SITE CLASSIFICATION REPORT SUMMARY

Classification Procedures:
Existing Subsurface Conditions: Refer attached test pit log(s) – Pit(s) 162,163 and Drawing 10.
Bulk Earthworks: Filling within the block placed under Level 1 control as defined in AS 3798 – 2007 (Ref 1).
Laboratory Results: Previous laboratory testing results indicated liquid limit ranging from 52-81%, plasticity index ranging from 39-68% and linear shrinkage ranging from 13.5-22%.

Site Classification: Site classification in accordance with AS2870 - 2011 (Ref 2) provides guidance on the patterns and magnitude of moisture related seasonal ground movements that must be considered in design. Based on the current soil profile / state, on limited subsurface information, soil reactivity and allowing for variation in the subsoil profile, the overall site would be equivalent to high range Class M* (moderately reactive/filled) conditions. The site classification must be reassessed should the subsurface profile change by either cutting or filling and/or if the presence of service trenches, retaining walls or submerged structures are within the zone of influence of the proposed footings. Reference must be made to the comments provided below.

Footing Systems: Given the marginal site classification, it is recommended that a H1 type footing system be adopted. Reference must be made to AS2870-2011 (Ref 2) which indicates footing systems that are appropriate for each site classification. All footings must found within a uniform bearing stratum of suitable strength/material, below the zone of influence of any service trenches, backfill zones, retaining walls or underground structures. Masonry walls should be articulated in accordance with current best practice. Dwelling design must ensure uniform moisture conditions are maintained in the vicinity of footings. Footing systems must be confirmed by a structural engineer taking into consideration any onsite or offsite constraints.

Maintenance Guidelines: Reference should be made to the attached CSIRO Sheet BTF 18 ‘Foundation Maintenance & Footing Performance’ to comments about gardens, landscaping and trees on the performance of foundation soils and in particular in respect to maintaining good surface drainage. It notes that minor cracking in most structures is inevitable, and it describes site maintenance practices aimed at minimising foundation movements that can lead to cracking damage.

Comments/ Limitations: The successful purchaser must make their own interpretations, deductions and conclusions from the information made available and will need to accept full responsibility for such interpretations, deductions and conclusions.

Development specific geotechnical investigations must be undertaken.
Additional topsoils / filling may have been spread subsequent to the investigation.
Site preparation prior to the construction should include removal of all vegetation, topsoil and any uncontrolled filling.
All new filling must be placed under controlled conditions (AS 3798-2007), otherwise Class P (problem site) conditions would be warranted.
Some variability in subsurface conditions must be anticipated.
Moisture condition of site soils and/or the presence of groundwater may vary considerably from time of investigation compared to at the time of construction.
Depending on the depth of site cut and trenches, rock excavation may be required.
It is recommended that footing excavations be inspected by a geotechnical engineer.
This report must be read in conjunction with the attached “Limitations” and notes “About this Report”.

References:

Attachments: Limitations & About this Report
Explanatory Notes
Test Pit Log(s) Pit(s) 162,163
Drawing 10
Limitations

Douglas Partners (DP) has prepared this report for this project at Stage 1 Strathnairn in accordance with DP’s proposal dated 9 August 2017 and acceptance received from Calibre Consulting (ACT) Pty Ltd dated 29 September 2018. The work was carried out under an amended Calibre Consulting (ACT) Pty Ltd Professional Services Agreement. This report is provided for the exclusive use of Calibre Consulting (ACT) Pty Ltd for this project only and for the purposes as described in the report. It should not be used by or relied upon for other projects or purposes on the same or other site or by a third party. Any party so relying upon this report beyond its exclusive use and purpose as stated above, and without the express written consent of DP, does so entirely at its own risk and without recourse to DP for any loss or damage. In preparing this report DP has necessarily relied upon information provided by the client and/or their agents.

The results provided in the report are indicative of the sub-surface conditions on the site only at the specific sampling and/or testing locations, and then only to the depths investigated and at the time the work was carried out. Sub-surface conditions can change abruptly due to variable geological processes and also as a result of human influences. Such changes may occur after DP’s field testing has been completed.

DP’s advice is based upon the conditions encountered during this investigation. The accuracy of the advice provided by DP in this report may be affected by undetected variations in ground conditions across the site between and beyond the sampling and/or testing locations. The advice may also be limited by budget constraints imposed by others or by site accessibility.

This report must be read in conjunction with all of the attached and should be kept in its entirety without separation of individual pages or sections. DP cannot be held responsible for interpretations or conclusions made by others unless they are supported by an expressed statement, interpretation, outcome or conclusion stated in this report.

This report, or sections from this report, should not be used as part of a specification for a project, without review and agreement by DP. This is because this report has been written as advice and opinion rather than instructions for construction.

The contents of this report do not constitute formal design components such as are required, by the Health and Safety Legislation and Regulations, to be included in a Safety Report specifying the hazards likely to be encountered during construction and the controls required to mitigate risk. This design process requires risk assessment to be undertaken, with such assessment being dependent upon factors relating to likelihood of occurrence and consequences of damage to property and to life. This, in turn, requires project data and analysis presently beyond the knowledge and project role respectively of DP. DP may be able, however, to assist the client in carrying out a risk assessment of potential hazards contained in the Comments section of this report, as an extension to the current scope of works, if so requested, and provided that suitable additional information is made available to DP. Any such risk assessment would, however, be necessarily restricted to the geotechnical components set out in this report and to their application by the project designers to project design, construction, maintenance and demolition.
Introduction

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

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

Copyright

This report is the property of Douglas Partners Pty Ltd. The report may only be used for the purpose for which it was commissioned and in accordance with the Conditions of Engagement for the commission supplied at the time of proposal. Unauthorised use of this report in any form whatsoever is prohibited.

Borehole and Test Pit Logs

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

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

Groundwater

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

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

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

Reports

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

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

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

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

July 2010
About this Report

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

Information for Contractual Purposes
Where information obtained from this report is provided for tendering purposes, it is recommended that all information, including the written report and discussion, be made available. In circumstances where the discussion or comments section is not relevant to the contractual situation, it may be appropriate to prepare a specially edited document. DP would be pleased to assist in this regard and/or to make additional report copies available for contract purposes at a nominal charge.

Site Inspection
The company will always be pleased to provide engineering inspection services for geotechnical and environmental aspects of work to which this report is related. This could range from a site visit to confirm that conditions exposed are as expected, to full time engineering presence on site.
Sampling
Sampling is carried out during drilling or test pitting to allow engineering examination (and laboratory testing where required) of the soil or rock.

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

Undisturbed samples are taken by pushing a thin-walled sample tube into the soil and withdrawing it to obtain a sample of the soil in a relatively undisturbed state. Such samples yield information on structure and strength, and are necessary for laboratory determination of shear strength and compressibility. Undisturbed sampling is generally effective only in cohesive soils.

Test Pits
Test pits are usually excavated with a backhoe or an excavator, allowing close examination of the in-situ soil if it is safe to enter into the pit. The depth of excavation is limited to about 3 m for a backhoe and up to 6 m for a large excavator. A potential disadvantage of this investigation method is the larger area of disturbance to the site.

Large Diameter Augers
Boreholes can be drilled using a rotating plate or short spiral auger, generally 300 mm or larger in diameter commonly mounted on a standard piling rig. The cuttings are returned to the surface at intervals (generally not more than 0.5 m) and are disturbed but usually unchanged in moisture content. Identification of soil strata is generally much more reliable than with continuous spiral flight augers, and is usually supplemented by occasional undisturbed tube samples.

Continuous Spiral Flight Augers
The borehole is advanced using 90–115 mm diameter continuous spiral flight augers which are withdrawn at intervals to allow sampling or in-situ testing. This is a relatively economical means of drilling in clays and sands above the water table. Samples are returned to the surface, or may be collected after withdrawal of the auger flights, but they are disturbed and may be mixed with soils from the sides of the hole. Information from the drilling (as distinct from specific sampling by SPTs or undisturbed samples) is of relatively low reliability, due to the remoulding, possible mixing or softening of samples by groundwater.

Non-core Rotary Drilling
The borehole is advanced using a rotary bit, with water or drilling mud being pumped down the drill rods and returned up the annulus, carrying the drill cuttings. Only major changes in stratification can be determined from the cuttings, together with some information from the rate of penetration. Where drilling mud is used this can mask the cuttings and reliable identification is only possible from separate sampling such as SPTs.

Continuous Core Drilling
A continuous core sample can be obtained using a diamond tipped core barrel, usually with a 50 mm internal diameter. Provided full core recovery is achieved (which is not always possible in weak rocks and granular soils), this technique provides a very reliable method of investigation.

Standard Penetration Tests
Standard penetration tests (SPT) are used as a means of estimating the density or strength of soils and also of obtaining a relatively undisturbed sample. The test procedure is described in Australian Standard 1289, Methods of Testing Soils for Engineering Purposes - Test 6.3.1.

The test is carried out in a borehole by driving a 50 mm diameter split sample tube under the impact of a 63 kg hammer with a free fall of 760 mm. It is normal for the tube to be driven in three successive 150 mm increments and the 'N' value is taken as the number of blows for the last 300 mm. In dense sands, very hard clays or weak rock, the full 450 mm penetration may not be practicable and the test is discontinued.

The test results are reported in the following form.

- In the case where full penetration is obtained with successive blow counts for each 150 mm of, say, 4, 6 and 7 as:
  
  \[ N = 13 \]

- In the case where the test is discontinued before the full penetration depth, say after 15 blows for the first 150 mm and 30 blows for the next 40 mm as:
  
  \[ 15, 30/40 \text{ mm} \]
Sampling Methods

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

Dynamic Cone Penetrometer Tests / Perth Sand Penetrometer Tests

Dynamic penetrometer tests (DCP or PSP) are carried out by driving a steel rod into the ground using a standard weight of hammer falling a specified distance. As the rod penetrates the soil the number of blows required to penetrate each successive 150 mm depth are recorded. Normally there is a depth limitation of 1.2 m, but this may be extended in certain conditions by the use of extension rods. Two types of penetrometer are commonly used.

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

- Cone penetrometer - a 16 mm diameter rod with a 20 mm diameter cone end is driven using a 9 kg hammer dropping 510 mm (AS 1289, Test 6.3.2). This test was developed initially for pavement subgrade investigations, and correlations of the test results with California Bearing Ratio have been published by various road authorities.
Description and Classification Methods
The methods of description and classification of soils and rocks used in this report are based on Australian Standard AS 1726-1993, Geotechnical Site Investigations Code. In general, the descriptions include strength or density, colour, structure, soil or rock type and inclusions.

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

<table>
<thead>
<tr>
<th>Type</th>
<th>Particle size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boulder</td>
<td>&gt;200</td>
</tr>
<tr>
<td>Cobble</td>
<td>63 - 200</td>
</tr>
<tr>
<td>Gravel</td>
<td>2.36 - 63</td>
</tr>
<tr>
<td>Sand</td>
<td>0.075 - 2.36</td>
</tr>
<tr>
<td>Silt</td>
<td>0.002 - 0.075</td>
</tr>
<tr>
<td>Clay</td>
<td>&lt;0.002</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Type</th>
<th>Particle size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse gravel</td>
<td>20 - 63</td>
</tr>
<tr>
<td>Medium gravel</td>
<td>6 - 20</td>
</tr>
<tr>
<td>Fine gravel</td>
<td>2.36 - 6</td>
</tr>
<tr>
<td>Coarse sand</td>
<td>0.6 - 2.36</td>
</tr>
<tr>
<td>Medium sand</td>
<td>0.2 - 0.6</td>
</tr>
<tr>
<td>Fine sand</td>
<td>0.075 - 0.2</td>
</tr>
</tbody>
</table>

The proportions of secondary constituents of soils are described as:

<table>
<thead>
<tr>
<th>Term</th>
<th>Proportion</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>And</td>
<td>Specify</td>
<td>Clay (60%) and Sand (40%)</td>
</tr>
<tr>
<td>Adjective</td>
<td>20 - 35%</td>
<td>Sandy Clay</td>
</tr>
<tr>
<td>Slightly</td>
<td>12 - 20%</td>
<td>Slightly Sandy Clay</td>
</tr>
<tr>
<td>With some</td>
<td>5 - 12%</td>
<td>Clay with some sand</td>
</tr>
<tr>
<td>With a trace of</td>
<td>0 - 5%</td>
<td>Clay with a trace of sand</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Description</th>
<th>Abbreviation</th>
<th>Undrained shear strength (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very soft</td>
<td>vs</td>
<td>&lt;12</td>
</tr>
<tr>
<td>Soft</td>
<td>s</td>
<td>12 - 25</td>
</tr>
<tr>
<td>Firm</td>
<td>f</td>
<td>25 - 50</td>
</tr>
<tr>
<td>Stiff</td>
<td>st</td>
<td>50 - 100</td>
</tr>
<tr>
<td>Very stiff</td>
<td>vst</td>
<td>100 - 200</td>
</tr>
<tr>
<td>Hard</td>
<td>h</td>
<td>&gt;200</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Relative Density</th>
<th>Abbreviation</th>
<th>SPT N value</th>
<th>CPT qc value (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very loose</td>
<td>vl</td>
<td>&lt;4</td>
<td>&lt;2</td>
</tr>
<tr>
<td>Loose</td>
<td>l</td>
<td>4 - 10</td>
<td>2 - 5</td>
</tr>
<tr>
<td>Medium dense</td>
<td>md</td>
<td>10 - 30</td>
<td>5 - 15</td>
</tr>
<tr>
<td>Dense</td>
<td>d</td>
<td>30 - 50</td>
<td>15 - 25</td>
</tr>
<tr>
<td>Very dense</td>
<td>vd</td>
<td>&gt;50</td>
<td>&gt;25</td>
</tr>
</tbody>
</table>
Soil Origin

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

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

Transported soils may be further subdivided into:

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

**Rock Strength**

Rock strength is defined by the Point Load Strength Index ($I_s(50)$) and refers to the strength of the rock substance and not the strength of the overall rock mass, which may be considerably weaker due to defects. The test procedure is described by Australian Standard 4133.4.1 - 2007. The terms used to describe rock strength are as follows:

<table>
<thead>
<tr>
<th>Term</th>
<th>Abbreviation</th>
<th>Point Load Index $I_s(50)$ MPa</th>
<th>Approximate Unconfined Compressive Strength MPa*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely low</td>
<td>EL</td>
<td>&lt;0.03</td>
<td>&lt;0.6</td>
</tr>
<tr>
<td>Very low</td>
<td>VL</td>
<td>0.03 - 0.1</td>
<td>0.6 - 2</td>
</tr>
<tr>
<td>Low</td>
<td>L</td>
<td>0.1 - 0.3</td>
<td>2 - 6</td>
</tr>
<tr>
<td>Medium</td>
<td>M</td>
<td>0.3 - 1.0</td>
<td>6 - 20</td>
</tr>
<tr>
<td>High</td>
<td>H</td>
<td>1 - 3</td>
<td>20 - 60</td>
</tr>
<tr>
<td>Very high</td>
<td>VH</td>
<td>3 - 10</td>
<td>60 - 200</td>
</tr>
<tr>
<td>Extremely high</td>
<td>EH</td>
<td>&gt;10</td>
<td>&gt;200</td>
</tr>
</tbody>
</table>

* Assumes a ratio of 20:1 for UCS to $I_s(50)$. It should be noted that the UCS to $I_s(50)$ ratio varies significantly for different rock types and specific ratios should be determined for each site.

**Degree of Weathering**

The degree of weathering of rock is classified as follows:

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

**Degree of Fracturing**

The following classification applies to the spacing of natural fractures in diamond drill cores. It includes bedding plane partings, joints and other defects, but excludes drilling breaks.

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fragmented</td>
<td>Fragments of &lt;20 mm</td>
</tr>
<tr>
<td>Highly Fractured</td>
<td>Core lengths of 20-40 mm with some fragments</td>
</tr>
<tr>
<td>Fractured</td>
<td>Core lengths of 40-200 mm with some shorter and longer sections</td>
</tr>
<tr>
<td>Slightly Fractured</td>
<td>Core lengths of 200-1000 mm with some shorter and longer sections</td>
</tr>
<tr>
<td>Unbroken</td>
<td>Core lengths mostly &gt; 1000 mm</td>
</tr>
</tbody>
</table>
Rock Descriptions

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

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

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

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

<table>
<thead>
<tr>
<th>Term</th>
<th>Separation of Stratification Planes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thinly laminated</td>
<td>&lt; 6 mm</td>
</tr>
<tr>
<td>Laminated</td>
<td>6 mm to 20 mm</td>
</tr>
<tr>
<td>Very thinly bedded</td>
<td>20 mm to 60 mm</td>
</tr>
<tr>
<td>Thinly bedded</td>
<td>60 mm to 0.2 m</td>
</tr>
<tr>
<td>Medium bedded</td>
<td>0.2 m to 0.6 m</td>
</tr>
<tr>
<td>Thickly bedded</td>
<td>0.6 m to 2 m</td>
</tr>
<tr>
<td>Very thickly bedded</td>
<td>&gt; 2 m</td>
</tr>
</tbody>
</table>
Symbols & Abbreviations

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

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

Water
▷ Water seep
▽ Water level

Sampling and Testing
A Auger sample
B Bulk sample
D Disturbed sample
E Environmental sample
U50 Undisturbed tube sample (50mm)
W Water sample
pp Pocket penetrometer (kPa)
PID Photo ionisation detector
PL Point load strength Is(50) MPa
S Standard Penetration Test
V Shear vane (kPa)

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

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

Coating or Infilling Term
cln clean
cn coating
he healed
inf infilled
stn stained
ti tight
vn veneer

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

Shape
cu curved
ir irregular
pl planar
st stepped
un undulating

Roughness
po polished
ro rough
sl slickensided
sm smooth
vr very rough

Other
fg fragmented
bnd band
qtz quartz

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

Defect Type
B Bedding plane
Cs Clay seam
Cv Cleavage
Cz Crushed zone
Ds Decomposed seam
F Fault
J Joint
Lam Lamination
Pt Parting
Sz Sheared Zone
V Vein
Symbols & Abbreviations

Graphic Symbols for Soil and Rock

General
- Asphalt
- Road base
- Concrete
- Filling

Soils
- Topsoil
- Peat
- Clay
- Silty clay
- Sandy clay
- Gravelly clay
- Shaly clay
- Silt
- Clayey silt
- Sandy silt
- Sand
- Clayey sand
- Silty sand
- Gravel
- Sandy gravel
- Cobbles, boulders
- Talus

Sedimentary Rocks
- Boulder conglomerate
- Conglomerate
- Conglomeratic sandstone
- Sandstone
- Siltstone
- Laminite
- Mudstone, claystone, shale
- Coal
- Limestone

Metamorphic Rocks
- Slate, phyllite, schist
- Gneiss
- Quartzite

Igneous Rocks
- Granite
- Dolerite, basalt, andesite
- Dacite, epidote
- Tuff, breccia
- Porphyry
Foundation Maintenance and Footing Performance: A Homeowner’s Guide

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 18 (BTF 18) 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.

<table>
<thead>
<tr>
<th>GENERAL DEFINITIONS OF SITE CLASSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>A</td>
</tr>
<tr>
<td>S</td>
</tr>
<tr>
<td>M</td>
</tr>
<tr>
<td>H</td>
</tr>
<tr>
<td>E</td>
</tr>
<tr>
<td>A to P</td>
</tr>
<tr>
<td>P</td>
</tr>
</tbody>
</table>
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 erode 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 under 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 footings 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 dishy. This is often accompanied by some doors binding on the floor or the door head, together with some cracking of cornice mutes. 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 joints, 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 drying, but other cracks open up. The roof lines may become convex.

Doming and cracking 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 drying.

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 move 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.

Uphaul 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 stress 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/bulging 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 rainfall 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, creating localized problems such as erosion, saturation and migration of water under the building.

**Classification of Damage with Reference to Walls**

<table>
<thead>
<tr>
<th>Description of typical damage and required repair</th>
<th>Approximate crack width limit (see Note 3)</th>
<th>Damage category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hairline cracks</td>
<td>&lt;0.1 mm</td>
<td>0</td>
</tr>
<tr>
<td>Fine cracks which do not need repair</td>
<td>&lt;1 mm</td>
<td>1</td>
</tr>
<tr>
<td>Cracks noticeable but easily filled. Doors and windows stick slightly</td>
<td>&lt;5 mm</td>
<td>2</td>
</tr>
<tr>
<td>Cracks can be repaired and possibly a small amount of wall will need to be replaced. Doors and windows stick. Service pipes can fracture. Weather tightness often impaired</td>
<td>5–15 mm (or a number of cracks 3 mm or more in one group)</td>
<td>3</td>
</tr>
<tr>
<td>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</td>
<td>15–25 mm but also depend on number of cracks</td>
<td>4</td>
</tr>
</tbody>
</table>

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 water table 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
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 joints 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 fail 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.

This BTF was prepared by John Lewer FAIB, MIAMERA, Partner, Construction Diagnosis.
<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Description of Strata</th>
<th>Sampling &amp; In Situ Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4</td>
<td>SANDY CLAY—very stiff to hard, dry to moist, red brown, medium plasticity sandy clay</td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Pit discontinued at 1.5 m - limit of investigation

**Dynamic Penetrometer Test (blows per mm)**

<table>
<thead>
<tr>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**WATER OBSERVATIONS:** No free groundwater observed

**REMARKS:** Surface levels and coordinates are approximate only and must not be relied upon.
SANDY CLAY-hard, dry to moist, brown red grey, medium plasticity sandy clay

from 1.3m, becoming red brown

Pit discontinued at 2.0m - limit of investigation

**Sampling & In Situ Testing Legend**

- A: Auger sample
- B: Bulk sample
- BLK: Block sample
- C: Core drilling
- D: Disturbed sample
- E: Environmental sample
- G: Gas sample
- P: Piston sample
- T: Tube sample (x mm dia.)
- W: Water sample
- X: Water level
- Y: Water level
- B: Bulk sample
- PL: Point load axial test (Is (50) (MPa))
- PLA: Point load axial test (Is (50) (MPa))
- PD: Photo-ionisation detector (ppm)
- P: Piston sample
- S: Standard penetration test
- SV: Shear vane (kPa)

**Dynamic Penetrometer Test** (blows per 150mm)

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Sampling &amp; In Situ Testing</th>
<th>Water</th>
<th>Dynamic Penetrometer Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Remarks:**
Surface levels and coordinates are approximate only and must not be relied upon.

**WATER OBSERVATIONS:** No free groundwater observed
NOTE: Base drawing from Calibre Consulting (ACT) Pty Ltd

LEGEND
- Test Pit Location
- Block Number
- Block Boundary
- Section Boundary
- Stage Boundary

CLIENT: Calibre Consulting (ACT) Pty Ltd
OFFICE: Canberra
DRAWN BY: SDG
SCALE: NTS
DATE: 20.05.2019

PROJECT No: 77358.22
DRAWING No: 10
REVISION: 0

TITLE: Test Pit Location Plan
Strathnairn Stage 1B
Blocks 11-17 Section 27, Strathnairn