11 April 2017
5QS Ref: 7405

Mr P King
C/- Icon Water
GPO Box 366
CANBERRA ACT 2601

Dear Sir,

RE: Limited Geotechnical Investigation
Proposed Dwelling
293 Matcham Road, Matcham

1. Introduction

As requested, 5QS Barker Harle has carried out a limited geotechnical investigation at the above property. The purpose of the investigation was to provide comment on:

- The assessed risk of slope instability on the property, in accordance with the methodology set out in guidelines prepared by the Australian Geomechanics Society Sub-committee on Landslide Risk Management, in 'Australian Geomechanics', Vol 37 No 2 [Ref 1];
- Site classification in line with the Australian Standard AS 2870–2011, 'Residential slabs and footings [Ref 2] and;
- Geotechnical guidelines for development on the site.

For the purpose of the investigation, the client supplied 5QS Barker Harle with pdf copies of the following:

- Detail survey plan of the property prepared by Alan Bardsley Registered Surveyors (ref 280034.PRO, dated 21/11/2007); and
- A three-sheet set of architectural plans prepared by Warwick Ralph (ref 4173, Rev A dated March 2017).

The architectural plans included a site and location plan with topographical contours at 1 m interval in the area of the proposed development.

The scope of this investigation included a desktop review of available published information, field work carried and preparation of this report.

For the purpose of a qualitative assessment of the risk of slope instability on the site, this report makes reference to the terms defined in the Australian Geomechanics Society Landslide Taskforce paper, *Practice note guidelines for landslide risk management*, in 'Australian Geomechanics' Vol 42 No 1 [Ref 3].

This report should be read in conjunction with the attached 'General Notes'.

2. Background Information

The property, identified as Lot 1 in DP 561056, is situated on the northern side of Matcham Road, Matcham, and occupies an irregular shaped allotment of some 2.43 hectares.

The proposed development area is situated in the south-eastern corner of the property.

Descriptions of the site, background information on the desktop study and the results of the field work were provided in 5QS Barker Harle Report 6758, dated 21 June 2016 [Ref 4].

3. Data Interpretation

3.1 Proposed Development

Based on the drawings provided by the client, it is understood that proposed development of the property will involve the construction of a new single-level flexible-clad dwelling with a garage and workshop undercroft.

The client-supplied drawings show the garage and workshop area will be constructed using reinforced concrete-filled masonry blocks supported on a concrete slab. The single-level living area of the dwelling and the undercroft area will be accommodated by cutting to maximum depths of about 1 m and 2.5 m, respectively.

3.2 Subsurface Conditions

From the results of the field work shown in Ref 4, subsurface conditions in the proposed development area of the property consist of natural cohesive and silty soils. Dynamic cone penetrometer [DCP] refusal was encountered at a depth of 0.95 m at test location DCP 2.

It is interpreted that soils depths in the proposed development area are of the order of 1 m to 2 m overlying weathered rock. No signs of large scale instability were observed on the site.

4. Assessment of Slope Instability Risk

The site was assessed as a **"Category 3 – High Hazard Area"** for potential landslip hazard as defined in Tables M1 and M2 of the document 'Development Control Plan 2013 – Geotechnical Requirements for Development Applications', for the Gosford local area of Central Coast Council [CCC].

A copy of CCC's classification system, set out in Tables M1 and M2 of DCP 2013, has been attached to this report.

An assessment of the risk to both property and life due to failure mechanisms on the site has been undertaken with reference to the Australian Geomechanics Society Landslide Taskforce paper, 'Practice note guidelines for landslide risk management' [Ref 3].

Risk analysis can be broken up into four components, namely:

- Hazard identification;
- Frequency analysis, or estimation of likelihood of occurrence;
- Consequence analysis; and
- Risk estimation.

An assessment of slope instability risk was carried out based on semi-quantitative interpretations of likelihood and consequence, in line with the terminology of Ref 3, for each of the following hazards identified on this site from the desktop study and fieldwork:

- Hazard 1: Soil flow / creep of surficial soils – “Possible”, associated with likely depths of soil on site, and “Minor”; and
- Hazard 2: Localised rotational / sliding failure of new retaining walls – “Likely” and “Insignificant”.

The risk ratings for the above hazards are assessed to be “Medium” and “Low”, respectively. Ref 1 indicates that development of sites with an assessed risk level of “Low” or less are generally acceptable to regulators. Ref 3 indicates that development of a site with assessed risk level of ‘Moderate’ or lower is usually acceptable to regulators provided steps are taken to ensure the ongoing monitoring and maintenance of the hazard. In this instance, this would involve adherence to the guidelines set out in Section 5.5 and Section 6 of this report. Reducing the consequence of Hazard 1 to ‘Insignificant’ would reduce the risk level to ‘Low’.

Table 1 gives a summary of the risk assessment data for the site.

Table 1 – Site assessment summary data

<table>
<tr><td>Assessor</td><td colspan="2">Peter Fennell</td><td colspan="3">Assessment date</td><td>11/04/2017</td></tr>
<tr><td>Street No</td><td>293</td><td>Street</td><td colspan="2">Matcham Road</td><td>Suburb</td><td>Matcham</td></tr>
<tr><td>Lot No</td><td colspan="2">1</td><td>Section</td><td>–</td><td>DP</td><td>561056</td></tr>
<tr><td colspan="4">Site Data:</td><td colspan="2">Land Area 1 (1)</td><td>Land Area 2</td></tr>
<tr><td colspan="4">Site classification to AS 2870–2011</td><td colspan="2">Class ‘P’</td><td rowspan="8">Not applicable (2)</td></tr>
<tr><td colspan="4">Land slope</td><td colspan="2">Up to 27°</td></tr>
<tr><td colspan="4">Geology</td><td colspan="2">Rnt - s</td></tr>
<tr><td colspan="4">Surface soils</td><td colspan="2">Clay & silt natural soils</td></tr>
<tr><td colspan="4">Instability risk type</td><td colspan="2">Soil creep;
retaining wall failure</td></tr>
<tr><td colspan="4">Risk assessment</td><td colspan="2">Low to Medium</td></tr>
<tr><td colspan="4">Geotechnical inspections required?</td><td colspan="2">Yes</td></tr>
<tr><td colspan="4">Risks from adjoining land</td><td colspan="2">No</td></tr>
</table>

Notes to Table 1:
(1) Land Area 1 is the property identified as Lot 58 in DP 9179
(2) No additional land area divisions required

It is anticipated that the risk associated with Hazard 1 could be reduced to 'Low' by ensuring that all footings for the proposed structure are founded within weathered rock. It is recommended that all footing excavations be inspected by a suitably qualified engineer.

The assessed risk to loss of life due to the hazards identified above is estimated to be in the order of 2×10^{-6} to $\times 1 \times 10^{-7}$, which is less than the risk level deemed in Ref 1 as "tolerable" for new and existing development. There are no established individual or societal risk acceptance criteria for the loss of life due to a hazardous event such as a landslide or rock fall.

Australian Geoguide LR7 (attached) discusses "acceptable" and "tolerable" levels of risk which have been proposed by several authorities including the ANCOLD Guidelines for Risks from Large Dams.

It is considered that the proposed development of the property would be feasible from a slope stability viewpoint.

5. Geotechnical Guidelines for Site Development

5.1 General

Effective risk management on the site would be achieved by including in the proposed development design features which either reduce the likelihood of occurrence of a potential slope movement hazard or ameliorate the consequences of a landslip event.

Examples of such risk management measures are given in the following sections.

5.2 Footings

All proposed footing systems should be designed in accordance with AS2870–2011 (Ref 2) or engineering principles.

Consideration will need to be given to the required extent of excavation, including removal of any existing trees and site regrading, when selecting and designing the footing system.

All footing systems must be either founded on or piered to underlying bedrock. Foundations exposed for footing construction should be viewed by a qualified geotechnical engineer prior to placement of concrete. Footings near proposed or existing excavations should be founded below or behind the zone of influence of the base of the excavation.

5.3 Excavations

It is noted the proposed dwelling has been designed to be accommodated on the site by cutting to depths in the order of 1 m to 2.5 m.

All excavations in soil to depths exceeding 0.8 m on this site must be supported by engineer-designed retaining walls.

Permanent unsupported cuts in soil must be battered in accordance with the requirements of the Building Code of Australia, but in no case should be steeper than 2H:1V and must be protected from erosion. Where applicable, the excavation design should incorporate surcharge loads from slopes, retaining walls, structures and other improvements within the vicinity of the excavation.

Drainage measures should be implemented above and behind all excavations to intercept both surface and subsurface water movement.

5.4 Filling

It is recommended that no filling be placed in the proposed development area of the property.

5.5 Earthworks in General

Council's development guidelines should be reviewed during site planning as they might impose other height limitations or support requirements on site cuts and fills.

5.6 Retaining Walls

All retaining walls on this site should be engineer-designed in accordance with the requirements of Australian Standard AS 4678–2002, 'Earth-retaining structures' (Ref 5).

All retaining structures should be designed to support, where appropriate, surcharge loading due to any sloping ground surface above the retaining walls. All retaining walls should be constructed with adequate surface and subsurface drainage to the Engineer's and Council's requirements.

5.7 Site Drainage

The effective drainage from the site of surface and subsurface water is important to ensure the stability of the surface soil and the longer-term performance of footing systems and retaining walls.

The property should be developed and maintained in accordance with the guidelines set out in Section 3 of the BCA and Appendix B of Ref 2. In particular, the following measures are recommended:

- Catch/dish drains formed at the top and dish and rubble drains installed at the toe of all batters;
- Subsoil drains installed behind new retaining walls;
- Cut areas sloped to fall away from proposed building areas and water not be allowed to pond around buildings;
- The site be graded to prevent water from ponding on all areas of compacted fill;
- Surface stormwater and subsoil water collected and disposed of in accordance with Council's requirements; and
- Erosion control measures to be undertaken during construction to Council's requirements.

6. Site Classification

The site is classified as '**Class P**' (Problem site) as defined in Ref 2. This classification was based on the presence of filling found encountered during the walkover assessment and site testing. It is anticipated that shallow footings founded within, or supported by piles or piers founded on or within, weathered rock beneath all filling may be proportioned for a **Class 'S'** ('Slightly Reactive') site.

Footings for the proposed dwelling are required to be founded below the zone of influence of:

- all existing footings; and
- all existing and proposed retaining walls on the site and on the neighbouring sites.

All footings for the proposed development should be designed using engineering principles and in accordance with the provisions of AS 2870–2011. Footings should be founded on consistent strata for all of the proposed structure.

It is recommended all footing installation work be inspected by an appropriately qualified engineer who can confirm the founding levels and bearing capacities assumed for design.

This site classification has not allowed for the effects of trees, poor site drainage, or leaking plumbing and exceptional moisture. These should be taken into consideration in the design of footing systems and the site should be maintained as outlined in the attached CSIRO Brochure BTF 18. General information on site classification can be found in the attachment section of this report.

The superstructure of the proposed dwelling should be articulated at all changes in footing system or support conditions. Articulation of masonry should be provided in accordance with clause 3.3.1.8 of the Building Code of Australia.

7. Report Limitations and Site Variations

5QS Barker Harle has prepared this report on a geotechnical investigation for proposed development at No 293 Matcham Road, Matcham, in accordance with 5QS Barker Harle's proposal by email of 13 March 2017.

The following is a guide as to the intended scope and use of this report.

- This report is provided for the exclusive use of Mr Phil King for the purposes as described in the report. It may not be used or relied upon for other purposes or by a third party. 5QS Barker Harle can accept no responsibility for loss or damage arising out of the use of this report beyond its purpose as stated above, or incurred by any third party relying on the report without the express written consent of 5QS Barker Harle. In preparing this report 5QS Barker Harle has necessarily relied upon information provided by the client and/or their agents.

- The extent of testing associated with this assessment is limited to the borehole and DCP test probe locations and variations in ground conditions may occur. The data from the test locations have been used to provide an interpretation of the likely subsurface profile at the site of the proposed development. 5QS Barker Harle should be contacted immediately if subsurface conditions are subsequently encountered that differ from those described in this report so that we can review and re-interpret the geotechnical model on the basis of the additional data.

- The scope of this investigation does not include any comment on the potential excavatability of the subsurface materials on site.

- Neither this report, nor sections from this report, should be used as part of a specification for a project without review and agreement by 5QS Barker Harle. This is because this report has been written as advice and opinion rather than instructions for construction.
- This report must be read in conjunction with all of the attachments.
- The recommendations provided in this report represent a summary of our technical advice. Please discuss the recommendations with the undersigned if you require any clarification.

Yours faithfully
5QS Barker Harle

Peter Fennell
MIE Aust

8. References

1. Landslide risk management concepts and guidelines,
   in ‘Australian Geomechanics’, Vol 37 No 2 (May 2002)
2. Australian Standard AS 2870–2011, ‘Residential slabs and footings’,
   Standards Australia (January 2011)
3. Practice note guidelines for landslide risk management,
   in ‘Australian Geomechanics’, Vol 42, No 1 (March 2007)
4. ‘On-site Effluent Disposal Capability Assessment at Lot 1 DP 561056 No 293 Matcham Road, Matcham’, 5QS Barker Harle Report Ref 6758 (21 June 2016)
5. Australian Standard AS 4678–2002, ‘Earth-retaining structures’,
   Standards Australia (February 2002)

Attachments:

1. General Notes
2. Australian Geoguides LR7 (Landslide Risk) and LR8 (Hillside Construction Practice)
3. Tables M1 and M2 from Gosford City Council’s ‘Development Control Plan 2013 – Geotechnical Requirements for Development Applications’
4. Site Classification Notes
5. CSIRO Document BTF 18

General Notes

Introduction
These notes are supplied with all geotechnical reports from **5QS Barker Harle** and therefore may contain information not necessarily relevant to this report.

The purpose of the report is set out in the introduction section of this report. It should not be used by any other party, or for any other purpose, as it may not contain adequate or appropriate information in these events.

Engineering Reports
5QS Barker Harle reports are prepared by qualified personnel and are based on information obtained, and on modern engineering standards of interpretation and analysis of that information. Where the report has been prepared for a specific design proposal the information and interpretation may not be relevant if the design proposal is changed. If the design proposal or construction methods change, **5QS Barker Harle** request to be notified and will be pleased to review the report and the sufficiency of the investigation work.

Geotechnical reports are based on information gained from limited subsurface test boring and sampling, supplemented by knowledge of local geology and experience. For this reason, the report must be regarded as interpretative, rather than a factual document, limited, to some extent, by the scope of information on which it relies.

***5QS Barker Harle** cannot accept responsibility for problems that develop if it is not consulted after factors considered in the report's development have changed.*

Every care is taken with the report as it relates to interpretation of subsurface condition, discussion of geotechnical aspects and recommendations or suggestions for design and construction. However, **5QS Barker Harle** cannot always anticipate or assume responsibility for:

- Unexpected variations in ground conditions – the potential for this will depend partly on bore spacing and sampling frequency.
- The actions of contractors responding to commercial pressures.

If these occur, **5QS Barker Harle** will be pleased to assist with investigation or advice to resolve the matter.

A Geotechnical Engineering Report May Be Subject To Misinterpretation
Costly problems can occur when other design professionals develop their plans based on misinterpretations of a geotechnical engineering report. To help avoid these problems, **We** should be retained to review the adequacy of plans and specifications relative to geotechnical issues.

Engineering Logs Should Not Be Separated From The Engineering Report.
Final engineering logs are developed by the Geotechnical Engineer based upon interpretation of field logs and laboratory evaluation of field samples. Only final engineering logs are included in geotechnical engineering reports. To minimize the likelihood of engineering log misinterpretation, *give contractors ready access to the complete geotechnical engineering report*.

Site Inspection
5QS Barker Harle will always be pleased to provide services for geotechnical aspects of work to which this report is related. This could range from a site visit, to full time engineering presence on site.

Change In Conditions
Subsurface conditions may be modified by constantly changing natural forces. Because a geotechnical engineering report is based on conditions, which existed at the time of subsurface exploration, *construction decisions should not be based on a geotechnical engineering report whose adequacy may have been affected by time*.

Construction operations at or adjacent to the site and natural events such as floods, earthquakes or groundwater fluctuations may also affect subsurface conditions and thus, the continuing adequacy of a geotechnical report. **We** should be kept apprised of any such events, and should be consulted to determine if additional tests are necessary.

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

Ground Water
Unless otherwise indicated the water levels given on the engineering logs are levels of free water or seepage in the test hole recorded at the given time of measuring. This may not accurately represent actual ground water levels, due to one or more of the following:

- In low permeability soils, ground water although present may enter the hole slowly, or perhaps not at all during the time it is left open.
- A localised perched water table may lead to an erroneous indication of the true water table.
- Water table levels will vary from time to time with seasons or recent prior weather changes. They may not be the same at the time of construction as indicated at the time of investigation.

Accurate confirmation of levels can only be made by appropriate instrumentation techniques and monitoring programs.

General Notes – Continued

Foundation Depth

Where referred to in the report, the recommended depth of any foundation, (piles, caissons, footings etc) is an engineering estimate of the depth to which they should be constructed. The estimate is influenced and perhaps limited by the fieldwork method and testing carried out in connection with the site investigation, and other pertinent information as has been made available. The depth remains, however, an estimate and therefore liable to variation. Foundation drawings, designs and specifications based upon this report should provide for variations in the final depth depending upon the ground conditions at each point of support.

Engineering Logs

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

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

Drilling Methods

The following is a summary of drilling methods currently used by **5QS Barker Harle**, with comments on their use and application.

Continuous Sample Drilling: The soil sample is obtained by screwing a 75 or 100mm auger into the ground and withdrawing it periodically to remove the soil. This is the most reliable method of drilling in soils as the moisture content is unchanged and soil structure, strength, appearance etc. is only partially affected.

Test Pits: These are excavated using a backhoe or tracked excavator, allowing close examination of insitu soil if it is safe to descend into the pit. The depth of digging is limited to about 3 metres for a backhoe, and about 5 metres for an excavator. A potential disadvantage is the disturbance of the site caused by the excavation.

Hand Auger: The soil sample is obtained by screwing a 75mm Auger into the ground. This method is usually restricted to approximately 1.5 to 2 metres in depth, and the soil structure and strength is significantly disturbed.

Continuous Spiral Flight Augers: The soil sample is obtained by using a 90 – 115mm diameter continuous spiral flight auger which is withdrawn at intervals to allow sampling or insitu testing. This is a relatively economical means of drilling in clays, and in sands above the water table. Samples, returned to the surface, are very disturbed and may be contaminated. Information from the drilling is of relatively lower reliability. SPT's or undisturbed sampling may be combined with this method of drilling for reasonably satisfactory sampling.

Hand Penetrometers

Hand Penetrometer tests are carried out by driving a rod into the ground with a falling weight hammer and recording the number of blows for successive 50mm increments of penetration.

Two, relatively similar tests are used:

1. Perth Sand Penetrometer (AS 1289.5.3.3) – A 16mm flat ended rod is driven with a 9kg hammer, dropping 600mm. This test was developed for testing the density of sands and is mainly used in granular soils and loose fill.

2. Cone Penetrometer/Scala Penetrometer
(AS 1289.5.3.2) – A 16mm rod with a 20mm diameter cone end is driven with a 9kg hammer dropping 510mm. The test was developed initially for pavement subgrade investigations, and correlations of the test results with California Bearing Ratio (CBR) have been published by various road authorities.

Sampling

Sampling is carried out during drilling to allow engineering examination, and laboratory testing of the soil or rock.

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

Undisturbed samples are taken by pushing a think walled sample tube into the soils and withdrawing this with a sample of soil in a relatively undisturbed state contained inside. Such samples yield information on structure and strength, and are necessary for laboratory determination of shear strength and compressibility. Undisturbed sampling is generally effective only in cohesive soils. Details of the type and method of sampling are given in the report.

Laboratory Testing

Laboratory testing is carried out in accordance with Australian Standard 1289 series, Methods of Testing Soils for Engineering Purposes. Details of the test procedure used are given on the individual report forms.

LANDSLIDE RISK

Concept of Risk

Risk is a familiar term, but what does it really mean? It can be defined as *"a measure of the probability and severity of an adverse effect to health, property, or the environment."* This definition may seem a bit complicated. In relation to landslides, geotechnical practitioners (GeoGuide LR1) are required to assess risk in terms of the likelihood that a particular landslide will occur and the possible consequences. This is called landslide risk assessment. The consequences of a landslide are many and varied, but our concerns normally focus on loss of, or damage to, property and loss of life.

Landslide Risk Assessment

Some local councils in Australia are aware of the potential for landslides within their jurisdiction and have responded by designating specific "landslide hazard zones". Development in these areas is often covered by special regulations. If you are contemplating building, or buying an existing house, particularly in a hilly area, or near cliffs, go first for information to your local council.

Landslide risk assessment must be undertaken by a geotechnical practitioner. It may involve visual inspection, geological mapping, geotechnical investigation and monitoring to identify:

- potential landslides (there may be more than one that could impact on your site)
- the likelihood that they will occur
- the damage that could result
- the cost of disruption and repairs and
- the extent to which lives could be lost.

Risk assessment is a predictive exercise, but since the ground and the processes involved are complex, prediction tends to lack precision. If you commission a landslide risk assessment for a particular site you should expect to receive a report prepared in accordance with current professional guidelines and in a form that is acceptable to your local council, or planning authority.

Risk to Property

Table 1 indicates the terms used to describe risk to property. Each risk level depends on an assessment of how likely a landslide is to occur and its consequences in dollar terms. "Likelihood" is the chance of it happening in any one year, as indicated in Table 2. "Consequences" are related to the cost of repairs and temporary loss of use if a landslide occurs. These two factors are combined by the geotechnical practitioner to determine the Qualitative Risk.

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

The terms "unacceptable", "may be tolerated", etc. in Table 1 indicate how most people react to an assessed risk level. However, some people will always be more prepared, or better able, to tolerate a higher risk level than others.

Some local councils and planning authorities stipulate a maximum tolerable level of risk to property for developments within their jurisdictions. In these situations the risk must be assessed by a geotechnical practitioner. If stabilisation works are needed to meet the stipulated requirements these will normally have to be carried out as part of the development, or consent will be withheld.

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.

Risk to Life

Most of us have some difficulty grappling with the concept of risk and deciding whether, or not, we are prepared to accept it. However, without doing any sort of analysis, or commissioning a report from an "expert", we all take risks every day. One of them is the risk of being killed in an accident. This is worth thinking about, because it tells us a lot about ourselves and can help to put an assessed risk into a meaningful context. By identifying activities that we either are, or are not, prepared to engage in we can get some indication of the maximum level of risk that we are prepared to take. This knowledge can help us to decide whether we really are able to accept a particular risk, or to tolerate a particular likelihood of loss, or damage, to our property (Table 2).

In Table 3, data from NSW for the years 1998 to 2002, and other sources, is presented. A risk of 1 in 100,000 means that, in any one year, 1 person is killed for every 100,000 people undertaking that particular activity. The NSW data assumes that the whole population undertakes the activity. That is, we are all at risk of being killed in a fire, or of choking on our food, but it is reasonable to assume that only people who go deep sea fishing run a risk of being killed while doing it.

It can be seen that the risks of dying as a result of falling, using a motor vehicle, or engaging in water-related activities (including bathing) are all greater than 1:100,000 and yet few people actively avoid situations where these risks are present. Some people are averse to flying and yet it represents a lower risk than choking to death on food. Importantly, the data also indicate that, even when the risk of dying as a consequence of a particular event is very small, it could still happen to any one of us any day. If this were not so, no one would ever be struck by lightning.

Most local councils and planning authorities that stipulate a tolerable risk to property also stipulate a tolerable risk to life. The AGS Practice Note Guideline recommends that 1:100,000 is tolerable in newly developed areas, where works can be carried out as part of the development to limit risk. The tolerable level is raised to 1:10,000 in established areas, where specific landslide hazards may have existed for many years. The distinction is deliberate and intended to prevent the concept of landslide risk management, for its own sake, becoming an unreasonable financial burden on existing communities. Acceptable risk is usually taken to be one tenth of the tolerable risk (1:1,000,000 for new developments and 1:100,000 for established areas) and efforts should be made to attain these where it is practicable and financially realistic to do so.

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

More information relevant to your particular situation may be found in other AUSTRALIAN GEOGUIDES:

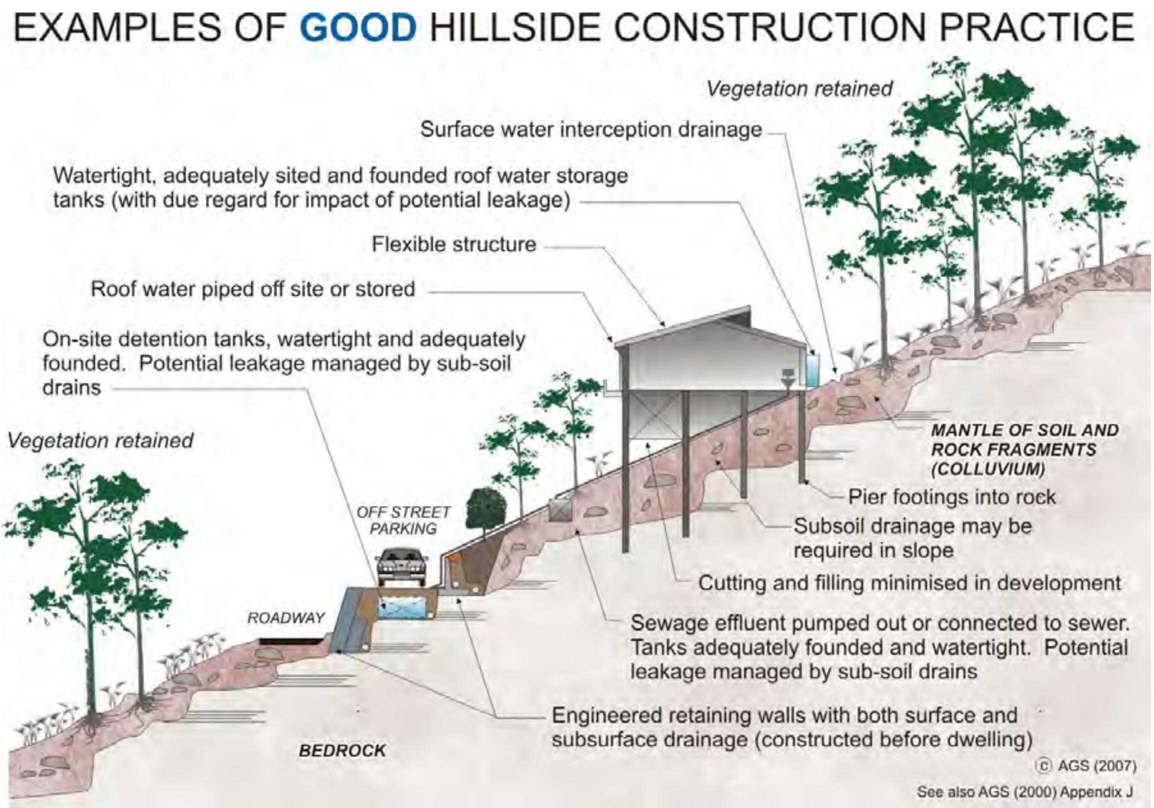
- GeoGuide LR1 - Introduction
- GeoGuide LR2 - Landslides
- GeoGuide LR3 - Landslides in Soil
- GeoGuide LR4 - Landslides in Rock
- GeoGuide LR5 - Water & Drainage
- GeoGuide LR6 - Retaining Walls
- GeoGuide LR8 - Hillside Construction
- GeoGuide LR9 - Effluent & Surface Water Disposal
  GeoGuide LR10 - Coastal Landslides
- GeoGuide LR11 - Record Keeping

The Australian GeoGuides (LR series) are a set of publications intended for property owners; local councils; planning authorities; developers; insurers; lawyers and, in fact, anyone who lives with, or has an interest in, a natural or engineered slope, a cutting, or an excavation. They are intended to help you understand why slopes and retaining structures can be a hazard and what can be done with appropriate professional advice and local council approval (if required) to remove, reduce, or minimise the risk they represent. The GeoGuides have been prepared by the Australian Geomechanics Society, a specialist technical society within Engineers Australia, the national peak body for all engineering disciplines in Australia, whose members are professional geotechnical engineers and engineering geologists with a particular interest in ground engineering. The GeoGuides have been funded under the Australian governments' National Disaster Mitigation Program.

AUSTRALIAN GEOGUIDE LR8 (CONSTRUCTION PRACTICE)

HILLSIDE CONSTRUCTION PRACTICE

Sensible development practices are required when building on hillsides, particularly if the hillside has more than a low risk of instability (GeoGuide LR7). Only building techniques intended to maintain, or reduce, the overall level of landslide risk should be considered. Examples of good hillside construction practice are illustrated below.



WHY ARE THESE PRACTICES GOOD?

Roadways and parking areas - are paved and incorporate kerbs which prevent water discharging straight into the hillside (GeoGuide LR5).

Cuttings - are supported by retaining walls (GeoGuide LR6).

Retaining walls - are engineer designed to withstand the lateral earth pressures and surcharges expected, and include drains to prevent water pressures developing in the backfill. Where the ground slopes steeply down towards the high side of a retaining wall, the disturbing force (see GeoGuide LR6) can be two or more times that in level ground. Retaining walls must be designed taking these forces into account.

Sewage - whether treated or not is either taken away in pipes or contained in properly founded tanks so it cannot soak into the ground.

Surface water - from roofs and other hard surfaces is piped away to a suitable discharge point rather than being allowed to infiltrate into the ground. Preferably, the discharge point will be in a natural creek where ground water exits, rather than enters, the ground. Shallow, lined, drains on the surface can fulfil the same purpose (GeoGuide LR5).

Surface loads - are minimised. No fill embankments have been built. The house is a lightweight structure. Foundation loads have been taken down below the level at which a landslide is likely to occur and, preferably, to rock. This sort of construction is probably not applicable to soil slopes (GeoGuide LR3). If you are uncertain whether your site has rock near the surface, or is essentially a soil slope, you should engage a geotechnical practitioner to find out.

Flexible structures - have been used because they can tolerate a certain amount of movement with minimal signs of distress and maintain their functionality.

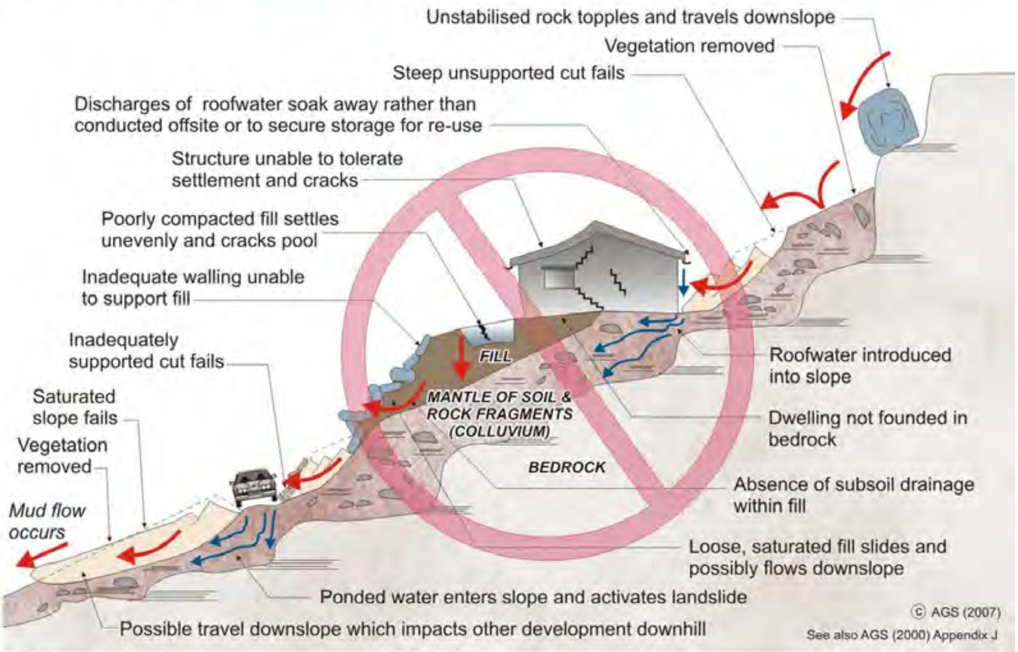
Vegetation clearance - on soil slopes has been kept to a reasonable minimum. Trees, and to a lesser extent smaller vegetation, take large quantities of water out of the ground every day. This lowers the ground water table, which in turn helps to maintain the stability of the slope. Large scale clearing can result in a rise in water table with a consequent increase in the likelihood of a landslide (GeoGuide LR5). An exception may have to be made to this rule on steep rock slopes where trees have little effect on the water table, but their roots pose a landslide hazard by dislodging boulders.

Possible effects of ignoring good construction practices are illustrated on page 2. Unfortunately, these poor construction practices are not as unusual as you might think and are often chosen because, on the face of it, they will save the developer, or owner, money. You should not lose sight of the fact that the cost and anguish associated with any one of the disasters illustrated, is likely to more than wipe out any apparent savings at the outset.

ADOPT GOOD PRACTICE ON HILLSIDE SITES

AUSTRALIAN GEOGUIDE LR8 (CONSTRUCTION PRACTICE)

EXAMPLES OF POOR HILLSIDE CONSTRUCTION PRACTICE



WHY ARE THESE PRACTICES POOR?

Roadways and parking areas - are unsurfaced and lack proper table drains (gutters) causing surface water to pond and soak into the ground.

Cut and fill - has been used to balance earthworks quantities and level the site leaving unstable cut faces and added large surface loads to the ground. Failure to compact the fill properly has led to settlement, which will probably continue for several years after completion. The house and pool have been built on the fill and have settled with it and cracked. Leakage from the cracked pool and the applied surface loads from the fill have combined to cause landslides.

Retaining walls - have been avoided, to minimise cost, and hand placed rock walls used instead. Without applying engineering design principles, the walls have failed to provide the required support to the ground and have failed, creating a very dangerous situation.

A heavy, rigid, house - has been built on shallow, conventional, footings. Not only has the brickwork cracked because of the resulting ground movements, but it has also become involved in a man-made landslide.

Soak-away drainage - has been used for sewage and surface water run-off from roofs and pavements. This water soaks into the ground and raises the water table (GeoGuide LR5). Subsoil drains that run along the contours should be avoided for the same reason. If felt necessary, subsoil drains should run steeply downhill in a chevron, or herring bone, pattern. This may conflict with the requirements for effluent and surface water disposal (GeoGuide LR9) and if so, you will need to seek professional advice.

Rock debris - from landslides higher up on the slope seems likely to pass through the site. Such locations are often referred to by geotechnical practitioners as "debris flow paths". Rock is normally even denser than ordinary fill, so even quite modest boulders are likely to weigh many tonnes and do a lot of damage once they start to roll. Boulders have been known to travel hundreds of metres downhill leaving behind a trail of destruction.

Vegetation - has been completely cleared, leading to a possible rise in the water table and increased landslide risk (GeoGuide LR5).

DON'T CUT CORNERS ON HILLSIDE SITES - OBTAIN ADVICE FROM A GEOTECHNICAL PRACTITIONER

More information relevant to your particular situation may be found in other Australian GeoGuides:

- GeoGuide LR1 - Introduction
- GeoGuide LR2 - Landslides
- GeoGuide LR3 - Landslides in Soil
- GeoGuide LR4 - Landslides in Rock
- GeoGuide LR5 - Water & Drainage
- GeoGuide LR6 - Retaining Walls
- GeoGuide LR7 - Landslide Risk
- GeoGuide LR9 - Effluent & Surface Water Disposal
- GeoGuide LR10 - Coastal Landslides
- GeoGuide LR11 - Record Keeping

The Australian GeoGuides (LR series) are a set of publications intended for property owners; local councils; planning authorities; developers; insurers; lawyers and, in fact, anyone who lives with, or has an interest in, a natural or engineered slope, a cutting, or an excavation. They are intended to help you understand why slopes and retaining structures can be a hazard and what can be done with appropriate professional advice and local council approval (if required) to remove, reduce, or minimise the risk they represent. The GeoGuides have been prepared by the Australian Geomechanics Society, a specialist technical society within Engineers Australia, the national peak body for all engineering disciplines in Australia, whose members are professional geotechnical engineers and engineering geologists with a particular interest in ground engineering. The GeoGuides have been funded under the Australian governments' National Disaster Mitigation Program.

Table M1 – Low and Medium Hazard Areas

Category		**Category 1** **Low Hazard Area**	**Category 2** **Medium Hazard Area**
General Description		Areas not susceptible to significant landslip hazard; instability not expected unless major site changes occur. Often represented by low slope profiles in stratified rocks and nearly flat in alluvial deposits.	Land areas of potential landslip hazard and possible soil creep or a moderately steep soil covered slope. Instability may occur during and after extreme climatic conditions. Represented by relatively steeper topography in stratified rocks and low slope profiles in alluvial deposits.
Implications for Development		Good engineering and conventional building/development practices usually sufficient for safe development in these areas.	Restrictions on nature and extent of development [especially earthworks] may be required.
Identification Criteria	Rh	Slopes between 0° and ≤ 18° in plateau areas. At least 25 metres from any prominent cliff line.	Slopes > 18° and ≤ 23°. In proximity [within 25 metres] of cliff lines.
Identification Criteria	Rnt Rnt-s Sandstone sequences. Rnt.-m Mudstone sequences	Slopes between 0° and ≤ 12½°. At least 100 metres from any prominent cliff line. Slopes between 0° and ≤ 10°. At least 100 metres from any prominent cliff line.	Slopes > 12½° and ≤ 22° In proximity [within 25 metres] of cliff lines. Slopes > 10° and ≤ 18°. In proximity [within 25 metres] of prominent cliff lines.
Identification Criteria	Rnp	Slopes > 0° and ≤ 5°.	Slope > 6° and ≤ 12°.
Identification Criteria	Qa & Qd Qhd & Qhbr	Slopes > 0° and ≤ 5° and • At least 50m away from a lake shore or river flat, and • At least 60m away from a beach.	Slope > 5° and ≤ 18° and where groundwater > 3m below surface. Slope > 5° and ≤ 24° and where groundwater < 3m below surface Or within 50m of lake shore/river flat.
Identification Criteria	Qs [deeper than 2 metres]	Slopes > 0° and ≤ 5° And at least 25m away from a cliff area.	Slopes > 5° and ≤ 18° and where groundwater > 3m below surface. Slope > 5° and ≤ 12° and where groundwater < 3m below surface. Or within 25m of a cliff area.

Table M2 – High and immediate High Hazard Areas

Category		Category 3 High Hazard Area	Category 4 Immediate High Hazard Area
General Description		Land areas susceptible to soil creep, landslip and rockfalls due to steep slope profiles in stratified formations and proximity of land to cliff areas and alluvial deposits. Localised known areas of landslip and/or rockfalls may occur within the area. Commonly seepage problems occur in the area	Land areas of potential landslip hazard and possible soil creep or a moderately steep soil covered slope. Instability may occur during and after extreme climatic conditions. Represented by relatively steeper topography in stratified rocks and low slope profiles in alluvial deposits.
Implications for Development		Significant restrictions on nature and extent of development [especially earthworks and drainage] usually required. The risk associated with development in these areas are often higher than normal.	Unsuitable for development unless localised areas can be re-rated to Category 3 or better. Any development usually subject to substantial restriction.
Identification Criteria	Rh	Slopes > 23° and ≤ 33° and in proximity [within 10 metres] of cliff lines.	Slopes > 33°. Prominent cliff areas or coastal bluff areas.
	Rnt Rnt-s Sandstone sequences. Rnt.-m Mudstone sequences	Slopes > 22° and ≤ 29°. In proximity [within 10 metres] of cliff lines. Slopes > 18° and ≤ 24° and in proximity [within 10 metres] of cliff lines.	Slopes > 29°. Prominent cliff or coastal bluff areas. Slopes > 24°. Prominent cliffs or coastal bluff areas.
	Rnp	Slopes > 12° and ≤ 18°	Slopes > 18° and cliff or bluff areas.
	Qa & Qd Qhd & Qhbr	Slopes > 18° and ≤ 27° and where groundwater is > 3m below surface. Slopes > 12° and ≤ 15° and where groundwater > 3m below surface And at least 60m from a beach.	Slopes > 27° and where groundwater > 3m below surface. Slopes > 15° and where groundwater < 3m below surface. Beachfront areas and within 60m of beach.
	Qs [deeper than 2 metres]	Slopes > 18° and ≤ 27° and where groundwater > 3m below surface. Slopes > 12° and ≤ 15° and where groundwater < 3m below surface. And at least 25m from a cliff area.	Slopes > 27° and where groundwater > 3m below surface. Slopes > 15° and where groundwater < 3m below surface. Or within 25m of a cliff area.

Site Classification Notes

General

Site classification is a method adopted in residential development for quantifying the anticipated surface movements that may occur on a site, generally due to soil reactivity. Soil reactivity is an appreciable change in soil volume due to a change in the moisture content of the soil. The extent of ground movement due to a reactive clay soil depends on the degree of reactivity of the clay, depth of clay in the soil profile, the depth of potential moisture variation in the soil and the change in soil suction that occurs from dry to wet soil conditions.

AS2870 – 2011 "Residential Slabs and Footings" classifies soil profiles in terms of their potential for shrink/swell movement due to changes in moisture content, to be slight (Class S), moderate (Class M), high (Class H1 or H2) or extreme (Class E). Sites with little or no reactivity are classified rock or sand (Class A), see table 2.1 below.

For classes; M, H1, H2 and E, further classification may be required, based on the depth of the expected moisture change. For sites with deep-seated moisture changes characteristic of dry climates and corresponding to a design depth of suction change (refer to AS 2870 – 2011, clause 2.3.3) equal to or greater than 3m, the classification shall be M-D, H1-D, H2-D, or E-D as appropriate.

AS2870 – 2011 Table 2.1 "Classification Based on Site Reactivity"

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 – 20mm
M	Moderately reactive clay or silt sites, which may experience moderate ground movement from moisture changes	20 – 40mm
H1	Highly reactive clay sites, which may experience high ground movement from moisture changes	40 – 60mm
H2	Highly reactive clay sites, which may experience very high ground movement from moisture changes	60 – 75mm
E	Extremely reactive sites, which may experience extreme ground movement from moisture changes	> 75mm

Site Classification Notes - Continued

Problem Sites

Sites which include soft soils such as soft clay, silt or loose sands, landslip, mine subsidence, collapsing soils, soils subject to erosion or fill sites greater than 0.8m for sand and 0.4m for material other than sand are classified as Problem sites (Class P).

Classification Methods

Classification for sites other than class P sites shall be determined from at least one of the following methods:

- Identification of the soil profile based upon a visual assessment of the site and surrounding areas, excavated test pits and falling weight penetrometers probes.
- Interpretation of the current performance of existing buildings within the region that are founded on a similar soil profile.
- Site classification based on characteristic surface movement in accordance with AS2870 – 2011, clause 2.2.3, with parameters obtained from laboratory test results.

Effect of Trees

The presence of trees on a site can potentially affect the performance of the footing system by having an exaggerated effect on the moisture conditions of the soil. As a general rule, sites where trees are located within the mature height of the tree from the property boundary, will be classified as a Problem site (Class P).

There are a number of methods used to assess the potential impact of a tree on the reactive performance of a site. These include:-

- AS2870 provides a design method to account for the presence of trees within and in the vicinity of the proposed building footprint.
- The 'Foundation and Footings Society of Victoria Method' proposes a grading of trees with respect to the effect of their roots on nearby structures and suggests how their influence may be reduced.

A tree effect score and tree effect are determined from tables CH5.1 and CH5.2 respectively.

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.

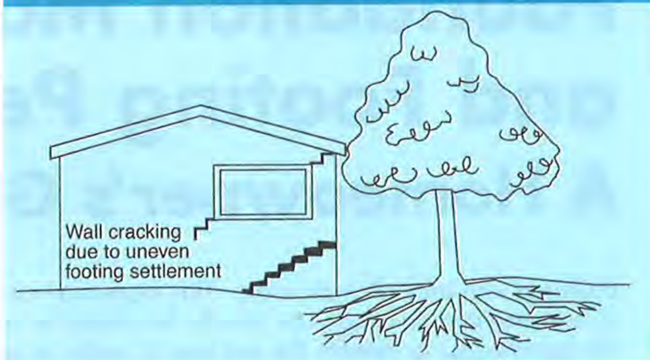
Seasonal swelling/shrinkage in clay

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.

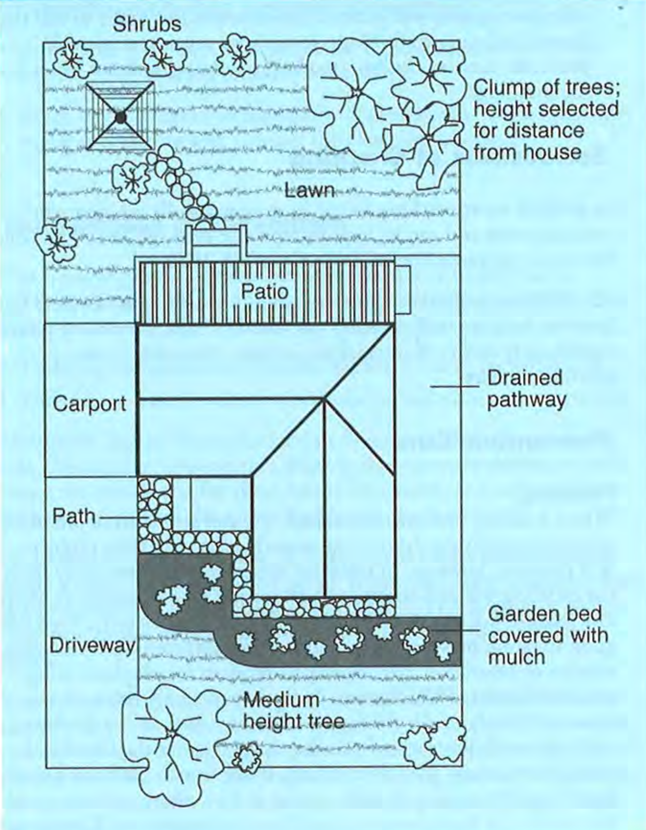
Protection of the building perimeter
It is essential to remember that the soil that affects footings extends well beyond the actual building line. Watering of garden plants, shrubs and trees causes some of the most serious water problems.

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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