Geotechnical Site Investigation and Landslide Risk Assessment - Proposed Pool and Deck

Lot 7 / DP7090

38 Lindley Avenue, Narrabeen NSW 2101

Submitted To

Mike Greer
38 Lindley Avenue, Narrabeen NSW 2101

Site Number
148964

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Document Revision History

Date	Rev	Author	Approved by	Comments
21-Dec-21	0	Dave Fisher	Joe McPherson	First Edition

List of Appendices

APPENDIX A: Site Plan, Borehole Logs and Explanatory Notes

APPENDIX B: Site Photography

APPENDIX C: Good Hillside Construction Practice

REFERENCED STANDARDS:

AS 1726-2017, Geotechnical site investigations, Standards Australia, Sydney, Retrieved from SAI Global

AS 2159-2009, Piling-Design and Installation, Standards Australia, Sydney, Retrieved from SAI Global

AS 2870-2011, Residential slabs and footings, Standards Australia, Sydney, Retrieved from SAI Global

AS 3798-2007, Guidelines on earthworks for commercial and residential developments, Standards Australia, Sydney, Retrieved from SAI Global

AS 4678-2002, Earth-retaining structures, Standards Australia, Sydney, Retrieved from SAI Global

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1 Introduction

Intrax Consulting Engineers has completed a geotechnical investigation for the proposed residential development at 38 Lindley Avenue, Narrabeen NSW, which includes a proposed pool and deck.

This report outlines a summary of geotechnical site investigations carried out on 12th August 2020 and 8th February 2021, which were completed for site classification and assessment of the permeability of near-surface soils at the northern end of the site. The report includes an assessment of slope stability, landslide risk and geotechnical recommendations and design parameters for foundations and retaining systems.

2 Background Information

This office has previously undertaken geotechnical investigations for the proposed development including referencing geological and topographical maps, a site walkover inspection, an assessment of the site boundary conditions and observation of existing conditions. Previous works comprised investigation for Metricon Homes (site classification Ref: 148964 - GEO - Site Classification Report [A] dated 13 August 2020, investigation of soil permeability Ref: 148964-GEO-PERC-Lot. 7, Lindley Avenue, Narrabeen, Nsw, 2101_V.0 dated 10 February 2021 and landslide risk assessment Ref: 148964 GEO-LRA-Narrabeen_V.0 dated 9 September 2021).

2.1 Referenced Documents

At the time this report was prepared, the following external documents were reviewed.

- Architectural landscape plan prepared by Sticks and Stones [Prj No. 1105, Dwg Nos F101 dated 10.12.2021],
- Section E10 of the Warringah Development Control Plan (Northern Beaches Council website) and
- Stormwater Layout SH.1 and Stormwater Details SH.1 (Ref: M9915-714763^{C}) dated 7 September 2021 by Ibrahim Stormwater Consultants.

2.2 Project and Site Description

2.2.1 Project Description

The proposed development incorporates construction of a cast-in-situ concrete pool and timber deck adjacent to the northern edge of a new dwelling (to be constructed) at 38 Lindley Avenue, Narrabeen.

Intrax understand that the proposed pool will be positioned within the north-eastern portion of the property, constructed primarily above ground, and may require excavation to a maximum depth of approximately 1 m. The proposed timber deck will occupy the area to the west of the pool and be constructed at a similar level to the pool surround, which will be 50 mm lower than the ground floor level of the main dwelling.

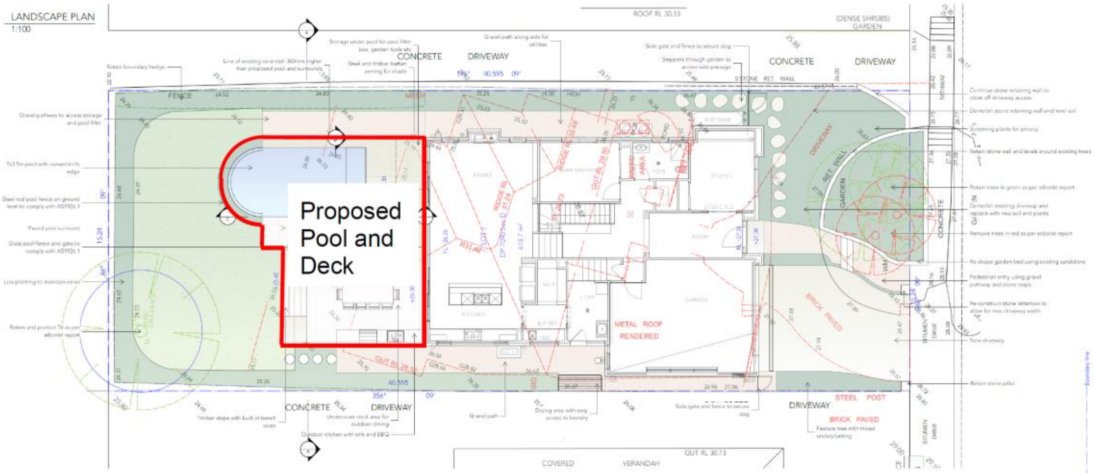


Figure 1: Proposed pool and deck

2.3 Site Description

The site is bound by Lindley Avenue to the south and by residential properties, similar to the subject site, to the east, west and north. Outcrops of sandstone bedrock or detached blocks of sandstone bedrock are visible near the street frontage of the site and just beyond the northern site boundary, where subvertical elevation relief of up to about 3 m is present.

Across the eastern site boundary, the site is supported by a retaining wall which is up to about 2 m high and is constructed from sandstone flagging with cement infill above a concrete driveway. The sandstone flagging retaining wall along the eastern boundary of the site appears to generally be in good condition, however we note that no obvious drainage mechanism from behind the wall was observed. The top of the sandstone flagging has been extended up approximately 0.4 m with loose, horizontally placed sandstone flagging near the north-eastern corner of the site.

The northern site boundary is supported above the neighbouring concrete driveway by retaining walls constructed from sandstone flagging with cement infill, which are founded on ‘blocky’ sandstone bedrock and infill gaps in the sandstone blocks. The sandstone flagging retaining walls near the northern site boundary appear to be poor condition. Surface levels across the southern and western site boundaries are similar under existing (pre-development) conditions.

We understand that the existing stormwater management system comprises downpipes that discharge to the ground surface, and the owner of the property has indicated that he has not previously received complaints from downslope neighbours regarding the uncontrolled discharge of stormwater.

The average slope of the site and immediate surrounds is approximately 6°, and the maximum slope downhill (to the north of the site) is up to approximately 14° to 15°.

Site conditions on the date of inspection are visible in the attached photography in Appendix B.

3 Method of Investigation

3.1 Desktop Assessment

Geological maps from the Geological Survey of NSW, aerial photography and our local experienced were used to assess the anticipated site conditions and the area geology.

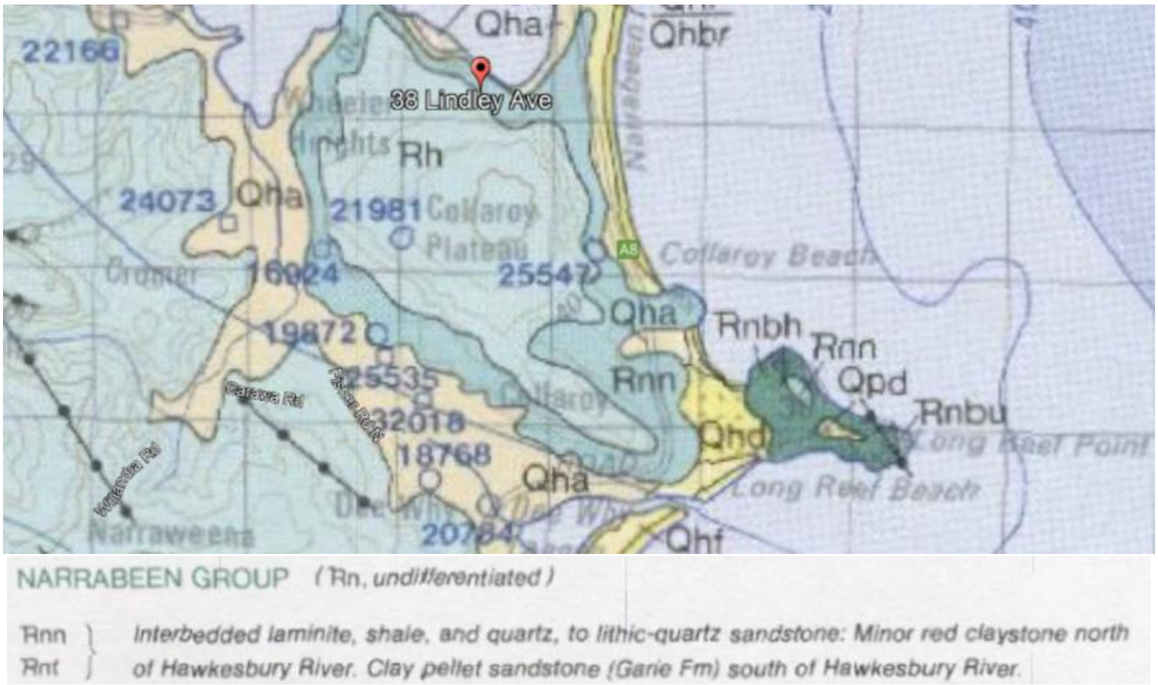
3.2 Fieldwork

The initial fieldwork consisted of drilling a total of two (2) boreholes to depths of 0.8 m and 1.1 m using a hand auger, and one Dynamic Cone Penetration (DCP) test, which refused to further penetration at a depth of approximately 0.9 m. Fieldwork for our permeability assessment comprised drilling three (3) additional boreholes using a hand auger to a maximum depth of 0.8 m. The approximate locations of the boreholes are shown on the attached site plan in Appendix A. The subsurface materials were visually classified in accordance with AS1726-2017: *Geotechnical Site Investigation*.

4 Results of Investigation

4.1 Desktop Assessment

Investigation of geological maps from the Geological survey of NSW indicates that the expected site geology comprises interbedded laminite, shale and quartz to quartz lithic sandstone of the Narrabeen Group, which is consistent with observations made during our site visit.



NARRABEEN GROUP (Rn, undifferentiated)

Rnn } Interbedded laminite, shale, and quartz, to lithic-quartz sandstone: Minor red claystone north
Rnt } of Hawkesbury River. Clay pellet sandstone (Garie Fm) south of Hawkesbury River.

Figure 2: Extract of local geology, 1:100,000 scale geological map, Series Sheet 9130 Sydney First Edition, 1983

4.2 Subsurface Conditions

The boreholes revealed substrata typically consisting of the following soil profile. Refer to borehole logs in Appendix A for details.

FILL	Silty Sand, dark brown or brown, with root fibres
Residual Soil	Sandy CLAY; high plasticity, grey and red brown, generally w>PL, firm to stiff
Inferred BEDROCK	Sandstone bedrock (or possibly detached sandstone blocks) is inferred at a depth of approximately 0.8 m to 1 m in the vicinity of the proposed pool footprint.

4.2.1 Ground Water

Groundwater was not intersected during borehole drilling. Substrata conditions encountered are such that infiltration and occurrence of perched water at the interface between different material layers should not be unexpected. We anticipate that fill materials may become saturated during rainfall, and that in the medium to long term (following rainfall) under existing conditions, the soil profile will be become fully drained.

5 Slope Stability Assessment

5.1 Introduction

The subject site is located within an area defined by the Warringah Development Control Plan (Northern Beaches Council) as Landslip Risk Class E due to the anticipated ground slopes in excess of 15 degrees and geological conditions including 'Colluvial & residual soils & bouldery talus, with detached blocks of sandstone on steeper escarpment areas, developed on Narrabeen Group or Hawkesbury Sandstone.'

With respect to the scope of the proposed development, the likelihood of landslide hazards occurring (risk) and the consequences of those hazards are evaluated. The mitigation methods are proposed to maintain the serviceability and reliability (safety) of the development, to reduce the future risk to an acceptable level.

A slope stability assessment was conducted during the investigation as per guidelines provided by Australian Geomechanics Society Practice Note Guidelines for Landslide Risk Management Landslide Task Force 2007, presented in Appendix C.

5.2 Risk Analysis/Assessment

5.2.1 Risk Management Terminology

Risk is defined as a measure of the probability and severity of an adverse effect to health, property or the environment. (Australian Geomechanics Society Landslide Taskforce. 2007).

Risk is a product of the chance of an event (likelihood) and the consequences.

A comprehensive list of terms can be found in the Australian Geomechanics Society Practice Note Guidelines for Landslide Risk Management Landslide Task Force 2007, which is presented in Appendix C.

5.2.2 Hazard Identification and Likelihood

The identified hazards associated are summarised as follows:

Hazard A- surface flow of earth (earth-debris flow):

During prolonged rain events, there is a potential for surficial soils to become saturated. As such, movement of the surface soil downslope has been considered under this scenario. The sudden collapse of a retaining wall which supports the northern site boundary has the potential to cause damage or injury. The potential exists for retaining walls supporting saturated soils to collapse due to inadequate structural design or deficiencies in construction. It is imperative that new retention along the northern site boundary be designed and constructed. Due to the condition of the existing retaining walls along the northern site boundary, we consider that this event may be considered **"unlikely"** in the short term and **"possible"** in the medium to long term under existing site conditions due to degradation of the retaining wall overtime. Provided that new retention along the northern site boundary is engineer designed and constructed to modern standards, and that the proposed dwelling is founded below the zone of influence of the existing retaining wall along the eastern site boundary, we consider that the likelihood of such an event could be reduced to **"rare"** under proposed conditions.

Hazard B - shallow translational/ rotational slide:

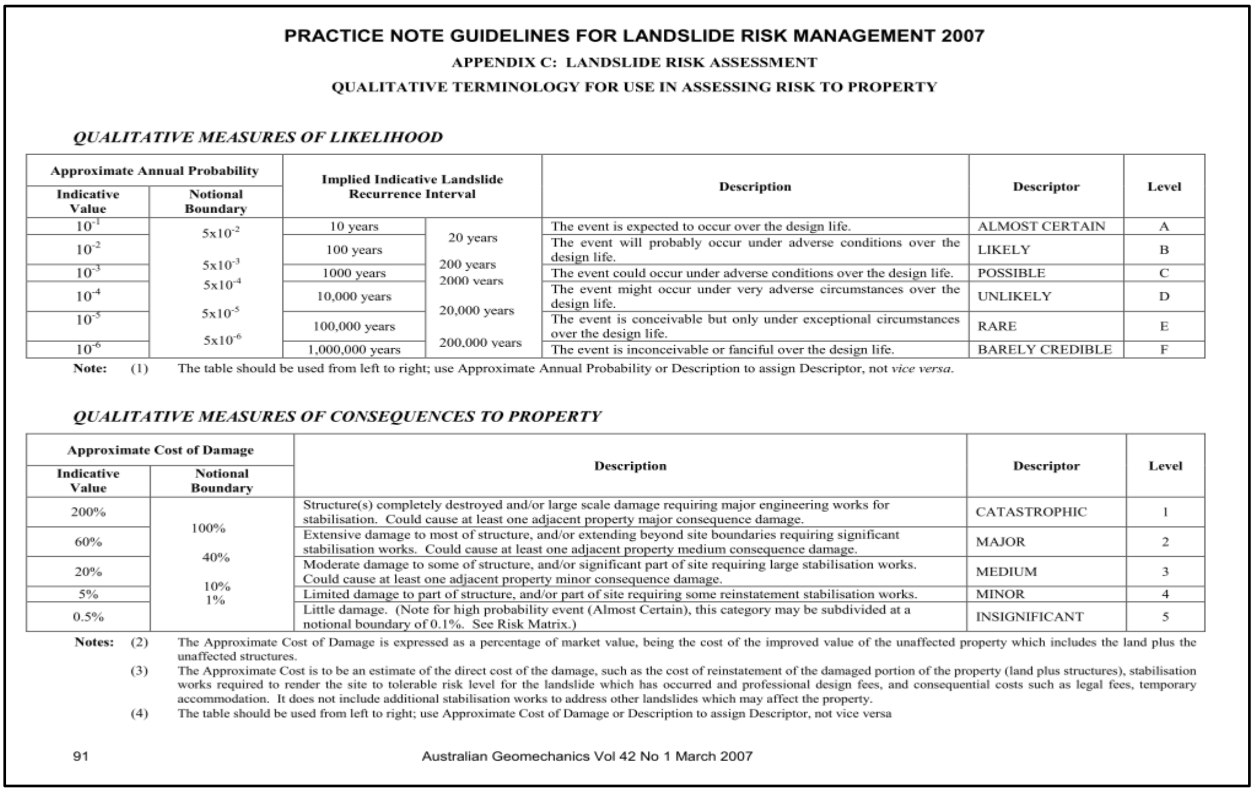
This mechanism describes an event where the soil moves downslope due to failure along a circular slip surface. No indicators of slope failure were present at the time of our inspection on the subject site or adjacent properties. As the inferred geological model for this site includes sandstone bedrock (or the presence of detached sandstone blocks) from a relatively shallow depth, we consider that the likelihood of Hazard B is **"barely credible"** under the existing or proposed conditions, provided that construction loads or new footings for the proposed structures do not apply any additional surcharge to existing retaining walls along the northern or eastern site boundaries.

5.2.3 Consequence Values

Consequences of the possible hazards are identified by using the table Qualitative Measures of Consequences to Property of Appendix C of AGS Landslide Risk Management - 2007 document in table 4, and assessed as follows;

Hazard A
'Minor' damage to the neighbouring property may be anticipated due to an occurrence of Hazard A.

Hazard B
The proposed land use for the development involves additional loading to the footprint of the proposed structure due to an increase in the size of the dwelling. The consequences of damage to property which could be caused by Hazard B are considered 'medium'. A deep-seated regional earth slide landslip has the potential to severely damage foundations and could potentially cause injury or loss of life, especially if the slide was rapid, not giving sufficient warning to inhabitants.



PRACTICE NOTE GUIDELINES FOR LANDSLIDE RISK MANAGEMENT 2007

APPENDIX C: LANDSLIDE RISK ASSESSMENT

QUALITATIVE TERMINOLOGY FOR USE IN ASSESSING RISK TO PROPERTY

QUALITATIVE MEASURES OF LIKELIHOOD

Approximate Annual Probability		Implied Indicative Landslide Recurrence Interval		Description	Descriptor	Level
Indicative Value	Notional Boundary					
10^{-1}	$5x10^{-2}$	10 years	20 years	The event is expected to occur over the design life.	ALMOST CERTAIN	A
10^{-2}	$5x10^{-3}$	100 years	200 years	The event will probably occur under adverse conditions over the design life.	LIKELY	B
10^{-3}	$5x10^{-4}$	1000 years	2000 years	The event could occur under adverse conditions over the design life.	POSSIBLE	C
10^{-4}	$5x10^{-5}$	10,000 years	20,000 years	The event might occur under very adverse circumstances over the design life.	UNLIKELY	D
10^{-5}	$5x10^{-6}$	100,000 years	200,000 years	The event is conceivable but only under exceptional circumstances over the design life.	RARE	E
10^{-6}		1,000,000 years		The event is inconceivable or fanciful over the design life.	BARELY CREDIBLE	F

Note: (1) The table should be used from left to right; use Approximate Annual Probability or Description to assign Descriptor, not *vice versa*.

QUALITATIVE MEASURES OF CONSEQUENCES TO PROPERTY

Approximate Cost of Damage		Description	Descriptor	Level
Indicative Value	Notional Boundary			
200%	100%	Structure(s) completely destroyed and/or large scale damage requiring major engineering works for stabilisation. Could cause at least one adjacent property major consequence damage.	CATASTROPHIC	1
60%	40%	Extensive damage to most of structure, and/or extending beyond site boundaries requiring significant stabilisation works. Could cause at least one adjacent property medium consequence damage.	MAJOR	2
20%	10%	Moderate damage to some of structure, and/or significant part of site requiring large stabilisation works. Could cause at least one adjacent property minor consequence damage.	MEDIUM	3
5%	1%	Limited damage to part of structure, and/or part of site requiring some reinstatement stabilisation works.	MINOR	4
0.5%		Little damage. (Note for high probability event (Almost Certain), this category may be subdivided at a notional boundary of 0.1%. See Risk Matrix.)	INSIGNIFICANT	5

Notes: (2) The Approximate Cost of Damage is expressed as a percentage of market value, being the cost of the improved value of the unaffected property which includes the land plus the unaffected structures.

(3) The Approximate Cost is to be an estimate of the direct cost of the damage, such as the cost of reinstatement of the damaged portion of the property (land plus structures), stabilisation works required to render the site to tolerable risk level for the landslide which has occurred and professional design fees, and consequential costs such as legal fees, temporary accommodation. It does not include additional stabilisation works to address other landslides which may affect the property.

(4) The table should be used from left to right; use Approximate Cost of Damage or Description to assign Descriptor, not vice versa

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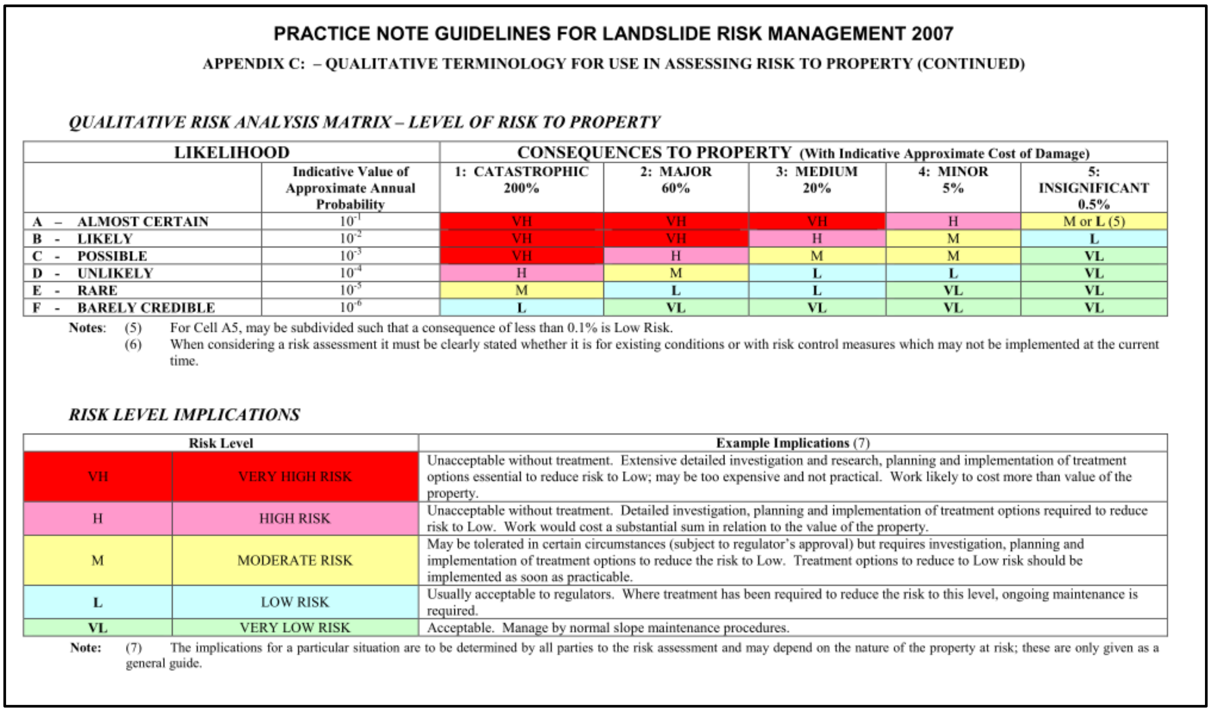
Figure 2: Landslide Risk Assessment

Terminology used in Figure 3 are used to describe the risk levels of the identified hazards. In the scope of the AGS Guideline-2007 (Appendix D), low risk levels are acceptable. The risk management plan described in the following section shall be carried out to limit the hazards to an acceptable risk level.



PRACTICE NOTE GUIDELINES FOR LANDSLIDE RISK MANAGEMENT 2007

APPENDIX C: – QUALITATIVE TERMINOLOGY FOR USE IN ASSESSING RISK TO PROPERTY (CONTINUED)

QUALITATIVE RISK ANALYSIS MATRIX – LEVEL OF RISK TO PROPERTY

LIKELIHOOD		CONSEQUENCES TO PROPERTY (With Indicative Approximate Cost of Damage)				
	Indicative Value of Approximate Annual Probability	1: CATASTROPHIC 200%	2: MAJOR 60%	3: MEDIUM 20%	4: MINOR 5%	5: INSIGNIFICANT 0.5%
A – ALMOST CERTAIN	10^{-1}	VH	VH	VH	H	M or L (5)
B - LIKELY	10^{-2}	VH	VH	H	M	L
C - POSSIBLE	10^{-3}	VH	H	M	M	VL
D - UNLIKELY	10^{-4}	H	M	L	L	VL
E - RARE	10^{-5}	M	L	L	VL	VL
F - BARELY CREDIBLE	10^{-6}	L	VL	VL	VL	VL

Notes: (5) For Cell A5, may be subdivided such that a consequence of less than 0.1% is Low Risk.
(6) When considering a risk assessment it must be clearly stated whether it is for existing conditions or with risk control measures which may not be implemented at the current time.

RISK LEVEL IMPLICATIONS

Risk Level		Example Implications (7)
VH	VERY HIGH RISK	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 value of the property.
H	HIGH RISK	Unacceptable without treatment. Detailed investigation, planning and implementation of treatment options required to reduce risk to Low. Work would cost a substantial sum in relation to the value of the property.
M	MODERATE RISK	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 practicable.
L	LOW RISK	Usually acceptable to regulators. Where treatment has been required to reduce the risk to this level, ongoing maintenance is required.
VL	VERY LOW RISK	Acceptable. Manage by normal slope maintenance procedures.

Note: (7) The implications for a particular situation are to be determined by all parties to the risk assessment and may depend on the nature of the property at risk; these are only given as a general guide.

Figure 3: Extract Appendix C – AGS (2007)

5.2.4 Risk Assessment for Property

The following table is a brief risk assessment to highlight the potential risk of landslides to the proposed development/allotment associated with the current hazards identified during the site inspection and fieldwork. The assessment below assumes that all recommended controls are implemented, including the reconstruction of retaining structures near the northern site boundary.

Table 2: Landslide Risk Assessment

Landslide Event	Likelihood	Consequence	Risk
Hazard A	"Rare"	Medium	**Low**
Hazard B	"Barely Credible"	Medium	**Very Low**

The above terminology is taken from the AGS Practice note guidelines for Landslide Risk Management (2007) – Appendix C (as reproduced below).

5.2.5 Recommendations – Risk Management

Based on the site investigation and observations made during the assessment completed by this office, it is concluded that the proposed development is considered to have an acceptably low risk.

The following items are considered good hillside practice and should be considered in the typical design elements of construction on site. It is recommended that all sites cuts [if necessary] >600mm are retained by engineer designed retention system design based on the soils strength parameters given in section 5.5 of this report.

The following precautionary measures must be followed to maintain the low risk to property and to life.

- All site cuts >600mm shall be retained by an engineer designed retaining system. Installation of drainage behind the retaining walls must be installed.
- Our preference is for all surface and run off water to be collected and discharged to a legal point of discharge, and for ponding of surface water within the site to be avoided. We understand, however, that due to the absence of an easement for stormwater drainage, an on-site detention basin and drainage via an orifice plate and 'level spreader' system has been proposed by the hydraulic engineer. The hydraulic engineer also indicated that downslope retaining walls would require capacity for full height hydrostatic loading. We have previously recommended that weep holes be incorporated into the design of any new downslope retaining walls to alleviate the potential for transient hydrostatic pressures on the adjacent retaining wall (along the eastern boundary of the site, which we infer is unlikely to be reconstructed). Any further changes to the drainage system design are to be reviewed by Intrax Consulting Engineers.
- Once the roof is constructed temporary down pipes must be installed and they must be connected to storm water pit or a legal water point discharge.
- Any exposed surfaces must be revegetated as soon as construction works are completed with natural grasses and shrubs (ideally fast-growing plants with vigorous root system), which will eventually minimise surface erosion and siltation.
- Footings for the proposed pool must be founded below the zone of influence of the retaining walls, or otherwise considered in the design of new retaining walls.
- Excavation for the proposed pool is generally anticipated to be achievable using conventional earthmoving equipment (bucket attached to a hydraulic excavator). Nominal trimming of, and / or excavation into sandstone bedrock will be required to construct footings for the proposed pool and deck due to the presence of filling materials over inferred sandstone bedrock at the northern end of the site.
- Where rock excavation is required, we recommend limiting the machine size to maximum 2T excavator with rock hammer. Consideration should also be given to methods of operation which limit the transmission of vibrations during hammering.

Note: Intrax would be required to review any drawings prior to construction to ensure the recommendations of this report can be achieved.

5.3 Site Classification in Accordance With AS2870-2011

In accordance with AS2870-2011 "Residential Slabs and Footings Construction" a site classification of **Class "P"** is applicable to this site **due to abnormal moisture conditions – trees and existing building on site and trees on adjacent sites.**

This site is subject to abnormal moisture conditions which must be alleviated or allowed for in the design of the footing system. In the absence of these abnormal moisture conditions, the designing engineer should recognise that the natural soils encountered on this site result in a **"Class M"** site classification applying to this site.

On the basis of the findings in this investigation, including visual-tactile identification of the soil profile combined with this writer's local knowledge and experience, the characteristic surface movement (Ys) on this site – under normal conditions – has been estimated to be in the range of **20 mm to 40 mm**.

5.4 Foundations

5.4.1 Pad Footings and Piled Foundations

Where piles are proposed, we recommend that bored, cast in situ piers are used at this site. We anticipate that attempts to install screw piles would likely result in premature refusal of the piles. Pad footings or bored piles embedded at least 100 mm into sandstone may be designed for an allowable bearing pressure of 300 kPa in end bearing only.

5.5 Excavation and Retention

5.5.1 Excavation

We anticipate that bulk excavation for the proposed pool will be required to approximately 1 m below existing levels. In the vicinity of the proposed pool, we anticipate that uncontrolled fill will be encountered to a depth of about 0.8 m. In the absence of retention or battering, we do not anticipate that the fill materials will be self-supporting for any significant time period, therefore, we recommend that the sides of the excavation be laid back at about 1 (Horizontal) :2 (Vertical) [i.e. 65°] and that no construction loads (machinery or materials) be applied within the zone of influence of the open excavation. Some minor slumping of material into the excavation should not be unexpected where these relatively steep excavation angles are adopted, especially during or following rainfall. This advice is only applicable where the proposed depth of excavation is limited to 1m below adjacent surface levels.

Care will also need to be taken to avoid applying construction loads within the zone of influence of nearby retaining walls along the eastern boundary of the site and near the northern site boundary. Where the potential exists for the pool excavation to undermine any existing footings or buried services, the excavation must be supported by engineer designed cast in-situ retention installed prior to the commencement of excavation.

5.5.2 Retention Design Parameters

The following parameters established from Rankine's theory are valid in the design of a retention system. These values assume that the soil being retained/supported has a horizontal backfill surface.

Table 1: Geotechnical soil and retention design parameters

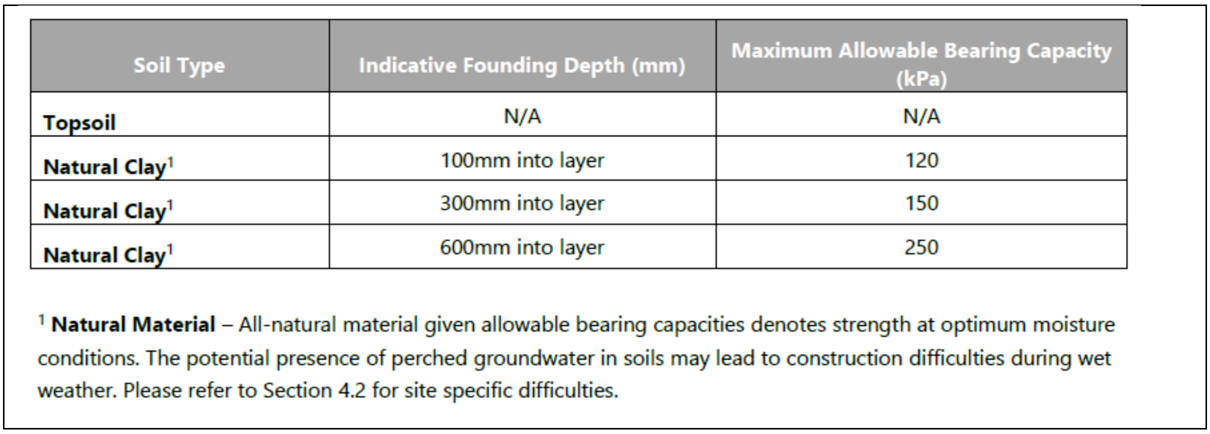
Material Description	Depth*	Unit weight (kN/m^3)	Su (kPa)	Friction angle (°)	Ka#	Kp#	K_0#
Granular (Sandy) FILL	Up to 2m	18	-	28	0.36	2.77	0.53
silty CLAY	Up to 2m	19	60	26	0.39	2.56	0.56
Weathered Sandstone	>2m	21	180	28	0.36	2.77	0.53

**Approximate depth based on borehole logs completed during geotechnical investigation*

$^{\#}K_a$, K_p and K_o are the active, passive and at-rest earth pressure coefficients.

The above parameters assume that any groundwater water is effectively and permanently drained from behind the retaining wall to below the excavation level, and that any adjacent surcharge loads are superimposed.

Allowable bearing pressures provided in our previous report (site classification Ref: 148964 - GEO - Site Classification Report [A] dated 13 August 2020) are relevant for foundation loading and have been repeated below for convenience.



Soil Type	Indicative Founding Depth (mm)	Maximum Allowable Bearing Capacity (kPa)
Topsoil	N/A	N/A
Natural Clay[1]	100mm into layer	120
Natural Clay[1]	300mm into layer	150
Natural Clay[1]	600mm into layer	250

[1] **Natural Material** – All-natural material given allowable bearing capacities denotes strength at optimum moisture conditions. The potential presence of perched groundwater in soils may lead to construction difficulties during wet weather. Please refer to Section 4.2 for site specific difficulties.

Excerpt from Site Classification Report

Footings embedded at least 100mm into sandstone may be designed for an allowable bearing pressure of 300kPa.

5.6 Inspections (Hold Points)

Intrax **must** be engaged at the following stages:

1. In the event soil conditions encountered differ significantly from those described within this report.
2. If project design is altered significantly from drawings reviewed and outlined or project described within this report
3. To confirm safe batter angles and excavation construction during construction.
4. Any sign of instability during construction or along the boundary retaining walls including but not limited to:
   a. Noticeable movement
   b. Tension cracks
   c. Displaced material at the base of the cut/wall

Intrax **should** be engaged at the following stages:

5. Review of engineer design for proposed retaining walls.
6. At the time of the following construction;
   - Foundation material and allowable bearing pressures
   - Site drainage

6 Limitations of Report

1. The recommendations in this report are based on the following:
    a. Information about the site & its history, proposed site treatment and building type conveyed to us by the client and or their agent
    b. Professional judgements and opinions using the most recent information in soil testing practice that is available to us.
    c. The location of our test sites and the information gained from this and other investigations.

    Should the client or their agent neglect to supply us with correct or relevant information, including information about previous buildings, trees or past activities on the site, or should changes be made to the building type, size and or/position, this report may be made obsolete, irrelevant or unsuitable. In such cases, Intrax will not accept any liability for the consequences and Intrax reserves the right to make an additional charge if more testing or a change to the report is necessary.

2. The recommendations made in this report may need to be reviewed should any site works disturb any soil 200mm below the proposed founding depth.

3. The descriptions of the soils encountered in the boreholes follow those outlined in AS1726-2017; Geotechnical Site Investigations. Colour descriptions can vary with soil moisture content and individual interpretation.

4. If the site conditions at the time of construction differ from those described in this report then Intrax must be contacted so a site inspection can be carried out prior to any footing being poured. The owner/builder will be responsible for any fees associated with this additional work.

5. This report assumes that the soil profile observed in the boreholes are representative of the entire site. If the soil profile and site conditions appear to differ substantially from those reported herein, then Intrax should be contacted immediately and this report may need to be reviewed and amended where appropriate. The owner/builder will be responsible for any fees associated with this additional work.

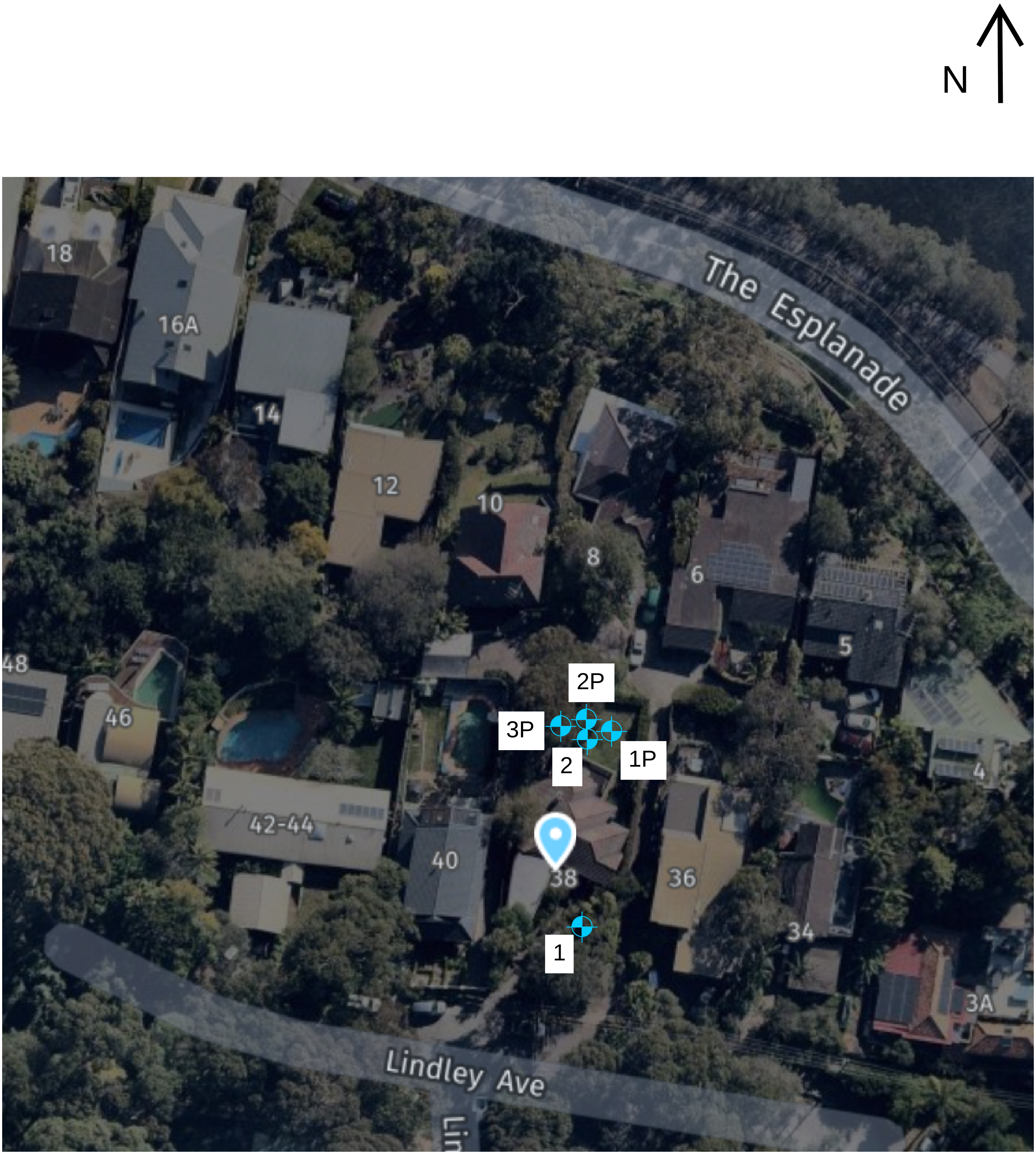
6. The user of this report must take into account the following limitations. Soil and drilling depths are given to a tolerance of +/- 200mm.

    It must be understood and a condition of acceptance of this report is that whilst every effort is made to identify fill material across the site, difficulties exist in determining fill material, in particular, for example, well compacted site or area derived fill, when utilising a small diameter auger. Consequently Intrax emphasises that we will not be responsible for any financial losses, consequential or otherwise, that may occur as a result of not accurately determining the fill profile across the site.

7. Finally, no responsibility will be taken for this report if it is altered in any way or is not reproduced in full.

Appendix A

Site Plan, Borehole Logs and Explanatory Notes



Client Name: Metricon Homes Pty Ltd - NSW	Scale: NTS
	Date: 20/8/2021
Site Address: 38 Lindley Ave, Narrabeen, NSW	Sheet: 1 of 1
Drawing: Site Plan	Project No: 148964 / Version: 1

Intrax

Civil
Forensic
Hydraulic
Structural
Surveying
Residential
Geotechnical
Building Services

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New South Wales	02 4869 5666
Queensland	07 3813 5617
South Australia	08 8165 0122

A.B.N 31 106 481 252
www.intrax.com.au

Site Address:	**Lot. 7, Lindley Avenue, Narrabeen, Nsw, 2101**						HAND AUGER	HAND AUGER
Horizon	**USC**	**Soil Type**	**Moisture**	**Density/ Consistency/ Strength**	**Plasticity**	**Description**	**Borehole 1**	**Borehole 2**
EXISTING SURFACE LEVEL							0	0
TOPSOIL	SM	silty SAND trace clay gravel	Moist	Loose		black grey	0 - 500	0 - 400
A	CH	sandy CLAY trace gravel	Moist, Wet of Plastic Limit	Firm Stiff	High Plasticity	grey red brown	500 - 1100	400 - 800
				Intrax ID #:		148964	REFUSAL ON STIFF CLAY	REFUSAL ON STIFF CLAY
				Date of Fieldwork		12/08/2020	Groundwater Not Encountered	Groundwater Not Encountered

Intrax

TEST: 1P

Sheet 1 OF 1

Project:	-			Date Started:	
Location:	Lot. 7, Lindley Avenue, Narrabeen, Nsw, 2101			Date Completed:	
Position:		Contractor:		Logged:	DF
Job No.:	148964	Drill Rig:	Drill Rig	Checked:	GY
Client:	Metricon Homes Pty Ltd : Metricon Homes Pty Ltd - NSW	Inclination:	-90°	Date:	10/2/2020

Drilling					Sampling / Testing			Field Material Description					
Method	Penetration Resistance	Water	Depth (m)	*Depth* RL	Sample or Test	DCP	Recovered	Graphic Log	Group Symbol	Material Description	Moisture Condition	Consistency / Density	Origin and Aditional Observations
HA			0.0					▨	SP	FILL: gravelly SAND; fine to coarse grained, grey brown	M	L to MD	FILL
			0.2	*0.20*				▨	SM	FILL: silty SAND; fine to medium grained, with gravel	M	MD	
			0.8	*0.80*						Hole Terminated at 0.80 m Refusal			
			1.0										
			1.2										

Refer to explanatory notes for definitions
and abbreviations

TEST: 2P

Sheet 1 OF 1

Project:	-			Date Started:	
Location:	Lot. 7, Lindley Avenue, Narrabeen, Nsw, 2101			Date Completed:	
Position:		Contractor:		Logged:	DF
Job No.:	148964	Drill Rig:	Drill Rig	Checked:	GY
Client:	Metricon Homes Pty Ltd : Metricon Homes Pty Ltd - NSW	Inclination:	-90°	Date:	10/2/2020

Drilling					Sampling / Testing			Field Material Description					
Method	Penetration Resistance	Water	Depth (m)	*Depth* RL	Sample or Test	DCP	Recovered	Graphic Log	Group Symbol	Material Description	Moisture Condition	Consistency / Density	Origin and Aditional Observations
HA			0.0 0.2 0.4	*0.45*				▨	ML	FILL: sandy SILT; low plasticity, grey orange, with roof material, trace bricks	w ≈ PL	F	FILL
			0.6 0.8 1.0 1.2							Hole Terminated at 0.45 m Refusal			

Refer to explanatory notes for definitions and abbreviations

TEST: 3P

Sheet 1 OF 1

Project:	-			Date Started:	
Location:	Lot. 7, Lindley Avenue, Narrabeen, Nsw, 2101			Date Completed:	
Position:		Contractor:		Logged:	DF
Job No.:	148964	Drill Rig:	Drill Rig	Checked:	GY
Client:	Metricon Homes Pty Ltd : Metricon Homes Pty Ltd - NSW	Inclination:	-90°	Date:	10/2/2020

Drilling					Sampling / Testing			Field Material Description					
Method	Penetration Resistance	Water	Depth (m)	*Depth* RL	Sample or Test	DCP	Recovered	Graphic Log	Group Symbol	Material Description	Moisture Condition	Consistency / Density	Origin and Aditional Observations
HA			0.0 0.2	*0.30*				▨	ML	FILL: sandy SILT; low plasticity, grey orange, with roof material, with gravel	w ≈ PL	F	FILL
			0.4 0.6 0.8 1.0 1.2							Hole Terminated at 0.30 m Refusal			

Refer to explanatory notes for definitions and abbreviations

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EXPLANATION OF NOTES, ABBREVIATIONS & TERMS USED ON BOREHOLE AND TEST PIT LOGS

DRILLING/EXCAVATION METHOD

HA	Hand Auger	W	Washbore	PT	Push Tube
MA-	Mechanical Auger Drilling	HQ	Diamond Core - 63 mm	EX	Excavator
-V	V-Bit	NMLC	Diamond Core - 52 mm	HAD	Hollow Auger Drilling
-TC	TC-Bit, e.g. ADT	NQ	Diamond Core - 47 mm		

PENETRATION/EXCAVATION RESISTANCE

L	Low resistance. Rapid penetration possible with little effort from the equipment used.
M	Medium resistance. Excavation/possible at an acceptable rate with moderate effort from the equipment used
H	High resistance. Further penetration is possible at a slow rate and requires significant effort from the equipment
R	Refusal or Practical Refusal. No further progress possible without the risk of damage or unacceptable wear to the digging implement or machine.

These assessments are subjective and are dependent on many factors including the equipment power, weight, condition or excavation or drilling tools, and experience of the operator.

WATER

∇	Water level at date shown	⇐	Partial water loss
⇒	Water inflow	|⇐|	Complete water loss

NO Ground Water Not Observed: Ground water obersvation not possible. Ground water may or may not be present

NE Ground Water Not Encountered: Ground water was not evident during excavation or a short time after completion. However, groundwater could be present in less permeable strata. Inflow may have been observed had the borehole/test pit been left open for a longer period.

SAMPLING AND TESTING

SPT	Standard Penetration Test to AS1289.6.3.1 - 2004	DS	Disturbed sample
3,6,9 N=15	3,6,9 = blows per 150mm. N = blows per final 300mm penetration	BDS	Bulk disturbed sample
30/80mm	Practical refusal, with blows and depth of penetration before refusal occurred	U63	Undisturbed thin wall push tube sample, nominal sample diameter denoted in millimetres
RW	Penetration caused under rod weight only	W	Water sample
HW	Penetration caused under hammer and rod weight only	G	Gas sample
HB	Hammer bounce without penetration	V	pilcon shear vane (kPa)
R	Refusal to test	PP	Pocket penetrometer (kPa)
		FP	Field permeability test over section noted
DCP	Dynamic Cone Penetrometer Test to AS1289.6.3.2 - 1997	ES	Environmental sample
DCP (p)	Dynamic Cone Penetrometer Test to AS1289.6.3.3 - 1997 Perth Sand Penetrometer	PI	Plastic Index (%)
		PL	Plastic Limit (%)
6	6 = blows per 100mm of penetration	LL	Liquid Limit (%)
		MC	Moisture Content (%)
		CBR	Californian Bearing Ration (%)

ROCK CORE RECOVERY

TCR = Total Core Recovery (%)

$$= \frac{Length\ of\ core\ recovered}{Length\ of\ core\ run} \times 100$$

RQD = Rock Quality Designation (%)

$$= \frac{\sum Axial\ lengths\ of\ core > 100\ mm}{Length\ of\ core\ run} \times 100$$

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EXPLANATION OF NOTES, ABBREVIATIONS & TERMS USED ON BOREHOLE AND TEST PIT LOGS - SOIL DESCRIPTION (AS1726 - 2017)

SOIL CLASSIFICATION SYSTEM

Coarse Grained Soil

GW	Well graded gravels, gravel-sand mixtures, little or no fines
GP	Poorly-graded gravels, gravel-sand mixtures, little or no fines, uniform gravels
GM	Silty gravels, gravel-sand-silt mixtures
GC	Clayey gravels, gravel-sand-clay mixtures
SW	Well-graded sands, gravelly sands, little or no fines
SP	Poorly-graded sands, gravelly sand, little or no fines
SM	Silty sands, sand-silt mixtures
SC	Clayey sands, sand-clay mixtures

Fine Grained Soils

ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or silts with low plasticity
CL, CI	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays
OL	Organic silts and organic silty clays of low plasticity
MH	Inorganic silts, micaceous or diatomaceous fine sand for silty soils
CH	Inorganic clays of high plasticity
OH	Organic clays of medium to high plasticity, organic silts
PT	Peat, humus, swamp soils with high organic contents

First Letter: G = Gravel, S = Sand, M = Silt, C = Clay; Second Letter: W = Well-graded, P = Poorly-graded, M = Mixture, O = Organic, L = Low plasticity, H = High plasticity

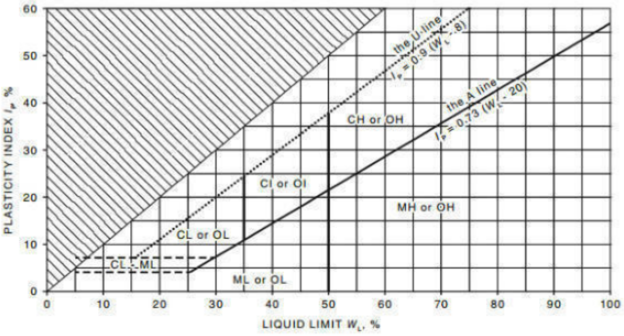
Soils may be a combination of multiple soil classifications where borderline

PARTICLE SIZE

Soil	Major Division	Sub-Division	Particle Size (mm)
Coarse	Boulders		>200
	Cobbles		63 - 200
	Gravel	Coarse	20 - 63
		Medium	6 - 20
		Fine	2.36 - 6
	Sand	Coarse	0.6 - 2.36
		Medium	0.2 - 0.6
		Fine	0.075 - 0.2
Fine	Silt		0.002 - 0.075
	Clay		< 0.002

0.075mm is the approximate minimum particle size discernible by eye

PLASTICITY CHART



MOISTURE CONDITION

Coarse	D	Dry	Sands and gravels are free flowing.
	M	Moist	Soils are darker than in the dry condition and may feel cool. Sands and gravels tend to cohere.
	W	Wet	Soils exude free water. Sands and gravels tend to cohere.
Fine	PL	Plastic Limit	Moisture content of fine grain soils are described; as below plastic limit (<PL), near to plastic limit (=PL), above plastic limit (>PL), near to the liquid limit (=LL), or above the liquid limit (>LL)
	LL	Liquid Limit	

CONSISTENCY AND DENSITY

Fine Grained Soils

			Pocket Pentrometer Reading (kPa)
VS	Very Soft	Exudes between fingers when squeezed	<25
S	Soft	Can be moulded by light finger pressure	20 - 50
F	Firm	Can be moulded by strong finger pressure	50 - 100
St	Stiff	Cannot be moulded by fingers. Can be indented by thumb	100 - 200
VSt	Very Stiff	Can be indented by thumb nail	200 - 400
H	Hard	Can be indented by thumb nail with difficulty	>400

Coarse Grained Soil

		Density Index %	'N' Value
VL	Very Loose	≤15	0 - 4
L	Loose	15 - 35	4 - 10
MD	Medium Dense	35 - 65	10 - 30
D	Dense	65 - 85	30 - 50
VD	Very Dense	>85	>50

SECONDARY OR MINOR SOIL COMPONENTS

Designation of components	In coarse grained soils				In fine grained soils	
	%Fines	Terminology	%Accessory Coarse Fraction	Terminology	%Sand/gravel	Terminology
Minor	≤5	'trace' clay/silt	≤15	'trace' sand/gravel	≤15	'trace' sand/gravel
	5 - 12	'with' clay/silt	15 - 30	'with' sand/gravel	15 - 30	'with' sand/gravel
Secondary	> 15	Prefix silty or clayey	>30	Prefix sandy or gravelly	>30	Prefix sandy or gravelly

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EXPLANATION OF NOTES, ABBREVIATIONS & TERMS USED ON BOREHOLE AND TEST PIT LOGS - ROCK DESCRIPTION (AS1726 - 2017)

STRENGTH OF INTACT ROCK

Symbol	Term	Point Load Index, (I_{s50}) MPa	Field Guide to Strength
VL	Very Low	$0.03 \le I_{s50} < 0.1$	Material crumbles under firm blows with sharp end of pick; can be peeled with knife; pieces up to 30mm thick can be broken by finger pressure
L	Low	$0.1 \le I_{s50} < 0.3$	Easily scored with knife; indentations 1mm to 3mm after firm blow with pick point; core 150mm long and 50mm diameter can be broken by hand; sharp edges of core friable
M	Medium	$0.3 \le I_{s50} < 1.0$	Readily scored with knife; core 150mm long and 50mm diameter can be broken by hand with difficulty
H	High	$1.0 \le I_{s50} < 3$	Core 150mm long and 50mm diameter cannot be broken by hand but can be broken by single firm blow of pick; rock rings under hammer
VH	Very High	$3 \le I_{s50} < 10$	Hand held specimen breaks with pick after more than one blow; rock rings under hammer
EH	Extremely High	$10 \le I_{s50}$	Specimen requires many pick blows to break intact rock, rock rings under hammer

Material with rock strength less than 'Very Low' are described using soil properties

DEGREE OF ROCK WEATHERING

Term		Symbol		Definition
Residual Soil		RS		Soil derived from the weathering of rock; the mass structure and material fabric are no longer evident the soil has not been significantly transported.
Extremely Weathered		XW		Material is weathered to such an extent that it has soil properties, i.e. it either disintegrates or can be remoulded, in water. Fabric of original rock still visible.
Highly Weathered	Distinctly Weathered	HW	DW	Rock strength is changed by weathering. The whole of the rock material is discoloured, usually by iron staining or bleaching to the extent that the colour of the original rock is not recognizable. Some minerals are decomposed to clay minerals. Porosity may be increased by leach, or may be decreased due to deposition of weathering products in pores.
Moderately Weathered		MW		The whole of the rock material is discoloured, usually by iron staining or bleaching to the extent that the colour of the original rock is not recognisable, but shows little or no change of strength from fresh rock.
Slightly Weathered		SW		Rock is slightly discoloured but shows little or no change of strength from fresh rock
Fresh		FR		Rock shows no sign of decomposition or staining

Distinctly Weathered is to be used when it is not possible to differentiate between highly and moderately weathered.

Extremely Weathered material is to be described using soil properties

ROCK MASS PROPERTIES

Term	Separation of Stratification Planes
Thinly laminated	< 6mm
Laminated	6mm to 20 mm
Very thinly bedded	20mm to 60mm
Thinly bedded	60mm to 200mm
Medium bedded	0.2m to 0.6m
Thickly bedded	0.6m to 2.0m
Massive	< 2m

Term	Description
Fragmented	Primarily fragments < 20mm length and mostly of width < core diameter
Highly fractured	Core lengths generally less than 20mm to 40mm with occasional fragments
Fractured	Core lengths mainly 30mm to 100mm with occasional shorter and longer pieces
Slightly fractured	Core lengths generally 0.3m to 1.0m with occasional longer and shorter sections
Unbroken	Core has no fractures

DEFECT TYPES AND DESCRIPTIONS

Defect Type		**Defect Shape**		**Surface Roughness**		**Defect Coatings**	
BR	Bedding parting	PL	Planar	VR	Very rough	CL	Clean
JT	Joint	ST	Stepped	RO	Rough	ST	Stained
SR	Sheared surface	CR	Curved	SM	Smooth	VN	Veneer
SZ	Sheared zone	IR	Irregular	PO	Polished	CT	Coating
SS	Sheared seam	UN	Undulating	SL	Slickenside		
CS	Crushed seam						
IS	Infill seam						
XS	Extremely Weathered Seam						

Vertical Boreholes - The dip of the defect is given from the horizontal

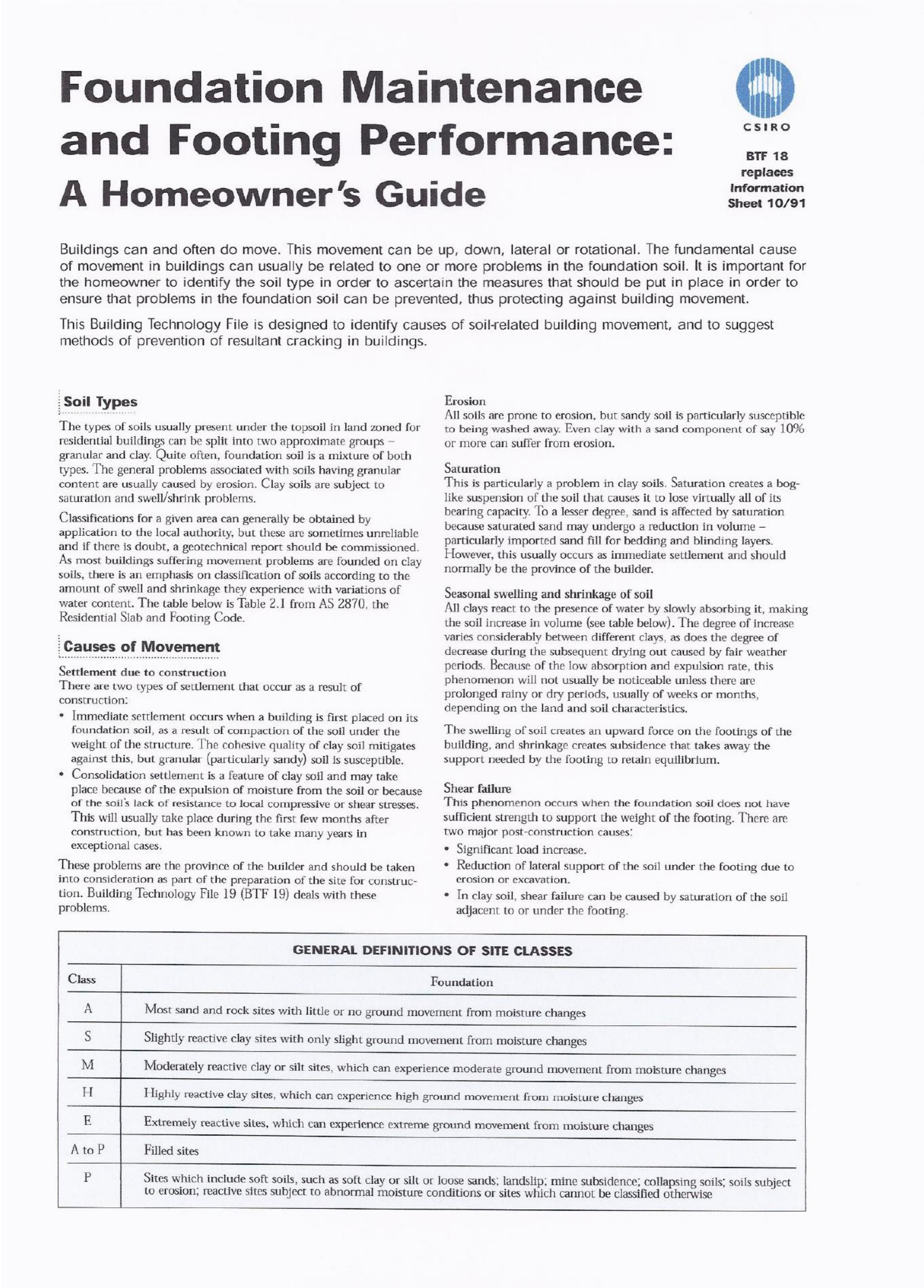
Inclined Boreholes - The angle of the defect is given from the core axis

Appendix B

Site Photography

Appendix C

Good Hillside Construction Practice



Foundation Maintenance and Footing Performance:
A Homeowner's Guide

CSIRO

BTF 18 replaces Information Sheet 10/91

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

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

Soil Types

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

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

Causes of Movement

Settlement due to construction

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

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

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

Erosion

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

Saturation

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

Seasonal swelling and shrinkage of soil

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

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

Shear failure

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

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

GENERAL DEFINITIONS OF SITE CLASSES

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

Tree root growth

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

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

Unevenness of Movement

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

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

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

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

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

Effects of Uneven Soil Movement on Structures

Erosion and saturation

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

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

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

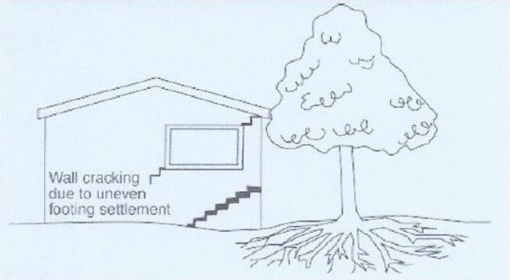
Seasonal swelling/shrinkage in clay

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

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

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

Trees can cause shrinkage and damage



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

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

Movement caused by tree roots

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

Complications caused by the structure itself

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

Effects on full masonry structures

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

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

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

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

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

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

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

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

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

Water Service and Drainage

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

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

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

Seriousness of Cracking

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

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

Prevention/Cure

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

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

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

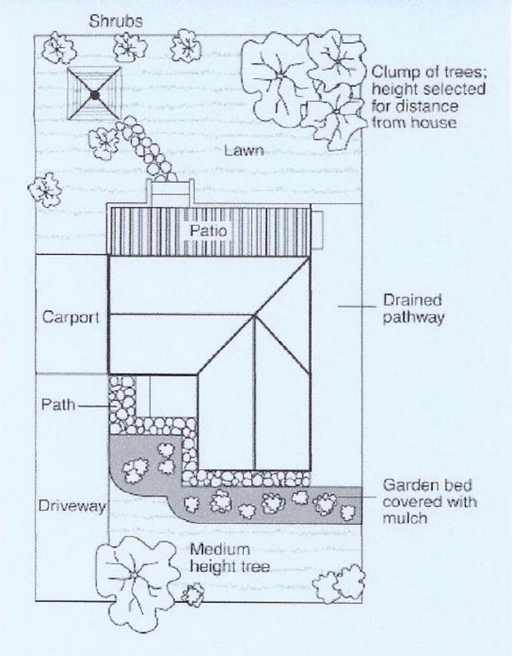
Protection of the building perimeter
It is essential to remember that the soil that affects footings extends well beyond the actual building line. Watering of garden plants, shrubs and trees causes some of the most serious water problems.

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

CLASSIFICATION OF DAMAGE WITH REFERENCE TO WALLS

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

Gardens for a reactive site



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

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

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

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

Condensation

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

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

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

The garden

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

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

Existing trees

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

Information on trees, plants and shrubs

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

Excavation

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

Remediation

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

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

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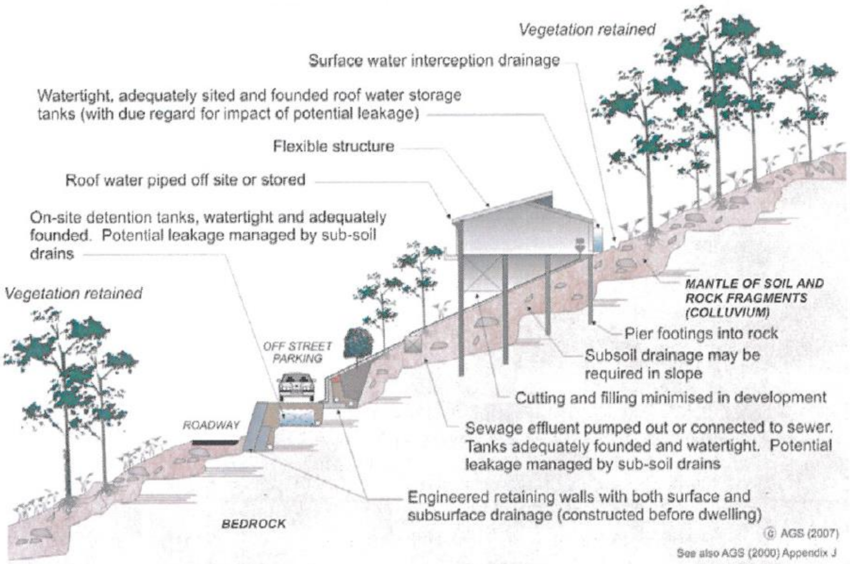
AUSTRALIAN GEOGUIDE LR8 (CONSTRUCTION PRACTICE)

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.

EXAMPLES OF **GOOD** HILLSIDE CONSTRUCTION PRACTICE



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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.

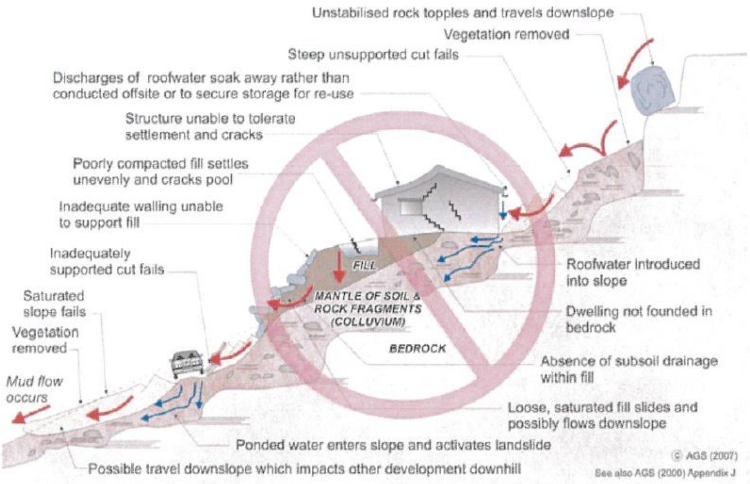
Vegetation clearance - on soil slopes has been kept to a reasonable minimum. Trees, and to a lesser extent smaller vegetation, take large quantities of water out of the ground every day. This lowers the ground water table, which in turn helps to maintain the stability of the slope. Large scale clearing 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



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WHY ARE THESE PRACTICES POOR?

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

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

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

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

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

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

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

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

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

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

GeoGuide LR10 - Coastal Landslides

- GeoGuide LR11 - Record Keeping

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