Armidale Dumaresq

Development Control Plan 2012

Section 2 Site Analysis and General Controls

Chapter 2.6 Earthworks and Geotechnical Investigations

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Part 1 General provisions

1.1 Introduction

The former Armidale City Council commissioned DJ Douglas & Partners Pty Ltd to carry out a study of geotechnical hazards within the Armidale city area (*Report on Geotechnical Hazards Study Prepared for the Council of the City of Armidale -November 1992)* to provide development guidelines and to assist Council staff in assessing development proposals under the *Environmental Planning and Assessment Act 1979*. This study included a review of the local geology and groundwater conditions and gathered data pertaining to various potential hazards from various authorities and companies.

The study developed risk categories to assist in the assessment of potential hazards within Armidale (this study does not include areas in the former Dumaresq Shire) and identified risks associated with earthworks when inappropriately performed or monitored. The risk assessment techniques used are discussed in the following sections of the report:

a) Slope Instability

b) Shrink-Swell Movements in Soil

c) Spring Activity

In addition, the provisions for undertaking earthworks, including cut and fill and the construction of retaining walls and batters are addressed in this chapter.

1.2 Objectives

The objectives of this chapter are:

O.1 To ensure that geotechnical risks are recognised.

O.2 To ensure earthworks do not impact on local amenity.

O.3 To ensure earthworks do not impact negatively on site safety and stability.

O.4 To ensure that information in this report is used to undertake precautionary works and develop appropriate engineering solutions for development where these hazards exist.

1.3 Land to which this chapter applies

This chapter applies to land in the Armidale Dumaresq local government area.

1.4 Addressing the guidelines of this chapter

The guidelines for earthworks and geotechnical matters are set out in this chapter. These are expressed in the form of objectives which need to be addressed for each development proposal. For each objective (O), 'acceptable solutions' (S) are provided which, if met, will ensure compliance. Alternative approaches may be proposed, provided these adequately address the relevant objectives and comply with legislation.

Part 2 Earthworks and retaining walls

Where development consent for earthworks (or for development involving ancillary earthworks) is required, the impact of the earthworks on the site must be considered. Please address the relevant matters for consideration in *LEP 2012* Clause 6.1 Earthworks and the following controls.

Objectives

O.1 To limit the extent and visual impact of earthworks within a site, particularly along adjoining boundaries.

O.2 To minimise the visual impact and amenity of earthworks on both the site, and the adjoining

	properties.
O.3	To ensure that where excavation and/or filling are carried out, appropriate measures are in place to ensure site stability and prevent erosion and sedimentation.
O.4	To ensure that excavation, filling and/or retaining walls do not create a stormwater nuisance or adverse environmental impacts on surrounding land or waterways.
2.1	**General earthworks matters**
S.1	Buildings on sloping sites shall be sited and designed to minimise the extent of earthworks and associated retaining walls.
S.2	Excavation, filling, batters and/or retaining walls must not redirect the flow of surface water onto an adjoining property.
2.2	**Excavation of sloping sites**
S.3	All excavation greater than 600mm shall be structurally supported by a retaining system that is designed by a qualified engineer. The design must include a drainage system that does not redirect the overland flow of stormwater onto adjoining property.
S.4	Excavation must not reduce the cover of underground utility services.
S.5	Excavated sites shall be battered to an appropriate grade where possible, and landscaped in accordance with an approved Landscaping Plan.
S.6	Excavation associated with the erection of, or alterations or additions to, a building or ancillary development (other than a swimming pool) must: a) in the R1, R2 and RU5 zones, not be more than 1.5m below existing ground level; or b) in the RU1, RU4, E3, E4 and R5 zones, not be more than 2m below existing ground level; or c) in the IN1 and IN2 zones, not be more than 3m below existing ground level;
S.7	An unprotected embankment must not extend more than: a) in the R1, R2, RU5 and business zones, 2m horizontally beyond the external wall of the building or ancillary development; or b) in the RU1, RU4, E3, E4 and R5 zones, 4m horizontally beyond the external wall of the building or ancillary development; or c) in the industrial zones, 4m horizontally beyond the external wall of the building or ancillary development.
S.8	Excavation associated with the erection of, or alterations or additions to, a swimming pool must be not more than the depth required for the pool structure.
2.3	**Fill of sloping sites**
S.9	Fill associated with the construction of, or an alteration or addition to, a building or ancillary development, must be contained wholly within the footprint of the building or ancillary development.
S.10	Exposed fill may be constructed using an unprotected embankment if the building or ancillary development has a setback of more than 2m from a side or rear boundary, if: a) the fill is not more than 600mm above ground level (existing), and b) the fill (but not the embankment) does not extend more than 1m beyond an external wall of the dwelling house or ancillary development, and c) the toe of the unprotected embankment has a setback of at least 400mm from a side or

rear boundary.

S.11 Where fill requires the construction of a retaining wall, the fill must be adequately contained by a retaining wall that is not higher than 600mm (including the height of any batters) above existing ground level.

2.4 Retaining walls

S.12 Where excavation requires the construction of a retaining wall, the wall:

a) where forward of the front façade of the building, must not be more than 1m above existing ground level.

b) where located behind the front façade of the building, must not be more than 3m above existing ground level.

S.13 Where fill requires the construction of a retaining wall, the fill must be adequately contained by a retaining wall that is not higher than 600mm (including the height of any batters) above existing ground level.

S.14 All retaining walls greater than 600mm must be designed by a qualified engineer. The design must include a drainage system that does not redirect the overland flow of stormwater onto adjoining property.

S.15 Retaining systems are to be separated from any other structural retaining system on the site by at least 2m measured horizontally.

S.16 Retaining walls are to be constructed using materials that blend with the natural landscape.

2.5 Batters

S.17 Excavated sites shall be battered at a maximum grade of 1 in 2 for landscaping and 1 in 4 for grassed areas.

S.18 Batters must be landscaped in accordance with an approved Landscaping Plan.

S.19 Retaining systems are to be separated from any other structural retaining system on the site by at least 2m measured horizontally.

Part 3 Geotechnical assessment

The DJ Douglas & Partners report (Appendix 1) describes the natural and site development induced geotechnical hazards within Armidale.

Suggested procedures for identification and inclusion of geotechnical hazards and risk assessment in development applications submitted are discussed in Section 8. A full summary of these procedures is presented in Table 8.1, addressing slope, soil, springs and earthworks categories, including design considerations to be undertaken.

A series of four drawings were prepared as part of the study, delineating approximate boundaries of geotechnical units, soil shrink-swell zones, slope instability risk zones and potential spring hazard zones.

The slope instability drawing (No. 13837/3) and the spring drawing (13837/4) are used to assess risk categories and these drawings are cross-referred in Table 8.1.

The provisions of Table 8.1 will apply to all new building and subdivision development requiring Development Consent or Complying Development Certification in areas of potential spring activity or medium or above risk of slope activity as shown on the slope instability drawing (No. 13837/3) and the spring drawing (13837/4), with the term ‘Requirements for Engineering or Building Approval’ in Table 8.1 to be read as ‘Requirements for Construction Certification’.

For sites which are potentially spring affected or subject to medium or above risk of slope activity, an engineer’s certification is required in connection with applications for new subdivision or building work involving any new footing systems or earthworks, except where the work is only for new ancillary domestic/commercial structures such as carports and decks, provided these are small (<50m^2), single storey, and of flexible construction (e.g. timber or steel framed vs. masonry), and will not impose any significant structural loading on any other building.

The following is a summary of relevant recommendations and suggestions presented in the D J Douglas report for development control purposes:

a) the risk of slope instability is to be assessed based on work by Walker et al published in Australia Geomechanics News;

b) sites in 'medium' or above risk categories with respect to slope instability are to be subjected to specific engineering and geotechnical review;

c) Australian Standard AS2870 'Residential Slabs and Footings' is to be adopted for shrink-swell assessment of all soils;

d) sites classified as 'low' or greater risk of slope instability and underlain by likely basalt flows or tertiary sediments are subject to engineering assessment;

e) the guidelines presented in Australian Standard AS3798 'Guidelines on Earthworks for Commercial and Residential Developments' are to be adopted for use in all earthworks developments except where more stringent guidelines are presented in Section 6.4 of this chapter as being more appropriate to local conditions;

f) design and construction of footing systems for residential buildings are to be carried out in accordance with Australian Standard AS 2870 'Residential Slabs and Footings';

g) for commercial and industrial buildings, recommended footing depths are presented in Table 7.2;

h) risk categories are to be defined for slope and spring hazard categories and for soils at building application stage.

REPORT ON
GEOTECHNICAL HAZARD STUDY
CITY OF ARMIDALE

PREPARED FOR
THE COUNCIL OF THE CITY OF ARMIDALE

13837
NOVEMBER 1992

Geotechnical Consultants
D.J. Douglas & Partners Pty Ltd

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Project N°: 13837
KAB/jm

REPORT ON
GEOTECHNICAL HAZARD STUDY
CITY OF ARMIDALE

1. INTRODUCTION

This report presents the results of a study of selected geotechnical potential hazards associated with development within the City of Armidale. The work was performed at the request of the Council of the City of Armidale. A draft was previously submitted on 12 October 1992. The contents of this draft were discussed at a seminar given by DJ Douglas & Partners on 20 October 1992. This present report was prepared after reviewing comments received during and soon after the seminar.

The object of the study was to provide Council with guidelines on initial assessment of development risk as related to sloping terrain, reactive soils and spring activity. This was to take the form of a list of identified prerequisites for developers to address under various hazard categories. In addition, sound guidelines were to be developed to assist Council with monitoring of local earthworks and to form the basis of a sound earthworks policy for local developers to follow during construction.

In particular, the study was to assist Council in being able to assess development proposals under S.90(1)(g) of the Environmental Planning and Assessment Act 1979, which requires Council to consider "whether ..... land ..... is unsuitable for ..... development by reason of its being, or being likely to be, subject to ..... subsidence, slip or ..... to any other risk".

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The scope of work of the study comprised a series of meetings and liaisons with Council staff, local engineers, government departments and staff from the University of New England, coupled with a review of previous geotechnical reports undertaken by D J Douglas & Partners and brief tours of inspection of various identified hazard localities within the Armidale City area for mapping purposes.

Full details of the work undertaken, the information obtained, the conclusions drawn and recommendations made are presented in the following sections.

2. TECHNICAL APPROACH

In order to gather as much background data as possible within the initial stages of this study the following steps were undertaken:

(i) review of all previous geotechnical investigation reports performed by DJ Douglas & Partners within the City of Armidale;

(ii) consultation with officers of Armidale City Council;

(iii) consultation with various authorities and consultants, both government and private sectors.

A site visit was made to Armidale on 11 to 13 August 1992 by a senior geotechnical engineer and senior engineering geologist from DJ Douglas & Partners. During this visit, an information transfer meeting was held with Council staff and access gained to all relevant council maps, records and aerial photographs. In addition, valuable discussion was had with Council technical staff.

Prior to visiting Armidale, discussions were held with the following authorities in order to obtain general geotechnical information relating to the vicinity:

(i) State Rail Authority, Geotechnical Sector, Sydenham;

(ii) Road & Traffic Authority, Operations, (Roads & Bridges), Tamworth.

While in Armidale, meetings were held with the following bodies for the same purpose:

(i) Tierney & Partners Pty Ltd, Consulting Engineers;

(ii) RF Wright & Associates, Consulting Engineers;

(iii) Department of Mineral Resources, Armidale;

(iv) Department of Agronomy and Soil Science, University of New England;

(v) Department of Geography, University of New England;

(vi) Department of Conservation and Land Management, incorporating Soil Conservation Service of NSW.

Additional consultation was held with some of the above bodies during preparation of the following sections of this study for clarification of terminology.

Based on selected mapping performed during the site visit to Armidale and on information provided by the Department of Mineral Resources, Soil Conservation Service and Armidale City Council, detailed slope, geology and soils information was plotted and used to categorise various hazards in terms of risk.

Additional risk analysis was performed based on in-house experience gained with the Standards Association of Australia codes for foundations and earthworks.

3. SITE DESCRIPTION

The City of Armidale comprises an irregular shaped area (refer Drawings 13837/1 to 3) of approximately 33 km² with maximum north-south and east-west plan dimensions of 6.5 km and 5.5 km respectively. The area is bounded on all sides by the Dumaresq Shire.

The land use within the City of Armidale includes extensive commercial and residential development on both consolidated urban and semi-rural lots, which comprise about 50% of the total area. Significant areas are dedicated to educational use (particularly the campus of the University of New England), sporting activities and farming (primarily on the northern and eastern margins of the city area).

The principal topographic features of the city area are as follows:

* Flood Plains
  The flood plain of the meandering Dumaresq Creek, generally 100 m to 400 m wide, lies between RL 960 and RL 980, and trends east to southeast. Lesser flood plains are associated with north-south trending tributary creeks (principally Martins Gully). A distinct constriction (some 40 m wide) of the Dumaresq Creek flood plain occurs at the intersection with the eastern city boundary. The stream gradient of Dumaresq Creek averages 0.2% within the city area while the associated flood plains have gradients typically less than 3% and include low lying sections subject to seasonal high water tables (particularly noted by the Soil Conservation Service of NSW in Martins Gully, adjacent to the Main Northern Railway near the southern city boundary, and adjacent to Dumaresq Creek near Grafton Road).

* <u>Remnant Ridge Features</u>
  Remnant basal ridges and branches form the higher elevations within the city area, principally at the southern margin on the slopes of Translator Hill (RL 1118) and at the northern margin (RL 1080). Ridge crests are typically gently sloping with gradients in the range <3% to 7% steepening to 15% to 25% (with isolated areas with gradients to 40%) on upper hillslopes at the boundaries of basalt flows and either side of incised natural drainage lines.

* <u>Gentle Middle Slopes</u>
  Gently sloping middle and footslopes, with gradients generally in the range of 3% to 7%, occur between the flood plains of Dumaresq Creek and its tributaries and the remnant basalt ridges.

The topography has been significantly modified by human activity in only isolated locations within the city area. These are specifically sited as follows:

* at the Armidale Brickworks (refer Drawing 13837/1) where an area of approximately 240 m x 180 m was previously quarried for clays, and is now understood to be undergoing backfilling operations;

* along the route of the Main Northern Railway, comprising 6.3 km of cuttings and fillings embankments .

Elsewhere within the city, only minor modification of the natural surface can be observed, where excavation or filling has taken place during road construction, residential and commercial development.

Areas of filled ground reported by Council officers are shown on Drawing 13837/1.

4. GEOLOGY

4.1 Stratigraphy

Reference to the Armidale and Dumaresq 1:25000 Geological Compilation Sheets (Department of Mineral Resources) indicates that the City of Armidale is underlain by a complex stratigraphic succession of rocks and unconsolidated soils ranging from Carboniferous to Recent age. The distribution of lithological units after Department of Mineral Resources is reproduced in Drawing 13837/1. It is noted that the distribution of lithological units, as geologically mapped (unpublished) by the University of New England (UNE), varies from that shown on Drawing 13837/1, particularly in respect to the distribution of Tertiary sediments and volcanic rocks. Discussions with staff of the Department of Mineral Resources indicated that their published data is approximate only. It is not known which of the two data bases (UNE or Department of Mineral Resources) is more accurate. However, preference was given to published data and hence the Department of Mineral Resources data was used as reference.

The boundaries indicated on Drawing 13837/1 may require review with time as further data is collected.

A summary of lithologies, geological structure and weathering profiles is presented below in order of decreasing age.

4.1.1 Sandon Beds (Carboniferous Age)

The Sandon Beds (denoted C_S in Drawing 13837/1) comprise a variable sedimentary sequence of cherts, argillites and greywacke which have undergone low grade metamorphism associated with regional folding of the strata.

Weathering profiles developed on the Sandon Beds are highly variable in depth, with the depth to fresh materials generally ranging from 3 m to in excess of 22 m, as indicated by past site investigations within the study area.

During the early Tertiary Period, extensive erosion of the surface of the Sandon Beds resulted in stream entrenchment, with local relief of up to 400 m in the Armidale region.

4.1.2 Armidale Beds (Tertiary Age)

The Armidale Beds (denoted Ts in Drawing 13837/1) comprise lake and stream sedimentary deposits of early Tertiary (Eocene) age, deposited unconformably over the eroded Carboniferous surface. The beds comprise conglomerate, sandstone, grit, ferruginous cherty shale and "greybilly".

Voisey (ref 1) attributes the extensive outcrops of greybilly to contact metamorphism at the base of the overlying basalt. However, the greybilly is interpreted by Francis and Walker (ref 2) as a silcrete duricrust of Palaeocene to Eocene age.

Plate 1 (Appendix B) shows tertiary sediments exposed in a road cutting in Madgwick Drive, North Armidale. Here, colluvial and residual soils are seen to overlie interbedded, partially cemented sands and gravels, underlain by fine grained sediments seen as fretting in exposure.

Within the City of Armidale, geological mapping (Drawing 13837/1) indicates the Tertiary sediments at elevations ranging from approximate RL 975 to RL 1080. It is considered probable that a more extensive development of Tertiary sediments is present below the remnant basalt capping. Francis and Walker (ref 2) indicate the following:

* Lateritic weathering profiles have formed on Armidale Beds fluvial sediments, with nodular manganiferous laterite up to 1 m thick at the top of the profiles, being underlain by some 4 m of mottled deeply weathered material with traces of sedimentary stratification.

* The lateritic surface slopes from approximate RL 1030 to RL 975, with average gradients of 5° to 10°, and extends down

to 6 m above the Dumaresq Creek flood plain in some locations.

4.1.3 Benvenue Basalts (Tertiary Age)

The Benvenue Basalts (denoted Tv in Drawing 13837/1) disconformably overlie the Armidale Beds and predominantly comprise multiple alkali olivine basalt and related nepheline or analcime basanite flows, tuffaceous sediments (up to 70 m thick) and intrusives of lower Oligocene to lower Miocene age. Basalt flow directions are reported as toward the northeast at 10° to 15°. Volcanic breccia is described at the base of the sequence in several locations.

Francis and Walker (ref 2) suggest the following:

* the flows were extruded from numerous local sources and may not have formed a complete basalt cover;

* lateritic weathering accompanied the basaltic eruptions, producing deep weathering (to the order of 7 m thick) in at least three general locations at elevations between RL 1110 and RL 975;

* the stratigraphy of relict laterite profiles is complex, being characterised by localised development and erosional truncation prior to burial by subsequent flows.

Within the City of Armidale, geological mapping (refer Drawing 13837/1) indicates the Tertiary basalts to occur at elevations ranging from approximately RL 994 to RL 1118.

4.1.4 Recent Alluvium (Quaternary Age)

Stream activity during the Quaternary period has resulted in the formation of flood plain deposits of dark coloured clays up to 600 m wide, in and adjacent to the flood plain of the current Dumaresq Creek, Martins Gully and tributary gullies adjacent to the Main Northern Railway at the southern boundary of the City of Armidale. Geological mapping (Drawing 13837/1) indicates that the alluvial deposits (denoted Qa) principally lie between RL 1066 and RL 960 approximately.

4.2 Soils

4.2.1 Soil Types and Properties from Soil Conservation Service of NSW

The Armidale office of the Soil Conservation Service of New South Wales has previously carried out urban capability and land use studies in a range of study areas around the periphery of the City of Armidale. These comprise North Armidale, South Armidale, Armidale City North East Sector and Dumaresq Shire (refer 3, 4, 5 & 6). This data indicates an extensive range of soil types and respective physical and chemical properties. Estimates of shrink-swell potential made by the Soil Conservation Service for the various soil types described are reproduced in Drawing 13837/2. The distribution of soil types and physical properties are described as being related to the local terrain and the associated geological/geomorphic interactions.

Within the urbanised sections of the City of Armidale, information regarding soil distribution and properties, including manmade (filling) soils has also been included in Drawing 13837/2. This is generally based on records and observations by officers of the Armidale City Council.

A summary of the major soil types defined within the Soil Conservation Service of NSW study areas is presented in Table 4.1 below. Only the shrink-swell characteristics, however, have been reproduced in attached Drawing 13837/2, as being of most significant hazard potential. The definition of the various shrink-swell categories used by the Soil Conservation Service is produced in Table 4.2 below from information presented in the North Armidale study (ref 3).

TABLE 4.1 - SUMMARY OF MAJOR SOIL TYPES
SOIL CONSERVATION SERVICE OF NEW SOUTH WALES STUDY AREAS

SOIL TYPE	PHYSIOGRAPHY	PARENT LITHOLOGY	DESCRIPTION	TYPICAL DEPTH	USCS	SHRINK-SWELL	EROSION HAZARD	SOIL DRAINAGE
BLACK CRACKING CLAYS	Terraces, sideslopes footslopes and drainage plains	Basalt or alluvium derived from basalt	Dark grey and black clay loam to clay surface soils 0.25 m deep overlying paler coloured clay subsoil. Variants include mottled grey subsoil and high stone content.	Variable to >2 m	CH, MH	High to very high	High	Poor to impeded
STONEY BASALT SOILS	Edge of basalt flows, crests and steeper side slopes	Basalt	Dark red-brown clays dispersed between basalt fragments and joint blocks. coloured clay subsoil. Variants include mottled grey subsoil and high stone content.	Variable <0.5 m	CH, HH	High	Moderate	Poor
HIGHLY WEATHERED STONEY BASALT SOILS	Sideslopes	Basalt	Brown light sandy loam to 0.3 m deep over orange brown to yellow clay loam or clay subsoils. Highly weathered basalt fragments throughout.	<1.5 m		Moderate	High	Moderate
CHOCOLATE SOILS	Crests and midslope benches	Basalt	Dark brown to reddish brown clay loam surface soil 0.15 to 0.3 m deep overlying brown/red-brown clay subsoil. Underlain by highly weathered basalt. In some locations the basalt is overlain by a yellow clay subsoil.	Variable 1.0 m to 1.5 m	CH, MH, ML	High to very low	Moderate	Poor
BROWN CRACKING CLAYS	Sideslopes	Basaltic tuff and fossil lateritic materials	Reddish to dark brown clay loam 0.25 m deep over reddish brown, medium clay subsoils.	<1 m	CH, MH	High to very high	Moderate	Poor to impeded
BROWN GRAVELLY SOILS	Upper sideslopes, variable gradient <10% to >25% adjacent to drainage lines.	Colluvium derived from basalts and from insitu Armidale Beds sedimentary rocks.	Grey brown or dark brown sandy loam to fine sandy clay loam soil to 0.45 m deep overlying brown to yellow brown light grey subsoils. Gravel content high, rock outcrops may occur within the soil group	0.5 m to 1.1 m	CL, ML	Low to moderate	Moderate to high	Impeded
DUPLEX GRAVELLY SOILS	Lower sideslopes and footslopes	Armidale Beds sedimentary rocks	Brown to reddish-brown sandy loam to clay loam to 0.4 m deep over variable loam or clay subsoil.	1 m	SC, SM, CL	Low to moderate	High	Good to moderate
YELLOW DUPLEX SOILS	Crests, sideslopes, footslopes and drainage plains	Sandon Beds	Brown sandy loam to light sandy clay loam surface soil 0.2 m to 0.6 m deep over yellow brown sandy to light clay subsoil.	≥1 m	CH	High	Moderate to high	Impeded

NOTE: USCS - Unified Soil Classification System

TABLE 4.2 - SHRINK-SWELL CATEGORIES

SHRINK-SWELL POTENTIAL	LINEAR SHRINKAGE %
Low	0-12
Moderate	12-17
High	17-21
Very High	>21

The above categories are based solely on the results of linear shrinkage tests. This is the linear decrease, in one dimension only, of a soil sample when oven dried from the moisture content at the liquid limit, expressed as a percentage of the original dimension. The linear shrinkage test is more fully described in Test C4.1 of AS 1289 (ref 7).

4.2.2 Gilgai

The presence of 'gilgai' is noted within the City of Armidale, following discussion with staff of the Department of Agronomy and Soil Science, UNE.

This phenomenon, as reported by Hubble et al (ref 8), comprises the formation of small hummocks and hollows by upward displacement of material during repeated shrink-swell movements of clay subsoils. Gilgai features are typically formed where conditions are as follows:

* level or very gently sloping plains with soil depths of at least 1 m and a high variation in seasonal moisture content;

* black-earth swelling and texture-contrasted soils with thick subsoil clay horizons.

Attached Plate 2 (refer Appendix B) shows a typical gilgai formation near the University of New England. The more brown soil in the central portion of the photograph is ascending with respect to the darker black soil either side.

4.2.3 Trap Soil

The term 'trap soil' is used locally to describe a slightly clayey silty fine sand or sandy silt found on low lying ground up to a depth of approximately 0.3 m to 0.5 m below ground level. This is often directly underlain by clay soils of much lower permeability than the overlying trap soils. Accordingly, when prolonged wet conditions occur, the overlying trap soils, which may often be weakly cemented in dry weather, cannot drain downwards and quickly reduce in strength to a soft condition, thus becoming difficult to traffic and rendering excavation difficult due to side wall slumping.

Plate 3 (refer Appendix B) shows a typical trap soil layer overlying a plastic clay near the University of New England.

4.2.4 Extent of Gilgai and Trap Soil Formations

Insufficient information was available on the extent of gilgai and trap soils formations within the study area to allow inclusion in the attached mapping. It is considered possible, however, that trap soils may relate to the duplex soils described by SCS (refer Table 4.1) and that gilgai formations may be occurring over much of the black cracking clays, as also described by SCS, where the topography is reasonably flat.

5. GROUNDWATER

Published data with respect to groundwater within the City of Armidale appears limited. The South Armidale survey of the Soil Conservation Service of New South Wales (ref 4) indicates the presence of a permanent spring located near the eastern boundary of the study area, but does not define the location.

A study of groundwater characteristics of sections of the Dumaresq Shire adjacent to the City of Armidale was carried out by Patterson (ref 9). General findings of the study included the following:

* Producing aquifers include both sands of the Armidale Beds (Ts) and weathered basalt intervals (Tv) in the Translator Hill Area.

* Groundwater sources adjacent to the Old Inverell Road (Bundarra Road) 1 to 2 km west of the city boundary are derived from a single sand aquifer located under the youngest basalt flow. Springs associated with the outcrop of the aquifer were characterised by flows ranging from 5000 to 90,000 litres/day.

The locations of spring or seepage activities either noted previously by Council staff or observed during the current study are shown on Drawing 13837/1. Also included are the locations of small farm dams interpreted as probably spring fed. The distribution of these features indicates a concentration of spring or seepage features at or close to the base of basalt flows, with a lesser number within basalt units.

It is considered that lateritic bands within the basalt sequences are likely to control drainage paths, either directly or as local aquicludes, where significant clay formation has occurred during the lateritic weathering process.

A typical spring location is indicated on Plate 4 in Appendix B. This is located in the Arboretum, adjacent to Kentucky Street (New England Highway).

6. GEOTECHNICAL HAZARD ASSESSMENT

The following sections describe the assessment of natural and site development induced geotechnical hazards within the City of Armidale.

6.1 Assessment of the Hazard of Slope Instability

Since the development of steep sites involves acceptance by the owner of a certain level of risk following development, it is recommended that all land proposed for development in the City of Armidale be classified in accordance with the risk methods of slope instability presented in Walker et al (Ref 10). The general categories adopted therein are reproduced below in Table 6.1. Prior to application of these risk categories to local conditions, an assessment was first made which included consideration of the following items:

* Published geological mapping and probable inaccuracies indicated by comparison of varying information sources.

* Information regarding reported areas of instability supplied by Council, local engineering consultants and staff of the University of New England.

* Information regarding intermittent and permanent spring or seepage activity.

* Observations of slope gradients from topographic plans.

* Field observations during the current study.

* Interpolation of field observations in undeveloped areas to developed areas with similar topographic and geological features.

* Review of selected stereo pair air photographs held by Council.

On the basis of the above items, the study area has been subdivided into provisional risk zones (of instability) as indicated in Table 6.2. The approximate zone boundaries are shown on Drawing 13837/3. It is anticipated that these zone boundaries will eventually either be modified or confirmed by more extensive site investigation during subdivision planning or site redevelopment. For this reason it is recommended that sites in 'medium' or greater risk categories (as identified by Drawing 13837/3) be subjected to specific geotechnical review as further discussed in Section 8 below.

TABLE 6.1 - CLASSIFICATION OF RISK OF SLOPE INSTABILITY

RISK OF INSTABILITY	EXPLANATION	IMPLICATIONS FOR DEVELOPMENT
VERY HIGH	Evidence of active or past landslips or rockface failure; extensive instability may occur.	Unsuitable for development unless major geotechnical work can satisfactorily improve the stability. Extensive geotechnical investigation necessary. Risk after development may be higher than usually accepted.
HIGH	Evidence of active soil creep or minor slips or rockface instability; significant instability may occur during and after extreme climatic conditions.	Development restrictions and/or geotechnical works required. Geotechnical investigation necessary. Risk after development may be higher than usually accepted.
MEDIUM	Evidence of possible soil creep or a steep soil covered slope; significant instability can be expected if the development does not have due regard for the site conditions.	Development restrictions may be required. Engineering practices suitable to hillside construction necessary. Geotechnical investigation may be needed. Risk after development generally no higher than usually accepted.
LOW	No evidence of instability observed; instability not expected unless major site changes occur.	Good engineering practices suitable for hillside construction required. Risk after development normally acceptable.
VERY LOW	Typically shallow soil cover with flat to gently sloping topography.	Good engineering practices should be followed.

This table is an extract from GEOTECHNICAL RISKS ASSOCIATED WITH HILLSIDE DEVELOPMENT as presented in Australian Geomechanics News, Number 10, December, 1985, which discusses the matter more fully.

TABLE 6.2 - DEFINITION OF INSTABILITY RISK ZONES (as indicated on Drawing 13837/3)

RISK OF INSTABILITY	EXPLANATION
Very Low	Flat to gently sloping topography (gradient generally < 3% but with some areas in the range 3% to 5%) on flood plains, ridges and terraces. Typical shallow soil cover in ridge and terrace locations.
Low	No evidence of instability observed, instability not expected unless major site changes occur. Gently sloping topography (gradient typically in the range 3% to 12%) on footslopes, crests and side slopes.
Medium	Evidence of possible soil creep (Plate 2) or a steep soil covered slope. Significant instability can be expected if works do not have regard for site conditions. Typical gradients in the range 12% to 40% but may be reduced to approximately 8% where the stratigraphy indicates potential for groundwater discharge onto soil covered slopes. Downslope creep may be enhanced in areas underlain by soils with high shrink-swell potential.
Medium to High	Similar to medium risk zone, but including areas indicated by Council as having potential for slip, particularly when water-charged.
High	Evidence of active soil creep or minor slips. Significant instability may occur during and after extreme climatic conditions. A single area adjacent to Gordon and Chestnut Streets, North Armidale, with slope gradients in the range 20% to 35%, has been included within this risk zone. It is interpreted as including the toe of an old landslip (Plate 3).

Specific examples of 'medium' and 'high' risk zone categories are indicated on Plates 5 and 6 in Appendix B.

In Table 6.1 above, reference is made to "good engineering practices". A summary of such considered good practices for sites in risk categories of 'medium' or greater is presented in Table 6.3 below along with illustrations of both good and poor construction practice in Figure 6.1 (both reproduced from Walker et al (ref 10)).

The main points of greatest significance to the steeper portions of sloping sites are as follows:

(i) Minimise cuts and fillings and provide adequately designed walls or batter slopes to ensure stability of all cuts and fillings; this applies to house platforms and to access roads/driveways and footpaths.

(ii) Proposed cuts deeper than 1 m and fillings higher than 1 m should be subject to geotechnical review prior to construction. It is expected that cuts and fills greater than 1 m would need to be supported by engineer designed retaining structures. Cuts and fills less than 1 m should be battered down to a slope of 2H:1V and 2.5H:1V (respectively) and protected from erosion. Note here that the above batters are for stability consideration only. If maintenance of vegetation is required, then soil slopes may require to be no steeper than 5H:1V (to enable lawn mower equipment to operate) in accordance with Council's existing standards.

(iii) Provide good surface and subsurface drainage with no discharge on slopes.

(iv) Support house loads on footings founded on rock where practicable.

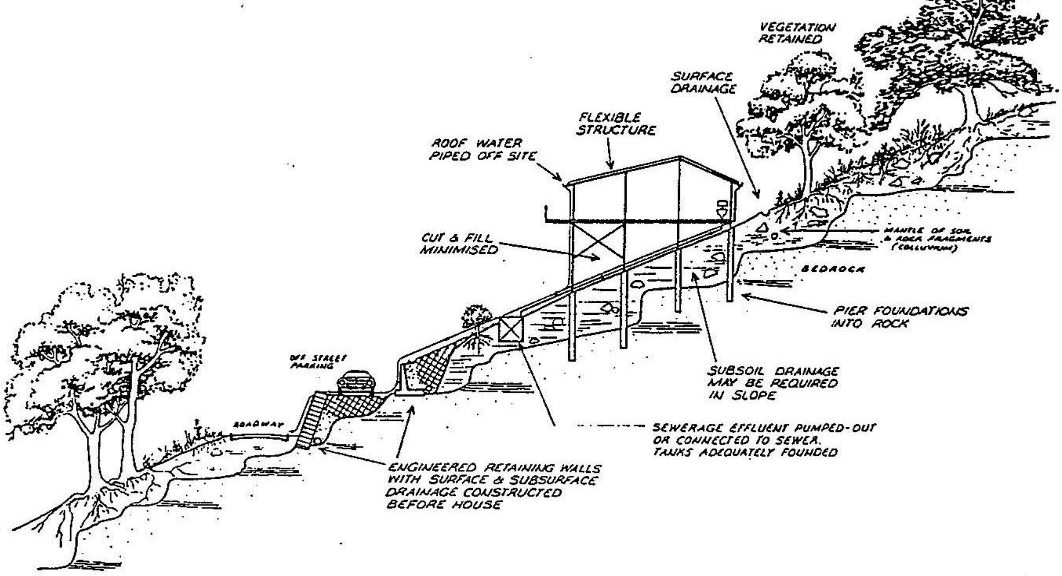
(v) Revegetate all earthworks speedily to minimise surface erosion.

TABLE 6.3 - SOME GUIDELINES FOR HILLSIDE CONSTRUCTION

	GOOD ENGINEERING PRACTICE	POOR ENGINEERING PRACTICE
ADVICE		
GEOTECHNICAL ASSESSMENT	Obtain advice from a qualified, experienced geotechnical consultant at early stage of planning and before site works.	Prepare detailed plan and start site works before geotechnical advice.
PLANNING		
SITE PLANNING	Having obtained geotechnical advice, plan the development with the Risk of Instability and Implications for Development in mind.	Plan development without regard for the Risk of Instability.
DESIGN AND CONSTRUCTION		
HOUSE DESIGN	Use flexible structures which incorporate properly designed brickwork, timber or steel frames, timber or panel cladding. Consider use of split levels. Use decks for recreational areas where appropriate.	Floor plans which require extensive cutting and filling. Movement intolerant structures.
SITE CLEARING	Retain natural vegetation wherever practicable.	Indiscriminately clear the site.
ACCESS & DRIVEWAYS	Satisfy requirements below for cuts, fills, retaining walls and drainage. Council specifications for grades may need to be modified. Driveways and parking areas may need to be fully supported on piers.	Excavate and fill for site access before geotechnical advice.
EARTHWORKS	Retain natural contours wherever possible.	
CUTS	Minimise depth. Support with engineered retaining walls or batter to appropriate slope. Provide drainage measures and erosion control.	Large scale cuts and benching. Unsupported cuts. Ignore drainage requirements.
FILLS	Minimise height. Strip vegetation and topsoil and key into natural slopes prior to filling. Use and compact clean fill materials. Batter to appropriate slope or support with engineered retaining wall. Provide surface drainage and appropriate subsurface drainage.	Loose or poorly compacted fill. Block natural drainage lines. Fill over existing vegetation and topsoil. Include stumps, trees, vegetation, topsoil, boulders, building rubble etc in fill.
ROCK OUTCROPS & BOULDERS	Remove or stabilise boulders which may become unstable. Support rock faces where necessary.	Disturb or undercut detached blocks or boulders.
RETAINING WALLS	Engineer design to resist applied soil and water forces. Found on rock where practicable. Provide subsurface drainage within wall backfill and surface drainage on slope above. Construct wall as soon as possible after cut/fill operation.	Construct a structurally inadequate wall such as sandstone flagging, brick or unreinforced blockwork. Lack of subsurface drains and weepholes.
FOUNDATIONS	Support on or within rock where practicable. Use rows of piers or strip foundations oriented up and down slope. Design for lateral creep pressures. Backfill foundation excavations to exclude ingress of surface water.	Found on topsoil, loose fill, detached boulders or undercut cliffs.
SWIMMING POOLS	Engineer designed. Support on piers to rock where practicable. Provide with under-drainage and gravity drain outlet where practicable. Design for high soil pressures which may develop on uphill side whilst there may be little or no lateral support on downhill side.	
DRAINAGE		
SURFACE	Provide at tops of cut and fill slopes. Discharge to street drainage or natural water courses. Provide generous falls to prevent blockage by siltation and incorporate silt traps. Line to minimise infiltration and make flexible where possible. Special structures to dissipate energy at changes of slope and/or direction.	Discharge at top of fills and cuts. Allow water to pond on bench areas.
SUBSURFACE	Provide filter around subsurface drain. Provide drain behind retaining walls. Use flexible pipelines with access for maintenance. Prevent inflow of surface water.	
SEPTIC & SULLAGE	Usually requires pump-out or mains sewer systems; absorption trenches may be possible in some low risk areas. Storage tanks should be water-tight and adequately founded.	Discharge sullage directly onto and into slopes.
EROSION CONTROL & LANDSCAPING	Control erosion as this may lead to instability. Revegetate cleared area.	Failure to observe earthworks and drainage recommendations when landscaping.
DRAWINGS AND SITE VISITS DURING CONSTRUCTION		
DRAWINGS	Building Application drawings should be viewed by geotechnical consultant.	
SITE VISITS	Site Visits by consultant may be appropriate during construction.	
INSPECTION AND MAINTENANCE BY OWNER		
OWNER'S RESPONSIBILITY	Clean drainage systems; repair broken joints in drains and leaks in supply pipes. Where structural distress is evident seek advice. If seepage observed, determine cause or seek advice on consequences.	

This table is an extract from GEOTECHNICAL RISKS ASSOCIATED WITH HILLSIDE DEVELOPMENT as presented in Australian Geomechanics News, Number 10, December, 1985, which discusses the matter more fully.

EXAMPLES OF GOOD HILLSIDE PRACTICE



EXAMPLES OF POOR HILLSIDE PRACTICE

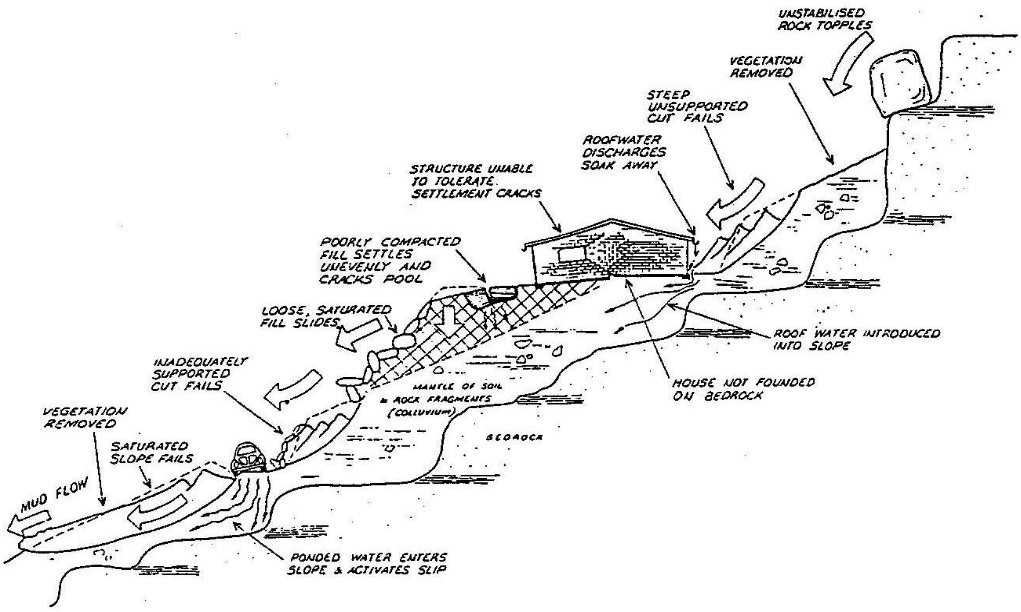


FIGURE 6.1 Illustrations of Good and Poor Hillside Practice

This figure is an extract from GEOTECHNICAL RISKS ASSOCIATED WITH HILLSIDE DEVELOPMENT as presented in Australian Geomechanics News, Number 10, December, 1985, which discusses the matter more fully.

(vi) All swimming pools should be engineered and well supported, with underdrainage installed to guard against leakage into the subgrade.

(vii) Filling placed on the lots for roadworks and driveways should be placed on a benched subgrade and compacted in horizontal lifts of 300 mm maximum loose thickness to a minimum dry density ratio of 100% Standard (Test E1.1 of AS 1289 (ref 7)). All such filling should be placed in accordance with AS 3798 (ref 14) and the guidelines presented in Section 6.4 below.

6.2 Assessment of the Hazard of Shrink-Swell Movements in Soil

The assessment of potential for shrink-swell movements of soils has been limited to the study areas of the Soil Conservation Service of NSW and restricted areas for which records are held by the Armidale City Council. The distribution of the potential for shrink-swell movements with seasonal moisture change in the above areas is shown on Drawing 13837/2.

As previously discussed in Section 4.2 above, the shrink-swell assessment has been based solely on linear shrinkage testing. The soil mapping which forms the basis of Drawing 13837/2 was carried out some considerable time ago (1979 to 1980), prior to extensive additional studies on the mechanism and measurement of shrink-swell, first by the NSW Builders Licensing Board (ref 11) and latterly as presented in AS 2870.1 (ref 12) and AS 2870.2 (ref 13). It is based on a crude assessment of plasticity and appears to take no account of soil suction and its variation with depth, depth of the cracked zone, climate, soil permeability, and presence of either bedrock or water table within the depth of suction influence. Since these latter parameters are all now considered of importance in assessing predicted surface movement due to seasonal shrink and swell, it follows that the classification indicated in Drawing 13837/2 is now somewhat dated. In addition, it is considered possible that in some instances such a classification based solely on plasticity may be misleading. However, in the absence of other more recent data it has been included in this study with the suggestion that it be used for comparative purposes only and as a preamble to more detailed additional classification.

Since AS 2870 (ref 12 and 13) allows consideration of all the above influencing factors in shrink-swell assessment it is recommended that this code be adopted for shrink-swell assessment relating to all proposed development within the City of Armidale. This code provides not only a means of classification but also guidance on suitable footing types for each soil class in order to reduce distress to generally acceptable levels (refer Section 7).

Classification of a clay site under AS 2870 is undertaken utilising one or more of the following methods:

"(a) Visual assessment of the site and interpretation of performance of existing masonry building walls on light strip footings which have existed for no less than 15 years in a similar soil assessed in accordance with Table [6.4].

(b) Identification of the soil profile and a classification from established data on the performance of the soil profile.

(c) Computation of the predicted surface movement (y_s) in accordance with engineering principles."

With respect to (c) above, the predicted surface movement (y_s) is calculated as laid out in Appendix D of AS 2870.2 (ref 13). The relationship between y_s, foundation material and designated site class is presented in Table 6.4 below. In addition, the relationship between site class and typical shrink-swell induced damage categories, which may be incurred by residential masonry, is also presented.

A full explanation of these damage categories is presented in Appendix A of AS 2870.1 (ref 10) and also reproduced in CSIRO Sheet No 10-91 (contained in Appendix C of this report). This latter sheet has been

FIGURE 6.2 - ROCK STRENGTH AND FRACTURING DEFINITION

ROCK STRENGTH

Rock strength is defined by the Point Load Strength Index (Is 50) and refers to the strength of the rock substance in the direction normal to the bedding. The test procedure is described by the International Society of Rock Mechanics (Reference).

Strength Term	Is(50) MPa	Field Guide	Approx. qu MPa*
Extremely Low:		Easily remoulded by hand to a material with soil properties.	
	0.03		0.7
Very Low:		May be crumbled in the hand. Sandstone is "sugary" and friable.	
	0.1		2.4
Low:		A piece of core 150 mm long x 50 mm dia. may be broken by hand and easily scored with a knife. Sharp edges of core may be friable and break during handling.	
	0.3		7
Medium:		A piece of core 150 mm long x 50 mm dia. can be broken by hand with considerable difficulty. Readily scored with knife.	
	1		24
High:		A piece of core 150 mm long x 50 mm dia. core cannot be broken by unaided hands, can be slightly scratched or scored with knife.	
	3		70
Very High:		A piece of core 150 mm long x 50 mm dia. may be broken readily with hand held hammer. Cannot be scratched with pen knife.	
	10		240
Extremely High:		A piece of core 150 mm long x 50 mm dia. is difficult to break with hand held hammer. Rings when struck with a hammer.	

*The approximate unconfined compressive strength (qu) shown in the table is based on an assumed ratio to the point load index of 24:1. This ratio may vary widely.

DEGREE OF FRACTURING

This classification applies to diamond drill cores and refers to the spacing of all types of natural fractures along which the core is discontinuous. These include bedding plane partings, joints and other rock defects, but exclude known artificial fractures such as drilling breaks.

Term	Description
Fragmented:	The core is comprised primarily of fragments of length less than 20 mm, and mostly of width less than the core diameter.
Highly Fractured:	Core lengths are generally less than 20 mm — 40 mm with occasional fragments.
Fractured:	Core lengths are mainly 30 mm — 100 mm with occasional shorter and longer section.
Slightly Fractured:	Core lengths are generally 300 mm —1000 mm with occasional longer sections and occasional sections of 100 mm — 300 mm.
Unbroken:	The core does not contain any fracture.

REFERENCE

– International Society of Rock Mechanics, Commission on Standardisation of Laboratory and Field Tests, Suggested Methods for Determining the Uniaxial Compressive Strength of Rock Materials and the Point Load Strength Index, Committee on Laboratory Tests Document No. 1. Final Draft October 1972.

Prepared by the Sydney Group of the Australian Geomechanics Society, January, 1975.

TABLE 6.4 - SITE CLASSES & PREDICTED SURFACE MOVEMENT
AFTER AS 2870 (ref 10 & 11)

FOUNDATION MATERIAL	CLASS	PREDICTED SURFACE MOVEMENT (y_s)	CHARACTERISTIC PERFORMANCE OF MASONRY (VENEER OR FULL) BUILDINGS ON LIGHT STRIP FOOTINGS
Most silt and some clay sites	S	$\leq$20 mm	Rare Category 0 to 1 damage
Moderately reactive clay sites	M	20 mm $< y_s \leq$ 40 mm	Often Category 1 damage but rarely Category 2 damage (The site may show cracking in dry periods).
Highly reactive clay sites	H	40 mm $< y_s \leq$ 70 mm	Often Category 1 or 2 damage with occasional Category 3 damages or more severe (Ground cracking is common in dry periods).
Extremely reactive clay sites	E	$y_s >$ 70 mm	Often Category 3 or more severe damage and area is usually well known for damage to houses and structures (Deep ground surface cracking occurs in dry spells).

NOTE: For damage categories see Appendix C (Table A2 and A2).

enclosed as a guide to developers and home owners in order to minimise risk related to shrink-swell movement and provide appropriate precautions relating to layout of trees and gardens and maintenance of gardens and plumbing leaks.

The predicted surface movement and hence shrink-swell class is used for footing selection and design in accordance with AS 2870. However, the predicted surface movement is influenced by cutting or filling. Hence, it is important that each block in a clay site development be independently assessed for shrink-swell potential when full details of the proposed layout are available, in order to allow selection of the appropriate footing system.

For purposes of the operation of AS 2870, additional classes of site are presented therein as follows:

FOUNDATION	CLASS
Most sand and rock sites	A
Sites which include: soft soils, such as soft clays or silts or loose sands; landslip; mine subsidence; collapsing soils; or soils subject to erosion.	P

The formation of 'gilgai' within the City of Armidale is discussed in Section 4.2 above. Site development to minimise the risk of structural damage from this concentrated form of shrink-swell movement would generally require detection of the feature prior to site clearing, probably by an experienced soil scientist or geotechnical engineer.

The development of a better understanding of the distribution of gilgai soils would suitably be included with the strategy for improvement of local site knowledge detailed in Section 9.

6.3 Assessment of Geotechnical Hazard Associated with Spring Activity

The presence of permanent and intermittent spring activity associated with Tertiary basalt and sedimentary sequences is described in Section 5. The approximate (and possibly inaccurate) definition of lithological boundaries is also noted.

It is considered that principal hazards associated with spring activity are related to:

* the risk of destabilisation of cut soil slopes by erosion and saturation of principally Tertiary sands;

* the risk of creep movement or slippage in cut rock slopes along water softened planes of weakness principally in claystones and relict lateritic layers of high clay content;

* the softening of road subgrade or building foundations within or downslope of the spring line resulting in bearing capacity failure or unacceptably high settlements.

As permanent springs are generally obvious during site selection and development, it is considered that intermittent springs, which may not be easily identified during dry periods, pose the greatest hazard to development. Accordingly, proposed subdivisions or developments on areas of likely basalt flows or Tertiary sediments should be subject to engineering assessment, in particular where these areas are associated with a slope instability risk category of 'low' or greater.

As part of all site investigation works and preliminary studies it is recommended that assessment of the presence of springs be carried out following the guidelines presented in Table 6.5 below.

TABLE 6.5 - CLASSIFICATION OF SPRING ACTIVITY

RISK CATEGORY	INFORMATION BASE	IMPLICATION FOR DEVELOPMENT
Absent	Where there is no previous history of spring activity and location is not underlain by basalt flows (Tv) or Tertiary alluvium (Ts)	Little or no apparent risk from spring activity. However, geological boundaries are approximate only. There-fore careful observation required during development to confirm absence of alluvial material. Good drainage practices should be employed.
Possibly Present	Where no information exists on whether or not springs are present but site is directly underlain by known basalt flows (Tv) or Tertiary alluvium (Ts).	Initially a moderate risk due to lack of information. Engineering assessment should be employed to confirm or deny presence of springs prior to development and recategorise as absent or present.
Present	Where springs are historically known to exist in locations or are presently evident.	High risk of instability or damage due to spring activity. Development should not proceed unless carefully engineered drainage is employed to reduce risk.

LEGEND: Tv denotes Tertiary basalt flows as denoted on Drawing 13837/1
Ts denotes Tertiary alluvium flows as denoted on Drawing 13837/1

In order to assist in assessment of the presence of springs, Drawing 13837/4 has been produced. Potential spring hazard zones are approximately delineated on this drawing where the approximate boundaries of the basalt flows and the Tertiary alluvium (from Drawing 13837/1) overlap with the approximate slope instability risk categories of 'low' or greater (from Drawing 13837/3).

6.4 Development Induced Risk and Earthworks

6.4.1 General

Some of the risks associated with site development have already been discussed in Section 6.1 as particularly pertinent to sloping sites. In general terms, however, there are risks associated with all forms of earthworks, particularly due to inappropriately battered and/or retained cutting and filling, inadequate compaction of filling, inadequate treatment of subgrade or foundation soils prior to placing of filling or construction of footings, and insufficient if any quality control testing of compaction.

It is recommended that the guidelines presented in AS 3798 (ref 14) be adopted for use in all earthworks development within the City of Armidale. A summary of some of the more critical points is presented in Section 6.4.2 to 6.4.4 below. Some of the guidelines presented below are more stringent and/or more extensive than presented in AS 3798 and should be adopted as being more appropriate to local conditions. Reference is made, where appropriate, to specific clauses of AS 3798 (ref 14).

6.4.2 Site Preparation

(a) Topsoil Stripping - The area on which any filling is to be placed should be stripped of all vegetation and any highly organic or soft wet topsoil (refer Clause 6.1.5 of AS 3798).

(b) Slope Preparation - Where proposed filling is to abut against sloping ground steeper than 8 horizontal to 1 vertical, benches should be cut in excess of 100 mm deep to prevent the development of continuous low shear strength surfaces (refer Clause 6.1.6 of AS 3798). All cut benches should also conform either to cut batter requirements of Table 6.6 below for level ground, or the information presented in Section 6.1 above for sloping terrain.

(c) Foundation Preparation - Where springs or seepages are present in the foundation area they should be allowed for in the design and appropriate drainage measures taken (refer Clause 6.1.7 of AS 3798).

(d) Test Rolling - All foundation soils which are to have filling placed over them should be test rolled after stripping and slope or foundation preparation and any soft spots detected removed to an appropriate depth as determined by a suitably qualified engineer. It may be advantageous in some cases to consider use of a geofabric or a bridging layer of coarse granular material under engineering advice. Test rolling should be carried out using either a smooth steel wheeled roller, pneumatic tyred roller or ballasted highway truck (refer Clause 5.4 of AS 3798).

(e) Groundwater - Rolling to achieve compaction is likely to be difficult if there is a shallow groundwater table. Problems can occur if excavation is undertaken too close to the water table which may rise in wet weather conditions. Excavation should not be carried out closer than generally 1 m to the water table unless special arrangements are made to control groundwater during excavation and any subsequent construction and backfilling.

6.4.3 Stability of Excavations

Guidelines are presented in Table 6.6 below (for initial planning purposes only) for suitable batters in level ground (very low slope instability risk as defined in Table 6.1 and 6.2 and Drawing 13837/3) at which excavations may be cut for longterm stability against shearing failure. They are subject to inspection by an appropriately qualified engineer.

TABLE 6.6 - SAFE BATTER CUTS FOR LONGTERM STABILITY

STRATUM TYPE	MAXIMUM SLOPE HEIGHT (m)	BATTER CUT (H:V)
Sand	less than 3	2:1
Clay (at least stiff or better	less than 2	1.5:1
Very low strength or low strength fractured rock	Less than 4	1:1 (subject to jointing and bedding dip)
Medium strength, slightly fractured rock	less than 4	0.25:1 (subject to jointing and bedding dip)

The values in Table 6.6 apply to situations where there is horizontal ground above and below the cut and **do not** apply to cuts in long slopes. Similarly they **do not** apply to situations where groundwater is apparent on the cut face.

If maintenance of vegetation is required, then soil slopes may require to be no steeper than 5H to 1V (to enable lawn mower equipment to operate) in accordance with Council's existing standards.

Stiff clay in Table 6.6 is defined as having an undrained shear strength of greater than 50 kPa when measured by a suitably qualified person.

Rock strength terms and fracture spacings are defined in Figure 6.2 below.

The batter slopes presented for rock may not be appropriate where bedding is dipping downslope or where extensive joints or discontinuities are present.

6.4.4 Filling

(a) Compaction of Filling - Minimum relative compaction values are recommended for earthworks filling in Table 6.7 below.

TABLE 6.7 - MINIMUM COMPACTION VALUES

	COHESIVE SOILS	GRANULAR SOILS
Form filling	Light rolling	Light rolling
Light floor load support Residential construction	95% standard	97% standard or 65% density index
Heavy floor load support Commercial construction	98% standard	100% standard or 75% density index
Footing Support	100% standard	97% modified or 80% density index
Road embankments >500 mm below subgrade	95% standard	97% standard or 65% density index
Top 500 mm	100% standard	100% standard or 80% density index
Concrete Floor Subbase		95% modified
Road base - subbase - basecourse		95% modified 98% modified

In the above, light floor loadings are considered as not in excess of 20 kPa on average for slabs, 100 kPa for strip or pad footings, and applicable to free standing single storey and some double storey houses. For commercial developments, engineering assessment should be made of the bearing capacity and deformation of filling prior to adoption of the above and whether or not the minimum relative compaction requires to be increased.

The minimum relative compaction values stated above refer to AS 1289 (ref 7) as follows:

Standard Compaction - test method E1.1 or E1.2
Modified Compaction - test method E2.1 or E2.2
Density Index - test method E6.1

The values presented in Table 6.7 above are the same as, but in a few cases slightly higher than, those presented in AS 3798 (ref 14). It is considered that they are more appropriate for local conditions (refer also Clauses 5.1 to 5.6, 6.2.2 and 6.2.4 of AS 3798).

(b) Filling Moisture Content - It is recommended that all structural cohesive soil filling (ie. filling, other than form filling, beneath buildings and roads as presented in Table 6.6 above) be placed and compacted at a moisture content within the range of OMC - 2% to OMC + 2%, where OMC is the optimum moisture content for standard compaction as determined by test E1.1 or E1.2 of AS 1289 (ref 7). In addition, such filling should not be allowed to become drier than OMC -2% or wetter than OMC + 2%, in between lifts or prior to placing of concrete or pavement materials. This is in order to minimise any possible post-construction shrinkage or swelling (refer also Clause 6.2.3 of AS 3798).

(c) Compaction Adjacent to Retaining Walls - Heavy earthmoving plant and self propelled rollers should not be allowed to operate on cohesive soils close to retaining walls, within the zone of selected compaction indicated in Figure 6.3 below, unless special allowance has been made for such additional loadings by a suitably qualified engineer in the retaining wall design. This is due to the high horizontal forces that can be generated by compaction of clay soils. Within this zone of influence, either lighter equipment should be used (such as 600 mm wide hand controlled rollers, or hand controlled power rammers) or else cohesionless, more readily compactable materials. For all retaining walls greater than 1 m high, guidance on compaction and material types to be used within this zone and on use of drains behind retaining walls should be presented by the developer's engineer at Building Approval submission stage (refer also Clause 6.2.6 of AS 3798).

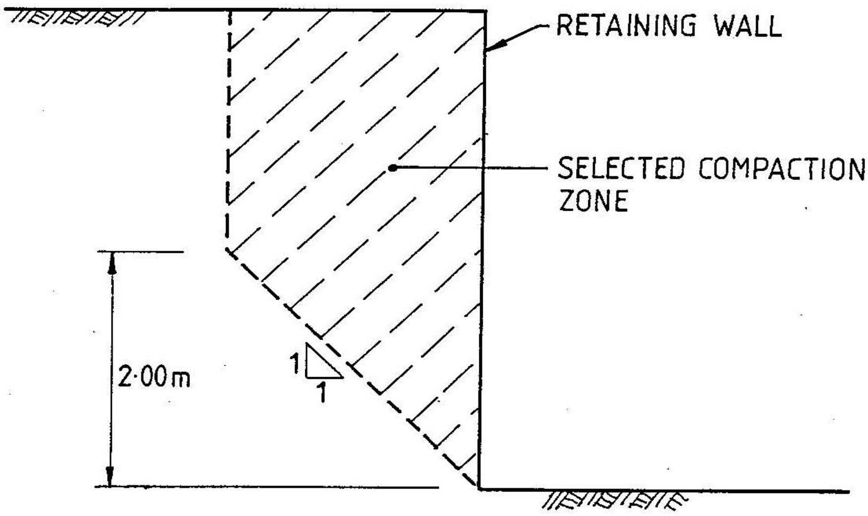


FIGURE 6.3 ZONE REQUIRING SELECTED COMPACTION BEHIND A RETAINING WALL.

7. FOOTING DESIGN

7.1 Residential Footings

After the site is classified in accordance with AS 2870 (ref 11 and 12) it is recommended that the design and construction of footing systems for residential buildings be carried out in accordance with AS 2870.

Part 1 of the code (AS 2870.1) provides design rules for various types of footings in the various soil classes. These are summarised in Table 7.1 below.

Part 2 of the code (AS 2870.2) includes reference to Class P sites (refer Section 6.2 above) and the use of pier and beam, comments on mine subsidence and design for collapsing soil.

TABLE 7.1 - FOOTING TYPES AS APPROPRIATE FOR REACTIVE SOILS (from AS 2870)

CLASSIFICATION	APPLICABLE FOOTINGS FOR VARIOUS CONSTRUCTIONS
A	SOG, FS, PF & ST footing designs given for all building types.
S	As above.
M	SR, WR, SSD, PFR, STR, PBS, & PS suitable for clad frame and articulated masonry veneer and masonry veneer; SR, PBS, PS & STR only for articulated masonry; SR, PBS & PS for full masonry.
H	SR, PBS, PS, STR & WR suitable for clad frame and articulated masonry veneer; SR, PBS, PS & WR for masonry veneer; VR, PBS & PS for articulated masonry; no system prescribed for full masonry.
E	Refer Section 5 of Code.
P	Design by engineering principles.

LEGEND:
SOG - slab on ground
FS - footing slab
PF(R) - pad footing (reactive soil)
SR(R) - strip footing (reactive soil)
ST - stiffened raft
WR - waffle raft
SSD - slab with deep edge beam
PBS - pier & beam/pier & slab
PS - piled system

7.2 Commercial and Industrial Buildings

Where reactive soils are encountered on commercial and industrial building sites, AS 2870 is not applicable for design and construction of footing systems.

For most industrial sites and many commercial sites (e.g. shopping centres), the whole site is paved. Thus, there may be some initial adjustment if the soils at the time of construction are not close to their equilibrium value, but seasonal movements should otherwise be negligible. However, if there is extensive landscaping without other protection, significant problems could occur with shallow footings.

For most situations, the use of 'shallow' footings will be feasible, with depth dependent upon the circumstances. Minimum recommended footing depths are given in Table 7.2 below with distinction between

UPEF - unprotected external footings - generally supporting the external walls, without adjacent paving or possibly with low shrub landscaping adjacent;

PEF - protected external footings - where there is surface paving extending for at least 1.5 m (S or M soils) or 2.5 m (H or E) beyond the building;

IF - internal footings - more than 2 m from the external wall.

TABLE 7.2 - MINIMUM FOOTING DEPTHS

SOIL CLASS	FOOTING TYPE		
	UPEF (m)	PEF (m)	IF (m)
E	1.5	1.0	0.6
H	1.2	0.8	0.5
M	1.0	0.6	0.4
S	0.6	0.4	0.3

As an alternative to strip footings a raft foundation may be preferred, with a 'rat wall' around the perimeter. The depth of the turned down wall (which may or may not be incorporated into the raft) should be the same as for UPEF or PEF footings as appropriate. No wall would be needed with Class S.

8. INFORMATION AND PROCEDURES SUGGESTED FOR COUNCIL APPROVAL

In order to minimise geotechnical related risk associated with development within the City of Armidale, a list of requirements is presented in Table 8.1 below relating to hazard assessment and procedures developed in Section 6 above. It is suggested that these potential hazards be considered by all developers and identified in their submission to Council at the appropriate stage noted.

In general, it is recommended that risk categories be defined by the appropriate persons indicated for slope and springs hazard categories at development approval stage. At building approval stage it is recommended that confirmation be undertaken by the developer that the risk category is still appropriate for slope and springs and that the proposal is in compliance with all requirements for that category. Risk categories for soils (Class based on AS 2870, ref 12 and 13) should be defined at building application stage.

All categorisation of risk, verification of bearing capacity, design of retaining walls and spring stabilising/drainage measures as indicated in Table 8.1 and cross referenced therein, should be provided by a suitably qualified person fully conversant with local conditions.

During earthworks construction and prior to structural erection, additional verification inspection should be performed to confirm that risk categories for soils and springs hazard categories are as assessed at development approval stage.

TABLE 8.1 - GUIDELINES FOR RISK ASSESSMENT AND DEVELOPMENT

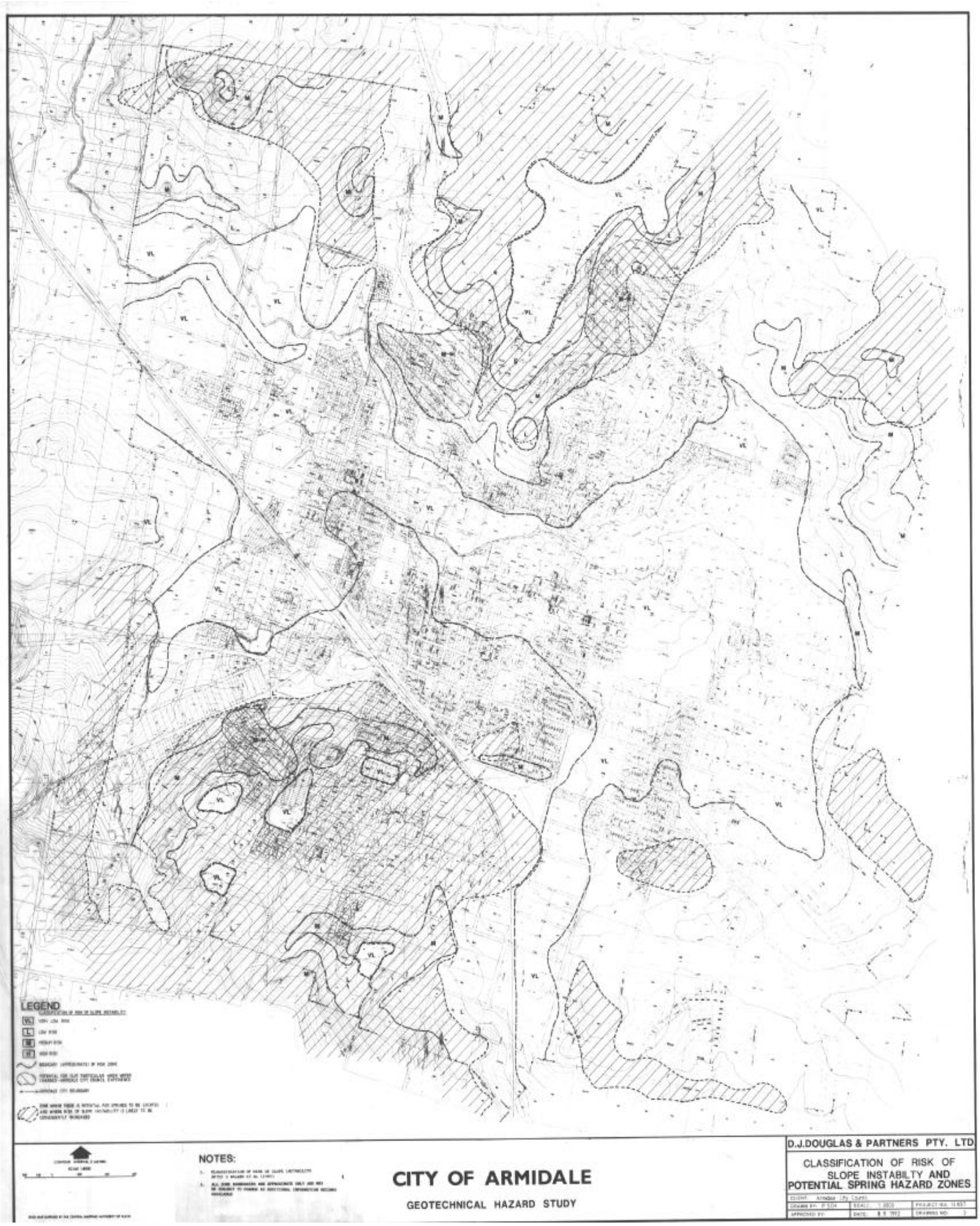
HAZARD CATEGORY	RISK CATEGORIES DEFINED	REQUIREMENTS FOR DEVELOPMENT APPROVAL	REQUIREMENTS FOR ENGINEERING OR BUILDING APPROVAL
SLOPE	Very low, low, medium, high	1. Risk category to be assessed by either of the following: (i) competent person using Drawing 13837/3 (refer also Table 6.1 and 6.2); (ii) competent geotechnical engineer based on the results of field investigation. 2. No development approval to be granted in 'high' risk category or greater unless stability works are to be included as part of proposed development to effectively reduce risk to that of 'low' category or less. Such stability works shall be designed by a competent engineer and based on the results of investigation by a competent geotechnical engineer.	1. Detailed design to conform to good engineering practice as defined in Section 6.1 for all risk categories. 2. For 'medium' risk categories and above (i) all retaining walls greater than 1 m high to be designed by a competent engineer; (ii) all formed slopes greater than 2 m high to have a stability check by a competent engineer, except that for 'high' risk and above the stability check will be performed by a competent geotechnical engineer; (iii) all footings, retention systems and drainage shall be in accordance with Table 6.3 and Figure 6.1 to effectively reduce risk to that of 'low' category or less.
SOILS	Class A, S, M, H, E, P	1. Risk category assessment not required for development approval.	1. Assess risk category (Class) based on AS 2870 (refer Section 6.2 and Table 6.4) for each lot in proposed subdivision. Assessment to be carried out by a competent engineer for all clay soil sites. 2. In all risk categories (Classes) the following applies: (i) detailed design of footings to conform to AS 2870 (refer Section 7.1) for residential development and Section 7.2 for commercial development; (ii) substrata bearing capacity requirements for design to be verified by a competent engineer.
SPRINGS	Absent, Present	1. Competent person to assess whether or not each lot in proposed subdivision is in potential spring hazard zone as indicated in Drawing 13837/4. 2. For lots within the potential spring hazard	1. Where springs are denoted as 'present', by a competent person, engineer or geotechnical engineer, detailed design is to include: (i) suitable engineered measures to stabilise all springs;

TABLE 8.1 - GUIDELINES FOR RISK ASSESSMENT AND DEVELOPMENT (Continued)

HAZARD CATEGORY	RISK CATEGORIES DEFINED	REQUIREMENTS FOR DEVELOPMENT APPROVAL	REQUIREMENTS FOR ENGINEERING OR BUILDING APPROVAL
SPRINGS Continued		zone as indicated in Drawing 13837/4, development approval will only be granted provided either: (i) a report is submitted by a competent engineer or competent geotechnical engineer stating that springs are `absent' or (ii) where springs are denoted as `present', by a competent person, engineer or geo-technical engineer, subdivision design is to include suitable engineered measures to stabilise all springs and protect all existing structures likely to be affected by changes in spring activity brought about by subdivision earthworks.	(ii) suitable engineered measures to protect proposed structures and all existing structures likely to be affected by changes in spring activity brought about by engineering or building.
EARTHWORKS	-	1. Identify all proposed areas of cutting and filling on plan. 2. Where filling is to be undertaken, development approval shall only be granted where full time inspection and testing is to be performed by a NATA registered laboratory (refer AS 3798 Appendix B) to ensure suitability of each lot for footings). 3. All earthworks are to be undertaken in accordance with AS 3798 except where more stringent requirements are presented in Section 6.4 of this study, when the latter will apply.	1. An earthworks specification is to be presented in accordance with Section 6.4 of the text. 2. Ensure all formed slopes are designed in accordance with: (i) Table 6.6 for `very low' slope risk cuts; (ii) Section 6.1, Table 6.3, and Figure 6.1 for `low' slope risk and greater areas of cutting and filling. 3. All earthworks are to be undertaken in accordance with AS 3798 except where more stringent requirements are presented Section 6.4 of this study, when the latter will apply.

NOTE: Drawings 13837/3 and 13837/4 are presented in good faith based on limited information available at time of their preparation.
Where Drawings 13737/3 and 13837/4 are used during assessment of slope and spring risk categories, no liability can be accepted by the Council of the City of Armidale or by DJ Douglas & Partners Pty Ltd for the presence of any higher risk categories than shown on these drawings as may be subsequently proved by engineering investigation.

DRAWING 13837/3



LEGEND
NOTES
CITY OF ARMIDALE
GEOTECHNICAL HAZARD STUDY
D.J.DOUGLAS & PARTNERS PTY. LTD
POTENTIAL SPRING HAZARD ZONES

APPENDIX A

LIST OF REFERENCES

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12. AS 2870.1 "Residential Slabs and Footings - Part 1: Construction", Standards Association of Australia, 1988.

13. AS 2870.2 "Residential Slabs and Footings - Part 2: Guide to Design by Engineering Principles", Standards Association of Australia, 1988.

14. AS 3798 "Guidelines on Earthworks for Commercial and Residential Developments", Standards Association of Australia, 1990.

APPENDIX B

LIST OF PHOTOGRAPHIC PLATES

PLATE 1 - Tertiary sediments exposed in a road cutting in Madgwick Drive, North Armidale, at the proposed intersection with the proposed arterial by-pass.

PLATE 2 - 'Gilgai' formation in black soil near the University of New England.

PLATE 3 - 'Trap Soil' overlying plastic clay near the University of New England.

PLATE 4 - Typical spring formation, Arboretum, adjacent to Kentucky Street (New England Highway).

PLATE 5 - Possible soil creep suggested by minor terracing of steeper slope sections, adjacent to the western end of Ash Tree Drive, North Armidale area. Medium risk (refer Table 6.2 in text).

PLATE 6 - Stream base and adjacent hillslopes north of Gordon Street and west of Chestnut Avenue. Lobate nature of hillslope and deflection of trees suggest the presence of ancient landslip movement. High risk (refer Table 6.2 in text).

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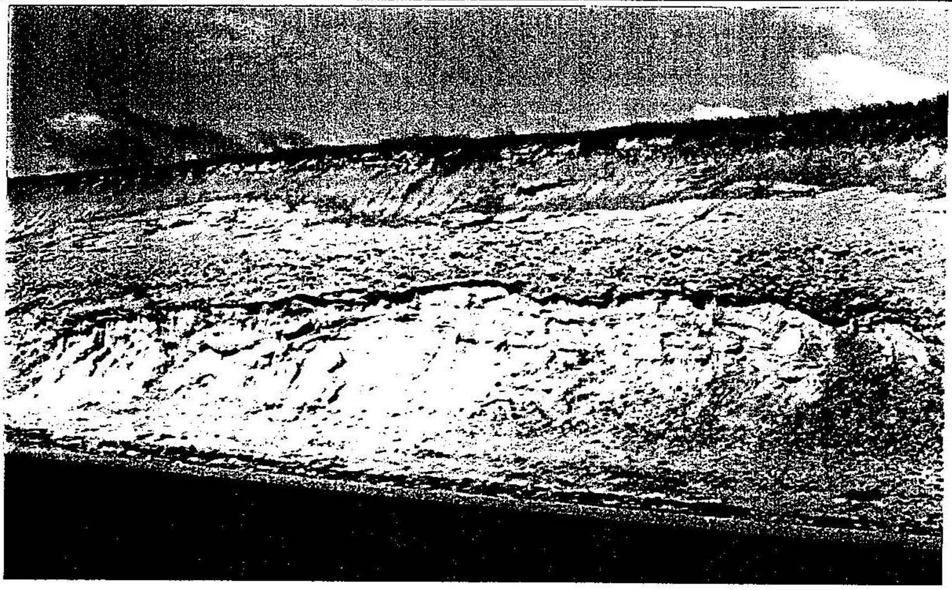
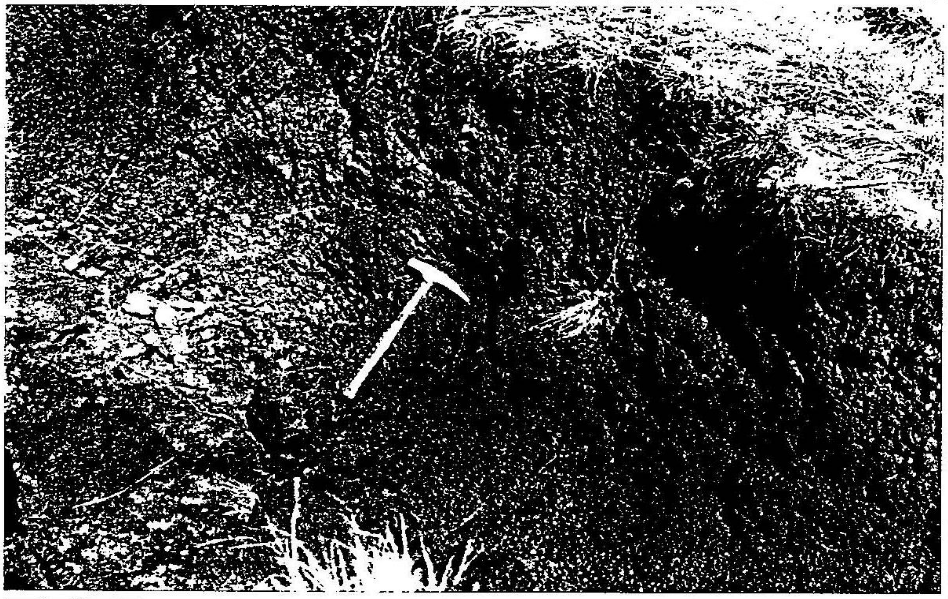
PLATE 1



Tertiary sediments exposed in a road cutting in Madgwick Drive, North Armidale, at the proposed intersection with the proposed arterial by-pass.

PLATE 2



'Gilgai' formation in black soil near the University of New England.

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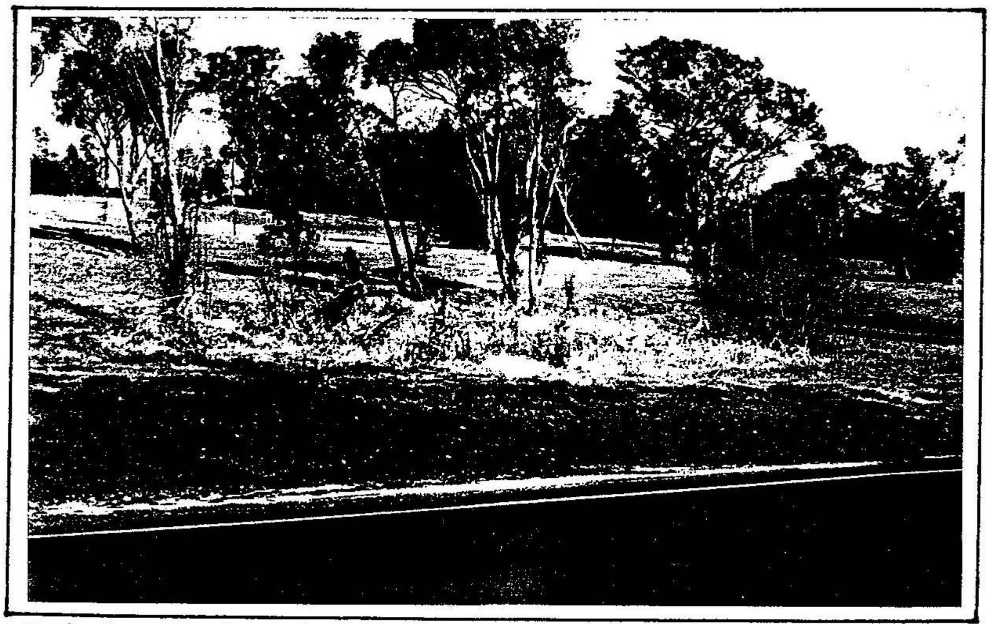
PLATE 3

'Trap Soil' overlying plastic clay near the University of New England.

PLATE 4

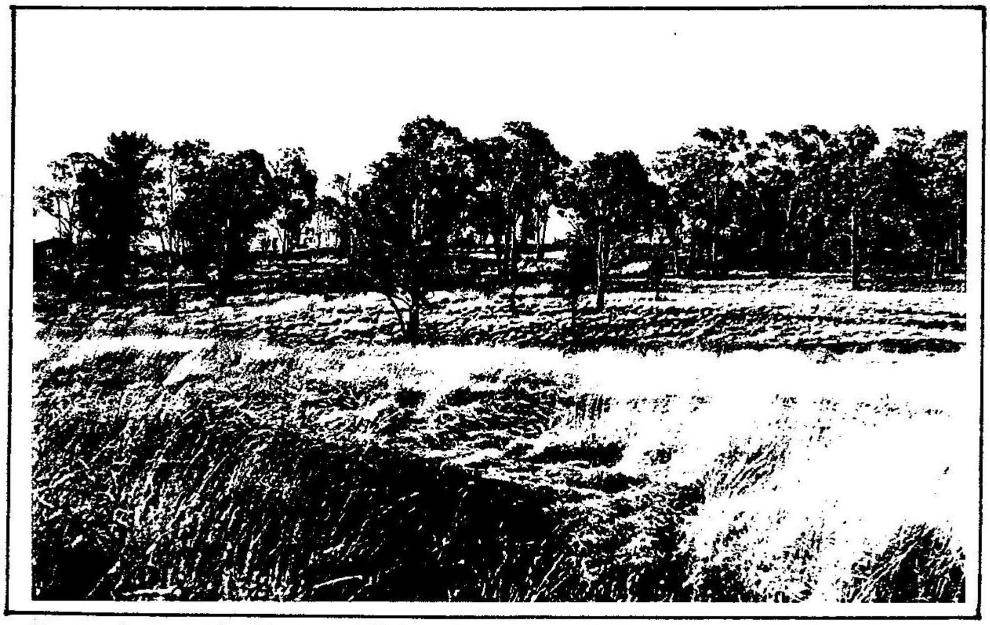


Typical spring formation, Arboretum, adjacent to Kentucky Street (New England Highway).

PLATE 5

Possible soil creep suggested by minor terracing of steeper slope sections, adjacent to the western end of Ash Tree Drive, North Armidale area. Medium risk (refer Table 6.2 in text).

PLATE 6



Stream base and adjacent hillslopes north of Gordon Street and west of Chestnut Avenue, Lobate nature of hillslope and deflection of trees suggest the presence of ancient landslip movement. High risk (refer Table 6.2 in text).

APPENDIX C

GUIDE TO HOME OWNERS ON FOUNDATION MAINTENANCE AND FOOTING PERFORMANCE

DIVISION OF BUILDING, CONSTRUCTION AND ENGINEERING
information service

Sheet No. 10-91
Revised November 1988

Note: This is a revision of CSIRO Division of Building Research Information Sheet No. 10-91. (The Division of Building Research is now incorporated as part of the Division of Building, Construction and Engineering.)

GUIDE TO HOME OWNERS ON FOUNDATION MAINTENANCE AND FOOTING PERFORMANCE (updated for AS 2870-1988)

1. INTRODUCTION

This guide was prepared by Dr P.F. Walsh of CSIRO, with advice from the Standards Australia Committee on Residential Slabs and Footings, to provide guidance to home owners on their responsibilities for the care of a clay foundation, and to discuss the performance that can be expected from a footing system. (The ground that supports a house is called a foundation, and the concrete structure that transfers the load to this foundation is the footing system).

The best information about the design and construction of footing systems is contained in the Australian Standard 'AS 2870 – Residential Slabs and Footings'. That Standard gives a system of site classification, prescribed footing and slab designs and construction methods that provides an excellent footing system for Australian houses. However, a warning is given that the chance of a footing failure is higher if extreme site conditions, such as the following, are permitted to occur.

(a) planting of trees too close to a footing;
(b) excessive watering of gardens adjacent to the house;
(c) lack of maintenance of site drainage; and
(d) failure to repair plumbing leaks.

The Standard further states that compliance with this guide is a way to avoid extreme site conditions.

Clay foundations are the cause of major problems for houses. Clays are very fine-grained soils that are plastic and sticky when wet, and hard and strong when dry. All clays swell or shrink to some degree as they become wet or dry out. 'Reactive' clays swell or shrink to such an extent that foundation movements can damage houses.

All house sites are classified. Reactive-clay sites are classified as M, H, or E, in order of increasing reactivity. Proper maintenance of such clay sites requires that the moisture content of the clay should be kept reasonably constant.

Some minor cracking of masonry walls is almost inevitable despite proper design, construction and maintenance. Very slight cracks up to 1 mm wide could be expected in most houses. Larger cracks, up to 5 mm, may occur in some houses with properly designed and constructed footings, if reactive clay sites have been subject to large changes of moisture. Cracks larger than 5 mm are regarded as significant damage.

Further information on these topics is given in the following sections. The guide has been updated to be consistent with the revised edition of AS 2870 which was published in 1989.

2. SITE CLASSIFICATION

AS 2870 requires all sites to be classified by an engineer or the builder. The emphasis has been placed on reactive clays that swell and shrink with changes of moisture content because these are the most common cause of problems. The classification system is fairly complicated but, as a general guide, the following may be helpful in understanding the system for clay sites.

S Clays that have not given trouble in the past.

M Moderately reactive clays that may cause minor damage to brick houses on old-style light strip footings. Moderately reactive clays are common and occur, for example, in eastern Melbourne and western Sydney.

H Highly reactive clays that often damage houses, paths and fences. Examples occur in northern and western Melbourne and in parts of Adelaide.

E Extremely reactive clays that frequently damage houses even with strong footings. No examples occur in major cities except Adelaide. Other occurrences include outback NSW, Darling Downs and Horsham.

Since the precautions necessary depend on the reactivity of the site, the owner should check the classification that is shown on the house plans.

The maintenance of the building and the site is the responsibility of the owner, and so the owner should be familiar with the requirements of this guide.

3. CARE OF CLAY FOUNDATIONS

All clays move with changes of moisture content, so the aim is to minimise such changes in the clay by

- draining the site;
- keeping gardens and trees away from the house;
- adequate but moderate garden watering; and
- repairing plumbing leaks.

On a reactive-clay site there are some restrictions on the way the owner can develop the garden around the house. These restrictions apply mainly to brick houses. In most cases, only minimal precautions are justified for framed houses clad with timber or sheeting.

The site must be well drained. Under no circumstances should water be allowed to lie against the house or even near the house. The ground immediately next to the

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house should be graded away with a slope of about 50 mm over the first metre. Suitable surface drains should be provided to take the surface water away from the house. Where topsoil is brought in, it should not interfere with the site drainage, nor should it raise the ground level enough to block the weepholes in the brick walls or any subfloor vents.

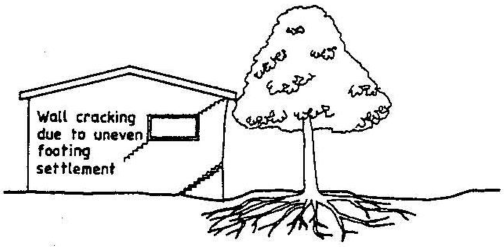
Large garden beds are best not located near the house. This will avoid the possibility of introducing too much moisture to the foundation clay by over watering. The zone near the house should be planned for paths or covered with gravel and plastic sheeting. Small shrubs may be planted at reasonable spacings.

Gardens and lawns should be watered adequately but not excessively. Uniform, consistent watering can be important to prevent damage to the foundation during dry spells such as droughts or dry summers.

Trees and large shrubs require substantial amounts of water, and if the soil near the tree dries out, the roots will extend in search of soil moisture. Tree watering is important in late summer and in drought. The use of slow drip watering systems may be appropriate. It has also been found useful to drill holes near trees and fill them with gravel to allow water better access to the tree roots. Otherwise, clays will shrink as they dry, and a house may settle as shown below.

Removal of large trees creates the opposite problem. As soil moisture is gradually restored, clays swell and may lift shallow footings.

Many factors determine the extent of clay drying by trees, and the more important include the soil type, the size and number of trees, and their species. Trees obtain moisture from roots that spread sideways and the drying zone is influenced by the extent of these roots. For single trees, the drying zone is usually one-half to twice the tree height, but the zone may be larger for groups or rows of trees. Although it is known that the species can influence the extent and severity of the drying zone, little definite information is available. Some Australian trees are particularly efficient in extracting water from very dry soils and can be more dangerous than non-Australian species that use large amounts of water in normal conditions. The effect of tree drying on the amount of movement is also related to the reactivity of the clay. To minimise the risk of damage, trees (especially groups of trees) should not be planted near the house on a reactive clay site, and the following limits are recommended.



TREES CAUSE SHRINKAGE AND DAMAGE

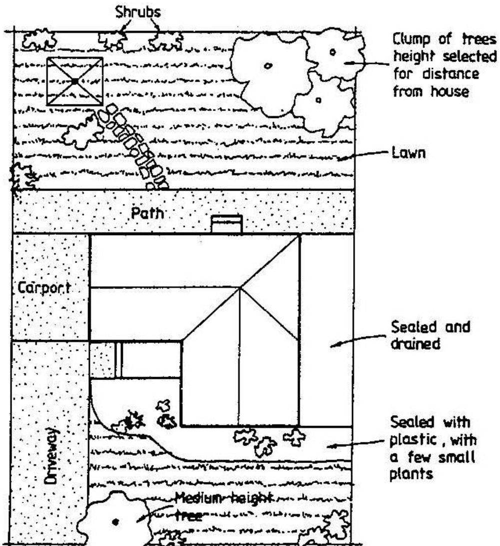
d = 1 1/2 h for Class E sites
d = 1 h for Class H sites
d = 3/4 h for Class M sites

where d is the distance of the tree from the house, and h is the eventual mature height of the tree. These values should be increased by 50% if the trees are in a dense group. These rules mean that on the average suburban block, trees that grow higher than 8 to 9 m are often impractical unless the owner accepts the risk of some damage to the house. If large trees are desired, it may be practical to adopt a specially designed footing system, e.g., a piled footing system.

A leak in the plumbing can cause the footings of a house on a reactive clay to move. The water seeps into the clay causing it to swell and push the footing system upwards. Any obvious leaks in stormwater, drainage, or sewerage pipes should be investigated. Leaking water pipes can be detected by turning off all the taps and checking if the water meter records any flow.

The above restrictions may seem onerous for new home owners, but lack of site maintenance on a reactive clay can cause damage to the house. Still, the whole issue should be kept in some perspective. The damage to houses caused by reactive clays is mostly unsightly cracks in the brickwork. In the typical Australian brick-veneer house, the brickwork does not support the structure. It is the timber frame that carries the walls and roof loads, so brick cracks do not affect the structural safety of the house.

If owners choose to disregard some of the above restrictions and, say, plant large trees all around the house, they should not blame the builder, the engineer, or the Council if the house suffers some cracking.



GARDENS FOR REACTIVE SITES

4. PERFORMANCE OF FOOTING SYSTEMS

All building materials move. Concrete and timber shrink, bricks grow, and so on. Many building practices have been evolved to reduce the damage that such movements cause, and the minor difficulties that arise are usually repaired without significant problems.

The footing of a house is more likely to move on reactive clays. Some house walls may be more sensitive than usual, and may crack even though the footing system has performed its design task. Such cracking must be expected occasionally and this is expressed in the performance requirements of AS 2870 (see Appendix A).

The performance requirement of AS 2870 suggests that Category 0 to 1 damage may be expected for houses on a reactive-clay site, but that the damage is of little consequence. Category 2 is clearly not satisfactory (isolated cracks up to 5 mm wide), but it still does not constitute significant failure and could be expected to occur under adverse conditions for the occasional house.

For these categories of damage, it is the intention of AS 2870 that consequent repairs are part of the normal house maintenance and are therefore the responsibility of the owner.

Nonetheless, to ensure that the damage does not proceed to a more serious state, the owner should take some action.

(a) Check that the recommendations on site treatment, drainage, garden arrangement, trees etc., have been observed.

(b) Keep a record of the crack width against the time of the year. If the damage is as high as Category 2 and seems to be increasing, the owner should consult the builder who may be able to offer more specific advice. If this does not prove satisfactory, the owner should engage a consulting engineer who specialises in house footings.

(c) Engage a plumber to check for leaks if this is suspected to be the cause.

(d) Replace soil mositure in dry spells by watering. Such watering can be more effective if holes or trenches are dug into the clay. The holes or trenches should be filled with compacted crushed rock or gravel and moderately watered. Some trees may need to be removed or kept pruned.

Complete stability is difficult to achieve, so repairs to damaged walls should include methods that will disguise further movements. Extra joints should be included in external masonry walls and further cracking in internal walls can be concealed by flexible paints, wall paper, or panelling. Repairing of cracks with brittle fillers should be avoided unless the cracks have stabilised.

For the more serious categories of damage, the steps to be taken are similar, except that there should be little delay in seeking advice. Remedial action for significant failure may still only include attention to stabilising moisture conditions as described above, but could also involve constructing a concrete wall in the ground to stop drying of the foundation clay. Underpinning is usually not satisfactory in reactive clays.

Experience indicates that lack of maintenance is responsible for many failures. Even with proper design and site maintenance the occasional failure may still occur because footing behaviour is so complex.

5. SHRINKAGE OF CONCRETE FLOORS

Concrete needs water. Firstly to allow the fresh concrete to flow and, secondly, to develop strength during its first few weeks. As a slab starts to dry, it shrinks and tries to contract. Some of this movement is restrained or resisted by friction on the bottom of the slab and by the beams in the ground. This restraint causes tension or stretching forces in the slab and these forces are often large enough to crack the slab.

Shrinkage cracking is almost inevitable and does not represent failure. Most owners never notice the cracks because they often do not occur until after the carpets are laid. Cracks under brittle or sensitive floor coverings are of concern but the risk of damage can be reduced by using flexible mortars and glues for fixing slate and tiles, etc. Also it helps to delay installing the floor covering until after the shrinkage has occurred. The length of delay should be at least three months after the slab has started to dry (i.e. from the time the slab is last wet from rain or during construction.

6. ADHESIVE-FIXED FLOOR COVERINGS

A concrete slab takes a long time to dry. For example, under temperate conditions a slab will take about three months to dry. Moisture in the concrete can interfere with the bond or break down the adhesive used to attach floor coverings. However, a range of adhesives is available for various floor coverings and these should perform quite well on slabs that have been allowed to dry sufficiently.

7. CONCLUSION

This guide has been prepared to advise owners on how to care for the foundation of their houses and what to expect from a well-designed footing system. The main concern with foundation maintenance is to prevent the foundation soil becoming too wet or too dry, and a variety of recommendations are given to achieve this.

Additional information may be found in the following reports which are available from their publishers.

CSIRO (1985). 'House Cracking in Drought Periods', CSIRO Australia Information Sheet No. 10-88. Division of Building Research.

Cameron, D.A. and Earl, I. (1982). Trees and Houses: A Question of Function. Cement and Concrete Association, Melbourne.

Martin, K.G., Lewis, R.K., Palmer, R.E. and Walsh, P.F. (1983). Floor Coverings on Concrete Slab-on-ground. CSIRO Australia Division of Building Research Report.

Cameron, D.A. and Walsh, P.F. (1984). Damage to Buildings on Clay Soils. National Trust Technical Bulletin 5.1.

APPENDIX A

(This Appendix forms an integral part of AS 2870-1988)

TABLE A1
CLASSIFICATION OF DAMAGE WITH REFERENCE TO WALLS

Description of typical damage and required repair	Approximate crack width limit (see Note 1)	Category and damage degree (see Note 2)
Hairline cracks.	< 0.1 mm	0 Negligible
Fine cracks which do not need repair.	< 1 mm	1 Very slight
Cracks noticeable but easily filled. Doors and windows stick slightly.	< 5 mm	2 Slight
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 to 15 mm (or a number number of cracks 3 to 5 mm in one group)	3 Moderate
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 (see Note 3), some loss of bearing in beams. Service pipes disrupted.	15 to 25 mm but also depends on number of cracks	4 Severe

TABLE A2
CLASSIFICATION OF DAMAGE WITH REFERENCE TO CONCRETE FLOORS

Description of typical damage	Approximate crack width limit in floor	Change in offset from a 3 m straight edge centred over defect (see Note 5)	Category and degree of damage
Hairline cracks, insignificant movement of slab from level.	< 0.3 mm	< 8 mm	0 Negligible
Fine but noticeable cracks. Slab reasonably level.	< 1.0 mm	< 10 mm	1 Very slight
Distinct cracks. Slab noticeably curved or changed in level.	< 2.0 mm	< 15 mm	2 Slight
Wide cracks. Obvious curvature or change in level.	2 to 4 mm	15 to 25 mm	3 Moderate
Gaps in slab. Disturbing curvature or change in level.	4 to 10 mm	> 25 mm	4 Severe

NOTES:

1. Crack width is only one factor in assessing category of damage and should not be used on its own as a direct measure of that damage.
2. In assessing the degree of damage, account shall be taken of the location in the building or structure where it occurs, and also of the function of the building or structure.
3. Local deviation of slope, from the horizontal or vertical, of more than 1/100 will normally be clearly visible. Overall deviations in excess of 1/150 are undesirable.
4. Account should be taken of the past history of damage in order to assess whether it is stable or likely to increase.
5. The straight edge is centred over the defect, usually a crack, and supported at its ends by equal height spacers. The change in offset is then measured relative to this straight edge.