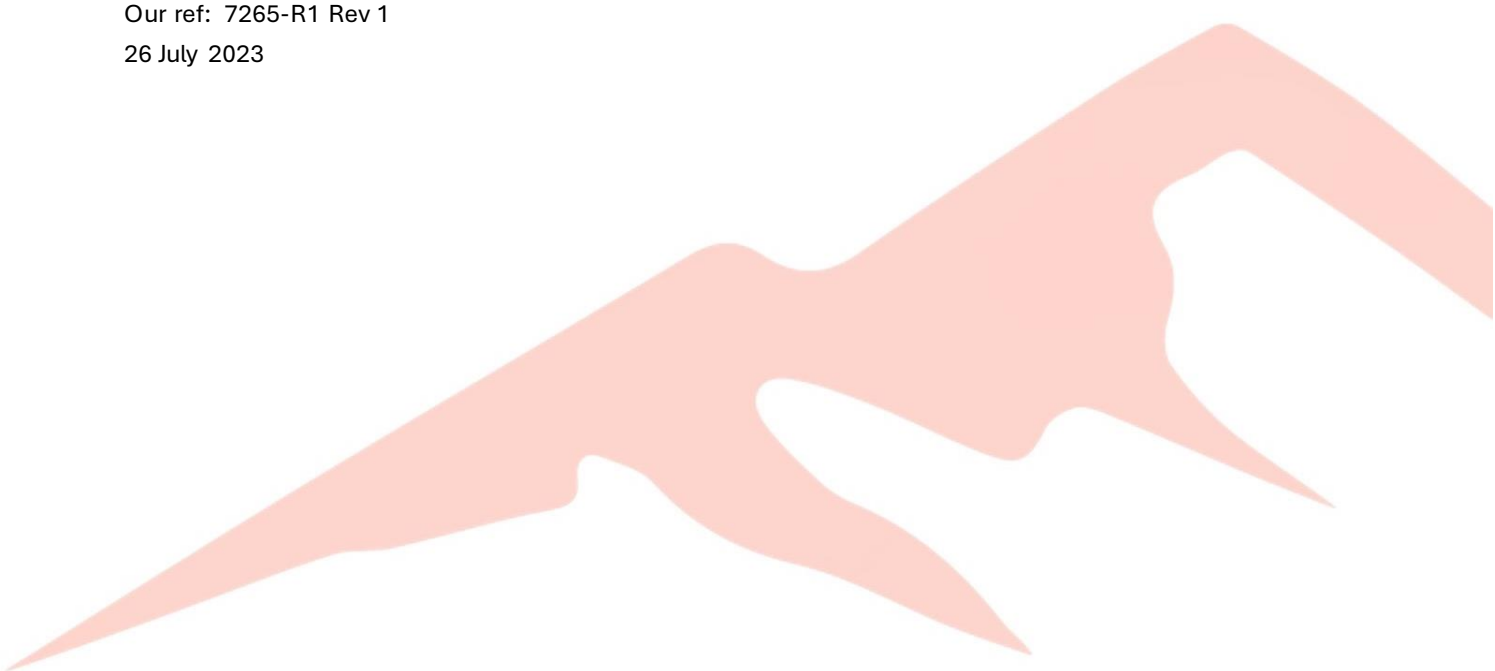
James and Tracey Smail c/o Alexander & Co

Proposed Residential Development
38 Bower Street, Manly NSW

Geotechnical Investigation

Our ref: 7265-R1 Rev 1
26 July 2023



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For and on behalf of
AssetGeoEnviro

Mark Bartel

Mark Bartel
BE, MEngSc, GMQ, CPEng, RPEQ/NER(Civil), DEP/PRE (NSW)
Managing Director | Senior Principal Geotechnical Engineer

Document Control

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1	Secure PDF	Carolin Schmidt	Alexander & Co
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Suite 2.06 / 56 Delhi Road
North Ryde NSW 2113
02 9878 6005
assetgeoenviro.com.au

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1. Introduction

1.1 General

This report presents the results of a geotechnical investigation for a Proposed Residential Development at 38 Bower Street, Manly NSW (the Site). The investigation was commissioned on 7 June 2023 by Carolin Schmidt of Alexander & Co on behalf of James and Tracey Smail. The work was carried out in accordance with the proposal by AssetGeoEnviro (Asset) dated 26 May 2023, reference 7265-P1.

Drawings supplied to us for this investigation comprised:

- Architectural plans (prepared by: Alexander & Co; project: 0567; drawing set issued: 21 July 2023).

Based on the supplied drawings, we understand that the project involves the construction of alterations and additions to an existing house, with a new enlarged garage with new driveway levels, new external staircase, a first-floor extension, and extension to the lower ground floor existing under croft, roof alterations, and landscaping works (drawing reference: 0567-1002-[A] & 0567-1003-[A]).

1.2 Scope of Work

The main objectives of the investigation were to assess the surface and subsurface conditions and to provide comments and recommendations relating to:

- Preliminary slope instability risk appraisal.
- Key geotechnical constraints to the development.
- Excavation conditions, methodology and monitoring.
- Subgrade preparation and earthworks.
- Site Classification to AS2870–2011 "Residential Slabs and Footings".
- Suitable foundation options.
- Allowable bearing pressure for shallow foundation / piles and shaft adhesion
- Groundwater levels and dewatering requirements.
- Underpinning
- Commentary on settlement.

The following scope of work was carried out to achieve the project objectives:

- A review of existing regional maps and reports relevant to the Site held within our files.
- Visual observations of surface features.
- Subsurface investigation at 3 locations to sample and assess the nature and consistency of subsurface soils and bedrock at accessible areas of the Site.
- Drilling and logging of nominally three hand auger boreholes and three Dynamic Cone Penetrometer (DCP) soundings to a depth of up to 2m or refusal, whichever occurs first, to aid with assessment of insitu conditions.
- Engineering assessment and reporting.

This report must be read in conjunction with the attached "Important Information about your Geotechnical Report" and "Important Information about your Landslide Risk Assessment" in Appendix A. Attention is drawn to the limitations inherent in site investigations and the importance of verifying the subsurface conditions inferred herein. Landslide risk considerations presented in this report must be read in conjunction with the attached GeoGuides for Slope Management and Maintenance.

2. Site Description

The Site is located on the northern side of Bower Street as shown in Figure 1. It has a street frontage of about 16.3m wide and is about 53.3m deep, measured approximately at the centre of the site. The Site is bounded to the east and west by residential unit developments and to the north by Marine parade adjoining Shelly Beach. The site is roughly trapezoidal in shape with an approximate total area of 825.3m^2. It is legally registered as Lot 25 in Deposited Plan DP8075.

Topographically, the Site is in flaking slope where the residential building is located while the remaining site is characterised by steep slope transitioning to cliff at the northern boundary of the site. The total elevation change between the Bower St., at southern boundary and Marine Parade is about 24.4m.

At the time of the investigation, the Site was occupied by a four storey, brick rendered residence with a maximum building height of 7.7m. An overview of the existing residence is shown in Photo 1. The area in the vicinity of the residence was generally grassed or gardened with a limited paved area for the existing driveway towards the garage and tiled footpath leading to the house entrance at the front and rear. Based on a visual observation of external building features, the existing dwelling and paving appears to be in overall good condition with no obvious signs of cracking and ground settlement. Exposed sandstone can also be seen at northern port of the site generally loping towards Marine parade. Additional sandstone outcrop is observed at the western side of existing building, which is exposed due to excavation conducted to build the lower ground and ground levels. Evidence of pick/hammer marks is seen on the side of the rock indicating it has been excavated previously to form the current profile. This rock is assessed to be massive and of high strength, assessed as Class 3 Sandstone[1].

The northern part of the site is landscaped following the steep ground profile that transitions to a cliff around the site boundary. Sandstone outcrop was observed throughout the northern sloping ground profile with some areas of the sloping face covered with backfilled soil for landscaping purposes, which are retained by stone walls. It is not known if the stone facing is to an engineered wall or is part of a gravity retaining wall. The stone masonry walls appear to be in fair condition with no obvious sign of rotation or bulging, but no weep holes were observed exiting the wall and drainage condition behind the wall is unknown, and some mortar had deteriorated. On the cliff side (northern part of the site towards Marine Parade), the site is accessible only through the steel stairs. The elevated region between Marine Parade and the site boundary is bounded by masonry retaining wall, which is assessed to be in fair condition.

Site drainage is primarily via overland flow to the north and north-east. Some seepage was observed below the backfill and/or on the surface of the sandstone outcrop.

Medium sized trees are located on the side of Bower Street around the site entrance whereas the northern part of the site is covered with medium sized trees.

[1] Pells, P.J.N., Mostyn, G. & Walker, B.F., Foundations on Sandstone and Shale in the Sydney Region, Australian Geomechanics Journal, December 1998.

3. Fieldwork

The fieldwork was undertaken on 14 June 2023 by a Project Geotechnical Engineer from Asset and included invasive investigation at 3 locations.

The test locations are shown in the attached Figure 2 and were set out by our Geotechnical Engineer by measurements relative to existing site features. Surface levels at the test locations were estimated by interpolation from levels shown on the survey plan provided (prepared by: Alexander & Co; ref: 0567-1002-[A] & 0567-1003-[A] ; dated: 9/06/23).

The invasive investigation included drilling of hand-drilled boreholes and conducting Dynamic Cone Penetrometer (DCP) soundings at 3locations. The boreholes were auger drilled to a maximum depth of 0.9m below ground level (bgl) and were discontinued at the recorded depths due to refusal. The DCP soundings were terminated at depths of 0.4m to 0.7m at 'solid'/'practical' refusal.

The subsurface conditions encountered were logged during drilling and testing. On completion of logging and sampling, the boreholes were backfilled with the drilling spoil.

Engineering logs are provided in Appendix B together with their explanatory notes.

4. Subsurface Conditions

4.1 Geology

The 1:100,000 Sydney Geological Map indicates the Site is underlain by Hawkesbury Sandstone comprising of a medium to coarse-grained quartz sandstone with minor shale and laminate lenses. Small portion of the site may be situated on the adjoining coarse quartz sand with varying amount of shell fragments in the northern boundary.

4.2 Subsurface Conditions

A generalised geotechnical model for the Site has been developed is shown in Table 1. For a detailed description of the subsurface conditions, refer the attached engineering logs and explanatory notes. For specific design input, reference should be made to the logs and/or the specific test results, in place of the following summary.

Table 1 – Generalised Site Geotechnical Model

Unit	Origin	Description	Depth to Top of Unit [1] (m)	Unit Thickness [1] (m)
1a	Fill	Variable material including clayey SAND, sandy CLAY, silty SAND, dark brown, generally moist very loose to medium dense granular material, soft to firm, moist <wp medium plastic cohesive material.	Ground surface	0.3
1b	Fill	SAND and gravelly SAND, dark brown, yellow, dark brown mottled yellow, generally medium dense to dense, moist granular material.	0.3	0.3 to 0.55
2	Bedrock[2]	SANDSTONE, fine to medium grained, extremely weathered, extremely low strength, assessed Class 5 Sandstone or better.	0.6 to 0.85	Not proven beyond a depth of 0.9m

Notes:

1. The depths and unit thicknesses are based on the information from the test locations only and do not necessarily represent the maximum and minimum values across the Site.
2. Rock classification to Pells, P.J.N., Mostyn, G. & Walker, B.F., Foundations on Sandstone and Shale in the Sydney Region, Australian Geomechanics Journal, December 1998.

Special Note for DCP testing

Caution must be used when inferring subsurface conditions from DCP results. Refusal can be encountered on obstructions such as gravel, cemented materials, rock floaters, or other inclusions within a soil mass. DCP testing on soils with a gravel component or cementation can indicate a higher density than actual. Also, the DCP results in clay soils are significantly affected by the in-situ moisture content. It is therefore strongly recommended that an experienced Geotechnical Engineer is engaged to confirm the inferred subsurface conditions during construction and to provide advice where subsurface conditions are significantly different.

4.3 Groundwater

Groundwater was not observed in the boreholes during auger drilling to depths of 0.6m to 0.9m bgl. Minor seepage was observed in the northern rock out crops/cliff area adjoining Marine Parade.

It is noted that the groundwater observation may have been made before water levels had stabilised. No long-term groundwater monitoring was carried out.

5. Discussions & Recommendations

5.1 Key Geotechnical Site Constraints

Key geotechnical constraints to the development include excavation conditions, groundwater control (during construction and long-term), temporary shoring, permanent retaining, foundation conditions, and hazards related to slope instability risk. Recommendations for design and construction of the development are provided in the following sections.

5.2 Landslide Risk

A limited, preliminary level, landslide risk assessment has been carried out for this site, using the methods of AGS 2007[2].

The basis of the preliminary assessment undertaken for this site and important factors relating to slope conditions and the impacts of the development that commonly influence landslide risks are discussed in the attached "Important Information about your Landslide Risk Assessment", and the attached GeoGuides.

The preliminary assessment has been carried out by:

- Consideration of the likely slope failure mechanisms and the likely initiating circumstances that could affect the elements at the Site. The type and mode of landslide failure has also been classified.
- **Risk to Property**. For each case, the likely consequences with respect to future development have been considered. The current assessed probability of occurrence of each event has been estimated on a qualitative basis. The consequences and probability of occurrence have been combined for each case to provide the risk assessment.
- **Risk to Life**. For each case, the risk for the person most at risk is assessed based on multiplying the indicative annual probability of the occurrence of the hazard, the probability of spatial impact, the temporal probability, the vulnerability, and the probability of not evacuating. The risk is then compared with acceptable and tolerable risk criteria.

The following general potential hazards/events are identified for this site and relate to slope instability:

A. Topple of masonry wall adjacent to Marine Parade.
B. Collapse of jointed sandstone pieces within the cliff line at Northern end of the site.
C. Topple of small masonry landscaping retaining walls distributed throughout the site.
D. Slide of fill behind the small landscaping walls.

For the hazards / events identified, the elements of a future development on the Site that are at risk are the proposed dwelling and associated site development comprising services, utilities, and retaining walls. Table A provides our preliminary risk assessment for the Site with respect to risk to property, and Table B provides our preliminary risk assessment for the Site with respect to risk to life.

Erosion of the weaker sandstone units that have weathered to form overhangs is a relatively slow process with rates up to 5mm/year determined in marine environments by previous research (Dragovich. D, Crozier. PJ, and Braybrooke. JC[3]). This rate of weathering would result in up to 0.5m of erosion on the weaker horizons in 100yrs – which will not impact the stability of the site or the proposed residential development over the design life.

[2] Landslide Risk Management, Australian Geomechanics, Vol 42, No. 1, March 2007.

[3] Dragovich. D., 2000. Weathering mechanisms and rates of decay of Sydney Dimension sandstone. Sydney City: Sydney's dimension stone and other sandstone geomaterials. Geol Soc Aust. Springwood.
Crozier. PJ, and Braybrooke. JC, 1992 – The morphology of Northern Sydney's Rocky Headlands, their rates and styles of regression and implications for coastal development, Twenty Sixth Newcastle Symposium on Advances in the Study of the Sydney Basin.

Where development does take into consideration the possible failure mechanisms and adopts the good engineering practice for hillside development, it is envisaged that the outcome of such a development would be a **Low** risk assessed with respect to property and the risk with respect to life would be **Acceptable**. Further geotechnical input is considered essential to ensure that these risk outcomes are achieved.

The existing boundary stone landscaping retaining walls distributed throughout the northern part of the site are assessed to be non-engineered walls. The existing condition of the walls show some deterioration with mortar between sandstone blocks flaking off. Further, no weep holes were observed within the wall and drainage condition behind the wall is unknown. We have assessed the likelihood of those sandstone as ''Possible". However, the risk to property is assessed as "Acceptable" given the distance from the existing dwelling. In terms of the risk to life, since the access to the rear yard is limited to few people leading to low vulnerability and the potential impact of the small retaining (<1m height) is minimal, the risk to life is accessed as "Acceptable" (see Table B). Notwithstanding, we recommend installation of weep holes on sandstone walls to control the seepage and to improve the existing condition of stone retaining wall with respect to potential toppling.

The development should be carried out in accordance with good engineering practice that is described in the attached GeoGuides, and in accordance with the general recommendations in the following sections.

5.3 Earthworks

5.3.1 Excavation

The excavation for the proposed development is anticipated to be partially within soils, and mostly within sandstone bedrock. Excavation within the soils and extremely weathered bedrock would be achievable using conventional earthmoving equipment (i.e., hydraulic excavator bucket) or hand excavation methods.

Excavation within the less weathered bedrock will likely require the use of a hydraulic hammer fitted to an excavator, possibly supplemented by rock saw and rock splitting techniques, or by heavy-duty hand-operated demolition hammers or similar.

5.3.2 Vibration Management

Australian Standard AS 2187: Part 2-2006 recommends the frequency dependent guideline values and assessment methods given in BS 7385 Part 2-1993 "Evaluation and measurement for vibration in buildings Part 2" as they "are applicable to Australian conditions". The standard sets guide values for building vibration based on the lowest vibration levels above which damage has been credibly demonstrated. These levels are judged to give a minimum risk of vibration-induced damage, where the minimal risk for a named effect is usually taken as a 95% probability of no effect.

Sources of vibration that are considered in the standard include demolition, blasting (carried out during mineral extraction or construction excavation), piling, ground treatments (e.g., compaction), construction equipment, tunnelling, road and rail traffic and industrial machinery.

For residential structures, BS 7385 recommends vibration criteria of 7.5 mm/s to 10 mm/s for frequencies between 4 Hz and 15 Hz, and 10 mm/s to 25 mm/s for frequencies between 15 Hz to 40 Hz and above. These values would normally be applicable for new residential structures or residential structures in good

condition. Higher values would normally apply to commercial structures, and more conservative criteria would normally apply to heritage structures.

However, structures can withstand vibration levels significantly higher than those required to maintain comfort for their occupants. Human comfort is therefore likely to be the critical factor in vibration management.

Excavation methods should be adopted which limit ground vibrations at the adjoining developments to not more than 10mm/sec. Vibration monitoring is recommended to verify that this is achieved. However, if the contractor adopts methods and/or equipment in accordance with the recommendations in Table 2 for a ground vibration limit of 5mm/sec, vibration monitoring may not be required.

The limits of 5mm/sec and 10mm/sec are expected to be achievable if rock breaker equipment or other excavation methods are restricted as indicated in Table 2.

Table 2 – Recommendations for Rock Breaking Equipment

Distance from adjoining structure (m)	Maximum Peak Particle Velocity 5mm/sec		Maximum Peak Particle Velocity 10mm/sec*	
	Equipment	Operating Limit (% of Maximum Capacity)	Equipment	Operating Limit (% of Maximum Capacity)
1.5 to 2.5	Hand operated jackhammer only	100	300 kg rock hammer	50
2.5 to 5.0	300 kg rock hammer	50	300 kg rock hammer or 600 kg rock hammer	100 50
5.0 to 10.0	300 kg rock hammer or 600 kg rock hammer	100 50	600 kg rock hammer or 900 kg rock hammer	100 50

* Vibration monitoring is recommended for 10mm/sec vibration limit.

At all times, the excavation equipment must be operated by experienced personnel, per the manufacturer's instructions, and in a manner, consistent with minimising vibration effects.

Use of other techniques (e.g., chemical rock splitting, rock sawing), although less productive, would reduce or possibly eliminate risks of damage to adjoining property through vibration effects transmitted via the ground. Such techniques may be considered if an alternative to rock breaking is necessary. If rock sawing is carried out around excavation boundaries in not less than 1m deep lifts, a 900kg rock hammer could be used at up to 100% maximum operating capacity with an assessed peak particle velocity not exceeding 5 mm/sec, subject to observation and confirmation by a Geotechnical Engineer at the commencement of excavation.

It is pointed out that the rock classification system used in Table 1 is intended primarily for use in the design of foundations and is not intended to be used to directly assess rock excavation characteristics. Excavation contractors should refer to the detailed engineering logs, core photographs, laboratory strength tests, and inspection of rock core, and should not rely solely on the rock classifications presented in geotechnical engineering reports when assessing the suitability of their excavation equipment for the proposed development. Further geotechnical advice must be sought if rock excavation characteristics are critical to the proposed development.

It should be noted that vibrations that are below threshold levels for building damage may be experienced at adjoining developments. Rock excavation methodology should also consider acceptable noise limits as per the "Interim Construction Noise Guideline" (NSW EPA).

5.3.3 Subgrade Preparation

The following general recommendations are provided for subgrade preparation for earthworks, pavements, slab-on-ground construction, and minor structures:

- Strip existing fill and topsoil. Remove unsuitable materials from the Site (e.g., material containing deleterious matter). Stockpile remainder for re-use as landscaping material or remove from site.
- Excavate natural soils and rock, stockpiling for re-use as engineered fill or remove to spoil.
- Where rock is exposed at footing invert level, it should be free of loose, "drummy" and softened material before concrete is poured.
- Where soil is exposed in bulk excavation level, compact the upper 150mm depth to a density index (AS1289.5.6.1–1998) not less than 80%. Areas which show visible heave under compaction equipment should be over-excavated a further 0.3m and replaced with approved fill compacted to a density index not less than 80%.

Any waste soils being removed from the Site must be classified in accordance with current regulatory authority requirements to enable appropriate disposal to an appropriately licensed landfill facility. Asset can provide further advice on this matter if required.

5.3.4 Filling

Where filing is required, place in horizontal layers over prepared subgrade and compact as per Table 3.

Table 3 – Compaction Specifications

Parameter	Cohesive Fill	Non-Cohesive Fill
Fill layer thickness (loose measurement): • Within 1.5m of the rear of retaining walls • Elsewhere	 0.2m 0.3m	 0.2m 0.3m
Density: • Beneath Pavements • Beneath Structures • Upper 150mm of subgrade	 ≥ 95% Std ≥ 98% Std ≥ 100% Std	 ≥ 70% ID ≥ 80% ID ≥ 80% ID
Moisture content during compaction	± 2% of optimum	Moist but not wet

Filling within 1.5m of the rear of any retaining walls should be compacted using lightweight equipment (e.g., hand-operated plate compactor or ride-on compactor not more than 3 tonnes static weight) to limit compaction-induced lateral pressures.

Any soils to be imported onto the Site for backfilling and reinstatement of excavated areas should be free of contamination and deleterious material and should include appropriate validation documentation in accordance with current regulatory authority requirements which confirms its suitability for the proposed land use. Asset can provide further advice on this matter if required.

5.3.5 Batter Slopes

Recommended maximum slopes for permanent and temporary batters are presented in Table 4.

Table 4 – Recommended Maximum Dry Batter Slopes

Unit	Maximum Batter Slope (H : V)	
	Permanent	Temporary
Class 5 Sandstone	1.5 : 1	0.75 : 1
Class 4 (or better) Sandstone	vertical *	vertical *

* Subject to inspection by a Geotechnical Engineer and carrying out remedial works as recommended (e.g., shotcrete, rock bolting).

5.4 Site Classification

Due to the presence of trees, fill, existing site structures (causing abnormal moisture conditions), and potential landslide risk, the Site is classified as a Class P (Problem) Site in accordance with AS 2870–2011 "Residential Slabs and Footings". This requires that footings be designed from first principles, rather than adopting prescriptive designs as per AS2870-2011.

Where the existing fill is removed and replaced with non-reactive engineered fill, or where footings are keyed into the underlying natural sandstone bedrock, then footings may be designed and constructed in accordance with the requirements in AS2870-2011 for a Class A/S/M/H1/H2 site.

Footings should also be designed as per the recommendations in Section 5.6.

The classification and footing recommendations given above and in Section 5.6 are provided on the basis that the performance expectations set out in Appendix B of AS2870–2011 are acceptable and that future site maintenance is in accordance with CSIRO BTF 18, a copy of which is attached.

An experienced Geotechnical Engineer should review footing designs to check that the recommendations of the geotechnical report have been included and should assess footing excavations to confirm the design assumptions.

5.5 Salinity & Aggressivity

Whilst no specific laboratory testing has been carried out to assess the aggressiveness of soil to concrete and steel, based on the subsurface profile as described above and the Site conditions, we consider that the soils would likely be non-saline, mildly aggressive with respect to buried concrete and non-aggressive to buried steel structures. Further testing would be required to confirm this.

5.6 Footings

Suitable footings might comprise strip or pad footings keyed into sandstone bedrock, and may be designed for the parameters in Table 5, which are adopted based on Pells et al[4].

[4] Pells, P.J.N., Mostyn, G., Bertuzzi, R., Wong, P, Classification of Sandstones and Shales in the Sydney Region: A Forty Year Review, Australian Geomechanics Journal, Vol. 54, No. 2, June 2019.

Table 5 – Footing Design Parameters

Founding Stratum	Maximum Allowable (Serviceability) Values (kPa)			Ultimate Strength Limit State Values (kPa)			
	End Bearing	Shaft Friction: Compression #	Shaft Friction: Tension	End Bearing	Shaft Friction: Compression #	Shaft Friction: Tension*	Typical E_{field} MPa
Class 5 Sandstone	700	100	50	2,100	150	75	100
Class 4 Sandstone	1,000	350	175	3,000	250	250	300

Note: Parameters for Class 4/5 Shale provided for strip and pad footings and bored piles only – these should not be used for CFA, CIS, or Steel Screw piles.

* Uplift capacity of piles in tension loading should also be checked for inverted cone pull out mechanism.

Clean socket of roughness category R2 or better is assumed.

An experienced Geotechnical Engineer should review footing designs to check that the recommendations of the geotechnical report have been included and should assess footing excavations to confirm the design assumptions.

5.7 Groundwater Control

Limited groundwater observations made for this investigation are described in Section 4.3. The observations indicate that groundwater is unlikely to be a constraint to the proposed development. However, good practice should be followed to cater for potential groundwater, such as designing retaining walls with adequate subsoil drainage and installation of weep holes. Further geotechnical advice must be sought if significant groundwater is encountered during construction.

5.8 Excavation Support

Excavation of soil and rock results in stress changes in the remaining material and some ground movement is inevitable. The magnitude and extent of lateral and vertical ground movements will depend on the design and construction of the excavation support system. Experience and published data suggest that lateral movements of an adequately designed and installed retention system in soil and weathered rock will typically be in the range of 0.2% to 0.5% of the retained height. The extent of the horizontal movement behind the excavation face typically varies from 1.5 to 3 times the excavated height.

5.8.1 Excavation Support Construction Methodology

Where temporary or permanent batter slopes as per Section 5.3.5 cannot be accommodated in the development or are not desired, temporary shoring and/or permanent retaining will be required.

It is considered likely that temporary excavation batters could be adopted for the Site. Therefore, permanent retaining walls could be constructed without temporary shoring.

5.8.2 Excavation Support Design Parameters

Support system design may be based on the parameters given in Table 6. Cantilever walls or walls with only a single row of anchors/props may be designed for a triangular earth pressure distribution with the lateral pressure being determined as follows:

$\sigma_z = K_{o,a,p} \; z \; \gamma$ where σ_z = lateral earth pressure (kPa) at depth z

$K_{o,a,p}$ = earth pressure coefficient
o = 'at rest', a = 'active', p = 'passive'

z = depth (m)

γ = unit weight of soil / rock (kN/m^3)

Table 6 – Excavation Support Design Parameters

Material	Moist Unit Weight (γ_m) kN/m^3	'Active' Lateral Earth Pressure Coefficient [1] (K_a)	'At Rest' Coefficient [1] (K_o)	'Passive' Coefficient [2] (K_p)
Fill	18.0	0.35	0.5	N/A
Class 5 Sandstone [3]	21.0	0.2	0.4	6
Class 4 Sandstone [3]	22.0	0.1	0.3	15

Notes to table:

1. These values assume that some wall movement and relaxation of horizontal stress will occur due to the excavation. Actual in-situ K_0 values may be higher, particularly in the rock units.
2. Includes a reduction factor to the ultimate value of K_p to consider strain incompatibility between active and passive pressure conditions. Parameters assume horizontal backfill and no back of wall friction.
3. The values for rock assume no adversely dipping joints or other defects are present in the bedrock. All excavation rock faces should be inspected regularly by an experienced Geotechnical Engineer / Engineering Geologist as excavation proceeds.

The parameters for the 'at rest' condition (K_o) should be used for the design of lateral earth pressures where adjacent footings/structures are located within the 'zone of influence' of the wall. The 'zone of influence' may be taken as a line extending upwards and outwards at 45° above horizontal from the base of the wall. Piles for cantilever walls should be socketed below bulk excavation level by a depth at least equal to the retained height. For assessment of passive restraint embedded below excavation level, we recommend a triangular pressure distribution.

5.8.3 Surcharge

Allowance must also be made for surcharge loadings and footing loads from adjacent structures.

5.8.4 Hydrostatic Pressure

Where an adequate subsoil drainage system designed by an appropriately qualified and experienced Hydraulic / Stormwater Engineer is provided behind non-tanked retaining walls, no allowance for hydrostatic pressure would be necessary.

5.9 Potential Impacts on Adjacent Developments

Potential geotechnical risks of construction on adjoining developments could include; vibration effects due to rock excavation and settlement/deflection of adjacent footings due to the basement excavation.

These risks have been discussed in the relevant sections of this report. We assess that if the development is designed and constructed in accordance with the recommendations given in this report, these effects are anticipated to have negligible impact and be within acceptable limits.

6. Limitations

In addition to the limitations inherent in site investigations (refer to the attached Information Sheets), it must be pointed out that the recommendations in this report are based on assessed subsurface conditions from limited investigations. To confirm the assessed soil and rock properties in this report, further investigation would be required such as coring and strength testing of rock and should be carried out if the scale of the development warrants, or if any of the properties are critical to the design, construction, or performance of the development.

It is recommended that a qualified and experienced Geotechnical Engineer be engaged to provide further input and review during the design development; including site visits during construction to verify the Site conditions and provide advice where conditions vary from those assumed in this report. Development of an appropriate inspection and testing plan should be carried out in consultation with the Geotechnical Engineer.

This report may have included geotechnical recommendations for design and construction of temporary works (e.g., temporary batter slopes or temporary shoring of excavations). Such temporary works are expected to perform adequately for a relatively short period only, which could range from a few days (for temporary batter slopes) up to six months (for temporary shoring). This period depends on a range of factors including but not limited to: site geology; groundwater conditions; weather conditions; design criteria; and level of care taken during construction. If there are factors which prevent temporary works from being completed and/or which require temporary works to function for periods longer than originally designed, further advice must be sought from the Geotechnical Engineer and Structural Engineer.

This report and details for the proposed development should be submitted to relevant regulatory authorities that have an interest in the property (e.g., Council) or are responsible for services that may be within or adjacent to the Site (e.g., Sydney Water), for their review.

Asset accepts no liability where our recommendations are not followed or are only partially followed. The document “Important Information about your Geotechnical Report” in Appendix A provides additional information about the uses and limitations of this report.

Landslide Risk Assessment Tables

Table A – Landslide Risk Assessment (Risk to Property)

Table B – Landslide Risk Assessment (Risk to Life)

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Table A - Preliminary Landslide Risk Assessment (Risk to Property)
38 Bower Street, Manly

Possible Hazards			Consequences (Note 2)	Assessed Likelihood	Risk (Note 1)	Risk Treatment and Comments
Failure Envisaged	**Failure Mode**	**Initiating Circumstances**				
A - Topple of wall adjacent to Marine Parade	Topple	`	Minor	Unlikely	Low	No risk treatment necessary.
B - Collapse of overhang	Topple	Erosion, further undercutting, vibration, groundwater affecting	Minor	Unlikely	Low	Seek further advice advice if cliff conditions change.
C - Topple of rock landscaping walls	Slide	Groundwater, cutting and filling	Insignificant	Possible	Low	Recommend installling weep holes.
D - Slide of lanscaping fill on rock	Slide	Ground water, cutting and fill, surcharge	Insignificant	Possible	Low	Recommend installling weep holes.

Notes:

1. The risk assessment addresses only the consequences to property from potential landslide events considered relevant to the subject site. Injury to persons or potential for fatality from land sliding is not assessed in this table (refer Table B). The risk assessment is based on a preliminary appraisal only, carried out by inspection. Further assessment or quantification of the assessed geotechnical risks for the subject property would require additional data and/or investigation.
2. The consequences are for a development that is designed to accomodate the potential landslide risk or has demonstrated adequate performance over many years.
3. Refer to report and associated figures for illustration of possible hazards / slope failure mechanisms.
4. Refer to attachments for definitions and explanations of terms used in the risk assessment.

assetgeoenviro

Table B - Preliminary Landslide Risk Assessment (Risk to Life)
38 Bower Street, Manly

Possible Hazard	Use of Affected Structure	Likelihood	Indicative Annual Probability P (H)	Probability of Spatial Impact P (S:H)	Temporal Probability P (T:S)	Vulner-ability V (D:T)	Probability of becoming Trapped	Risk for Person Most at Risk [Risk Evaluation]	Risk Outcome: A = Acceptable T = Tolerable NT = Not Tolerable
A - Topple of wall adjacent to Marine Parade	Pedestrain road (Marine Parade)	Unlikely	1.0E-04	1.00	0.50	0.05	0.05	1.25E-07	A
B - Collapse of overhang	Rear yard	Unlikely	1.0E-04	0.10	6.90E-04	1.00	1.00	6.90E-09	A
D - Topple of rock landscaping walls	Landscape/Access stairs and walk ways	Possible	1.0E-03	0.75	0.14	0.05	0.05	2.63E-07	A
E - Slide of lanscaping fill on rock	Landscape/Access stairs and walk ways	Possible	1.0E-03	0.75	0.14	0.05	0.05	2.63E-07	A

Notes:

1. The appraisal of the assessed risk relative to acceptable and tolerable risks is based on Table 1 of AGS (2007) – Reference 1, for a new development.
2. Risk mitigation will be required to ensure that the assessed risk outcome during and after the proposed development is acceptable. Referred to report for further details.
3. This table must be read in conunction with Table A.
4. Risk Outcome:
   A = Acceptable ≤ 10-6
   T = Tolerable ≤ 10-5
   NT = Not Tolerable - treatment options to be assessed and implemented
5. Temporal probability for A = 12 hrs per day (0.5), B = 0.5hrs per month (6.9E-4), D = 10 people per day x twice x 10 mins (0.14)

Figures

0 1:1500@A4 50m

APPROXIMATE ONLY – SUBJECT TO DETAIL SURVEY.

SOURCE: SIX MAPS

THIS DRAWING IS USED TO ILLUSTRATE SITE LOCATION ONLY, AND MUST NOT BE USED FOR ANY OTHER PURPOSE. COPYRIGHT OF SOURCE DRAWING REMAINS WITH SIX MAPS.

issue	date	description
A	16.06.23	INITIAL ISSUE

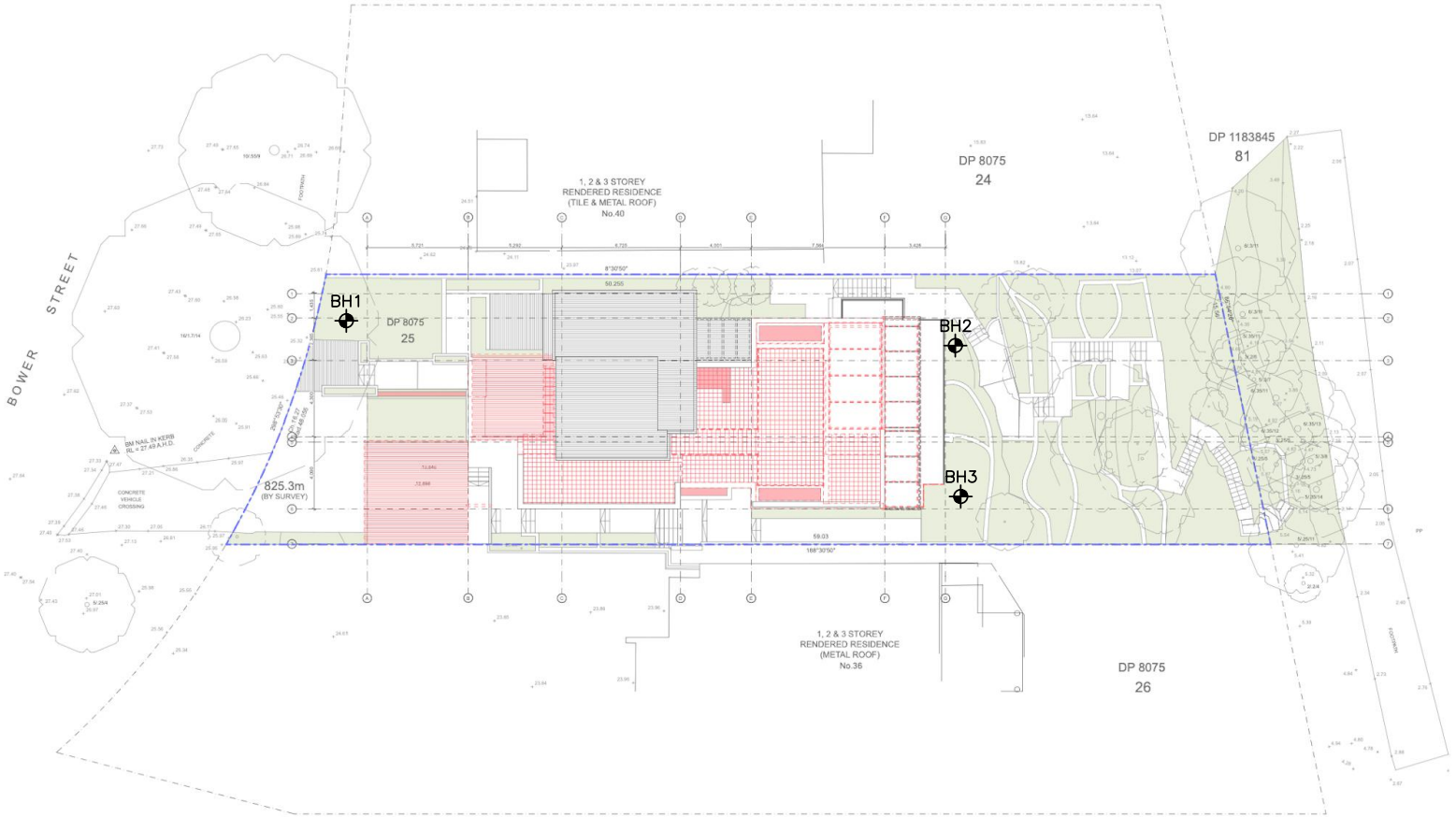
assetgeoenviro
2.06/56 Delhi Rd
North Ryde NSW 2113
t: 02 9878 6005
e: info@assetgeoenviro.com.au

Proposed Residential Development
38 Bower Street,
Manly NSW
for
James and Tracey Smail
c/– Alexander & Co

SITE LOCALITY

drawn: AS
date: 16.06.2023
checked: MAB
scale: 1:1500 A4

job no.: 7265
fig: 1
issue: A



APPROXIMATE ONLY – SUBJECT TO DETAIL SURVEY.

SOURCE: Site Plan (Existing & Demolition) (PREPARED BY: Alexander & Co.; REF: 0567–1002–A; DATED: 9/6/2023).

LEGEND

Borehole

0 1: 400 25m

issue	date	description
A	16.06.23	INITIAL ISSUE

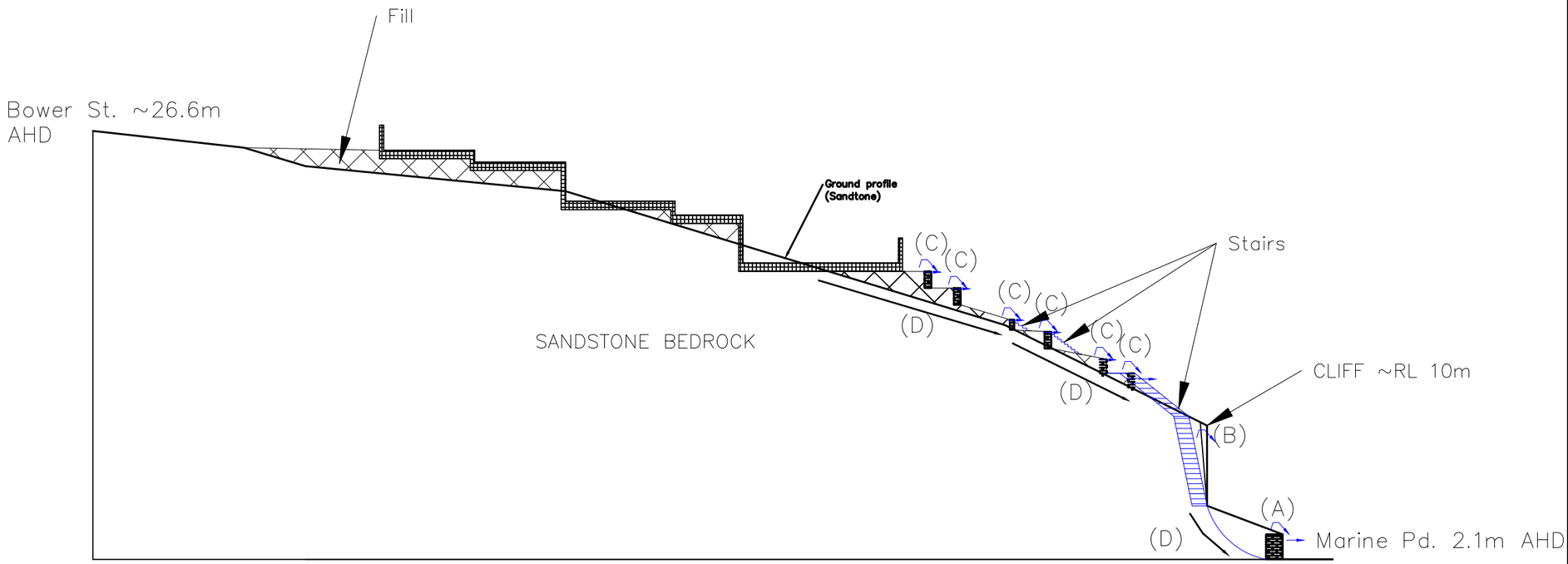
assetgeoenviro
2.06/56 Delhi Rd
North Ryde NSW 2113
t: 02 9878 6005
e: info@assetgeoenviro.com.au

Proposed Residential Development
38 Bower Street,
Manly NSW
for
James and Tracey Smail
c/– Alexander & Co

TEST LOCATIONS

drawn: AS
date: 16.06.2023
checked: MAB
scale: 1:400 A4

job no.: 7265
fig: 2
issue: A



	Type	Failure Mode
(A)	Masonry/stone wall	Sliding & Overturning
(B)	Sandstone cliff	Wedge failure
(C)	Small wall	Sliding & Overturning
(D)	Sliding of fill	Translation & rotational

Approximate only – subject to detail survey.

Source: "Alexander & Co;ref: 0567–1002–[A] & 0567–1003–[A] ; dated: xxx9/06/23"
This drawing is used to illustrate general cross section for landslide risk assessment and must not be used for any other purpose.

0 1:400 A3 25m

issue	date	description
A	11.07.23	Initial issue

assetgeoenviro
2.06/56 Delhi Rd
North Ryde NSW 2113
t: 02 9878 6005
e: info@assetgeoenviro.com.au

Proposed Residential Development
Address: 38 Bower St. Manly
for
Client: James and Tracey Smail c/o Alexander & Co

Site cross–section

drawn: AT
date: 11.07.23
checked: MAB
scale: 1:400 A3

job no.: 7265
fig: 3
issue: A

Appendix A

Important Information about your Geotechnical Report
Important Information about your Landslide Risk Assessment
GeoGuides (pp1-17)
CSIRO BTF 18

Important Information about your Geotechnical Report

Scope of Services

The geotechnical report ("the report") has been prepared in accordance with the scope of services as set out in the contract, or as otherwise agreed, between the Client and Asset Geotechnical Engineering Pty Ltd ("Asset"), for the specific site investigated. The scope of work may have been limited by a range of factors such as time, budget, access and/or site disturbance constraints.

The report should not be used if there have been changes to the project, without first consulting with Asset to assess if the report's recommendations are still valid. Asset does not accept responsibility for problems that occur due to project changes if they are not consulted.

Reliance on Data

Asset has relied on data provided by the Client and other individuals and organizations, to prepare the report. Such data may include surveys, analyses, designs, maps, and plans. Asset has not verified the accuracy or completeness of the data except as stated in the report. To the extent that the statements, opinions, facts, information, conclusions and/or recommendations ("conclusions") are based in whole or part on the data, Asset will not be liable in relation to incorrect conclusions should any data, information or condition be incorrect or have been concealed, withheld, misrepresented, or otherwise not fully disclosed to Asset.

Geotechnical Engineering

Geotechnical engineering is based extensively on judgment and opinion. It is far less exact than other engineering disciplines. Geotechnical engineering reports are prepared for a specific client, for a specific project and to meet specific needs, and may not be adequate for other clients or other purposes (e.g., a report prepared for a consulting civil engineer may not be adequate for a construction contractor). The report should not be used for other than its intended purpose without seeking additional geotechnical advice. Also, unless further geotechnical advice is obtained, the report cannot be used where the nature and/or details of the proposed development are changed.

Limitations of Site Investigation

The investigation program undertaken is a professional estimate of the scope of investigation required to provide a general profile of subsurface conditions. The data derived from the site investigation program and subsequent laboratory testing are extrapolated across the site to form an inferred geological model, and an engineering opinion is rendered about overall subsurface conditions and their likely behavior regarding the proposed development. Despite investigation, the actual conditions at the site might differ from those inferred to exist, since no subsurface exploration program, no matter how comprehensive, can reveal all subsurface details and anomalies.

The engineering logs are the subjective interpretation of subsurface conditions at a particular location and time, made by trained personnel. The actual interface between materials may be more gradual or abrupt than a report indicates.

Therefore, the recommendations in the report can only be regarded as preliminary. Asset should be retained during the project implementation to assess if the report's recommendations are valid and whether changes should be considered as the project proceeds.

Subsurface Conditions are Time Dependent

Subsurface conditions can be modified by changing natural forces or man-made influences. The report is based on conditions that existed at the time of subsurface exploration. Construction operations adjacent to the site, and natural events such as floods, or ground water fluctuations, may also affect subsurface conditions, and thus the continuing adequacy of a geotechnical report. Asset should be kept appraised of any such events and should be consulted to determine if any additional tests are necessary.

Verification of Site Conditions

Where ground conditions encountered at the site differ significantly from those anticipated in the report, either due to natural variability of subsurface conditions or construction activities, it is a condition of the report that Asset be notified of any variations and be provided with an opportunity to review the recommendations of this report. Recognition of change of soil and rock conditions requires experience, and it is recommended that a suitably experienced geotechnical engineer be engaged to visit the site with sufficient frequency to detect if conditions have changed significantly.

Reproduction of Reports

 Where information from the accompanying report is to be included in contract documents or engineering specification for the project, the entire report should be included to minimize the likelihood of misinterpretation from logs.

Report for Benefit of Client

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

Data Must Not Be Separated from The Report

The report presents the site assessment and must not be copied in part or altered in any way.

Logs, figures, drawings, test results etc. included in our reports are developed by professionals based on their interpretation of field logs (assembled by field personnel) and laboratory evaluation of field samples. These data should not under any circumstances be redrawn for inclusion in other documents or separated from the report in any way.

Report Recommendations not Followed

Where the recommendations of the report are not followed or are only partially followed, there may be significant implications for the project (e.g., commercial loss, property loss or damage, personal injury, or loss of life). Consult Asset if you are not intending to follow all the report recommendations, to assess what the implications could be. Asset does not accept responsibility where the report recommendations have not been followed or have only been partially followed.

Other Limitations

Asset will not be liable to update or revise the report to consider any events or emergent circumstances or fact occurring or becoming apparent after the date of the report.

Important Information about your Landslide Risk Assessment

BASIS OF THE ASSESSMENT

Our assessment of the stability of the land is presented in the framework of Landslide Risk Management (Australian Geomechanics Society, Vol 42, No 1, March 2007). The attached GeoGuides provide further information on landslide risk management and maintenance.

This assessment is based on a visual inspection of the property and also the immediate adjoining land. Limited subsurface investigation may also have been undertaken as part of this appraisal. Slope monitoring has not been carried out within or adjacent to the property for the purpose of this appraisal. The opinions expressed in this report also take into account our relevant local experience.

The property is within an area where landslip and/or subsidence have occurred, or where there is a risk of landslide. Important factors relating to slope conditions and the impact of development which commonly influence the landslide risks are discussed herein.

An owner's decision to acquire, develop or build on land within an area such as this involves the understanding and acceptance of a level of risk. It is important to recognise that soil and rock movements are an ongoing geological process, which may be affected by development and land management within the site or on ad- joining land. Soil and rock movements may cause visible damage to structures even where the risk of slope failure is considered low. This report is intended only to assess the landslide risk apparent at the time of inspection.

Our opinion is provided on the present landslide risk for the land specifically referenced in the title to this report. Foundations suitable for future building development are discussed in relation to slope stability considerations. Limited foundation advice may be provided. If so, advice is intended to guide the footing design for the proposed development. However, this report is not intended as, is not suitable for, and must not be used in lieu of a detailed foundation investigation for final design and costing of foundations, retaining walls or associated structures.

LIMITATIONS OF THE ASSESSMENT PROCEDURE

The assessment procedures carried out for this appraisal are in accordance with the recommendations in Landslide Risk Management (Australian Geomechanics Society, Vol 42, No 1, March 2007), and with accepted local practice.

The following limitations must be acknowledged:

- the assessment of the stability of natural slopes requires a great degree of judgment and personal experience, even for experienced practitioners with good local knowledge;
- the assessment must be based on development of a sound geological model; slope processes and process rates influencing land sliding or landslide potential will vary according to geomorphologic influences;
- the likelihood that land sliding may occur on a given slope is generally hard to predict and is associated with significant uncertainties;
- different practitioners may produce different assessments of risk;
- actual risk of land sliding cannot be determined; risk changes with time;
- consequences of land sliding need to be considered in a rational framework of risk acceptance;
- acceptable risk in relation to damage to property from landslide activity is subjective; it remains the responsibility of the owner and/or local authority to decide whether the risk is acceptable; the geotechnical practitioner can assist with this judgment;
- the extent and methods of investigation for assessment of landslide risk will be governed by experience, by the perceived risk level, and by the degree to which the risk or consequences of land sliding are accepted for a specific project;
- the assessment may be required at a number of stages of the project or development; frequently (due to time or budget constraints imposed by the client) there will be no opportunity for long-term monitoring of the slope behaviour or groundwater conditions, or for on-going opportunity for the slope processes and performance of structures to be reviewed during and after development; such limitations should be recognised as relevant to the assessment.

DEVELOPMENT ON SLOPES

Some risk of slope instability is always attached to the development of land on slopes.

Guidelines for hillside construction and examples of good practices for hillside developments are described in the attached GeoGuides.

THE AUSTRALIAN GEOGUIDES FOR SLOPE MANAGEMENT AND MAINTENANCE

AGS Landslide Taskforce, Slope Management and Maintenance Working Group

The Australian Geomechanics Society (AGS) presents on the following pages a guideline on slope management and maintenance, as part of the landslide risk management guidelines developed under the National Disaster Funding Program (NDMP). This Guideline is aimed at home owners, developers and local councils, but also has applicability to a larger audience which includes builders and contractors, consultants, insurers, lawyers, government departments and in fact any person, or organisation, with a responsibility for the management or maintenance of a slope. The objective is to inform those with little or no knowledge of geotechnical engineering about landslides.

Each GeoGuide is a stand-alone document, which is formatted so that it can be printed on two sides of a single A4 sheet. It is expected that the set of GeoGuides will increase with time to cover a range of topics. As things stand:

- **GeoGuide LR1** is an introductory sheet that should be read by all users, since it explains what the LR (landslide risk) series is about and defines terms.
- **GeoGuides LR2, 3 and 4** explain why landslides occur and provide information on different types of landslide.
- **GeoGuide LR5** discusses the critical part that water often plays in relation to landslide occurrence and discusses measures that can be adopted to limit its effect.
- **GeoGuide LR6** refers to retaining walls and their maintenance.
- **GeoGuide LR7** puts the concept of landslide risk into an everyday context, so users can relate a particular landslide risk to other risks that they know they are prepared to take, sometimes on a daily basis.
- **GeoGuide LR8** retains the ideas of good and poor hillside construction practice originally provided by an AGS sub-committee in 1985.
- **GeoGuide LR9** concentrates specifically on effluent and surface water disposal, which is an important topic in some development areas.
- **GeoGuide LR10** is specifically aimed at those who have property on the coast and could be susceptible to coastal erosion processes.
- **GeoGuide LR11** provides information about the benefits of keeping records on inspection and maintenance activities and provides a proforma record sheet for users.

It is recognised that the GeoGuides are likely to be upgraded from time to time. Feedback on use and suggested changes should be sent to the National Chair of the Australian Geomechanics Society. The latest versions of the GeoGuides will be downloadable from the AGS website www.australiangemechanics.org

Through the NDMP, Australian governments (at Commonwealth, State and Local Government levels) are also funding the development of a Landslide Zoning Guideline (AGS 2007a), and a Practice Note Guideline (AGS 2007c) to which interested readers seeking in-depth information should refer.

ACKNOWLEDGEMENTS

These guidelines have been prepared by The Australian Geomechanics Society with funding from the National Disaster Mitigation Program, the Sydney Coastal Councils Group, and The Australian Geomechanics Society.

The Australian Geomechanics Society established a Working Group within a Landslide Taskforce to develop the guidelines. The development of the guidelines was managed by a Steering Committee. Membership of the Working Group, Taskforce and Steering Committee is listed in the Appendix.

Drafts of these GeoGuides have been subject to review by members of the AGS Landslide Taskforce, members of the geotechnical profession and local government.

REFERENCES

AGS (2007a) Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Management. Australian Geomechanics Society, *Australian Geomechanics*, Vol 42, No1.

AGS (2007c). Practice Note Guidelines for Landslide Risk Management. Australian Geomechanics Society. *Australian Geomechanics*, Vol 42, No1,

AGS (2007e). The Australian GeoGuides for slope management and maintenance –. Australian Geomechanics Society. *Australian Geomechanics*, Vol 42, No 1, - this paper.

AUSTRALIAN GEOGUIDE LR1 (INTRODUCTION)

INTRODUCTION TO LANDSLIDE RISK

Photographs courtesy of Greg Kotze and Tony Phillips

AUSTRALIAN GEOGUIDES

The **Australian GeoGuides (LR series)** are a set of information sheets on the subject of landslide risk management and maintenance, published by the Australian Geomechanics Society (AGS). They provide background information intended to help people without specialist technical knowledge understand the basic issues involved. Topics covered include:

LR1 - Introduction	LR2 - Landslides	LR3 - Landslides in Soil
LR4 - Landslides in Rock	LR5 - Water & Drainage	LR6 - Retaining Walls
LR7 - Landslide Risk	LR8 - Hillside Construction	LR9 - Effluent & Surface Water Disposal
LR10 - Coastal Landslides	LR11 - Record Keeping	

The GeoGuides explain why slopes and retaining structures can be a hazard and what can be done with appropriate professional advice and local authority approval (if required) to remove, or reduce, the risk they represent.

Preparation of the GeoGuides has been funded by Australian governments through the National Disaster Mitigation Program (NDMP). This is a national program aimed at identifying and addressing natural disaster risk priorities across Australia. Technical input has been provided by experienced geotechnical engineers, engineering geologists and local government and government agency representatives from around Australia.

BACKGROUND

A number of landslides and cliff collapses occurred in Australia in the 1980's and 1990's in which lives were lost. Of these the Thredbo landslide probably received the most publicity, but there were several others. During this period the AGS issued a number of advisory notes to practitioners in relation to the assessment of landslide risk and its reduction. Building on these notes, and responding to changes in technology, a technical paper known as AGS2000 was prepared. It was followed in 2002 by an intensive nation-wide educational campaign attended by a large number of interested professionals from government departments and private industry. This resulted in an increased awareness of the risks associated with unstable slopes and a changed approach in many government departments responsible for regional planning, domestic development, roads, railways and the maintenance of natural features such as cliffs.

STATUS OF THE GEOGUIDES

The GeoGuides reflect the essence of good practice as perceived by a large number of geotechnical engineers, engineering geologists and other practitioners such as local government planners. **The GeoGuides are generic and do not, and cannot, constitute advice in relation to a specific situation. This must be sought from a geotechnical practitioner with first hand knowledge of the site.** It is expected that some local councils will refer to the GeoGuides and their companion publications in planning and building legislation. Check with your local council to see how it regards these documents. Companion publications to the GeoGuides are:

- AGS (2007a) Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Management Australian Geomechanics Society, *Australian Geomechanics*, Vol 42, No1 and its associated commentary (AGS 2007b).
- AGS (2007c). Practice Note Guidelines for Landslide Risk Management. Australian Geomechanics Society. *Australian Geomechanics*, Vol 42, No1 2007, and its associated "Commentary" (AGS 2007d).

Copies of the above documents are available on the AGS website www.australiangeomechanics.org

TERMINOLOGY

Terminology tends to change with time and place and with the context in which it is used. The terms listed below have the following meanings in the GeoGuides:

Consequence	the outcome, or potential outcome, arising from the occurrence of a landslide expressed quantitatively, or qualitatively, in terms of loss, disadvantage, damage, injury, or loss of life.
Discontinuity	in relation to the ground is a crack, a bedding plane (a boundary between strata) or fault (a plane along which the ground has sheared) which forms a plane of weakness and reduces the overall strength of the ground.
Equilibrium	the condition when the forces on a mass of soil or rock in the ground, or on a retaining structure, are equal and opposite.
Factor of safety (FOS)	theoretically the forces available to prevent a part of the ground, or a retaining structure, from moving divided by those trying to move it. A FOS of one or less indicates that failure is likely to occur, but not how likely it is. To allow for unknowns and to limit movements engineers always aim to achieve a FOS significantly larger than one.
Failure	when part of the ground experiences movement as a result of the out of balance forces on it. Failure of a retaining structure means it is no longer able to fulfil its intended function.
Geotechnical practitioner	when referred to in the Australian GeoGuides (LR series), is a professional geotechnical engineer, or engineering geologist, with chartered status in a recognised national professional institution and relevant training, experience and core competencies in landslide risk assessment and management. In some government departments, technical officers are specifically trained to undertake some of the functions of a geotechnical practitioner.
Hazard	a condition with the potential for causing an undesirable consequence. In relation to landslides this includes the location, size, speed, distance of travel and the likelihood of its occurrence within a given period of time.
Landslide	the movement, or the potential movement, of a mass of rock, debris, or earth down a slope.
Likelihood	a qualitative description of probability, or frequency, of occurrence.
Partial saturation	the condition in the ground above the water table where both air and water are present as well as soil, or rock.
Perched water table	a water table above the true water table supported by a low permeability stratum.
Permeability	a measure of the ability of the ground to allow water to flow through it.
Risk	a measure of the probability and severity of an adverse effect to life, health, property or the environment.
Slip failure	landslide.
Stable	the condition when failure will not occur. Over geological time no part of the ground can be considered stable. Over short periods (eg the life of a structure) stability implies a very low likelihood of failure.
Retaining structure	anything built by humans which is intended to support the ground and inhibit failure.
Structure	in relation to rock, or soil, means the spacing, extent, orientation and type of discontinuities found in the ground at a particular location.
Tension crack	a distinct open crack that normally develops in the ground around a landslide and indicates actual, or imminent , failure.
Water table	the level in the ground below which it is saturated and the voids are filled with water.

Photograph courtesy of Phil Flentje

AUSTRALIAN GEOGUIDE LR2 (LANDSLIDES)

LANDSLIDES

What is a Landslide?

Any movement of a mass of rock, debris, or earth, down a slope, constitutes a “landslide”. Landslides take many forms, some of which are illustrated. More information can be obtained from Geoscience Australia, or by visiting its Australian Landslide Database at www.ga.gov.au/urban/factsheets/landslide.jsp. Aspects of the impact of landslides on buildings are dealt with in the book "Guideline Document Landslide Hazards" published by the Australian Building Codes Board and referenced in the Building Code of Australia. This document can be purchased over the internet at the Australian Building Codes Board's website www.abcb.gov.au .

Landslides vary in size. They can be small and localised or very large, sometimes extending for kilometres and involving millions of tonnes of soil or rock. It is important to realise that even a 1 cubic metre boulder of soil, or rock, weighs at least 2 tonnes. If it falls, or slides, it is large enough to kill a person, crush a car, or cause serious structural damage to a house. The material in a landslide may travel downhill well beyond the point where the failure first occurred, leaving destruction in its wake. It may also leave an unstable slope in the ground behind it, which has the potential to fail again, causing the landslide to extend (regress) uphill, or expand sideways. For all these reasons, both "potential" and "actual" landslides must be taken very seriously. They present a real threat to life and property and require proper management.

Identification of landslide risk is a complex task and must be undertaken by a geotechnical practitioner (GeoGuide LR1) with specialist experience in slope stability assessment and slope stabilisation.

What Causes a Landslide?

Landslides occur as a result of local geological and groundwater conditions, but can be exacerbated by inappropriate development (GeoGuide LR8), exceptional weather, earthquakes and other factors. Some slopes and cliffs never seem to change, but are actually on the verge of failing. Others, often moderate slopes (Table 1), move continuously, but so slowly that it is not apparent to a casual observer. In both cases, small changes in conditions can trigger a landslide with serious consequences. Wetting up of the ground (which may involve a rise in ground water table) is the single most important cause of landslides (GeoGuide LR5). This is why they often occur during, or soon after, heavy rain. Inappropriate development often results in small scale landslides which are very expensive in human terms because of the proximity of housing and people.

Does a Landslide Affect You?

Any slope, cliff, cutting, or fill embankment may be a hazard which has the potential to impact on people, property, roads and services. Some tell-tale signs that might indicate that a landslide is occurring are listed below:

- open cracks, or steps, along contours
- ground water seepage, or springs
- bulging in the lower part of the slope
- hummocky ground
- trees leaning down slope, or with exposed roots
- debris/fallen rocks at the foot of a cliff
- tilted power poles, or fences
- cracked or distorted structures

These indications of instability may be seen on almost any slope and are not necessarily confined to the steeper ones (Table 1). Advice should be sought from a geotechnical practitioner if any of them are observed. Landslides do not respect property boundaries. As mentioned above they can "run-out" from above, "regress" from below, or expand sideways, so a landslide hazard affecting your property may actually exist on someone else's land.

Local councils are usually aware of slope instability problems within their jurisdiction and often have specific development and maintenance requirements. **Your local council is the first place to make enquiries if you are responsible for any sort of development or own or occupy property on or near sloping land or a cliff.**

TABLE 1 - Slope Descriptions

Appearance	Slope Angle	Maximum Gradient	Slope Characteristics
Gentle	0°- 10°	1 on 6	Easy walking.
Moderate	10°- 18°	1 on 3	Walkable. Can drive and m anoeuvre a car on driveway
Steep	18°- 27°	1 on 2	Walkable with effort. Possible to drive straight up or down roughened concrete driveway, but cannot practically manoeuvre a car.
Very Steep	27°- 45°	1 on 1	Can only climb slope by cl utching at vegetation, rocks etc.
Extreme	45°- 64°	1 on 0.5	Need rope access to climb slope
Cliff	64°- 84°	1 on 0.1	Appears vertical. Can absei l down.
Vertical or Overhang	84°- 90±°	Infinite	Appears to o verhang. Abseiler likely to lose contact with the face.

Some typical landslides which could affect residential housing are illustrated below:

AUSTRALIAN GEOGUIDE LR2 (LANDSLIDES)

Rotational or circular slip failures (Figure 1) - can occur on moderate to very steep soil and weathered rock slopes (Table 1). The sliding surface of the moving mass tends to be deep seated. Tension cracks may open at the top of the slope and bulging may occur at the toe. The ground may move in discrete "steps" separated by long periods without movement. More rapid movement may occur after heavy rain.

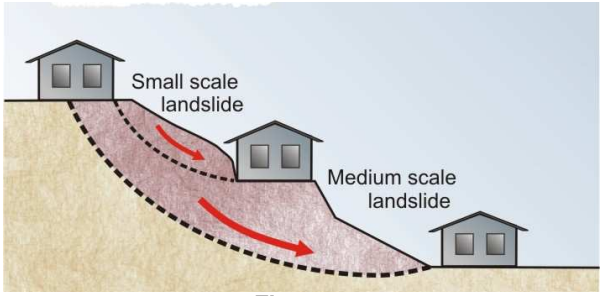


Figure 1

Translational slip failures (Figure 2) - tend to occur on moderate to very steep slopes (Table 1) where soil, or weak rock, overlies stronger strata. The sliding mass is often relatively shallow. It can move, or deform slowly (creep) over long periods of time. Extensive linear cracks and hummocks sometimes form along the contours. The sliding mass may accelerate after heavy rain.

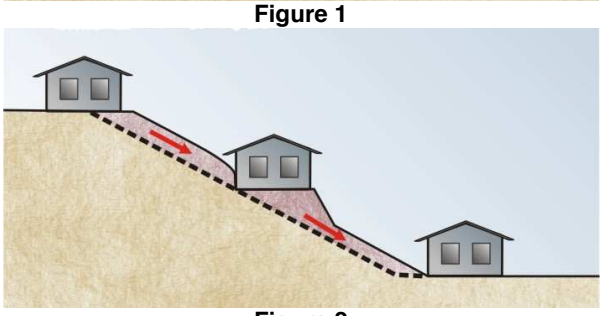


Figure 2

Wedge failures (Figure 3) - normally only occur on extreme slopes, or cliffs (Table 1), where discontinuities in the rock are inclined steeply downwards out of the face.

Rock falls (Figure 3) - tend to occur from cliffs and overhangs (Table 1).

Cliffs may remain apparently unchanged for hundreds of years. Collections of boulders at the foot of a cliff may indicate that rock falls are ongoing. Wedge failures and rock falls do not "creep". Familiarity with a particular local situation can instil a false sense of security since failure, when it occurs, is usually sudden and catastrophic.

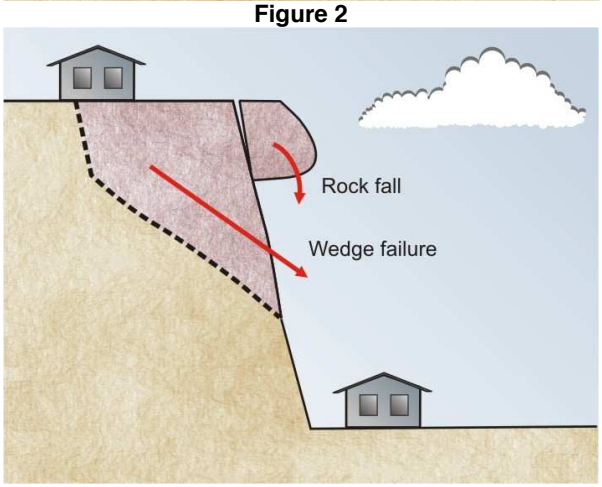


Figure 3

Debris flows and mud slides (Figure 4) - may occur in the foothills of ranges, where erosion has formed valleys which slope down to the plains below. The valley bottoms are often lined with loose eroded material (debris) which can "flow" if it becomes saturated during and after heavy rain. Debris flows are likely to occur with little warning; they travel a long way and often involve large volumes of soil. The consequences can be devastating.

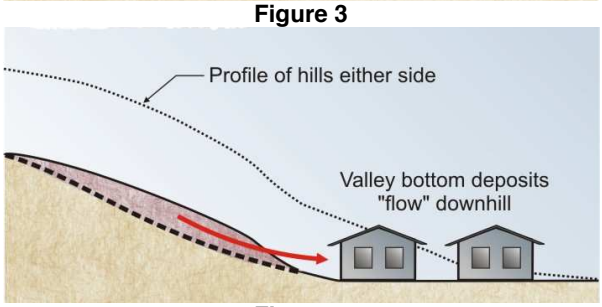


Figure 4

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

- GeoGuide LR1 - Introduction
- GeoGuide LR3 - Soil Slopes
- GeoGuide LR4 - Rock Slopes
- GeoGuide LR5 - Water & Drainage
- GeoGuide LR6 - Retaining Walls
- GeoGuide LR7 - Landslide Risk
- GeoGuide LR8 - Hillside Construction
- GeoGuide LR9 - Effluent & Surface Water Disposal
- GeoGuide LR10 - Coastal Landslides
- GeoGuide LR11 - Record Keeping

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LANDSLIDES IN SOIL

Landslides occur on soil slopes and the consequences can include damage to property and loss of life. Soil slopes exist in all parts of Australia and can even occur in places where rock outcrops can be seen on the surface. If you live on, or below, a soil slope it is important to understand why a landslide might occur and what you can do to reduce the risk it presents.

It is always worth asking the question *"why is this slope here?"*, because the answer often leads to an understanding of what might happen in the future. Slopes are usually formed by weathering (breakdown) and erosion (physical movement) of the natural ground - the "parent material". Many factors are involved including rain, wind, chemical change, temperature variation, plant growth, animal activity and our own human enthusiasm for development. The general process is outlined in Figure 1.

The upper levels of the parent material progressively weather over thousands, or millions, of years, losing strength. This can result in a surface layer which looks similar to the parent material (although its colour has probably changed) but has the strength of a soil - this is called "residual soil". At some stage the weathered surface layer is exposed to the elements and fragments are transported down the slope. In this context a fragment could be a single sand grain, a boulder, or a landslide. The time scale could be anything from a few seconds to many thousands of years. The transported fragments often collect on the lower slopes and form a new soil layer that blankets the original slope - "colluvium". If material reaches a river or the sea it is deposited as "alluvium" or as a "marine deposit". With appropriate changes in river and sea level this material can again find itself on the surface to commence another cycle of weathering and erosion. In places often, but not only, near the coast, this can include sand sized fragments which form beaches and are sometimes blown back onto the land to form dunes.

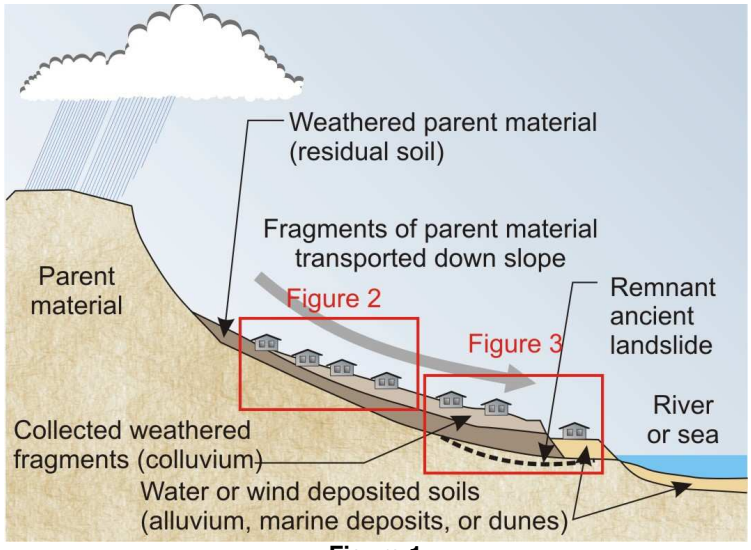

Figure 1

Landslides can occur almost anywhere on a soil slope. Slides can be rotational, translational, or debris flows (see GeoGuide LR2) and may have a number of causes.

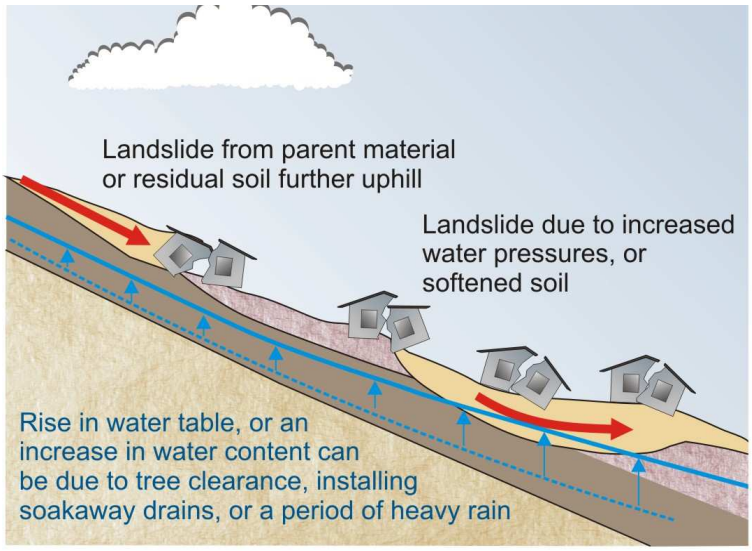

Figure 2

AUSTRALIAN GEOGUIDE LR3 (LANDSLIDES IN SOIL)

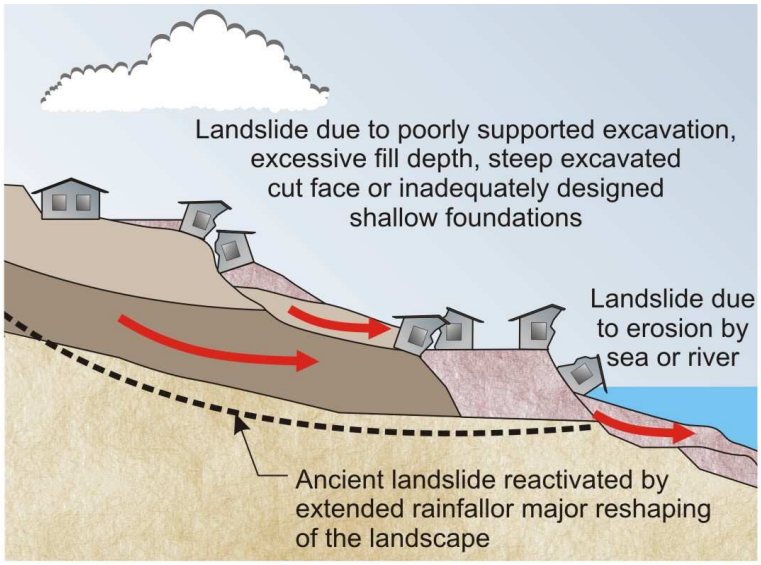

Figure 3

Some of the more common causes of landslides in soil are:

1) Falls of the parent material or residual soil from above, due to natural weathering processes (Figure 2).
2) Increased moisture content and consequent softening of the soil, or a rise in the water table. These can be due to excessive tree clearance, ill-considered soak-away drainage or septic systems, or heavy rainfall (Figure 2).
3) Excavation without adequate support, increased surface load from fill placement, or inadequately designed shallow foundations (Figure 3).
4) Natural erosion at the toe of the slope due to scour by a river or the sea (Figure 3).
5) Re-activation of an ancient landslide (Figure 3).

Most soil slopes appear stable, but they all achieved their present shape through a process of weathering and erosion and are often sensitive to minor changes in the factors that affect their stability. As a general rule, human activities only improve the situation if they have been designed to do so. Once this idea is understood, it is probably easy to see why the following basic rules are so important and should not be ignored without seeking site specific advice from a geotechnical practitioner:

- Do not clear trees unnecessarily.
- Do not cut into a slope without supporting the excavated face with an engineer designed structure.
- Do not add weight to a slope by placing earth fill or constructing buildings with inadequately designed shallow foundations (Note: in certain circumstances weight is added to the toe of a slope to inhibit landslide movement, but this must be carried out in accordance with a proper engineering design).
- Do not allow water from storm water drains, or from septic waste or effluent disposal systems to soak into the ground where it could trigger a landslide.

More information in relation to good and poor hillside construction practice is given in GeoGuide LR8. With appropriate engineering input it is often possible to reduce the likelihood, or consequences, of a landslide and so reduce the risk to property and to life. Such measures can include the construction of properly designed storm water and sub-soil drains, surface protection (GeoGuide LR5) and retaining walls (GeoGuide LR6). **Design should be undertaken by a geotechnical practitioner and will normally require local council approval.**

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

- GeoGuide LR1 - Introduction
- GeoGuide LR2 - Landslides
- GeoGuide LR4 - Landslides in Rock
- GeoGuide LR5 - Water & Drainage
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LANDSLIDES IN ROCK

Rocks have been formed by many different geological processes and may have been subjected to intense pressure, large scale distortion, extreme temperature and chemical change. As a result there are many different rock types and their condition varies enormously. Rock strength varies and is often significantly reduced by the presence of discontinuities (GeoGuide LR1). You may think that rock lasts forever, but in reality it weathers under the combined effects of water, wind, chemical change, temperature variation, plant growth and animal activity and erodes with time. Rock is often the parent material that ends up forming soil slopes (GeoGuide LR3). Inevitably different rocks have different physical and chemical characteristics and they weather and erode to form different types of soil.

Weathering can lead to landslides (GeoGuide LR2) on rock slopes. The type of landslide depends on the nature of rock, the way it has weathered and the presence or absence of discontinuities. It is hard to generalise, though normally a specific combination of discontinuities and material types will be the determining factor and these are often underground and out of sight. Typical examples are provided in the figures 1 to 4. A geotechnical practitioner can assess the landslide risk and propose appropriate maintenance measures. This often entails making geological observations over an area significantly larger than the site and a review of available background information, including records of known landslides and aerial photographs. Depending on the amount of information available, geotechnical investigation may or may not be needed. Every site is different and every site has to be assessed individually.

It is impossible to predict exactly when a landslide will occur on a rock slope, but failure is normally sudden and the consequences can be catastrophic.

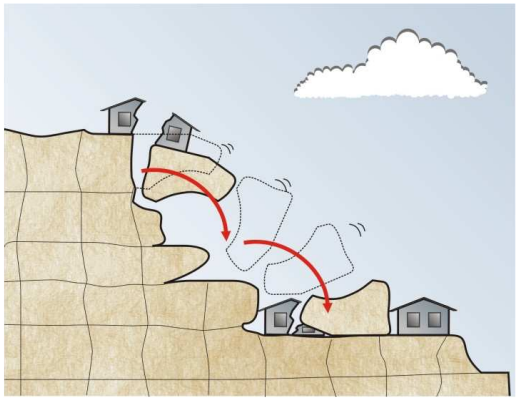

Figure 1 - Failure of an undercut block

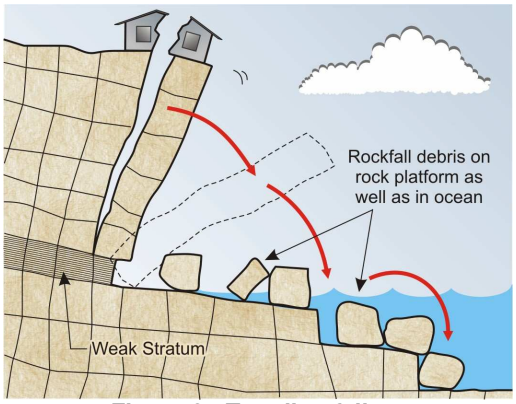

Figure 2 - Toppling failure

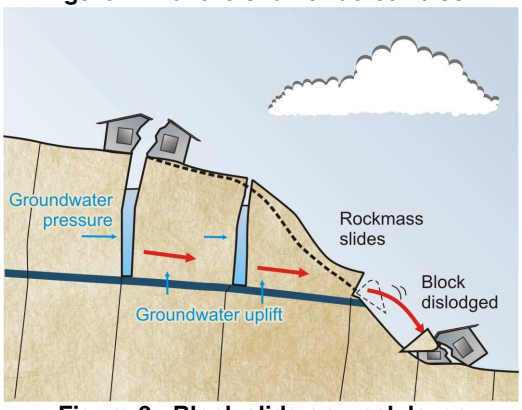

Figure 3 - Block slide on weak layer

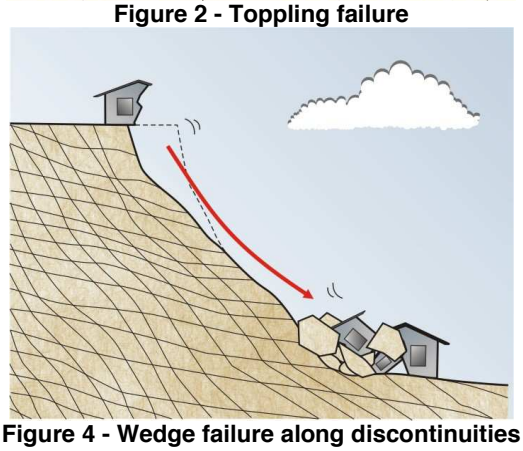

Figure 4 - Wedge failure along discontinuities

If the landslide risk is assessed as being anything other that Low, or Very Low, (GeoGuide LR7) it may be possible to carry out work aimed at reducing the level of risk.

The most common options are:

1) Trimming the slope to remove hazardous blocks of rock.
2) Bolting, or anchoring, to fix hazardous blocks in position and prevent movement.
3) Installation of catch fences and other rockfall protection measures to limit the impact of rockfalls.
4) Deep drainage designed to limit changes in the ground water table (GeoGuide LR5).

Although such measures can be effective, they need inspection and on-going maintenance (GeoGuide LR11) if they are to be effective for periods equivalent to the life of a house. **Design should be undertaken by a geotechnical practitioner and will normally require local council approval.** It should be appreciated that it may not be viable to carry out remedial works in all circumstances: for example where the landslide is on someone else's property, where the cost is out of proportion to the value of the property, or where the risk inherent in carrying out the work is actually greater than the risk of leaving things as they are. In situations such as these, development may be considered inappropriate.

ROCK SLOPE HAZARD REDUCTION MEASURES

Removal of loose blocks - may be effective but, depending on rock type, ongoing erosion can result in more blocks becoming unstable within a matter of years. Routine inspection, every 5 or so years, may be required to detect this.

Rock bolts and rock anchors (Figure 5) - can be installed in the ground to improve its strength and prevent individual blocks from falling. Rock bolts are usually tightened using a torque wrench, whilst rock anchors carry higher loads and require jacking. Both can be designed to be "permanent" using stainless steel, or sheathing, to inhibit corrosion, but the cost can be up to 10 times that of the "temporary" alternative. You should inspect rock bolts and rock anchors for signs of water seepage, rusting and deterioration around the heads at least once every 5 years. If you notice any of these warning signs, have them checked by a geotechnical practitioner. It is recommended that you keep copies of design drawings and maintenance records (GeoGuide LR11) for the anchors on your site and pass them on to the new owner should you sell.

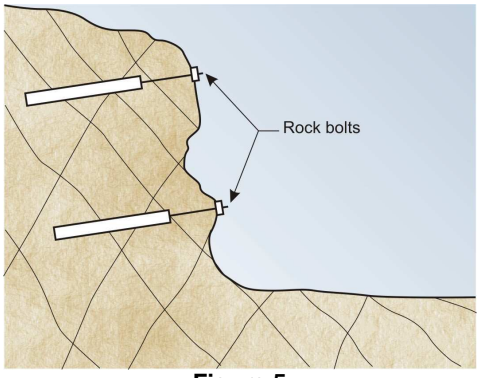

Figure 5

Rock fall netting, catch fences and catch pits (Figure 6) - are designed to catch or control falling rocks and prevent them from damaging nearby property. You should inspect them at least once every 5 years, and after major falls, and arrange for fallen and trapped rocks to be removed if they appear to be filling up. Check for signs of corrosion and replace steel elements and fixings before they lose significant strength.

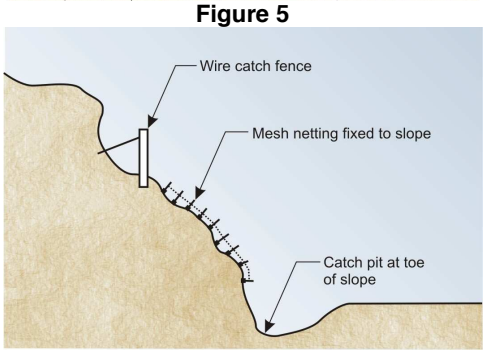

Figure 6

Cut-off drains (Figure 7) - can be used to intercept surface water run-off and reduce flows down the cliff face. Suitable drains are often excavated into the rock, or constructed from mounds of concrete, or stabilised soil, depending on conditions. Drains must be laid to a fall of at least 1% so they drain adequately. Frequent inspection is needed to ensure they are not blocked and continue to function as intended.

Clear trees and large bushes (Figure 7) - from slopes since roots can prize boulders from the face increasing the landslide hazard.

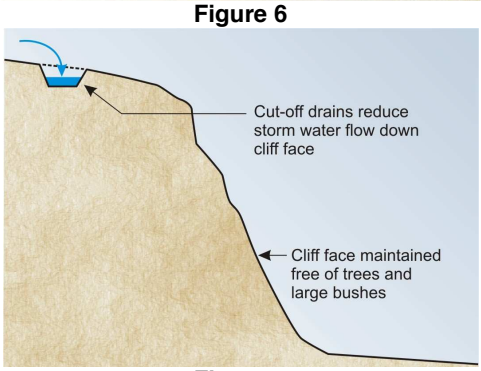

Figure 7

Natural cliffs and bluffs - often present the greatest hazard and yet are easily overlooked, because they have "been there forever". They can exist above a building, road, or beach, presenting the risk of a rock falling onto whatever is below. They also sometimes support buildings with a fine view to the horizon. Cliffs should be observed frequently to ensure that they are not deteriorating. You may find it convenient to use binoculars to look for signs of exposed "fresh" rock on the face, where a recent fall has occurred, or to go to the foot of the cliff from time to time to see if debris is collecting. A thorough inspection of a cliff face is often a major task requiring the use of rope access methods and should only be undertaken by an appropriately qualified professional. If tension cracks are observed in the ground at the top of a cliff take immediate action, since they could indicate imminent failure. **If you have any concerns at all about the possibility of a rock fall seek advice from a geotechnical practitioner.**

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WATER, DRAINAGE & SURFACE PROTECTION

One way or another, water usually plays a critical part in initiating a landslide (GeoGuide LR2). For this reason, it is a key factor to be controlled on sites with more than a low landslide risk (GeoGuide LR7).

Groundwater and Groundwater Flow

The ground is permeable and water flows through it as illustrated in Figure 1. When rain falls on the ground, some of it runs along the surface ("surface water run-off") and some soaks in, becoming groundwater. Groundwater seeps downwards along any path it can find until it meets the water table: the local level below which the ground is saturated. If it reaches the water table, groundwater either comes to a halt in what is effectively underground storage, or it continues to flow downwards, often towards a spring where it can seep out and become surface water again. Above the water table the ground is said to be "partially saturated", because it contains both water and air. Suctions can develop in the partially saturated zone which have the effect of holding the ground together and reducing the risk of a landslide. Vegetation and trees in particular draw large quantities of water out of the ground on a daily basis from the partially saturated zone. This lowers the water table and increases suctions, both of which reduce the likelihood of a landslide occurring.

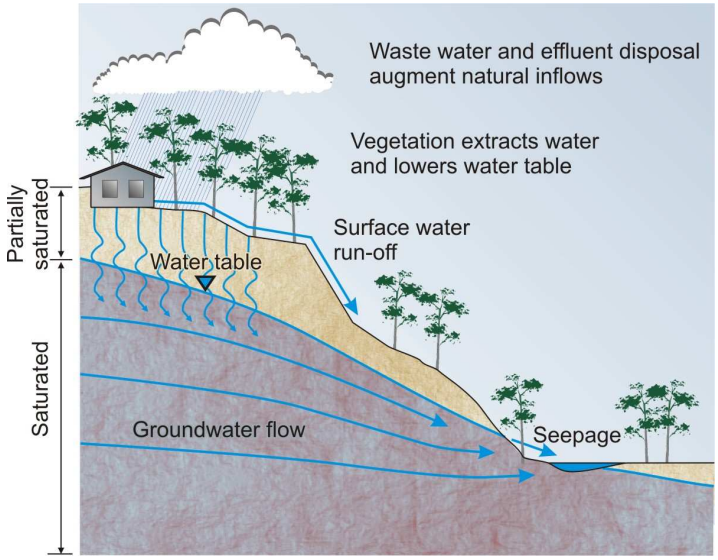

Figure 1 - Groundwater flow

Groundwater Flow and Landslides

The landslide risk in a hillside can be affected by increase in soak-away drainage or the construction of retaining walls which inhibit groundwater flow. The groundwater is likely to rise after heavy rain, but it can also rise when human interference upsets the delicate natural balance. Activities such as felling trees and earthworks can lead to:

- a reduction in the beneficial suctions in the partially saturated zone above the water table.
- increased static water pressures below the water table,
- increased hydraulic pressures due to groundwater flow,
- loss of strength, or softening, of clay rich strata,
- loss of natural cementing in some strata,
- transportation of soil particles.

Any of these effects, or a combination of them, can lead to landslides like those illustrated in GeoGuides LR2, LR3 and LR4.

Limiting the Effect of Water

Site clearance and construction must be carefully considered if changes in groundwater conditions are to be limited. GeoGuide LR8 considers good and poor development practices. Not surprisingly much of the advice relates to sensible treatment of water and is not repeated here. Adoption of appropriate techniques should make it possible to either maintain the current ground water table, or even cause it to drop, by limiting inflow to the ground.

If drainage measures and surface protection are relied on to keep the risk of a landslide to a tolerable level, it is important that they are inspected routinely and maintained (GeoGuide LR11).

The following techniques may be considered to limit the destabilising effects of rising groundwater due to development and are illustrated in Figure 2.

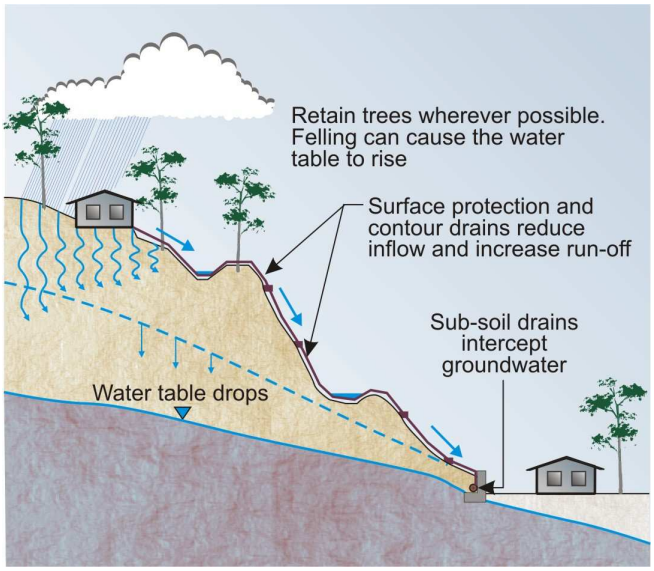

Figure 2 - Techniques used to control groundwater flow

Surface water drains (dish drains, or table drains) - are often used to prevent scour and limit inflow to a slope. Other than in rock, they are relatively ineffective unless they have an impermeable lining. You should clear them regularly, and as required, and not less than once a year. If you live in an area with seasonal rainfall, it is best to do this near the end of the dry season. If you notice that soil or rock debris is falling from the slope above, determine the source and take appropriate action. This may mean you have to seek advice from a geotechnical practitioner.

Surface protection - is sometimes used in addition to surface water drainage to prevent scour and minimise water inflow to a slope. You should inspect concrete, shotcrete or stone pitching for cracking and other signs of deterioration at least once a year. Make sure that weepholes are free of obstructions and able to drain. If the protection is deteriorating, you should seek advice from a geotechnical practitioner.

Sub-soil drains - are often constructed behind retaining walls and on hillsides to intercept groundwater. Their function is to remove water from the ground through an appropriate outlet. It is important that subsoil drains are designed to complement other measures being used. They should be laid in a sand, or gravel, bed and protected with a graded stone or geotextile filter to reduce the chance of clogging. Sub-soil drains should always be laid to a fall of at least 1 vertical on 100 horizontal. Ideally the high end should be brought to the surface, so it can be flushed with water from time to time as part of routine maintenance procedures.

Deep, underground drains - are usually only used in extreme circumstances, where the landslide risk is assessed as not being tolerable and other stabilisation measures are considered to be impractical. They work by permanently lowering the water table in a slope. They are not often used in domestic scale developments, but if you have any on your site be aware that professional maintenance is essential. If they are not maintained and stop working, the water table will rise and a landslide may even occur during normal weather conditions. Both an increase or a reduction in the normal flow from deep drains could indicate a problem if it appears to be unrelated to recent rainfall. If changes of this sort are observed, you should have the drains and your site checked by a geotechnical practitioner.

Documentation - design drawings and specifications for geotechnical measures intended to minimise landslide risk can be of great assistance to a geotechnical specialist, or structural engineer, called in to inspect and report on them. Copies of available documentation should be retained and passed to the new owner when the property is sold (GeoGuide LR11). You should also request details of an appropriate maintenance program for drainage works from the designer and keep that information with other relevant documentation and maintenance records.

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RETAINING WALLS

Retaining walls are used to support cuts and fills. Some are built in the open and backfill is placed behind them (gravity walls). Others are inserted into the ground (cast *in situ* or driven piles) and the ground is subsequently excavated on one side. Retaining walls, like all man-made structures, have a finite life. Properly engineered walls should last 50 years, or more, without needing significant repairs. However, not all walls fit this category. Some, particularly those built by inexperienced tradesmen without engineering input, can deflect and even fail because they are unable to withstand the pressures that develop in the ground around them or because the materials from which they are built deteriorate with time. **Design of retaining walls more than 900mm high should be undertaken by a geotechnical practitioner or structural engineer and normally require local council approval.**

Retaining walls have to withstand the weight of the ground on the high side, any water pressure forces that develop, any additional load (surcharge) on the ground surface and sometimes swelling pressures from expansive clays. These forces are resisted by the wall itself and the ground on the low side. Engineers calculate the forces that the retained ground, the water, and the surcharge impose on a wall (the disturbing force) as well as the maximum force that the wall and ground on the low side can provide to resist them (the restoring force). The ratio of the restoring force to the disturbing force is called the "factor of safety" (GeoGuide LR1). Permanent retaining walls designed in accordance with accepted engineering standards will normally have a factor of safety in the range 1.5 to 2.

Never add surcharge to the high side of a wall (e.g. place fill, erect a structure, stockpile bulk materials, or park vehicles) unless you know the wall has been designed with that purpose in mind.

Never more than lightly water plants on the high side of a retaining wall.

Never excavate at the toe of a retaining wall.

Any of these actions will reduce the factor of safety of the wall and could lead to failure. If in doubt about any aspect of an existing retaining wall, or changes you would like to make near one, seek advice from a geotechnical practitioner, or a structural engineer. This GeoGuide sets out basic inspection requirements for retaining walls and identifies some common signs that might indicate all is not well. GeoGuide LR11 provides information about records that should be kept.

GRAVITY WALLS

Gravity walls are so called because they rely on their own weight (the force of gravity) to hold the ground behind in place.

Formed concrete and reinforced blockwork walls (Figure 1) **-** should be built so the backfill can drain. They should be inspected at least once a year. Look for signs of tilting, bulging, cracking, or a drop in ground level on the high side, as any of these may indicate that the wall has started to fail. Look for rust staining, which may indicate that the steel reinforcement is deteriorating and the wall is losing structural strength ("concrete cancer"). Ensure that weep holes are clear and that water is able to drain at all times, as high water pressures behind the wall can lead to sudden and catastrophic failure.

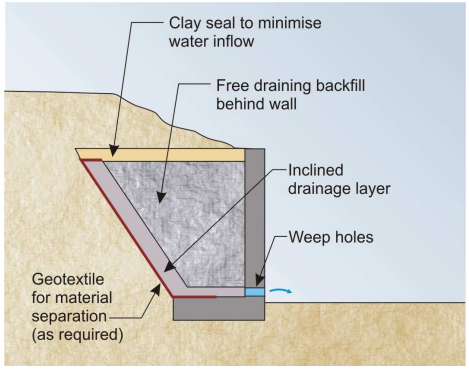

Figure 1- Typical formed concrete wall

Concrete "crib" walls (Figure 2) **-** should be filled with clean gravel, or "blue metal" with a nominated grading. Sometimes soil is used to reduce cost, but this is undesirable, from an engineering perspective, unless internal drainage is incorporated in the wall's construction. Without backfill drainage, a soil filled crib wall is likely to have a lower factor of safety than is required. Crib walls should be inspected as for formed concrete walls. In addition, you should check that material is not being lost through the structure of the wall, which has large gaps through it.

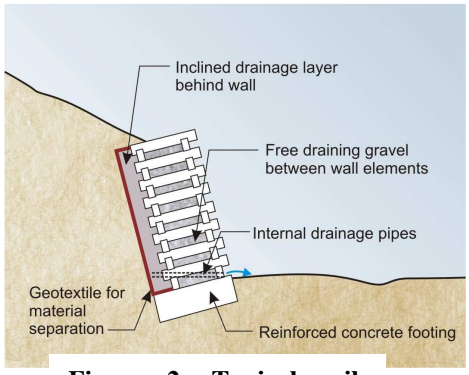

Figure 2 -Typical crib

Timber "crib" walls - should be checked as for concrete crib walls. In addition, check the condition of the timber. Once individual elements show signs of rotting, it is necessary to have the wall replaced. If you are uncertain seek advice from a geotechnical practitioner, or a structural engineer.

Masonry walls: natural stone, brick, or interlocking blocks (Figure 3) - more than about 1m high, should be wider at the bottom than at the top and include specific measures to permit drainage of the backfill. They should be checked as for formed concrete walls. Natural stone walls should be inspected for signs of deterioration of the individual blocks: strength loss, corners becoming rounded, cracks appearing, or debris from the blocks collecting at the foot of the wall.

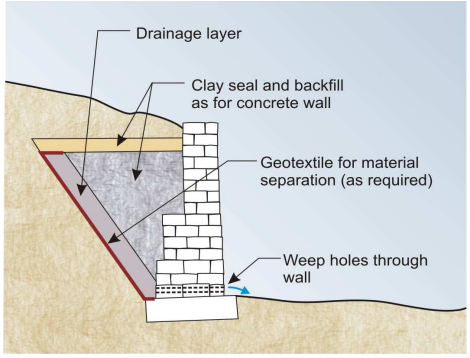

Figure 3 -Typical masonry wall

Old Masonry walls (Figure 4) - Many old masonry retaining walls have not been built in accordance with modern design standards and often have a low "factor of safety" (GeoGuide LR1). They may therefore be close to failure and a minor change in their condition, or loading, could initiate collapse. You need to take particular care with such structures and seek professional advice sooner rather than later. Although masonry walls sometimes deflect significantly over long periods of time collapse, when it occurs, is usually sudden and can be catastrophic. Familiarity with a particular situation can instil a false sense of confidence.

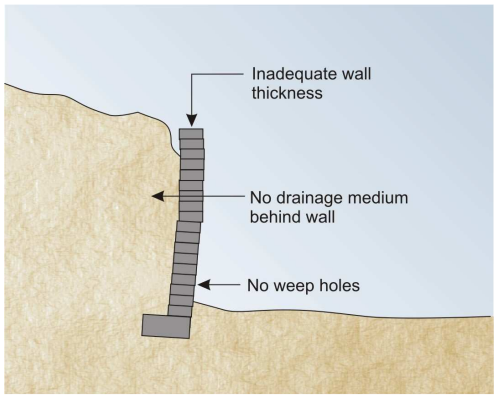

Figure 4 - Poorly built masonry wall

Reinforced soil walls (Figure 5) **-** are made of compacted select fill in which layers of reinforcement are buried to form a "reinforced soil zone". The reinforcement is all important, because it holds the soil "wall" together. Reinforcement may be steel strip, or mesh, or a variety of geosynthetic ("plastic") products. The facing panels are there to protect the soil "wall" from erosion and give it a finished appearance.

Most reinforced soil walls are proprietary products. Construction should be carried out strictly in accordance with the manufacturer's instructions. Inspection and maintenance should be the same as for formed concrete and concrete block walls. If unusual materials such as timber, or used tyres, are used as a facing it should be checked to see that it is not rotting, or perishing.

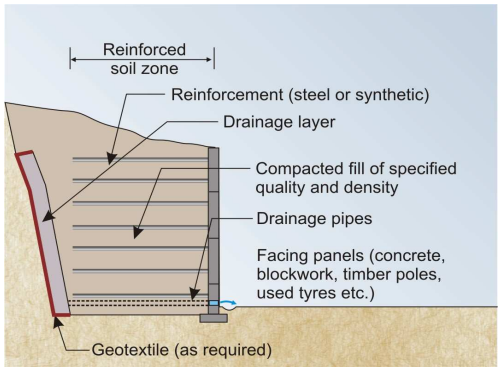

Figure 5 - Typical reinforced soil wall

OTHER WALLS

Cantilevered and anchored walls (Figure 6) **-** rely on earth pressure on the low side, rather than self-weight, to provided the restoring force and an adequate factor of safety. These walls may comprise:

- a line of touching bored piers (contiguous bored pile wall) or
- sprayed concrete panels between bored piers (shotcrete wall) or
- horizontal timber or concrete planks spanning between upright timber or steel soldier piles or
- steel sheet piles.

Depending on the form of construction and ground conditions, walls in excess of 3 m height normally require at least one row of permanent ground anchors.

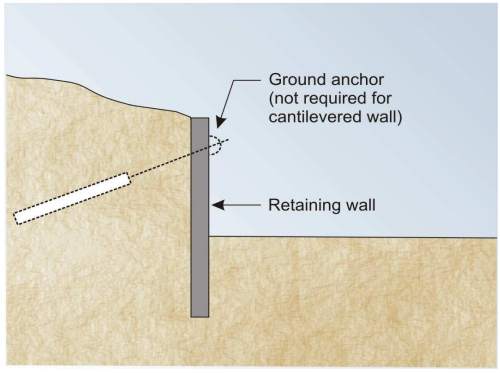

Figure 6 - Typical cantilevered or anchored wall

INSPECTION

All walls should be inspected at least once a year, looking for tilting and other signs of deterioration. Concrete walls should be inspected for cracking and rust stains as for formed concrete gravity walls. Contiguous bored pile walls can have gaps between the piles - look for loss of soil from behind which can become a major difficulty if it is not corrected. Timber walls should be inspected for rot, as for timber crib walls. Steel sheet piles should be inspected for signs of rusting. In addition, you should make sure that ground anchors are maintained as described in GeoGuide LR4 under the heading "Rock bolts and rock anchors".

One of the most important issues for walls is that their internal drainage systems are operational. Frequently verify that internal drainage pipes and surface interception drains around the wall are not blocked nor have become inoperative.

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

- GeoGuide LR1 - Introduction
- GeoGuide LR2 - Landslides
- GeoGuide LR3 - Landslides in Soil
- GeoGuide LR4 - Landslides in Rock
- GeoGuide LR5 - Water & Drainage
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LANDSLIDE RISK

Concept of Risk

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

Landslide Risk Assessment

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

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

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

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

Risk to Property

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

TABLE 2: LIKELIHOOD

Likelihood	Annual Probability
Almost Certain	1:10
Likely	1:100
Possible	1:1,000
Unlikely	1:10,000
Rare	1:100,000
Barely credible	1:1,000,000

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

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

TABLE 1: RISK TO PROPERTY

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

AUSTRALIAN GEOGUIDE LR7 (LANDSLIDE RISK)

Risk to Life

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

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

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

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

TABLE 3: RISK TO LIFE

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

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- GeoGuide LR4 - Landslides in Rock
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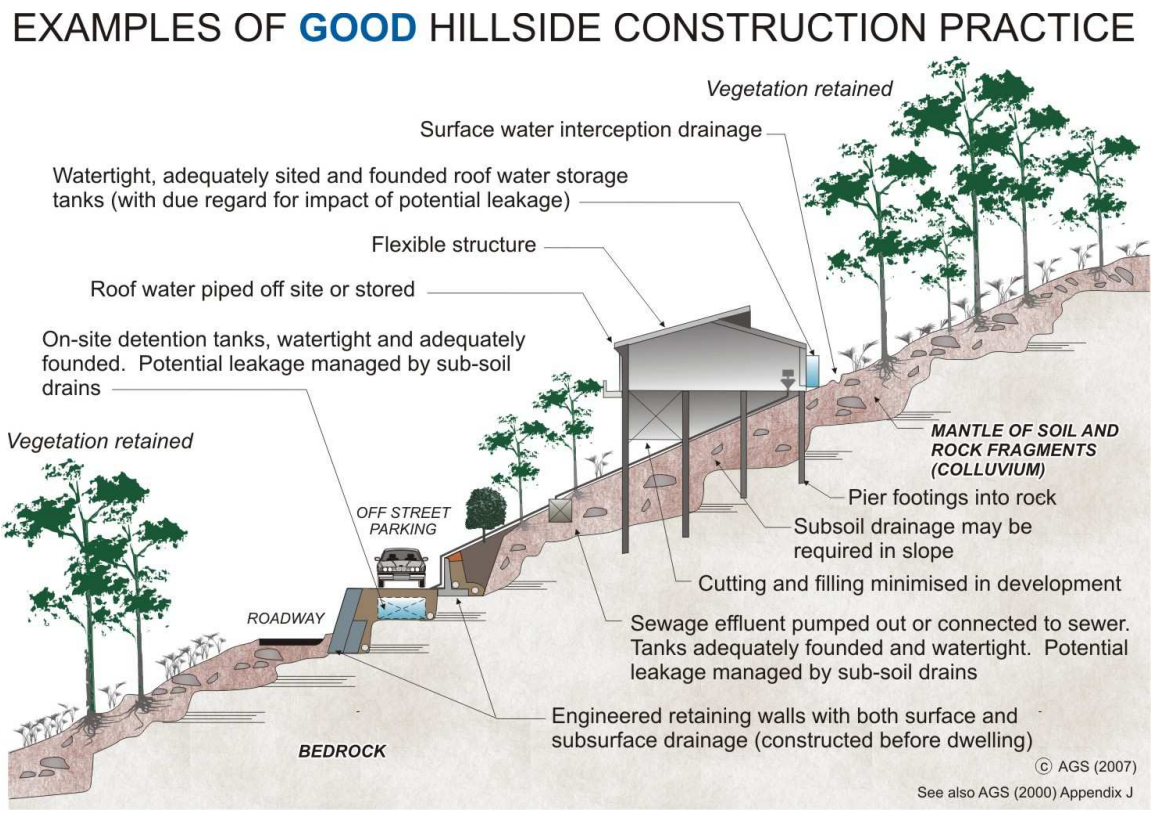
AUSTRALIAN GEOGUIDE LR8 (CONSTRUCTION PRACTICE)

HILLSIDE CONSTRUCTION PRACTICE

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



WHY ARE THESE PRACTICES GOOD?

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

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

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

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

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

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

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

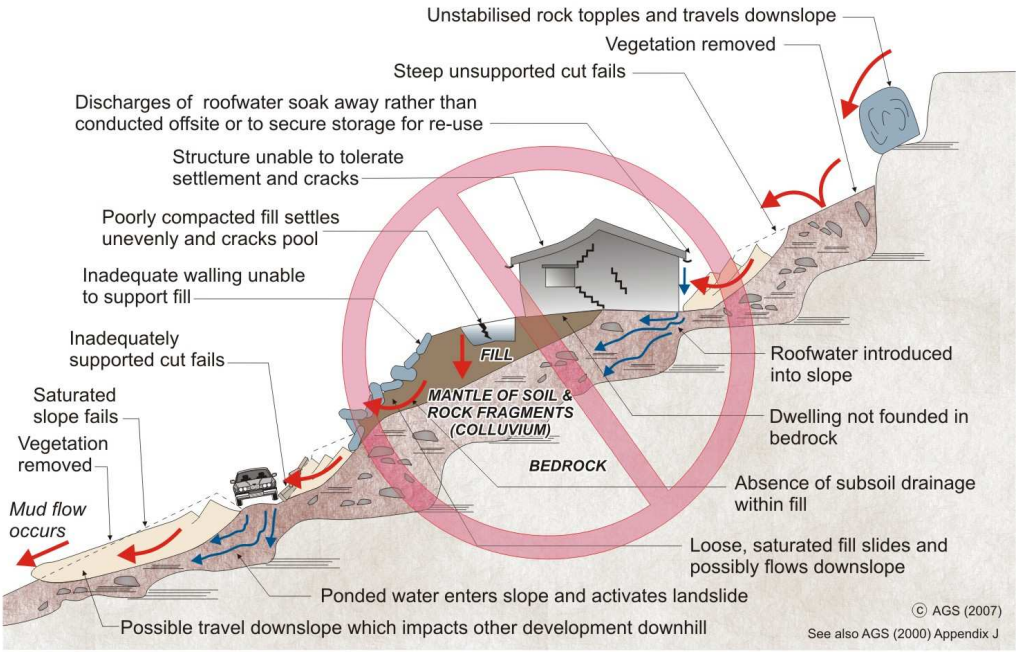
Vegetation clearance - on soil slopes has been kept to a reasonable minimum. Trees, and to a lesser extent smaller vegetation, take large quantities of water out of the ground every day. This lowers the ground water table, which in turn helps to maintain the stability of the slope. Large scale clearing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

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

ADOPT GOOD PRACTICE ON HILLSIDE SITES

AUSTRALIAN GEOGUIDE LR8 (CONSTRUCTION PRACTICE)

EXAMPLES OF **POOR** HILLSIDE CONSTRUCTION PRACTICE



WHY ARE THESE PRACTICES POOR?

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

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

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

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

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

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

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

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

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AUSTRALIAN GEOGUIDE LR9 (EFFLUENT DISPOSAL)

EFFLUENT AND SURFACE WATER DISPOSAL

EFFLUENT AND WASTEWATER

All households generate effluent and wastewater. The disposal of these products and their impact on the environment are key considerations in the planning of safe and sustainable communities. Cities and townships generally have reticulated water, sewer and stormwater systems, which are designed to deliver water and dispose of effluent and wastewater with minimal impact on the environment. However, many smaller communities and metropolitan fringe suburbs throughout Australia are un-sewered. Some of these are located in hillside or coastal settings where landslides present a hazard.

Processes by which wastewater can affect slope stability

As explained in GeoGuides LR3 and LR5, groundwater variations have a significant impact on slope stability. Inappropriate disposal of effluent and wastewater may result in the ground becoming saturated. The result is equivalent to a localised rise of the groundwater table and may have the potential to cause a landslide (GeoGuides LR2, LR5 and LR8).

On-site effluent disposal

In un-sewered areas disposal of effluent must be achieved through suitable methods. These methods usually involve containment within the boundaries of the site ("on-site disposal"). State environment protection agencies and local government authorities can usually provide advice on suitable disposal systems for your area. Such systems may include:

- *Septic systems,* which involve a storage/digestion tank for solids, with disposal of the liquid effluent via absorption trenches and beds, leach drains, or soak wells. Such systems are best suited to areas not prone to landslides.
- *Aerobic treatment units* which incorporate an individual household treatment plant to aid breakdown of the waste into a higher quality effluent. Such effluent is further treated and disposed of by surface or sub-surface irrigation, sub-soil dripper, or shallow leach drain system.
- *Nutrient retentive leaching systems* which utilise septic tanks to process the solid and liquid wastes in conjunction with discharge of the effluent through sand filters, media filters, mound systems and nutrient retentive leaching systems, which strip the effluent of nutrients.

Toilet (and sometimes kitchen) waste is known as *black water.* Other, less contaminated, wastewater streams from showers, baths and laundries are known as *grey water*. *Grey water re-use systems* allow a household to conserve water from bathrooms, kitchens and laundries, for re-use on gardens and lawns.

Recommendations for effluent disposal

In areas prone to landslide hazard, it is recommended that whatever effluent disposal system is employed, it should be designed by a qualified professional, familiar with how such a system can impact on the local environment. Local council, and in some instances state environment protection agency, approval is usually required as well. Many local authorities require a site assessment report, which covers all relevant issues. If approved, the report's recommendations must be incorporated in the system design. Reduction in the volume of effluent is beneficial so composting toilets and highly rated (i.e. low consumption) water appliances are recommended. It should be noted that in some state and local government jurisdictions there are restrictions on the alternative measures that can be applied. Consideration should be given to applying treated wastewater to land at low rates and over as large an area as possible. Further guidance can be found in Australian Standard AS/NZS 1547:2000 On-site domestic wastewater management.

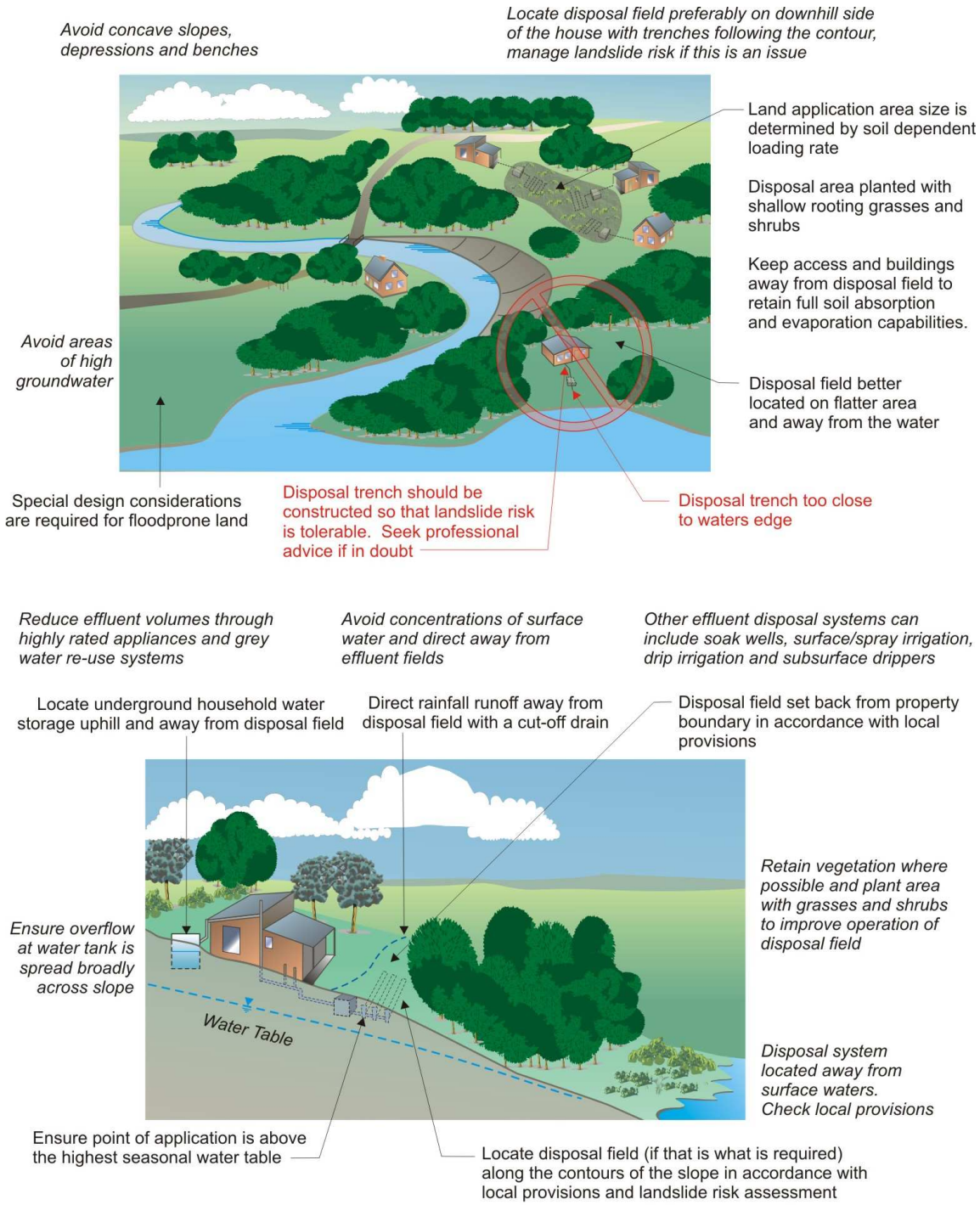
Effluent disposal fields should be sited with due consideration to the overall landscape and the individual characteristics of the property. Some guidance is provided. In particular, effluent fields should be located downslope of the building, away from stormwater, or *grey water*, discharge areas and where there is minimal potential for downstream pollution. Set backs and buffer distances vary from state to state and local requirements should be adhered to. All systems require regular maintenance and inspection. Efficient operation of the system must be a priority for property owners/occupiers to ensure safe and sustainable communities. Responsibility for maintenance rests with owners.

SURFACE WATER DRAINAGE

Attention to on-site surface water management is also important. Runoff from developments, including buildings, decks, access tracks and hardstand areas should be collected and discharged away from the development and other effluent disposal fields. Particular care must be given to the design of overflows on water tanks, as this is often overlooked. Discharge from any development should be spread out as much as possible, unless it can be directed to an existing natural water course. Ponding of water on hillsides and the concentration of water flows on slopes must be avoided.

It is recommended that a specific drainage plan and strategy should be developed in conjunction with the effluent disposal system for sites with a high potential for slope instability. Maintenance of the surface water drainage system is as important as maintenance of the effluent disposal system and again the responsibility rests with owners.

AUSTRALIAN GEOGUIDE LR9 (EFFLUENT DISPOSAL)



Note: Adapted from EPA Vic. Publication 451 (March 1996) "Code of Practice - Septic Tanks", which was sourced from Vic. Department of Planning and Loddon-Campaspe Regional Planning Authority.

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LANDSLIDES IN THE COASTAL ENVIRONMENT

Coastal Instability

The coast presents a particularly dynamic environment where change is often the norm. Hazards exist in relation to both cliffs and sand dunes. The coast is also the most heavily populated part of Australia and always regarded as "prime" real estate, because of the views and access to waterways and beaches.

Photo courtesy Greg Kotze

Waves, wind and salt spray play a significant part, causing dunes to move and cliff-faces to erode well above sea level. Our response is often to try to neutralise these effects by doing such things as dumping rock in the sea, building groynes, dredging, or carrying out dune stabilisation. Such works can be very effective, but ongoing maintenance is usually needed and total reconstruction may be necessary after a relatively short working life.

Of particular significance are extreme events that cause destruction on a scale that ignores our efforts at coastal protection. Records show that cliffs have collapsed, taking with them backyards which had been relied upon as a buffer between a house and the ocean. Sand dunes have also been washed away resulting in the dramatic loss of homes and infrastructure. As with most landslide issues, even though such events may be infrequent, they could happen tomorrow. It is easy to be lulled into a false sense of security on a calm day.

In coastal areas, typical landslide hazards (GeoGuides LR1 to LR4) are compounded by coastal erosion which, over time, undercuts cliffs and eventually results in failure. In the case of sand dunes, dune erosion and dune slumping have equally dramatic effects. Coastal locations are subject to particular processes relating to fluctuating water tables, inundation under storm tides and direct wave attack. Large sections of our more sandy coastline are receding under present sea conditions. The hazards are progressive and likely to be exacerbated through climate change.

Coastal Development

If you own, or are responsible for, a coastal property it is important that you understand that, where the shore line is receding, there is a greater landslide risk than would be the case on a similar site inland. The view may make the risk worthwhile, but does not reduce it.

Coastal Landslides

Coastal landslides are little different from other landslides in that the signs of failure (GeoGuides LR2) and the causes (LR3, LR4 & LR5) are largely the same. The main difference relates to the overriding influence of wave impact, tidal movement, salt spray and high winds.

Cliff failures

In addition to the processes that produce cliff instability on inland cliffs, coastal cliffs are also subjected to repeated cycles of wetting and drying which can be accompanied by the expansive effect of salt crystal growth in gaps in the rocks. These processes accelerate the deterioration of coastal cliffs. At the base of cliffs, direct wave attack and the impact of boulders moved by wave action causes undercutting and hence instability of the overall face. Figure 2 of GeoGuide LR4 provides an example. Whilst the processes leading to coastal cliff collapse may take years, failure tends to be catastrophic and with little warning. In many cases, waves produced by large oceanic storms are the trigger assisted by rainfall to produce collapse. These are also the conditions in which you are more likely to be inside your home and oblivious to unusual noises or movements associated with imminent failure.

Sand dune escarpment and slope failures

An understanding of coastal processes is essential when determining beach erosion potential. Waves produced by large oceanic storms can erode beaches and cut escarpments into dunes. These may be of relatively short duration, when beach re-building happens after the storm, but can be a permanent feature where long term beach recession is taking place. In many locations, houses and infrastructure are sited on or immediately behind coastal dunes. After an escarpment has eroded, those assets may be lost or damaged by subsequent slumping of the dune. It is important that, on erodible coastal soils, the potential for landward incursion of an erosion escarpment is determined. Having done this, the likelihood of slope instability can be established as part of the landslide risk management process. Injury, death and structural damage have occurred around the Australian coast from collapsing sand escarpments.

Photo courtesy DNR NSW

AUSTRALIAN GEOGUIDE LR10 (COASTAL LANDSLIDES)

The large scale and potentially high speed of coastal erosion processes means that major civil engineering work and large cost is normally involved in their control. The installation of rock bolts (LR4), drainage (LR5), or retaining walls (LR6) on a single house site may be necessary to provide local stability, but are unlikely to withstand the attack of a large storm on a beach or cliff-line.

BUILDING NEAR CLIFFS AND HEADLANDS

Coastal cliffs and headlands exist because the rock that they are made from is able to resist erosion. Even so, cliff-faces are not immune and will continue to collapse (Figure 1) by one or other of the mechanisms shown on GeoGuide LR4. If you live on a coastal cliff, you should undertake inspection and maintenance as recommended in LR4 and the other GeoGuides, as appropriate. The top of the cliff, its face, and its base should be inspected frequently for signs of recent rock falls, opening of cracks, and heavy seepage which might indicate imminent failure. Since the sea can remove fallen rocks rapidly, inspections should be made shortly after every major storm as a matter of course. **If collapses are occurring seek advice from an appropriately experienced geotechnical practitioner. Advise you local council if you believe erosion is rapid or accelerating.**

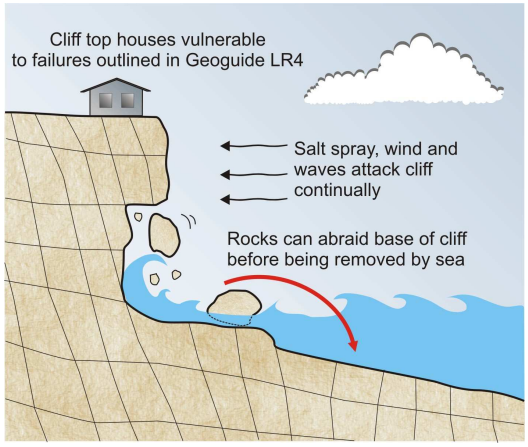


Figure 1

Building on Coastal Dunes

Any excavation in a natural dune slope is inherently unstable and must be supported and maintained (GeoGuide LR6). Dunes are particularly susceptible to ongoing erosion by wind and wave action and extreme changes can occur in a single storm. Whilst vegetation can help to stabilise dunes in the right circumstances, unfortunately a single storm has the potential to cut well into dunes and, in some cases, remove an entire low lying dune system or shift the mouth of a river. **As for cliffs, it is appropriate to observe the effects of major storms on the coastline. If erosion is causing the coastline to recede at an appreciable rate, seek advice from suitably experienced geotechnical and coastal engineering practitioners and bring it to the attention of the local council.**

Photo courtesy DNR NSW

CLIMATE CHANGE

The coastal zone will experience the most direct physical impacts of climate change. A number of reviews of global data indicate a general trend of sea level rise over the last century of 0.1 - 0.2 metres. Current rates of global average sea level rise, measured from satellite altimeter data over the last decade, exceed 3 mm/year and are accelerating. The most authoritative and recent (at the time of writing) report on climate change (IPCC, 2007) predicts a global average sea level rise of between 0.2 and 0.8 metres by 2100, compared with the 1980 - 1999 levels (the higher value includes the maximum allowance of 0.2 m to account for uncertainty associated with ice sheet dynamics).

In addition to sea level rise, climate change is also likely to result in changes in wave heights and direction, coastal wind strengths and rainfall intensity, all of which have the capacity to impact adversely on coastal dunes and cliff-faces. A Guideline for responding to the effects of climate change in coastal areas was published by Engineers Australia in 2004.

References

Engineers Australia 2004 'Guidelines for responding to the effects of climate change in coastal and ocean engineering." The National Committee on Coastal and Ocean Engineering , Engineers Australia , updated 2004.

IPCC (2007) *Climate Change 2007: The Physical Science Basis.* Summary for Policy Makers. Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).

Nielsen, A.F., Lord D.B. and Poulos, H.G. (1992). 'Dune Stability Considerations for Building Foundations', *Aust. Civil Eng. Transactions* CE No.2, 167-174.

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

- GeoGuide LR1 - Introduction
- GeoGuide LR2 - Landslides
- GeoGuide LR3 - Landslides in Soil
- GeoGuide LR4 - Landslides in Rock
- GeoGuide LR5 - Water & Drainage
- GeoGuide LR6 - Retaining Walls
- GeoGuide LR7 - Landslide Risk
- GeoGuide LR8 - Hillside Construction
- GeoGuide LR9 - Effluent & Surface Water Disposal
- GeoGuide LR11 - Record Keeping

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

AUSTRALIAN GEOGUIDE LR11 (RECORD KEEPING)

RECORD KEEPING

It is strongly recommended that records be kept of all construction, inspection and maintenance activities in relation to developments on sloping blocks. In some local authority jurisdictions, maintenance requirements form part of the building consent conditions, in which case they are mandatory.

CONSTRUCTION RECORDS

If at all possible, you should keep copies of drawings, specifications and construction (i.e. "as built") records, particularly if these differ from the design drawings. The importance of these documents cannot be over-emphasised. If a geotechnical practitioner comes to a site to carry out a landslide risk assessment and is only able to see the face of a retaining wall, the heads of some ground anchors, or the outlets of a number of sub-soil drains, it may be necessary to determine how these have been built and how they are meant to work before completing the assessment. This could involve drilling through the wall to determine how thick it is, or probing the length of the drains, or even ignoring the anchors altogether, because it is uncertain how long they are. Such "investigation" of something that may only have been built a few years before is, at best, a waste of time and money and, at worst, capable of coming up with a misleading answer which could affect the outcome of the assessment. Documentary information of this sort often proves to be invaluable later on, so treat it with as much importance as the title deeds to your property.

INSPECTION AND MAINTENANCE RECORDS

If you follow the recommendations of the Australian GeoGuides it is likely that you will either carry out periodic inspections yourself, or you will engage a geotechnical practitioner to do them for you. The collected records of these inspections will provide a detailed history of changes that might be occurring and will indicate, better than your own memory, whether things are deteriorating and, if so, at what rate. Unfortunately, without some form of written record, all information is usually lost each time a property is sold. It is recommended that a prospective purchaser should have a pre-purchase landslide risk assessment carried out on a hillside site, in much the same way that they would commission a structural assessment, or a pest inspection, of the building. If the vendor has kept good records, then the assessment is likely to be quicker and cheaper, and the outcome more reliable, than if none are available. Each site is different, but noting the following would normally constitute a reasonable record of an inspection/maintenance undertaken:

- date of inspection/maintenance and the name and professional status of the person carrying it out
- description of the specific feature (eg. cliff face, temporary rock bolt, cast *in situ* retaining wall, shallow leach drain system)
- sketch plans, sketches and photographs to indicate location and condition
- activity undertaken (eg. visual inspection; cleared vegetation from drain; removed fallen rock about 500 mm diameter)
- condition of the feature and any matters of concern (e.g. weep holes damp and flowing freely; rust on anchor heads getting worse; shotcrete uncracked and no sign of rust stains; ground saturated around leach field)
- specific outcomes (eg. no action necessary; geotechnical practitioner called in to advise on the state of the anchors; cliff face to be trimmed following the most recent rock fall; leach field to be rebuilt at new location)

A proforma record is provided overleaf for convenience. Photographs and sketches of specific observations can prove to be very useful and should be included whenever possible. Geotechnical practitioners may devise their own site specific inspection/maintenance records.

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

- GeoGuide LR1 - Introduction
- GeoGuide LR2 - Landslides
- GeoGuide LR3 - Landslides in Soil
- GeoGuide LR4 - Landslides in Rock
- GeoGuide LR5 - Water & Drainage
- GeoGuide LR6 - Retaining Walls
- GeoGuide LR7 - Landslide Risk
- GeoGuide LR8 - Hillside Construction
- GeoGuide LR9 - Effluent & Surface Water Disposal
- GeoGuide LR10 - Coastal Landslides

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

AUSTRALIAN GEOGUIDE LR11 (RECORD KEEPING)

INSPECTION/MAINTENANCE RECORD

(Tick boxes as appropriate and add information as required) Date.....

Site location (street address / lot & DP numbers / map reference / latitude and longitude)

.....

FEATURE	Inspected	Maintained	Tested	By Owner	By Professional
Slopes & surface protection:					
☐ Natural slope/cliff ☐ Cut/fill slope					
☐ Surface water drains					
☐ Shotcrete ☐ Stone pitching ☐ Other					
Retaining walls:					
☐ Cast in situ concrete ☐ Concrete block					
☐ Masonry (natural stone) ☐ Masonry (brick, block)					
☐ Cribwall (concrete) ☐ Cribwall (timber)					
☐ Anchored wall ☐ Reinforced soil wall					
☐ Sub-soil drains ☐ Weep holes					
Ground improvement:					
☐ Rock bolts					
☐ Ground anchors ☐ Soil nails					
☐ Deep subsoil drains					
Effluent and storm water disposal systems:					
☐ Effluent treatment system					
☐ Effluent disposal field					
☐ Storm water disposal field					
Other:					
☐ Netting ☐ Catch fence ☐ Catch pit					
☐					
☐					
☐					

Observations/Notes (Add pages/details as appropriate)

.....

.....

.....

Attachments: ☐ Sketch(es) ☐ Photograph(s) ☐ Other (eg measurements, test results)

Record prepared by ..... (name): .....(signature)

Contact details: Phone:..... E-mail:.....

Professional Status (in relation to landslide risk assessment):.....

APPENDIX

AUSTRALIAN GEOMECHANICS SOCIETY

STEERING COMMITTEE

Andrew Leventhal, GHD Geotechnics, Sydney, Chair
Robin Fell, School of Civil and Environmental Engineering, UNSW, Sydney, Convenor Guidelines on Landslide Susceptibility, Hazard and Risk Working Group
Tony Phillips, Consultant, Sydney, Convenor Slope Management and Maintenance Working Group
Bruce Walker, Jeffery and Katauskas, Sydney, Convenor Practice Note Working Group
Geoff Withycombe, Sydney Coastal Councils Group, Sydney

WORKING GROUP - Guidelines on Slope Management and Maintenance
Tony Phillips, Tony Phillips Consulting, Sydney, Convenor
Henk Buys, NSW Roads and traffic Authority, Parramatta
John Braybrooke, Douglas Partners, Sydney
Tony Miner, A.G. Miner Geotechnical, Geelong

LANDSLIDE TASKFORCE
Laurie de Ambrosis, GHD Geotechnics, Sydney
Mark Eggers, Pells Sullivan Meynink, Sydney
Max Ervin, Golder Associates, Melbourne
Angus Gordon, retired, Sydney
Greg Kotze, GHD, Sydney
Arthur Love, Coffey Geotechnics, Newcastle
Alex Litwinowicz, GHD Geotechnics, Brisbane
Tony Miner, A.G. Miner Geotechnical, Geelong
Fiona MacGregor, Douglas Partners, Sydney
Garry Mostyn, Pells Sullivan Meynink, Sydney
Grant Murray, Sinclair Knight Merz, Auckland
Garth Powell, Coffey Geotechnics, Brisbane
Ralph Rallings, Pitt and Sherry, Hobart
Ian Stewart, NSW Roads and Traffic Authority, Sydney
Peter Tobin, Wollongong City Council, Wollongong
Graham Whitt, Shire of Yarra Ranges, Lillydale

Foundation Maintenance and Footing Performance:
A Homeowner's Guide

CSIRO

BTF 18 replaces Information Sheet 10/91

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

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

Soil Types

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

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

Causes of Movement

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

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

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

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

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

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

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

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

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

GENERAL DEFINITIONS OF SITE CLASSES

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

Tree root growth

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

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

Unevenness of Movement

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

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

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

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

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

Effects of Uneven Soil Movement on Structures

Erosion and saturation

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

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

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

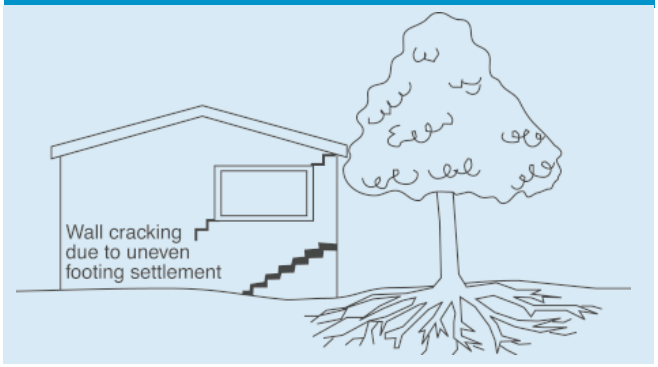
Seasonal swelling/shrinkage in clay

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

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

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

Trees can cause shrinkage and damage



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

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

Movement caused by tree roots

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

Complications caused by the structure itself

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

Effects on full masonry structures

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

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

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

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

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

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

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

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

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

Water Service and Drainage

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

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

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

Seriousness of Cracking

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

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

Prevention/Cure

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

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

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

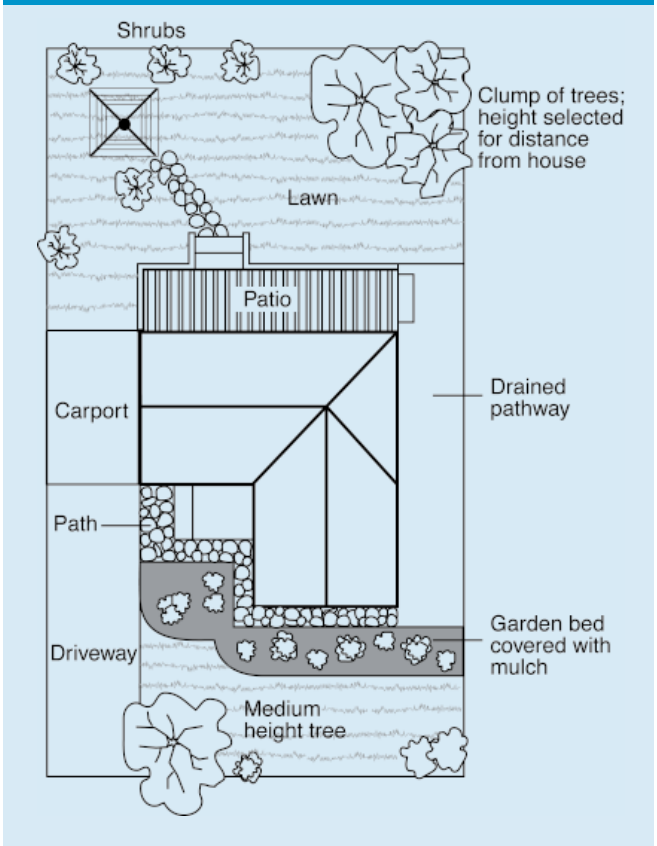
Protection of the building perimeter
It is essential to remember that the soil that affects footings extends well beyond the actual building line. Watering of garden plants, shrubs and trees causes some of the most serious water problems.

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

CLASSIFICATION OF DAMAGE WITH REFERENCE TO WALLS

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

Gardens for a reactive site



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

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

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

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

Condensation

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

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

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

The garden

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

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

Existing trees

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

Information on trees, plants and shrubs

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

Excavation

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

Remediation

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

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

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

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Appendix B

Soil & Rock Explanation Sheets
Borehole Logs
DCP Logs

Soil and Rock Explanation Sheets (1 of 2)

Log Abbreviations & Notes

METHOD

borehole logs

AS	auger screw *
AD	auger drill *
RR	roller / tricone
W	washbore
CT	cable tool
HA	hand auger
D	diatube
B	blade / blank bit
V	V-bit
T	TC-bit

* bit shown by suffix e.g. ADV

excavation logs

NE	natural excavation
HE	hand excavation
BH	backhoe bucket
EX	excavator bucket
DZ	dozer blade
R	ripper tooth

coring
NMLC, NQ, PQ, HQ

SUPPORT

borehole logs

N	nil
M	mud
C	casing
NQ	NQ rods

excavation logs

N	nil
S	shoring
B	benched

CORE—LIFT

casing installed

barrel withdrawn

NOTES, SAMPLES, TESTS

D	disturbed
B	bulk disturbed
U50	thin-walled sample, 50mm diameter
HP	hand penetrometer (kPa)
SV	shear vane test (kPa)
DCP	dynamic cone penetrometer (blows per 100mm penetration)
SPT	standard penetration test
N*	SPT value (blows per 300mm)
	* denotes sample taken
Nc	SPT with solid cone
R	refusal of DCP or SPT

USCS SYMBOLS

GW	Gravel and gravel-sand mixtures, little or no fines.
GP	Gravel and gravel-sand mixtures, little or no fines, uniform gravels
GM	Gravel-silt mixtures and gravel-sand-silt mixtures.
GC	Gravel-clay mixtures and gravel-sand-clay mixtures.
SW	Sand and gravel-sand mixtures, little or no fines.
SP	Sand and gravel sand mixtures, little or no fines.
SM	Sand-silt mixtures.
SC	Sand-clay mixtures.
ML	Inorganic silt and very fine sand, rock flour, silty or clayey fine sand or silt with low plasticity.
CL, CI	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays.
OL	Organic silts
MH	Inorganic silts
CH	Inorganic clays of high plasticity.
OH	Organic clays of medium to high plasticity, organic silt
PT	Peat, highly organic soils.

MOISTURE CONDITION

D	dry
M	moist
W	wet
Wp	plastic limit
Wl	liquid limit

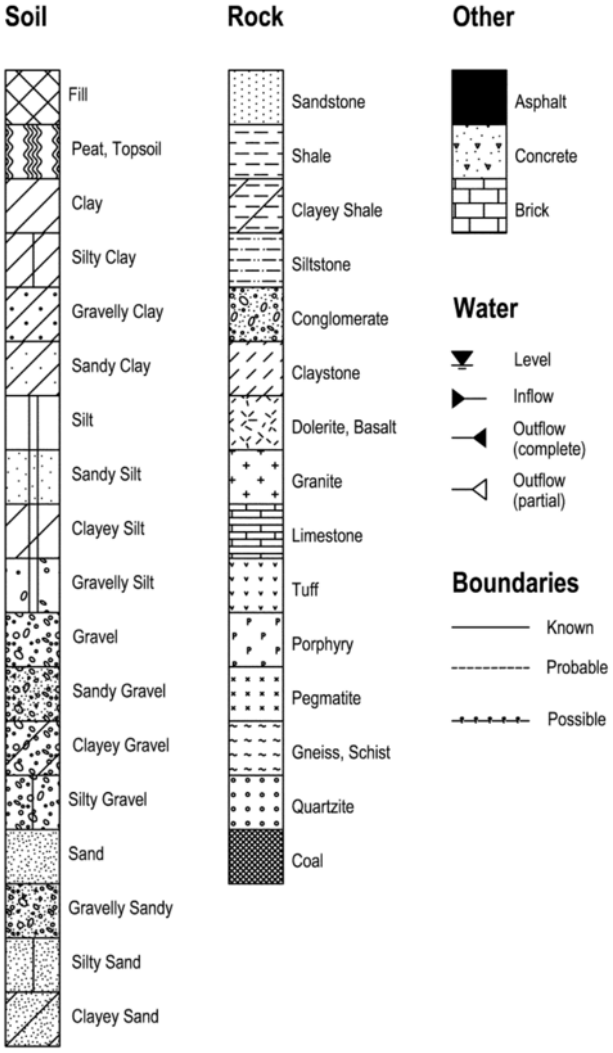
CONSISTENCY

VS	very soft
S	soft
F	firm
St	stiff
VSt	very stiff
H	hard
Fb	friable

DENSITY INDEX

VL	very loose
L	loose
MD	medium dense
D	dense
VD	very dense

Graphic Log



WEATHERING

XW	extremely weathered
HW	highly weathered
MW	moderately weathered
SW	slightly weathered
FR	fresh

STRENGTH

VL	very low
L	low
M	medium
H	high
VH	very high
EH	extremely high

RQD (%)

= sum of intact core pieces > 2 x diameter / total length of core run drilled x 100

DEFECTS:

type

JT	joint
PT	parting
SZ	shear zone
SM	seam

coating

cl	clean
st	stained
ve	veneer
co	coating

shape

pl	planar
cu	curved
un	undulating
st	stepped
ir	irregular

roughness

po	polished
sl	slickensided
sm	smooth
ro	rough
vr	very rough

inclination
measured above axis and perpendicular to core

Soil and Rock Explanation Sheets (2 of 2)

AS1726–2017

Soils and rock are described in the following terms, which are broadly in accordance with AS1726–2017.

Soil

MOISTURE CONDITION

Term	Description
Dry	Looks and feels dry. Fine grained and cemented soils are hard, friable or powdery. Uncemented coarse grained soils run freely through hand.
Moist	Soil feels cool and darkened in colour. Fine grained soils can be moulded. Coarse soils tend to cohere.
Wet	As for moist, but with free water forming on hand.

Moisture content of cohesive soils may also be described in relation to plastic limit (W_P) or liquid limit (W_L) [>> much greater than, > greater than, < less than, << much less than].

CONSISTENCY OF FINE-GRAINED SOILS

Term	Su (kPa)	Term	Su (kPa)
Very soft	< 12	Very Stiff	>100 – ≤200
Soft	>12 – ≤25	Hard	> 200
Firm	>25 – ≤50	Friable	–
Stiff	>50 – ≤100		

RELATIVE DENSITY OF COARSE-GRAINED SOILS

Term	Density Index (%)	Term	Density Index (%)
Very Loose	< 15	Dense	65 – 85
Loose	15 – 35	Very Dense	>85
Medium Dense	35 – 65		

PARTICLE SIZE

Name	Subdivision	Size (mm)
Boulders		> 200
Cobbles		63 – 200
Gravel	coarse	19 – 63
	medium	6.7 – 19
	fine	2.36 – 6.7
Sand	coarse	0.6 – 2.36
	medium	0.21 – 0.6
	fine	0.075 – 0.21
Silt		0.002 – 0.075
Clay		< 0.075

MATERIAL DELINEATION

Sand or gravel	>65% above 0.075mm
Clay or silt	>35% below 0.075mm

MINOR COMPONENTS

Term	Proportion by Mass:	
	coarse grained	*fine grained*
Trace	≤ 5%	≤ 5%
With	>15% ≤ 30%	>5% – ≤12%

SOIL ZONING

Layers	Continuous across exposures or sample.
Lenses	Discontinuous, lenticular shaped zones.
Pockets	Irregular shape zones of different material.

SOIL CEMENTING

Weakly	Easily broken up by hand pressure in water or air.
Moderately	Effort is required to break up by hand in water or in air.

USCS SYMBOLS

Symbol	Description
GW	Gravel and gravel-sand mixtures, little or no fines.
GP	Gravel and gravel-sand mixtures, little or no fines, uniform gravels.
GM	Gravel-silt mixtures and gravel-sand-silt mixtures.
GC	Gravel-clay mixtures and gravel-sand-clay mixtures.
SW	Sand and gravel-sand mixtures, little or no fines.
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SC	Sand-clay mixtures.
ML	Inorganic silt and very fine sand, rock flour, silty or clayey fine sand or silt with low plasticity.
CL, CI	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays.
OL	Organic silts
MH	Inorganic silts
CH	Inorganic clays of high plasticity.
OH	Organic clays of medium to high plasticity, organic silt
PT	Peat, highly organic soils.

Rock

SEDIMENTARY ROCK TYPE DEFINITIONS

Rock Type	Definition (more than 50% of rock consists of .....)
Conglomerate	... gravel sized (>2mm) fragments.
Sandstone	... sand sized (0.06 to 2mm) grains.
Siltstone	... silt sized (<0.06mm) particles, rock is not laminated.
Claystone	... clay, rock is not laminated.
Shale	... silt or clay sized particles, rock is laminated.

LAYERING

Term	Description
Massive	No layering apparent.
Poorly Developed	Layering just visible. Little effect on properties.
Well Developed	Layering distinct. Rock breaks more easily parallel to layering.

STRUCTURE

Term	Spacing (mm)	Term	Spacing
Thinly laminated	<6	Medium bedded	200 – 600
Laminated	6 – 20	Thickly bedded	600 – 2,000
Very thinly bedded	20 – 60	Very thickly bedded	> 2,000
Thinly bedded	60 – 200		

STRENGTH (NOTE: Is50 = Point Load Strength Index)

Term	Is50 (MPa)	Term	Is50 (MPa)
Very Low	0.03 – 0.1	High	1.0 – 3.0
Low	0.1 – 0.3	Very High	3.0 – 10.0
Medium	0.3 – 1.0	Extremely High	>10.0

WEATHERING

Term	Description
Residual Soil	Material is weathered to an extent that it has soil properties. Rock structures are no longer visible, but the soil has not been significantly transported.
Extremely	Material is weathered to the extent that it has soil properties. Mass structures, material texture & fabric of original rock is still visible.
Highly	Rock strength is significantly changed by weathering; rock is discolored, usually by iron staining or bleaching. Some primary minerals have weathered to clay minerals.
Moderately	Rock strength shows little or no change of strength from fresh rock; rock may be discolored.
Slightly	Rock is partially discolored but shows little or no change of strength from fresh rock.
Fresh	Rock shows no signs of decomposition or staining.

DEFECT DESCRIPTION

Type	
Joint	A surface or crack across which the rock has little or no tensile strength. May be open or closed.
Parting	A surface or crack across which the rock has little or no tensile strength. Parallel or sub-parallel to layering/bedding. May be open or closed.
Sheared Zone	Zone of rock substance with roughly parallel, near planar, curved or undulating boundaries cut by closely spaced joints, sheared surfaces or other defects.
Seam	Seam with deposited soil (infill), extremely weathered insitu rock (XW), or disoriented usually angular fragments of the host rock (crushed).
Shape	
Planar	Consistent orientation.
Curved	Gradual change in orientation.
Undulating	Wavy surface.
Stepped	One or more well defined steps.
Irregular	Many sharp changes in orientation.
Roughness	
Polished	Shiny smooth surface.
Slickensided	Grooved or striated surface, usually polished.
Smooth	Smooth to touch. Few or no surface irregularities.
Rough	Many small surface irregularities (amplitude generally <1mm). Feels like fine to coarse sandpaper.
Very Rough	Many large surface irregularities, amplitude generally >1mm. Feels like very coarse sandpaper.
Coating	
Clean	No visible coating or discolouring.
Stained	No visible coating but surfaces are discolored.
Veneer	A visible coating of soil or mineral, too thin to measure; may be patchy
Coating	Visible coating =1mm thick. Thicker soil material described as seam.

Borehole Log

BH no:	**BH1**
sheet:	1 of 1
job no.:	7265

client:	Alexander & Co.	**started:**	14.6.2023
principal:	James and Tracey Smail	**finished:**	14.6.2023
project:	Proposed Residential Development	**logged:**	AT
location:	38 Bower Street, Manly NSW	**checked:**	MAB
equipment:	HA&DCP	**RL surface:**	24.6 m approx.
diameter:	75mm **inclination:** -90° **bearing:** --- **E:** **N:**	**datum:**	AHD

drilling information | **material information**

method	support	water	notes samples, tests, etc	RL	depth metres	graphic log	USCS symbol	material description (soil type: plasticity or particle characteristics, colour, secondary and minor components.)	moisture condition	consistency/ density index	hand penetro-meter kPa (100 200 300 400)	structure and additional observations
HA&DCP	N	NONE OBSERVED		24.5			SC	Clayey SAND with trace Gravel, fine to medium grained sand, dark brown, some root fibers	M	VL		Fill with roots and decomosed leaf
										L		
					0.3		SP	SAND with trace of gravel, fine to medium grained sand, subangular gravel, dark brown				Fill
										MD		
					0.5							
HA				24.0	0.6			SANDSTONE, extremely weathered, inferred Class 5 Sandstone, grey/pale grey mottled yellow				Bedrock
					0.8			Hand auger terminated at 0.8m due to refusal on bedrock. Borehole No: BH1 terminated at 0.8m				Bedrock
				23.5	1.0							
					1.5							

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Borehole Log

BH no:	**BH2**
sheet:	1 of 1
job no.:	7265

client:	Alexander & Co.	**started:**	14.6.2023
principal:	James and Tracey Smail	**finished:**	14.6.2023
project:	Proposed Residential Development	**logged:**	AT
location:	38 Bower Street, Manly NSW	**checked:**	MAB
equipment:	HA&DCP	**RL surface:**	17.8 m approx.
diameter:	75mm **inclination:** -90° **bearing:** --- **E:** **N:**	**datum:**	AHD

drilling information | **material information**

method	support	water	notes samples, tests, etc	RL	depth metres	graphic log	USCS symbol	material description (soil type: plasticity or particle characteristics, colour, secondary and minor components.)	moisture condition	consistency/ density index	hand penetro-meter kPa (100 200 300 400)	structure and additional observations
HA&DCP	N	NONE OBSERVED		17.5	0.3		SC	Sandy CLAY, dark brown, fine to medium grained sand, medium plasticity, grass roots	<Wp	S / F		Fill with grass roots
HA					0.5		SW	SAND with some gravel, dark brown/brown mottled yellow, fine to medium grained sand, subangular gravel	M	MD		Fill
					0.65			SANDSTONE, extremely weathered, grey/pale grey mottled yellow, inferred as Class 5 Sandstone				Bedrock
				17.0	0.7			Hand auger terminated at 0.7m due to refusal on bedrock. Borehole No: BH2 terminated at 0.7m				Bedrock
				16.5	1.0				<Wp			
					1.5							

7265 GINT LOGS.GPJ 14/7/23

REFER TO EXPLANATION SHEETS FOR DESCRIPTION OF TERMS AND SYMBOLS USED — Borehole Log - Revision 10

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Borehole Log

BH no:	**BH3**
sheet:	1 of 1
job no.:	7265

client:	Alexander & Co.	**started:**	14.6.2023
principal:	James and Tracey Smail	**finished:**	14.6.2023
project:	Proposed Residential Development	**logged:**	AT
location:	38 Bower Street, Manly NSW	**checked:**	MAB
equipment:	HA&DCP	**RL surface:**	17.5 m approx.
diameter:	75mm **inclination:** -90° **bearing:** --- **E:** **N:**	**datum:**	AHD

drilling information | **material information**

method	support	water	notes samples, tests, etc	RL	depth metres	graphic log	USCS symbol	material description (soil type: plasticity or particle characteristics, colour, secondary and minor components.)	moisture condition	consistency/ density index	hand penetro-meter kPa (100 200 300 400)	structure and additional observations
HA&DCP	N	NONE OBSERVED					SM	Silty SAND, fine to medium grained sand, dark brown, fine to medium grained sand, grass root fibers	M	L		Fill with grass roots
										MD		Fill
					0.3		SP	Gravelly SAND, dark brown with yellow, fine to medium grained sand, subangular gravel				
HA										VD		
				17.0	0.5							
					0.85			SANDSTONE, grey/pale grey mottled yellow, extremely weathered, inferred Class 5 Sandstone				Bedrock
					0.9			Hand auger terminated at 0.9m due to refusal on bedrock. Borehole No: BH3 terminated at 0.9m				Bedrock
				16.5	1.0							
				16.0	1.5							

REFER TO EXPLANATION SHEETS FOR DESCRIPTION OF TERMS AND SYMBOLS USED

Borehole Log - Revision 10

A: 2.06 / 56 Delhi Road, North Ryde NSW 2113 P: 02 9878 6005 W: assetgeoenviro.com.au

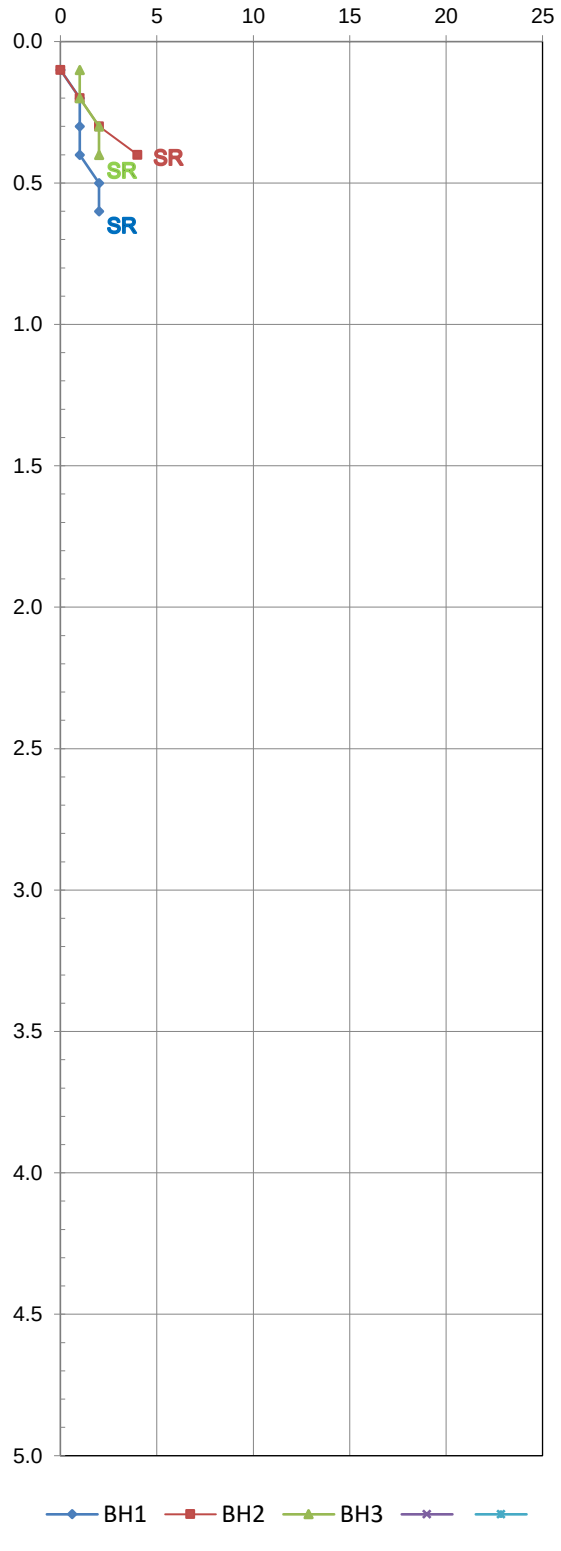
Dynamic Cone Penetrometer

Sheet:	1 of 1
Job No:	7265

client:	Alexander & Co.	**started:**	6/16/2023
principal:	James and Tracey Smail	**finished:**	6/16/2023
project:	Proposed Residential Development	**logged:**	AS
location:	38 Bower Street, Manly NSW	**checked:**	MAB
equipment:	9kg hammer, 510mm drop, cone tip		
standard:	AS1289.6.3.2-1997		

Depth (m)	Test Results (blows / 100mm)				
	BH1	BH2	BH3		
0.00 – 0.10	0	0	1		
0.10 – 0.20	1	1	1		
0.20 – 0.30	1	2	2		
0.30 – 0.40	1	4	2		
0.40 – 0.50	2	SR	SR		
0.50 – 0.60	2				
0.60 – 0.70	SR				
0.70 – 0.80					
0.80 – 0.90					
0.90 – 1.00					
1.00 – 1.10					
1.10 – 1.20					
1.20 – 1.30					
1.30 – 1.40					
1.40 – 1.50					
1.50 – 1.60					
1.60 – 1.70					
1.70 – 1.80					
1.80 – 1.90					
1.90 – 2.00					
2.00 – 2.10					
2.10 – 2.20					
2.20 – 2.30					
2.30 – 2.40					
2.40 – 2.50					
2.50 – 2.60					
2.60 – 2.70					
2.70 – 2.80					
2.80 – 2.90					
2.90 – 3.00					
3.00 – 3.10					
3.10 – 3.20					
3.20 – 3.30					
3.30 – 3.40					
3.40 – 3.50					
3.50 – 3.60					
3.60 – 3.70					
3.70 – 3.80					
3.80 – 3.90					
3.90 – 4.00					
4.00 – 4.10					
4.10 – 4.20					
4.20 – 4.30					
4.30 – 4.40					
4.40 – 4.50					
4.50 – 4.60					
4.60 – 4.70					
4.70 – 4.80					
4.80 – 4.90					
4.90 – 5.00					

Plot (blows / 100mm vs depth)



Notes:

RL = ground surface level (m) AHD

TD = target depth, PR = practical refusal (15+ blows per 100mm), SR = "solid" refusal (no further penetration and "solid" ringing sound from slide hammer)

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Appendix D

Site Photos

Photo 1

Overview of existing residence at the front, looking north from Bower St.

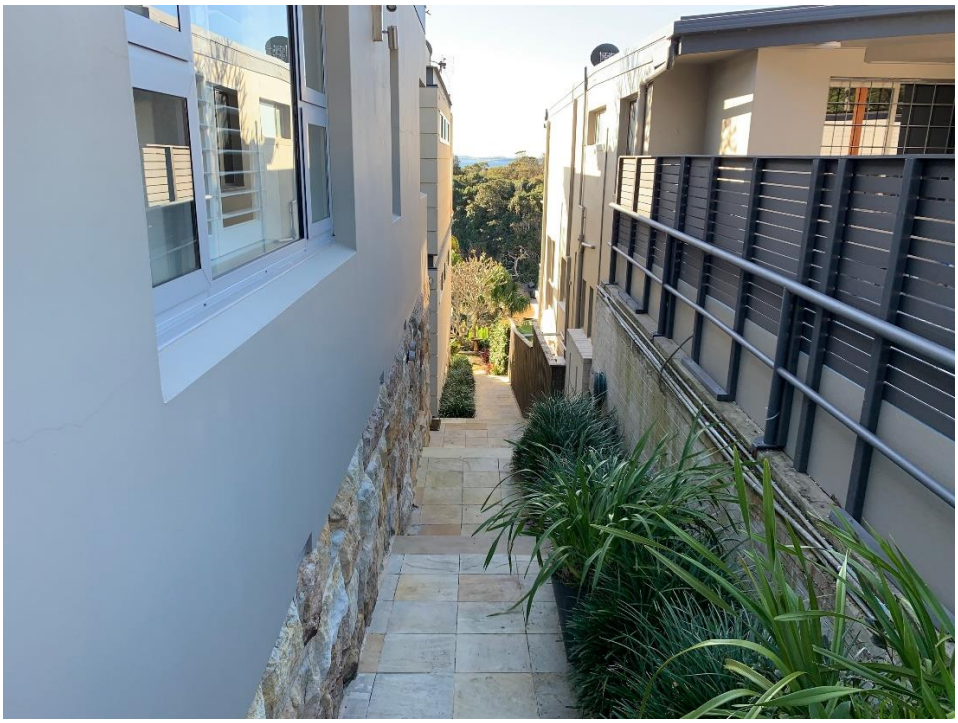

Photo 2

Paved tile access to the rear of residence, looking north.

Photo 3

Overview of masonry retaining wall and sandstone outcrop at the side, looking south.

Photo 4

Overview small retaining walls and at the rear, looking west.

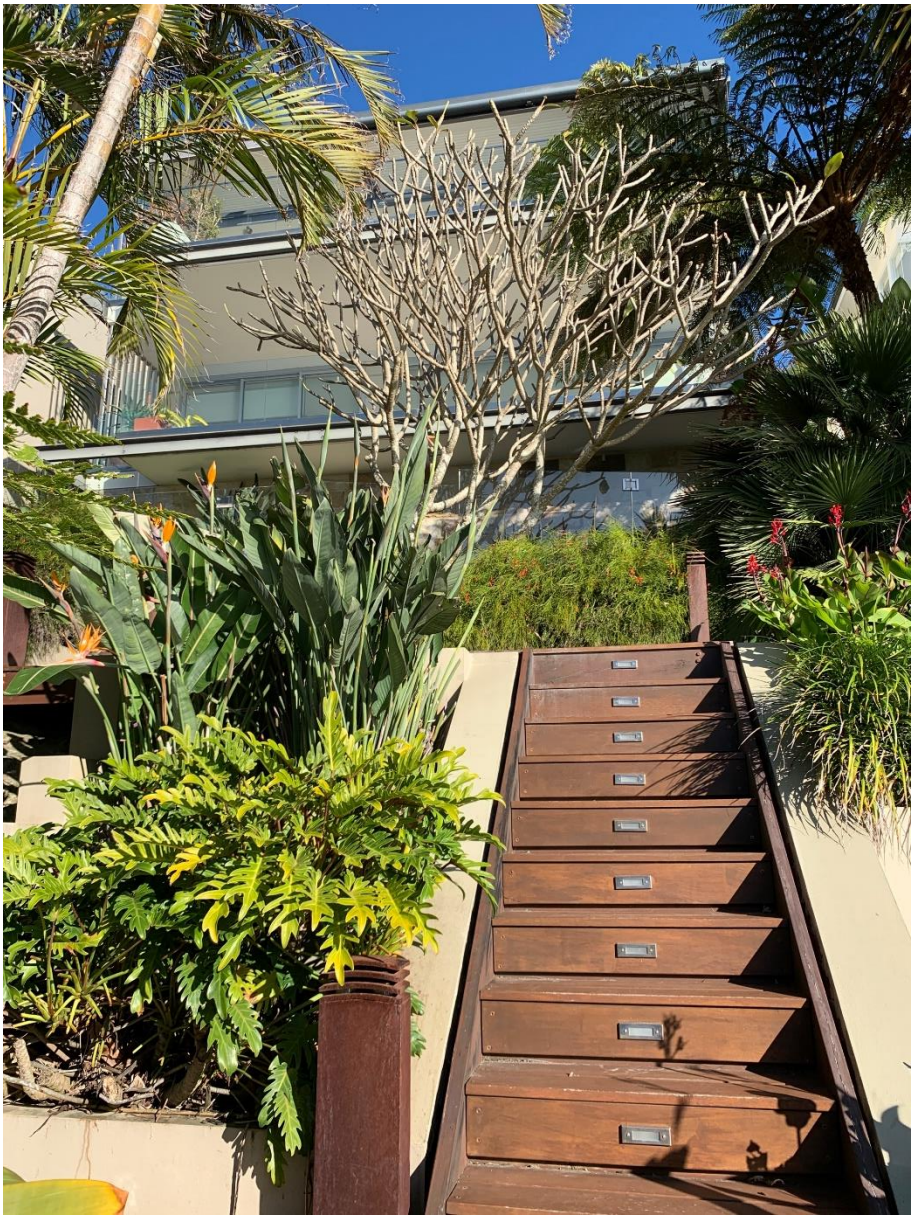

Photo 5

Stair to access the residence from Marine.

Photo 6

Sandstone outcrop at the rear cliff and minor seepage on rock.

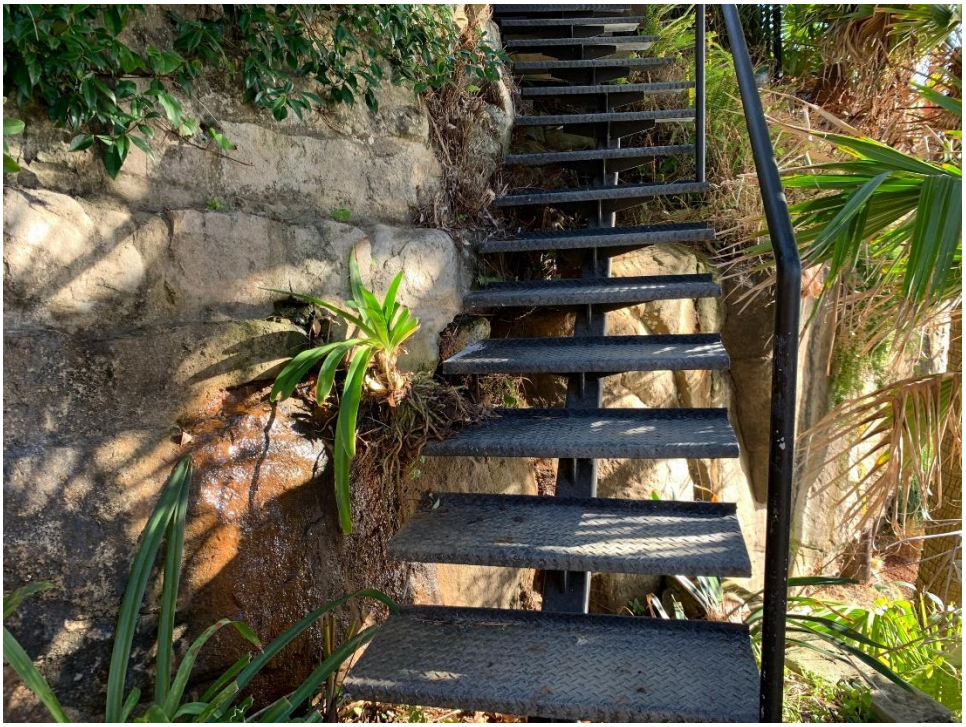

Photo 7

Steel stair anchored to the sandstone cliff. Seepage beneath masonry retaining wall.

Photo 8

Exposed sandstone cliff and retaining wall view from Marine Parade, looking west.

Photo 9

Exposed sandstone cliff and retaining wall view from Marine Parade, looking west. Seepage on the masonry wall.

Photo 10

Exposed sandstone cliff and vegetation, view from Marine Parade looking south.