ASCT

GEOTECHNICAL SITE INVESTIGATION

Prepared by ASCT – Northern Rivers office, for Lewis Barakat.

SUBJECT SITE

17 McDonald Pace, Evans Head, NSW 2473.

ASCT REFERENCE

H23-3755.

Northern Rivers
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ASCT

12th June 2023

Ref No: H23-3755.

Dear Lewis Barakat,

Re: Proposed Multi Use Development at 17 McDonald Place, Evans Head, NSW 2473.

Australian Soil and Concrete Testing Pty Ltd (ASCT) is pleased to present the completed *Geotechnical Site Investigation* report, in response to your request.

As per your commission, ASCT was tasked with investigation works appropriate to classification of the site in accordance with *Australian Standard AS 2870 – Residential Slabs & Footings*, and associated parameters requisite to the proper design & construction of a structural footings system.

Details of our investigation process, the findings and results are contained within the body of this report. However, please find below a summation of the investigation results;

Site Classification (AS 2870)	Normal Site - Class S – Slightly Reactive
Characteristic Surface Movement (Y_s)	0 to 20mm, Site Class 'S – Slightly Reactive'
Allowable Bearing Capacity	100 to 300 kPa
Groundwater	Encountered at 1.7 to 1.9m Depths

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1.0 Introduction & Understanding

The subject of this site investigation report is;

17 McDonald Place, Evans Head, NSW 2473.

It is our understanding that a multi-use development is proposed for the site. Accurate information regarding the 'footprint' of the proposed structure was available at the time of investigation.

Information, including anecdotal evidence, provided by our client has been accepted as accurate & complete, and incorporated into the investigation process as appropriate.

2.0 Desktop Study

ASCT maintains an extensive library of previous AS 2870 site classifications. This important resource is consulted with every ASCT site investigation, and appropriate information has been employed during this investigation.

A limited inspection of the available aerial photography, provided no significant information regarding the site history.

Inspection of soil mapping for the area, *TWEED HEADS - Geological Series Sheet SH 56-3 (1:250,000)*, predicts soils of the *Qx – Coastal & Estuarine Plain* origin.

The site was determined to lie within *Climatic Zone 1*, and therein have a *Depth of design suction change* (H_s) in the order of 1.5m.

Having regard to the guidance provided within AS 2870, a value of *Soil suction change* (ΔpF) of 1.2 Pico farads (pF) was deemed appropriate for the site.

3.0 Field Work

Field work at the investigation site was conducted by ASCT representative on the 23rd May 2023.

These works included;

- Recording of all significant site features having, or potentially having, an effect on the site classification.
- Recording the location, and/or physical measurements, of certain significant features (e.g.: ASCT test holes, Tree heights, Slopes, Structures).
- Digital photography.
- A determination of the ultimate bearing pressure exhibited by the site soils.
- Excavation, and logging of one or more test holes.
- An assessment of groundwater conditions.
- The retrieval of one or more soil samples, for subsequent laboratory testing.

3.1 Site Description

The site as found by ASCT on the day of the field work is described below. Photo and a simple plan of the site are included in Appendix A.

The site is located in an established residential area amidst flat terrain.

The site contains an existing single storey dwelling (to be removed).

No trees or vegetation which could affect the sites normal moisture conditions were observed.

No significant water sources were observed.

No outcropping of boulders is evident within the site.

At the time of investigation vehicle/drill rig access onto the site was easily achievable.

3.2 Sub-Surface Profile

Detailed borehole logs, in accordance with AS 1726 section 6.2, are included in Appendix A.

In essence; the sub-surface profile consists of Silty Sand (SM) and Sand (SP) underlain by Indurated Sand (SM) through to the target investigation depth of 3m.

The site exhibits uncontrolled fill materials, of a non-reactive type, up to a depth of 0.7m.

The investigation results indicate that an essentially uniform sub-surface profile exists across the site.

The sub-surface conditions encountered are unlikely to hinder normal footing construction.

3.3 Groundwater

During the investigation field-work, groundwater was encountered at a depth of 1.7 to 1.9m below the existing surface (consult the borehole logs in Appendix A).

The presence of groundwater table/seepage depends on rainfall, ground conditions, permeability, adjacent creek/river water levels and will differ over time.

While it is impossible to accurately predict future levels in a complex groundwater system, especially in a limited investigation such as this, ASCT believes that groundwater is unlikely to be of detriment to the proposed footings system.

4.0 Laboratory Work

During the field-work phase a disturbed soil sample was retrieved from Borehole 1, at a depth of 0.5m.

The sample was submitted to our NATA accredited Ballina facility for testing, in accordance with;

AS 1289.3.1.2 – Liquid Limit of a Soil (One point Casagrande).

Due to the non-plastic nature of the material lab results were unobtainable.

A California Bearing Ratio (CBR) sample was taken in sandy soils near the surface level and lab test results and pavement design parameters are included in Section 10.0 of this report. A copy of NATA endorsed Ratio (CBR) test is included in Appendix A.

5.0 Characteristic Surface Movement

Incorporating appropriate values for the Climatic Zone, depth of design suction change (H_S), soil suction change (ΔpF), lateral restraint factor (α), the thickness of each layer (h), and the properties of each layer (Instability Index I_{pt}); We have calculated the expected volume change associated with natural changes in soil moisture, and its' effect at the surface of the soil profile.

The resultant value is known as the *Characteristic Surface Movement* (Y_S), and we have determined it to be in the order of 0 to 20mm in line with AS 2870 Site Class S – "Slightly Reactive".

6.0 Site Problems

AS 2870 contains a list of potential problems that exclude a site from being classified under one of the 'Normal' classifications. Such sites are classified as Class P, so that the issues can be addressed using a tailored solution, by a professional Engineer.

ASCT is pleased to report that none of these potential problems were encountered at your site.

7.0 Foundation Options

Given the expected foundation conditions, high level (if viable), steel screw and driven/bored pier foundations are expected to be suitable to support the proposed development. Any elements (including footings and slabs) that require support at ground level will need to be founded through underlying natural medium dense or stronger sandy soils (generally encountered between 0.6m and 0.7m depths, refer borehole logs). The following allowable end bearing pressures are applicable for high level (pad, strip and raft) and steel screw piled footings.

- 100 kPa – Founded minimum 0.5m and deeper into natural medium dense sandy soils.
- 200 kPa – Founded minimum 0.5m and deeper into natural dense sandy soils.
- 300 kPa – Founded minimum 0.5m and deeper into natural very dense sandy soils.

Footings proportioned in accordance with the above recommendations and considering 1000 kN working loads should have load induced/expected settlements of no greater than about 1%-2% of the footing width.

Allowable pile end bearing pressure for driven/bored pier foundation are given below.

- 400 kPa – Founded minimum three pile diameters and deeper into natural dense sandy soils.
- 600 kPa – Founded minimum three pile diameters and deeper into natural very dense sandy soils.

The following allowable shaft adhesion values are available below the base of the excavation.

Strata	**Allowable Shaft Adhesion**
Top 1000 mm	Zero
Natural Medium Dense Sandy Soils	10 kPa
Natural Dense Sandy Soils	20 kPa
Natural Very Dense Clayey Soils	30 kPa

Bored pier foundation expected settlements are not generally to be expected to exceed 1% to 2% of the pile diameter.

Reference can be made to AS2159-2009 for the detail pile design and construction procedures.

The selection of suitable foundation option is to be at the discussion of the structural engineer.

It is appropriate that footing excavations be inspected by a suitably qualified geotechnician or geotechnical engineer in order to validate design assumptions.

8.0 Retaining Wall Design Parameters

The following parameters are applicable for the design of piles/retaining structures;

Strata	**Drained Friction Angle, Φ' (⁰)**	**Unit Weight, γ KN/m^3**
Natural Medium Dense Sandy Soils	28	18
Natural Dense Sandy Soils	30	20
Natural Very Dense Sandy Soils	32	20

9.0 Safe Batters

For the strata encountered, we recommend the following safe temporary and permanent batter angles for cut batters up to 3.0m high:

Strata	**Temporary**	**Permanent**
Fill/Natural Sandy Soils	30^{O}	18^{O}

NOTE: Permanent batter slopes require adequate crest, toe drainages and batter slope protection against erosion.

When using safe batters, the following should also be noted:

If steeper than recommended batters are proposed, it is also appropriate to engage a suitably qualified geotechnical engineer for further advice.

It is recommended that no surcharge loadings, including construction equipment, to be placed within distance of 3.0 m from the crest of a temporary cut batter.

Good site drainage is required in order to achieve the above angles, including the use of spoon drains etc to divert water away from the batters and to stop water cascading over the batters.

10.0 CBR Test Results and Pavement Design Parameters

CBR test results are summarised below.

Borehole No.	Field Moisture Content	Standard Maximum Dry Density	Optimum Moisture Content	Swell Value	CBR Value	Expansive Nature*
BH01 Subgrade – Sandy Soils	10.7%	1.635t/m^3	13.7%	0.0%	15%	Low

NOTE: * - Based on Austroads 2017 Part 2, Table 5.2: Guide to Classification of Expansive Soils.

Based on CBR = 15%, an estimated modulus of subgrade reaction will be 60 kPa/mm.

11.0 Earthworks, Site Preparation and Trafficability (If Applicable)

Any earthworks undertaken should be carried out in a responsible manner in accordance with the relevant parts of AS3798 – 2007. It is recommended that all earthworks be carried out under Level 1 inspection and testing arrangements as detailed in clause 8.2 of AS3798-2007.

Prior to the placement of any structural fill across the site, any topsoil, unsuitable, deleterious and organically contaminated surface soils should be stripped to depths exposing competent ground. In addition, any tree roots remaining from any clearing operations should be completely removed.

The stripped surface prior to filling should be tyned, moisture conditioned and re-compacted to the minimum density ratios detailed in AS 3798-2007 of 95% Standard compaction for residential and 98% standard compaction for commercial developments.

All bulk fill materials should be placed in layers of approximately 0.2m loose and be moisture conditioned within the range of ±2% of Optimum Moisture Content (OMC). Then compacted to the minimum density ratios detailed in AS 3798-2007 of 95% Standard compaction for residential developments and 98% standard compaction for commercial developments.

Where medium to high plasticity clays are proposed to be re-used as new structural filling materials in building or pavement areas, it is recommended that the cohesive material be placed at depth and granular material, or weathered rock be placed close to the subgrade level. This will reduce the effects of seasonal moisture changes and foundations soil reactivity and improve surface trafficability.

It is appropriate to maintain surface drainage conditions during earthworks and ensure that runoff water is discharged away from the construction area to prevent any water ponding. Generally, clayey, and silty materials are susceptible to moisture changes.

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12.0 Responsibilities

The Australian Standard AS 2870 includes the following statements "*Footing design and construction involves a number of steps: site classification, selection of the footings system, structural design, construction in accordance with the required design details and construction methods, and proper maintenance. In particular, the owner has a responsibility to ensure the site is properly maintained and the Standard attempts to guide owners in this area.*".

We draw your attention to this responsibility and have provided a copy of the CSIRO BTF-18 "Foundation maintenance and Footing performance: A Homeowner's Guide" to assist you. The measures suggested in the CSIRO guide are simple & cost effective, and we recommend that you observe them in consultation with your designer.

We have taken every care to be to accurate, complete & objective in the execution of your commission. Should you have any queries, or require further assistance, please do not hesitate to contact our office. This report is your intellectual property and we will not provide it to any 3rd party without your permission. May we also respectfully request that if you provide this report to others (e.g.: your builder): you provide it in its' entirety, to avoid any miscommunication.

Yours faithfully,
Australian Soil & Concrete Testing Pty Ltd

Zar Harper
Engineering Geologist

Sam Jeyan
Senior Geotechnical Engineer
(MIEAust, NER, RPEQ, RPEng)

Attachments:

Limitations of Geotechnical Site Investigation

APPENDIX A – Site Photo, Site Plan, Borehole Logs and CBR Test Results

CSIRO Homeowners Guide

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LIMITATIONS OF GEOTECHNICAL SITE INVESTIGATION

COMMISSION OF SERVICES

This geotechnical site assessment report ("The Geotechnical Report") has been prepared in accordance with the commission set out in the contract or quote, or as otherwise agreed between the Customer and Australian Soil & Concrete Testing P/L (ASCT). The commission may be limited by a range of factors such as time, cost, accessibility or site constraints and conditions.

RELIANCE ON INFORMATION PROVIDED

In preparing the report, ASCT has relied upon information provided, surveys, analyses, designs, plans and other documentation provided by the customer or other individuals and organisations, most of which are referred to in preparing the report. Except as otherwise stated in the report, ASCT has not verified the accuracy or completeness of the information provided to the extent that the statements, opinions, facts, information, conclusions and recommendations in the report are based in whole or in part on the information provided. The recommendations and conclusions are contingent upon the accuracy and completeness of the information provided. ASCT will not be liable in relation to incorrect conclusions should any provided information or site condition be incorrect or have been concealed, withheld, mis-represented or otherwise not fully disclosed to ASCT.

GEOTECHNICAL INVESTIGATION

Geotechnical site classification is based extensively on judgment and opinion. It is far less exact than other engineering disciplines. Geotechnical lot classification reports are prepared to meet the specific needs of individuals. This report was prepared expressly for the Customer and expressly for the purposes indicated. Use by any other persons for any purpose or by the customer for a different purpose, may result in problems which ASCT cannot be responsible for. The Customer should not use this report for other than its intended purpose without seeking additional geotechnical advice.

THIS GEOTECHNICAL REPORT IS BASED ON SITE SPECIFIC FACTORS

This geotechnical report is based on a subsurface investigation which only identifies the conditions at the locations and time when the investigation was undertaken. Unless further geotechnical advice is obtained this geotechnical report cannot be used when the nature of the site is changed or when the proposed development is modified for the site.

This geotechnical report cannot be applied to an adjacent site. The *Limitations of Geotechnical Site Investigation* in making an assessment of a site from a limited number of boreholes or test pits is the possibility that actual conditions may vary from those identified at the investigation locations. The Site investigation identifies specific subsurface conditions only at those points from which samples have been taken. The investigation programme undertaken is used to provide a general profile of the subsurface condition. The information obtained from the site investigation and subsequent laboratory testing is used to form a presumed opinion regarding the overall subsurface conditions and their likely behaviour with regard to the proposed development. The borehole logs are the subjective interpretation of the limited site investigation and cannot always be definitive.

SUBSURFACE CONDITIONS ARE TIME DEPENDENT

A geotechnical report is based on conditions which existed at the time of site investigation. The subsurface conditions may change due to natural forces or man-made influences. Civil works at or adjacent to the site and natural events such as floods or groundwater fluctuations may also affect subsurface conditions and the relevance of the geotechnical report. The geotechnical report should therefore be regarded as preliminary and ASCT should be consulted if unexpected conditions are encountered to determine the impact on the recommendations of the report.

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SLOPE STABILITY
This report does not cover slope stability. If this is required, an independent assessment and investigation should be undertaken by a qualified Geotechnical Engineer.

AVOID MISINTERPRETATION
The geotechnical report may be misinterpreted by other design professionals. ASCT should be retained to explain relevant geotechnical findings and to review the adequacy of plans and specifications and the implications to the report. The geotechnical report should be maintained as a whole and should not be copied, divided or altered.

GEOTECHNICAL INVOLVEMENT DURING CONSTRUCTION
It is recommended that ASCT should be retained through the construction stage to confirm the actual subsurface conditions are consistent with the geotechnical report. If variations are encountered additional tests may be required to confirm conditions comply with the design specifications and advise on changes to the construction if required.

REPORT FOR BENEFIT OF CUSTOMER
The geotechnical report has been prepared for the benefit of the customer and no other party. ASCT assumes no responsibility and will not be liable to any other person or organisation for, or in relation to, any matter dealt with or conclusion expressed in the report. ASCT will not be responsible for any loss or damage suffered by any other person or organisation arising from matters dealt with or conclusion expressed in the report (including, without limitation, matters arising from any negligent act or omission of ASCT or any loss or damage suffered by any other party relying upon the matters dealt with or conclusions expressed in the report). Other parties should not rely upon the report or the accuracy and completeness of any conclusions and should make their own enquiries and obtain independent advice in relation to such matters.

OTHER LIMITATIONS
ASCT will not be liable to update or revise the report to take into account any events of emergent circumstances or facts occurring or becoming apparent after the date of the report.

APPENDIX A – Site Photo, Site Plan, Borehole Logs and CBR Test Results.

View of the site facing a south easterly direction.

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Plan of the site, with ASCT test positions.

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BOREHOLE LOG SHEET - 1

Client:	Lewis Barakat	**ASCT Ref No:**	H23-3755
Project:	17 McDonald Place, Evans Head	**Client Ref No:**	NA
Borehole Position:	See Site Sketch	**Drilling Method:**	Power Auger
Surface Elevation:	Existing Surface Level	**Drill Bit:**	100mm Ø TC

Depth (m)	Graphic Symbol	Group Symbol	Soil Description (AS 1726)	Consistency / Relative Density / Rock Strength	DCP Blows / 100mm	Test Sample
					Cone Tip	
0.0		SM	**Silty SAND, FILL:** dark grey, non plastic, no dry	Loose	2	
0.1			strength, fine to medium grained, moist.		1	
0.2					2	
0.3				Medium Dense	3	
0.4					3	
0.5					4	Disturbed
0.6		SP	**SAND, NATURAL: NATURAL:** white, no plastic,	Medium Dense	5	
0.7			no dry strength, fine grained, moist.		5	
0.8					5	
0.9					5	
1.0					5	
1.1					5	
1.2				Dense	6	
1.3					7	
1.4					7	
1.5					7	
1.6				Very Dense	11	
1.7		SP	**Moisture change:** very moist.		10	
1.8					10	
1.9		SP	**Moisture change:** wet *(groundwater encountered)*		12	
2.0					Stopped	
2.1						
2.2						
2.3						
2.4						
2.5						
2.6		SM	**Indurated SAND, NATURAL:** dark brown, non plastic,	Very Dense		
2.7			no dry strength, fine grained, moist.			
2.8						
2.9						
3.0			**DRILLING TERMINATED:** target depth reached.			
3.1						
3.2						
3.3						
3.4						
3.5						
3.6						
3.7						
3.8						
3.9						
4.0						
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4.8						
4.9						
5.0						

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BOREHOLE LOG SHEET - 2

Client:	Lewis Barakat	**ASCT Ref No:**	H23-3755
Project:	17 McDonald Place, Evans Head	**Client Ref No:**	NA
Borehole Position:	See Site Sketch	**Drilling Method:**	Power Auger
Surface Elevation:	Existing Surface Level	**Drill Bit:**	100mm Ø TC

Depth (m)	Graphic Symbol	Group Symbol	Soil Description (AS 1726)	Consistency / Relative Density / Rock Strength	DCP Blows / 100mm *Cone Tip*	Test Sample
0.0		**SM**	**Silty SAND, FILL:** dark grey, non plastic, no dry	Loose	1	
0.1			strength, fine to medium grained, moist.		1	
0.2		**SM**	**AS ABOVE:** with clay, low plasticity.		2	
0.3					1	
0.4					2	
0.5				Medium Dense	3	
0.6					3	
0.7		**SP**	**SAND, NATURAL: NATURAL:** pale grey, no plastic,	Medium Dense	3	
0.8			no dry strength, fine grained, moist.		3	
0.9					3	
1.0					4	
1.1					5	
1.2				Dense	6	
1.3					7	
1.4					8	
1.5		**SP**	**Moisture change:** very moist.		9	
1.6					8	
1.7		**SP**	**Moisture change:** wet *(groundwater encountered)*		9	
1.8					9	
1.9					10	
2.0			**DRILLING TERMINATED:** target depth reached.		Stopped	
2.1						
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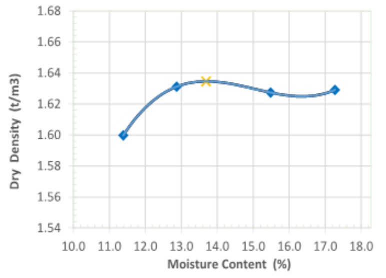
Report on AS CBR and MDD

Client:	Lewis Barakat	Report No:	**2955-1-CBR**
Client Address:	17 McDonald Place, Evans Head	Report Date:	7/06/2023
Project:	17 McDonald Place, Evans Head	Report Page:	Page 1 of 1
Works Component:	Material Assessment	Project No:	2955
Material Used(Source):	Existing	Test Request/Order:	**NA**
Material Description:	Sand	Lot Number:	NA
Lot Boundaries:	-	ITP/PCP Number:	-
Lab Test Date/s:	Laboratory testing 30/05/2023 to 07/06/2023	Control Line:	NA

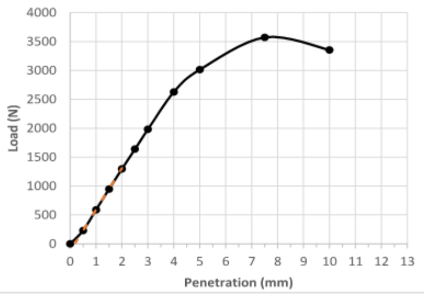
Sample Number	Sample Date	Chainage/Location	Offset	Level of Test	Test Depth
7655	**26/05/2023**	**BH01**	**NA**	**Subgrade**	**NA**

Parameters	Units	Test Results		Information
Pretreatment Regime	--	No Pretreatment		
Portion Retained on AS Sieve	%	0% on 19mm		Retained material excluded from CBR
Material Plasticity (Liquid Limit)	--	Sand / Granular		By Technician's Assessment
Sample Curing Time	hrs	MDD = 4 hrs	CBR = 24 hrs	
Soil Particle Density	t/m3	2.67		Estimated value only**
Maximum Dry Density (MDD)	t/m3	1.635		Standard compactive effort
Optimum Moisture Content (OMC)	%	13.7		
Field Moisture Content	%	Field 10.7 %		Passing 19.0mm portion
Compaction Moisture Content	%	Achieved 13.9 %	LMR = 101.5%	Specified LMR = 100%
Compaction Dry Density	t/m3	Achieved 1.63 t/m3	LDR = 99.5%	Specified LDR = 100%
Surcharge Load	kg	4.5		
Period of Soaking	Days	Soaked - 4 Days		Dry Density (after soaking) = 1.63 t/m3.
Specimen Swell	%	0.0		
Moisture Content - Top 30mm	%	18.8		After Penetration
Moisture Content - Remaining	%	18.5		After Penetration

Dry Density Vs Moisture Content



Load-Penetration Curve



Material CBR Value (%)

15

California Bearing Ratios

$CBR_{2.5}$ = 13

$CBR_{5.0}$ = 15

Including an Applied Correction of 0.2 mm

Sampling & Test Methods (Results relate only to the items sampled/tested)

AS 1289.1.2.1, Cl 6.5.3: (1998)Disturbed Soil Sampling - Powered - Auger
AS 1289.1.1: (2001)Preparation of disturbed soil samples
AS1289.2.1.1: (2005) Moisture Content of a Soil (Oven Drying)
AS1289.5.1.1: (2017)Dry Density/Moisture content relation of a soil (Standard)
AS1289.6.1.1: (2014)California Bearing Ratio of a soil (remoulded specimen)

** NATA accreditation does not cover the performance of this service

Report Remarks & Endorsement

NATA

Accredited for compliance with ISO/IEC 17025 - Testing.
NATA Accreditation number: 19644

Issued By:
D.Kennedy
Approved Signatory

WB011 - Rev 31, 06/02/2023

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Foundation Maintenance and Footing Performance: A Homeowner's Guide

CSIRO PUBLISHING

BTF 18-2011 replaces Information Sheet 10/91

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

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

Soil Types

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

Classifications for a given area can generally be obtained by application to the local authority, but these are sometimes unreliable and if there is doubt, a geotechnical report should be commissioned. As most buildings suffering movement problems are founded on clay soils, there is an emphasis on classification of soils according to the amount of swell and shrinkage they experience with variations of water content. The table below is Table 2.1 from AS 2870-2011, the Residential Slab and Footing Code.

Causes of Movement

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

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

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

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

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

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

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

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

- Significant load increase.
- Reduction of lateral support of the soil under the footing due to erosion or excavation.

In clay soil, shear failure can be caused by saturation of the soil adjacent to or under the footing.

GENERAL DEFINITIONS OF SITE CLASSES

Class	Foundation
A	Most sand and rock sites with little or no ground movement from moisture changes
S	Slightly reactive clay sites, which may experience only slight ground movement from moisture changes
M	Moderately reactive clay or silt sites, which may experience moderate ground movement from moisture changes
H1	Highly reactive clay sites, which may experience high ground movement from moisture changes
H2	Highly reactive clay sites, which may experience very high ground movement from moisture changes
E	Extremely reactive sites, which may experience extreme ground movement from moisture changes

Notes
1. Where controlled fill has been used, the site may be classified A to E according to the type of fill used.
2. Filled sites. Class P is used for sites which include soft fills, such as clay or silt or loose sands; landslip; mine subsidence; collapsing soils; soil subject to erosion; reactive sites subject to abnormal moisture conditions or sites which cannot be classified otherwise.
3. Where deep-seated moisture changes exist on sites at depths of 3 m or greater, further classification is needed for Classes M to E (M-D, H1-D, H2-D and E-D).

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

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

Unevenness of Movement

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

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

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

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

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

Effects of Uneven Soil Movement on Structures

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

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

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

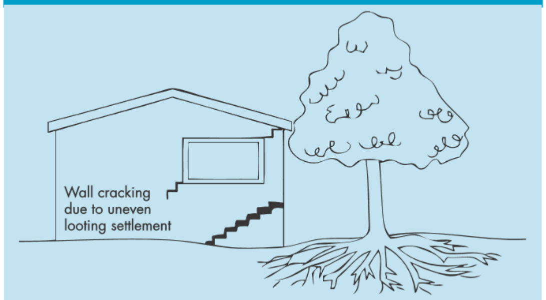
Seasonal swelling/shrinkage in clay
Swelling foundation soil due to rainy periods first lifts the most exposed extremities of the footing system, then the remainder of the perimeter footings while gradually permeating inside the building footprint to lift internal footings. This swelling first tends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

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

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

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.

Trees can cause shrinkage and damage



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

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

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

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

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

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

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

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

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

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

Effects on framed structures

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

Effects on brick veneer structures

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

Water Service and Drainage

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

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

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

Seriousness of Cracking

In general, most cracking found in masonry walls is a cosmetic nuisance only and can be kept in repair or even ignored. The table below is a reproduction of Table C1 of AS 2870-2011.

AS 2870-2011 also publishes figures relating to cracking in concrete floors, however because wall cracking will usually reach the critical point significantly earlier than cracking in slabs, this table is not reproduced here.

Prevention/Cure

Plumbing

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

Ground drainage

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

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

Protection of the building perimeter

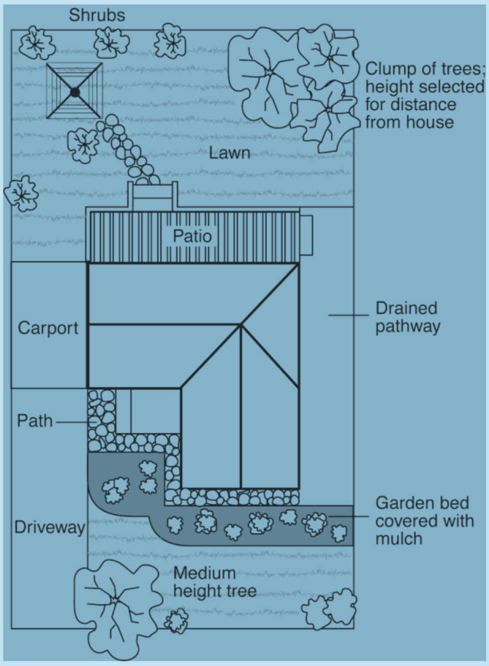
It is essential to remember that the soil that affects footings extends well beyond the actual building line. Watering of garden plants, shrubs and trees causes some of the most serious water problems.

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

CLASSIFICATION OF DAMAGE WITH REFERENCE TO WALLS

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

Gardens for a reactive site



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

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

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

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

Condensation

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

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

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

The garden

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

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

Existing trees

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

Information on trees, plants and shrubs

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

Excavation

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

Remediation

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

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

This BTF was prepared by John Lewer FAIB, MIAMA, Partner, Construction Diagnosis.

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