Preliminary Geotechnical Investigation

Farnell Street, Forbes, NSW 2871

Prepared for: Land and Housing Corporation c/- ADW Johnson Pty Ltd

EP3269.001v2 17 January 2024

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Farnell Street, Forbes, NSW 2871

Land and Housing Corporation c/- ADW Johnson Pty Ltd
7/335 Hillsborough Road
Warners Bay NSW 2282

17 January 2024

Our Ref: EP3269.001

LIMITATIONS

This Preliminary Geotechnical Investigation was conducted on the behalf of Land and Housing Corporation c/- ADW Johnson Pty Ltd for the purpose/s stated in **Section 1**.

EP Risk has prepared this document in good faith, but is unable to provide certification outside of areas over which EP Risk had some control or were reasonably able to check. The report also relies upon information provided by third parties. EP Risk has undertaken all practical steps to confirm the reliability of the information provided by third parties and do not accept any liability for false or misleading information provided by these parties.

It is not possible in a Preliminary Geotechnical Investigation to present all data, which could be of interest to all readers of this report. Readers are referred to any referenced investigation reports for further data.

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1 Introduction

EP Risk Management Pty Ltd (EP Risk) was engaged by ADW Johnson Pty Ltd (ADWJ) to undertake a Desktop Preliminary Geotechnical Investigation for the proposed residential subdivision at Farnell Street, Forbes NSW 2871. The Site is legally defined as Lot 7332/DP1166365, Lot 7025/DP1020631, Lot 7317/DP1166614 and part of Lot 1/DP1077961 and is approximately 12.3 hectares in size. The aim of the desktop study is to provide the following:

- Indicative subsurface conditions.
- Preliminary flexible pavement design in accordance with Council Engineering Guidelines and expected subgrade CBR.
- Preliminary site classification in accordance with AS2870-2011 Residential slabs and footings and AS1170 Structural Design Actions.

1.1 Scope of Work

The scope of the investigation included the following:

- Undertaking a desktop study to collect and review available information related to the Site.

This Geotechnical Report has been prepared in accordance with our proposal (EP16812 dated 27 May 2023) and includes the findings of the investigation scope along with:

- Preliminary identification of geological units likely to be encountered onsite.
- Preliminary pavement design.
- Preliminary site classification.

2 Site Location and Description

The Site comprises of a large irregular shaped portion of land, bound by Farnell Street to the east, Dawson Street to the south, Watson Close to the north, and adjacent properties to the west. The topography of the Site is relatively flat to gently undulating with elevations ranging from a Reduced Level (RL) of 249m above the Australian Height Datum (AHD) in the southern portion of the Site to approximately RL 262m in the northern portion of Site.

Based on topographical information sourced from Nearmap, Site vegetation generally comprises of short grass with various ground vegetation and matures trees scattered across the northern portion of the Site. Several informal unsealed access tracks are also noted across the Site.

Site drainage is assumed to be overland flow via surface contours flowing from the southern portion of site to the northern boundary. The Site location is shown in Figure 1, an excerpt from SIX maps.

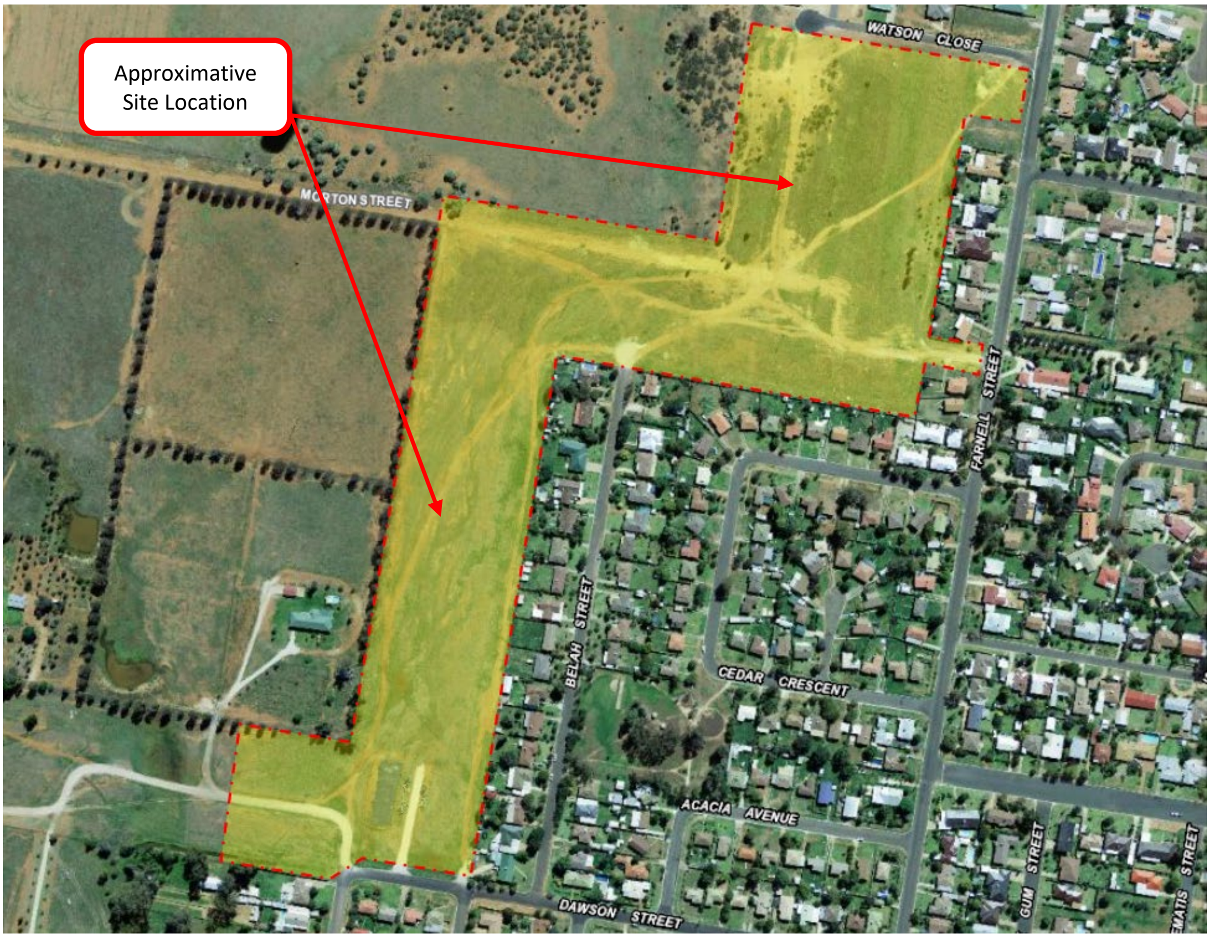


Figure 1. Site Location (excerpt from SIX maps)

3 Desktop Study

3.1 Regional Geology

Based on geological data sourced from NSW Government website (www.minview.geoscience.nsw.gov.au), the Site surface geology comprises of Quaternary Aged Colluvial and Residual Deposits, known to contain undifferentiated colluvial and residual deposits and by Ludlow aged sandstone. An excerpt of the geological map is shown in Figure 2.

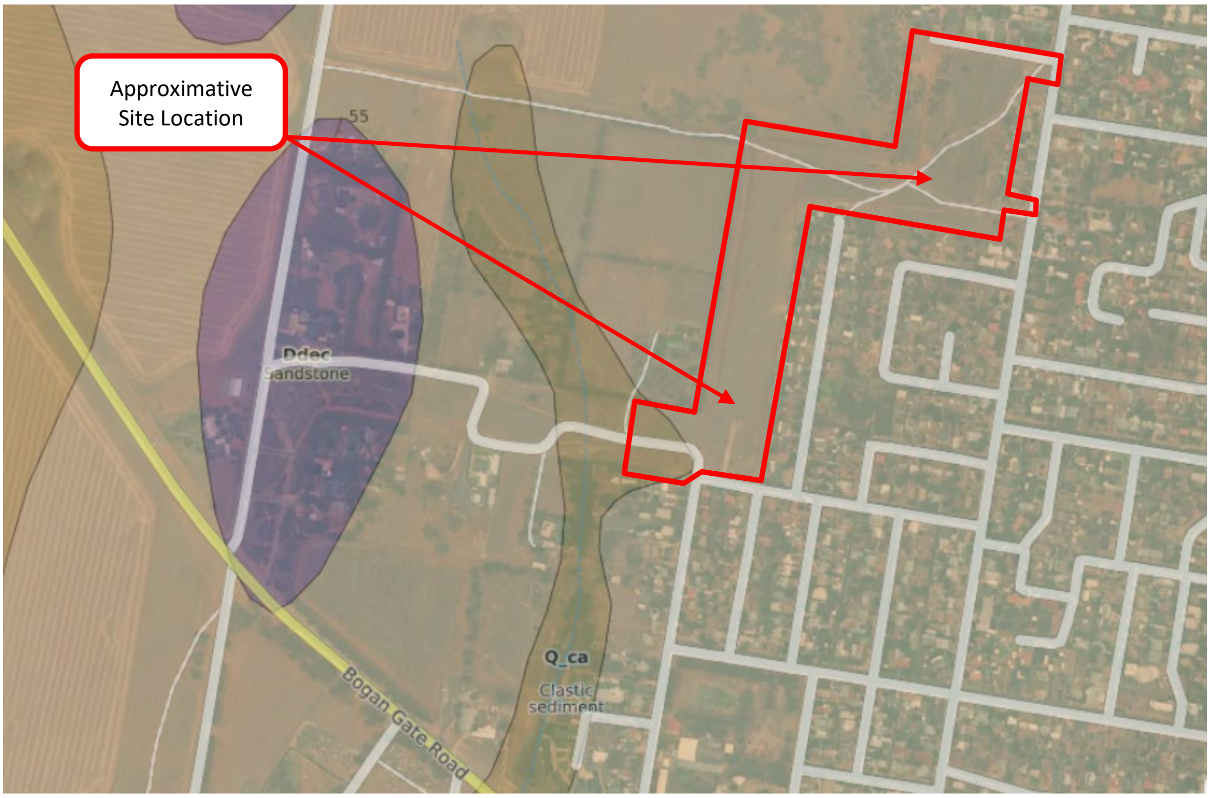


Figure 2. Geological Map Excerpt

3.2 Soil Landscape

With reference to the NSW Department of Industry, Resources and Energy (www.environment.nsw.gov.au), onsite soil landscapes have been identified to comprise of Bald Hill (SI5507bh). The landscape is described as having narrow elongated crests, ridges and gently inclined sideslopes at Forbes and south-west of Forbes on predominantly sandstones. Sandstones are the dominant lithology with minor shales, mudstone, limestones and volcanics. Some limitations of the Bald Hill soils include water erosion hazard, rock outcrop, shallow, strongly acidic, and highly permeable soils with low fertility.

Based on the lithology of the site soil with various components of silt sand and clay would be expected to predominate. Colluvial soils will likely be siltier and sandier in nature and the residual soils having higher clay contents. Shallow rock can be expected across the site.

4 Preliminary Pavement Design

4.1 Design Traffic

Preliminary design traffic loadings and pavement thickness design calculations have been undertaken by EP Risk in general accordance with Forbes Shire Council general practice. The preliminary pavement design has been undertaken based on the indicative design traffic presented in Table 1.

Table 1. Indicative Road Type and Design ESA's

Road Type	Road Identification	Design ESA’s
Collector	TBC	6.0×10^5
Local Access	TBC	2.0×10^5

Where traffic data varies from the above assumptions, a review of pavement design may be required.

4.2 Pavement Design Parameters

The preliminary pavement design thickness has been undertaken in accordance with the following assumptions:

- Design subgrade CBR of 3% for Sandy CLAY and Clayey SAND soil materials and engineering fill placed as controlled fill.
- Design subgrade CBR of 6.0% if extremely weathered bedrock material is encountered onsite and where subgrade treatment is undertaken (cement/lime treatment).

The above assumptions need to be confirmed following the intrusive geotechnical investigation and soil laboratory testing. The design subgrade CBR (%) has been assumed based on the geological units expected to be encountered onsite and will need to be confirmed by intrusive testing at a later date. Where filling is undertaken greater than 0.6 m depth, the CBR of the fill material should be considered for the design CBR. All fill materials should be a minimum of CBR 3% based on 4-day soak when compacted to 100% standard relative density and SOMC.

4.3 Preliminary Pavement Thickness Options

The option of pavement design utilising flexible unbound pavement materials for Sandy CLAY/Clayey SAND subgrade with a CBR of 3% is detailed in Table 2.

Table 2. Preliminary Flexible Pavement Composition (Subgrade CBR 3%)

Pavement Layer	Road Type: Local Access	Road Type: Collector	Road Type: Local Access	Road Type: Collector
Wearing Course (mm)	40 AC14*	50 AC14*	40 AC14*	50 AC14*
Basecourse (mm)	150	150	150	150
Subbase (mm)	240 (150)	300 (150)	150	150
Select** (mm)	(300)	(300)	-	-
Total thickness (mm)	430 (640)	500 (650)	340	350
Subgrade CBR (%)	min 3%	min 3%	min 6%	min 6%
Allowable DESA	2.0×10^5	6.0×10^5	2.0×10^5	6.0×10^5

*AC14 (dense grade mix) with 10mm primer seal placed under the asphaltic concrete wearing surface.
**Where reactive clay has a CBR swell ≥2.5% the pavement option using a select subgrade should be adopted (shown in brackets).

As alternative to the asphalt concrete the roads can be covered by a two-coat bituminous flush seal wearing course, subject to council approval. In this case, the thickness of subbase/select needs to be increased by the thickness of asphalt layer. A minimum of fourteen days duration shall apply prior to application of subsequent asphalt layer(s). That period may be extended or shortened subject to approval by Council.

The determination of a weathered rock subgrade suitable to adopt a CBR 6% subgrade should be undertaken by a geotechnical consultant or suitably qualified council engineer. If the soaked CBR of the subgrade is <3%, the subgrade could be chemically stabilised to a minimum depth of 300mm. Lime stabilisation could be considered to improve the CBR <3% for low strength subgrade material and typically, stabilisation with 2-3% lime can improve the subgrade CBR to ≥5% but this would need to be confirmed with site specific laboratory soaked CBR testing. Alternatively, a low-strength subgrade with a CBR <3% encountered at the design subgrade level (DSL) shall be removed and replaced with 0.6m of CBR >3% site-won material.

Where weathered bedrock is encountered at the design subgrade level (DSL), the pavement thickness design as indicated in Table 2 should be adopted. Where consistent bedrock is encountered at the DSL, adoption of the CBR 6% design is appropriate following ripping and re-compaction to a depth of 300mm below DSL.

4.4 Subgrade Preparation

Where construction of a new pavement is proposed, subgrade preparation should be in general accordance with the following procedures.

- Remove topsoil to the design subgrade level (DSL).
- Excavation of colluvial/residual soil/weathered bedrock to design subgrade level.
- Ripping the insitu subgrade (including weathered bedrock) 300-350mm below DSL and recompact to a minimum 100% of SMDD. Moisture content should be within 70% to 90% of SOMC (generally -3% to -1% dry of SOMC) and care is required not to compact the subgrade at high levels of relative compaction at moisture significantly dry of SOMC as this will create swell potential, particularly in reactive/expansive clay subgrades.
- Static proof-rolling of the exposed subgrade using a heavy (minimum 10-tonne) roller under the direction of an experienced geotechnical consultant.
- Loose or yielding areas should be excavated and replaced with compacted select fill or suitable subgrade replacement comprising material of similar consistency to the subgrade.

- Testing of the subgrade by soaked CBR testing to confirm the design parameters.

Where filling or subgrade replacement is required, the materials employed should be free of organics or other deleterious materials. The material should also have a maximum particle size of 100mm or one-third of the layer thickness, with a minimum soaked CBR of 3% or 6% depending on the pavement option adopted. Following satisfactory preparation of the subgrade, the pavement should be placed in accordance with the designer's recommendations.

4.5 Materials

4.5.1 Specifications and Compaction Requirements

Pavement materials and compaction requirements for new pavement construction should conform to Forbes Shire Council requests and the following conditions in Table 3.

Table 3. New Unbound Pavement Construction: Material Specification and Compaction Requirements

Pavement Course	Material Specification Recommendation	Compaction Requirements
Base Course High quality crushed rock (Class 2 for local roads)	Material complying with TfNSW QA Specifications 3051 Category D CBR ≥80%, with 2% < PI < 6%	Min 98% Modified (AS 1289 5.2.1) or Min 102% Standard (AS 1289 5.1.1)
Subbase Subbase quality crushed rock	Material complying with TfNSW QA Specifications 3051 Category D and CBR ≥30% with PI < 10%	Min 95% Modified (AS 1289 5.2.1) or Min 100% Standard (AS 1289 5.1.1)
Select	CBR ≥30%	Min 100% Standard (AS 1289 5.1.1)
Subgrade or replacement	Minimum CBR≥3% or 6% depending on pavement option.	Min 100% Standard (AS 1289 5.1.1)

All granular pavement material quality should be in general accordance with TfNSW QA Specification 3051 for Traffic Category D "Light" for local roads and Traffic Category B "Heavy for collector roads. Where recycled base or subbase are proposed conformance with the Council specifications are required.

Minimum testing on all potential imported pavement materials should be in accordance with TfNSW 3051 Ed 7. Pre-treatment of material prior to testing would be advisable for materials subject to breakdown.

4.6 Preliminary Site Classification

EP Risk were requested to provide Preliminary Site Classification in accordance with AS 2870-2011 for the Residential Development.

Australian Standard AS 2870-2011 establishes performance requirements and specific designs for common foundation conditions as well as providing guidance on the design of footing systems using engineering principles. Site classes as defined on Table 2.1 and 2.3 of AS 2870-2011 are presented in Table 4.

Table 4. General Definition of Site Classes

Site Class	Foundation	Characteristic Surface Movement
A	Most sand and rock sites with little or no ground movement from moisture changes	
S	Slightly reactive clay sites, which may experience only slight ground movement from moisture changes	0 – 20 mm
M	Moderately reactive clay or silt sites, which may experience moderate ground movement from moisture changes	20 – 40 mm
H1	Highly reactive clay sites, which may experience high ground movement from moisture changes	40 – 60 mm
H2	Highly reactive clay sites, which may experience very high ground movement from moisture changes	60 – 75 mm
E	Extremely reactive sites, which may experience extreme ground movement from moisture changes	> 75 mm
A to P	Filled sites (refer to clause 2.4.6 of AS 2870-2011)	
P	Sites which include soft soils, such as soft clay or silt or loose sands; landslip; mine subsidence; collapsing soils; soils subject to erosion; reactive sites subject to abnormal moisture conditions or sites which cannot be classified otherwise.	

Reactive sites are sites consisting of clay soils that swell on wetting and shrink on drying, resulting in ground movements that can damage lightly loaded structures. The amount of ground movement is related to the physical properties of the clay and environmental factors such as climate, vegetation and watering. A higher probability of damage can occur on reactive sites where abnormal moisture conditions occur, as defined in AS 2870-2011, due to factors such as:

- Presence of trees on the building site or adjacent site, removal of trees prior to or after construction, and the growth of trees too close to a footing. The proximity of mature trees and their effect on foundations should be considered when determining building areas within each allotment (refer to AS 2870-2011.
- Failure to provide adequate site drainage or lack of maintenance of site drainage, failure to repair plumbing leaks and excessive or irregular watering of gardens; and
- Unusual moisture conditions caused by removal of structures, ground covers (such as pavements), drains, dams, swimming pools, tanks etc.

In regard to the performance of footings systems, AS 2870-2011 states “footing systems designed and constructed in accordance with this Standard on a normal site (see Clause 1.3.2) that is

(a) not subject to abnormal moisture conditions; and

(b) maintained such that the original site classification remains valid and abnormal moisture conditions do not develop;

are expected to usually experience no damage, a low incidence of damage category 1 and an occasional incidence of damage category 2.”

Damage categories are defined in Appendix C of AS 2870-2011, which is reproduced in CSIRO Information Sheet BTF 18*, Foundation Maintenance and Footing Performance: A Homeowner’s Guide.*

The laboratory testing to determine the shrink swell index will need to be undertaken to confirm assumptions.

Based on the anticipated soil profiles, and in accordance with AS 2870-2011, the site in its existing condition and in the absence of abnormal moisture conditions received site classifications from ranging from **Class M-D**, moderately reactive to **Class H1-D**, highly reactive.

The above classifications assume that all foundations are founded below any topsoil, uncontrolled fill or slope wash within natural soil profile or on engineered fill. Characteristic surface movements in the range of 20 mm to 60mm can be anticipated based depending on soil profile and depth to rock. Specific investigation for individual lots may be able to provide an alternate lower classification based on uniform depth to rock or lower reactivity over the soil profile. The Site Classifications assume that all footings (edge beams, internal beams, and load support thickenings) are founded below any topsoil, slopewash, fill or other deleterious material and have been based on assumed waffle type slab construction. Where footings are uniformly founded in bedrock (not anticipated), the adoption of a Class A of Class S could be considered.

As noted in **Section 2**, the Site was had scattered trees. Clause 1.3.3 of AS 2870-2011 nominates that the presence of trees could result in abnormal moisture conditions at the Site should the trees be located within the building areas (including new planting and street landscaping). In such situations, AS 2870-2011 nominates adoption of a Class P classification.

Designs and design methods presented in AS 2870-2011 are based on the performance requirement that significant damage can be avoided if site conditions are properly maintained. Performance requirements and foundation maintenance are outlined in Appendix B of AS 2870-2011. The above site classification assumes that the performance requirements as set out in Appendix B of AS 2870-2011 are acceptable and that site foundation maintenance is undertaken to avoid extremes of wetting and drying.

Details on appropriate site and foundation maintenance practices are presented in Appendix B of AS 2870-2011 and in CSIRO Information Sheet BTF 18*, Foundation Maintenance and Footing Performance: A Homeowner's Guide*, which is attached as **Appendix A** of this report.

Adherence to the detailing requirement outlined in Section 5 of AS 2870-2011 is essential, in particular Section 5.6 *Additional requirements for Classes M, H1 and H2 sites*, including architectural restrictions, plumbing and drainage requirements.

4.7 Footings

All foundations should be designed and constructed in accordance with 2870-2011, *Residential Slabs and Footings* with reference to site classifications as presented in Section 5.1.

All footings should be founded below any topsoil, slopewash, deleterious soils or uncontrolled fill. All footings for the same structure should be founded on strata of similar stiffness and reactivity to minimise the risk of differential movement and should be confirmed by specific investigation for proposed structures.

Potential for differential movement should be considered due to variation in depth to rock and filling across the Site and articulation incorporated into the design.

4.7.1 High Level Footings

High-level footing alternatives could be expected to comprise slabs on ground with edge beams or pad footings for the support of concentrated loads. Such footings designed in accordance with engineering principles and founded in stiff or better soils (below topsoil, slopewash, uncontrolled fill or other deleterious material) may be proportioned on an allowable bearing capacity of 100 kPa.

Where controlled lot filling has been carried out, high-level footing types should be founded below any topsoil onto the engineered fill that is placed and compacted in accordance with AS3798-2007.

Footings designed in accordance with engineering principles and founded uniformity on competent weathered rock (not anticipated) may be proportioned on an allowable bearing capacity of 500 kPa. The founding conditions should be assessed by a geotechnical consultant or experienced engineer to confirm suitable conditions.

4.7.2 Piered Footings

Piered footings are considered as an alternative to deep edge beams or high-level footings and provide an alternate founding solution. It is suggested that bored pier footings, founded in stiff or better natural clay could be proportioned on an end bearing pressure of 150 kPa or if founded in competent weathered rock, could be proportioned on an end bearing pressure of 400 kPa.

All footings should be founded below any topsoil, slopewash, deleterious soils or uncontrolled fill. All footings for the same structure should be founded on strata of similar stiffness and reactivity to minimise the risk of differential movements.

Inspection of high level or pier footings excavations should be undertaken to confirm the founding conditions and the base should be cleared of fall-in prior to the formation of the footings.

4.8 Detailed Investigation

Detailed investigation including test pitting and or test bores will need to be undertaken prior to the final design with laboratory testing on representative samples of the soil encountered during the investigation to confirm the design parameters used in this report.

5 References

- Australian Standards ÄS1170-2002 Structural Design Actions.
- Australian Standards AS2870-2011Residential Slabs and Footings.
- Australian Standards AS3798-2007 Guidelines on earthworks for commercial and residential developments.
- Austroads AGPT02-17, “Guide to Pavement Technology Part 2: Pavement Structural Design,” Austroads Ltd, 2017
- Austroads AGPT04B-07, Guide to Pavement Technology Part 4B: Asphalt, Austroads Ltd, May 2007
- eSPADE, Online website of NSW Office of Environment and heritage (www.environment.nsw.gov.au)
- NSW Department of Planning and Environment, Resources and Geoscience (www.resourcesandgeoscience.nsw.gov.au)
- TfNSW QA Specification 3051 (Ed 7 Rev 0), “Granular Base and Subbase Materials for Surfaced Road Pavements,” Roads and Maritime Services, April 2011
- TfNSW Supplement Version 2.1, “Austroads Supplement for Guide to Pavement Structural Design,” TfNSW, 2015

Appendix A

FOUNDATION MAINTENANCE AND FOOTING PERFORMANCE

Foundation Maintenance and Footing Performance: A Homeowner's Guide

CSIRO

BTF 18 replaces Information Sheet 10/91

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

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

Soil Types

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

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

Causes of Movement

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

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

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

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

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

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

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

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

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

GENERAL DEFINITIONS OF SITE CLASSES

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

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

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

Unevenness of Movement

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

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

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

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

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

Effects of Uneven Soil Movement on Structures

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

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

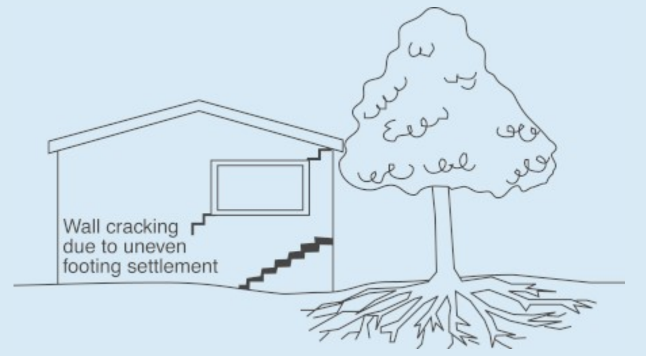
Isolated piers affected by erosion or saturation of foundations will eventually lose contact with the bearers they support and may tilt or fall over. The floors that have lost this support will become bouncy, sometimes rattling ornaments etc.

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

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

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

Trees can cause shrinkage and damage



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

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

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

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

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

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

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

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

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

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

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

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

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

Water Service and Drainage

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

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

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

Seriousness of Cracking

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

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

Prevention/Cure

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

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

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

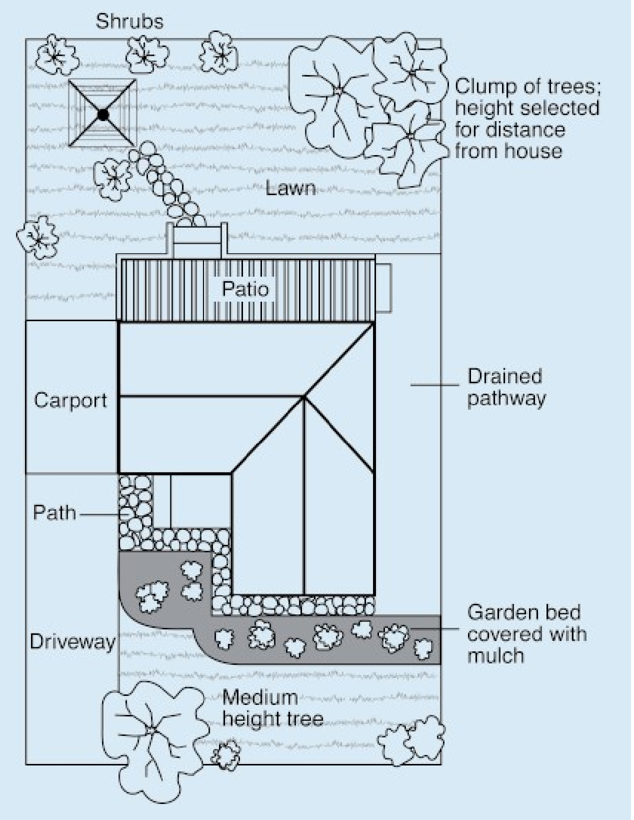
Protection of the building perimeter
It is essential to remember that the soil that affects footings extends well beyond the actual building line. Watering of garden plants, shrubs and trees causes some of the most serious water problems.

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

CLASSIFICATION OF DAMAGE WITH REFERENCE TO WALLS

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

Gardens for a reactive site



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

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

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

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

Condensation

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

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

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

The garden

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

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

Existing trees

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

Information on trees, plants and shrubs

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

Excavation

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

Remediation

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

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

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