SITE AND SOIL EVALUATION REPORT

FOUNDATION, WINDLOADING AND LANDSLIDE RISK ASSESSMENT

**13 Steen Court, Blackmans Bay**

**January 2026**

Doyle Soil Consulting: 6/76 Auburn Rd Kingston Beach 7050 – 0488 080 455 – robyn@doylesoilconsulting.com.au

## Founding Statement

Dr Richard Doyle is a highly qualified geologist, geomorphologist and soil scientist with over 40 years work experience in earth sciences. He has a B.Sc. (Hons) in geology and physical geography (Victoria University of Wellington, NZ), an M.Sc. in geology awarded with distinction specialising in geomorphology, erosion and soil development (Victoria University of Wellington, NZ) and a PhD in soil science from UTAS. Dr Doyle is a Certified Professional Soil Scientist (CPSS) of the Australian Society of Soil Science of which he is former state and national president. He has authored numerous landslides risk, coastal erosion, inundation and other earth-based risk assessments for Tasmanian councils and has over 100 scientific publications in journals, books and conference proceedings. He has been an expert witness in numerous court cases, tribunals and mediation hearings.

## SITE INFORMATION

**Client:** Kelly and Tom De Hoog

**Address:** 13 Steen Court, Blackmans Bay (CT 139641/26)

**Site Area:** Approximately 880 $m^2$

**Date of inspection:** 14/01/2026

**Building type:** New house

**Services:** Reticulated water supply and sewer

**Relevant Planning Overlays:** Landslide Hazard Area LOW

**Mapped Geology** - Mineral Resources Tasmania 1:25 000 Blackmans Bay: **Jd -**dolerite; **Rqph -** Triassic sandstone, siltstone, mudstone down slope -along western boundary

**Soil Depth:** 0.7 – 0.8 m

**Subsoil Drainage:** Well drained

**Drainage lines/water courses:** none

**Vegetation:** pasture

**Rainfall in previous 7 days**: Approximately 4.2 mm

**Slope:** up to 19° NW

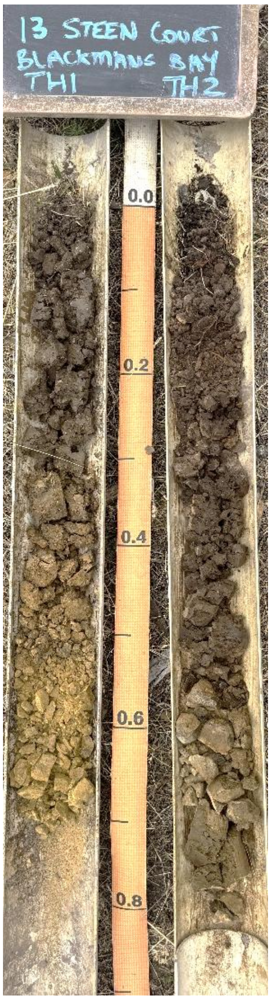
## SITE ASSESSMENT AND SAMPLE TESTING

Site investigation and soil classification in accordance with AS 2870-2011 *Residential slabs and footings* and in accordance with AS 4055-2021 *Wind load for Housing.* Test holes were dug using a Christie Post Driver Soil Sampling Kit, comprising CHPD78 Christie Post Driver with Soil Sampling Tube (50 mm OD x 1600/2100 mm). For test hole and DCP locations, see Appendix 1.

- Two test hole (TH) cores:
  - TH1 with effective refusal at 0.5 m
  - TH2 with refusal at 0.8 m
- One Dynamic Cone Penetrometer (DCP) test:
  - DCP1 with refusal at 0.8 m
- Emerson Dispersion test on subsoils and linear shrinkage tests on all likely founding layers.

  - All clays = Emerson Class 8 (non-dispersive)

## SOIL PROFILES – Test Hole 1




| Depth (m) | Horizon | Description and field texture grade | USCS Class |
|---|---|---|---|
| 0 - 0.3 | A1 | Greyish brown (2.5YR 5/2), **Silty Light Clay,** strong medium angular blocky structure, dry stiff consistency | **CH** |
| 0.3 – 0.5 | $B2_1$ | White yellowish brown (2.5YR 6/4) **Silty Light Clay,** strong medium angular body structure, dry very stiff consistency | **CH** |
| 0.5 – 0.7 | Cw | Platy sandy mudstone bedrock<br><br>Refusal | **GW** |

## SOIL PROFILES – Test Hole 2

| Depth (m) | Horizon | Description and field texture grade | USCS Class |
|---|---|---|---|
| 0 – 0.2 | A1/Fill | dark grey (7.5YR 4/1) **Gritty Sandy Clay Loam,** Common gravels, dry dense consistency, strong fine angular blocky structure | **SC** |
| 0.2 – 0.6 | A1 | Greyish brown (2.5YR 5/2), **Silty Light Clay,** strong medium angular blocky structure, dry stiff consistency | **CH** |
| 0.6 – 0.7 | Stone line | Dolerite boulder | **N/A** |
| 0.7 – 0.8 | $B2_1$ | Light olive brown (2.5YR 5/3), **Medium Clay,** massive, dry stiff consistency<br><br>**Refusal on dolerite bedrock** | **CH** |

## SITE AND SOIL COMMENTS

The soil profiles are formed from clayey colluvium derived from Jurassic dolerite. The profiles are shallow, with refusal occurring at approximately 0.5 to 0.8 m. The field textures of the soil profile are dominated by clay, which is highly reactive, weakly to moderately structured and non-dispersive. The DCP indicates a low bearing capacity to at least 0.5 m. Founding on the underlying, highly competent, dolerite and/or sandstone bedrock, at approximately 0.5 – 0.8 m depth, is recommended.

Additional, and previous, testing by Doyle Soil Consulting at 11 Steen Court found hard dolerite bedrock at 0.4 – 0.5 m depth.

## LINEAR SHRINKAGE AND SOIL REACTIVITY

Samples of the clayey subsoils were tested for reactivity using the linear shrinkage test. Linear shrinkage provides an approximate guide to aid site classification (for foundations) based on the reactivity of clays. The results suggest the clays are highly reactive (refer to tables below and *AS2870-2011 clause 2.1.2 table 2.1*).

| TH # | Depth (m) | Length of mould (mm) | Longitudinal Shrinkage (LS) in mm | LS (%) | Soil Class |
|---|---|---|---|---|---|
| 1 & 2 | $B2_1$ | 125 | 23.0 | 18.4 | H – 1 |

## DCP TESTS AND ESTIMATED BEARING CAPACITY

A minimum bearing capacity of 100 kPa is required for strip and pad footings and under the edge footings and associated slab foundations (refer to tables below and *AS2870-2011 clause 2.4.5*). We provide an estimated allowable soil bearing capacity based on a review of published literature relating field Dynamic Cone Penetrometer (DCP) readings to triaxial soil strength tests.

The DCP penetrometer is a method of estimating *in situ* strength of the soil. Soil moisture level at the time of measurement will greatly affect DCP readings. Moisture-related variability in soil bearing capacity is most pronounced in coherent soils (clays and silty clays) which may be stiff/hard when dry but become soft/firm when moist/slightly moist.

Surface layers (upper ~0.7 m) are subject to seasonal variation in soil moisture content, leading to possible higher DCP values in summer/drought conditions. Soil moisture below ~0.7 m will vary less with the season, meaning DCP values; hence, soil-bearing capacity at these depths is likely to be representative of year-round conditions.

When estimating the suitable foundation depth, we take into account the interplay between soil bearing capacity and seasonally variable soil moisture conditions in the upper layers (refer to *soil consistency* in Soil Profile descriptions). The subsoils in the upper 0.7 m were slightly moist when tested (January ’26).

The data from DCP1 indicate the bearing capacity of the soil is at a *suitable* strength below 0.7 m. However, the highly competent bedrock at approximately 0.8 m would be the *recommended* foundation material.

Based on the DCP data and core depths, the recommended foundation depth can range from approximately 0.7 to 0.8 m.

| **DCP 1** | | | | |
|---|---|---|---|---|
| **Depth (mm)** | **DCP n-number (Blows/100 mm)** | **DCP Penetration Index (mm/Blow)** | **Estimated Allowable Bearing Capacity (kPa = n x 30)** | **Likely Variance (+/-)** |
| 0 - 100 | 7 | 14.3 | 210 | 70 |
| 100 - 200 | 8 | 12.5 | 240 | 80 |
| 200 - 300 | 8 | 12.5 | 240 | 80 |
| 300 - 400 | 5 | 20.0 | 150 | 50 |
| 400 - 500 | 9 | 11.1 | 270 | 90 |
| 500 - 600 | 12 | 8.3 | 360 | 120 |
| 600 - 700 | 24 | 4.2 | 720 | 240 |
| 700 - 800 | 30 | 3.3 | 900 | 300 |

## WIND CLASSIFICATION

The following wind classification for the site is in accordance with AS 4055-2021 (*Wind loads for Housing*). For structures other than class 1 and class 10 structures, or that exceed the geometric limits in Clause 1.2 of AS 4055-2021, the wind classification shall be calculated in accordance with AS 1170.2-2021 (*Structural Design Actions – Wind Actions)*.

The wind classification for the site, per AS 4055-2021:

| | |
|---|---|
| Region: | **A** |
| Terrain Category: | **TC1 – open water within 500 m** |
| Shielding Classification: | **FS – full shielding** |
| Topographic Classification: | **T2 – middle 3rd of 1:4.5 slope feature** |
| Wind Classification: | **N3** |
| Design Wind Gust Speed ($V_{h,u}$): | **50 m/sec** |

## SITE CLASSIFICATION (per AS2870:2011) AND RECOMMENDATIONS

For standard foundations (100 kPa bearing capacity), the site meets the criteria for a **Class M** (moderately reactive) site classification. The dominant reactivity of expected surface movement under normal soil moisture ranges for the location is 20 – 40 mm. Founding on the underlying, highly competent, dolerite and/or sandstone bedrock, at approximately 0.5 – 0.8 m depth, is recommended.

**Note 1 –** If founded entirely on underlying competent dolerite and/or sandstone bedrock (as recommended), below approximately 0.5 to 0.8 m, and no part of the foundations, be it a slab, pier or footing, is in contact with/or is supported by the subsoils, then **Class A** would become an appropriate site classification.

**Note 2 –** All foundations require ongoing adequate drainage and vegetation management – please refer to the attached CSIRO foundation management BTF 18 sheet.

**Note 3 –** If any foundations are placed on FILL that is > 0.5 m in depth, then **Class P** is applicable.

**Note 4 –** Based on the upper 0.6 m of soil, all plumbing fixtures and fittings should be suitable for a **Class M** site, per *Appendix G AS/NZS 3500.2.2021*.

**General Notes –** Important points pertinent to the maintenance of foundation soil conditions

This report relates to the soil and site conditions on the property at the time of the site assessment. The satisfactory long-term performance of footings is dependent upon ongoing site maintenance by the owner.

Examples of abnormal moisture conditions developing after construction include the following:

A) The effect of trees too close to the footings.
B) Excessive or irregular watering of gardens adjacent to the footings.
C) Failure to maintain site drainage affecting footings.
D) Failure to repair plumbing leaks affecting footings.

E) Loss of vegetation from near the building.

All earthworks on site must comply with AS 3798-2007 Guidelines on Earthworks for commercial and residential developments.

## LANDSLIDE RISK ASSESSMENT

**Introduction**

The entire property at 13 Steen Court Blackmans Bay, is located within the Low Landslide Hazard overlay.

According to Mineral Resources Tasmania (MRT), the Low Landslide Hazard areas have no known active landslides but are identified as *susceptible* to land sliding. In this instance, the Low hazard band is so classified due to slope angle – specifically, *"Remaining areas slopes 11-20 degrees".*

This section of the report addresses the surrounding landform, soil materials and local geomorphology to assess the potential for landslip to occur. The associated likelihood and risks with the potential landslide hazard are examined and best practice mitigation measures are recommended to ensure a tolerable risk can be achieved and maintained.

**Geomorphology, Soils and Geology**

The development is located on the northern slopes of a dolerite-capped ridge spur (SW-NE). The slope angle around the building envelope approximately 19°. The local landform is naturally water-shedding, meaning (concentrated) flows of water run-off are not expected to flow toward the development area.

The soil profiles are formed from clayey colluvium derived from the upslope and underlying Jurassic dolerite. The natural profiles are shallow, with a maximum observed depth of unconsolidated material (soil and regolith) of approximately 0.8 m. The local clays are highly reactive, weakly to moderately structured and non-dispersive

## Geotechnical Assessment of Landslip Hazard

The proposed works at 13 Steen Court Blackmans Bay are within the LOW Landslide Hazard Area overlay. The overlay is produced by:

- Recording observations of land instability in and surrounding the study area (the landslide database).
- Analysis of the processes that control each landslide type.
- Computer-assisted modelling that simulates each of the landslide processes to predict areas that could be affected by future landslides.

The proposed development area falls under the Tasmanian Planning Scheme – Kingborough - State Planning Provisions Code E3.0 Landslide Code.

Per section E3.2.1, this code applies to:

a) Development for buildings and works or subdivision on land within a Landslide Hazard Area.
b) Use of land for vulnerable use or hazardous use within a Landslide Hazard Area.

The site is assessed according to E3.7.1 (Buildings and Works) and E3.7.3 (Major Works) of the Scheme.

## Potential for Mass Movement of Soil and Geological Materials

Elevated water content is a common trigger mechanism for landsliding in unconsolidated soil regolith on sloping ground. The mostly water-shedding landform (convex cross and downslope profiles) suggests minimal flows of run-on water are directed toward the site. However, any cut and fill levelled areas, if not adequately drained, may accumulate water. Site stormwater design should avoid this outcome.

The shallow (0.5 – 0.8 deep) soil profiles have very low potential for deep-seated, rotational, landsliding. However, they are highly reactive and may exhibit slow downslope *creep* over time.

The Jurassic dolerite and Triassic sandstone units are, typically, highly competent lithologies and founding into the bedrock will mitigate land-sliding concerns at the proposed house.

In its current state, the site appears stable regarding severe land sliding, with no evidence of deep-seated landslide hazards, i.e., 3 – 10 m of soft regolith, at the site or in the near vicinity.

**Measures to Mitigate Against Instability**

All cuts ≥ 2.0 m into unconsolidated soil/regolith require engineered design solutions, i.e., retention with appropriate drainage both above and below the cutting. We note that the maximum observed depth of unconsolidated material was 0.8m

For cuts < 2.0 m into unconsolidated soil/regolith should be appropriately drained and use a gentle 1V: 2H (vertical: horizontal).

Fill material should be granular and placed in lifts of maximum 0.2 m in height and adequately compacted per AS3798-2007.

Vegetation should be retained, maintained or established, where possible, to stabilise soils and associated slopes.

Appropriate sediment and erosion control measures to in place during all phases of construction. Minimising soil disturbance throughout the construction phase and adopt appropriate and safe management of run-off and run-on waters.

The risk of land instability within the proposed building envelope can be reduced via use of current best practice for construction on sloping sites (refer to extract: *Good hillside construction practice from the Australian Geomechanics Society (Appendix 3) and CSIRO BTF-18.*

**Landslide Risk Analysis**

Risk assessment of land sliding relates to a measure of the probability and severity of an adverse effect to health, property, or the environment:

Likelihood of occurrence of any form of mass movement e.g., soil creep, debris flow, slumping, landslide, rock fall etc, including its likely scale (size, area, volume) would be affected by the proposed location and scale of construction.

In this case, the likelihood of land sliding on the property is LOW, based on the data and information collected and assessed for this site. This can be reduced to a VERY LOW risk by following the recommendations in this report.

Consequences to life, property and services is LOW if the site is appropriately developed as specifically outlined in this report. Thus, the overall RISK of landsliding will be reduced to LOW and remain so if these guidelines and recommendations are followed in full.

## Compliance with E3.7.1 of Kingborough Interim Planning Scheme

**Objective:**

To ensure that landslide risk associated with building and works other than minor extensions, in Landslide Hazard Areas, is:

a) acceptable risk; or
b) tolerable risk, having regard to the feasibility and effectiveness of measures required to manage the landslide hazard.

| **Acceptable Solution A1** | **Comments** |
|---|---|
| No acceptable solution. | |

| **Performance Solution P1** | **Comments** |
|---|---|
| Buildings and works must satisfy all the following: | |
| a) no part of the buildings and works is in a High Landslide Hazard Area | Complies |
| b) the landslide risk associated with the buildings and works is either:<br>i. acceptable risk; or<br>ii. capable of feasible and effective treatment through hazard management measures, so as to be tolerable risk. | The risk of landsliding is low/acceptable provided:<br>- the proposed dwelling should be founded on the dolerite and/or sandstone bedrock at 0.5 – 0.8 m depth.<br>- suitable retention, batter angles and landscaping techniques be adopted on all cuts, (outlined in the mitigation strategies of this report).<br>- appropriate building site drainage be installed during the construction phase and maintained during occupation. |

**<u>Compliance with E3.7.3 of Kingborough Interim Planning Scheme</u>**

**Objective:**

To ensure that landslide risk associated with major works in Landslide Hazard Areas, is:

c) acceptable risk; or
d) tolerable risk, having regard to the feasibility and effectiveness of measures required to manage the landslide hazard.

| Acceptable Solution A1 | Comments |
|---|---|
| No acceptable solution. | |

| Performance Solution P1 | Comments |
|---|---|
| Buildings and works must satisfy all the following: | |
| c) no part of the buildings and works is in a High Landslide Hazard Area | Complies |
| d) the landslide risk associated with the buildings and works is either:<br>iii. acceptable risk; or<br>iv. capable of feasible and effective treatment through hazard management measures, so as to be tolerable risk. | The risk of landsliding is low/acceptable provided:<br>- the proposed dwelling should be founded on the dolerite and/or sandstone bedrock at 0.5 – 0.8 m depth.<br>- suitable retention, batter angles and landscaping techniques be adopted on all cuts, (outlined in the mitigation strategies of this report).<br>- appropriate building site drainage be installed during the construction phase and maintained during occupation. |

## REPORT LIMITATIONS

Whilst every attempt is made to describe sub-surface conditions, natural variation will occur that cannot be determined by limited investigative soil testing. Therefore, discrepancies are possible between test results and observations during construction. It is our intention to accurately indicate the most probable soil type(s) and conditions for the area assessed. However, due to the nature of sampling an area, variations in soil type, soil depth and site conditions may occur.

We accept no responsibility for any differences between what we have reported and actual site and soil conditions for particular regions we could not directly assess at the time of inspection.

It is recommended that during construction, Doyle Soil Consulting and/or the design engineer be notified of any major variation to the foundation conditions as predicted in this report. Any changes to the site through excavations may alter the site classification.

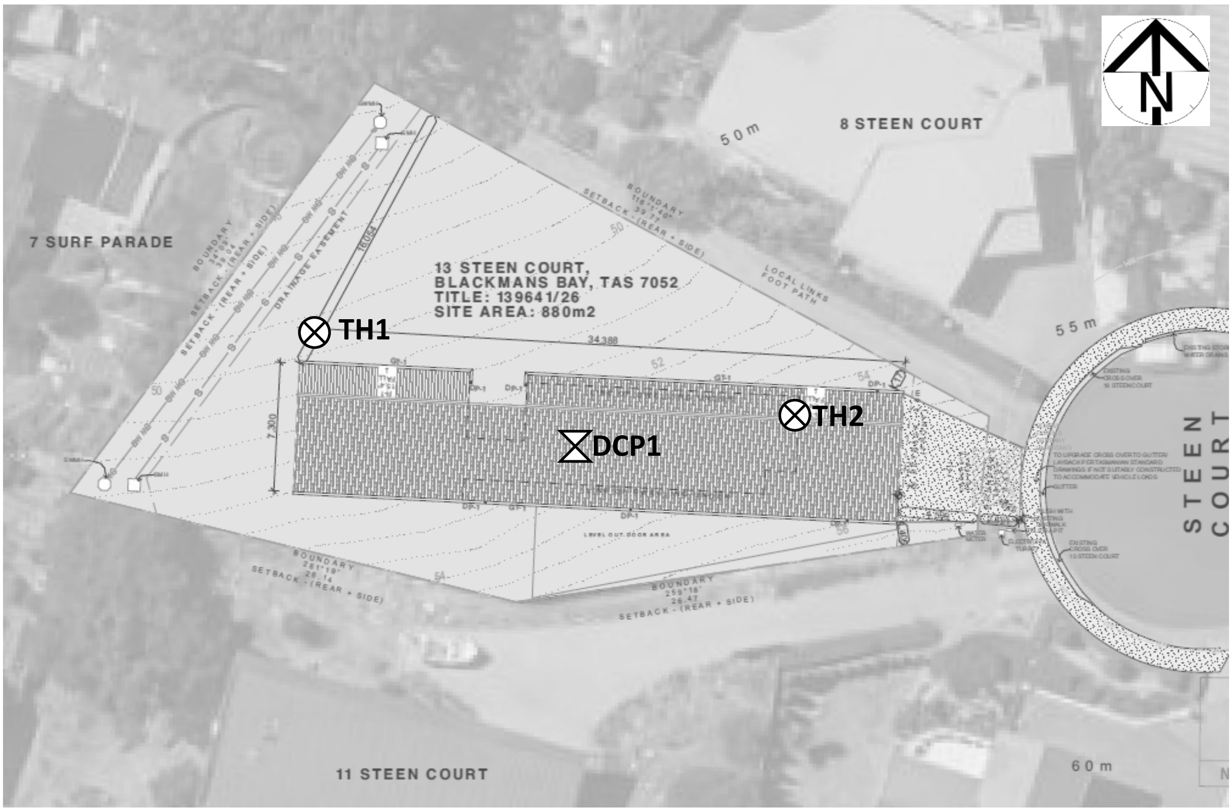
In these cases, it is expected that the owner consults the author for a reclassification. This report requires certification via a form 55 certificate from Doyle Soil Consulting to validate its contents.

Because site discrepancies may occur between this report and actual site conditions, it is a condition of certification of this report that the builder be provided with a copy of this report.

**Rowan Mason**
B.Agr.Sc.(Hons).
**Soil Scientist**

**Dr. Richard Doyle**
B.Sc.(Hons), M.Sc.(Geol), Ph.D. (Soil Sci.),
CPSS (Certified Prof Soil Scientist)
**Geologist and Soil Scientist**

# APPENDIX 1 – Approximate test hole and DCP locations




# APPENDIX 2 – Definitions of Soil Horizons

| Horizon name | Meaning |
|---|---|
| **A1** | Dark topsoils, zone of maximum organic activity |
| **A2 or E** | Leached, light/pale washed-out sandy layer |
| **A3 or AB** | Transition from A to B, more like A |
| **B1 or BA** | Transition from A to B, more like B |
| **B2** | Main subsoils layer with brown colouration, accumulations of clay, humus, iron oxide, etc |
| **B3** | Transitional from B2 to C |
| **C** | Weakly weathered soil parent materials |
| **Subscript** | **Meaning** |
| **r** | Reducing conditions (anaerobic) |
| **t** | Enriched in translocated clay |
| **s** | Iron/aluminium oxide accumulations in subsoil |
| **g** | Mottled, suggesting periodic/seasonal wetness |
| **m** | Cemented layer (oxides, carbonates, humus, silica etc) |
| **k** | Calcium carbonate (lime) accumulation |
| **h** | Humus accumulation in subsoil |

# Appendix 3 – Risk tables

Extracted from *Australian Geomechanics Journal Volume 42 No.1 March 2007 - Australian GeoGuide LR7 (Landslide Risk)*.

| TABLE 1: RISK TO PROPERTY | | |
|---|---|---|
| **Qualitative Risk** | | **Significance - Geotechnical engineering requirements** |
| Very high | VH | **Unacceptable** without treatment. Extensive detailed investigation and research, planning and implementation of treatment options essential to reduce risk to Low. May be too expensive and not practical. Work likely to cost more than the value of the property. |
| High | H | **Unacceptable** without treatment. Detailed investigation, planning and implementation of treatment options required to reduce risk to acceptable level. Work would cost a substantial sum in relation to the value of the property. |
| Moderate | M | **May be tolerated** in certain circumstances (subject to regulator's approval) but requires investigation, planning and implementation of treatment options to reduce the risk to Low. Treatment options to reduce to Low risk should be implemented as soon as possible. |
| Low | L | **Usually acceptable** to regulators. Where treatment has been needed to reduce the risk to this level, ongoing maintenance is required. |
| Very Low | VL | **Acceptable**. Manage by normal slope maintenance procedures. |

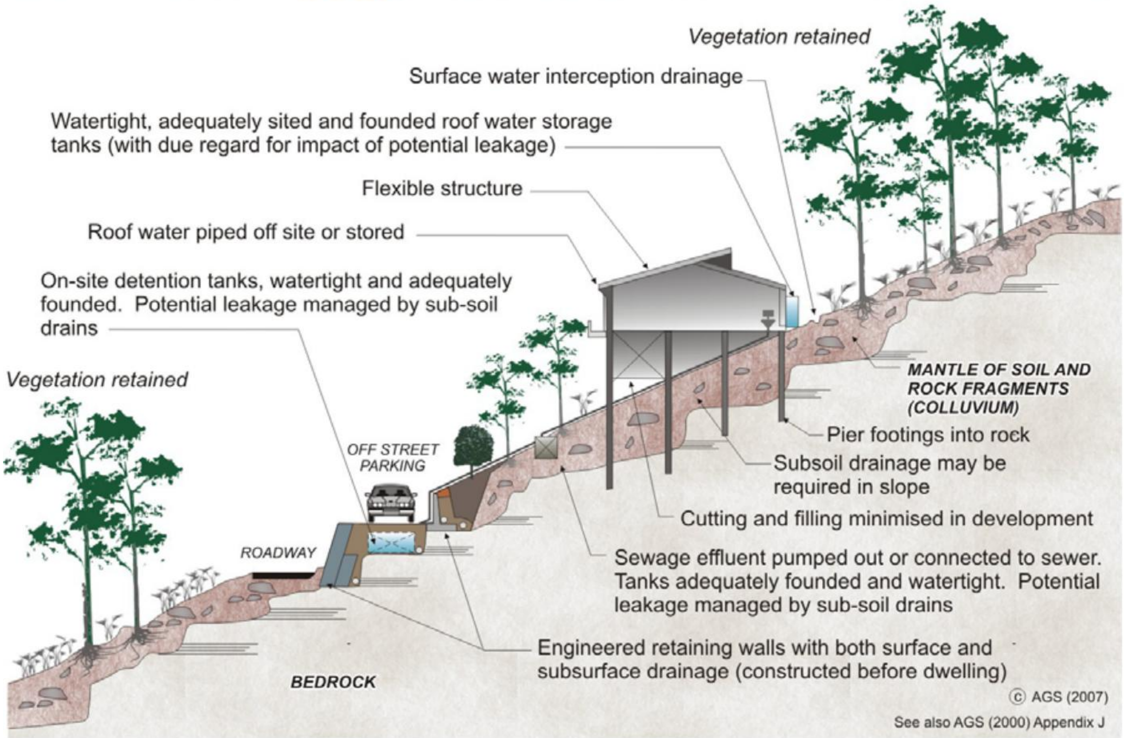
| TABLE 2: LIKELIHOOD | |
|---|---|
| Likelihood | Annual Probability |
| Almost Certain | 1:10 |
| Likely | 1:100 |
| Possible | 1:1,000 |
| Unlikely | 1:10,000 |
| Rare | 1:100,000 |
| Barely Credible | 1:1,000,000 |

| TABLE 3: RISK TO LIFE | |
|---|---|
| **Risk** (deaths per participant per year) | **Activity/Event Leading to Death** (NSW data unless noted) |
| 1:1,000 | Deep sea fishing (UK) |
| 1:1,000 to 1:10,000 | Motor cycling, horse riding, ultra-light flying (Canada) |
| 1:23,000 | Motor vehicle use |
| 1:30,000 | Fall |
| 1:70,000 | Drowning |
| 1:180,000 | Fire/burn |
| 1:660,000 | Choking on food |
| 1:1,000,000 | Scheduled airlines (Canada) |
| 1:2,300,000 | Train travel |
| 1:32,000,000 | Lightning strike |

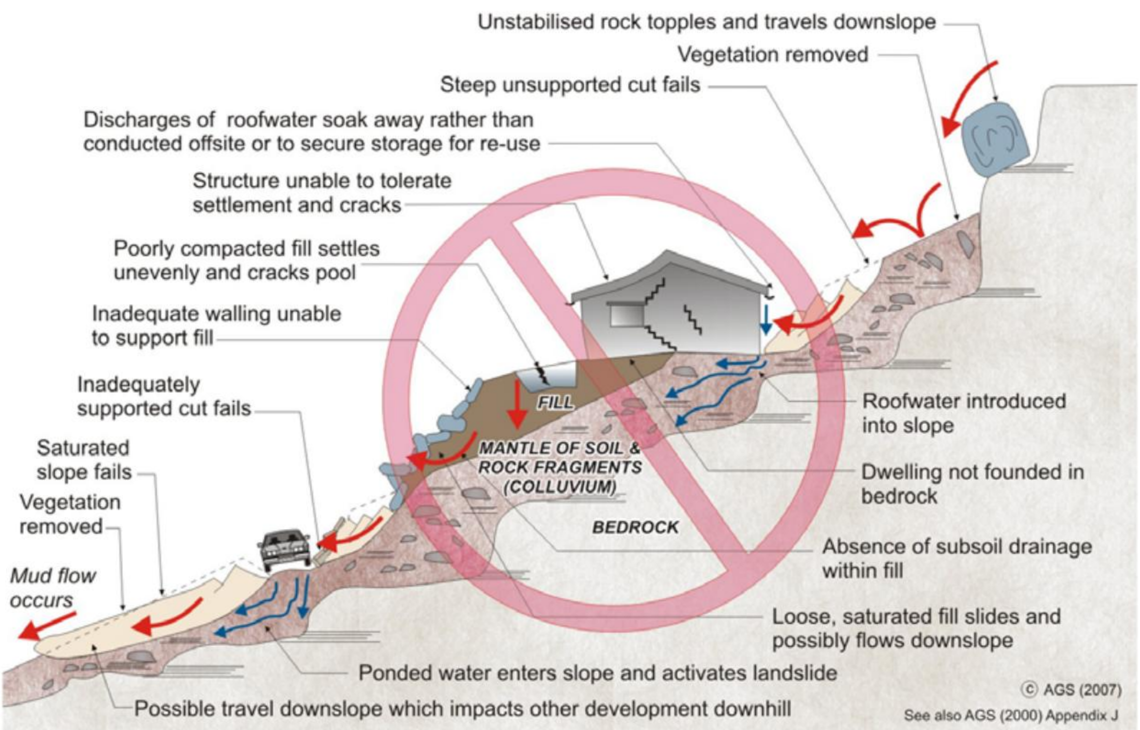
# Appendix 4 – Guidelines for hillside construction

Extracted from *Australian Geomechanics Journal Volume 42 No.1 March 2007 - Australian GeoGuide LR8 (Construction Practice)*.

## EXAMPLES OF GOOD HILLSIDE CONSTRUCTION PRACTICE




## EXAMPLES OF POOR HILLSIDE CONSTRUCTION PRACTICE



# CERTIFICATE OF QUALIFIED PERSON – ASSESSABLE ITEM

**Section 321**

Form **55**

| To: | | |
|---|---|---|
| TP Admin | | *Owner name* |
| PO Box 901 | | *Address* |
| Launceston TAS | 7250 | *Suburb/postcode* |

## Qualified person details:

| | | | |
|---|---|---|---|
| Qualified person: | Richard Doyle | | |
| Address: | 6/76 Auburn Rd | Phone No: | 0488 080 455 |
| | Kingston Beach 7050 | Fax No: | |
| Licence No: | N/A | Email address: | robyn@doylesoilconsulting.com.au |

Qualifications and Insurance details:

Geologist and Soil Scientist PhD
Certified Professional Soil Scientist (CPSS)
Professional Indemnity cover –

About Underwriting -Lloyd's of London
ENG 24 000305

*(description from Column 3 of the Director's Determination - Certificates by Qualified Persons for Assessable Items*

Speciality area of expertise: Geotechnical

*(description from Column 4 of the Director's Determination - Certificates by Qualified Persons for Assessable Items)*

## Details of work:

| | | | |
|---|---|---|---|
| Address: | 13 Steen Court | Lot No: | 26 |
| | Blackmans Bay 7052 | Certificate of title No: | 139641/26 |

The assessable item related to this certificate: Site assessment for slope stability

*(description of the assessable item being certified)*
*Assessable item includes –*
- *a material;*
- *a design*
- *a form of construction*
- *a document*
- *testing of a component, building system or plumbing system*
- *an inspection, or assessment, performed*

## Certificate details:

Certificate type: Geotechnical Assessment

*(description from Column 1 of Schedule 1 of the Director's Determination - Certificates by Qualified Persons for Assessable Items n)*

This certificate is in relation to the above assessable item, at any stage, as part of - *(tick one)*

building work, plumbing work or plumbing installation or demolition work: [X]

or

a building, temporary structure or plumbing installation: [ ]

In issuing this certificate the following matters are relevant –

| | |
|---|---|
| Documents: | The attached Geotechnical Assessment Report for the address detailed above in, ‘Details of Work’. |
| Relevant calculations: | Refer to above report. |
| References: | AS1726-2017 Geotechnical site investigations<br>AS2870-2011 Residential slabs and footings |

*Substance of Certificate: (what it is that is being certified)*

Geotechnical Assessment -Site and soil classification

*Scope and/or Limitations*

The classification applies to the site as inspected and does not account for future alteration to foundation conditions as a result of earthworks, drainage condition changes or variations in site maintenance.

**I certify the matters described in this certificate.**

| | *Signed:* | *Certificate No:* | *Date:* |
|---|---|---|---|
| Qualified person: | | 1933 | 20/1/2026 |

CERTIFIED PROFESSIONAL SOIL SCIENTIST
CPSS
Dr Richard Doyle

# 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).

**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.

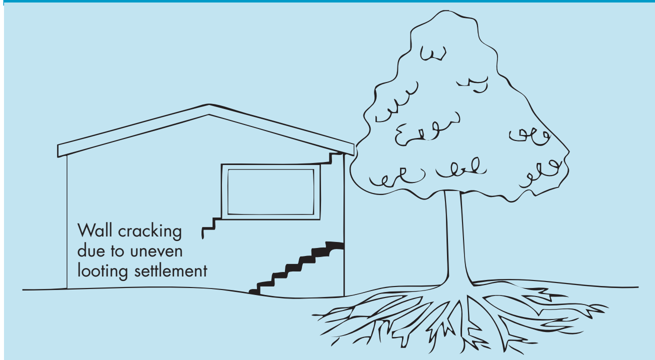
**Seasonal swelling/shrinkage in clay**
Swelling foundation soil due to rainy periods first lifts the most exposed extremities of the footing system, then the remainder of the perimeter footings while gradually permeating inside the building footprint to lift internal footings. This swelling first tends 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**

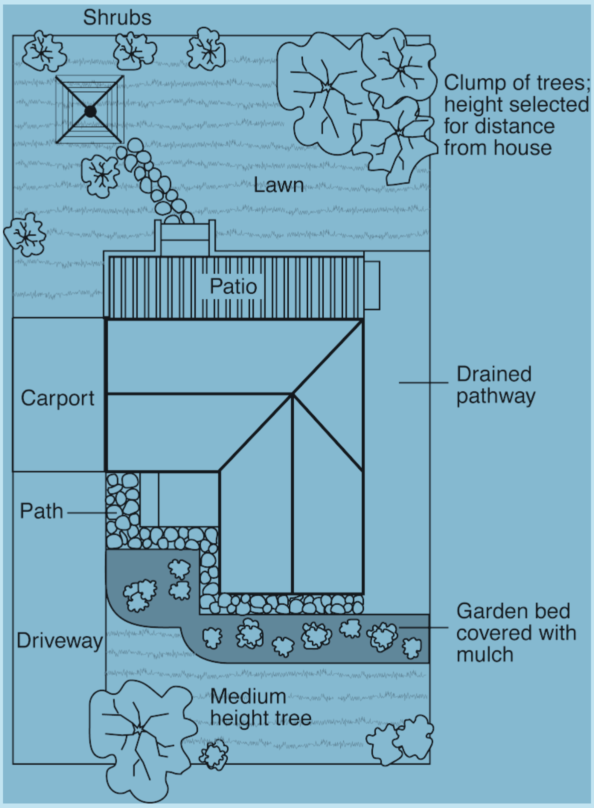
It is essential to remember that the soil that affects footings extends well beyond the actual building line. Watering of garden plants, shrubs and trees causes some of the most serious water problems.

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.

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