# Limited Geotechnical Investigation

At

## Lot A DP 339787
## 166 Booker Bay Road, Booker Bay

For

## W & F Laureti

22 December 2022
5QS Ref: 222093

5QS CONSULTING GROUP

www.5QS.com.au

22 December 2022
5QS Ref: 222093

**W & F Laureti**
166 Booker Bay Road
BOOKER BAY NSW 2257

Dear Mr & Mrs Laureti,

## Re: Limited Geotechnical Investigation
## Proposed Residential Development – Lot A DP 339787
## 166 Booker Bay Road, Booker Bay

The following report presents the results of a limited geotechnical investigation undertaken at the above property.

If you have any further enquiries, please do not hesitate to contact the undersigned.

For and on behalf of
**5QS Consulting Engineers NSW/ACT**

[redacted]

**Peter Fennell**
Principal

# Contents

**1. Introduction ........ 1**

**2. Site Description ........ 2**

**3. Background Information ........ 5**

3.1 Geological Setting ........ 5
3.2 Soil Landscape ........ 5
3.3 Acid Sulfate Soil Risk Mapping ........ 5

**4. Fieldwork ........ 5**

4.1 Methods ........ 5
4.2 Results ........ 6

**5. Data Interpretation ........ 9**

5.1 Proposed Development ........ 9
5.2 Interpretative Geotechnical Model ........ 9

**6. Acid Sulfate Soil Risk ........ 9**

6.1 Screen Testing ........ 9
6.2 Interpretation of Acid Sulfate Soil Risk ........ 10

**7. Comments on ASS Management ........ 10**

**8. Site Classification ........ 12**

**9. Geotechnical Guidelines for Site Development ........ 12**

9.1 Footings ........ 12
9.2 Earthworks in General ........ 13
9.3 Site Drainage ........ 14

**10. How to Use This Report ........ 14**

**11. References ........ 16**

## Attachments

1. Dynamic cone penetrometer probe logs
2. Engineering logs
3. General Notes
4. Lime Types
5. Site Classification Notes
6. CSIRO Sheet BTF18

# Limited Geotechnical Investigation

**Lot A DP 339787**
**No 166 Booker Bay Road, Booker Bay**

## 1. Introduction

As requested by Ms Louise Williams of LAW Building Design, on behalf of Mr Frank and Mrs Wendy Laureti, 5QS Consulting Engineers NSW/ACT [5QS] has carried out a limited geotechnical investigation at the above property. The purpose of the investigation was to provide factual and interpretative data on subsurface conditions, including presence of filling and depths to groundwater, and comments on the following:

- Background information on topography, site geology, soil landscape, acid sulfate soil [ASS] risk;
- Assessment of the risk of occurrence of acid sulfate soils [ASS] and the need for an ASS management plan;
- Site classification in line with Australian Standard AS 2870–2011, 'Residential slabs and footings', for on-ground slab foundation areas [Ref 1];
- Advice on suitable footing types and founding levels, and aggressivity of site soils and groundwater towards buried structural elements; and
- Geotechnical parameters for engineering design of shallow and deep footings, including maximum allowable bearing capacity and probable settlements.

For the purpose of the investigation, 5QS was provided with a pdf copy of architectural plans prepared by LAW Building Design, comprising ground and upper level floor plans, and external perspective views (front and rear) of the proposed development, Ref: 211023, in 4 sheets dated June 2022.

Based on the supplied information, it is understood that proposed development of the property will comprise additions and alterations, including a granny flat above the existing garage, and a rooftop entertaining area above the existing two-storey flexible-clad dwelling.

The scope of this assessment included a desktop review of available published information, field work and preparation of this report. The following sections give the results of the assessment and comments on the above investigation scope.

This report should be read in conjunction with the attached 'General Notes'.

## 2. Site Description

The site, identified as Lot A in DP 339787 [the site], occupies a roughly rectangular-shaped allotment with an area of some 698 $m^2$ situated on the eastern side of Booker Bay Road, Booker Bay.

The site is bounded by Booker Bay Road Road to the west, by existing residential development to the north and south, and by Brisbane Water to the east.

Ground slopes on the site are near level.

The site is occupied by a two-storey fibre flexible-clad dwelling and separate flexible-clad garages/outbuildings.

Vegetation on the site comprises established grass cover and garden shrubs.

Views of the site can be seen in photographs P1 to P5.

**Photograph P1** – View towards east, taken from Booker Bay Road

**Photograph P2** – View towards north-east, taken from footpath in front of No 166 Booker Bay Road

**Photograph P3** – View west through north, taken from edge of garden bed along southern boundary; showing existing garages and concrete-paved areas

**Photograph P4** – View towards west, taken from the jetty on Brisbane Water

**Photograph P5** – View towards north-west, taken from jetty

# 3. Background Information

## 3.1 Geological Setting

Reference to the 'Sydney 1:100 000 geological series sheet, 9130 (Edition 1)', published by the Department of Mineral Resources, Geological Survey of NSW (Ref 2) indicates that the site is underlain by beach ridge sediments of Quaternary (Holocene) age, comprising quartz sands with minor shell content, and interdune silts and fine sands.

## 3.2 Soil Landscape

According to the 'Sydney 1:100 000 soil landscape series sheet 9131–9231', and associated report published by the NSW Department of Conservation and Land Management (Ref 3) the site lies within the Narrabeen beach soil landscape.

The Narrabeen soil landscape is characterised by beaches and coastal foredunes on marine sands. Local relief is up to 6 m on beaches and less than 20 metres on foredunes. Slope gradients are less than 3 % on beaches and up to 45 % on foredunes. Limitations of the Narrabeen beach soil landscape include extreme wind and wave erosion hazard, and non-cohesive soil of very low fertility and high permeability.

## 3.3 Acid Sulfate Soil Risk Mapping

According to the Broken Bay 1:25 000 series acid sulfate soil [ASS] risk map [Ref 4], the site is situated in an area of aeolian sandplain at surface elevations in the order of 1 to 2 m to the Australian height datum [AHD] with a high probability of ASS occurrence within 1 m below the natural ground surface.

Ref 4 indicates that the site is near an inferred boundary with an area of aeolian sandplain, situated to the south-west, at surface elevations in the order of 2 to 4 m AHD which has a low probability of ASS occurrence at depths between 1 m and 3 m below the ground surface.

# 4. Fieldwork

## 4.1 Methods

The field work, carried out on 8 November 2022, comprised three dynamic cone penetrometer [DCP] tests (DCP 1, DCP 2 and DCP 3) and drilling of two boreholes (BH1 and BH2) by hand auger methods.

The boreholes and DCP tests were located approximately in plan by tape measurements relative to surface features on the site plan prepared by LAW Building Design. Surface levels at the test locations were inferred from floor levels to AHD shown on the elevations and section.

The approximate locations of the boreholes and DCP tests can be seen in Figure 1.

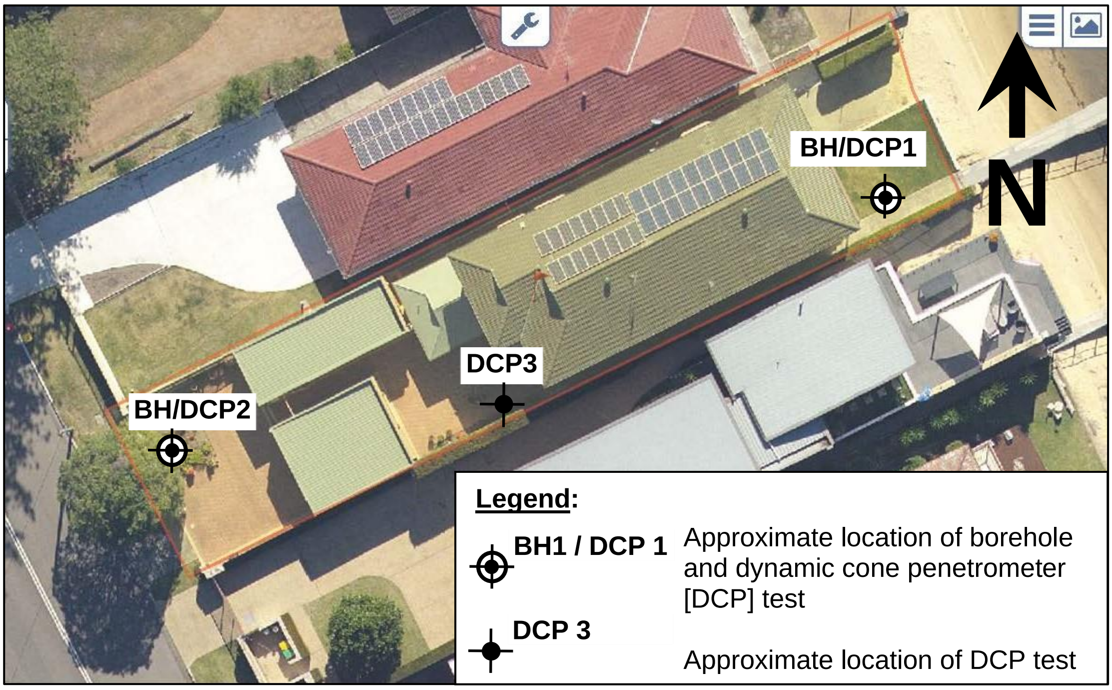



**Figure 1** – Test location plan

### 4.2 Results

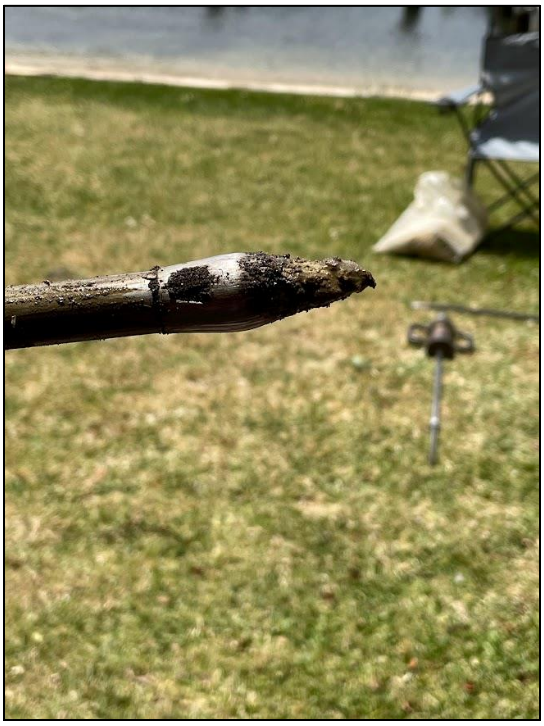
The DCP probes at test locations DCP 1, DCP 2 and DCP 3 were all driven to termination at 4 m depth below existing surface levels. The results of DCP testing were used to interpret the density / consistency of the soil profiles encountered at the borehole test locations.

The boreholes at test locations BH1 and BH2 were excavated to the limit of investigation at depths of 1.85 m and 1.3 m, respectively. The subsurface profile encountered at the borehole test locations comprised fine- to coarse-grained sand filling to depths ranging from 0.2 m to 0.9 m, overlying fine- to coarse-grained natural sand with shell fragments to the limit of investigation.

Groundwater seepage was encountered at 1.35 m depth in the borehole test location BH1 only.

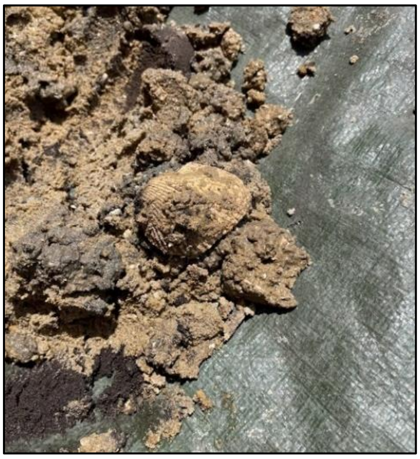
Logs of the DCP tests and engineering logs of the boreholes are provided in the attachment section of this report.

Photographs of the test results can be seen below in photos P6 to P15.




**Photographs P6 and P7** – Detail of DCP probe tip on removal, and test spoil taken at test location BH1, respectively


**Photographs P8 and P9** – Detail of spoil in Jarrett auger and spoil layers from test location BH1, respectively

**Photographs P10 and P11** – Detail of borehole and spoil, taken at test location BH3


**Photographs P12 and P13** – Detail of probe tip on removal,
taken at test locations BH3 and BH2, respectively


**Photographs P14 and P15** – Detail of samples and spoil
taken at test location BH2, respectively

# 5. Data Interpretation

## 5.1 Proposed Development

Based on the information provided, it is understood that proposed development of the site will comprise addition of a granny flat above the existing garage, as well as additions to the existing upper floor of the property, and construction of a firepit area adjoining the foreshore.

It is anticipated that earthworks involving only minor filling of the site will be carried out in order to achieve Council's minimum flood clearance levels for the proposed development.

## 5.2 Interpretative Geotechnical Model

The subsurface conditions on the site within the footprint of the proposed development are interpreted to comprise sandy soils of very loose to loose consistency to depths in the order of 0.55 m to 0.95 m ranging to medium dense with loose to very loose bands below depths in the order of 3 m to 5 m. Groundwater is present at about 1.35 m depth (approximate RL 0.2 AHD).

The variations in density of the inferred sandy profile beneath the borehole limits of investigation were interpreted from the results of dynamic cone penetrometer [DCP] testing at test locations DCP 1, DCP 2 and DCP 3, and are shown in Table 1 below.

**Table 1 –** Variation of soil density with depth at borehole / DCP test locations

| **Soil Density Range** | **Depth range (m) at test location** | | |
|---|---|---|---|
| | **BH1 / DCP 1** | **BH2 / DCP 2** | **DCP 3** |
| Depth limit of borehole | 1.85 m | 1.3 m | – |
| **Very loose** | Surface to 0.9 | Surface to 0.6 | Surface to 0.6 |
| **Very loose to loose** | 0.9 to 4.0 (1) (LOI) | 2.3 to 3.6 | 2.0 to 3.5 |
| **Loose to medium dense** | – | 3.6 to 4.0 (LOI) | 0.6 to 2.0 |
| **Medium dense** | – | 0.9 to 2.3 | 3.5 to 4.0 (LOI) |
| **Depth limit of DCP testing** | **4.0 m** | **4.0 m** | **4.0 m** |

Notes to Table 2:

LOI Limit of investigation

(1) Loose to medium dense from 0.9 m to 1.7 m and 2.8 m to 3.3 m

# 6. Acid Sulfate Soil Risk

## 6.1 Screen Testing

Samples of the soil profile were recovered from the boreholes and screened for the presence of actual and/or potential ASS in accordance with the procedures outlined in the NSW Acid Sulfate Soil Advisory Committee (ASSMAC) document, 'Acid Sulfate Soils Assessment Guidelines' [Ref 5]. The results of ASS screening are summarised in Table 2.

**Table 2 –** Summary results of ASS screening

| Sample ID | Sample Depth [a] (m) | Sample Description | Screening Test Results | | | |
|---|---|---|---|---|---|---|
| | | | pH | | | Strength of Reaction [b] |
| | | | $pH_F$ | $pH_{FOX}$ | $pH_F$ - $pH_{FOX}$ | |
| BH1 | 0.35-0.45 | SAND, dark brown to black | 6.6 | 5.4 | **1.2** | 1 |
| BH1 | 1.3-1.4 | SAND, pale brown and grey, with shell | 7.6 | 6.9 | **0.6** | 1 |
| BH1 | 1.75-1.85 | SAND, dark brown, with shell | 7.5 | 5.9 | **1.5** | 2 |
| BH2 | 0.45-0.55 | SAND, dark brown to black | 7.3 | 5.8 | **1.5** | 1 |
| BH2 | 1.0-1.1 | SAND, pale brown and grey, with shell | 7.9 | 6.6 | **1.2** | 1 |
| BH2 | 1.7-1.8 | SAND, pale grey | 8.3 | 6.7 | **1.6** | 1 |
| Guideline [c] | | Sands to loamy sands<br>Sandy loams to light clays<br>Medium to heavy clays & silty clays | <4 [d] | <3.5 [e] | ≥ 1 [e] | - |

Notes to Table 2:

a Depth below ground surface

b Strength of Reaction

1 no or slight reaction
2 moderate reaction
3 high reaction
4 very vigorous reaction
F bubbling/frothy reaction, indicative of organics
H heat generated

c ASSMAC, 'Acid Sulfate Soils Assessment Guidelines' [Ref 5]

d For actual acid sulphate soils (AASS)

e Indicative value only for potential acid sulfate soils (PASS)

$pH_{FOX}$ - soil peroxide pH test
$pH_F$ - soil pH Test (1:5 soil:distilled water)
(1:4 soil:distilled water, following oxidation of soil with 30% $H_2O_2$)
Figure in **BOLD TYPE** is an indicator of potential ASS

### 6.2 Interpretation of Acid Sulfate Soil Risk

Based on the desktop review of published information, observations of subsurface conditions on site and the results of laboratory testing of soils on, and in the area local to, the site it is interpreted that the soils present at depth on the property **are neither actual nor potential acid sulfate soils**.

Soils with the potential to generate ASS conditions on site might be present at depths greater than 1.8 m below the existing ground surface levels.

Based on the above comments, it is considered that **no specific ASS management plan is required for the construction of development involving proposed excavations to depths not greater than 1.8 m.**

## 7. Comments on ASS Management

Acid sulfate soils [ASS] in their natural state pose little problem. One of the best forms of minimising ASS impacts is to **not disturb or modify the soils from their natural state, where practicable, and to transport no excavated materials off site**.

Project elements must be designed to minimise the depth of excavation where practicable. Excavations and/or dewatering to depths below 1.8 m might intercept ASS materials and must be managed in accordance with an ASS management plan.

The primary focus of all excavation work on this site should be to minimise ASS impacts by **not disturbing or modifying the soils from their natural state, where practicable, and to transport no excavated materials off the site**. ASS management strategies will only need to be used for soils excavated below 1.8 m depth.

Where it is not practicable to limit site excavations to a maximum depth of 2.5 m below existing ground surface levels the following strategies to manage the impact of acid sulfate soils should be adopted:

- *Minimise ASS disturbance* by, where practicable, **not disturbing or modifying the soils from their natural state, and to transport no excavated materials off site.** Construction activities should, where practicable, aim to minimise the disturbance of the acid sulfate soils by limiting excavation extent and depth.
- *Limit the use of dewatering measures on the site unless essentially required*. Lowering the ground water table, for example, by spear point extraction or pumping from open pits or trenches, has the potential to expose ASS and cause them to oxidise, as well as generating acidic soil-water leachate. When the exposed soils again contact water, the products of ASS oxidation generate acid runoff. **No dewatering is to be carried out within the natural soil profile on this site without further detailed geotechnical assessment**.
- *Minimise air exposure time of excavated soils*. The length of time that excavated acid sulfate soils are exposed to air is to be minimised so as to reduce oxidation levels. **Progressive development of excavations and regular spraying of excavation are to be used to minimise exposure times.**
- *Dose excavated soils and the surfaces of site excavations using an acid-neutralising agent.* **Excavated ASS materials are to be dosed with Grade 1 Agricultural lime**, at a nominal rate of 15 kg per tonne of excavated soil (to be confirmed by the results of detailed chemical analysis), and mixed using appropriate methods to control generation and movement of acid runoff. The base and sides of excavations and trenches within ASS materials should be dosed with agricultural lime at a nominal rate of 1 kg/m$^2$.

- *<u>Control the movement of leachate from oxidised ASS on the site</u>.* Control all leachate movement using diversion and/or containment during site excavation work. **Excavation works are not to be undertaken during periods of wet weather or if wet weather is imminent**.
- *<u>Monitor the process of neutralising acid products</u>.* Excavated soils, groundwater and soil-water leachate that have been dosed with acid-neutralising agents are to be tested for pH level prior to re-use on site only.

It should be noted that there are health risks associated with the use of acid-neutralising agents such as lime which need to be addressed prior to site work. Contractors should undertake a risk assessment in relation to the use of lime and obtain a Material Safety Data Sheet for the particular lime-based materials that are proposed to be used. For descriptions of lime types, refer to the information sheet in the attachments to this report.

If off-site disposal is required, additional testing may be needed to determine the waste classification in accordance with NSW EPA waste classification guidelines.

# 8. Site Classification

The site is classified as **Class 'P' (Problem site)** as defined in Ref 1. This classification was based on the presence of very loose to loose sands to depths of up to 4 m. This site classification has made no allowance for poor site drainage or leaking plumbing. These factors should be taken into consideration in the design of footing systems.

The site should be maintained as outlined in the attached CSIRO Brochure BTF 18. General information on site classification can be found in the attachment section of this report.

# 9. Geotechnical Guidelines for Site Development

## 9.1 Footings

All proposed footing systems should be designed in accordance with Ref 1. Consideration will need to be given to the required extent of excavation and filling of the site, including removal of any existing trees and site regrading, when selecting and designing the footing system.

It is anticipated that high-level footings such as strips, pads, and waffle-pod or raft slabs supported on piles or piers, would be a suitable support system for the proposed development. It is anticipated that steel screw piles, driven piles and auger grouted displacement piles [AGDP] would be feasible means of installing deep foundations on this site. Deep footings such as driven piles and AGDP founded within the dense sands likely to be encountered below depths in the order of 4 m to 5 m (RL –2.5 to –3.5 AHD) may be proportioned for an average shaft adhesion of 75 kPa for serviceability based on the perimetal area of the pile within the natural profile beneath all filling and a maximum allowable end bearing capacity of 750 kPa. A basic geotechnical strength reduction factor ($\varphi_{gb}$) of 0.45 was used to estimate allowable capacities from ultimate values in accordance with Clause 4.3.2 of AS 2159–2009, 'Piling design and installation' (Ref 6).

The anticipated total settlements of high-level footings supported on deep foundations designed in accordance with this report for serviceability loading would be up to 1 % of the principal footing dimension, or in the order of 5 mm to 15 mm with differential settlements likely to be in the order of 5 mm to 10 mm.

The use of driven piles will require careful consideration of the possible impacts on nearby structures from ground-induced vibrations due to the operation of piling equipment. The actual capacity of piles driven to a design set should be confirmed using the Hiley pile driving formula, dynamic wave analysis or equivalent methods at the time of installation.

Screw pile design and performance can vary significantly from one manufacturer configuration to another. The capacity of steel screw piles should be confirmed by the contractor at the time of installation.

Proposed footing systems should be designed and founded such that they are outside or below the zone of influence of all trenches, excavations and retaining walls in their vicinity. The zone of influence is defined by an envisaged line drawn upwards, and away, from the base of the excavation at a grade of about 2.5H:1V for granular (sand/gravel) soils.

All footing installation work should be inspected by an appropriately qualified engineer who can confirm the founding levels and bearing capacities assumed for design.

### 9.2 Earthworks in General

Council's development guidelines should be reviewed during site planning as development guidelines may impose height limitations or support requirements on site cuts and filling.

Where earthworks generate excess materials which require disposal to an off-site location, the excavated spoil is considered a waste material under current NSW environmental legislation. All materials to be disposed to an off-site location require a waste classification in accordance with the guidelines, Regulations and Orders of the NSW EPA.

All materials which cannot be classified as ‘Special Waste’ or ‘Liquid Waste’, or which cannot be pre-classified according to the EPA waste classification guidelines, must be sampled and tested for contamination in order to determine the appropriate waste classification prior to transport off site.

Note that Part 5.6, Section 143 of the Protection of the Environment Operations (POEO) Acts 1997 states that it is an offence for waste to be transported to a place that cannot lawfully be used as a facility to accept that waste. It is the duty of the owner and transporter of the waste to ensure that the waste is disposed of appropriately. 5QS can accept no liability for the unlawful disposal of waste materials from any site.

### 9.3 Site Drainage

The effective drainage from the site of surface and subsurface water is important to ensure the stability of the surface soil and the long-term performance of footing systems and retaining walls.

The property should be developed and maintained in accordance with the guidelines set out in Section 3 of the BCA and Appendix B of Ref 1.

In particular, the following measures are recommended:

- Catch/dish drains formed at the top, and dish and rubble drains installed at the toe of all batters, and subsoil drains installed behind new retaining walls;
- All surface water should be prevented from concentrating on this site;
- Cut areas sloped to fall away from proposed building areas and water not be allowed to pond around buildings, and the site graded to prevent water from ponding on all areas of compacted fill;
- Surface stormwater and subsoil water collected and disposed of in line with Council’s requirements; and
- Sediment and erosion control measures are to be undertaken during construction to Council’s requirements.

## 10. How to Use This Report

5QS Consulting Engineers NSW/ACT [5QS] has prepared this report on a limited geotechnical investigation for a proposed dwelling at No 166 Booker Bay Road, Booker Bay in accordance with the services proposal by 5QS email of 24 October 2022.

The following is a guide as to the intended scope and use of this report.

- This report has not been prepared for the purpose of informing design of any Class 2 development or mixed-use development with a Class 2 building component under the definitions of the Design and Building Practitioners Act 2020 and Regulation 2021.
- This report is provided for the exclusive use of Frank and Wendy Laureti for the purposes as described in the report. It may not be used or relied upon for other purposes or by a third party. 5QS can accept no responsibility for loss or damage arising out of the use of this report beyond its purpose as stated above, or incurred by any third party relying on the report without the express written consent of 5QS. In preparing this report 5QS has necessarily relied upon information provided by the client and/or their agents.
- The extent of testing associated with this assessment is limited to the borehole and DCP probe locations and variations in ground conditions may occur. The data from the test locations have been used to provide an interpretation of the likely subsurface profile at the site of the proposed development. The interpretation may or may not precisely represent the actual subsurface conditions at the site. 5QS should be contacted immediately if subsurface conditions are subsequently encountered that differ from those described in this report so that we can review and re-interpret the geotechnical model on the basis of the additional data.
- The scope of this investigation does not include any comment on the potential excavatability of the subsurface materials on site.
- Neither this report, nor sections from this report, should be used as part of a specification for a project without review and agreement by 5QS. This is because this report has been written as advice and opinion rather than instructions for construction.
- This report must be read in conjunction with all of the attachments.
- The recommendations provided in this report represent a summary of our technical advice. Please discuss the recommendations with the undersigned if you require any clarification.

**CT**

## 11. References

1. Australian Standard AS 2870–2011, ‘Residential slabs and footings’, Standards Australia (January 2011)

2. ‘Sydney 1:100 000 geological series sheet, 9130 (Edition 1)’, Geological Survey of NSW (1983)

3. ‘Sydney 1:100 000 soil landscape series sheet 9130 (Fourth Edition)’ and associated report, NSW Department of Environment, Climate Change and Water (2009)

4. ‘Broken Bay 1:25 000 acid sulfate soil risk map – Edition Two’ NSW Department of Land and Water Conservation (December 1997)

5. ‘ASSMAC Acid Sulphate Soils Assessment Guidelines’, NSW Acid Sulphate Soil Management Advisory Committee (August 1998)

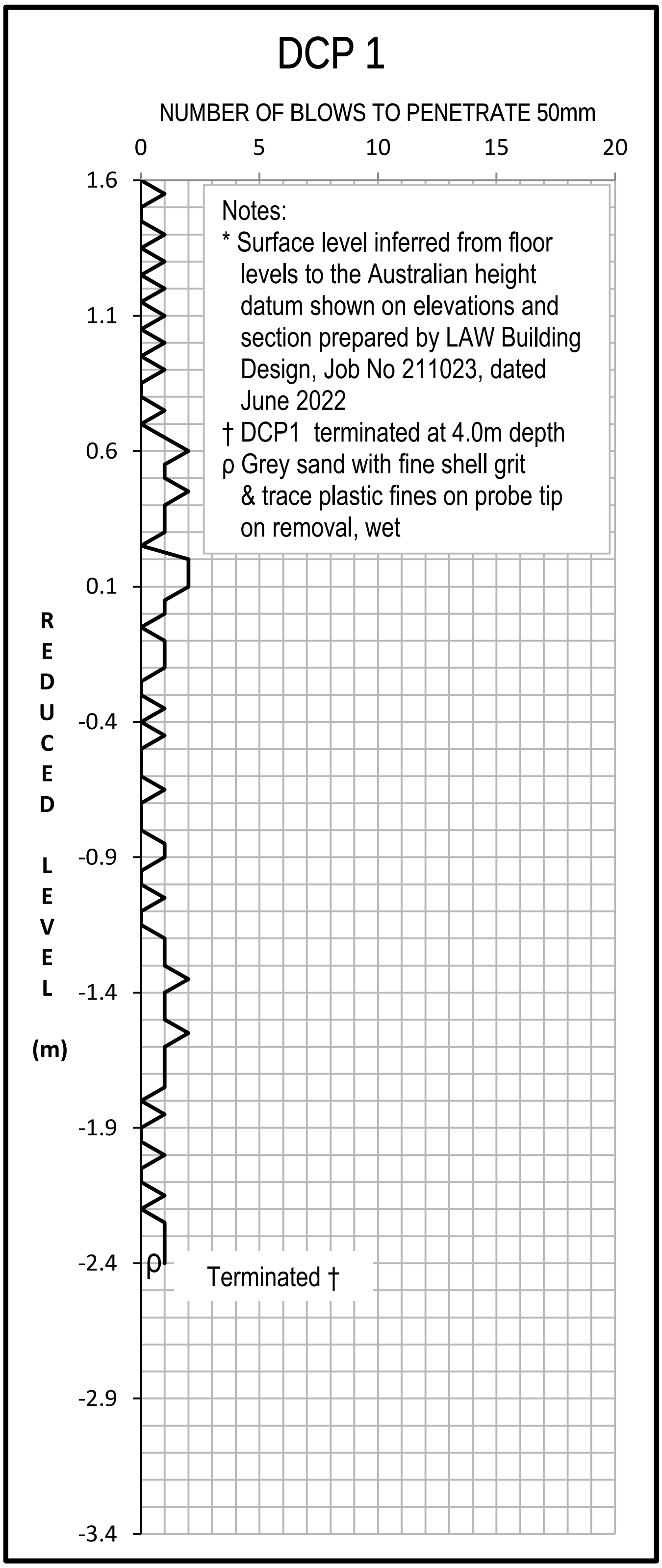
6. Australian Standard AS 2159–2009, ’Piling–Design and installation’, Standards Australia (November 2009)

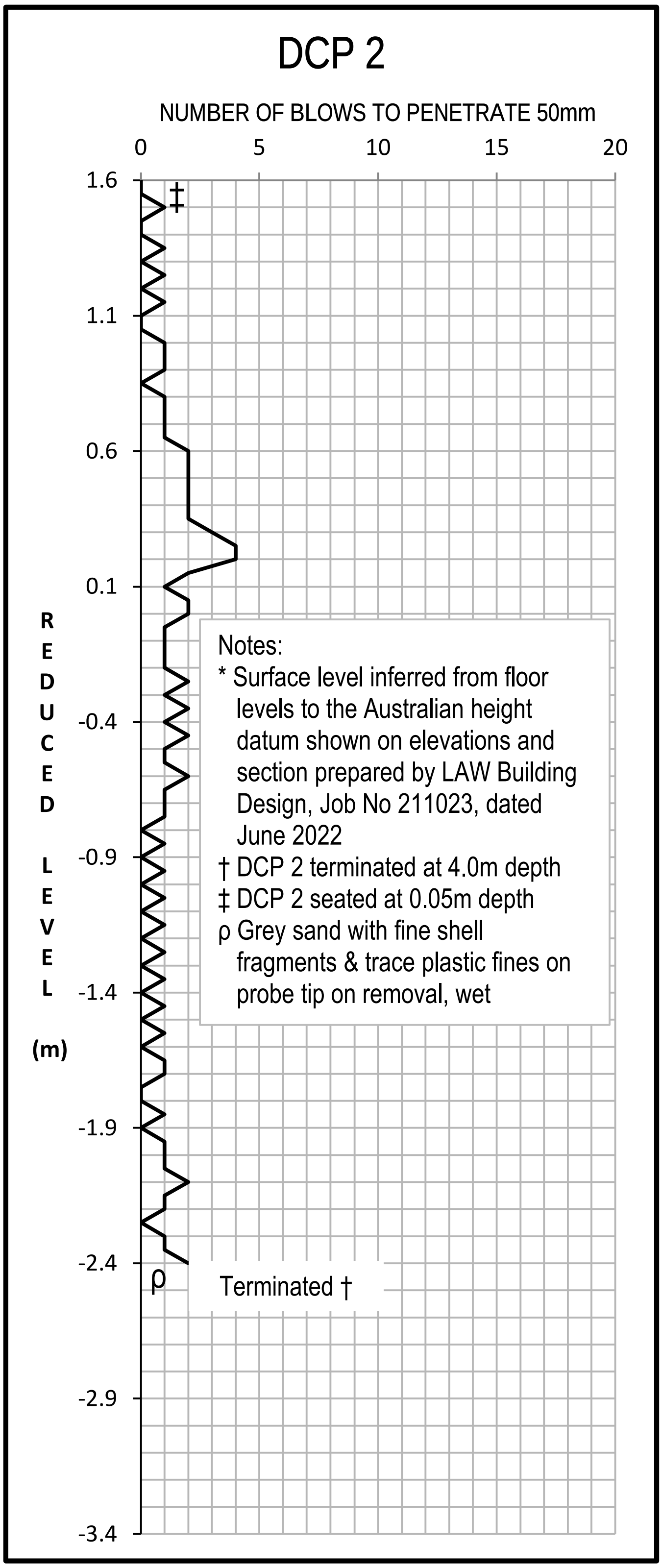
# DYNAMIC CONE PENETROMETER LOG

| | | | |
|---|---|---|---|
| Location: | 166 Booker Bay Road, Booker Bay | | |
| Client: | W & F Laureti | 5QS Ref: | 222093 |
| Position: | Refer to test location plan - Drawing 222093/G1 | Date: | 08-Nov-22 |
| Groundwater: | Nil encountered | Logged By: | PAF/KAF |

* Surface RL: 1.6 AHD

* Surface RL: 1.6 AHD

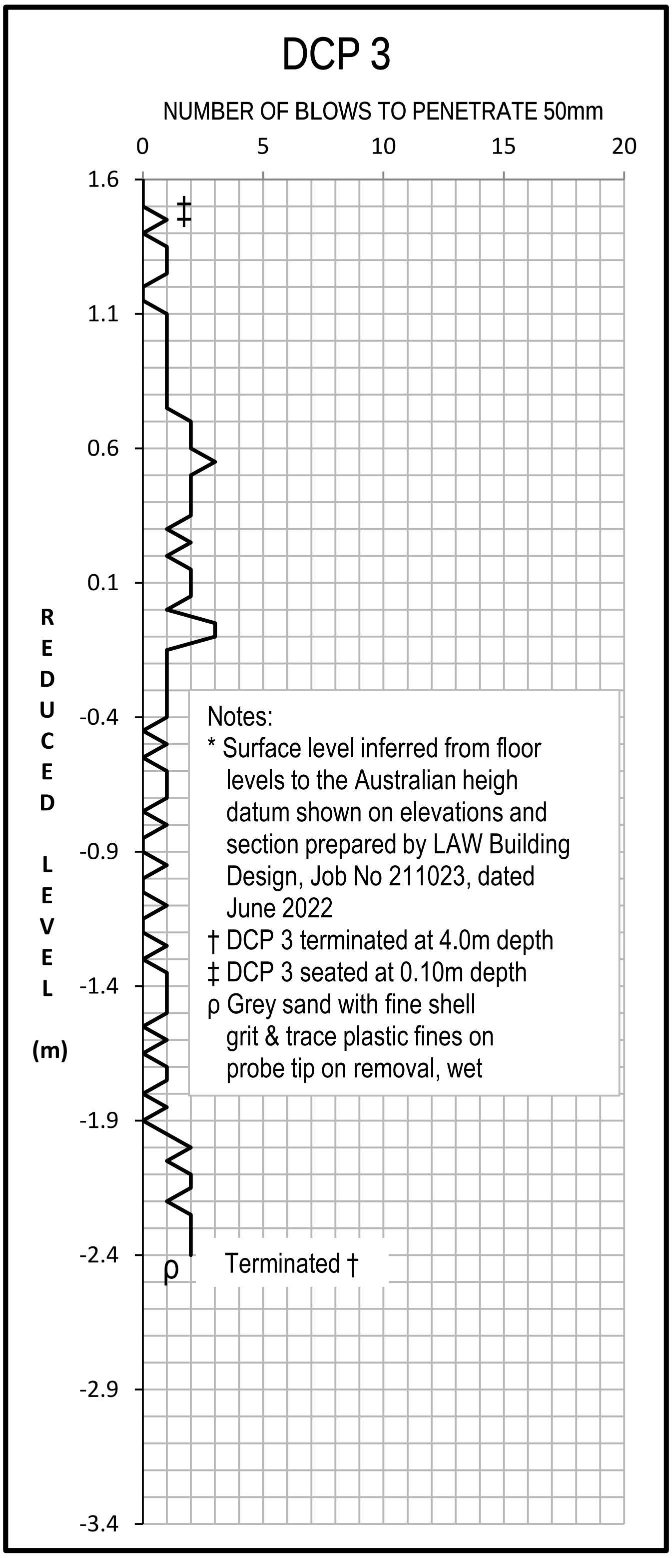


# DYNAMIC CONE PENETROMETER LOG

| | | | |
|---|---|---|---|
| Location: | 166 Booker Bay Road, Booker Bay | | |
| Client: | W & F Laureti | 5QS Ref: | 222093 |
| Position: | Refer to test location plan - Drawing 222093/G1 | Date: | 08-Nov-22 |
| Groundwater: | Nil encountered | Logged By: | PAF/KAF |

* Surface RL: 1.6 AHD




Notes:
* Surface level inferred from floor levels to the Australian heigh datum shown on elevations and section prepared by LAW Building Design, Job No 211023, dated June 2022
† DCP 3 terminated at 4.0m depth
‡ DCP 3 seated at 0.10m depth
ρ Grey sand with fine shell grit & trace plastic fines on probe tip on removal, wet

# ENGINEERING LOG

5QS CONSULTING GROUP

| | | | |
|---|---|---|---|
| Location: | 166 Booker Bay Road, Booker Bay | Borehole No: | BH1 |
| Client: | W & F Laureti | Equipment: | Hand Augers † |
| Position: | See Test Location Plan - Drawing 222093/G1 | Logged By: | PAF/KAF |
| Surface RL: | Unknown * | Job No: | 222093 |
| Groundwater: | Nil Encountered | Date: | 08/11/2022 |

| Depth in metres | Progress | Water | Sample Type | USCS | Material/Strata | Plasticity | Structure and Additional Comments |
|---|---|---|---|---|---|---|---|
| 0.0 | | NIL | | SP | FILLING - sand, fine to coarse grained, dark grey, dry to slightly moist | NP | mortar, root fibres throughout |
| 0.3 | | | 0.35 D 0.45 | SP | FILLING - sand, fine to coarse grained, dark grey brown, moist | NP | |
| | | | | SP | FILLING - sand, fine to medium grained, dark grey brown, moist | NP | shell fragments |
| 0.9 | | | | SP | SAND with clay - fine to coarse grained, yellow brown, moist to wet, shell grit and fragments to 40mm maximum size throughout | NP | |
| 1.15 | | | 1.3 D 1.4 | SP | SAND - fine to coarse grained, grey green, wet, shell fragments throughout, trace plastic fines | NP | |
| 1.5 | | | 1.75 D 1.85 | SP | SAND - fine to coarse grained, grey, fine shell fragments throughout, wet | NP | |
| 1.85 | | | | | BH1 terminated at 1.85m depth, limit of investigation | | Density / consistency of soils below logged profile inferred from results of DCP testing |
| 4.0 | | | | | | | End DCP1 at 4.0m depth |

**Key**

Water: seeping; free standing

Plasticity: NP Non Plastic; L Low; M Medium; H High

Moisture: D dry; M moist; W wet

Sampling Data: U50 undisturbed sample 50mm diameter; D disturbed sample; NC cone penetrometer; B bulk sample

Consistency / Relative Density: VS very soft; S soft; F firm; St stiff; VSt very stiff; H hard; VL very loose; L loose; M medium dense; D dense; VSt very dense

**USCS Summary**

GW GRAVEL, well graded
GP GRAVEL, poorly graded
GM Silty GRAVEL
GC Clayey GRAVEL
SW SAND, well graded
SP SAND, poorly graded
SM Silty SAND
SC Clayey SAND
ML Low plasticity SILT
CL Low plasticity CLAY
MH High plasticity SILT
CH High plasticity CLAY
OL, OH, Pt Organic soils

**Comments**

* Surface RL unknown

† 160mm diameter clay cutter to 0.8m depth, then 75mm Jarrett auger to limit of investigation

Refer to explanation sheet for description of terms and symbols used

# ENGINEERING LOG

| | | | |
|---|---|---|---|
| Location: | 166 Booker Bay Road, Booker Bay | Borehole No: | BH2 |
| Client: | W & F Laureti | Equipment: | Hand Augers † |
| Position: | See Test Location Plan - Drawing 222093/G1 | Logged By: | PAF/KAF |
| Surface RL: | Not known * | Job No: | 222093 |
| Groundwater: | Nil Encountered | Date: | 08/11/2022 |

| Depth in metres | Progress | Water | Sample Type | Graphic Log | USCS | Material/Strata | Plasticity | Structure and Additional Comments |
|---|---|---|---|---|---|---|---|---|
| 0.0 | | | | | SP | FILLING - sand, fine to coarse grained, brown, dry to slightly moist | NP | fine roots throughout |
| 0.5 | | | 0.45 D 0.55 | | SP | SAND - fine to coarse grained, grey, dry to slightly moist, shells to 40mm maximum size<br>Slightly moist to moist from 0.65m depth<br>Pale grey from 0.65m depth | NP | |
| | | NIL | | | SP | SAND - fine to coarse grained, pale grey brown, moist to wet | NP | shell grit & fragments throughout |
| 1 | | | 1.0 D 1.1 | | SP | SAND - fine to coarse grained, grey yellow brown, moist to wet Shell fragments throughout and whole shells to 40mm maximum size | NP | |
| 1.5 | | | | | | BH2 terminated at 1.3m depth, limit of investigation | | Density / consistency of soils below logged profile inferred from results of DCP testing |
| 2 | | | | | | | | |
| 2.5 | | | | | | | | |
| 3 | | | | | | | | |
| 3.5 | | | | | | | | |
| 4 | | | | | | | | End DCP2 at 4.0m depth |

Consistency / Rel. Density: VS Fb, S VL, F L, St M, VSt D, H VD
Moisture: D, SM, M, W

**Key**

Water: seeping; free standing

Plasticity: NP Non Plastic; L Low; M Medium; H High

Moisture: D dry; M moist; W wet

Sampling Data: U50 undisturbed sample 50mm diameter; D disturbed sample; NC cone penetrometer; B bulk sample

Consistency / Relative Density: VS very soft; S soft; F firm; St stiff; VSt very stiff; H hard; VL very loose; L loose; M medium dense; D dense; VSt very dense

**USCS Summary**

GW GRAVEL, well graded
GP GRAVEL, poorly graded
GM Silty GRAVEL
GC Clayey GRAVEL
SW SAND, well graded
SP SAND, poorly graded
SM Silty SAND
SC Clayey SAND
ML Low plasticity SILT
CL Low plasticity CLAY
MH High plasticity SILT
CH High plasticity CLAY
OL, OH, Pt Organic soils

**Comments**

* Surface RL unknown

† 160mm diameter clay cutter to 0.8m depth, then 75mm Jarrett auger to limit of investigation

Refer to explanation sheet for description of terms and symbols used

# TERMS & SYMBOLS

## Unified Soil Classification System (UCS)

| | | | | |
|---|---|---|---|---|
| COARSE-GRAINED SOILS More than half the material (by weight) is individual grains visible to the naked eye | GRAVELLY SOIL More than half of the coarse fraction is larger than 4.75mm | CLEAN GRAVEL Will not leave a stain on wet palm | Substantial amounts of all grain particle sizes | GW |
| | | | Predominantly one size or range of sizes with some intermediate sizes missing | GP |
| | | DIRTY GRAVEL Will leave stain on wet palm | Non-plastic fines (to identify, see ML below) | GM |
| | | | Plastic fines (to identify, see CL below) | GC |
| | SANDY SOIL More than half of the coarse fraction is smaller than 4.75mm | CLEAN SAND Will not leave not leave a stain on wet palm | Wide range in grain size and substantial amounts of all grain particle sizes | SW |
| | | | Predominantly one size or range of sizes with some intermediate sizes missing | SP |
| | | DIRTY SAND Will leave stain on wet palm | Non-plastic fines (to identify, see ML below) | SM |
| | | | Plastic fines (to identify, see CL below) | SC |

| | Ribbon | Liquid Limit | Dry crushing strength | Dilatancy reaction | Toughness | Stickiness | |
|---|---|---|---|---|---|---|---|
| FINE-GRAINED SOILS More than half the material (by weight) is individual grains not visible to the naked eye (< 0.074mm) | None | <50 | None to slight | Rapid | Low | None | ML |
| | Weak | <50 | Medium to high | None to very slow | Medium to High | Medium | CL |
| | Strong | >50 | Slight to medium | Slow to medium | Medium | Low | MH |
| | Very Strong | >50 | High to very high | None | High | Very high | CH |
| HIGHLY ORGANIC SOILS | Readily identified by colour, odour, spongy feel and frequently by fibrous texture | | | | | | OL, OH, Pt |

## Description and classification of soils and rock in accordance with AS1726 'Geotechnical Site Investigations'

### Plasticity A2.4(b)

| Symbol | Descriptive term | Liquid limit (%) |
|---|---|---|
| NP | Non plastic | - |
| L | of low plasticty | < = 35 |
| M | of medium plasticity | > 35 < = 50 |
| H | of high plastic | > 50 |

### Moisture Condition A2.5(a)

| | |
|---|---|
| 'Dry' (D) | Cohesive soils; hard and friable or powdery, well dry of plastic limit. Granular soils; cohesionless and free-running |
| 'Moist' (M) | Soil feels cool, darkened in colour. Cohesive soils can be moulded. Granular soils tend to cohere. |
| 'Wet' (W) | Soil feels cool, darkened in colour. Cohesive soils usually weakened and free water forms on hand when handling. Granular soils tend to cohere. |

### Consistency terms - Cohesive soils TA4

| Term | USS (kPa) | Field guide to consistency |
|---|---|---|
| Very soft | < = 12 | Exudes between fingers when squeezed in hand |
| Soft | 12 - 25 | Can be moulded by light finger pressure |
| Firm | 25 - 50 | Can be moulded by strong finger pressure |
| Stiff | 50 - 100 | Cannot be moulded by fingers, can be indented by thumb |
| Vary stiff | 100 - 200 | Can be indented by thumb nail |
| Hard | > 200 | Can be indented with difficulty by thumbnail |

### Consistency terms - Non-Cohesive soils TA5

| Term | Density Index (%) |
|---|---|
| Very loose | < = 15 |
| Loose | 15 - 35 |
| Medium dense | 35 - 65 |
| Dense | 65 - 85 |
| Very Dense | > 85 |

# TERMS & SYMBOLS

## Symbols

### Soil

- Asphaltic Concrete or Hotmix
- Concrete
- Topsoil
- Fill
- Peat, Organic Clays and Silts (Pt, OL, OH)
- Clay (CL, CH)
- Silt (ML, MH)
- Sandy Clay (CL, CH)
- Silty Clay (CL, CH)
- Gravelly Clay (CL, CH)
- Sandy Silt (ML)
- Clayey Sand (SC)
- Silty Sand (SM)
- Sand (SP, SW)
- Clayey Gravel (GC)
- Silty Gravel (GM)
- Gravel (GP, GW)
- Loam

### Rock

- Claystone (massive)
- Siltstone (massive)
- Shale (laminated)
- Sandstone (undifferentiated)
- Sandstone, fine grained
- Sandstone, coarse grained
- Conglomerate
- Limestone
- Coal
- Dolerite, Basalt
- Tuff
- Porphyry
- Granite
- Pegmatite
- Schist
- Gneiss
- Quartzite
- Talus
- Alluvium

### Inclusions

- Rock Fragments
- Organic Material
- Ironstone Gravel, Laterite
- Shale Breccia in Sandstone

### Seams

- Seam >0.1m thick
- Seam 0.01m to 0.1m thick

# General Notes

## Introduction

These notes are supplied with all geotechnical reports from **5QS Consulting Group** and therefore may contain information not necessarily relevant to this report.

The purpose of the report is set out in the introduction section of this report. It should not be used by any other party, or for any other purpose, as it may not contain adequate or appropriate information in these events.

## Engineering Reports

**5QS Consulting Group** engineering reports are prepared by qualified personnel and are based on information obtained, and on modern engineering standards of interpretation and analysis of that information. Where the report has been prepared for a specific design proposal the information and interpretation may not be relevant if the design proposal is changed. If the design proposal or construction methods do change, **5QS Consulting Group** request that it be notified and will be pleased to review the report and the sufficiency of the investigation work.

Geotechnical reports are based on information gained from limited subsurface test boring and sampling, supplemented by knowledge of local geology and experience. For this reason, the report must be regarded as interpretative, rather than a factual document, limited, to some extent, by the scope of information on which it relies.

***5QS Consulting Group*** *cannot accept responsibility for problems which may develop if it is not consulted after factors considered in the report's development have changed.*

Every care is taken with the report as it relates to interpretation of subsurface condition, discussion of geotechnical aspects and recommendations or suggestions for design and construction. However, **5QS Consulting Group** cannot always anticipate or assume responsibility for:

- Unexpected variations in ground conditions – the potential for this will depend partly on bore spacing and sampling frequency.
- The actions of contractors responding to commercial pressures.

If these occur, **5QS Consulting Group** will be pleased to assist with investigation or advice to resolve the matter.

## A Geotechnical Engineering Report May Be Subject To Misinterpretation

Costly problems can occur when other design professionals develop their plans based on misinterpretations of a geotechnical engineering report. To help avoid these problems, **5QS Consulting Group** should be retained to review the adequacy of plans and specifications relative to geotechnical issues.

## Engineering Logs Should Not Be Separated From The Engineering Report.

Final engineering logs are developed by the Geotechnical Engineer based upon interpretation of field logs and laboratory evaluation of field samples. Only final engineering logs are included in geotechnical engineering reports. To minimize the likelihood of engineering log misinterpretation, *give contractors ready access to the complete geotechnical engineering report*.

## Site Inspection

**5QS Consulting Group** will always be pleased to provide inspection services for geotechnical aspects of work to which this report is related. This could range from a site visit, to full time engineering presence on site.

## Change In Conditions

Subsurface conditions may be modified by constantly changing natural forces. Because a geotechnical engineering report is based on conditions, which existed at the time of subsurface exploration, *construction decisions should not be based on a geotechnical engineering report whose adequacy may have been affected by time*.

Construction operations at or adjacent to the site and natural events such as floods, earthquakes or groundwater fluctuations may also affect subsurface conditions and thus, the continuing adequacy of a geotechnical report. **5QS Consulting Group** should be kept apprised of any such events, and should be consulted to determine if additional tests are necessary.

In the event that conditions encountered on site during construction appear to vary from those which were expected from the information contained in the report, **5QS Consulting Group** requests that it be immediately notified. Most problems are much more readily resolved when conditions are exposed during construction, than at some later stage, well after the event.

## Ground Water

Unless otherwise indicated the water levels given on the engineering logs are levels of free water or seepage in the test hole recorded at the given time of measuring. This may not accurately represent actual ground water levels, due to one or more of the following:

- In low permeability soils, ground water although present may enter the hole slowly, or perhaps not at all during the time it is left open.
- A localised perched water table may lead to an erroneous indication of the true water table.
- Water table levels will vary from time to time with seasons or recent prior weather changes. They may not be the same at the time of construction as indicated at the time of investigation.

Accurate confirmation of levels can only be made by appropriate instrumentation techniques and monitoring programs.

# General Notes – Continued

## Foundation Depth

Where referred to in the report, the recommended depth of any foundation, (piles, caissons, footings etc) is an engineering estimate of the depth to which they should be constructed. 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 depth remains, however, an estimate and therefore liable to variation. Foundation drawings, designs and specifications based upon this report should provide for variations in the final depth depending upon the ground conditions at each point of support.

## Engineering Logs

Engineering logs presented in the report are an engineering and/or geological interpretation of the subsurface conditions, and their reliability will depend to some extent on the frequency of sampling and the method of drilling or excavation. Ideally, continuous undisturbed sampling or core drilling will provide the most reliable assessment, but this is not always practicable, or possible to justify economically. In any case, the boreholes or test pits represent only a very small sample of the subsurface profile.

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

## Drilling Methods

The following is a summary of drilling methods currently used by **5QS Consulting Group**, and some comments on their use and application.

**Continuous Sample Drilling:** The soil sample is obtained by screwing a 75 or 100mm auger into the ground and withdrawing it periodically to remove the soil. This is the most reliable method of drilling in soils as the moisture content is unchanged and soil structure, strength, appearance etc. is only partially affected.

**Test Pits:** These are excavated using a backhoe or tracked excavator, allowing close examination of insitu soil if it is safe to descend into the pit. The depth of digging is limited to about 3 metres for a backhoe, and about 5 metres for an excavator. A potential disadvantage is the disturbance of the site caused by the excavation.

**Hand Auger:** The soil sample is obtained by screwing a 75mm Auger into the ground. This method is usually restricted to approximately 1.5 to 2 metres in depth, and the soil structure and strength is significantly disturbed.

**Continuous Spiral Flight Augers:** The soil sample is obtained by using a 90 – 115mm diameter continuous spiral flight auger which is withdrawn at intervals to allow sampling or insitu testing. This is a relatively economical means of drilling in clays, and in sands above the water table. Samples, returned to the surface, are very disturbed and may be contaminated. Information from the drilling is of relatively lower reliability. SPT's or undisturbed sampling may be combined with this method of drilling for reasonably satisfactory sampling.

## Hand Penetrometers

Hand Penetrometer tests are carried out by driving a rod into the ground with a falling weight hammer and recording the number of blows for successive 50mm increments of penetration.

Two, relatively similar tests are used:

1. Perth Sand Penetrometer (AS 1289.5.3.3) – A 16mm flat ended rod is driven with a 9kg hammer, dropping 600mm. This test was developed for testing the density of sands and is mainly used in granular soils and loose fill.

2. Cone Penetrometer/Scala Penetrometer
(AS 1289.5.3.2) – A 16mm rod with a 20mm diameter cone end is driven with a 9kg hammer dropping 510mm. The test was developed initially for pavement subgrade investigations, and correlations of the test results with California Bearing Ratio (CBR) have been published by various road authorities.

## Sampling

Sampling is carried out during drilling to allow engineering examination, and laboratory testing of the soil or rock.

Disturbed samples taken during drilling provide information on colour, type, inclusions and, depending on the amount of disturbance during drilling, some information on strength and structure.

Undisturbed samples are taken by pushing a think walled sample tube into the soils and withdrawing this with a sample of soil in a relatively undisturbed state contained inside. Such samples yield information on structure and strength, 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.

## Laboratory Testing

Laboratory testing is carried out in accordance with Australian Standard 1289 series, Methods of Testing Soils for Engineering Purposes. Details of the test procedure used are given on the individual report forms.

# Lime Types

## Agricultural Lime

Agricultural lime products contain calcium and magnesium compounds that are capable of reducing / neutralising soil acidity. Agricultural limes are graded in terms of particle fineness and, therefore, speed of reaction with the soil. A term referred to as the effective neutralizing value (ENV) is the measure of fineness of lime.

Grade 1 Agricultural lime is specified with a minimum ENV of 80.

## Hydrated Lime

"Hydrated lime" is a material, made from burnt lime, which consists essentially of calcium hydroxide or a combination of calcium hydroxide with magnesium oxide and magnesium hydroxide.

## Burnt Lime

"Burnt lime" is a material made from limestone that consists essentially of calcium oxide or a combination of calcium oxide with magnesium oxide.

## Quick Lime

“Quick Lime” is a material made from calcining limestone or shells, the heat driving off carbon dioxide and leaving lime. It is a white or grey caustic substance that develops great heat when treated with water, forming slaked lime.

# Site Classification Notes

## General

Site classification is a method adopted in residential development for quantifying the anticipated surface movements that may occur on a site, generally due to soil reactivity. Soil reactivity is an appreciable change in soil volume due to a change in the moisture content of the soil. The extent of ground movement due to a reactive clay soil depends on the degree of reactivity of the clay, depth of clay in the soil profile, the depth of potential moisture variation in the soil and the change in soil suction that occurs from dry to wet soil conditions.

AS2870 – 2011 "Residential Slabs and Footings" classifies soil profiles in terms of their potential for shrink/swell movement due to changes in moisture content, to be slight (Class S), moderate (Class M), high (Class H1 or H2) or extreme (Class E). Sites with little or no reactivity are classified rock or sand (Class A), see table 2.1 below.

For classes; M, H1, H2 and E, further classification may be required, based on the depth of the expected moisture change. For sites with deep-seated moisture changes characteristic of dry climates and corresponding to a design depth of suction change (refer to AS 2870 – 2011, clause 2.3.3) equal to or greater than 3m, the classification shall be M-D, H1-D, H2-D, or E-D as appropriate.

**AS2870 – 2011 Table 2.1 "Classification Based on Site Reactivity"**

| Class | Foundation | Characteristic Surface Movement |
|---|---|---|
| A | Most sand and rock sites with little or no ground movement from moisture changes | |
| S | Slightly reactive clay sites, which may experience only slight ground movement from moisture changes | 0 – 20mm |
| M | Moderately reactive clay or silt sites, which may experience moderate ground movement from moisture changes | 20 – 40mm |
| H1 | Highly reactive clay sites, which may experience high ground movement from moisture changes | 40 – 60mm |
| H2 | Highly reactive clay sites, which may experience very high ground movement from moisture changes | 60 – 75mm |
| E | Extremely reactive sites, which may experience extreme ground movement from moisture changes | > 75mm |

# Site Classification Notes - Continued

## Problem Sites

Sites which include soft soils such as soft clay, silt or loose sands, landslip, mine subsidence, collapsing soils, soils subject to erosion or fill sites greater than 0.8m for sand and 0.4m for material other than sand are classified as Problem sites (Class P).

## Classification Methods

Classification for sites other than class P sites shall be determined from at least one of the following methods:

- Identification of the soil profile based upon a visual assessment of the site and surrounding areas, excavated test pits and falling weight penetrometers probes.
- Interpretation of the current performance of existing buildings within the region that are founded on a similar soil profile.
- Site classification based on characteristic surface movement in accordance with AS2870 – 2011, clause 2.2.3, with parameters obtained from laboratory test results.

## Effect of Trees

The presence of trees on a site can potentially affect the performance of the footing system by having an exaggerated effect on the moisture conditions of the soil. As a general rule, sites where trees are located within the mature height of the tree from the property boundary, will be classified as a Problem site (Class P).

There are a number of methods used to assess the potential impact of a tree on the reactive performance of a site. These include:-

- AS2870 provides a design method to account for the presence of trees within and in the vicinity of the proposed building footprint.
- The ‘Foundation and Footings Society of Victoria Method’ proposes a grading of trees with respect to the effect of their roots on nearby structures and suggests how their influence may be reduced.

A tree effect score and tree effect are determined from tables CH5.1 and CH5.2 respectively.

# FOUNDATION MAINTENANCE AND FOOTING PERFORMANCE

**Understanding and preventing soil-related building movement**

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

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 home owner 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.

## 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. Table 1 below is a reproduction of Table 2.1 from Australian Standard AS 2870-2011, Residential slabs and footings.

## 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 may be the province of the builder and should be taken into consideration as part of the preparation of the site for construction.

### 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, from AS 2870). 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.

### 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.

**TABLE 1. 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, which may experience only slight ground movement from moisture changes |
| M | Moderately reactive clay or silt sites, which may experience moderate ground movement from moisture changes |
| H1 | Highly reactive clay sites, which may experience high ground movement from moisture changes |
| H2 | Highly reactive clay sites, which may experience very high ground movement from moisture changes |
| E | Extremely reactive sites, which may experience extreme ground movement from moisture changes |

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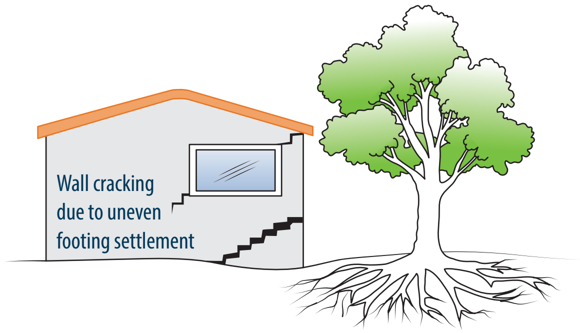


**FIGURE 1** Trees can cause shrinkage and damage.

- 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 through absorption. The swelling process will usually begin at the uphill extreme of the building, or on the weather side where the land is flat. Shrinkage usually begins on the side of the building 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.

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 causes 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. Table 2 below is a reproduction of Table C1 of AS 2870-2011.

AS 2870-2011 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 AND 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 may 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 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.

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.

**TABLE 2. CLASSIFICATION OF DAMAGE WITH REFERENCE TO WALLS.**

| Description of typical damage and required repair | Approximate crack width limit | Damage category |
|---|---|---|
| Hairline cracks | <0.1 mm | 0 – Negligible |
| Fine cracks which do not need repair | <1 mm | 1 – Very Slight |
| Cracks noticeable but easily filled. Doors and windows stick slightly. | <5 mm | 2 – Slight |
| 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 – Moderate |
| 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 depends on number of cracks | 4 – Severe |

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Warning: Although this Building Technology Resource 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, and mould.
- 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.

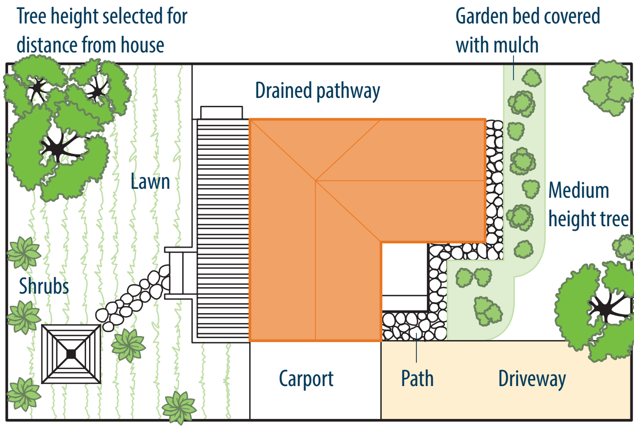


**FIGURE 2** Gardens for a reactive site.

### 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 home owner 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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For information about CSIRO testing services visit www.csiro.au/en/work-with-us/services
ISBN 9781486312962 (print)/9781486312979 (digital) © CSIRO 2021
(replaces Building Technology File 18, 18-2011 and Information Sheet 10/91)

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