Geotechnical Report

25-27 Boyd Street, Tweed Heads NSW

(Our Reference:39941-GR01_C)

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Client:	NSW Land and Housing Corporation
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1.0 INTRODUCTION

The following is a report on the geotechnical assessment of a 13-storey development with basement residential site in accordance with AS1726-2017. The purpose of the investigation is to provide guidance as to the expected foundation condition so that a suitable foundation design can be prepared for the proposed thirteen storey residential building.

1.1 Terminology

The methods used in this report to describe the soil profiles, including visual classification of material types encountered, are in accordance with Australian standard AS1726-2017 “Geotechnical Site Investigations”.

1.2 Limitations

The geotechnical section of Barnson Pty Ltd has conducted this investigation and prepared this report in response to specific instructions from the client to whom this report is addressed. This report is intended for the sole use of the client, and only for the purpose which it is prepared. Any third party who relies on the report or any representation contained in it does so at their own risk.

1.3 Geotechnical Testing

Representative samples from the site were subjected to the following range of tests in accordance with relevant method of Australian Standard AS1289:

- Linear Shrinkage (LS)
- PH
- Aggressivity Testing
- Atterberg Limits (PL, LL, PI)
- Standard Penetrometer Tests (SPT)
- Cone Penetrometer Testing (CPT)
- Acid sulphate testing

NATA endorsed reports are attached in ***Appendix C***.

2.0 GENERAL DESCRIPTION OF SITE

The site is situated in a residential area of Tweed Heads NSW.

The site consists of no grass or weed cover or trees.

The site is sloping slightly to the east. The site has existing units on the block with existing buildings and established houses surrounding the area.

Plate 1 –View of borehole 1 facing West (2022).

Plate 2 – General view of site facing West (2022).

Plate 3 – General view of site facing East (2022).

Plate 4 – General view of site facing West (2024).

Plate 5 – General view of site facing Northwest (2024).

Plate 6 – General view of site facing West (2024).

Plate 7 – General view of site facing Southwest (2024).

3.0 METHOD OF INVESTIGATION

On the 13th-15th of September 2022 and 4th of September 2024, site investigations were carried out at 25-27 Boyd Street, Tweed Heads NSW.

A drill rig with a flight auger and tungsten tip was used to excavate three (3) test holes. The supervising soil technician logged the soil profiles, which were recorded in the bore logs. Disturbed samples were taken from the depths shown in the bore logs. The bore logs are attached in ***Appendix B***.

The disturbed samples were returned to the Laboratory where Linear Shrinkage and Atterberg Limits testing was conducted on the samples to correlate the material's Shrink Swell Index in accordance with AS2870-2011. The results of the Linear Shrinkage tests and Atterberg Limits are attached in ***Appendix C***.

To evaluate the strength and consistency of the material present Four (4) Cone Penetrometer Tests (CPT) were conducted to refusal depths of less than 3m. The results of the Cone Penetrometer Tests are detailed in ***Appendix D***.

Standard Penetrometer Tests (SPT) were also performed on the site to evaluate the strength and consistency of the material present. The results of the Standard Penetrometer Tests are detailed on the borelogs in ***Appendix B***.

4.0 SUB-SURFACE CONDITIONS

From the bore logs attached it can be seen that the soil encountered to the test end point was as follows:

4.1 Fill

A 0.1m thick Concrete slab was cored at both borehole locations.

4.2 Sub-Soil

Aeolian soils were encountered throughout the boreholes. These generally comprised of moist to wet sands and clays to 25.0m.

4.3 Regional Geology

Reference to the New South Wales 1:1,000,000 Geological Map indicates the surrounding area consists of "*Greywacke, slate, phyllite, quartzite*".

Rock was not encountered to the boreholes end points of 25m. The depth to rock is not known. CPT refusal occurred in sand at depths less than 3m.

From a nearby Geotechnical investigation undertaken by Douglas Partners at 33-35 Boyd St. Tweed heads, rock was found at 15-16.5m depths, which is much shallower depth than this site.

4.4 Surface Water

Terranora Creek and Tweed Maraina are located 200m southeast of the site. Tweed River is situated 760m east of Boyd Street.

4.5 Groundwater Review

Groundwater was encountered during this investigation at the depths as indicated in the borehole logs and CPT attached ***Appendix B,*** being from 0.8m below surface level. It must be noted that groundwater depths and moisture conditions are affected by climatic conditions, tidal action, soil permeability and may therefore vary with time.

A search of the Water NSW Groundwater map showed no groundwater bores are situated on the development. Three groundwater bores are located within 500m of the development site as outlined in Table 1.

Table 1: Groundwater review

Groundwater Bore Reference	Date Installed	Distance	Total Depth (m)	WBZ (m)	SWL (m)	Yield (L/s)	Salinity Yield	Notes
GW306058	17/8/2006	75m W	2.5	1.6 to 2.5	1.6	N/a	N/a	Bore Removed. Strata is sandy clay and sand
GW303657	1/01/1970	430m NE	N/a	N/a	N/a	N/a	N/a	No information available
GW273047	1/11/2023	500m SE	11.25	2.9 to 5.2	N/a	N/a	N/a	Strata is sandy clay, sand, silt and siltstone

WBZ – Water Bearing Zone, SWL – Standing Water Level

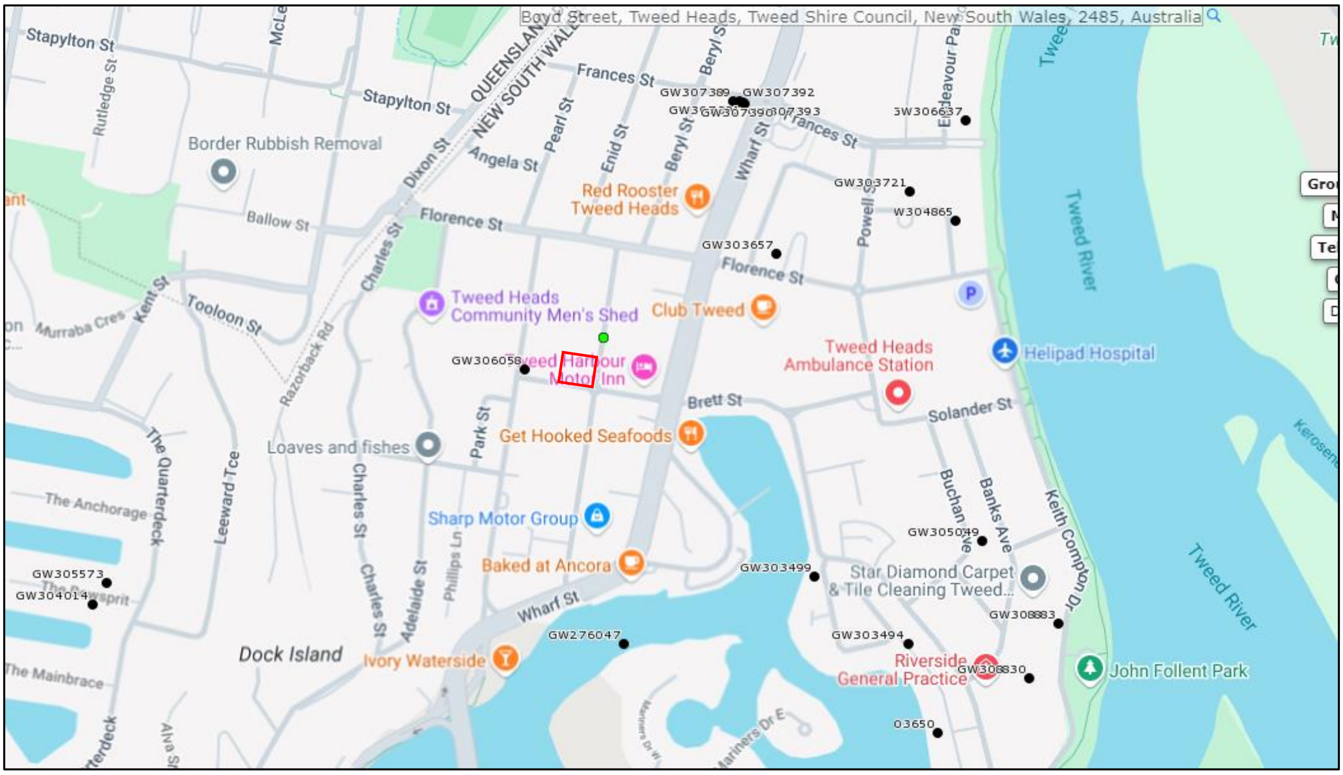

Plate 8 – Groundwater Bore Locations

5.0 NATA LABORATORY TESTING

Disturbed samples were taken during the field investigation. Laboratory testing was carried out on selected samples of all different material types, with details of the sampling and testing shown below:

Soil Index Properties testing was carried out on samples to aid in classification of the soils encountered and to assist in determining design parameters.

5.1 Linear Shrinkage Testing (L.S)

The shrinkage results are summarised in the below table:

Table 2: Linear Shrinkage Results

Borehole No.	Depth (m)	Proposed Structure	Linear Shrinkage (%)
Borehole 1	1.5m	Proposed Building	0.0
Borehole 1	4.5m	Proposed Building	0.0
Borehole 2	3.0m	Proposed Building	0.0
Borehole 2	6.0m	Proposed Building	0.0
Borehole 2	19.5m	Proposed Building	5.0
Borehole 2	22.0m	Proposed Building	6.5
Borehole 2	24.0m	Proposed Building	5.0

The above test results confirm the material as low plasticity.

5.2 Plasticity Index (PI)

The Plasticity Limit results are summarised in the below table:

Table 3: Atterberg Limits Results (PI)

Borehole No.	Proposed Structure	Depth	Liquid Limit (%)	Plasticity Index (%)
Borehole 1	Proposed Building	1.5m	Not Obtainable	Non-Plastic
Borehole 1	Proposed Building	4.5m	Not Obtainable	Non-Plastic
Borehole 2	Proposed Building	3.0m	Not Obtainable	Non-Plastic
Borehole 2	Proposed Building	6.0m	Not Obtainable	Non-Plastic
Borehole 2	Proposed Building	19.5m	32	9
Borehole 2	Proposed Building	22.0m	30	11
Borehole 2	Proposed Building	24.0m	32	13

Soils whose liquid and plastic limits cannot be determined with plasticity index value of 0 (non-plastic) tends to be sand with little or no clay or silt. Cohesive soils with a Plasticity Index range of 11-27% are likely to be moderately reactive to moisture change.

5.3 Seasonal Surface Movement

From the laboratory test results, as shown attached, an estimated ground surface movement (Ys) was calculated in accordance with AS2870-2011 (using a change in suction at the soil surface $\Delta\mu$ = 1.5pF and a depth of design suction change, Hs = 1.5m) being:

Ys = <20mm

The site has the known extraordinary feature of the existing buildings and pavements on the site. However, as the upper layers of soil are non-reactive sand, this will not affect the site classification and thus, it is our opinion that a Site Classification of 'S' should be adopted for the site in its present condition.

6.0 CONE PENETROMETER TEST (CPT)

The CPT results are presented in Table 3. CPT results are reported in ***Appendix D***.

CPT tests were conducted at locations shown on map in ***Appendix B*** to determine the in-situ properties including cone resistance (*qc*) and sleeve friction (*fs*). CPT refusal occurred at depths of less than 3m.

Table 4: Summary of CPT Soil Properties

CPT No.	Soil classification (CPT based)	Depth (m)	*qc* (MPa)	*fs* (MPa)
CPT1	Sand	1.0	9.8	0.06
CPT1	Gravelly Sand to Sand	2.0	>20	0.08
CPT1	Gravelly Sand to Sand	2.5	>20	0.40
CPT2	Sand	1.0	13.7	0.13
CPT2	Gravelly Sand to Sand	2.0	12.5	0.09
CPT2	Gravelly Sand to Sand	2.5	>20	0.21
CPT3	Sand	1.0	5.5	0.07
CPT3	Gravelly Sand to Sand	2.0	>20	0.17
CPT3	Gravelly Sand to Sand	2.5	>20	0.38
CPT4	Gravelly Sand to Sand	1.0	12.2	0.09
CPT4	Gravelly Sand to Sand	2.0	15.9	0.11
CPT4	Gravelly Sand to Sand	2.5	20.0	0.18

qc- cone resistance, fs-sleeve friction,

7.0 FOOTING DESIGN PARAMETERS DISCUSSIONS

The building is noted to be thirteen stories and have basement parking high and thus the column loads are anticipated to be very high. As rock was not encountered, the use of high-level footings such as pad / strip footings and raft slabs should be investigated. Alternatively, if deep footings are to be provided, then additional investigation may need to be undertaken to determine rock depth, as the material found in this investigation may be unsuitable in terms of sufficient strength to resist the large loads involved.

Design parameters for the various options are provided below:

7.1 High level Footings

The preliminary drawings provided indicate the building will not have a basement. Strip / pad footings or raft slabs would therefore be founded in loose to medium dense sands, with highly variable SPT N=4-10 and CPT cone resistance outlined in Table 3. The groundwater table is variable.

The allowable bearing capacity for footings a minimum 1.0m wide can be taken as 100kPa. Settlements of these footings can be estimated using elastic theory with a soil Young's modulus of 15MPa.

7.2 Pile Footings

Concrete cast in situ bored piles could be used, however the bored holes will not stay intact during excavation due to sandy nature of the subsoil and water table. Temporary or permanent casing would be needed to support the boreholes.

Grout injected continuous flight auger (CFA) piles may be more appropriate for this site.

Driven piles are not recommended due to vibration issues to surrounding buildings and the dense sand at depth will not allow sufficient pile embedment to develop full pile capacity.

The design parameters for use of concrete piles into ground are presented below:

Table 5: Geotechnical Design Values – Pile Footings (non-displacement)

Material Name	Nominal Depth (m)	Design SPT (N)	Ultimate Bearing Capacity (kPa)	Ultimate skin Friction Compression (kPa)	Modulus of Elasticity Vertical (MPa)
SAND, Loose	0-3	8	NA	NA	10
SAND, Medium	3-8	22	900	23	30
SAND, Dense	8-15	39	1800	30	50
CLAY, Firm / Stiff	15-25	NA	450	35	20

7.3 Pile Design Parameter Notes:

- A geotechnical strength reduction factor needs to be applied to the above values. Refer section 7.4 below.
- Pile ultimate base bearing capacities are based on pile length / diameter being greater than 4 and piles of a minimum 4.8m depth. Shallower depth bearing capacities are provided for completeness only and are not to be used for shallow foundations.
- The depth to rock was unable to be determined in the boreholes and CPT's. Should the design parameters above be insufficient for the applied loads, then further investigation will be required to determine the depth and strength of rock at the site.
- The values in sand include allowance for the restraint offered by overburden. If the depth of overburden is reduced by inclusion of a basement, then the values will need to be reviewed. The minimum pile diameter assumed is 600mm to depths of 4.8m and 900mm for depths up to 15m.

7.4 Geotechnical Reduction factor

In accordance with AS2159, a geotechnical reduction factor must be applied to the ultimate values presented in table 4. The selection of the strength reduction factor (ϕg) will be dependent on the specified pile testing.

Based on the extent of the current investigation and uniformity of material encountered, a geotechnical strength reduction factor of $\phi g=0.45$ is recommended for the building footings as per the assessment requirement of AS 2159. A higher value may be applied if in place testing is undertaken.

7.5 Construction Considerations - Footings

Contractors should make their own assessment of drilling / excavation equipment required to penetrate the soil. Temporary or permanent casing will be required to support bored pile holes through sand layers. Contractors should make their own assessment as to the type of casing.

We recommend that a suitably qualified experienced Geotechnical Engineer assess the pile foundations during construction to check that the ground conditions are as advised by this report.

7.6 Temporary Piling Platforms

Temporary working platforms to support piling cranes and ancillary construction plant are expected to be required. The design of the working platforms should account for the following:

- The geometry and loadings of the proposed piling rig
- The contractor’s construction methodology
- Coordination with bulk excavation work

7.7 Retaining Wall Design parameters

Retaining walls in medium dense sand should be designed for the below Rankine Method design parameters:

a. Active Pressure coefficient: K_a=0.36

b. At rest pressure coefficient: K_o=0.53

c. Passive Pressure Coefficient: K_p=2.77

d. Soil Density: 17 kN/m2.

Retaining walls should be provided with free draining backfill and have suitable subsoil drainage systems so that hydrostatic pressure does not build up behind the walls. Due to the shallow water table and possible impact of flooding, allowance should be made for buoyancy and water pressure.

8.0 BASEMENT RETAINING WALL DESIGN PARAMETERS

The final design of the basement must allow for groundwater levels and as such should be 'tanked' to prevent water ingress and designed to allow for the buoyancy forces. Dewatering may be required in accordance with a dewatering management plan.

Retaining structures shall be designed by an engineer and constructed to in accordance with the following earth pressure coefficients and procedures. The lateral pressure coefficients given in Table 6 are recommended for design.

Table 6: Earth Pressure Coefficients (non sloping crest backfill)

Material Name	Unit Weight (kN/M^3)	K_a	K_0	K_p
SAND, Loose	17	0.39	0.56	2.56
SAND, Medium	18	0.36	0.53	2.77
SAND, Dense	20	0.33	0.50	3.00
CLAY, Firm / Stiff	16	0.56	0.72	1.76

K_o – at rest, K_a – active, K_p - passive

- Ignore passive resistance (K_p) at the toe in the zone where future disturbance (e.g. service trenches) could occur.
- Allowance should be made for surcharge loads (over and above the lateral earth pressure coefficients presented above)
- Allowance should be made for wall loading caused by flooding or inundation, as appropriate. Such flooding may penetrate up to 0.75m depth (i.e. approximately $0.5H_s$ as defined in AS2870).
- Due to fluctuating water table and shallow depth of groundwater, allowance for buoyancy should be considered in the basement design for the full basement wall height.

9.0 ACID SULPHATE SOIL ASSESSMENT

The site is not mapped within Acid Sulphate Soil Risk or Acid Sulphate Soil Probability area (eSPADE).

Three soil samples were collected for acid sulphate screening (Table 5) and chromium suite testing (Table 6). The ASSMAC (Acid Sulphate Soils Management Advisory Committee) guidelines indicate potential acid sulphate soils (PASS) include:

- Soil pH_{fox} < 3.5 in and drop of 1 pH unit or more between pH_f and pH_{fox}.

The soil screening tests indicate the samples have pH_{fox} >3.5 and a drop >1 pH_{fox} (Table 5).

The chromium suite testing indicates the pH_{KCl} and net acidity are low. The Queensland ASS Technical Manual, Soil Management Guidelines presents soil action criteria considering soil texture and soil mass to be disturbed. Action criteria for net acidity in sand is 18 Mol H+/tonne (Table 6).

Table 7: Acid Sulphate Soil Screening Results

Borehole No.	Depth (m)	Soil Type	pH_f	pH_{fox}	pH change	Reaction
3	1.0	Sand	8.1	6.6	1.4	4 (extreme)
3	2.0	Sand	6.7	4.0	2.6	1 (slight)
3	3.0	Sand	5.1	4.0	1.1	1 (slight)
Guideline / Action Criteria			≤4	<4	≥1	-

pH_f – pH in water, pHfox – pH in hydrogen peroxide

Table 8: Acid Sulphate Chromium Suite Results

Borehole No.	Depth (m)	Soil Type	pH_{KCl}	TAA	S_{CR}	Net acidity (moles H+/T)
3	1.0	Sand	9.2	<5	<5	<5
3	2.0	Sand	7.3	<5	<5	<5
3	3.0	Sand	6.3	<5	<5	6
Guideline / Action Criteria			-	-	-	18

pH_{KCl} – pH in KCl, TAA – Titratable actual acidity (moles H+/tonne), S_{CR} – Chromium reducible sulphur (moles H+/tonne)

The acid sulphate screening and chromium suite testing indicate the three samples are not considered acid sulphate soil. Additional screen testing is recommended when earthwork and disturbance volumes are known.

10.0 CONCLUSION

The testing methods adopted are indicative of the site's sub-surface conditions to the depths excavated and to specific sampling and/or testing locations in this investigation, and only at the time the work was carried out.

The accuracy of geotechnical engineering advice provided in this report may be limited by unobserved variations in ground conditions across the site in areas between and beyond test locations and by any restrictions in the sampling and testing which was able to be carried out, as well as by the amount of data that could be collected given the project and site constraints.

These factors may lead to the possibility that actual ground conditions and materials behaviour observed at the test locations may differ from those which may be encountered elsewhere on the site.

If the sub-surface conditions are found to differ from those described in this report, we should be informed immediately to evaluate whether recommendations should be reviewed and amended if necessary.

Appendix A – General Notes

GEOTECHNICAL INVESTIGATION GENERAL NOTES

This report contains the results of a geotechnical investigation conducted for a specific purpose and client. The results should not be used by other parties, or for other purposes, as they may contain neither adequate nor appropriate information. In particular, the investigation does not cover contamination issues unless specifically required to do so by the client.

TEST HOLE LOGGING

The information on the test hole logs (boreholes, test pits, exposures etc.) is based on a visual and tactile assessment, except at the discrete locations where the test information is available (field and/or laboratory results). The borehole logs include both factual data and inferred information. Reference should be made to the relevant sheets for the explanation of logging procedures (Soil and Rock Descriptions, Core Log Sheet Notes etc).

GROUNDWATER

Unless otherwise indicated, the water levels presented on the borehole logs are the levels of free water or seepage in the bore hole recorded at the given time of measuring. The actual groundwater level may differ from this recorded level depending on material permeability's (i.e. depending on response time of the measuring instrument). Further, variations of this level could occur with time due to such effects as seasonal, environmental and tidal fluctuations or construction activities. Confirmation of groundwater levels, phreatic surfaces or piezometric pressures can only be made by appropriate instrumentation techniques and monitoring programmes.

INTERPRETATION OF RESULTS

The discussion or recommendations contained within this report normally are based on a site evaluation from discrete borehole area. Generalised, idealised or inferred subsurface conditions (including any geotechnical cross-sections) have been assumed or prepared by interpolation and/or extrapolation of these data. As such these conditions are an interpretation and must be considered as a guide only.

CHANGE IN CONDITIONS

Local variations or anomalies in the generalised ground conditions do occur in the natural environment, particularly between discrete borehole locations. Additionally, certain design or construction procedures may have been assumed in assessing the soil-structure interaction behaviour of the site. Furthermore, conditions may change at the site from those encountered at the time of the geotechnical investigation through construction activities and constantly changing natural forces.

Any change in design, in construction methods, or in ground conditions as noted during construction, from those assumed or reported should be referred to this firm for appropriate assessment and comment.

GEOTECHNICAL VERIFICATION

Verification of the geotechnical assumptions and/or model is an integral part of the design process – investigation, construction verification and performance monitoring. Variability is a feature of the natural environment and, in many instances, verification of soil or rock quality, or foundation levels are required. There may be a requirement to extend foundation depths to modify a foundation system or to conduct monitoring as a result of this natural variability. Allowance for verification by geotechnical personnel accordingly should be recognised and programmed during construction.

FOUNDATIONS

Where referred to in the report, the soil or rock quality, or the recommendation depth of any foundation (piles, caissons footings etc.) is an engineering estimate. The estimate is influenced and perhaps limited, by the fieldwork method and testing carried out in connection with the site investigation, and other pertinent information as has been made available. The material quality and/or foundation depth remains, however, an estimate and therefore liable to variation. Foundation drawings, designs and specifications should provide for variations in the final depth, depending upon the ground conditions at each point of support, and allow for geotechnical verification.

REPRODUCTION OF REPORTS

Where it is desired to reproduce the information contained in our geotechnical report, or other technical information, for the inclusion in contract documents or engineering specification of the subject development, such reproductions should include at least all of the relevant test hole and test data, together with the appropriate standard description sheets and remarks made in the written report of a factual or descriptive nature.

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Appendix B - Borehole Logs and Site Map

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BOREHOLE NUMBER 1

CLIENT NSW Land and Housing Corporation
PROJECT NAME Geotechnical Investigation
PROJECT NUMBER 39941
PROJECT LOCATION 25-27 Boyd Street, Tweed Heads NSW

DATE STARTED 13/9/22 **COMPLETED** 14/9/22
R.L. SURFACE
LONGITUDE ---
DRILLING CONTRACTOR Barnson
SLOPE 90°
LATITUDE ---
EQUIPMENT Drill Rig CEDR00917
HOLE LOCATION Borehole 1
HOLE SIZE 90mm
LOGGED BY NR
CHECKED BY NR
NOTES

Method	Samples	Depth (m)	Graphic Log	Classification Symbol	Material Description	SPT Results	Est. Allowable Bearing Capacity (kPa)	Additional Observations
Flight Auger & Tungsten Carbide (T.C) Bit		0.1			CONCRETE			CONCRETE
	Disturbed Sample LS = 0.0% PI = NP			SM	SAND: black: wet: medium dense: low plasticity	SPT = 6, 10, 12 N=22	12	AEOLIAN STANDING WATER LEVEL
	Disturbed Sample LS = 0.0% PI = NP					COLLAPSE		
		6		SM	SAND: grey: wet: medium dense: low plasticity			AEOLIAN
		10						

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CLIENT NSW Land and Housing Corporation

PROJECT NAME Geotechnical Investigation

PROJECT NUMBER 39941

PROJECT LOCATION 25-27 Boyd Street, Tweed Heads NSW

DATE STARTED 13/9/22 **COMPLETED** 14/9/22

R.L. SURFACE

LONGITUDE ---

DRILLING CONTRACTOR Barnson

SLOPE 90°

LATITUDE ---

EQUIPMENT Drill Rig CEDR00917

HOLE LOCATION Borehole 1

HOLE SIZE 90mm

LOGGED BY NR

CHECKED BY NR

NOTES

Method	Samples	Depth (m)	Graphic Log	Classification Symbol	Material Description	SPT Results	Est. Allowable Bearing Capacity (kPa)	Additional Observations
Flight Auger & Tungsten Carbide (T.C) Bit		10–15 (11, 12, 13, 14)		SM	SAND: grey; wet; medium dense; low plasticity *(continued)*			AEOLIAN
		15–20 (16, 17, 18, 19, 20)		CL	Sandy CLAY: yellow mottled grey; moist; firm; medium to high plasticity			ALLUVIAL

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BOREHOLE NUMBER 1

CLIENT NSW Land and Housing Corporation
PROJECT NAME Geotechnical Investigation
PROJECT NUMBER 39941
PROJECT LOCATION 25-27 Boyd Street, Tweed Heads NSW

DATE STARTED 13/9/22 **COMPLETED** 14/9/22
R.L. SURFACE
LONGITUDE ---
DRILLING CONTRACTOR Barnson
SLOPE 90°
LATITUDE ---
EQUIPMENT Drill Rig CEDR00917
HOLE LOCATION Borehole 1
HOLE SIZE 90mm
LOGGED BY NR
CHECKED BY NR
NOTES

Method	Samples	Depth (m)	Graphic Log	Classification Symbol	Material Description	SPT Results	Est. Allowable Bearing Capacity (KPa)	Additional Observations
Flight Auger & Tungsten Carbide (T.C) Bit		21 22 23 24 25		CL	Sandy CLAY: yellow mottled grey: moist: firm: medium to high plasticity *(continued)*			ALLUVIAL
		26 27 28 29 30			Borehole 1 terminated at 25m			

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BOREHOLE NUMBER 2

CLIENT NSW Land and Housing Corporation
PROJECT NAME Geotechnical Investigation
PROJECT NUMBER 39941
PROJECT LOCATION 25-27 Boyd Street, Tweed Heads NSW

DATE STARTED 14/9/22 **COMPLETED** 15/9/22
R.L. SURFACE
LONGITUDE ---
DRILLING CONTRACTOR Barnson
SLOPE 90°
LATITUDE ---
EQUIPMENT Drill Rig CEDR00917
HOLE LOCATION Borehole 2
HOLE SIZE 90mm
LOGGED BY NR
CHECKED BY NR
NOTES

Method	Samples	Depth (m)	Graphic Log	Classification Symbol	Material Description	SPT Results	Est. Allowable Bearing Capacity (kPa)	Additional Observations
Flight Auger & Tungsten Carbide (T.C) Bit		0.1			CONCRETE			CONCRETE
				SM	SAND: black; wet; loose; low plasticity			AEOLIAN
								STANDING WATER LEVEL
	Disturbed Sample LS = 0.0% PI = NP	3				SPT = 2, 4, 4 N=8		
		4		SM	SAND: black; wet; medium dense; low plasticity			AEOLIAN
	Disturbed Sample LS = 0.0% PI = NP	6				SPT = 10, 18, 40 N=18		
		10						

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NSW 2830
Telephone: 1300 BARNSON

BOREHOLE NUMBER 2

CLIENT NSW Land and Housing Corporation
PROJECT NAME Geotechnical Investigation
PROJECT NUMBER 39941
PROJECT LOCATION 25-27 Boyd Street, Tweed Heads NSW

DATE STARTED 14/9/22 **COMPLETED** 15/9/22
R.L. SURFACE
LONGITUDE ---
DRILLING CONTRACTOR Barnson
SLOPE 90°
LATITUDE ---
EQUIPMENT Drill Rig CEDR00917
HOLE LOCATION Borehole 2
HOLE SIZE 90mm
LOGGED BY NR
CHECKED BY NR
NOTES

Method	Samples	Depth (m)	Graphic Log	Classification Symbol	Material Description	SPT Results	Est. Allowable Bearing Capacity (kPa)	Additional Observations
Flight Auger & Tungsten Carbide (T.C) Bit		11, 12, 13, 14, 15, 16, 17		SM	SAND: black: wet: medium dense: low plasticity *(continued)*			AEOLIAN
	Disturbed Sample LS = 5.0% PI = 9%	18, 19, 20		CL	Sand CLAY: grey: moist: firm to stiff: medium plasticity		40kPa BY PP ON CUTT-INGS	ALLUVIAL

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BOREHOLE NUMBER 2

CLIENT NSW Land and Housing Corporation
PROJECT NAME Geotechnical Investigation
PROJECT NUMBER 39941
PROJECT LOCATION 25-27 Boyd Street, Tweed Heads NSW

DATE STARTED 14/9/22 **COMPLETED** 15/9/22
R.L. SURFACE
LONGITUDE ---
DRILLING CONTRACTOR Barnson
SLOPE 90°
LATITUDE ---
EQUIPMENT Drill Rig CEDR00917
HOLE LOCATION Borehole 2
HOLE SIZE 90mm
LOGGED BY NR
CHECKED BY NR
NOTES

Method	Samples	Depth (m)	Graphic Log	Classification Symbol	Material Description	SPT Results	Est. Allowable Bearing Capacity (kPa)	Additional Observations
Flight Auger & Tungsten Carbide (T.C) Bit		21		CL	Sand CLAY: grey: moist: firm to stiff: medium plasticity *(continued)*			ALLUVIAL
	Disturbed Sample LS = 6.5% PI = 11%	22					50kPa BY PP ON CUT-TINGS	
				CL	Sandy CLAY: yellow: moist: stiff: medium to high plasticity			ALLUVIAL
		23						
	Disturbed Sample LS = 5.0% PI = 13%	24					200kPa BY PP ON CUT-TINGS	
		25			Borehole 2 terminated at 25m			
		26						
		27						
		28						
		29						
		30						

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Geotechnical Log - Borehole 3

Latitude	:	Location	: 25-27 Boyd Street, Tweed Heads NSW	Job Number	: 39941
Longitude	:	Logged By	: NR	Client	: NSW Land and Housing Corporation
Total Depth : 4 m		Date	: 05/09/2024	Project	: Site Classification

Drilling Method	Depth (m)	Graphic Log	Classification Code	Material Description	DCP graph (0–26)	Samples: Disturbed sample	Remarks
Auger drill with TC bit	0.1		SM	Topsoil Silty SAND loose, brown, fine grained, dry.			
	0.8		SP	Alluvial SAND medium dense, brown, fine grained, slightly moist.			
	1		SM	Alluvial Silty SAND medium dense, white, fine grained, wet.			
	1.8		SM	Alluvial Silty SAND medium dense, white, fine grained, wet, groundwater encountered.			
			SM	Alluvial Silty SAND very dense, very dark brown, fine grained, wet.			

3 Terminated at 4m


CPT2
CPT1
BH2
BH1
CPT3
BH3
CPT4

Appendix C - NATA Laboratory Reports

Material Test Report

Report Number:	**39941-1**
Issue Number:	1
Date Issued:	27/09/2022
Client:	NSW Land and Housing Corporation Locked Bag 4009, Ashfield NSW 2131
Contact:	Jalpa Patel
Project Number:	39941
Project Name:	Site Classification
Project Location:	25-27 Boyd Street, Tweed Heads NSW
Work Request:	7051
Sample Number:	D22-7051A
Date Sampled:	13/09/2022
Dates Tested:	13/09/2022 - 27/09/2022
Sampling Method:	AS 1289.1.2.1 6.5.3 - Power auger drilling
Sample Location:	**Borehole 1, Depth: 1.5m**
Material:	Black SAND

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Dubbo Laboratory

16 L Yarrandale Road Dubbo NSW 2830

Phone: 1300 BARNSON

Email: jeremy@barnson.com.au

Accredited for compliance with ISO/IEC 17025 - Testing

Approved Signatory: Jeremy Wiatkowski

Geotechnical Technician

NATA Accredited Laboratory Number: 9605

Atterberg Limit (AS1289 3.1.2 & 3.2.1 & 3.3.1)		Min	Max
Sample History	Oven Dried		
Preparation Method	Dry Sieve		
Liquid Limit (%)	Not Obtainable		
Plastic Limit (%)	Not Obtainable		
Plasticity Index (%)	**Non Plastic**		

Linear Shrinkage (AS1289 3.4.1)		Min	Max
Moisture Condition Determined By	AS 1289.3.1.2		
Linear Shrinkage (%)	0.0		
Cracking Crumbling Curling	None		

Material Test Report

Report Number:	**39941-1**
Issue Number:	1
Date Issued:	27/09/2022
Client:	NSW Land and Housing Corporation Locked Bag 4009, Ashfield NSW 2131
Contact:	Jalpa Patel
Project Number:	39941
Project Name:	Site Classification
Project Location:	25-27 Boyd Street, Tweed Heads NSW
Work Request:	7051
Sample Number:	D22-7051B
Date Sampled:	13/09/2022
Dates Tested:	13/09/2022 - 27/09/2022
Sampling Method:	AS 1289.1.2.1 6.5.3 - Power auger drilling
Sample Location:	**Borehole 1, Depth: 4.5m**
Material:	Black SAND

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NATA
WORLD RECOGNISED ACCREDITATION

Approved Signatory: Jeremy Wiatkowski
Geotechnical Technician
NATA Accredited Laboratory Number: 9605

Atterberg Limit (AS1289 3.1.2 & 3.2.1 & 3.3.1)		Min	Max
Sample History	Oven Dried		
Preparation Method	Dry Sieve		
Liquid Limit (%)	Not Obtainable		
Plastic Limit (%)	Not Obtainable		
Plasticity Index (%)	**Non Plastic**		

Linear Shrinkage (AS1289 3.4.1)		Min	Max
Moisture Condition Determined By	AS 1289.3.1.2		
Linear Shrinkage (%)	0.0		
Cracking Crumbling Curling	None		

Material Test Report

Report Number:	**39941-1**
Issue Number:	1
Date Issued:	27/09/2022
Client:	NSW Land and Housing Corporation Locked Bag 4009, Ashfield NSW 2131
Contact:	Jalpa Patel
Project Number:	39941
Project Name:	Site Classification
Project Location:	25-27 Boyd Street, Tweed Heads NSW
Work Request:	7051
Sample Number:	D22-7051C
Date Sampled:	13/09/2022
Dates Tested:	13/09/2022 - 27/09/2022
Sampling Method:	AS 1289.1.2.1 6.5.3 - Power auger drilling
Sample Location:	**Borehole 2, Depth: 3.0m**
Material:	Black SAND

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NATA WORLD RECOGNISED ACCREDITATION

Approved Signatory: Jeremy Wiatkowski
Geotechnical Technician

NATA Accredited Laboratory Number: 9605

Atterberg Limit (AS1289 3.1.2 & 3.2.1 & 3.3.1)		Min	Max
Sample History	Oven Dried		
Preparation Method	Dry Sieve		
Liquid Limit (%)	Not Obtainable		
Plastic Limit (%)	Not Obtainable		
Plasticity Index (%)	**Non Plastic**		

Linear Shrinkage (AS1289 3.4.1)		Min	Max
Moisture Condition Determined By	AS 1289.3.1.2		
Linear Shrinkage (%)	0.0		
Cracking Crumbling Curling	None		

Material Test Report

Report Number: **39941-1**
Issue Number: 1
Date Issued: 27/09/2022
Client: NSW Land and Housing Corporation
Locked Bag 4009, Ashfield NSW 2131
Contact: Jalpa Patel
Project Number: 39941
Project Name: Site Classification
Project Location: 25-27 Boyd Street, Tweed Heads NSW
Work Request: 7051
Sample Number: D22-7051D
Date Sampled: 13/09/2022
Dates Tested: 13/09/2022 - 27/09/2022
Sampling Method: AS 1289.1.2.1 6.5.3 - Power auger drilling
Sample Location: **Borehole 2, Depth: 6.0m**
Material: Black SAND

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NATA
WORLD RECOGNISED ACCREDITATION

Approved Signatory: Jeremy Wiatkowski
Geotechnical Technician
NATA Accredited Laboratory Number: 9605

Atterberg Limit (AS1289 3.1.2 & 3.2.1 & 3.3.1)		Min	Max
Sample History	Oven Dried		
Preparation Method	Dry Sieve		
Liquid Limit (%)	Not Obtainable		
Plastic Limit (%)	Not Obtainable		
Plasticity Index (%)	**Non Plastic**		

Linear Shrinkage (AS1289 3.4.1)		Min	Max
Moisture Condition Determined By	AS 1289.3.1.2		
Linear Shrinkage (%)	0.0		
Cracking Crumbling Curling	None		

Material Test Report

Report Number: **39941-1**
Issue Number: 1
Date Issued: 27/09/2022
Client: NSW Land and Housing Corporation
Locked Bag 4009, Ashfield NSW 2131
Contact: Jalpa Patel
Project Number: 39941
Project Name: Site Classification
Project Location: 25-27 Boyd Street, Tweed Heads NSW
Work Request: 7051
Sample Number: D22-7051E
Date Sampled: 13/09/2022
Dates Tested: 13/09/2022 - 27/09/2022
Sampling Method: AS 1289.1.2.1 6.5.3 - Power auger drilling
Sample Location: **Borehole 2, Depth: 19.5m**
Material: Grey Sandy CLAY

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Approved Signatory: Jeremy Wiatkowski
Geotechnical Technician
NATA Accredited Laboratory Number: 9605

Atterberg Limit (AS1289 3.1.2 & 3.2.1 & 3.3.1)		Min	Max
Sample History	Oven Dried		
Preparation Method	Dry Sieve		
Liquid Limit (%)	32		
Plastic Limit (%)	23		
Plasticity Index (%)	**9**		

Linear Shrinkage (AS1289 3.4.1)		Min	Max
Moisture Condition Determined By	AS 1289.3.1.2		
Linear Shrinkage (%)	5.0		
Cracking Crumbling Curling	None		

Material Test Report

Report Number:	**39941-1**
Issue Number:	1
Date Issued:	27/09/2022
Client:	NSW Land and Housing Corporation Locked Bag 4009, Ashfield NSW 2131
Contact:	Jalpa Patel
Project Number:	39941
Project Name:	Site Classification
Project Location:	25-27 Boyd Street, Tweed Heads NSW
Work Request:	7051
Sample Number:	D22-7051F
Date Sampled:	13/09/2022
Dates Tested:	13/09/2022 - 27/09/2022
Sampling Method:	AS 1289.1.2.1 6.5.3 - Power auger drilling
Sample Location:	**Borehole 2, Depth: 22.0m**
Material:	Yellow Sandy CLAY

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NATA WORLD RECOGNISED ACCREDITATION

Approved Signatory: Jeremy Wiatkowski
Geotechnical Technician

NATA Accredited Laboratory Number: 9605

Atterberg Limit (AS1289 3.1.2 & 3.2.1 & 3.3.1)		Min	Max
Sample History	Oven Dried		
Preparation Method	Dry Sieve		
Liquid Limit (%)	30		
Plastic Limit (%)	19		
Plasticity Index (%)	**11**		

Linear Shrinkage (AS1289 3.4.1)		Min	Max
Moisture Condition Determined By	AS 1289.3.1.2		
Linear Shrinkage (%)	6.5		
Cracking Crumbling Curling	None		

Material Test Report

Report Number:	**39941-1**
Issue Number:	1
Date Issued:	27/09/2022
Client:	NSW Land and Housing Corporation Locked Bag 4009, Ashfield NSW 2131
Contact:	Jalpa Patel
Project Number:	39941
Project Name:	Site Classification
Project Location:	25-27 Boyd Street, Tweed Heads NSW
Work Request:	7051
Sample Number:	D22-7051G
Date Sampled:	13/09/2022
Dates Tested:	13/09/2022 - 27/09/2022
Sampling Method:	AS 1289.1.2.1 6.5.3 - Power auger drilling
Sample Location:	**Borehole 2, Depth: 24.0m**
Material:	Yellow Sandy CLAY

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NATA WORLD RECOGNISED ACCREDITATION

Accredited for compliance with ISO/IEC 17025 - Testing

Approved Signatory: Jeremy Wiatkowski
Geotechnical Technician

NATA Accredited Laboratory Number: 9605

Atterberg Limit (AS1289 3.1.2 & 3.2.1 & 3.3.1)		Min	Max
Sample History	Oven Dried		
Preparation Method	Dry Sieve		
Liquid Limit (%)	32		
Plastic Limit (%)	19		
Plasticity Index (%)	**13**		

Linear Shrinkage (AS1289 3.4.1)		Min	Max
Moisture Condition Determined By	AS 1289.3.1.2		
Linear Shrinkage (%)	5.0		
Cracking Crumbling Curling	None		

Appendix D – Cone Penetrometer Testing

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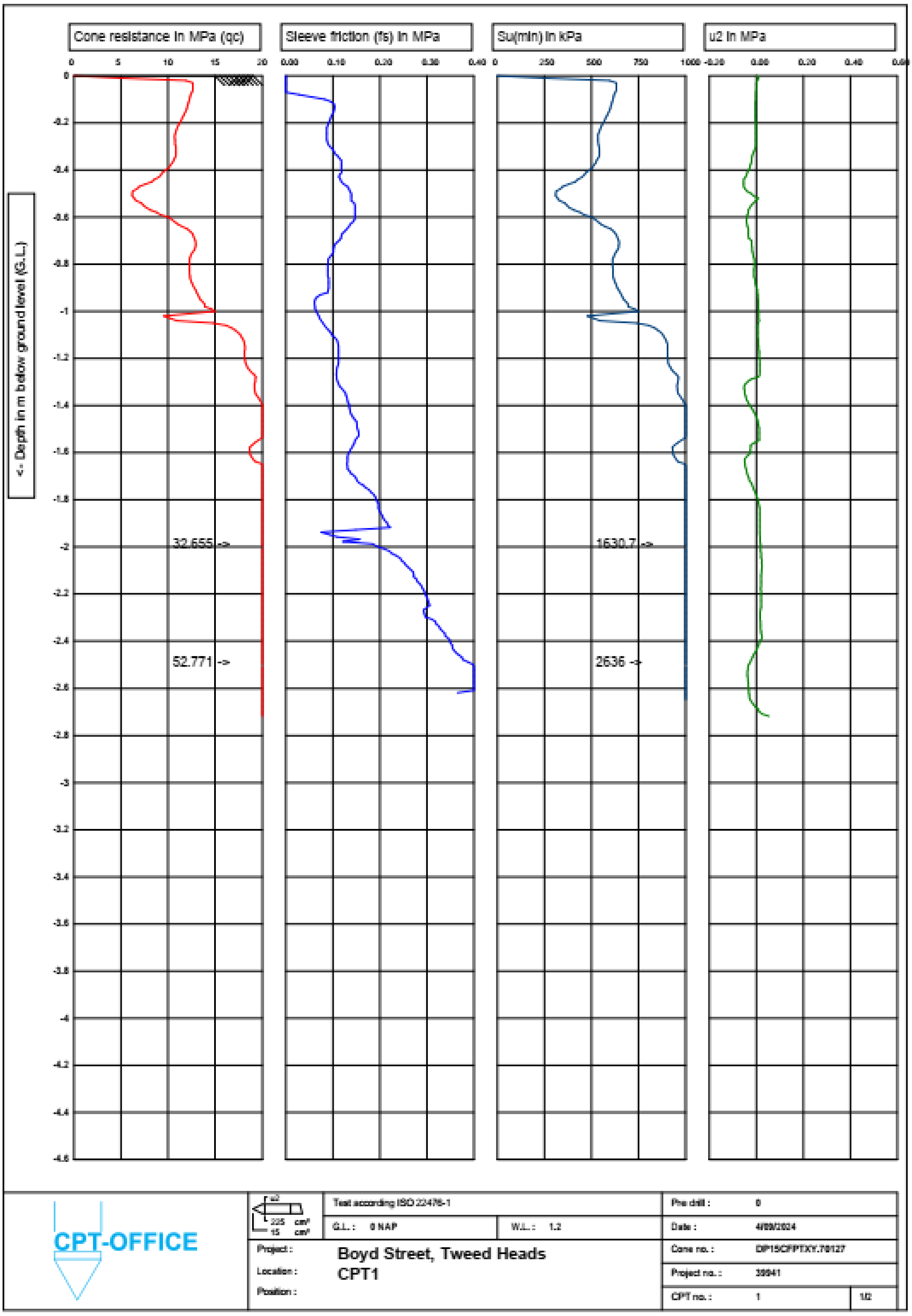
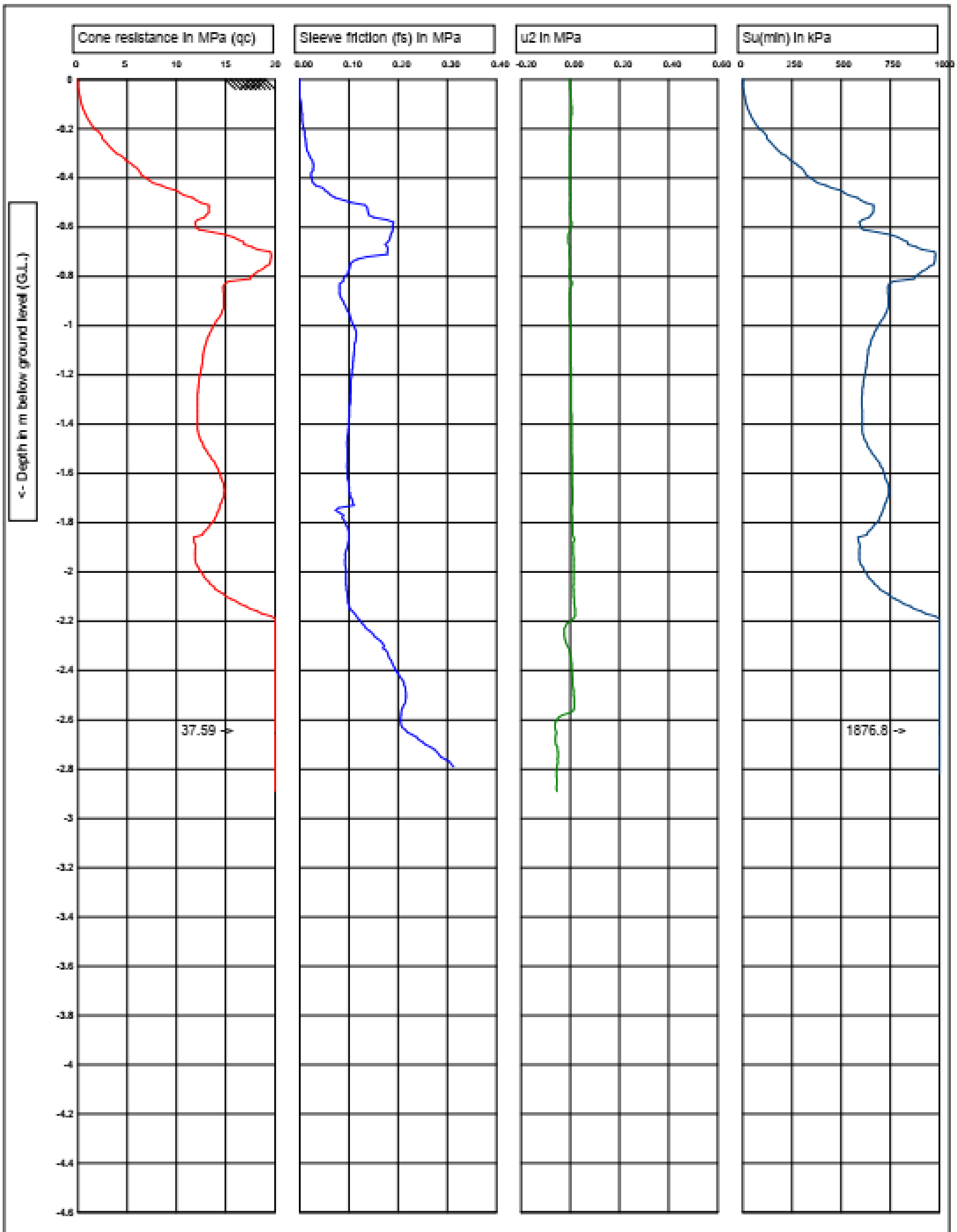
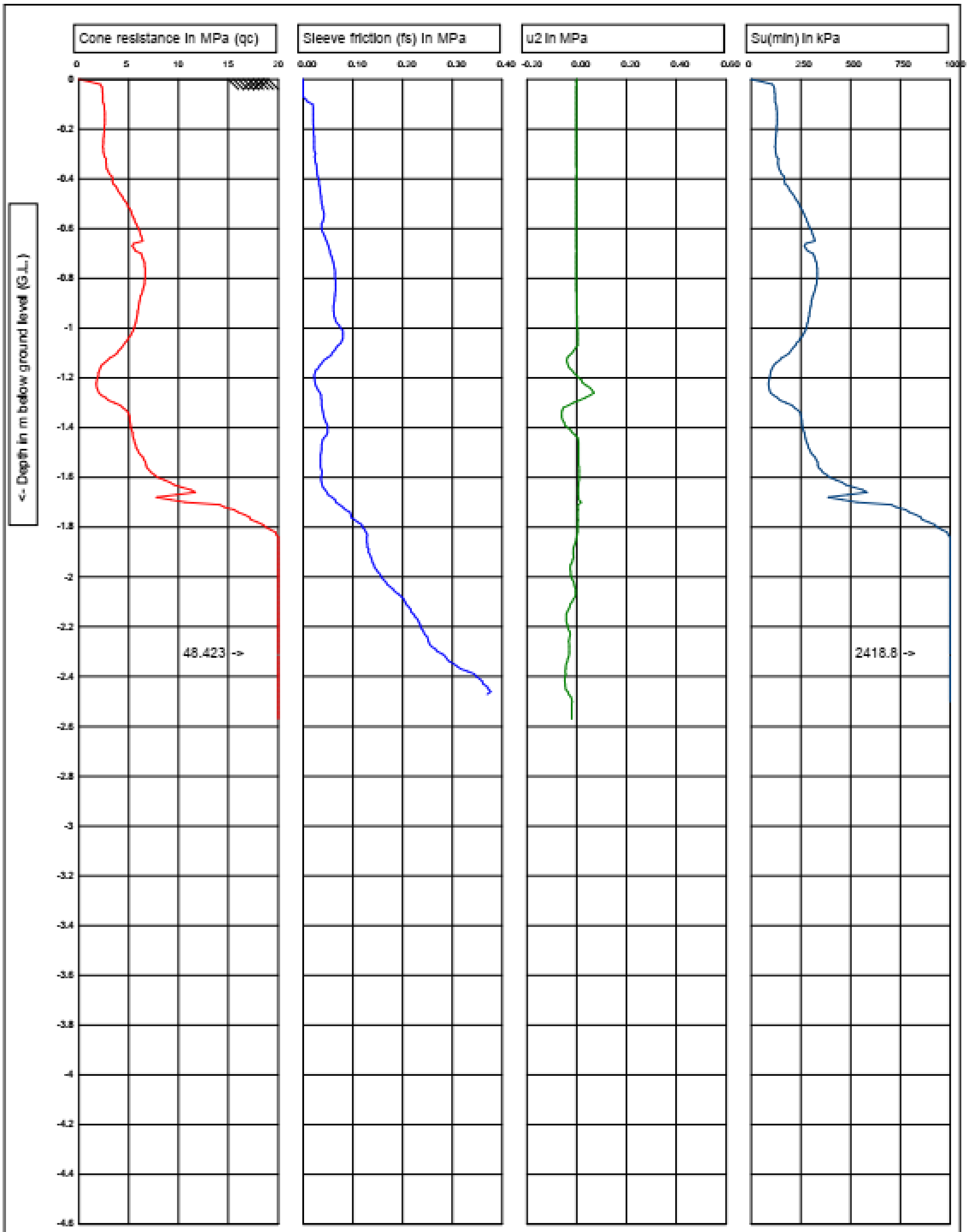


Cone resistance in MPa (qc)
Sleeve friction (fs) in MPa
Su(min) in kPa
u2 in MPa
0 5 10 15 20
0.00 0.10 0.20 0.30 0.40
0 250 500 750 1000
-0.20 0.00 0.20 0.40 0.60
<-- Depth in m below ground level (G.L.)
0 -0.2 -0.4 -0.6 -0.8 -1 -1.2 -1.4 -1.6 -1.8 -2 -2.2 -2.4 -2.6 -2.8 -3 -3.2 -3.4 -3.6 -3.8 -4 -4.2 -4.4 -4.6
32.655 -->
52.771 -->
1630.7 -->
2636 -->
CPT-OFFICE
u2
225 cm²
15 cm²
Test according ISO 22476-1
G.L. : 0 NAP
W.L. : 1.2
Project : Boyd Street, Tweed Heads
Location : CPT1
Position :
Pre drill : 0
Date : 4/09/2024
Cone no. : DP15CFPTXY.70127
Project no. : 39941
CPT no. : 1
1/2



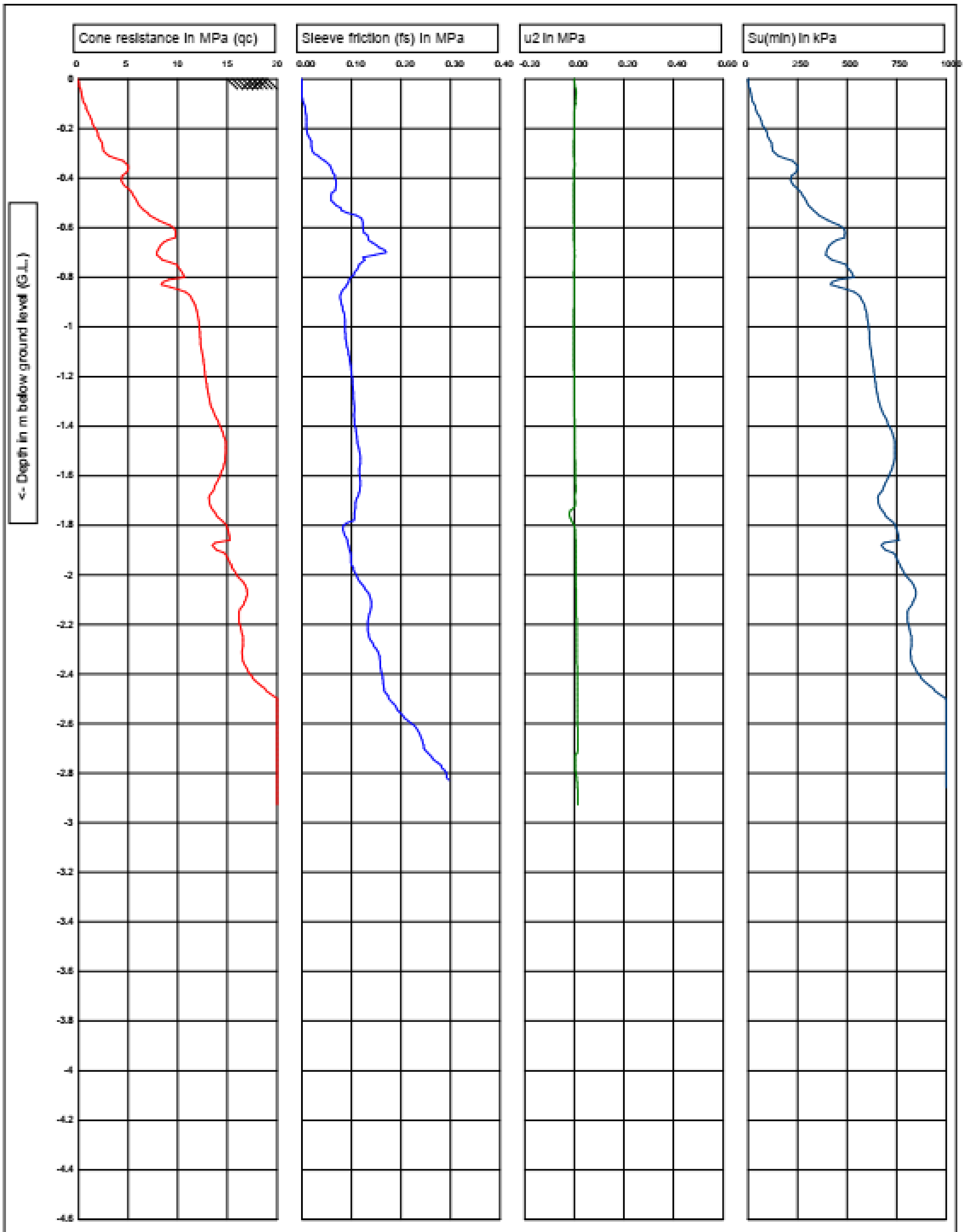
CPT-OFFICE

Test according ISO 22476-1		Pre drill :	0
G.L. : 0 NAP	W.L. : 0.8	Date :	4/09/2024
Project :	Boyd Street, Tweed Heads	Cone no. :	DP15CFPTXY.70127
Location :	CPT2	Project no. :	39941
Position :		CPT no. :	2 — 1/2



CPT-OFFICE

Test according ISO 22476-1		Pre drill :	0
G.L. : 0 NAP	W.L. : 0	Date :	4/09/2024
Project :	Boyd Street, Tweed Heads	Cone no. :	DP15CFPTXY.70127
Location :	CPT3	Project no. :	39941
Position :		CPT no. :	3 — 1/2



CPT-OFFICE	u2 / 225 cm² / 15 cm²	Test according ISO 22476-1	Pre drill :	0
		G.L. : 0 NAP / W.L. : 0	Date :	4/09/2024
	Project :	Boyd Street, Tweed Heads	Cone no. :	DP15CFPTXY.70127
	Location :	CPT4	Project no. :	39941
	Position :		CPT no. :	4 1/2

Appendix B - Borehole Logs and Site Map

ANALYTICAL REPORT

Accreditation No. 2562

CLIENT DETAILS		LABORATORY DETAILS	
Contact	Andrew Ruming	Manager	Shane McDermott
Client	BARNSON PTY LIMITED	Laboratory	SGS Alexandria Environmental
Address	UNIT 1 36 DARLING STREET DUBBO NSW 2830	Address	Unit 16, 33 Maddox St Alexandria NSW 2015
Telephone	61 1300227676	Telephone	+61 2 8594 0400
Facsimile	61 2 68845857	Facsimile	+61 2 8594 0499
Email	aruming@barnson.com.au	Email	au.environmental.sydney@sgs.com
Project	**39941**	SGS Reference	**SE270711 R0**
Order Number	**39941**	Date Received	9/9/2024
Samples	3	Date Reported	17/9/2024

COMMENTS

Accredited for compliance with ISO/IEC 17025 - Testing. NATA accredited laboratory 2562(4354).

SPOCAS and Chromium Suite subcontracted to SGS Cairns, 2/58 Comport St, Portsmith QLD 4870, NATA Accreditation Number: 2562, Site Number: 3146. Report No.

SIGNATORIES

Shane MCDERMOTT
Laboratory Manager

Ying Ying ZHANG
Laboratory Technician

Field pH for Acid Sulphate Soil [AN104] Tested: 12/9/2024

PARAMETER	UOM	LOR	3-1000 SOIL - 5/9/2024 SE270711.001	3-2000 SOIL - 5/9/2024 SE270711.002	3-3000 SOIL - 5/9/2024 SE270711.003
pHf	pH Units	-	8.1	6.7	5.1
pHfox	pH Units	-	6.8	4.0	4.0
Reaction Rate (pHfox)*	No unit	-	4	1	1
pH Difference*	pH Units	-10	1.4	2.8	1.2

pH in soil (1:5) [AN101] Tested: 12/9/2024

PARAMETER	UOM	LOR	3-1000 SOIL - 5/9/2024 SE270711.001	3-2000 SOIL - 5/9/2024 SE270711.002	3-3000 SOIL - 5/9/2024 SE270711.003
pH	pH Units	0.1	8.0	7.3	6.7

Conductivity and TDS by Calculation - Soil [AN106] Tested: 12/9/2024

PARAMETER	UOM	LOR	3-1000 SOIL - 5/9/2024 SE270711.001	3-2000 SOIL - 5/9/2024 SE270711.002	3-3000 SOIL - 5/9/2024 SE270711.003
Conductivity of Extract (1:5 dry sample basis)	µS/cm	1	61	14	11

Moisture Content [AN002] Tested: 11/9/2024

			3-1000	3-2000	3-3000
			SOIL	SOIL	SOIL
			-	-	-
			5/9/2024	5/9/2024	5/9/2024
PARAMETER	UOM	LOR	SE270711.001	SE270711.002	SE270711.003
% Moisture	%w/w	1	9.3	16.4	17.9

TAA (Titratable Actual Acidity) [AN219] Tested: 17/9/2024

			3-1000	3-2000	3-3000
			SOIL	SOIL	SOIL
			-	-	-
			5/9/2024	5/9/2024	5/9/2024
PARAMETER	UOM	LOR	SE270711.001	SE270711.002	SE270711.003
pH KCl*	pH Units	-	**9.2**	**7.3**	**6.3**
Titratable Actual Acidity	kg H2SO4/T	0.25	<0.25	<0.25	<0.25
Titratable Actual Acidity (TAA) moles H+/tonne	moles H+/T	5	<5	<5	<5
Titratable Actual Acidity (TAA) S%w/w	%w/w S	0.01	<0.01	<0.01	<0.01
Sulphur (SKCl)	%w/w	0.005	<0.005	<0.005	<0.005
Calcium (CaKCl)	%w/w	0.005	**0.20**	**0.017**	**0.013**
Magnesium (MgKCl)	%w/w	0.005	**0.006**	<0.005	<0.005

TPA (Titratable Peroxide Acidity) [AN218] Tested: 17/9/2024

PARAMETER	UOM	LOR	3-1000 SOIL - 5/9/2024 SE270711.001	3-2000 SOIL - 5/9/2024 SE270711.002	3-3000 SOIL - 5/9/2024 SE270711.003
Peroxide pH (pH Ox)	pH Units	-	8.8	4.2	3.8
TPA as kg H_2SO_4/tonne	kg H2SO4/T	0.25	<0.25	<0.25	<0.25
TPA as moles H+/tonne	moles H+/T	5	<5	<5	<5
TPA as S % W/W	%w/w S	0.01	<0.01	<0.01	<0.01
Titratable Sulfidic Acidity as moles H+/tonne	moles H+/T	5	<5	<5	<5
Titratable Sulfidic Acidity as kg H_2SO_4/tonne	kg H2SO4/T	0.25	<0.25	<0.25	<0.25
Titratable Sulfidic Acidity as S % W/W	%w/w S	0.01	<0.01	<0.01	<0.01
ANCE as % $CaCO_3$	% CaCO3	0.01	0.81	<0.01	<0.01
ANCE as moles H+/tonne	moles H+/T	5	161	<5	<5
ANCE as S % W/W	%w/w S	0.01	0.26	<0.01	<0.01
Peroxide Oxidisable Sulphur (Spos)*	%w/w	0.005	<0.005	0.006	0.007
Peroxide Oxidisable Sulphur as moles H+/tonne*	moles H+/T	5	<5	<5	<5
Sulphur (Sp)	%w/w	0.005	0.008	0.007	0.008
Calcium (Cap)	%w/w	0.005	0.36	0.019	0.015
Reacted Calcium (CaA)*	%w/w	0.005	0.16	<0.005	<0.005
Reacted Calcium (CaA)*	moles H+/T	5	81	<5	<5
Magnesium (Mgp)	%w/w	0.005	0.013	<0.005	<0.005
Reacted Magnesium (MgA)*	%w/w	0.005	0.008	<0.005	<0.005
Reacted Magnesium (MgA)*	moles H+/T	5	6	<5	<5
Net Acid Soluble Sulphur as % w/w*	%w/w	0.005	-	-	-
Net Acid Soluble Sulphur as moles H+/tonne*	moles H+/T	5	-	-	-

SPOCAS Net Acidity Calculations [AN220] Tested: 17/9/2024

PARAMETER	UOM	LOR	3-1000 SOIL - 5/9/2024 SE270711.001	3-2000 SOIL - 5/9/2024 SE270711.002	3-3000 SOIL - 5/9/2024 SE270711.003
s-Net Acidity	%w/w S	0.005	<0.005	<0.005	<0.005
a-Net Acidity	moles H+/T	5	<5	<5	**6**
Liming Rate*	kg CaCO3/T	0.1	<0.1	<0.1	-
Verification s-Net Acidity*	%w/w S	-20	**-0.17**	**0.00**	**0.00**
a-Net Acidity without ANCE*	moles H+/T	5	<5	<5	**6**
Liming Rate without ANCE*	kg CaCO3/T	0.1	<0.1	<0.1	-

Chromium Reducible Sulfur (CRS) [AN217] Tested: 17/9/2024

PARAMETER	UOM	LOR	3-1000 SOIL - 5/9/2024 SE270711.001	3-2000 SOIL - 5/9/2024 SE270711.002	3-3000 SOIL - 5/9/2024 SE270711.003
Chromium Reducible Sulfur (Scr)	%	0.005	<0.005	<0.005	<0.005
Chromium Reducible Sulfur (Scr)	moles H+/T	5	<5	<5	<5

Acid Neutralising Capacity (ANC) [AN214] Tested: 17/9/2024

PARAMETER	UOM	LOR	3-1000 SOIL - 5/9/2024 SE270711.001	3-2000 SOIL - 5/9/2024 SE270711.002
Acid Neutralisation Capacity (ANCBT) as % $CaCO_3$	% CaCO3	0.1	1.1	0.1
Acid Neutralisation Capacity (ANCBT) as kg H_2SO_4/t	kg H2SO4/T	0.1	11	1.2
ANC as % $CaCO_3$	% CaCO3	0.1	1.1	0.1
Lime Equivalence	% CaCO3	0.1	1.1	0.1
Acid Neutralisation Capacity (ANCBT) as acidity units	moles H+/T	3	220	25
Acid Neutralisation Capacity (ANCBT) as % S	%w/w S	0.005	0.36	0.040

Chromium Suite Net Acidity Calculations [AN220] Tested: 17/9/2024

			3-1000	3-2000	3-3000
			SOIL	SOIL	SOIL
			-	-	-
			5/9/2024	5/9/2024	5/9/2024
PARAMETER	UOM	LOR	SE270711.001	SE270711.002	SE270711.003
s-Net Acidity	%w/w S	0.005	<0.005	<0.005	<0.005
a-Net Acidity	moles H+/T	5	<5	<5	<5
Liming Rate*	kg CaCO3/T	0.1	<0.1	<0.1	<0.1
Verification s-Net Acidity*	%w/w S	-20	-0.24	-0.03	-0.03
a-Net Acidity without ANCBT*	moles H+/T	5	<5	<5	<5
Liming Rate without ANCBT*	kg CaCO3/T	0.1	<0.1	<0.1	<0.1
s-Net Acidity without ANC	%w/w S	0.005	<0.005	<0.005	<0.005

METHOD	METHODOLOGY SUMMARY
AN002	The test is carried out by drying (at either 40°C or 105°C) a known mass of sample in a weighed evaporating basin. After fully dry the sample is re-weighed. Samples such as sludge and sediment having high percentages of moisture will take some time in a drying oven for complete removal of water.
AN014	This method is for the determination of soluble sulfate (SO4-S) by extraction with hydrochloric acid. Sulphides should not react and would normally be expelled. Sulfate as Sulfur is determined by ICP.
AN101	pH in Soil Sludge Sediment and Water: pH is measured electrometrically using a combination electrode and is calibrated against 3 buffers purchased commercially. For soils, sediments and sludges, an extract with water (or 0.01M CaCl2) is made at a ratio of 1:5 and the pH determined and reported on the extract. Reference APHA 4500-H+.
AN104	pHF is determined on an extract of approximately 2g of as received sample in approximately 10 mL of deionised water with pH determined after standing 30 minutes.
AN104	pHFox is determined on an extract of approximately 2g of as received sample with a few mLs of 30% hydrogen peroxide (adjusted to pH 4.5 to 5.5) with the extract reaction being rated from slight to extreme, with pH determined after reaction is complete and extract has cooled. Referenced to ASS Laboratory Methods Guidelines, method 23Af-Bf, 2004. 0 No Reaction 1 Slight Reaction 2 Moderate Reaction 3 Strong/High Reaction 4 Extreme/Vigorous Reaction (gas evolution and heat generation)
AN106	Conductivity and TDS by Calculation: Conductivity is measured by meter with temperature compensation and is calibrated against a standard solution of potassium chloride. Conductivity is generally reported as µmhos/cm or µS/cm @ 25°C. For soils, an extract of as received sample with water is made at a ratio of 1:5 and the EC determined and reported on the extract, or calculated back to the as-received sample. Salinity can be estimated from conductivity using a conversion factor, which for natural waters, is in the range 0.55 to 0.75. Reference APHA 2510 B.
AN214	Acid Neutralising Capacity (ANC)or Neutralising Value (NV): The crushed or as received sample is reacted with excess normal acid (HCl) and then back titrated with standard sodium hydroxide to determine the acid consumed. The result is expressed as kg H2SO4/tonne or %CaCO3. Based on AS4969-13.
AN217	Dried pulped sample is mixed with acid and chromium metal in a rapid distillation unit to produce hydrogen sulfide (H2S) which is collected and titrated with iodine (I2(aq)) to measure SCR.
AN218	Soil samples are subjected to extreme oxidising conditions using hydrogen peroxide. Continuous application of heat and peroxide ensure all sulfide is converted to sulfuric acid. Excess peroxide is broken down by a copper catalyst prior to titration for acidity. Calcium, magnesium, and sulfur are determined by ICP-OES. Also included is a carbonate modification step which, depending on pH after the initial oxidation, gives a measure of ANC.
AN219	Dried pulped sample is extracted for 4 hours in a 1 M KCl solution. The ratio of sample to solution is 1:40. The extract is titrated for acidity. Calcium, magnesium, and sulfur are determined by ICP-AES.
AN220	Chromium Suite: Scheme for the calculation of net acidities and liming rates using a Fineness Factor of 1.5.

FOOTNOTES

*	NATA accreditation does not cover the performance of this service.	-	Not analysed.	UOM	Unit of Measure.
**	Indicative data, theoretical holding time exceeded.	NVL	Not validated.	LOR	Limit of Reporting.
***	Indicates that both * and ** apply.	IS	Insufficient sample for analysis.	↑↓	Raised/lowered Limit of Reporting.
		LNR	Sample listed, but not received.		

Unless it is reported that sampling has been performed by SGS, the samples have been analysed as received.
Solid samples expressed on a dry weight basis.

Where "Total" analyte groups are reported (for example, Total PAHs, Total OC Pesticides) the total will be calculated as the sum of the individual analytes, with those analytes that are reported as <LOR being assumed to be zero. The summed (Total) limit of reporting is calculated by summing the individual analyte LORs and dividing by two. For example, where 16 individual analytes are being summed and each has an LOR of 0.1 mg/kg, the "Totals" LOR will be 1.6 / 2 (0.8 mg/kg). Where only 2 analytes are being summed, the " Total" LOR will be the sum of those two LORs.

Some totals may not appear to add up because the total is rounded after adding up the raw values.

If reported, measurement uncertainty follow the ± sign after the analytical result and is expressed as the expanded uncertainty calculated using a coverage factor of 2, providing a level of confidence of approximately 95%, unless stated otherwise in the comments section of this report.

Results reported for samples tested under test methods with codes starting with ARS-SOP, radionuclide or gross radioactivity concentrations are expressed in becquerel (Bq) per unit of mass or volume or per wipe as stated on the report. Becquerel is the SI unit for activity and equals one nuclear transformation per second.
Note that in terms of units of radioactivity:

a. 1 Bq is equivalent to 27 pCi
b. 37 MBq is equivalent to 1 mCi

For results reported for samples tested under test methods with codes starting with ARS-SOP, less than (<) values indicate the detection limit for each radionuclide or parameter for the measurement system used. The respective detection limits have been calculated in accordance with ISO 11929.

The QC and MU criteria are subject to internal review according to the SGS QAQC plan and may be provided on request or alternatively can be found here: www.sgs.com.au/en-gb/environment-health-and-safety.

ANALYTICAL REPORT

Accreditation No. 2562

CLIENT DETAILS		LABORATORY DETAILS	
Contact	Admin	Manager	Jon Dicker
Client	SGS I&E EHS SYDNEY	Laboratory	SGS Cairns Environmental
Address	52010.000.120500.10.AU201 16/33 MADDOX STREET ALEXANDRIA NSW 2015	Address	Unit 2, 58 Comport St Portsmith QLD 4870
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Email	au.environmental.sydney@sgs.com	Email	AU.Environmental.Cairns@sgs.com
Project	**39941**	SGS Reference	**CE177330 R0**
Order Number	**SE270711**	Date Received	10 Sep 2024
Samples	3	Date Reported	16 Sep 2024

COMMENTS

Accredited for compliance with ISO/IEC 17025 - Testing. NATA accredited laboratory 2562(3146)

SIGNATORIES

Jon DICKER
Manager Northern QLD

Maristela GANZAN
Quality Manager

Parameter	Units	LOR	Sample Number: CE177330.001 Sample Matrix: Soil Sample Date: 05 Sep 2024 Sample Name: SE270711.001	CE177330.002 Soil 05 Sep 2024 SE270711.002	CE177330.003 Soil 05 Sep 2024 SE270711.003

Moisture Content Method: AN002 Tested: 11/9/2024

% Moisture	%w/w	0.5	9.2	17	21

TAA (Titratable Actual Acidity) Method: AN219 Tested: 16/9/2024

pH KCl	pH Units	-	9.2	7.3	6.3
Titratable Actual Acidity	kg H2SO4/T	0.25	<0.25	<0.25	<0.25
Titratable Actual Acidity (TAA) moles H+/tonne	moles H+/T	5	<5	<5	<5
Titratable Actual Acidity (TAA) S%w/w	%w/w S	0.01	<0.01	<0.01	<0.01
Sulphur (SKCl)	%w/w	0.005	<0.005	<0.005	<0.005
Calcium (CaKCl)	%w/w	0.005	0.20	0.017	0.013
Magnesium (MgKCl)	%w/w	0.005	0.006	<0.005	<0.005

Chromium Reducible Sulfur (CRS) Method: AN217 Tested: 16/9/2024

Chromium Reducible Sulfur (Scr)	%	0.005	<0.005	<0.005	<0.005
Chromium Reducible Sulfur (Scr)	moles H+/T	5	<5	<5	<5

Acid Neutralising Capacity (ANC) Method: AN214 Tested: 16/9/2024

ANC as % $CaCO_3$	% CaCO3	0.1	1.1	0.1	-
Lime Equivalence	% CaCO3	0.1	1.1	0.1	-
Acid Neutralisation Capacity (ANCBT) as % $CaCO_3$	% CaCO3	0.1	1.1	0.1	-
Acid Neutralisation Capacity (ANCBT) as kg H_2SO_4/t	kg H2SO4/T	0.1	11	1.2	-
Acid Neutralisation Capacity (ANCBT) as acidity units	moles H+/T	3	220	25	-
Acid Neutralisation Capacity (ANCBT) as % S	%w/w S	0.005	0.36	0.040	-

Chromium Suite Net Acidity Calculations Method: AN220 Tested: 16/9/2024

s-Net Acidity	%w/w S	0.005	<0.005	<0.005	<0.005
s-Net Acidity without ANC	%w/w S	0.005	<0.005	<0.005	<0.005
a-Net Acidity	moles H+/T	5	<5	<5	<5
Liming Rate	kg CaCO3/T	0.1	<0.1	<0.1	<0.1
Verification s-Net Acidity	%w/w S	-20	-0.24	-0.03	-0.03
a-Net Acidity without ANCBT	moles H+/T	5	<5	<5	<5
Liming Rate without ANCBT	kg CaCO3/T	0.1	<0.1	<0.1	<0.1

TPA (Titratable Peroxide Acidity) Method: AN218 Tested: 16/9/2024

Peroxide pH (pH Ox)	pH Units	-	8.8	4.2	3.8
TPA as kg H_2SO_4/tonne	kg H2SO4/T	0.25	<0.25	<0.25	<0.25
TPA as moles H+/tonne	moles H+/T	5	<5	<5	<5
TPA as S % W/W	%w/w S	0.01	<0.01	<0.01	<0.01
Titratable Sulfidic Acidity as moles H+/tonne	moles H+/T	5	<5	<5	<5
Titratable Sulfidic Acidity as kg H_2SO_4/tonne	kg H2SO4/T	0.25	<0.25	<0.25	<0.25
Titratable Sulfidic Acidity as S % W/W	%w/w S	0.01	<0.01	<0.01	<0.01
ANCE as % $CaCO_3$	% CaCO3	0.01	0.81	<0.01	<0.01
ANCE as moles H+/tonne	moles H+/T	5	161	<5	<5
ANCE as S % W/W	%w/w S	0.01	0.26	<0.01	<0.01
Peroxide Oxidisable Sulphur (Spos)	%w/w	0.005	<0.005	0.006	0.007
Peroxide Oxidisable Sulphur as moles H+/tonne	moles H+/T	5	<5	<5	<5
Sulphur (Sp)	%w/w	0.005	0.008	0.007	0.008
Calcium (Cap)	%w/w	0.005	0.36	0.019	0.015
Reacted Calcium (CaA)	%w/w	0.005	0.16	<0.005	<0.005
Reacted Calcium (CaA)	moles H+/T	5	81	<5	<5
Magnesium (Mgp)	%w/w	0.005	0.013	<0.005	<0.005
Reacted Magnesium (MgA)	%w/w	0.005	0.008	<0.005	<0.005
Reacted Magnesium (MgA)	moles H+/T	5	6	<5	<5
Net Acid Soluble Sulphur as % w/w	%w/w	0.005	-	-	-
Net Acid Soluble Sulphur as moles H+/tonne	moles H+/T	5	-	-	-

Parameter	Units	LOR	CE177330.001	CE177330.002	CE177330.003
		Sample Matrix	Soil	Soil	Soil
		Sample Date	05 Sep 2024	05 Sep 2024	05 Sep 2024
		Sample Name	SE270711.001	SE270711.002	SE270711.003

SPOCAS Net Acidity Calculations   Method: AN220   Tested: 16/9/2024

Parameter	Units	LOR	CE177330.001	CE177330.002	CE177330.003
s-Net Acidity	%w/w S	0.005	<0.005	<0.005	<0.005
a-Net Acidity	moles H+/T	5	<5	<5	6
Liming Rate	kg CaCO3/T	0.1	<0.1	<0.1	NA
Verification s-Net Acidity	%w/w S	-20	-0.17	0.00	0.00
a-Net Acidity without ANCE	moles H+/T	5	<5	<5	6
Liming Rate without ANCE	kg CaCO3/T	0.1	<0.1	<0.1	NA

MB blank results are compared to the Limit of Reporting
LCS and MS spike recoveries are measured as the percentage of analyte recovered from the sample compared the the amount of analyte spiked into the sample.
DUP and MSD relative percent differences are measured against their original counterpart samples according to the formula : *the absolute difference of the two results divided by the average of the two results as a percentage*. Where the DUP RPD is 'NA' , the results are less than the LOR and thus the RPD is not applicable.

Acid Neutralising Capacity (ANC) Method: ME-(AU)-[ENV]AN214

Parameter	QC Reference	Units	LOR	MB	DUP %RPD	LCS %Recovery
ANC as % $CaCO_3$	LB132596	% CaCO3	0.1	<0.1	0%	NA
Lime Equivalence	LB132596	% CaCO3	0.1	<0.1		
Acid Neutralisation Capacity (ANCBT) as % $CaCO_3$	LB132596	% CaCO3	0.1	<0.1	0%	104%
Acid Neutralisation Capacity (ANCBT) as kg H_2SO_4/t	LB132596	kg H2SO4/T	0.1	<0.1	0%	NA
Acid Neutralisation Capacity (ANCBT) as acidity units	LB132596	moles H+/T	3	<3	0%	NA
Acid Neutralisation Capacity (ANCBT) as % S	LB132596	%w/w S	0.005	<0.005	0%	NA

Chromium Reducible Sulfur (CRS) Method: ME-(AU)-[ENV]AN217

Parameter	QC Reference	Units	LOR	MB	DUP %RPD	LCS %Recovery
Chromium Reducible Sulfur (Scr)	LB132560	%	0.005	<0.005	0%	108%
Chromium Reducible Sulfur (Scr)	LB132560	moles H+/T	5	<5		

TAA (Titratable Actual Acidity) Method: ME-(AU)-[ENV]AN219

Parameter	QC Reference	Units	LOR	MB	DUP %RPD	LCS %Recovery
pH KCl	LB132561	pH Units	-	5.8	0 - 2%	101%
Titratable Actual Acidity	LB132561	kg H2SO4/T	0.25	<0.25	0%	NA
Titratable Actual Acidity (TAA) moles H+/tonne	LB132561	moles H+/T	5	<5	0%	105%
Titratable Actual Acidity (TAA) S%w/w	LB132561	%w/w S	0.01	<0.01	0%	106%
Sulphur (SKCl)	LB132561	%w/w	0.005	<0.005	0%	85%
Calcium (CaKCl)	LB132561	%w/w	0.005	<0.005	2%	97%
Magnesium (MgKCl)	LB132561	%w/w	0.005	<0.005	0%	96%

TPA (Titratable Peroxide Acidity) Method: ME-(AU)-[ENV]AN218

Parameter	QC Reference	Units	LOR	MB	DUP %RPD	LCS %Recovery
Peroxide pH (pH Ox)	LB132562	pH Units	-	6.3	0%	100%
TPA as kg H_2SO_4/tonne	LB132562	kg H2SO4/T	0.25	<0.25	0%	116%
TPA as moles H+/tonne	LB132562	moles H+/T	5	<5	0%	115%
TPA as S % W/W	LB132562	%w/w S	0.01	<0.01	0%	115%
ANCE as % $CaCO_3$	LB132562	% CaCO3	0.01	<0.01	0%	
ANCE as moles H+/tonne	LB132562	moles H+/T	5	<5	0%	
ANCE as S % W/W	LB132562	%w/w S	0.01	<0.01	0%	
Sulphur (Sp)	LB132562	%w/w	0.005	<0.005	0%	93%
Calcium (Cap)	LB132562	%w/w	0.005	<0.005	2%	105%
Magnesium (Mgp)	LB132562	%w/w	0.005	<0.005	0%	104%

METHOD	METHODOLOGY SUMMARY
AN002	The test is carried out by drying (at either 40°C or 105°C) a known mass of sample in a weighed evaporating basin. After fully dry the sample is re-weighed. Samples such as sludge and sediment having high percentages of moisture will take some time in a drying oven for complete removal of water.
AN214	Acid Neutralising Capacity (ANC)or Neutralising Value (NV): The crushed or as received sample is reacted with excess normal acid (HCl) and then back titrated with standard sodium hydroxide to determine the acid consumed. The result is expressed as kg H2SO4/tonne or %CaCO3. Based on AS4969-13.
AN217	Dried pulped sample is mixed with acid and chromium metal in a rapid distillation unit to produce hydrogen sulfide (H2S) which is collected and titrated with iodine (I2(aq)) to measure SCR.
AN218	Soil samples are subjected to extreme oxidising conditions using hydrogen peroxide. Continuous application of heat and peroxide ensure all sulfide is converted to sulfuric acid. Excess peroxide is broken down by a copper catalyst prior to titration for acidity. Calcium, magnesium, and sulfur are determined by ICP-OES. Also included is a carbonate modification step which, depending on pH after the initial oxidation, gives a measure of ANC.
AN219	Dried pulped sample is extracted for 4 hours in a 1 M KCl solution. The ratio of sample to solution is 1:40. The extract is titrated for acidity. Calcium, magnesium, and sulfur are determined by ICP-AES.
AN220	Chromium Suite: Scheme for the calculation of net acidities and liming rates using a Fineness Factor of 1.5.

FOOTNOTES

IS	Insufficient sample for analysis.	LOR	Limit of Reporting
LNR	Sample listed, but not received.	↑↓	Raised or Lowered Limit of Reporting
*	NATA accreditation does not cover the performance of this service.	QFH	QC result is above the upper tolerance
		QFL	QC result is below the lower tolerance
**	Indicative data, theoretical holding time exceeded.	-	The sample was not analysed for this analyte
***	Indicates that both * and ** apply.	NVL	Not Validated

Unless it is reported that sampling has been performed by SGS, the samples have been analysed as received.
Solid samples expressed on a dry weight basis.

Where "Total" analyte groups are reported (for example, Total PAHs, Total OC Pesticides) the total will be calculated as the sum of the individual analytes, with those analytes that are reported as <LOR being assumed to be zero. The summed (Total) limit of reporting is calcuated by summing the individual analyte LORs and dividing by two. For example, where 16 individual analytes are being summed and each has an LOR of 0.1 mg/kg, the "Totals" LOR will be 1.6 / 2 (0.8 mg/kg). Where only 2 analytes are being summed, the " Total" LOR will be the sum of those two LORs.

Some totals may not appear to add up because the total is rounded after adding up the raw values.

If reported, measurement uncertainty follow the ± sign after the analytical result and is expressed as the expanded uncertainty calculated using a coverage factor of 2, providing a level of confidence of approximately 95%, unless stated otherwise in the comments section of this report.

Results reported for samples tested under test methods with codes starting with ARS-SOP, radionuclide or gross radioactivity concentrations are expressed in becquerel (Bq) per unit of mass or volume or per wipe as stated on the report. Becquerel is the SI unit for activity and equals one nuclear transformation per second.
Note that in terms of units of radioactivity:

a. 1 Bq is equivalent to 27 pCi
b. 37 MBq is equivalent to 1 mCi

For results reported for samples tested under test methods with codes starting with ARS-SOP, less than (<) values indicate the detection limit for each radionuclide or parameter for the measurement system used. The respective detection limits have been calculated in accordance with ISO 11929.

The QC and MU criteria are subject to internal review according to the SGS QAQC plan and may be provided on request or alternatively can be found here: www.sgs.com.au/en-gb/environment-health-and-safety.

Appendix E - CSIRO Guide

Foundation Maintenance and Footing Performance: A Homeowner's Guide

BTF 18 replaces Information Sheet 10/91

Buildings can and often do move. This movement can be up, down, lateral or rotational. The fundamental cause of movement in buildings can usually be related to one or more problems in the foundation soil. It is important for the homeowner to identify the soil type in order to ascertain the measures that should be put in place in order to ensure that problems in the foundation soil can be prevented, thus protecting against building movement.

This Building Technology File is designed to identify causes of soil-related building movement, and to suggest methods of prevention of resultant cracking in buildings.

Soil Types

The types of soils usually present under the topsoil in land zoned for residential buildings can be split into two approximate groups – granular and clay. Quite often, foundation soil is a mixture of both types. The general problems associated with soils having granular content are usually caused by erosion. Clay soils are subject to saturation and swell/shrink problems.

Classifications for a given area can generally be obtained by application to the local authority, but these are sometimes unreliable and if there is doubt, a geotechnical report should be commissioned. As most buildings suffering movement problems are founded on clay soils, there is an emphasis on classification of soils according to the amount of swell and shrinkage they experience with variations of water content. The table below is Table 2.1 from AS 2870, the Residential Slab and Footing Code.

Causes of Movement

Settlement due to construction

There are two types of settlement that occur as a result of construction:

- Immediate settlement occurs when a building is first placed on its foundation soil, as a result of compaction of the soil under the weight of the structure. The cohesive quality of clay soil mitigates against this, but granular (particularly sandy) soil is susceptible.
- Consolidation settlement is a feature of clay soil and may take place because of the expulsion of moisture from the soil or because of the soil's lack of resistance to local compressive or shear stresses. This will usually take place during the first few months after construction, but has been known to take many years in exceptional cases.

These problems are the province of the builder and should be taken into consideration as part of the preparation of the site for construction. Building Technology File 19 (BTF 19) deals with these problems.

Erosion

All soils are prone to erosion, but sandy soil is particularly susceptible to being washed away. Even clay with a sand component of say 10% or more can suffer from erosion.

Saturation

This is particularly a problem in clay soils. Saturation creates a bog-like suspension of the soil that causes it to lose virtually all of its bearing capacity. To a lesser degree, sand is affected by saturation because saturated sand may undergo a reduction in volume – particularly imported sand fill for bedding and blinding layers. However, this usually occurs as immediate settlement and should normally be the province of the builder.

Seasonal swelling and shrinkage of soil

All clays react to the presence of water by slowly absorbing it, making the soil increase in volume (see table below). The degree of increase varies considerably between different clays, as does the degree of decrease during the subsequent drying out caused by fair weather periods. Because of the low absorption and expulsion rate, this phenomenon will not usually be noticeable unless there are prolonged rainy or dry periods, usually of weeks or months, depending on the land and soil characteristics.

The swelling of soil creates an upward force on the footings of the building, and shrinkage creates subsidence that takes away the support needed by the footing to retain equilibrium.

Shear failure

This phenomenon occurs when the foundation soil does not have sufficient strength to support the weight of the footing. There are two major post-construction causes:

- Significant load increase.
- Reduction of lateral support of the soil under the footing due to erosion or excavation.
- In clay soil, shear failure can be caused by saturation of the soil adjacent to or under the footing.

GENERAL DEFINITIONS OF SITE CLASSES

Class	Foundation
A	Most sand and rock sites with little or no ground movement from moisture changes
S	Slightly reactive clay sites with only slight ground movement from moisture changes
M	Moderately reactive clay or silt sites, which can experience moderate ground movement from moisture changes
H	Highly reactive clay sites, which can experience high ground movement from moisture changes
E	Extremely reactive sites, which can experience extreme ground movement from moisture changes
A to P	Filled sites
P	Sites which include soft soils, such as soft clay or silt or loose sands; landslip; mine subsidence; collapsing soils; soils subject to erosion; reactive sites subject to abnormal moisture conditions or sites which cannot be classified otherwise

Tree root growth

Trees and shrubs that are allowed to grow in the vicinity of footings can cause foundation soil movement in two ways:

- Roots that grow under footings may increase in cross-sectional size, exerting upward pressure on footings.
- Roots in the vicinity of footings will absorb much of the moisture in the foundation soil, causing shrinkage or subsidence.

Unevenness of Movement

The types of ground movement described above usually occur unevenly throughout the building's foundation soil. Settlement due to construction tends to be uneven because of:

- Differing compaction of foundation soil prior to construction.
- Differing moisture content of foundation soil prior to construction.

Movement due to non-construction causes is usually more uneven still. Erosion can undermine a footing that traverses the flow or can create the conditions for shear failure by eroding soil adjacent to a footing that runs in the same direction as the flow.

Saturation of clay foundation soil may occur where subfloor walls create a dam that makes water pond. It can also occur wherever there is a source of water near footings in clay soil. This leads to a severe reduction in the strength of the soil which may create local shear failure.

Seasonal swelling and shrinkage of clay soil affects the perimeter of the building first, then gradually spreads to the interior. The swelling process will usually begin at the uphill extreme of the building, or on the weather side where the land is flat. Swelling gradually reaches the interior soil as absorption continues. Shrinkage usually begins where the sun's heat is greatest.

Effects of Uneven Soil Movement on Structures

Erosion and saturation

Erosion removes the support from under footings, tending to create subsidence of the part of the structure under which it occurs. Brickwork walls will resist the stress created by this removal of support by bridging the gap or cantilevering until the bricks or the mortar bedding fail. Older masonry has little resistance. Evidence of failure varies according to circumstances and symptoms may include:

- Step cracking in the mortar beds in the body of the wall or above/below openings such as doors or windows.
- Vertical cracking in the bricks (usually but not necessarily in line with the vertical beds or perpends).

Isolated piers affected by erosion or saturation of foundations will eventually lose contact with the bearers they support and may tilt or fall over. The floors that have lost this support will become bouncy, sometimes rattling ornaments etc.

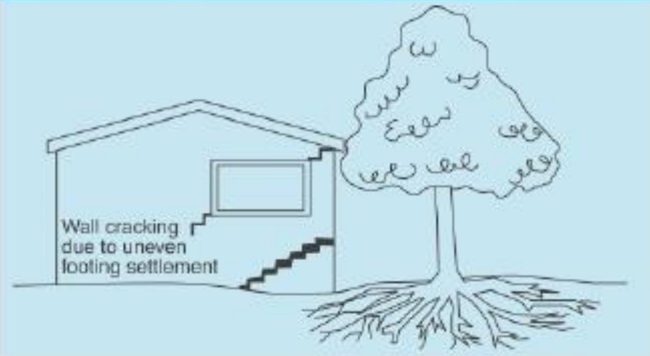
Seasonal swelling/shrinkage in clay

Swelling foundation soil due to rainy periods first lifts the most exposed extremities of the footing system, then the remainder of the perimeter footings while gradually permeating inside the building footprint to lift internal footings. This swelling first tends to create a dish effect, because the external footings are pushed higher than the internal ones.

The first noticeable symptom may be that the floor appears slightly dished. This is often accompanied by some doors binding on the floor or the door head, together with some cracking of cornice mitres. In buildings with timber flooring supported by bearers and joists, the floor can be bouncy. Externally there may be visible dishing of the hip or ridge lines.

As the moisture absorption process completes its journey to the innermost areas of the building, the internal footings will rise. If the spread of moisture is roughly even, it may be that the symptoms will temporarily disappear, but it is more likely that swelling will be uneven, creating a difference rather than a disappearance in symptoms. In buildings with timber flooring supported by bearers and joists, the isolated piers will rise more easily than the strip footings or piers under walls, creating noticeable doming of flooring.

Trees can cause shrinkage and damage



As the weather pattern changes and the soil begins to dry out, the external footings will be first affected, beginning with the locations where the sun's effect is strongest. This has the effect of lowering the external footings. The doming is accentuated and cracking reduces or disappears where it occurred because of dishing, but other cracks open up. The roof lines may become convex.

Doming and dishing are also affected by weather in other ways. In areas where warm, wet summers and cooler dry winters prevail, water migration tends to be toward the interior and doming will be accentuated, whereas where summers are dry and winters are cold and wet, migration tends to be toward the exterior and the underlying propensity is toward dishing.

Movement caused by tree roots

In general, growing roots will exert an upward pressure on footings, whereas soil subject to drying because of tree or shrub roots will tend to remove support from under footings by inducing shrinkage.

Complications caused by the structure itself

Most forces that the soil causes to be exerted on structures are vertical – i.e. either up or down. However, because these forces are seldom spread evenly around the footings, and because the building resists uneven movement because of its rigidity, forces are exerted from one part of the building to another. The net result of all these forces is usually rotational. This resultant force often complicates the diagnosis because the visible symptoms do not simply reflect the original cause. A common symptom is binding of doors on the vertical member of the frame.

Effects on full masonry structures

Brickwork will resist cracking where it can. It will attempt to span areas that lose support because of subsided foundations or raised points. It is therefore usual to see cracking at weak points, such as openings for windows or doors.

In the event of construction settlement, cracking will usually remain unchanged after the process of settlement has ceased.

With local shear or erosion, cracking will usually continue to develop until the original cause has been remedied, or until the subsidence has completely neutralised the affected portion of footing and the structure has stabilised on other footings that remain effective.

In the case of swell/shrink effects, the brickwork will in some cases return to its original position after completion of a cycle, however it is more likely that the rotational effect will not be exactly reversed, and it is also usual that brickwork will settle in its new position and will resist the forces trying to return it to its original position. This means that in a case where swelling takes place after construction and cracking occurs, the cracking is likely to at least partly remain after the shrink segment of the cycle is complete. Thus, each time the cycle is repeated, the likelihood is that the cracking will become wider until the sections of brickwork become virtually independent.

With repeated cycles, once the cracking is established, if there is no other complication, it is normal for the incidence of cracking to stabilise, as the building has the articulation it needs to cope with the problem. This is by no means always the case, however, and monitoring of cracks in walls and floors should always be treated seriously.

Upheaval caused by growth of tree roots under footings is not a simple vertical shear stress. There is a tendency for the root to also exert lateral forces that attempt to separate sections of brickwork after initial cracking has occurred.

The normal structural arrangement is that the inner leaf of brickwork in the external walls and at least some of the internal walls (depending on the roof type) comprise the load-bearing structure on which any upper floors, ceilings and the roof are supported. In these cases, it is internally visible cracking that should be the main focus of attention, however there are a few examples of dwellings whose external leaf of masonry plays some supporting role, so this should be checked if there is any doubt. In any case, externally visible cracking is important as a guide to stresses on the structure generally, and it should also be remembered that the external walls must be capable of supporting themselves.

Effects on framed structures
Timber or steel framed buildings are less likely to exhibit cracking due to swell/shrink than masonry buildings because of their flexibility. Also, the doming/dishing effects tend to be lower because of the lighter weight of walls. The main risks to framed buildings are encountered because of the isolated pier footings used under walls. Where erosion or saturation cause a footing to fall away, this can double the span which a wall must bridge. This additional stress can create cracking in wall linings, particularly where there is a weak point in the structure caused by a door or window opening. It is, however, unlikely that framed structures will be so stressed as to suffer serious damage without first exhibiting some or all of the above symptoms for a considerable period. The same warning period should apply in the case of upheaval. It should be noted, however, that where framed buildings are supported by strip footings there is only one leaf of brickwork and therefore the externally visible walls are the supporting structure for the building. In this case, the subfloor masonry walls can be expected to behave as full brickwork walls.

Effects on brick veneer structures
Because the load-bearing structure of a brick veneer building is the frame that makes up the interior leaf of the external walls plus perhaps the internal walls, depending on the type of roof, the building can be expected to behave as a framed structure, except that the external masonry will behave in a similar way to the external leaf of a full masonry structure.

Water Service and Drainage

Where a water service pipe, a sewer or stormwater drainage pipe is in the vicinity of a building, a water leak can cause erosion, swelling or saturation of susceptible soil. Even a minuscule leak can be enough to saturate a clay foundation. A leaking tap near a building can have the same effect. In addition, trenches containing pipes can become watercourses even though backfilled, particularly where broken rubble is used as fill. Water that runs along these trenches can be responsible for serious erosion, interstrata seepage into subfloor areas and saturation.

Pipe leakage and trench water flows also encourage tree and shrub roots to the source of water, complicating and exacerbating the problem.
Poor roof plumbing can result in large volumes of rainwater being concentrated in a small area of soil:

- Incorrect falls in roof guttering may result in overflows, as may gutters blocked with leaves etc.
- Corroded guttering or downpipes can spill water to ground.
- Downpipes not positively connected to a proper stormwater collection system will direct a concentration of water to soil that is directly adjacent to footings, sometimes causing large-scale problems such as erosion, saturation and migration of water under the building.

Seriousness of Cracking

In general, most cracking found in masonry walls is a cosmetic nuisance only and can be kept in repair or even ignored. The table below is a reproduction of Table C1 of AS 2870.

AS 2870 also publishes figures relating to cracking in concrete floors, however because wall cracking will usually reach the critical point significantly earlier than cracking in slabs, this table is not reproduced here.

Prevention/ Cure

Plumbing
Where building movement is caused by water service, roof plumbing, sewer or stormwater failure, the remedy is to repair the problem. It is prudent, however, to consider also rerouting pipes away from the building where possible, and relocating taps to positions where any leakage will not direct water to the building vicinity. Even where gully traps are present, there is sometimes sufficient spill to create erosion or saturation, particularly in modern installations using smaller diameter PVC fixtures. Indeed, some gully traps are not situated directly under the taps that are installed to charge them, with the result that water from the tap may enter the backfilled trench that houses the sewer piping. If the trench has been poorly backfilled, the water will either pond or flow along the bottom of the trench. As these trenches usually run alongside the footings and can be at a similar depth, it is not hard to see how any water that is thus directed into a trench can easily affect the foundation's ability to support footings or even gain entry to the subfloor area.

Ground drainage
In all soils there is the capacity for water to travel on the surface and below it. Surface water flows can be established by inspection during and after heavy or prolonged rain. If necessary, a grated drain system connected to the stormwater collection system is usually an easy solution.

It is, however, sometimes necessary when attempting to prevent water migration that testing be carried out to establish watertable height and subsoil water flows. This subject is referred to in BTF 19 and may properly be regarded as an area for an expert consultant.

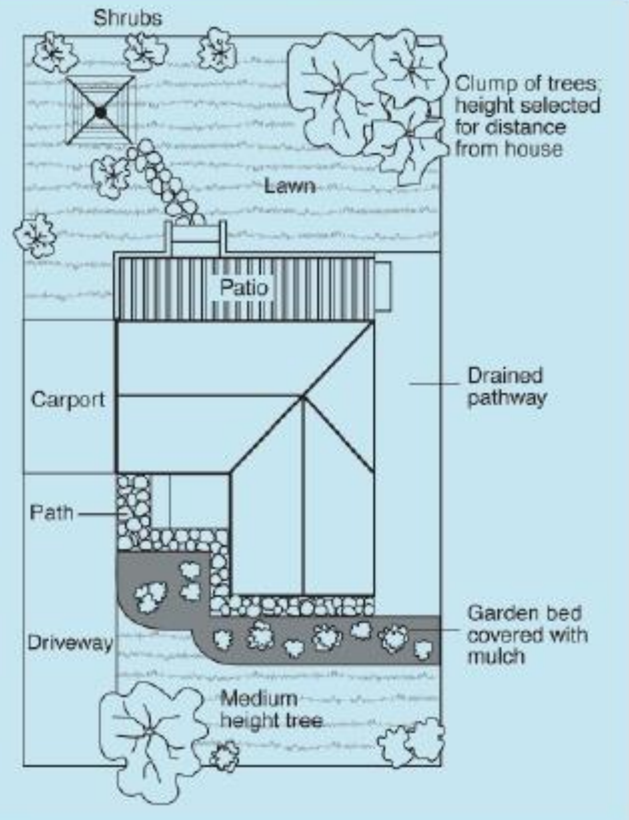
Protection of the building perimeter
It is essential to remember that the soil that affects footings extends well beyond the actual building line. Watering of garden plants, shrubs and trees causes some of the most serious water problems.

For this reason, particularly where problems exist or are likely to occur, it is recommended that an apron of paving be installed around as much of the building perimeter as necessary. This paving

CLASSIFICATION OF DAMAGE WITH REFERENCE TO WALLS

Description of typical damage and required repair	Approximate crack width limit (see Note 3)	Damage category
Hairline cracks	<0.1 mm	0
Fine cracks which do not need repair	<1 mm	1
Cracks noticeable but easily filled. Doors and windows stick slightly	<5 mm	2
Cracks can be repaired and possibly a small amount of wall will need to be replaced. Doors and windows stick. Service pipes can fracture. Weathertightness often impaired	5–15 mm (or a number of cracks 3 mm or more in one group)	3
Extensive repair work involving breaking-out and replacing sections of walls, especially over doors and windows. Window and door frames distort. Walls lean or bulge noticeably, some loss of bearing in beams. Service pipes disrupted	15–25 mm but also depend on number of cracks	4

Gardens for a reactive site



should extend outwards a minimum of 900 mm (more in highly reactive soil) and should have a minimum fall away from the building of 1:60. The finished paving should be no less than 100 mm below brick vent bases.

It is prudent to relocate drainage pipes away from this paving, if possible, to avoid complications from future leakage. If this is not practical, earthenware pipes should be replaced by PVC and backfilling should be of the same soil type as the surrounding soil and compacted to the same density.

Except in areas where freezing of water is an issue, it is wise to remove taps in the building area and relocate them well away from the building – preferably not uphill from it (see BTF 19).

It may be desirable to install a grated drain at the outside edge of the paving on the uphill side of the building. If subsoil drainage is needed this can be installed under the surface drain.

Condensation

In buildings with a subfloor void such as where bearers and joists support flooring, insufficient ventilation creates ideal conditions for condensation, particularly where there is little clearance between the floor and the ground. Condensation adds to the moisture already present in the subfloor and significantly slows the process of drying out. Installation of an adequate subfloor ventilation system, either natural or mechanical, is desirable.

Warning: Although this Building Technology File deals with cracking in buildings, it should be said that subfloor moisture can result in the development of other problems, notably:

- Water that is transmitted into masonry, metal or timber building elements causes damage and/or decay to those elements.
- High subfloor humidity and moisture content create an ideal environment for various pests, including termites and spiders.
- Where high moisture levels are transmitted to the flooring and walls, an increase in the dust mite count can ensue within the living areas. Dust mites, as well as dampness in general, can be a health hazard to inhabitants, particularly those who are abnormally susceptible to respiratory ailments.

The garden

The ideal vegetation layout is to have lawn or plants that require only light watering immediately adjacent to the drainage or paving edge, then more demanding plants, shrubs and trees spread out in that order.

Overwatering due to misuse of automatic watering systems is a common cause of saturation and water migration under footings. If it is necessary to use these systems, it is important to remove garden beds to a completely safe distance from buildings.

Existing trees

Where a tree is causing a problem of soil drying or there is the existence or threat of upheaval of footings, if the offending roots are subsidiary and their removal will not significantly damage the tree, they should be severed and a concrete or metal barrier placed vertically in the soil to prevent future root growth in the direction of the building. If it is not possible to remove the relevant roots without damage to the tree, an application to remove the tree should be made to the local authority. A prudent plan is to transplant likely offenders before they become a problem.

Information on trees, plants and shrubs

State departments overseeing agriculture can give information regarding root patterns, volume of water needed and safe distance from buildings of most species. Botanic gardens are also sources of information. For information on plant roots and drains, see Building Technology File 17.

Excavation

Excavation around footings must be properly engineered. Soil supporting footings can only be safely excavated at an angle that allows the soil under the footing to remain stable. This angle is called the angle of repose (or friction) and varies significantly between soil types and conditions. Removal of soil within the angle of repose will cause subsidence.

Remediation

Where erosion has occurred that has washed away soil adjacent to footings, soil of the same classification should be introduced and compacted to the same density. Where footings have been undermined, augmentation or other specialist work may be required. Remediation of footings and foundations is generally the realm of a specialist consultant.

Where isolated footings rise and fall because of swell/shrink effect, the homeowner may be tempted to alleviate floor bounce by filling the gap that has appeared between the bearer and the pier with blocking. The danger here is that when the next swell segment of the cycle occurs, the extra blocking will push the floor up into an accentuated dome and may also cause local shear failure in the soil. If it is necessary to use blocking, it should be by a pair of fine wedges and monitoring should be carried out fortnightly.

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