Investigation Summary Report

<table>
<thead>
<tr>
<th>Client</th>
<th>Calibre Professional Services Pty Ltd</th>
<th>Project No.</th>
<th>77356.33</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project</td>
<td>Proposed Residential Subdivision</td>
<td>Date</td>
<td>09 Jun 2020</td>
</tr>
<tr>
<td>Address</td>
<td>Stage 2A1, Strathnairn</td>
<td>Doc No.</td>
<td>R.113.Rev1</td>
</tr>
</tbody>
</table>

Introduction

This report presents the factual results of a geotechnical investigation undertaken at Block 2(p) Section 66 (BF), Strathnairn.

It is understood that the site will be developed as part of a future undetermined multi-unit residential development. The investigation described within was undertaken to broadly assess the site conditions. The owner 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.

The investigation comprised test pits excavation with in-situ testing and sampling of the subsurface strata. Details of the work undertaken are given in the report.

Description of Site

The site comprises an area of approximately 1.1 ha. It is bounded to the north by Grace Munro Crescent, to the west by Pro Hart Avenue, to the south and east by undeveloped blocks (Block 1 Section 66 and Block 8 Section 126). At the time of the site investigation, topsoil was spread but the site was bare of vegetation. A few stockpiles of construction material were located from the civil works that were to be removed as part of final clean up for the subdivision construction works.

Site Geology

Reference to BMR, 1992 indicates that the site is underlain by rock units of the Walker Volcanics. This typically comprise rhyodacite, dacite, rhyolite, andesite, limestone, calcareous shale and sandstone.

Fieldwork Methods

The field investigation applicable to Block 2 (p) Section 66 (BF), comprised the excavation of seven test pits (Pits 109, 113 – 116, 138 and 139) to depths of 1.4 - 1.7 m at the approximate locations shown in Figure 1 below. The test pits were excavated using a Kubota KX057-4 mini-excavator (~6 tonne) fitted with a 300 mm wide bucket working under the direction of a geotechnical engineer. Disturbed samples of the soils encountered in the test pits were collected for possible laboratory testing and to assist in strata identification. The test pits were located on site using a hand held GPS which is accurate only to about 3 – 5 m. Surface levels provided on the attached test pit logs were determined by interpolation of the finished surface level design drawings. Positions and levels must not be relied on.
Fieldwork Results

Details of the subsurface conditions encountered are summarised in the attached test pit logs. The logs must be read in conjunction with the attached notes and terms used to describe the soils and rocks.

Bulk Earthworks

Filling within the block was placed under Level 1 control as defined in AS 3798:2007.

Laboratory Results

Previous laboratory results across the Strathnairn Stage 2A1 area indicate liquid limit ranging from 48 - 81%, plasticity index ranging from 34 - 58% and linear shrinkage ranging from 9.5 - 14.5%.
Comments

- The site must be subject to a development specific geotechnical investigation.
- Additional topsoils/filling may have been spread subsequent to the investigation.
- Some variability in subsurface conditions must be anticipated.
- Development design must be undertaken by suitably qualified civil and structural engineers taking into consideration the site conditions including the existing drainage measures.
- 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.
- Hard rock excavation must be anticipated across the site should depths be greater than the test pit depths. Site excavation depths should take into consideration the depth to rock to reduce construction costs.
- All new fill must be placed under controlled conditions (AS 3798:2007). If fill is placed uncontrolled, those areas would require a Class P site classification and deemed not suitable to support loading.
- It is recommended that footing excavations be inspected by a geotechnical engineer.
- Site preparation prior to the construction of a dwelling should include removal of all vegetation, topsoil and uncontrolled fill.

References

BMR (1992), Geology of Canberra 1:100 000 Geological Series Sheet 8727, Bureau of Mineral Resources.


Limitations

This report must be read in conjunction with the attached “Limitations” and notes “About this Report”.

Douglas Partners Pty Ltd

Reviewed by

Guanghui Meng
Geotechnical Engineer

Attachments: Limitations
About this Report
Explanatory Notes
Test Pit Logs (Pits 109, 113 – 116, 138 and 139)
CSIRO Publication
Limitations

Douglas Partners (DP) has prepared this report for this project at Stage 2A1, Strathnairn in accordance with DP’s proposal dated 31 May 2019 and acceptance received from Calibre Professional Services Pty Ltd dated 06 April 2020. The work was carried out under DP’s Conditions of Engagement. This report is provided for the exclusive use of Calibre Professional Services 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 scope for work for this investigation/report did not include the assessment of surface or sub-surface materials or groundwater for contaminants, within or adjacent to the site. Should evidence of filling of unknown origin be noted in the report, and in particular the presence of building demolition materials, it should be recognised that there may be some risk that such filling may contain contaminants and hazardous building materials.

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:

- 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.
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: 4,6,7
  \[N=13\]
- In the case where the test is discontinued before the full penetration depth, say after 15 blows for the first 150 mm and 30 blows for the next 40 mm as: 15, 30/40 mm
The results of the SPT tests can be related empirically to the engineering properties of the soils.

**Dynamic Cone Penetrometer Tests / Perth Sand Penetrometer Tests**

Dynamic penetrometer tests (DCP or PSP) are carried out by driving a steel rod into the ground using a standard weight of hammer falling a specified distance. As the rod penetrates the soil the number of blows required to penetrate each successive 150 mm depth are recorded. 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 generally based on Australian Standard AS1726:2017, Geotechnical Site Investigations. 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>19 - 63</td>
</tr>
<tr>
<td>Medium gravel</td>
<td>6.7 - 19</td>
</tr>
<tr>
<td>Fine gravel</td>
<td>2.36 – 6.7</td>
</tr>
<tr>
<td>Coarse sand</td>
<td>0.6 - 2.36</td>
</tr>
<tr>
<td>Medium sand</td>
<td>0.21 - 0.6</td>
</tr>
<tr>
<td>Fine sand</td>
<td>0.075 - 0.21</td>
</tr>
</tbody>
</table>

The proportions of secondary constituents of soils are described as follows:

<table>
<thead>
<tr>
<th>In fine grained soils (&gt;35% fines)</th>
<th>Term</th>
<th>Proportion of sand or gravel</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>And</td>
<td>Specify</td>
<td>Clay (60%) and Sand (40%)</td>
<td></td>
</tr>
<tr>
<td>Adjective</td>
<td>&gt;30%</td>
<td>Sandy Clay</td>
<td></td>
</tr>
<tr>
<td>With</td>
<td>15 – 30%</td>
<td>Clay with sand</td>
<td></td>
</tr>
<tr>
<td>Trace</td>
<td>0 - 15%</td>
<td>Clay with trace sand</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>In coarse grained soils (&gt;65% coarse) - with clays or silts</th>
<th>Term</th>
<th>Proportion of fines</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>And</td>
<td>Specify</td>
<td>Sand (70%) and Clay (30%)</td>
<td></td>
</tr>
<tr>
<td>Adjective</td>
<td>&gt;12%</td>
<td>Clayey Sand</td>
<td></td>
</tr>
<tr>
<td>With</td>
<td>5 - 12%</td>
<td>Sand with clay</td>
<td></td>
</tr>
<tr>
<td>Trace</td>
<td>0 - 5%</td>
<td>Sand with trace clay</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>In coarse grained soils (&gt;65% coarse) - with coarser fraction</th>
<th>Term</th>
<th>Proportion of coarser fraction</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>And</td>
<td>Specify</td>
<td>Sand (60%) and Gravel (40%)</td>
<td></td>
</tr>
<tr>
<td>Adjective</td>
<td>&gt;30%</td>
<td>Gravelly Sand</td>
<td></td>
</tr>
<tr>
<td>With</td>
<td>15 - 30%</td>
<td>Sand with gravel</td>
<td></td>
</tr>
<tr>
<td>Trace</td>
<td>0 - 15%</td>
<td>Sand with trace gravel</td>
<td></td>
</tr>
</tbody>
</table>

The presence of cobbles and boulders shall be specifically noted by beginning the description with ‘Mix of Soil and Cobbles/Boulders’ with the word order indicating the dominant first and the proportion of cobbles and boulders described together.

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

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
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>
<tr>
<td>Friable</td>
<td>Fr</td>
<td>-</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>Density Index (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very loose</td>
<td>VL</td>
<td>&lt;15</td>
</tr>
<tr>
<td>Loose</td>
<td>L</td>
<td>15-35</td>
</tr>
<tr>
<td>Medium dense</td>
<td>MD</td>
<td>35-65</td>
</tr>
<tr>
<td>Dense</td>
<td>D</td>
<td>65-85</td>
</tr>
<tr>
<td>Very dense</td>
<td>VD</td>
<td>&gt;85</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;
- Extremely weathered material – formed from in-situ weathering of geological formations. Has soil strength but retains the structure or fabric of the parent rock;
- Alluvial soil – deposited by streams and rivers;
- Estuarine soil – deposited in coastal estuaries;
- Marine soil – deposited in a marine environment;
- Lacustrine soil – deposited in freshwater lakes;
- Aeolian soil – carried and deposited by wind;
- Colluvial soil – soil and rock debris transported down slopes by gravity;
- Topsoil – mantle of surface soil, often with high levels of organic material.
- Fill – any material which has been moved by man.

Moisture Condition – Coarse Grained Soils
For coarse grained soils the moisture condition should be described by appearance and feel using the following terms:
- Dry (D) Non-cohesive and free-running.
- Moist (M) Soil feels cool, darkened in colour. Sand forms weak ball but breaks easily.
- Wet (W) Soil feels cool, darkened in colour. Soil tends to stick together, free water forms when handling.

Moisture Condition – Fine Grained Soils
For fine grained soils the assessment of moisture content is relative to their plastic limit or liquid limit, as follows:
- 'Moist, dry of plastic limit' or 'w < PL' (i.e. hard and friable or powdery).
- 'Moist, near plastic limit' or 'w = PL' (i.e. soil can be moulded at moisture content approximately equal to the plastic limit).
- 'Moist, wet of plastic limit' or 'w > PL' (i.e. soils usually weakened and free water forms on the hands when handling).
- 'Wet' or 'w = LL' (i.e. near the liquid limit).
- 'Wet' or 'w > LL' (i.e. wet of the liquid limit).
Rock Strength

Rock strength is defined by the Unconfined Compressive Strength and it 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 Point Load Strength Index \( I_{S(50)} \) is commonly used to provide an estimate of the rock strength and site specific correlations should be developed to allow UCS values to be determined. The point load strength test procedure is described by Australian Standard AS4133.4.1-2007. The terms used to describe rock strength are as follows:

<table>
<thead>
<tr>
<th>Strength Term</th>
<th>Abbreviation</th>
<th>Unconfined Compressive Strength MPa</th>
<th>Point Load Index *</th>
<th>( I_{S(50)} ) MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>VL</td>
<td>0.6 - 2</td>
<td></td>
<td>0.03 - 0.1</td>
</tr>
<tr>
<td>Low</td>
<td>L</td>
<td>2 - 6</td>
<td></td>
<td>0.1 - 0.3</td>
</tr>
<tr>
<td>Medium</td>
<td>M</td>
<td>6 - 20</td>
<td></td>
<td>0.3 - 1.0</td>
</tr>
<tr>
<td>High</td>
<td>H</td>
<td>20 - 60</td>
<td></td>
<td>1 - 3</td>
</tr>
<tr>
<td>Very high</td>
<td>VH</td>
<td>60 - 200</td>
<td></td>
<td>3 - 10</td>
</tr>
<tr>
<td>Extremely high</td>
<td>EH</td>
<td>&gt;200</td>
<td></td>
<td>&gt;10</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>Residual Soil</td>
<td>RS</td>
<td>Material is weathered to such an extent that it has soil properties. Mass structure and material texture and fabric of original rock are no longer visible, but the soil has not been significantly transported.</td>
</tr>
<tr>
<td>Extremely weathered</td>
<td>XW</td>
<td>Material is weathered to such an extent that it has soil properties. Mass structure and material texture and fabric of original rock are still visible</td>
</tr>
<tr>
<td>Highly weathered</td>
<td>HW</td>
<td>The whole of the rock material is discoloured, usually by iron staining or bleaching to the extent that the colour of the original rock is not recognisable. Rock strength is significantly changed by weathering. Some primary minerals have weathered to clay minerals. Porosity may be increased by leaching, or may be decreased due to deposition of weathering products in pores.</td>
</tr>
<tr>
<td>Moderately weathered</td>
<td>MW</td>
<td>The whole of the rock material is discoloured, usually by iron staining or bleaching to the extent that the colour of the original rock is not recognisable, but shows little or no change of strength from fresh rock.</td>
</tr>
<tr>
<td>Slightly weathered</td>
<td>SW</td>
<td>Rock is partially discoloured with staining or bleaching along joints but shows little or no change of strength from fresh rock.</td>
</tr>
<tr>
<td>Fresh</td>
<td>FR</td>
<td>No signs of decomposition or staining.</td>
</tr>
<tr>
<td>Distinctly weathered</td>
<td>DW</td>
<td>Rock strength usually changed by weathering. The rock may be highly discoloured, usually by iron staining. Porosity may be increased by leaching or may be decreased due to deposition of weathered products in pores.</td>
</tr>
</tbody>
</table>

Note: If HW and MW cannot be differentiated use DW (see below)
**Rock Descriptions**

**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 occasional fragments</td>
</tr>
<tr>
<td>Fractured</td>
<td>Core lengths of 30-100 mm with occasional shorter and longer sections</td>
</tr>
<tr>
<td>Slightly Fractured</td>
<td>Core lengths of 300 mm or longer with occasional sections of 100-300 mm</td>
</tr>
<tr>
<td>Unbroken</td>
<td>Core contains very few fractures</td>
</tr>
</tbody>
</table>

**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 stronger. 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>
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)

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

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

Orientation
The inclination of defects is always measured from the perpendicular to the core axis.
- h: horizontal
- v: vertical
- sh: sub-horizontal
- sv: sub-vertical

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

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

Shape
- cu: curved
- ir: irregular
- pl: planar
- st: stepped
- un: undulating

Roughness
- po: polished
- ro: rough
- si: slickensided
- sm: smooth
- vr: very rough

Other
- fg: fragmented
- bnd: band
- qtz: quartz

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
- Cobble, 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
## TEST PIT LOG

**CLIENT:** Calibre Professional Services Pty Ltd  
**PROJECT:** Proposed Residential Subdivision  
**LOCATION:** Stage 2A1, Strathnairn  
**SURFACE LEVEL:** 577.6 AHD  
**EASTING:** 681614  
**NORTHING:** 6100093  
**DATE:** 13/5/2020  
**PIT No:** 109  
**PROJECT No:** 77356.33  
**SHEET:** 1 OF 1

### Sampling & In Situ Testing Legend

- **A:** Auger sample  
- **B:** Bulk sample  
- **C:** Core drilling  
- **D:** Disturbed sample  
- **E:** Environmental sample  
- **P:** Piston sample  
- **PL:** Point load axial test  
- **PLD:** Point load diametral test  
- **SZ:** Standard penetration test  
- **W:** Water sample  
- **WL:** Water level  
- **V:** Shear vane  
- **GM:** Gamma meter  
- **SW:** Soil wire  
- **GR:** Ground resistivity  
- **SO:** Soil oxygen  
- **SC:** Soil chemistry  
- **AND:** Antenna  
- **PLA:** Point load axial test (50) (MPa)  
- **PLD:** Point load diametral test (50) (MPa)  
- **PD:** Pocket penetrometer (kPa)  
- **PP:** Pocket penetrometer (kPa)  

### Dynamic Penetrometer Test (blows per mm)

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Description of Strata</th>
<th>Sampling &amp; In Situ Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>FILL/Sandy CLAY (CI/CH): medium to high plasticity, brown, fine to coarse grained sand, trace gravel to 50mm in size, dry to moist, w&lt;PL, hard, FILL</td>
<td></td>
</tr>
<tr>
<td>0.4</td>
<td>Silty CLAY (CL): low plasticity, orange-brown, trace fine gravel to 10mm and rootlets, dry to moist, w&lt;PL, hard, residual</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-from 0.9m, with gravel and ironstone nodules</td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>Pit discontinued at 1.5m - limit of investigation</td>
<td></td>
</tr>
</tbody>
</table>

**RIG:** Kubota KX057-4 mini excavator fitted with a 300mm wide bucket  
**LOGGED:** GM  
**SURVEY DATUM:** MGA94 Zone 55

**WATER OBSERVATIONS:** No free groundwater observed

**REMARKS:** Surface levels and coordinates are approximate only and must not be relied upon.
### Test Pit Log

**Department of Planning and Environment**

**Site:** Proposed Residential Subdivision

**Location:** Stage 2A1, Strathnairn

**Client:** Calibre Professional Services Pty Ltd

**Survey Datum:** MGA94 Zone 55

**Surface Level:** 574.7 AHD

**Easting:** 681633

**Northing:** 6099963

**Date:** 14/5/2020

**Sheet:** 1 of 1

---

### Sampling & In Situ Testing

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Description of Strata</th>
<th>Graphic Log</th>
<th>Sampling &amp; In Situ Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>FILL/Sandy CLAY (CI): medium plasticity, yellow-brown, fine to coarse grained sand, trace gravel to 20mm in size, dry to moist, w=PL, hard, regrade FILL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.4</td>
<td>Sandy CLAY (CL): low plasticity, grey, fine to coarse grained sand, with fine gravel and ironstone nodules to 10mm in size, trace rootlets and wilt, dry to moist, w=PL, dessicated, slopewash</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.7</td>
<td>Silty CLAY (CI/CH): medium to high plasticity, yellow-brown, trace fine gravel and ironstone nodules to 20mm in size, trace rootlets, dry to moist, w=PL, hard, residual</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>Silty CLAY (CI): medium plasticity, grey-brown, trace sandstone fragments and iron staining, dry to moist, w=PL, extremely weathered sandstone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.4</td>
<td>SANDSTONE: fine grained, grey-brown, dry to moist, medium strength, moderately weathered, highly fractured</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Pit discontinued at 1.4m
- slow progress

---

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

---

**Rig:** Kubota KX057-4 mini excavator fitted with a 300mm wide bucket

**Logged:** GM

**Survey Datum:** MGA94 Zone 55

**Water Observations:** No free groundwater observed

---

**Remainder of the document includes tables and diagrams related to the testing and sampling conducted during the pit excavation.**
**DESCRIPTION OF STRATA**

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Description of Strata</th>
<th>Graphic Log</th>
<th>Sampling &amp; In Situ Testing</th>
<th>Results &amp; Comments</th>
<th>Water</th>
<th>Dynamic Penetrometer Test (blows per mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>TOPSOIL FILL/Sandy SILT (ML): low plasticity, pale brown, grey, fine to medium grained sand, trace fine gravel and rootlets, dry to moist, w=PL, very stiff, FILL</td>
<td>D 0.4</td>
<td>pp = 320-420</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.25</td>
<td>Gravelly CLAY (CL): low plasticity, pale brown, fine gravel and siltstone nodules to 15mm in size, trace fine to coarse grained sand, moist to dry, w=PL, very stiff to hard, possible colluvial</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>Silty CLAY (CI): medium plasticity, yellow-brown, trace fine to coarse grained sand and gravel and ironstone nodules to 10mm in size, trace siltstone fragments, dry to moist, w=PL, hard, residual</td>
<td>0.7</td>
<td>pp &gt;400</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.95</td>
<td>Silty CLAY (CI): medium plasticity, grey-brown, trace sandstone fragments and iron staining, dry to moist, w=PL, extremely weathered sandstone</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.4</td>
<td>SANDSTONE: fine grained, grey-brown, dry to moist, low to medium strength, highly to moderately weathered, highly fractured</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.6</td>
<td>Pit discontinued at 1.6m - limit of investigation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**RIG:** Kubota KX057-4 mini excavator fitted with a 300mm wide bucket

**WATER OBSERVATIONS:** No free groundwater observed

**REMARKS:** Surface levels and coordinates are approximate only and must not be relied upon.
### Test Pit Log

**Test Pit Log**

**Surface Level:** 578.1 AHD  
**Easting:** 681633  
**Nordasting:** 6100046  
**Date:** 13/5/2020  
**Project No:** 77356.33  

**Sampling & In Situ Testing Legend**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description of Strata</th>
<th>Sampling &amp; In Situ Testing</th>
<th>Dynamic Penetrometer Test (blows per mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOPSOIL FILL/Sandy SILT (ML): low plasticity, dark grey, fine to medium grained sand, trace fine gravel to 20mm and rootlets, moist to dry, w&lt;PL, very stiff, FILL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravelly CLAY (CL): low plasticity, grey, ironstone nodules and gravel to 20mm in size, with silt, moist, w&lt;PL, very stiff to hard, possible colluvial</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silty CLAY (CI/CH): medium to high plasticity, yellow-brown, some orange, trace fine gravel to ironstone nodules to 10mm in size, moist, w&lt;PL, hard, residual</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silty CLAY (CH): high plasticity, yellow-grey, trace fine to coarse grained sand, moist to dry, w&lt;PL, hard, residual</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SANDSTONE: fine grained, yellow-grey, dry to moist, medium to high strength, moderately weathered, fractured</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- Surface levels and coordinates are approximate only and must not be relied upon.
- No free groundwater observed.
- Pit discontinued at 1.4m - refusal

**Rig:** Kubota KX057-4 mini excavator fitted with a 300mm wide bucket

**Logged:** GM

**Survey Datum:** MGA94 Zone 55

---

**Surface Levels and Coordinates:**

- **Surface Level:** 578.1 AHD
- **Easting:** 681633
- **Nordasting:** 6100046

**WATER OBSERVATIONS:**

- No free groundwater observed

**REMARKS:**

- Surface levels and coordinates are approximate only and must not be relied upon.

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

<table>
<thead>
<tr>
<th>Blows per mm</th>
<th>Test Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>SPT</td>
</tr>
<tr>
<td>10</td>
<td>Cone</td>
</tr>
<tr>
<td>15</td>
<td>Cone</td>
</tr>
<tr>
<td>20</td>
<td>Cone</td>
</tr>
</tbody>
</table>

---

**Sampling & In Situ Testing Legend:**

- **A** Auger sample
- **B** Bulk sample
- **BLK** Block sample
- **C** Coring
- **D** Disturbed sample
- **E** Environmental sample
- **F** Gas sample
- **G** Gas sample
- **H** Photo ionisation detector (ppm)
- **I** Point load axial test (kPa)
- **J** Point load diametral test (kPa)
- **K** Pocket penetrometer (kPa)
- **L** Standard penetration test
- **M** Water sample
- **N** Water level
- **O** Shear vane (kPa)

---

**Geotechnics I Environment I Groundwater**
### Description of Strata

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Type</th>
<th>Sampling &amp; In Situ Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.15</td>
<td>TOPSOIL FILL/Silty SAND (SM): fine to medium grained sand, dark brown, low plasticity fines, trace fine gravel to 10mm in size, dry to moist, medium dense, FILL</td>
<td></td>
</tr>
<tr>
<td>0.3</td>
<td>Sandy SILT (ML): low plasticity, grey, fine to coarse grained sand, trace fine gravel to 10mm in size, dry to moist, w&lt;PL, hard</td>
<td></td>
</tr>
<tr>
<td>0.9</td>
<td>Silty CLAY (CI/CH): medium to high plasticity, orange-brown, yellow-brown, trace fine to coarse grained sand and fine gravel to 10mm in size, moist, w&lt;PL, hard, residual</td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td>Sandy CLAY (CI/CH): medium to high plasticity, yellow-brown, fine to coarse grained sand, trace fine gravel to 10mm and weathered rhyodacite, dry to moist, w&lt;PL, hard, extremely weathered rhyodacite</td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>RHYODACITE: fine to coarse grained, yellow-brown, some white, dry to moist, low strength, highly weathered, fractured</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pit discontinued at 1.5m - limit of investigation</td>
<td></td>
</tr>
</tbody>
</table>

**RIG**: Kubota KX057-4 mini excavator fitted with a 300mm wide bucket  
**LOGGED**: GM  
**SURVEY DATUM**: MGA94 Zone 55

**WATER OBSERVATIONS**: No free groundwater observed

**REMARKS**: Surface levels and coordinates are approximate only and must not be relied upon.
**TOPSOIL FILL/Silty SAND (SM):** fine to medium grained sand, dark brown, low plasticity fines, trace fine gravel to 10mm in size, dry to moist, medium dense, FILL

**Sandy SILT (ML):** low plasticity, brown, fine to medium grained sand, trace fine gravel to 5mm in size and rootlets, moist to dry, w<PL, very stiff

**Silty CLAY (CL):** low plasticity, red-brown, trace fine gravel to 10mm in size and rootlets, moist and dry, w<PL, very stiff, residual

**Sandy CLAY (C/CH):** medium to high plasticity, pale orange-brown, fine to coarse grained sand, trace gravel to 20mm in size, dry to moist, w<PL, hard, extremely weathered rhyodacite

**RHYODACITE:** fine to coarse grained, orange-brown, dry to moist, low to medium strength, highly weathered, fractured

---

**Pit discontinued at 1.4m - slow progress**

---

**RIG:** Kubota KX057-4 mini excavator fitted with a 300mm wide bucket

**LOGGED:** GM

**SURVEY DATUM:** MGA94 Zone 55

**WATER OBSERVATIONS:** No free groundwater observed

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

---

**SAMPLING & IN SITU TESTING LEGEND**

| A | Auger sample | G | Gas sample | PID | Photo ionisation detector (ppm) |
| B | Bulk sample | P | Piston sample | PL(A) | Point load axial test (kN) (MPa) |
| BLK | Block sample | U | Tube sample x mm dia. | PL(D) | Point load diametral test (kN) (MPa) |
| C | Core drilling | W | Water sample | po | Pocket penetrometer (kPa) |
| D | Disturbed sample | W | Water sample | S | Standard penetration test |
| E | Environmental sample | H | Water level | V | Shear vane (kPa) |

---

**D O U G L A S  P A R T N E R S**

Geotechnics | Environment | Groundwater
### Test Pit Log

**Rig:** Kubota KX057-4 mini excavator fitted with a 300mm wide bucket  
**Logged:** GM  
**Survey Datum:** MGA94 Zone 55

**Water Observations:** No free groundwater observed

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

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Description of Strata</th>
<th>Sampling &amp; In Situ Testing</th>
<th>Dynamic Penetrometer Test (blows per mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>TOPSOIL FILL/Sandy SILT (ML): low plasticity, dark brown, fine to medium grained sand, trace fine gravel and rootlets, moist, w=PL, stiff, FILL.</td>
<td>1</td>
<td>D 0.4</td>
</tr>
<tr>
<td>0.65</td>
<td>Silty CLAY (CI): medium plasticity, red-brown, trace fine gravel and ironstone nodules to 5mm in size, moist, w=PL, stiff, residual.</td>
<td>1</td>
<td>D 1.0</td>
</tr>
<tr>
<td>1.2</td>
<td>Sandy CLAY (CI): medium plasticity, pale brown, some white, fine to coarse grained sand, trace gravel to 5mm and weathered rhyodacite, moist, w=PL, stiff, extremely weathered rhyodacite.</td>
<td>1</td>
<td>D 1.6</td>
</tr>
<tr>
<td>1.7</td>
<td>RHYODACITE: fine to coarse grained, yellow-brown, dry to moist, very low to low strength, highly weathered, fractured.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pit discontinued at 1.7m - limit of investigation.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Surface Level:** 579.3 AHD  
**Easting:** 681688  
**Northing:** 6100044  
**Date:** 14/5/2020  
**Pit No:** 139  
**Client:** Calibre Professional Services Pty Ltd  
**Project:** Proposed Residential Subdivision  
**Location:** Stage 2A1, Strathnairn

**Calibre Professional Services Pty Ltd**

**Proposed Residential Subdivision**

**Stage 2A1, Strathnairn**
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 19 (BT 19) deals with these problems.

Erosion

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

Saturation

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

Seasonal swelling and shrinkage of soil

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

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

Shear failure

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

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

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

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

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

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

Pipe leakage and trench water flows also encourage tree and shrub roots to the source of water, complicating and exacerbating the problem.

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

Seriousness of Cracking
In general, most cracking found in masonry walls is a cosmetic nuisance only and can be kept in repair or even ignored. The table below is a reproduction of Table C1 of AS 2870. AS 2870 also publishes figures relating to cracking in concrete floors, however because wall cracking will usually reach the critical point significantly earlier than cracking in slabs, this table is not reproduced here.

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

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

It is, however, sometimes necessary when attempting to prevent water migration that testing be carried out to establish watertable height and subsoil water flows. This subject is referred to in BTIF 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

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

The garden

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

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

Existing trees

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

Information on trees, plants and shrubs

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

Excavation

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

Remediation

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

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

This BTF was prepared by John Lever t/a BIM, MIAMA, Partner, Construction Diagnosis.