 50mm dia. can be broken by hand with considerable difficulty. Readily scored with knife.	24
Strong: (SW)	3	A piece of core 150mm long x 50mm dia. core cannot be broken by unaided hands, can be slightly scratched or scored with knife.	70
Very Strong (SW)	10	A piece of core 150mm long x 50mm dia. may be broken readily with hand held hammer. Cannot be scratched with pen knife.	240
Extremely Strong (Fr)	>10	A piece of core 150mm long x 50mm dia. is difficult to break with hand held hammer. Rings when struck with a hammer.	>240

The approximate unconfined compressive strength (qu) shown in the table is based on an assumed ration to the point load index of 24:1. This ratio may vary widely.

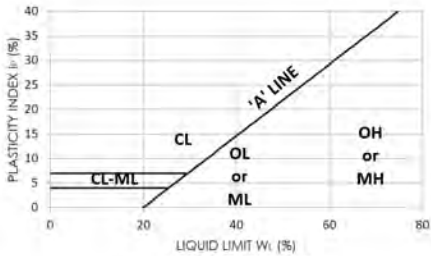
Unified Soil Classification System (Metricated)
Data for Description Indentification and Classification of Soils

MAJOR DIVISIONS		DESCRIPTION: Group Symbol	DESCRIPTION: Graphic Symbol	DESCRIPTION: TYPICAL NAME	DESCRIPTION: DESCRIPTIVE DATA	FIELD IDENTIFICATION		FIELD IDENTIFICATION: GRAVELS AND SANDS – GRADATIONS		NATURE OF FINES	DRY STRENGTH	Group Symbol	LABORATORY CLASSIFICATION	% [2] < 0.06mm	PLASTICITY OF FINE FRACTION			NOTES
COARSE GRAINED SOILS – More than 50% by dry mass, less than 60mm is greater than 0.06mm.	GRAVELS – More than 50% of coarse grains are greater than 2.0mm	GW		Well graded gravels and gravel-sand mixtures, little or no fines	Give typical name, indicate approximate percentages of sand and gravel, maximum size, angularity, surface condition and hardness of the coarse grains, local or geological name and other perfinent descriptive information, symbols in parenthesis. 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, 10mm maximum size, rounded and sub angular sand grains coarse to fine, about 15% non-plastic fines with low dry strength, well compacted and moist in place, light brown alluvial sand, (SM)	Determine approximate percentages of material over 60mm size, maximum size, shape, surface texture, hardness of material, geological description. Identify on estimated percentage mass of the various fractions.	COARSE GRAINED SOILS – More than half of the material less than 60mm is larger than 0.06mm; 0.05mm is about the smallest particle visible to the naked eye	GOOD	Wide range in grain size	"Clean" materials (not enough fines to band coarse grains)	None	GW	Use the gradation curve of material passing 60mm for classification of fractions according to criteria given under "Major Division".	0-5	-	>4	Between 1 and 3	1. Identify Fines by the method given for fine grained soils. 2. Borderline classifications occur when the percentage of fines (fraction smaller than 0.06mm size) is greater than 5% and less than 12%. Borderline classifications require the use of dual symbols eg SP-SM GW-GC
		GP		Poorly graded gravels and gravel sand mixtures, little or no fines				POOR	Predominantly one size or range of sizes			GP		0-5	-	Fails to comply with above		
	GRAVELLY SOILS	GM		Silty gravels, gravel-sand-silt mixtures				GOOD TO FAIR	"Dirty" materials (Excess of fines)	Fines are non-plastic (1)	None to medium	GM		12-50	Below 'A' line and Ip >7	-	-	
		GC		Clayey gravels gravel-sand-clay mixtures						Fines are plastic (1)		GC		12-50	Above 'A' line and Ip > 7	-	-	
	SANDS – More than 50% of coarse grains are greater than 2.0mm	SW		Well graded sands and gravelly sands, little or no fines				GOOD	Wide range in grain size	"Clean" materials (not enough fines to band coarse grains)	None	SW		0-5	-	>6	between 1 and 3	
		SP		Poorly graded sands and gravelly sands, little or no fines				POOR	Predominantly one size or range of sizes			SP		0-5	-	Fails to comply with above		
	SANDY SOILS – More than 50% of coarse grains are greater than 2.0mm	SM		Silty sand, sand-silt mixtures				GOOD TO FAIR	"Dirty" materials (Excess of fines)	Fines are non-plastic (1)	None to medium	SM		12-50	Below 'A' line or Ip < 4	-	-	
		SC		Clayey sands, sand-clay mixtures						Fines are plastic (1)		SC		12-50	Above 'A' line and Ip > 7	-	-	

SILT AND CLAY FRACTION

Fraction smaller than 0 20mm AS sieve size

MAJOR DIVISIONS		Group Symbol	Graphic Symbol	TYPICAL NAME	DESCRIPTIVE DATA	FIELD IDENTIFICATION	DRY STRENGTH	DILATANCY	TOUGHNESS	Group Symbol	LABORATORY CLASSIFICATION	
FINE GRAINED SOILS – More than 50% by dry mass, less than 60mm is less than 0.06mm	Liquid Limit less than 50%	ML		Inorganic silts, very fine sands, rock flour, silty or clayey fine sands.	Give typical name, indicate degree and character of plasticity, amount and maximum size of coarse grains, colour in wet condition, odour if any, local or geological name and r pertinent descriptive information, symbols in parenthesis. For undisturbed soil add information on structure, stratification, consistancy in undisturbed and remoulded states, moisture and drainage conditions. EXAMPLE Clayey Silt, brown, low plasticity, small percentage of fine sand, numerous vertical root-holes, firm and dry in place, fill, (ML).	FINE GRAINED SOILS – More than half of the material less than 50mm is less than 0.06mm	None to low	Quick to slow	None	ML	More than 50% passing 0.06mm	Below 'A' line
		CL		Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.			Medium to high	None to very slow	Medium	CL		Above 'A' line
		OL		Organic silts and organic silty clays of low plasticity			Low to medium	Slow	Low	OL		Below 'A' line
	Liquid Limit more than 50%	MH		Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts.			Low to medium	Slow to none	Low to medium	MH		Below 'A' line
		CH		Inorganic clays of high plasticity, fat clays.			High to very high	None	High	CH		Above 'A' line
		OH		Organic clays of medium to high plasticity.			Medium to high	None to very slow	Low to medium	OH		Below 'A' line
		Pt		Peat muck and other highly organic soils.		Readily identified by colour, odour, spongy feel and generally by fibrous texture				Pt*	*Effervescence with H2O2	



PLASTICITY CHART
FOR CLASSIFICATION
OF FINE GRAINED SOILS

FORTIFY
GEOTECH

Limitations in the Use and Interpretation of this Geotechnical Report

Our Professional services were performed, our findings obtained, and our recommendations prepared in accordance with generally accepted engineering principles and practices. This warranty is in lieu of all other warranties, either expressed or implied.

The geotechnical report was prepared for the use of the Owner in the design of the subject facility and should be made available to potential contractors and/or the Contractor for information on factual data only. This report should not be used for contractual purposes as a warranty of interpreted subsurface conditions such as those indicated by the interpretive boring and test pit logs, cross- sections, or discussion of subsurface conditions contained herein.

The analyses, conclusions and recommendations contained in the report are based on site conditions as they presently exist and assume that the exploratory borings, test pits, and/or probes are representative of the subsurface conditions of the site. If, during construction, subsurface conditions are found which are significantly different from those observes in the exploratory borings and test pits, or assumed to exist in the excavations, we should be advised at once so that we can review these conditions and reconsider our recommendations where necessary. If there is a substantial lapse of time between the submission of this report and the start of work at the site, or if conditions have changed due to natural causes or construction operations at or adjacent to the site, this report should be reviewed to determine the applicability of the conclusions and the recommendations considering the changed conditions and time lapse.

The Summary Boring Logs are our opinion of the subsurface conditions revealed by periodic sampling of the ground as the borings progressed. The soil descriptions and interfaces between strata are interpretive and actual changes may be gradual.

The boring logs and related information depict subsurface conditions only at the specific locations and at the particular time designated on the logs. Soil conditions at the other locations may differ from conditions occurring at these boring locations. Also, the passage of time may result in a change in the soil conditions at these boring locations.

Groundwater levels often vary seasonally. Groundwater levels reported on the boring logs or in the body of the report are factual data only for the dates shown.

Unanticipated soil conditions are commonly encountered on construction sites and cannot be fully anticipated by merely taking soil samples, borings or test pits. Such unexpected conditions frequently require that additional expenditures be made to attain a properly constructed project. It is recommended that the Owner consider providing a contingency fund to accommodate such potential extra costs.

This firm cannot be responsible for any deviation from the intent of this report including, but not restricted to, any changes to the scheduled time of construction, the nature of the project or the specific construction methods or means indicated in this report: nor can our firm be responsible for any construction activity on sites other than the specific site referred to in this report.