Central Coast Council

Terrigal Boardwalk

Geotechnical Interpretive Report

TBP-GE-GN-RPT-002

Rev A | 6 November 2018

Job number 261648

Arup Pty Ltd ABN 18 000 966 165

Arup
Level 5
151 Clarence Street
Sydney NSW 2000
Australia
www.arup.com

ARUP

Document Verification

ARUP

Job title	Terrigal Boardwalk	**Job number** 261648
Document title	Geotechnical Interpretive Report	**File reference**
Document ref	TBP-GE-GN-RPT-002	

Revision	**Date**	**Filename**	TBP-GE-GN-RPT-002.docx		
Draft 1	8 June 2018	**Description**	First draft		
			Prepared by	Checked by	Approved by
		Name	Rebecca Szczurowski	Landi Proctor	Timothy Mote
		Signature			
DraftRev A	Nov 2018	**Filename**	TBP-GE-GN-RPT-002_RevAdocx		
		Description	Draft issue to Client		
			Prepared by	Checked by	Approved by
		Name	Adrian Callus	Tim Mote	David Dack
		Signature			
Rev A	6 Nov 2018	**Filename**	TBP-GE-GN-RPT-002_RevAdocx		
		Description	Final Issued to Client		
			Prepared by	Checked by	Approved by
		Name	Adrian Callus	Tim Mote	David Dack
		Signature			
		Filename			
		Description			
			Prepared by	Checked by	Approved by
		Name			
		Signature			

Issue Document Verification with Document ☑

Contents

Drawings

Appendices

1 Introduction

1.1 Project overview

The proposed Terrigal Beach promenade to The Haven boardwalk (hereafter referred to as 'the boardwalk') is intended to improve the amenity and accessibility for tourists visiting the region. It is Central Coast Council's ('Council') ambition that the boardwalk would become a tourist attraction and a destination enhancing experience which compliments the natural coastal environment.

1.2 Purpose of the report

A geotechnical investigation has been undertaken by Arup to inform the design of the of the boardwalk. This geotechnical interpretive report presents the following:

- An overview of the existing topographical, geological and geomorphological information of the site.
- Geological and geomorphological mapping of existing site features, to assess the stability of the site, assess current risk levels and identify geotechnical issues and constraints on the proposed boardwalk.
- Factual data obtained during the geotechnical investigation performed by Arup in May 2018.
- Geotechnical interpretation of the ground conditions and engineering design parameters, identified site constraints and recommendations on constructability and detailed design of the boardwalk

1.3 Disclaimer

The ground is a product of continuing natural and man-made processes and therefore exhibits a variety of characteristics and properties that vary from place to place and can change through time. Geotechnical engineering involves gathering and assimilating the facts about these characteristics and properties in order to understand or predict the behaviour of the ground and groundwater on a particular site under certain conditions.

Arup may report such facts obtained by observation, excavation, probing and sampling, testing or by other means of investigation. If so, they are directly relevant only to the ground and groundwater at the place where, and the time when, the investigation was carried out, and are believed to be reported accurately.

Any interpretation or recommendation given by Arup shall be understood to be based on judgement and experience and not on greater knowledge of the facts than the reported investigations would imply. The information contained within this report shall be considered as for reference only.

This report has been prepared for the use of our Client in connection with the aforementioned project and takes into account particular requirements and instructions. It is not intended for use by any third party and no responsibility is undertaken to any third party.

2 Proposed Structure

Following consultation with the Council, the preferred option to carry through to Concept Design is an elevated boardwalk comprising of timber and perforated decking that would allow people to view the water beneath the viewing platforms. The eastern and western ends of the boardwalk, at The Haven and Terrigal Beach respectively, is to be on grade. While the portion adjacent to the existing rock platform and intertidal zone of The Haven are to be suspended on steel and concrete piers.

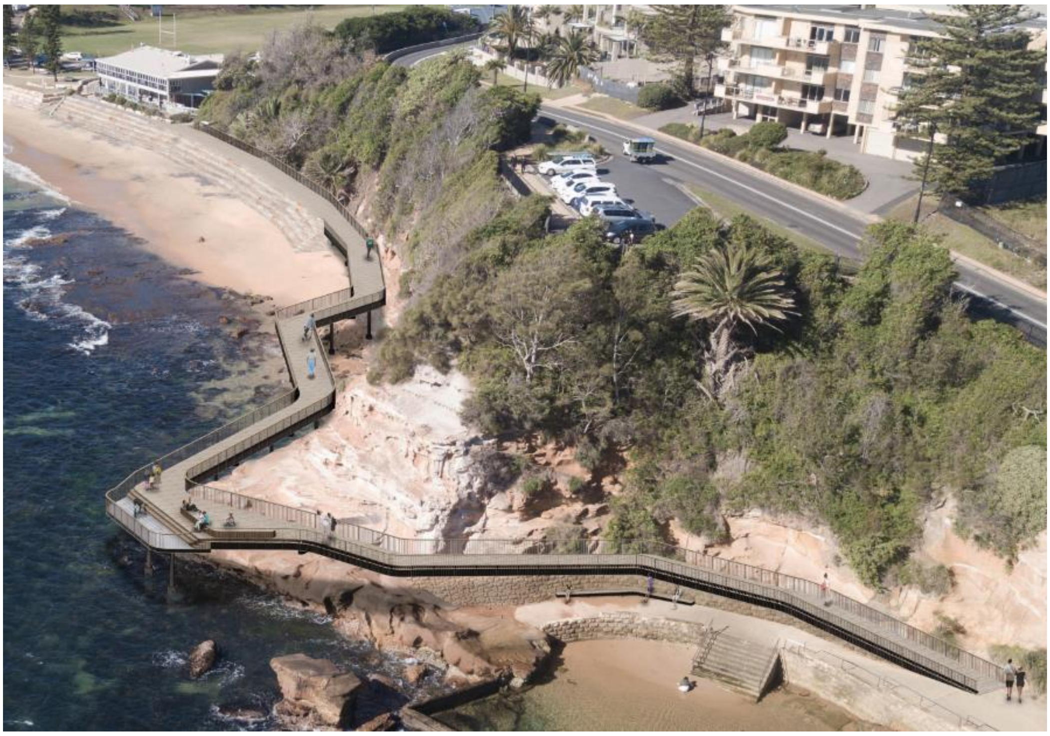


Figure 1 - Visualisation of proposed boardwalk (looking south-east)

3 Investigation

3.1 Fieldwork

The fieldwork for the subsurface investigation took place between the 22 May and the 25 May 2018 and comprised of the following:

- Four Boreholes (BH1 to BH4) progressed by auger and diamond core drilling techniques to final depths ranging between 8.29 metres below ground level (mbgl) and 8.80 mbgl. The boreholes were drilled by Rockwell Drilling Services Pty Ltd.
- Nine DCPs were performed on the overlying soil strength material to refusal on rock ranging in depth between 0.40 mbgl to 0.82 mbgl.

Prior to the ground investigation the site was cleared of services using electronic locating equipment from specialist sub consultants Down Under Detection Services Pty Ltd.

The fieldwork was carried out under the direction of an Arup geotechnical engineer who was present full time on site. The geotechnical engineer set out borehole locations, directed sub-contractors, logged the encountered subsurface profile and nominated sampling and testing.

The borehole and DCP locations are shown in Figure 3. The borehole logs (including field test results, Point Strength Index test results and groundwater observations) are provided in Appendix B. For details of the investigation procedure reference should be made to the Arup Geotechnical Explanatory Notes provided in Appendix A.

The test locations were set out by taped measurements from existing site features. The surface levels at the test locations have been estimated from spot levels on the provided survey plan (Plan Number: 7650 Issue: A dated 07/07/2017) prepared by Stephen Thorne and Associates Pty Ltd. The site datum is Australian Height Datum (AHD).

The cored rock strength material was assessed by examination of the recovered core and correlation with Point Load Strength Index tests. The recovered rock core was photographed and Point Load Strength Index tests were completed, at an approximate frequency of one test per metre, by the geotechnical engineer on site during the fieldwork. The results of the Point Load Strength Index tests are attached as Appendix D. The core photographs are presented with the borehole logs in Appendix B.

The DCP test results were correlated to density of the overlying the coarse grained material and used to inform the variation in rock levels across the site.

3.2 Groundwater observations

Groundwater observations were made in the boreholes during and on completion of coring. Water has been introduced as part of the coring process which may have obscured groundwater depth measurement in the time period after coring.

3.3 Laboratory testing

Selected samples were submitted to a NATA registered laboratory (Macquarie Geotech Pty Ltd) for soil and rock testing including:

- Particle size distribution (PSD) on two soil samples;
- Aggressivity tests on five core samples; and
- Unconfined compressive strength (UCS) tests on eight core samples.

The test results are presented in Section 4.5

4 The site

4.1 Site location

The extent of the proposed boardwalk is presented in Figure 1 (shown as the red dotted line), located along Terrigal Esplanade, Terrigal, NSW.

Figure 2 - Site location map (Central Coast Council Terrigal Master Plan Concept, 2017)

4.2 Topography

Based on the provided survey contour plan, and observations carried out during the fieldwork, the approximate proposed boardwalk alignment is located along the coastline bordered to the south by an inclined slope with variable steepness. The proposed boardwalk extends out around the headland where the rock face becomes very steep. There are rocky outcrops at the base of the slope and within the intertidal zone between the beach and the headland.

4.3 Existing structures

At the time of fieldwork, the site contained a stacked sandstone revetment wall, and stacked concrete culverts. South-east of the site there is a café/restaurant, the Reef Restaurant & Cove Café positioned at an elevated level of approximately 4.5 mAHD behind the stone wall structure.

4.4 Services

A utilities search has been performed via Dial Before You Dig (DBYD) service. Results of this survey indicated a storm water drainage culvert within the site. Visual Inspection of the Site indicate gas lines in proximity to the beach.

4.5 Subsurface conditions

4.5.1 Geology

Reference to the 1:100,000 geological map of Gosford-Lake Macquarie Special indicates that the site is underlain by the Terrigal Formation. It is described as interbedded laminate, shale and fine to coarse grained quartz to quartz-lithic sandstone; minor red claystone. This is consistent with the encountered conditions observed during the investigation.

For detailed subsurface conditions at each borehole location, reference should be made to the borehole logs in Appendix B. A geological cross section is presented in Drawing 2. The location of the geological section is presented in Drawing 1. A summary of the pertinent subsurface conditions is presented below.

4.5.2 Sand

Marine sand was encountered in all borehole locations. The thickness of sand was between 0.65m and 1.00m. The levels and thickness of sand for each borehole is summarised in Table 1.

4.5.3 Clay

High plasticity residual clay was encountered in three borehole locations. The clay was positioned directly above bedrock and was between 60mm and 200mm thick. The levels and thickness of clay for each borehole is summarised in Table 1

4.5.4 Sandstone

Interbedded sandstone and siltstone was encountered below sand and clay. The Sandstone was assessed to be moderately weathered to slightly weathered and low to medium strength.

The following defects were recorded:

- Horizontal extremely weathered seams up to 100mm thick;
- A number of undulating to planar bedding partings between 0-25 degrees;
- A number of undulating, stepped and planar joints between 15-90 degrees were recorded. Some joints were healed;
- Crushed seam up to 30mm thick typically filled with rock fragments and clay; and One clay seam 30mm thick was recorded.

The following core-loss was also recorded:

- BH2 at 8.55 150mm.

The core loss zones may be interpreted as representing clay seams, weathered seams or fractured bands of bedrock

4.5.5 Siltstone

Interbedded sandstone and siltstone was encountered below sand and clay. The siltstone was assessed to be highly weathered to moderately and very low to medium strength.

The following defects were recorded:

- Horizontal extremely weathered seams up to 90mm thick: and

One clay seam 40mm thick was recorded

4.6 Summary of stratigraphy

A summary of the stratigraphy encountered is summarised in Table 2 following. Bedrock units are classified based on Pells (1998) rock mass classification system. The siltstone lithology is classified under the Shale rock classification. A geological cross section is presented in Drawing 2.

Table 1 - General stratigraphy encountered

Borehole		**BH1**	**BH2**	**BH3**	**BH4**
Sand	Depth (mbgl)	0.00 – 0.65	0.00 – 1.00	0.00 – 0.90	0.00 – 0.65
	Thickness (m)	0.65	1.00	0.90	0.65
Clay	Depth (mbgl)	-	1.00 – 1.14	0.90 – 1.10	0.65 – 0.71
	Thickness (m)	-	0.14	0.2	0.06
Class V	Depth (mbgl)	Shale: 2.63 – 3.75	-	-	-
	Thickness (m)	Shale: 1.12	-	-	-
Class IV	Depth (mbgl)	Shale: 5.23 – 7.60, Sandstone:1.45 – 2.63, 3.75 – 5.23	Sandstone: 1.30 – 7.35	Shale: 1.10 – 3.20, 7.82 – 8.29, Sandstone: 3.2 – 6.25, 6.85 – 7.82	Shale: 1.05 – 1.45, Sandstone: 1.45 – 5.00
	Thickness (m)	Shale: 2.37, Sandstone: 1.18, 1.48	Sandstone: 6.05	Shale: 2.10, 0.47, Sandstone: 3.05, 0.97	Shale: 0.4, Sandstone: 3.55
Class III	Depth (mbgl)	Shale: 0.85 – 1.45	-	-	Sandstone: 5.00 – 7.25
	Thickness (m)	Shale: 0.60	-	-	Sandstone: 2.55
Class II	Depth (mbgl)	Sandstone: 7.60 – 8.55	-	-	Sandstone: 7.25 – 8.80
	Thickness (m)	Sandstone: 0.95	-	-	Sandstone: 1.55

4.7 Groundwater

Groundwater was typically encountered between 0.5mbgl in line with sea level. Water was introduced during core drilling and can obscures groundwater measurements during the course of fieldwork.

Water flush returns were typically 100% except in BH2 where the flush returns varied between 80-100%. This indicates a relatively impermeable rock mass. Ground water levels were measured after drilling. The water level was typically measured at between 0.9 mbgl and 2.00 mbgl.

Table 2 - Groundwater depths

Borehole ID	Encountered groundwater depth during drilling (mbgl)	Measured groundwater depth after drilling (mbgl)
BH1	0.5	1.5
BH2	0.5	0.9
BH3	Not recorded	2.0
BH4	Not recorded	1.0

4.8 In-situ testing

4.8.1 SPT tests

Standard Penetrometer Tests (SPTs) were undertaken almost continuously on the soil strength material in boreholes until reaching refusal on the underlying bedrock. The SPT tests show the coarse grained material to range in density between very loose to medium dense with the density typically increasing with depth. The SPT results are presented in the borehole logs in Appendix B. A summary of the density correlation with depth is presented in Table 3.

Table 3 - Summary of SPT results

Depth of SPT test (mbgl)	Borehole ID			
	BH1	BH2	BH3	BH4
0-0.45	VL	VL	VL	VL
0.5-0.95	VL	VL-MD	VL	VL-L (refusal)
1.00-1.45	-	MD (refusal)	MD (refusal)	-

4.8.2 DCP tests

A total of nine Dynamic Cone Penetrometer (DCP) tests were undertaken at the locations indicated on Figure 3 until refusal on bedrock. The DCP tests show that the sand was very loose to very dense, with density generally increasing with depth. Depth of refusal is indicative of depth to bedrock. The DCP logs are presented in Appendix C.

A summary of the correlated density with depth is presented in Table 4 below.

Table 4 - Summary of DCP test results

Depth (mbgl)	**DCP ID**								
	DCP 1	**DCP 2**	**DCP 3**	**DCP 4**	**DCP 5**	**DCP 6**	**DCP 7**	**DCP 8**	**DCP 9**
0-0.1	VL	VL	L	VL	VL	VL	VL	VL	VL
0.1-0.2	VL	VL	L	VL	VL	VL	L	VL	VL
0.2-0.3	VL	VL	MD	VL	VL	L	L	VL	L
0.3-0.4	MD	MD	VD	L	MD	MD	MD	L	L
0.4-0.5	D	MD		L	D	MD	MD	VD	MD
0.5-0.6	VD	D		MD	VD	MD	VD		MD
0.6-0.7	VD	VD		VD		VD			D
0.7-0.8		VD				VD			VD

4.8.3 Point load strength index

A total of 78 point load strength index tests were undertaken on rock core samples recovered from boreholes.

The point load tests indicated the Is(50) index strength ranged from 0.02 MPa to 0.74 MPa and 0.04MPa to 1.11MPa for diametral and axial tests respectively.

A plot of Is(50) index strength versus reduced level is presented in Figure 3. The profile of Is(50) with depth can be seen to be relatively uniform. The point load test results indicate that the rock core strength ranged from very low to high but was typically low to medium strength. There is a general trend of increase of rock strength with depth.

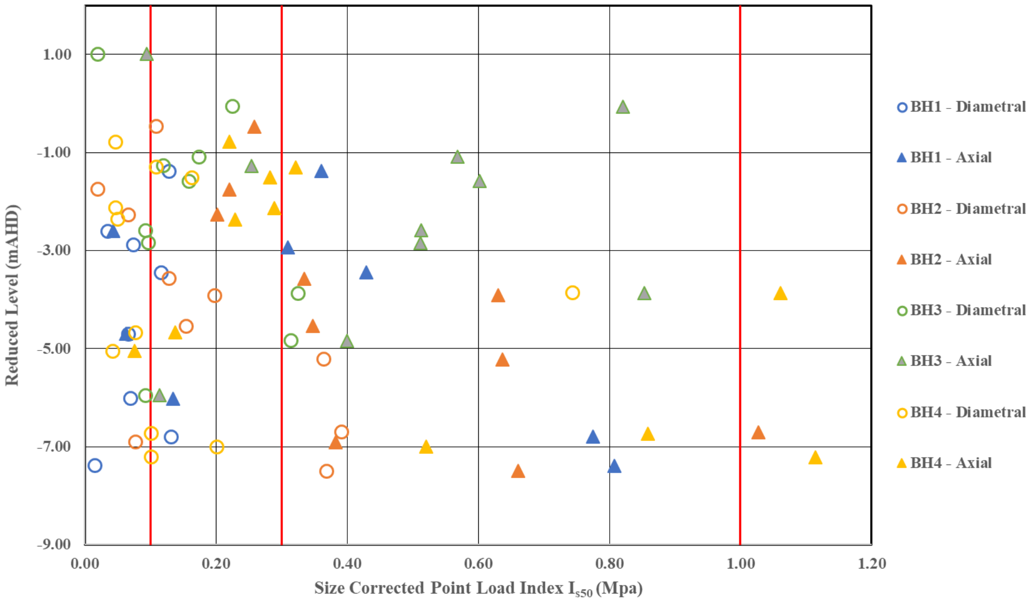


Figure 3 - Point load index strength vs reduced level

4.9 Laboratory test results

4.9.1 Particle size distribution tests

Particle size distribution (PSD) tests were completed for two samples. The test results indicate the two samples consist of predominately medium sized sand with one sample (BH1 0.5m to 0.65m) containing up to 22% fine grained material. Results of the PSD test are shown in Figure 4.

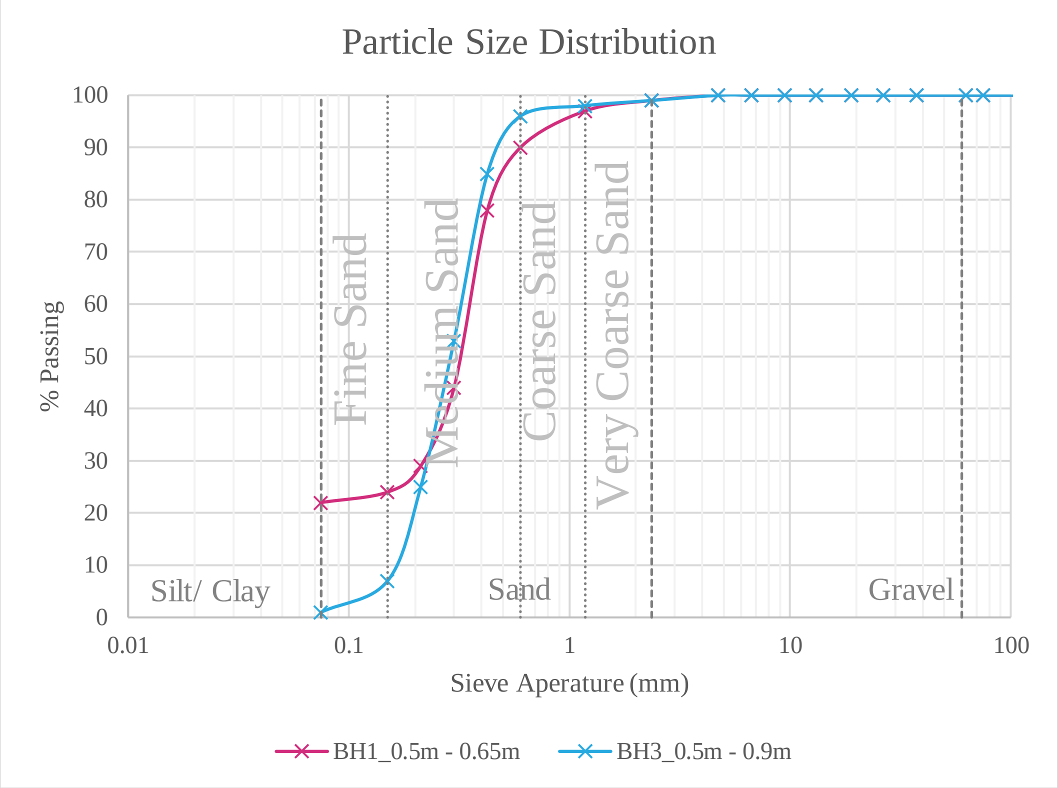


Figure 4 - Results of particle size distribution

4.9.2 Uniaxial compressive strength tests

A total of eight cored samples were tested for uniaxial compressive strength (UCS). Seven of the tests were performed in sandstone and one test was performed in siltstone. Testing results indicate sandstone to be of medium strength and siltstone to be of upper bound of very low strength. The test results by rock mass classification are summarised in Table 5.

Table 5 - Summary of UCS testing

UCS Test Summary	**Sandstone Class II**	**Sandstone Class III**	**Sandstone Class IV**	**Shale Class IV**
Number of UCS Tests	2	2	3	1
Min UCS (MPa)	9.1	7.7	7.6	1.9
Max UCS (MPa)	13.0	9.9	10.0	1.9
Average UCS (MPa)	11.1	8.8	9.2	1.9

Relationship between point load Is(50) values to UCS for sandstone are shown in Figure 5 - Point load Is(50) vs UCS Figure 5. The recommended correlation factor for Is(50) to UCS is summarised in Table 6.

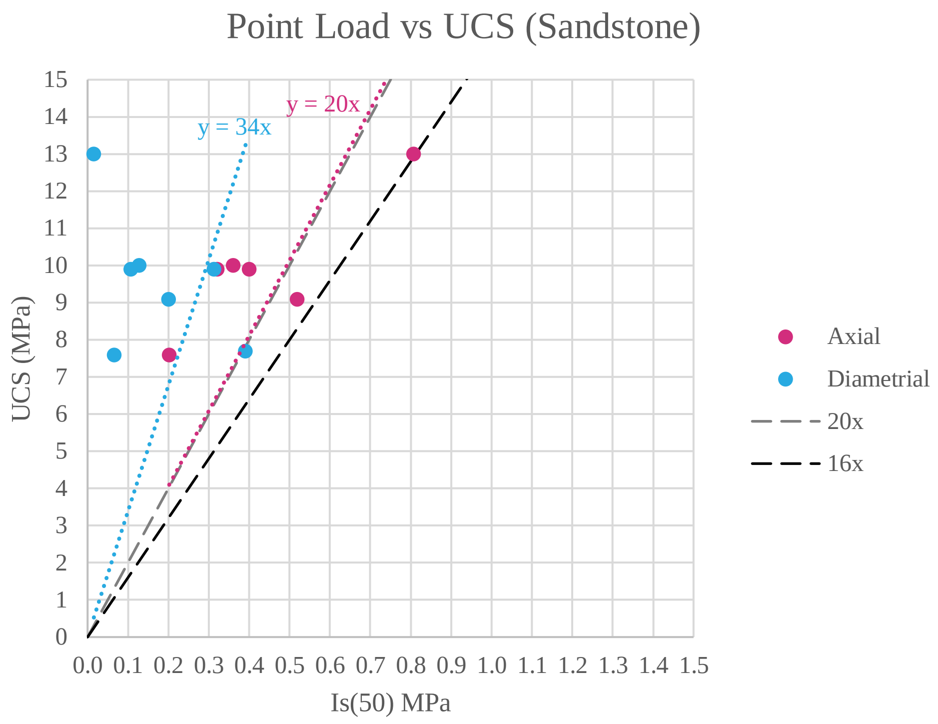


Figure 5 - Point load Is(50) vs UCS

Table 6 - Recommended Is(50) to UCS correlation factor

Rock Mass Lithology Type	**$Is_{(50)}$ to UCS Correlation Factor**
Shale	20
Sandstone	20

4.9.3 Aggressivity tests

A total of 5 rock samples were tested for aggressivity and are presented in Table 7. The exposure classification for concrete in accordance with AS2159 and AS5100 are shown in Table 8.

Aggressivity testing indicate the bedrock to be typically 'non-aggressive' to 'mild' for concrete piles. However, given the location of the project is situated within an active coastal environment, marine exposure classification is recommended.

Table 7 - Summary of aggressivity tests

BH_ID	**BH1**	**BH2**	**BH3**	**BH4**	**BH4**
From (m)	6.00	3.06	2.50	6.00	8.00
To (m)	6.10	3.23	2.60	6.10	8.17
Rock Class^1	SH-IV	SS-IV	SH-IV	SS-III	SS-II

BH_ID	BH1	BH2	BH3	BH4	BH4
Sulphate Content (ppm)	12.4	103	16.5	14.4	10.3
Sulphate Content (%)	0	0	0	0	0
Chloride ion content (ppm)	327.9	673.6	124.1	195	31
Chloride ion content (%)	0.03	0.07	0.01	0.02	0
pH	6.1	6	6.9	6.7	6.9

Note: 1. SH = SHALE, SS = Sandstone

Table 8 - Exposure classification

Australian Standard	Surface and Exposure Environment	Exposure Classification
AS2159	Sea water – Tidal/ splash zone	Severe
AS5100-2017	In tidal/ splash zone	C2

4.10 Geological mapping

Geological mapping was undertaken for the project area.

The project area can be classified into distinct geomorphological zones. The ground conditions encountered in each zone are summarised in Table 9 below. Reference should be made to Figure 6 for the location of the geomorphological zones described.

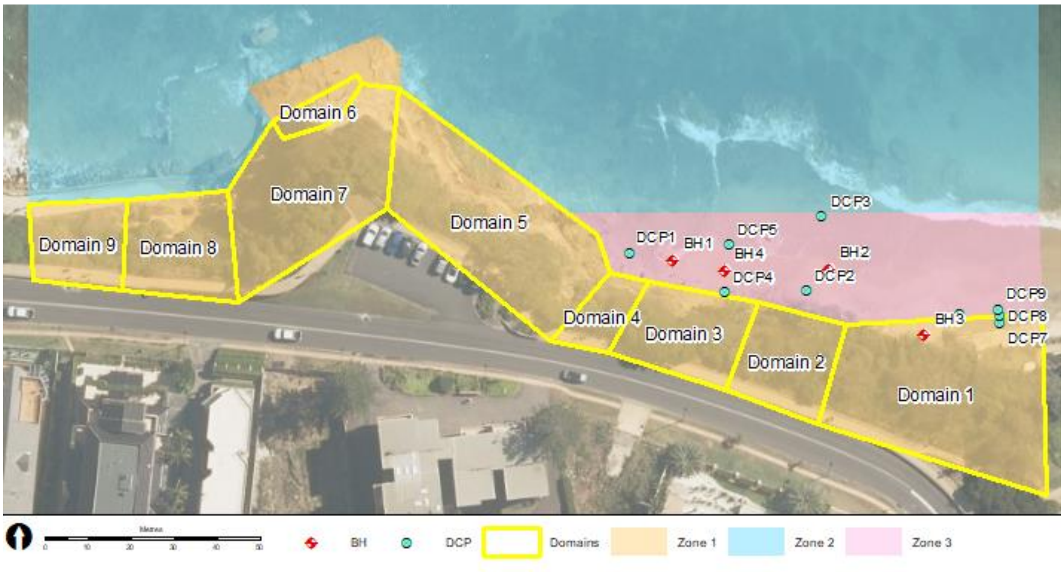


Figure 6 - Geological domains and geomorphological zones

Table 9 - Summary of ground conditions

Geomorphological Zone	Description	Ground conditions
Zone 1	Wave-cut platform	Exposed sandstone and siltstone bedrock. The wave-cut platform is formed by a competent sandstone bed of the Terrigal Formation, approximately 1.6m thick. The platform has

Geomorphological Zone	Description	Ground conditions
	Exposed rock creating the headland between Terrigal beach and The Haven	minor interbeds of siltstone, which have undergone preferential weathering, resulting in undercutting of the rock platform. The cliff behind the wave-cut platform is approximately 14m high based on the provided 2017 survey plan prepared by Stephen Thorne and Associates. The cliff comprises soil and/or extremely weathered rock, overlying interbedded sandstone and siltstone of the Terrigal Formation, variably weathered. The upper portion of the slope is covered by dense vegetation. Evidence of rockfalls was observed during 1994, 1997 and 2018 site walkover inspections. Sub-surface investigation was not undertaken at this location.
Zone 2	Tidal zone	Shallow marine sand overlying sandstone and siltstone bedrock. Exposed rock can be seen in the shallow water. Sub-surface investigation was not undertaken at this location.
Zone 3	Beach zone	Shallow marine sands (approximately 1m depth) overlying sandstone and siltstone bedrock. Sub-surface investigation undertaken within this zone.

Nine geological domains were delineated based on geological, geomorphological, and slope hazard classifications. Within each geologic domain slope stability hazards are identified. These include:

1. Small rockfall (<0.5m diameter) out of the steeper slope from weathering and root jacking.
2. Rockfall of boulders (0.5m to 2m in diameter) out of the near vertical cliff. Structural controlled from either the cliff face or above the eroding siltstone.
3. Soil debris flows off the crest of the slope.
4. Cliff collapse (up to 10m L x 3m W x 7m H) due to erosion of the weaker siltstone layer at the base of the geologic profile.
5. Landslide. Rotational or translation slides through the soil/residual soil profile

4.10.1 Domain 1

Domain 1 is predominantly a soil slope. The angle of the slope ranges from ~15° at the crest of the slope to around 45° at its steepest point. The average slope angle across the Domain is ~25°.

The slope stability hazards identified within Domain 1 are deep-seated rotational landslides or smaller surficial soil debris slump/flow.

Figure 7 - Wall and vegetated slope in Domain 1

4.10.2 Domain 2

Domain 2 is predominantly a soil slope above a layer of siltstone. The angle of the slope ranges from ~15° at the crest to an average of 35° for most of the slope.

The main slope stability hazard identified within Domain 1 is surficial soil debris slump/flow off the crest or rockfall from root jacking of boulders less than 0.5m in diameter.

Figure 8 - Profile photo of Domain 2 slope

4.10.3 Domain 3

The angle of the Domain 3 slope ranges from ~15° at the slope crest to 70° at the beach. The average slope angle across the Domain is ~45°.

Slope hazards present in Domain 3 are larger rockfalls (>0.5m diameter) and debris flows off the crest. The weaker siltstone layers has not been significantly eroded in Domain 3.

Figure 9 - Domain 3 cliff face

4.10.4 Domain 4

Domain 4 captures a natural bend in the cliff face and the focus of drainage from the crest. The angle of the Domain 4 slope ranges from ~10° at the slope crest to a maximum angle of 65° at the beach. The average slope angle across the Domain is ~50°. The weaker siltstone layer in Domain 4 is eroded back to ~2m from the present cliff face. This is likely due to focused wave action or increase groundwater in the bend.

The slope hazards identified with Domain 4 are rockfalls, debris flows, and cliff collapse from wave erosion.

Figure 10 - Domain 4 cliff face

4.10.5 Domain 5

The angle of the Domain 5 slope ranges from <10° which gradually becomes steeper to reach a maximum angle of 70° at the beach. The average slope angle across the Domain is ~50°.

The major hazard within Domain 5 is cliff collapse from the wave erosion of the weaker siltstone and undercutting the sandstone. Debris flows off the crest and smaller rockfall are also identified hazards.

Figure 11 - Domain 5 cliff face

4.10.6 Domain 6

Domain 6 represents the cliff nose. This is a moderately to steeply sloping cliff face that extends from Domain 7 to the rock platform. The slope angle gradually increases from ~15° up to ~65° across the Domain. The average slope angle is ~50°.

Rockfall hazard exists out of the steep cutting.

Figure 12 - Domain 6 (cliff nose) cliff face

4.10.7 Domain 7

Domain 7 has a moderately dipping slope that is relatively consistent across the Domain. The slope angle ranges from ~10° at the slope crest to a maximum steepness of 60°. The average slope angle across the Domain is ~40°.

Debris flows are the main slope hazard present.

Figure 13 - Domain 7 cliff face

4.10.8 Domain 8

Domain 8 has a moderately sloping cliff face. This Domain includes an existing footpath with benches set a few metres in front of the cliff face. The slope angle of Domain 8 ranges from ~45° up to 60°. The average slope angle across the Domain is ~45°.

The main hazard present in Domain 8 is rockfall and debris flow off the crest.

Figure 14 - Footpath, bench, and cliff face in Domain 8

4.10.9 Domain 9

Domain 9 has a moderately dipping slope. Domain 9 includes an existing footpath at both the crest and toe of the slope. The slope angle ranges from a maximum of

55° at the top of the slope down to ~10° at the base of the slope. The average slope angle is ~35°.

Landslide is the identified hazard in Domain 9.

Figure 15 - View of Domain 9 (vegetated slope) from Domain 8

5 Risk Assessment

A risk assessment of the proposed boardwalk has been carried out in accordance to the Australian Geomechanics Society (AGS) Guidelines for Landslide Risk Management (2007). The assessment is based on the information from our site observations and investigations which has allowed a qualitative assessment to both life and property.

- The assessment looks at risk to property
- Risk to person most at risk and
- Societal risk given the large tourism visitation.

The assessment has assumed that the elements most at risk are:

- The proposed boardwalk

Persons (such as residents, recreational users or Council employees etc) at the base of the slope and cliff face, or on the proposed boardwalk

The proposed boardwalk alignment at the time of writing this report is the concept design.

5.1 Risk to life – person most at risk

The annual probability of loss of life for the person most at risk from cliff regression was estimated using the equation:

$$R(lol) = P(H) \text{ x } P(S|H) \text{ x } P(T|S) \text{ x } V(D|T)$$

Where:

- H is an identified hazard
- R(lol) is the risk (annual probability of loss of life of an individual)
- P(H) is the annual probability of failure
- P (S|H) is the probability of spatial impact of the failure reaching a person present on the boardwalk taking into account the size of the hazard, travel distance and the length of the boardwalk.
- P(T|S) is the temporal spatial probability that a person is present
- V(D|T) is the vulnerability of the individual loss of life from person present at the time of failure.

5.2 Hazard identification

Five hazards with the potential to impact persons on the boardwalk were identified during the site geologic mapping (Table 10) with respect to each of the nine geologic domains (reference Section 4.10). Representative hazard sizes were estimated from the geologic mapping.

Table 10 - Identified hazards

Hazard	**Description**	**Extend of slope effected/ size of failure**	**Trigger**
SF	Small rockfall	<0.5m maximum diameter	Annual weather events and tree root jacking
RF	Boulder sized rockfall	>0.5m – 2m	1:10-year weather events and tree root jacking
DB	Soil debris off crest	3m x 5m x 1m	1:10-year rainfall event
CC	Cliff collapse	10m x 3m x 10m	Coastal erosion, Earthquake
LS	Landslide	5m x 10m x 2m	Extreme rainfall event (1:100-year), Earthquake

5.3 Annual probability of the failure event

The annual probability or likelihood P(H) of the five failure events within each respective domain are provided in Table 11. The probabilities are estimated by considering the recurrence of triggering events and are calibrated with observations of recent failure made on site and of historic records (e.g. recent cliff failure at the Skillion).

Table 11 - Annual probability of failure

Domain	**Hazard**	**P(H) Annual probability of failure event**
1	SF	1.0
	DB	0.1
	LS	0.01
2	SF	1.0
	DB	0.1
3	RF	0.1
	DB	0.1
4	RF	0.1
	DB	0.1
	CC	0.01
5	SF	1.0
	DB	0.1
	CC	0.01
6	SF	1.0
	RF	0.01
7	DB	0.1
8	SF	0.1
	DB	0.1
9	LS	0.01

5.4 Probability of Spatial Impact

The probability of spatial impact, P (S|H), estimates the likelihood of the failure impacting a person on the boardwalk taking into account the hazard sizes, travel distance, and length of the boardwalk impacted in each domain if a person is present.

The probability of the hazard reaching the boardwalk is estimated from the mapping and indicative cross-sections define each geologic domain provided in the figures below. Run-out and rockfall bounce are estimated using a 1:1 shadow angle plotted against the planning location of the boardwalk relative to the slow. This will be refined in the detailed design.

The probability that a hazard will impact a person if it reaches the board walk considered the hazard size is defined in Table 1 and the length of boardwalk in the domain. For example, a 1m boulder will only impact a portion of a 20m length of boardwalk.

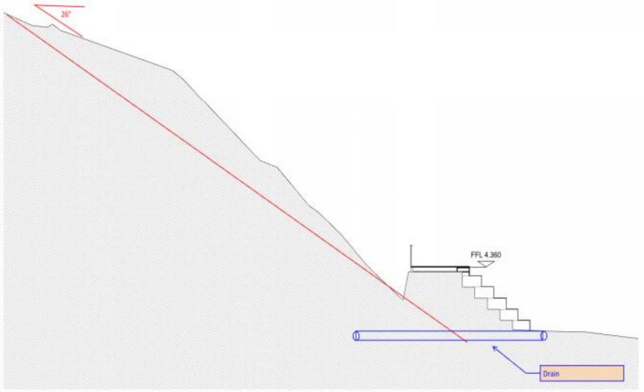


Figure 16 - Slope profile sketch through Domain 1

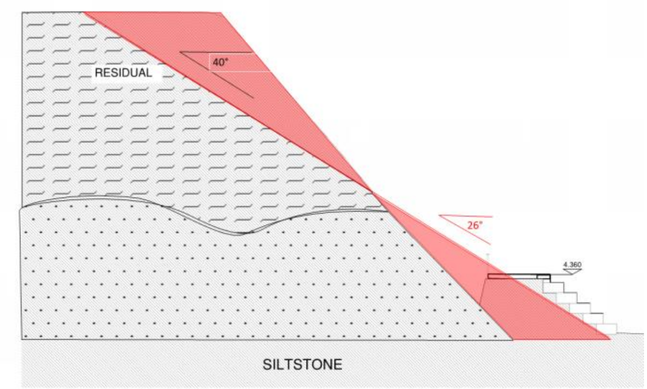


Figure 17 - Profile sketch through Domain 2

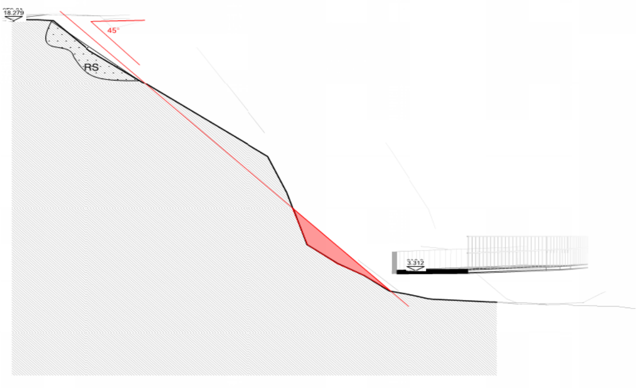


Figure 18 - Profile sketch through Domain 3

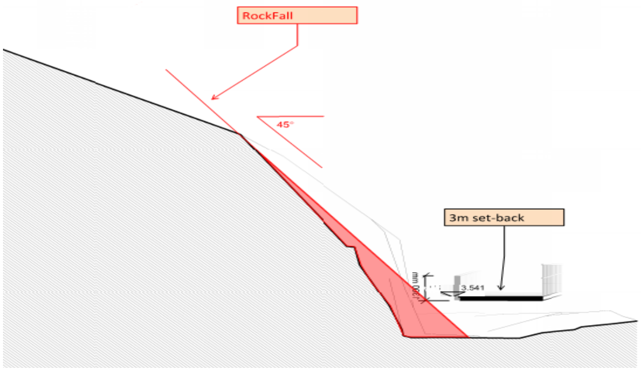


Figure 19 - Profile sketch through Domain 4

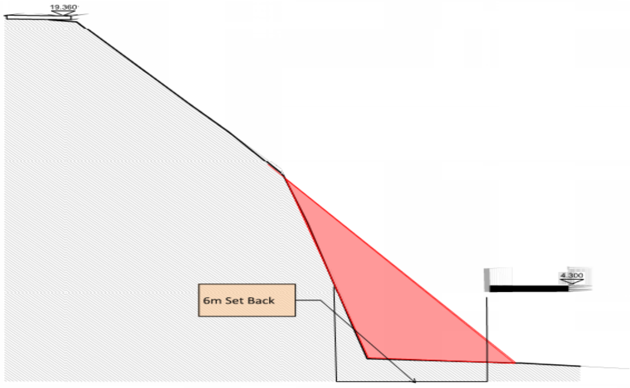


Figure 20 - Profile sketch through Domain 5

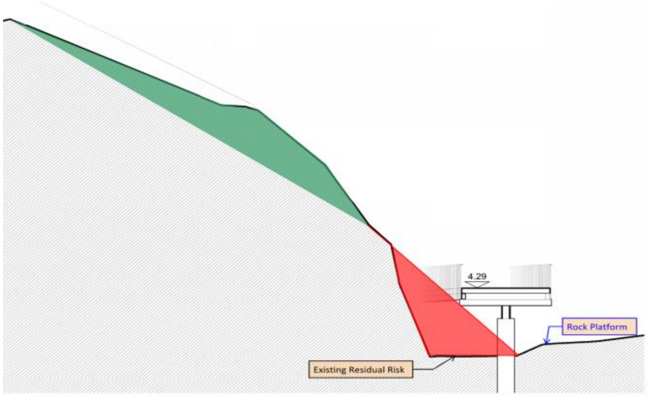


Figure 21 - Profile sketch through Domain 6

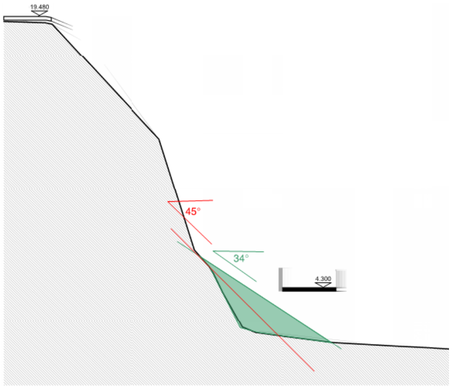


Figure 22 - Profile sketch through Domain 7

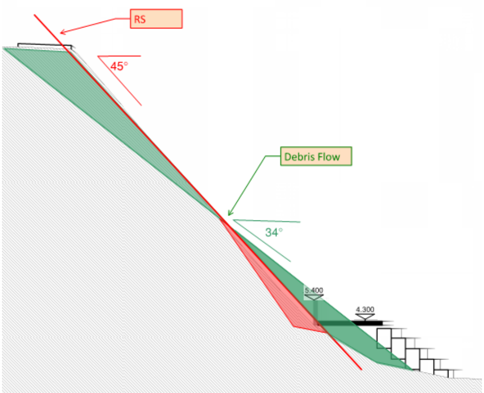


Figure 23 - Profile sketch through Domain 8

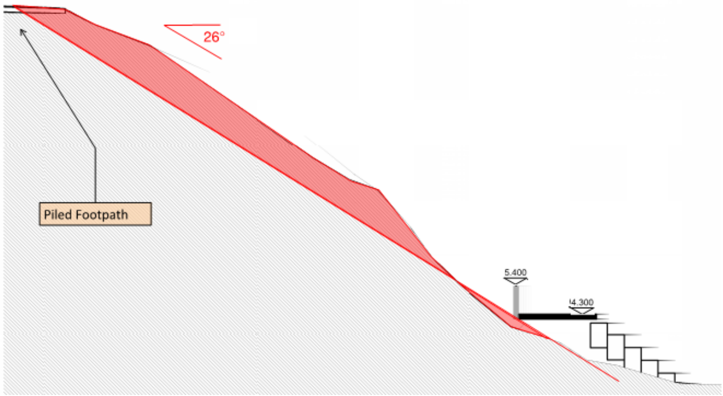


Figure 24 - Profile sketch through Domain 9

Table 12 - Probability of spatial impact

Domain	Perpendicular Length of Domain	Hazard	Probability of the hazard reaching the boardwalk	P(S|H) Probability that a person will be impacted by the Hazard if present
1	45m	SF	0.01	0.001
		DB	0.01	0.001
		LS	0.1	0.022
2	20m	SF	0.01	0.002
		DB	0.01	0.002
3	25m	RF	0.1	0.012
		DB	0.1	0.012
4	10m	RF	0.01	0.003
		DB	0.01	0.003
		CC	0.01	0.010
5	60m	SF	0.001	0.000
		DB	0.001	0.000
		CC	0.01	0.002
6	20m	SF	0.01	0.002
		RF	0.01	0.002
7	30m	DB	0.1	0.010
8	25m	RF	0.1	0.012
		DB	1.0	0.120
9	20m	LS	1.0	0.500

5.5 Vulnerability

The vulnerability (V (D|T)) of a person being killed by a rockfall if present and hit considers the size of the hazard.

A vulnerability of 0.5 is used for a direct impact of boulder >0.5m diameter following application of the AGS 2007 Landslide Guidance for Rockfall applied in Christchurch after the Canterbury Earthquake sequence in 2011.

A vulnerability of 0.10 is used for small rockfall and debris flow impacts.

Table 13 - Vulnerability

Hazard	Description	P(V|T) Vulnerability
SF	Small rockfall	0.10
RF	Boulder rockfall	0.50
DB	Soil debris flows off crest	0.10
CC	Cliff collapse	0.50
LS	Large landslide	0.50

5.6 Temporal spatial probability

Considering the person-most-at-risk, the following users of the boardwalk have been considered;

- Council workers carrying out maintenance on the boardwalk 1 hour per day
- Local resident walking on boardwalk daily with average walking rate of 4 seconds per 5m length every day of the year
- Tourist on the boardwalk with single visit of 2 hours.

Table 14 - Temporal spatial probability

Person	Description	P(T|S) Temporal spatial probability
Council Worker	1 hour per day	0.027
Resident Walker	10 minutes per day	0.007
Single visit tourist	1 hour over a single visit	0.0002

The Council Worker, with an annual occupancy of 1 hour per day, is considered the person-most-at-risk.

These estimates should be confirmed with Council during detailed design.

5.7 Assessed risk to life – person most at risk

The annual probability of loss of life for the person-most-at-risk across the geologic domains, considering the identified hazards is presented below summarises the risk for life of the person most at risk.

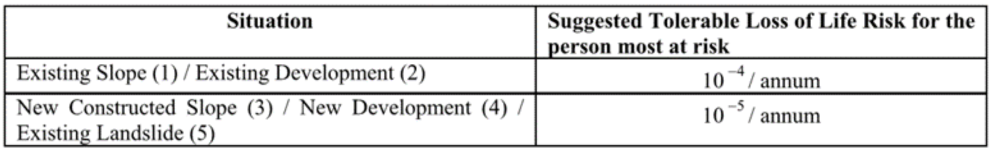
Table 15 - Assessed risk to life for person most at risk

Domain	Hazard	P(H)	P(S|H)	P(T|S)	V(D|T)	R(lol)
1	SF	1.000	0.001	0.027	0.10	10^{-6}
	DB	0.100	0.001	0.027	0.10	10^{-7}
	LS	0.010	0.022	0.027	0.50	10^{-6}
2	SF	1.000	0.002	0.027	0.10	10^{-5}
	DB	0.100	0.002	0.027	0.10	10^{-6}
3	RF	0.100	0.012	0.027	0.50	10^{-5}
	DB	0.100	0.012	0.027	0.10	10^{-6}
4	RF	0.100	0.003	0.027	0.50	10^{-5}
	DB	0.100	0.003	0.027	0.10	10^{-6}
	CC	0.010	0.010	0.027	0.50	10^{-6}
5	SF	1.000	0.0001	0.027	0.10	10^{-7}
	DB	0.100	0.0001	0.027	0.10	10^{-8}
	CC	0.010	0.002	0.027	0.50	10^{-7}
6	SF	1.000	0.002	0.027	0.10	10^{-5}
	RF	0.010	0.002	0.027	0.50	10^{-7}
7	DB	0.100	0.010	0.027	0.10	10^{-6}

Domain	**Hazard**	**P(H)**	**P(S|H)**	**P(T|S)**	**V(D|T)**	**R(lol)**
8	RF	0.100	0.012	0.027	0.50	10^{-5}
	DB	0.100	0.120	0.027	0.10	10^{-5}
9	LS	0.010	0.500	0.027	0.10	10^{-5}

AGS (2007) provides guidance for Tolerable Loss of Life Risk for a person-most at risk (Table 16). Considering this is a new development, acceptable risk level is recommended to be at or below 10^{-5}/annum.

Table 16 AGS Suggested Tolerable loss of life individual risk



Situation	Suggested Tolerable Loss of Life Risk for the person most at risk
Existing Slope (1) / Existing Development (2)	10^{-4} / annum
New Constructed Slope (3) / New Development (4) / Existing Landslide (5)	10^{-5} / annum

The calculated risk to the person most at risk considering the conceptual design shows the risk is at acceptable levels (Table 15).

5.8 Assessed risk to life – societal

Recognising the significant tourist population to the Central Coast and Terrigal and assessment of societal risk is considered appropriate. AGS 2007 provides guidance for the person-most-at-risk and recommends following ANCOLD 2003 for Societal Risk.

Only the larger coastal cliff collapse and landslides in Domains 1, 4, 5 and 9 are considered credible hazards that pose a risk to a larger population.

5.8.1 Population at risk

At the time of writing this report, estimates for boardwalk patronage had not been made available to Arup. An assumption of 1 million visitors per annum or 3,650 visitors per day assumptions have been made in order to complete the assessment.

For reference the Coogee to Bondi coastal walk, NSW, and the Twelve Apostles, Vic, have approximately 8,000 and 12,000 visitors per day, respectively.

Table 17 - Summary of assumed boardwalk patronage

Type	**Number of people per year**	**Average time spent on boardwalk**	**Population per annum**
Visitors to Terrigal	1,000,000	10 minutes	20

A population per annum of 20 means with 10 minutes average occupancy means that for every minute of the year there is 20 people on the boardwalk.

These estimates should be confirmed with Council during detailed design.

5.8.2 Cliff collapse event

Considering 20 people on the 255m boardwalk and a 10m cliff collapse/landslide, the population at risk exposed at any one time along the boardwalk is 1 person. Using a vulnerability of 0.5 for fatality from the hazard, the population at risk is 0.5 persons. As the population is less than 1, it suggests that considering societal risk for this failure is not appropriate.

5.8.3 Earthquake event triggering with widespread rockfall and cliff collapse

Considering a population of 20 during widespread rockfall and cliff collapse/landslides across the boardwalk, the populations exposed is conservatively estimated at 10 persons. Using a vulnerability of 0.5, the population at risk from fatality is 5.

A significant earthquake event that could generate ground accelerations to trigger widespread rockfall and cliff collapse across the boardwalk (Peak Ground Acceleration > 0.5g) has an annual probability of exceedance approaching 1:10,000 (10^{-5}). The probability of the widespread rockfall, landslide and cliff collapse reaching the boardwalk is 10-^{2}, therefore the frequency of this fatal failure is 10^{-7}.

Plotting five fatalities with a 10^{-7} frequency on the F-N diagram (ANCOLD 2003) shows the Societal Risk is Broadly Acceptable (Figure 25).

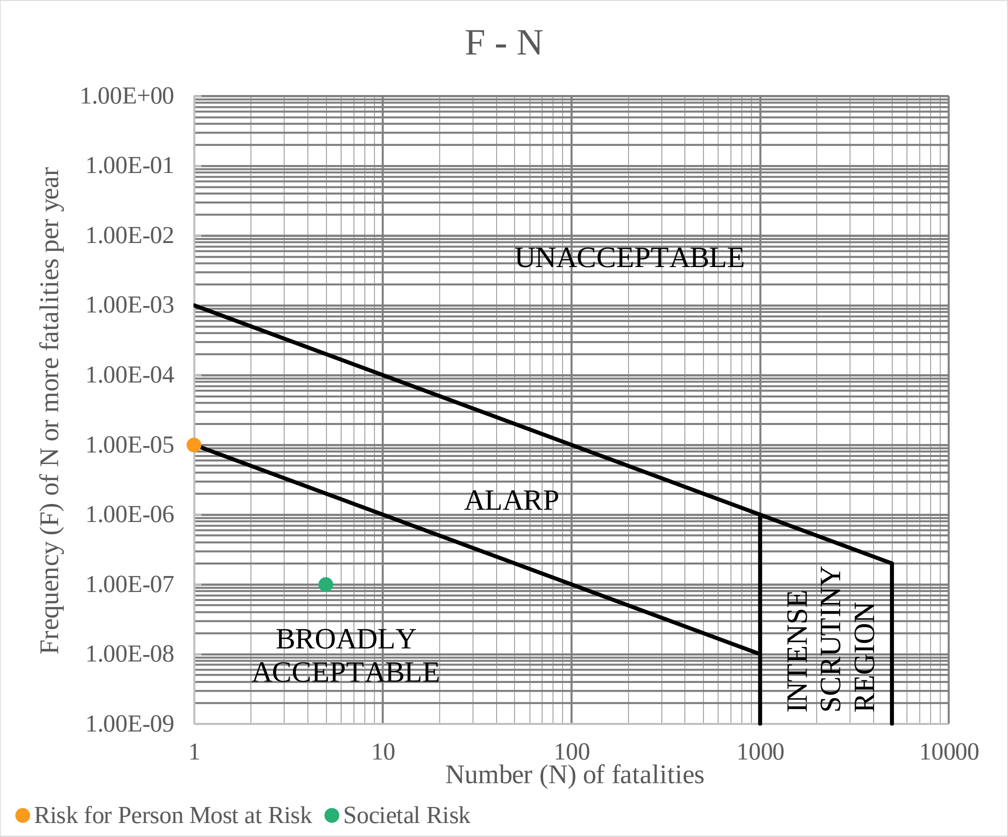


Figure 25 - Frequency vs Number of Fatalities considering 1M visitors per annum

6 Risk to Property

The proposed boardwalk alignment has been adopted with the setbacks provided for each Domain in Section 3.1 which will provide sufficient buffer should a failure occur and have negligible impact of the boardwalk.

In determining the consequences to the boardwalk, it has been assumed that size of slope failures will be limited to the extents outlined in Table 10 and that there is little detrimental impact on the adjoining sections of the boardwalk, and the rate of failure will be instantaneous. Further the cost of reconstruction and/or repair of the boardwalk has been established on a lineal rate estimated from the current project capital cost of $4.5M and a boardwalk length of approximately 200m. This results in a unit rate of $22,500 per metre of boardwalk. Therefore, the following approximate costs of have been adopted for each identified hazard.

Table 18 - Assessed consequences to Property

Hazard	Extend of slope effected/ size of failure	Approximate Cost of damage		Assessed Consequence to property
		Approximate cost	Indicative Value	
Small rockfall	<0.5m	$22,500	0.5%	Insignificant
Boulder rockfall	>0.5m			
Soil debris flows off crest	3m x 10m x 1m	$225,000	5%	Minor
Cliff collapse due to erosion of siltstone layer	10m x 3m x 10m	$450,000	10%	Medium
Landslide	5m x 10m x 2m			

Table 10 summaries the qualitative assessment of each of the geo hazards identified and the assessed consequences to the proposed boardwalk. In accordance with the criteria provided in AGS (2007) Low risk levels would be considered to be 'acceptable', Moderate risk levels would be considered to be 'tolerable'.

Table 19 - Summary of risk to property.

Geohazard	Small rockfall	Boulder rockfall	Soil debris flows off crest	Cliff collapse due to erosion of siltstone layer	Landslide
Affected Domains	1, 2, 3, 8	4, 5, 6, 7	2, 3, 4, 6, 7, 9	5, 6, 7	1, 2, 3
Size of Failure	<0.5m	>1m	10m	20m	20m
Assessed Likelihood	Almost Certain	Possible	Likely	Possible	Rare
Assessed Consequences	Insignificant	Minor	Insignificant	Minor	Medium
Risk	Moderate	Moderate	Moderate	Moderate	Low

7 Geotechnical Design parameters

The following section summarises the strength and deformation parameters for soil and rock units encountered along the proposed boardwalk. The recommendations have been made with consideration of the data collected during the investigation, published relationships and engineering judgement based upon previous experience.

7.1 Design parameters for soils

Limited soil was encountered overlying rock, and therefore limited testing has been carried out. The suggested design parameters have been based on the interpretation of the limited SPT 'N" values and DCP test results and are summarised in Table 20.

Poisson’s ratio typically ranges between 0.2 to 0.4 for unsaturated clays and sand. A value of 0.3 has been adopted.

Active, at-rest and passive earth pressures presented below have been derived from representative drained soil parameters and are for level backfill. Modification for the earth pressure coefficients will be required where a sloping backfill is apparent.

The shallow footing capacities for soil included in the table below are based on a specific geometry and are suitable for preliminary design, but require further refinement at subsequent design stages.

7.2 Rock mass characteristics

The behaviour of rock containing discontinuities or planes of weakness within them is controlled by the rock mass rather than the intact condition, the derivation of parameters for rock masses is inherently challenging because of the number of features to consider and their own variability in the field. Therefore, a rock mass classification, as outlined in Section 4.6, has been carried out to allow for the variation of the intact rock quality and the frequency condition to be rationalised along discrete classes.

The rock mass modulus and strength parameters have been adopted based on results of the investigation, published parameters and pervious experience with similar materials.

Table 20 - Summary of soil design parameters

Material type	**Consistency**	**Bulk unit weight (kN/m^3)**	**Peak friction angle (°)**	**Undrained shear strength (kPa)**	**Elastic modulus (MPa)**	**Poisson's Ratio**	**Ultimate capacity of shallow pad (kPa)[1]**	**Ultimate end bearing capacity (kPa)[2]**	**Ultimate shaft capacity (kPa)**
Marine Sands	Very loose to loose	17	28	-	5 - 10	0.3	-	-	10
	Medium dense	19	33	-	40	0.3	200	200 x z (max 1MPa)	25

Table 20 notes:

1. Assumed depth of shallow footing minimum of 0.5m below a horizontal ground surface and vertically applied load. These values do not account for groundwater table.
2. Minimum of 4 pile diameters in the founding material required to achieve provided bearing capacities, z is the depth below ground.

Table 21 - Summary of earth pressure coefficients

Material type	**Drained analysis**		
	Active earth pressure coefficient (Ka)	**Passive earth pressure coefficient (Kp)**	**At-rest earth pressure coefficient (Ko)**
Marine sands – Very loose to loose	0.36	2.8	0.53
Marine sands – Medium dense	0.29	3.4	0.46

Table 21 notes:

1. Assume horizontal surface in-front and behind a vertical wall.
2. No wall/soil friction has been assumed in earth pressure calculations.
3. In order to mobilise the full passive pressure, displacement is required and therefore must be considered in the design.

Table 22 - Summary of rock design parameters

Unit	**Rock Class**	**Bulk unit weight (kN/m^3)**	**Poisson's Ratio**	**Rock Mass Modulus (MPa)**	**Ultimate end bearing[1] (MPa)**	**Ultimate shaft adhesion[1,4] (kPa)**	**Allowable end bearing[2,3] (MPa)**
Siltstone	I	24	0.2	2000	100	1000	6
	II	24	0.2	1000	60	800	2
	III	24	0.25	600	20	500	1.5
	IV	24	0.25	300	5	150	1
	V	24	0.3	75	3	75	0.7
Sandstone	I	23	0.2	2000	120	3000	8
	II	23	0.2	1200	80	2500	6
	III	23	0.25	800	30	1200	4
	IV	23	0.25	400	10	500	3
	V	23	0.3	75	3	150	1

Table 22 notes:

1. Ultimate capacities are mobilized at large displacements—generally 5% to 10% of pile diameter (or minimum footing dimension) —and require reduction by ϕg for ULS design accordance with AS2159 – 2009 [1]. A lower bound value ϕg = 0.40 is advised for preliminary design, though it may be possible to justify higher values with pile testing during construction.
2. Serviceability capacities are mobilised at displacements of 1% pile diameter (or minimum footing dimension).
3. Where the design is dependent upon end-bearing resistance, piles must extend at least one pile diameter into the founding stratum to develop full design end-bearing and found at least three pile diameters above underlying weaker strata. A minimum of 0.5m embedment in the founding material to achieve shaft resistance.
4. Assumes a rock socket roughness category R2 (grooves of depth 1 mm to 4 mm, width greater than 2 mm, at spacing 50 mm to 200 mm) or better (Walker and Pells [2])
5. In the event of uplift, only ULS shaft friction can be relied upon and these values must be reduced by a factor of 0.75 in addition to the geotechnical reduction factor, and mechanisms of piston and cone failure must be considered (Pells et al [3]). Cone failure often controls for large tension forces in short rock sockets, particularly near ground surface.

8 Comments and recommendations

8.1 Construction method

Preliminary constructability assessments have been completed as part of the concept design process. Four distinct zones have been identified, as shown in Figure 26, which take into account access considerations and main construction activities anticipated to be carried out in each zone. The anticipated construction activities are summarised in Table 23, note that this is not an exhaustive list of possible activities.

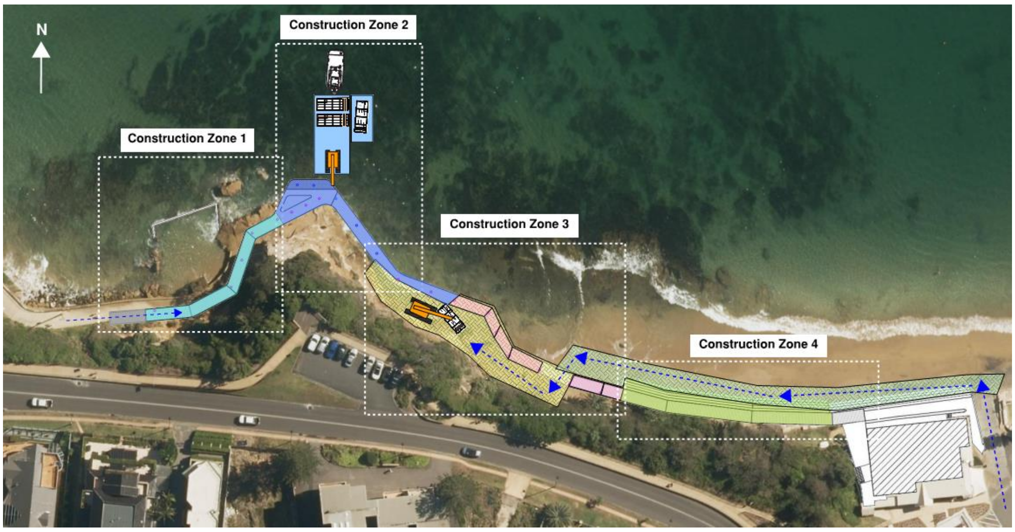


Figure 26 - Proposed construction methodology

The following construction considerations should be considered as they will impact the ultimate design solution, include additional construction activities than those listed in Table 23, and could have significant cost implications on the project:

- Foundation construction is to be both land and water based, depending on foundation positions. It is recommended that an Early Contractor Involvement (ECI) period be carried out alongside detail design to ensure adequate understanding of the constraints and constructability of the final boardwalk design.
- Locations the barge can access may be limited and consideration of tides will be required. Due to the shallow rock in the water will put limitations on the type of barge and it anchoring locations.
- Vibrations caused by heavy construction equipment either tracking or during excavation may increase the risk of rock fall from the nearby slope and cliff.

Table 23 - Construction methodology for each defined construction zone

	Areas within the construction zones	**Brief description of the proposed works**
Construction Zone 1	• Terrigal rockpool • Existing footpath onto the rock platform at western end of proposal	1. Closure of the Terrigal rockpool 2. Carry out cliff stabilisation and remediation works 3. Install piles to rock 4. Assemble and install boardwalk steelwork and decking
Construction Zone 2	• Rock platform area • Barge footprint in the ocean	1. Establishment of marine plant into fixed position north of the rock platform, if required 2. Install piles into rock and prefabricated steel pier 3. Lift prefabricated boardwalk superstructure to the piers and fix into position 4. Install decking and other fixtures as required
Construction Zone 3	• Intertidal zone between the rock platform and the proposed sandstone wall extension	1. Establishment of temporary causeway over the intertidal zone to enable land-based access 2. Install piles into rock and prefabricated steel pier 3. Lift prefabricated boardwalk superstructure to the piers and fix into position 4. Install decking and other fixtures as required
Construction Zone 4	• Beach area at eastern end of proposal • Existing sandstone wall at the Haven precinct	1. Establishment of platform to enable access for land-based plant along beach 2. Remove part of existing seawall for realignment and extension 3. Excavate sand to top of rock level and install sandstone blockwork wall 4. Fill behind new blockwork wall in staged increments 5. Reinstate drainage and culvert 6. Install footpath and miscellaneous items

8.2 Site preparation

To allow for construction of the on-grade portion of the boardwalk and access track in Construction Zones 1 and 4, adequate preparation. Therefore, it is recommended that the existing sandy subgrade, in Construction Zone 4 be proof rolled to improve the near surface compaction of the soils and assist in identifying any soft or unstable areas and should be completed in the following sequence:

- Removal of vegetation and stripping of any root affected soils if encountered.
- Proof roll the existing soil subgrade with at least eight passes of a minimum 8 tonne deadweight smooth drum roller. The sand subgrade will need to be thoroughly moistened before commencing proof rolling.
- A thin layer of road base (75mm thick) should be provided over the sand subgrade to allow of near surface compaction and prevent shearing during rolling.
- Any soft or unstable areas identified during proof rolling should be locally excavated down to a competent base and replace with engineered fill comprising DGS40 as defined by RMS QA Specification 3051, and compacted to at least 95% Modified Maximum Dry Density (MMDD) using an 8 tonne deadweight drum roller.
- Density tests should be carried out on the engineered fill to confirm the required density is achieved. The frequency of density testing should be in accordance to the requirements for Level 1 control in AS3798.

The temporary causeway material shall comprise of high strength and durable angular rock fill such as good quality sandstone. The rock fill shall have the following parameters:

- Single sized, 300mm crushed rock;
- Saturated Point Load Index (Is(50)) no less than 1.5MPa, and
- Maximum sulfate weight loss of 25%.

The rock full must not be end dumped and should be placed in maximum 0.6m thick loose layers using a large excavator. Each layer should be rigorously tamped down using the excavator bucket prior to placing of subsequent layers. Once the rock fill has extended up above the tidal variation, the surface should be graded level and heavily compacted with a smooth drum roller. The upper portion of the cause way above the tidal variation should comprise DGS40 material, as referenced above, may be utilised as a working surface.

Further, it is noted that a number of rock under cuts have been identified over the rock platform in Construction Zone 2. Therefore, it is recommended that prior to site works commencing, a qualified geotechnical engineer/engineering geologist inspect the rock platform and identify the location and extend of the rock under cuttings and these areas be demarcated to prevent surcharging the under cuttings with plant of building materials.

8.3 Foundation options

The following section summarises the geotechnical recommendations for the foundations of the proposed boardwalk.

8.3.1 Shallow foundations

It is recommended that shallow foundation be founded on rock, in order to avoid scour and undermining of the footings if founded in sands. Shallow footings, such as strip footings are feasible for the extension of the sandstone block wall in Construction Zone 4 and proposed retaining wall in Construction Zone 1 may be founded on rock and designed using the suggested ultimate bearing pressures presented in Table 22.

The geotechnical strength reduction factor, Φg, for design of pad or strip footings and culvert base slabs, shall be in accordance with AS5100.3-2017 (Tables 5.3.3.3A and 5.3.3.3B) [4]. The range of Φg indicated within AS5100.3 for pad footings ranges from 0.35 to 0.65. Based on the current investigation a Φg of 0.65 in considered appropriate.

It is recommended that footing excavations are inspected by a suitably qualified and experienced geotechnical engineer or engineering geologist during construction to ensure founding conditions are consistent with those on which design recommendations are based. Any loose or water-softened material should be removed prior to pouring concrete or a blinding layer is provided to the footing base.

8.3.2 Piled foundation

Based on the current design the boardwalk is suspended in parts of Construction Zone1 and of Construction Zones 2 and 3. Bored cast in place piles are considered most suitable for the foundation of the suspended portion of the boardwalk.

In Construction Zone 1 bored piles can be completed without the use of temporary casing to stabilise the bores during pile construction. However, bored piles located over Construction Zone 3, may require temporary casing when drilling through the existing sandy soils and the temporary causeway fill.

In Construction Zone 4, and potentially the northern portion of Construction Zone 3, piles are anticipated to be installed using a piling equipment mounted on a barge. Sacrificial steel casing will be reamed into the rock surface to seal against water inflows at the seabed level. the soil, if encountered, and rock profile would then be drilled out using conventional bored piling techniques.

It is recommended that concrete be poured using tremie methods, and as such concrete specifications should consider the required workability parameters. Concrete should be poured without delay, preferably immediately following completion of drilling and inspection, in order to avoid softening of the exposed foundation material.

High strength rock is anticipated on site, therefore, adequately sized piling rigs should be considered. It is noted that site access is constrained in Construction Zone 1 and 2. Smaller piling rigs will be required in this area, which will effect productivity rates and impact overall program.

Bored cast-in-place piles are to be constructed in accordance with AS 2159-2009 [1]. Based on an assessment of the site conditions an average risk rating for the design of bored piles socketed in weathered rock or better is between 2 to 2.5. In Table 4.3.2 (C) of AS2159-2009 [1], an average risk rating between 2 to 2.5 is defined as low risk and a Φg of 0.56 can be adopted.

AS2159-2009 requires integrity testing to be undertaken on piles where the adopted Φg is greater than 0.4. Based on the current proposed foundations which involves a bored pile with a plunged steel pier, and site access constraints, it is considered that the required amount of integrity testing may be difficult to be completed. The ultimate foundation design must consider these limitations when adopting reduction factors.

It is recommended that a qualified Geotechnical Engineer or Engineering Geologist inspect all piles to confirm that the anticipated ground conditions and design assumptions are satisfied.

Modulus of subgrade reaction, if required for soil for lateral pile support, these can be further developed using the proposed design stiffness parameters as provided in Table 22.

It is recommended to ignore the top 1.5D (AS 2159-2009, [1]) and the depth of any proposed scour when considering the lateral and vertical support to the pile foundation.

The rock platform in located in northern portion of Construction Zone 1 and in Construction Zone 2 may potential be undermined by wave action and erosion of a siltstone band located within the tidal variation height. Therefore, it recommended that the piles in the area, found below the siltstone band.

A serviceability check on the pile foundation under lateral and vertical load is also required, in accordance with AS 2159-2009 [1]. The pile shall be designed for serviceability by controlling or limiting pile movements so that deflections do not exceed the deflection limits. Calculations of lateral deflection and rotation of a pile and a pile group shall be carried out using geotechnical parameters that are appropriately selected and to which no reduction factor is applied. The designer shall select such parameters, taking into account the type of pile, the ground conditions, installation condition of the shaft and base and the direction and type of loading.

Refer to Section 8.5 for the exposure classification of the structures.

8.4 Retaining walls

The following list includes, but not limited to, considerations for the designs of gravity retaining walls:

- Retaining walls shall be assessed for stability and strength with appropriate design factors in accordance with AS5100.3:2017 [4].
- The design of the shallow foundations for the retaining wall shall consider the dimensions of the foundation for bearing capacity, base sliding and overturning failures.
- Where the ground level behind and/or in front of the wall vary, the wall should be assessed in representative sections to capture the variation in height.
- Passive resistance to the wall toe should not be considered in design.
- Groundwater levels over the life of the structure to be considered in design. Adequate drainage to be allowed for and maintenance of the drainage system should also be considered.
- Construction sequencing should be considered in the design, given the offset to the exiting slope. This would include temporary batters and over-excavation considerations prior to completion of the wall.
- Method of compaction of the retained soil should be considered so that the structure is not damaged. Compaction pressures should be allowed for in the design. Any surcharge affecting retaining structures should be allowed in the design.

8.5 Exposure classification

Based on the marine environment of the project site, exposure classifications for concrete in accordance with AS2159-2009 (Table 6.4.2 (A)) and AS5100.5-2017 (Table 4.3) are ‘Severe’ and ‘C2’ respectively.

8.6 Seismic classification

Based on the advice provided in AS1170.4-2007 ‘Structural design actions Part 4: Earthquake actions in Australia’ we consider the site to be classified as Class Be – Rock (based on Clause 4.2).

8.7 Remediation and stabilisation measures

The current concept alignment has been adopted to minimise the risk to both the boardwalk and the public using the boardwalk, which based on the current assessment, this has been achieved. However, should council wish to further reduce the perceived risks the following stabilisation measures can be consider. The design and implementation of any of the listed remediation works will be further developed as part of the detailed design as required.

- Cliff face scaling – removal of loose surface debris using chains attached to excavators and dragged across the face of the cliff prior to construction of the boardwalk;
- Removal of overground vegetation/unstable trees;
- Support of potentially unstable blocks or wedges with hot dipped galvanised or stainless steel fully grouted rock bolts;
- Support of siltstone bands, weak and/or fractured zones of bedrock with reinforced shotcrete supported by fully grouted rock bolts;
- Support of overhangs or undercuts at the base of cliff faces using cast in-situ underpins.
- In areas of potential soil debris/ or instability of the soil profile, use of erosion protection such as ‘jute mesh’, held in place with pins to promote vegetation growth.

The stabilisation measures outlined above may poorly impact the aesthetic outcome of the project if not completed by experienced contractors. At this stage of design, it is preferred that remediation be limited to cliff scaling and vegetation growth.

8.8 Slope risk management

The following various measures seek to manage and where appropriate maintain risk to ‘acceptable’ levels. These recommendations form an integral part of slope risk management and will also assist in the development of emergency response to safeguard the community from severe coastal storm events.

8.8.1 Monitoring

The identified potential hazards within the site area should be monitored on an annual basis and after periods of prolonged or heavy rainfall and significant storm events in order to assess existing conditions and any indicators of deterioration such as debris/boulders on the beach, rock platform, and/or damage to the proposed boardwalk.

As a basis, the following tentative definition of heavy rainfall and prolonged rainfall are provided as guidance and will be confirmed during detailed design:

- Heavy rainfall: at least 100mm of rainfall in one day; and
- Prolonged rainfall: at least 150mm of rainfall over a 5 day period.

It is recommended that a formal process with adequate documentation and reporting frequency be defined. Should instability occur during the monitoring period the following details must be recorded as part of the monitoring reports.

- Date of incident
- Weather conditions on the day and leading up to the incident

- Location sketch plan,
- Photographs and dimensions of the failed section (ie. block size, tension crack widths, landslide features).

Following an incident, completed monitoring reports should be provided to geotechnical engineers so that additional advice may be provided or assessment of specific stabilisation measures.

In addition, a detailed assessment of the slope should be undertaken by ab experienced engineering geologist/geotechnical engineer to assess current conditions against pervious monitoring reports.

8.8.2 Stormwater drainage

All existing subsurface drains, sewers and any other water carrying pipelines (eg, drainage pipe observed in Domain 1) must be subject to regular maintenance by asset owners. Maintenance should also include leak and/or damage detection for water carrying pipelines by experienced plumbers.

9 Summary

Preliminary foundation design and constructability recommendations have been completed as part of the concept design process considering ground conditions encountered at site during the investigation.

The currently proposed construction methodology is considered feasible, however early contractor engagement is recommended to provide additional constructability advice and highlight potential site constraints.

The currently documented boardwalk concept alignment has been assessed to be 10^{-5} or less for the person most at risk and 10^{-7} for societal risk which are considered acceptable levels of risk based on AGS (2007) and ANCOLD (2003) respectively. Further, on average the risk to property has been assessed to be moderate. Based on AGS guidelines, moderate risk levels can be tolerated.

It is considered that the newly constructed boardwalk with ongoing monitoring by Council and intermittent geotechnical assessment are an adequate method of slope risk management.

10 References

[1] Australian Standard, “AS2159-2009, Piling - Design and Installation,” 2009.

[2] B. F. a. P. P. J. N. Walker, “Construction of Bored Piles,” *Australian Geomechanics,* 1998.

[3] P. J. N. M. G. a. W. B. F. Pells, “Foundations on Sandstone and Shale in the Sydney Region,” *Australian Geomechanics.*

[4] Australian Standard, “AS5100.3-2017, Bridge Design, Part 3: Foundation and soil-supporting structures,” 2017.

[5] Pells, P.J.N, “SUBSTANCE AND MASS PROPERTIES FOR THE DESIGN OF ENGINEERING STRUCTURES IN THE HAWKESBURY SANDSTONE,” *Australian Geomechnics,* vol. 39, no. 3, 2004.

[6] Australian Geomechanics Society, “Practice Note Guidelines For Landslide Risk Management,” *Australian Geomechanics Journal and News of the Australian Geomechanics Society,* vol. Volume 42, no. 1, 2007.

[7] Australian National Committee on Large Dams, “Guidelines on Risk Assessment,” *ANCOLD,* 2003.

Drawings

Drawing 1 – Ground investigation location plan
Drawing 2 – Geological cross section

Legend

▲▲ Section Location

Ground Investigations

⊕ Borehole

⊗ Dynamic Cone Penetrometer

Client
Central Coast Council

Job Title
Terrigal Boardwalk

Figure Title
Ground Investigation Locations Plan

Metres
0 5 10 15 20

I2	4/09/2018	RS/ JW	AC	AC
Issue	Date	By	Chkd	Appd

ARUP
Level 10, 201 Kent Street
PO Box 76 Millers Point
Sydney, NSW 2000
Tel +61 (2)9320 9320 Fax +61 (2)9320 9321
www.arup.com

Scale at A3
1:400

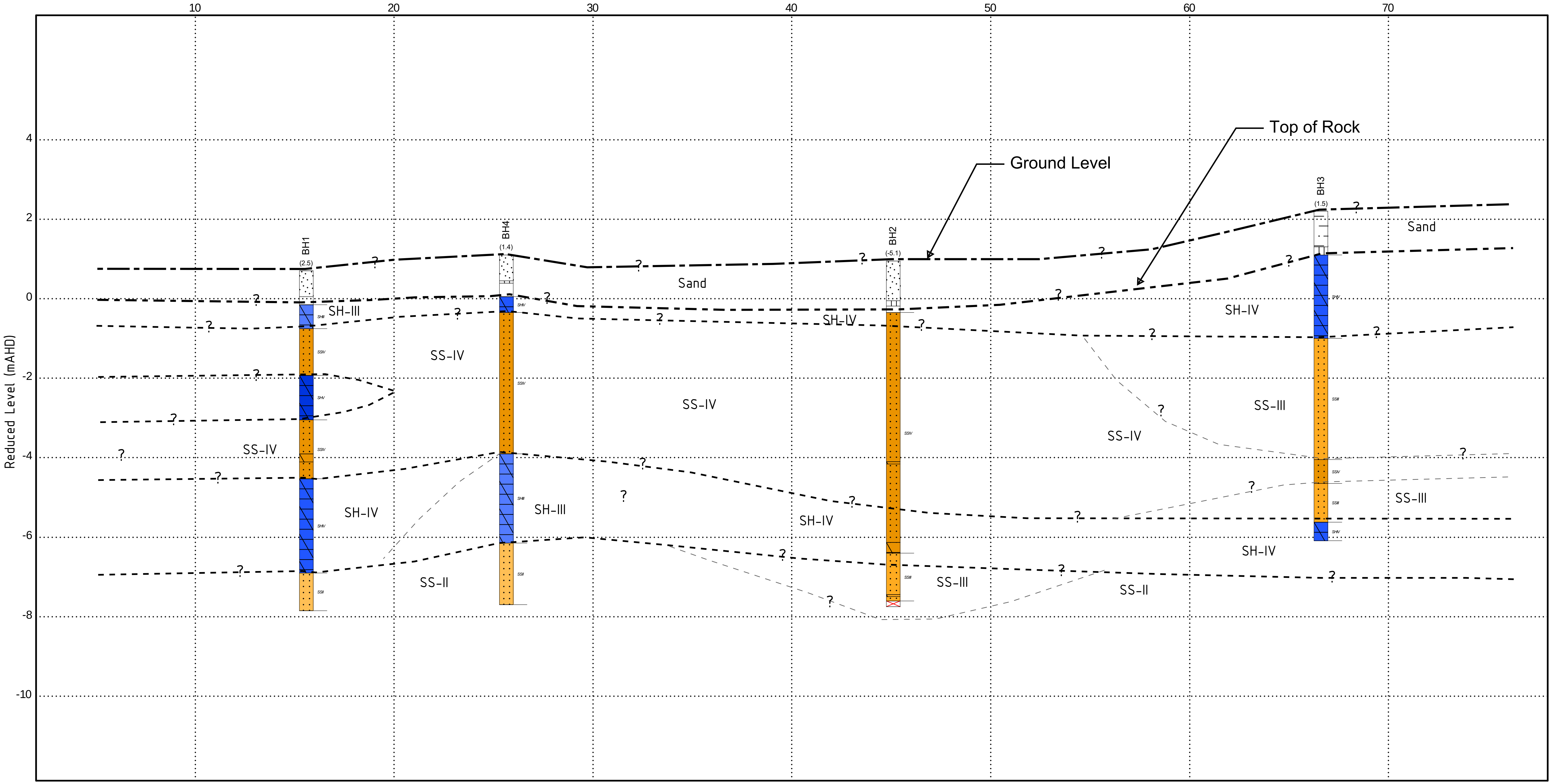
Figure Status
For Issue

Coordinate System
MGA94 Z56

Job No
261648

Drawing No
001

\\global.arup.com\australasia\SYD\Projects\261000\261648-00 Terrigal Boardwalk\Work\Internal\261648 Terrigal\GIS\Map\Terrigal_GI_MW_10.5_JW.mxd

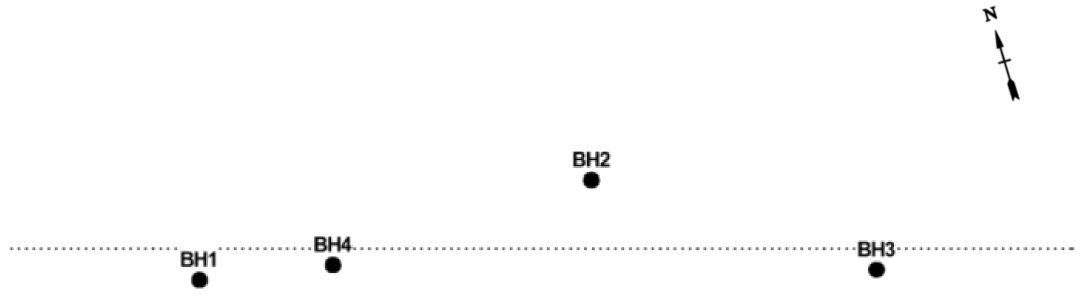


NOTES:
1) Unit boundaries are approximate
2) BH2 is offset approximately 6m
from the alignment

▭ SW - Well Graded SAND
▨ SP - Poorly Graded SAND
▨ SANDSTONE
▧ SILTSTONE
▥ Clay
☒ Core loss

🟫 Sandstone Class V
🟧 Sandstone Class IV
🟧 Sandstone Class III
🟨 Sandstone Class II

🟦 Shale Class IV
🟦 Shale Class III



ARUP

TITLE GEOLOGICAL CROSS SECTION
CLIENT Central Coast Council
PROJECT Terrigal Board walk
JOB No. 261648
SCALE 1:100V 1:200H
PAGE A3L

Drawing 2

PREPARED BY: RS/ JW
CHECKED BY: AC
DATE 3/09/2018

Appendix A

Geotechnical Explanatory Notes

Geotechnical Explanatory Notes

The report contains the results of a geotechnical investigation conducted for a specific purpose and client. The results should not be used by other parties, or for other purposes, as they may contain neither adequate nor appropriate information. In particular, the investigation does not cover contamination issues unless specifically required to do so by the Client.

DESCRIPTION AND CLASSIFICATION METHODS

Soil and rock descriptions are generally in accordance with the recommendations of Australian Standards AS 1726-2017 and cover the following properties:

SOIL
- Classification Group
- Soil Name
- Plasticity
- Grain Size (and shape)
- Colour
- Texture and Fabric
- Secondary Components
- Minor Components
- Moisture
- Consistency
- Structure
- Origin
- Other Relevant Information

ROCK
- Rock Name
- Grain Size
- Colour
- Fabric and Texture
- Strength
- Weathering
- Defects
- Weathering and / or alteration

CLASSIFICATION OF COARSE GRAINED SOILS (Table 9 AS1726:2017)

Note: Cu = Coefficient of uniformity, Cc = Coefficient of curvature

Major divisions		Group symbol	Typical names	Field classification of sand and gravel	Laboratory classification	
Coarse grained soil (more than 65% of soil excluding oversize fraction is greater than 0.075 mm)	GRAVEL (more than half of coarse fraction is larger than 2.36 mm)	GW	Gravel and gravel-sand mixtures, little or no fines	Wide range in grain size and substantial amounts of all intermediate sizes, not enough fines to bind coarse grains, no dry strength	≤5% fines	Cu >4 1<Cc <3
		GP	Gravel and gravel-sand mixtures, little or no fines, uniform gravels	Predominantly one size or range of sizes with some intermediate sizes missing, not enough fines to bind coarse grains, no dry strength	≤5% Fines	Fails to comply with above
		GM	Gravel-silt mixtures and gravel-sand-silt mixtures	'Dirty' materials with excess of non-plastic fines, zero to medium dry strength	≥12% fines, fines are silty	Fines behave as silt
		GC	Gravel-clay mixtures and gravel-sand-clay mixtures	'Dirty' materials with excess of plastic fines, medium to high dry strength	≥12% fines, fines are clayey	Fines behave as clay
	SAND (more than half of coarse fraction is smaller than 2.36 mm)	SW	Sand and gravel-sand mixtures, little or no fines	Wide range in grain size and substantial amounts of all intermediate sizes, not enough fines to bind coarse grains, no dry strength	≤5 fines	Cu >6 1<Cc >3
		SP	Sand and gravel-sand mixtures, little or no fines	Predominantly one size or range of sizes with some intermediate sizes missing, not enough fines to bind coarse grains, no dry strength	≤5% fines	Fails to comply with above
		SM	Sand-silt mixtures	'Dirty' materials with excess of non-plastic fines, zero to medium dry strength	≥12% fines, fines are silty	NA
		SC	Sand-clay mixtures	'Dirty' materials with excess of plastic fines, medium to high dry strength	≥12% fines, fines are clayey	

Dual classification (e.g. GP-GM) comprising the two group symbols separated by a dash are given to coarse grained soil with fines contents between 5% and 12%.

CLASSIFICATION OF FINE GRAINED SOILS (Table 10 AS1726:2017)

Major Divisions		Group symbol	Typical names	Field classification of silt and clay			Laboratory classification
				Dry strength	Dilatancy	Toughness	% < 0.075 mm
Fine grained soils (more than 35% of soil excluding oversize fraction is less than 0.075 mm)	SILT and CLAY (low to medium plasticity, %	ML	Inorganic silt and very fine sand, rock flour, silty or clayey fine sand or silt with low plasticity	None to low	Slow to rapid	Low	Below A line
		CL, CI	Inorganic clay of low to medium plasticity, gravelly clay, sandy clay	Medium to high	None to slow	Medium	Above A line
		OL	Organic silt	Low to medium	Slow	Low	Below A line
	SILT and CLAY (high plasticity)	MH	Inorganic silt	Low to medium	None to slow	Low to medium	Below A line
		CH	Inorganic clay of high plasticity	High to very high	None	High	Above A line
		OH	Organic clay of medium to high plasticity, organic silt	Medium to high	None to very slow	Low to medium	Below A line
	Highly organic soil	Pt	Peat, highly organic soil				

COMPOSITE SOIL TYPE

As most natural soils are a mixture of basic soil types, the primary soil is described and modified by secondary constituents as follows:

Designation of components	In coarse grained soils				In fine grained soils	
	% Fines	Terminology	% Accessory Coarse fraction	Terminology	% Sand/ gravel	Terminology
Minor	≤5	Add 'trace clay/silt' to description, as applicable	≤15	Add 'trace sand/gravel' to description, as applicable	≤15	Use 'trace'
	>5, ≤12	Add 'with clay/silt to description', as applicable	>15, ≤30	Add 'with and/gravel' to description, as applicable	>15, ≤30	Add 'with sand/gravel' to description, as applicable
Secondary	>12	Prefix soil name as 'silty' or 'clayey', as applicable	>30	Prefix soil name with 'sandy' or 'gravelly' as applicable	>30	Prefix soil name with 'sandy' or 'gravelly', as applicable

GRAIN SIZE

Designation	**Fines**		**Sand**			**Gravel**			**Cobbles**	**Boulders**
	Clay	Silt	Fine (f)	Medium (m)	Coarse (c)	Fine (f)	Medium (m)	Coarse (c)		
Grain size (mm)	<0.002	0.002 – 0.075	0.075 – 0.21	0.21 – 0.6	0.60 – 2.36	2.36 – 6.7	6.7 - 19	19 - 63	63 - 200	>200

COLOUR

Individual assessment of colour has been made at field moisture condition, or as received, using simple terms like **black**, **white**, **grey**, **red**, **brown**, **orange**, **yellow**, **green** or **blue**. No reference has been made to standard colour charts unless specifically stated. These may be modified where necessary using '**pale**', or '**dark**' or '**mottled**'. Borderline colours are described as a combination of colours e.g. **red-brown** etc. If one colour is more dominant this shall be the 2nd term e.g. If brown is dominant then '**red-brown**'.

Mottling is described as '(primary colour) mottled (secondary colour)'. Where a soil consists of two colours present in roughly equal proportions the colour description should be 'Mottled (first colour) and (second colour)'.

SOIL MOISTURE CONDITION

Condition	**Cohesive**	**Granular**
DRY (D)	Hard and friable or powdery, well dry of plastic limit	Cohesionless and free-running
MOIST (M)	Cool, darkened in colour, can be moulded	Cool, darkened in colour, tends to cohere
WET (W)	Weakened. Free water forms on hands when handling, soil tends to stick together	Tends to cohere

Symbol	**Description**
w < PL	Moist, dry of plastic limit
w ≈ PL	Moist, near plastic limit
w > PL	Moist, wet of plastic limit
w ≈ LL	Wet, near liquid limit
w > LL	Wet, wet of liquid limit

CONSISTENCY / RELATIVE DENSITY

Soil consistency / relative density is assessed based on a combination of in-situ testing and tactile field assessments. Where no in-situ testing is available, soil consistency is based solely on the tactile field assessment of the Engineer/Geologist.

Designation	**Field test**	**Undrained shear strength kPa**
Very Soft (VS)	Exudes between fingers when squeezed	<12
Soft (S)	Moulded by light finger pressure	>12 and ≤25
Firm (F)	Moulded by strong finger pressure	>25 and ≤50
Stiff (St)	Indented by thumb, cannot be moulded by fingers	>50 and ≤100
Very Stiff (VSt)	Indented by thumbnail	<100 and ≤200
Hard (H)	Indented with difficulty by thumbnail	>200
Friable	Can be easily crumbled or broken into small pieces by hand	-

Designation	**Density index %**
Very loose (VL)	≤15
Loose (L)	>15 and ≤35
Medium Dense (MD)	>35 and ≤65
Dense (D)	>65 and ≤ 85
Very Dense (VD)	>85

ROCK CLASSIFICATION TABLE (as per AS1726:2017)

Grain Size	**Sedimentary**	**Metamorphic**	**Igneous**		
			Acid	**Intermediate**	**Basic**
>2mm	Conglomerate, Breccia, Limestone	Gneiss	Granite	Diorite	Gabbro
0.06 - 2mm	Sandstone, Tuff, Limestone	Schist	Microgranite	Microdiorite	Dolorite
<0.06mm	Mudstone, Siltstone, Shale, Claystone, Limestone	Phyllite, Slate	Rhyolite	Andesite	Basalt

ROCK STRENGTH (as per AS1726:2017)

Designation		Very Low (VL)	Low (L)	Medium (M)	High (H)	Very High (VH)	Extremely High (EH)
Guide to strength	**Field test**	Material crumbles under firm blows with sharp end of pick. Pieces up to 3cm thick can be broken by finger pressure	Easily scored with knife. A piece of core 150mm long and 50mm diameter may be broken by hand.	Readily scored by knife; a piece of core 150mm long by 50mm diameter can be broken by hand with difficulty	A piece of core 150mm long by 50mm diameter cannot be broken by hand but can be broken by a pick with single firm blow	Hand specimen breaks with pick after more than one blow; rock rings under hammer	Specimen requires many blows with geological pick to break through intact material; rock rings under hammer
	Point Load Strength Index Is_{50} (MPa)	0.03 – 0.10	0.10 – 0.30	0.30 – 1.0	1.0 – 3.0	3.0 – 10.0	>10.0
Uniaxial Compressive Strength (MPa)		0.6 – 2.0	2.0 – 6.0	6.0 – 20.0	20.0 – 60.0	60.0 - 200	>200

ROCK WEATHERING Based on visual identification as per AS1726:2017

Term		Symbol	Field appearance
Residual Soil		RS	Soil developed on extremely weathered rock; the mass structure and substance fabric are no longer evident; there is a large change in volume but the soil has not been significantly transported
Extremely Weathered		XW	Rock is weathered to an extent that it has 'soil' properties, i.e. it either disintegrates or can be remoulded, in water
Distinctly Weathered (DW)	Highly Weathered[1]	HW	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. Rock strength is significantly changed by weathering. Some primary minerals have weathered to clay minerals. Porosity may be increased by leaching, or may be decreased due to deposition of weathering products in pores.
	Moderately Weathered[1]	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

1. **Notes:** Where it is not practical to distinguish between highly weathered and moderately weathered, rock, the term 'Distinctly Weathered' may be used. 'Distinctly Weathered' is defined as: 'Rock strength usually changed by weathering. The rock may be highly discoloured, usually by iron staining. Porosity may be increased by leaching, or may be decreased due to deposition of weathering products in pores. There is some change in rock strength.'

BEDDING STRATIFICATION

Term		Description	Separation of Stratification Planes
Stratification not recognisable		Massive	-
Stratification more than 20 mm apart	Bedded	Very thickly bedded	>2 m
		Thickly bedded	0.6 - 2 m
		Medium bedded	0.2 - 0.6 m
		Thinly bedded	60 mm-0.2 m
		Very thinly bedded	20 – 60 mm
Stratification planes less than 20 mm apart	Laminated	Thickly laminated	6 – 20 mm
		Thinly laminated	<6 mm

Table based on Geological Society of London Engineering Group Working Party report on *The Logging of Rock Cores for Engineering Purposes* - Q J Eng Geol Vol 3, 1970, pp1-24.

DEFECT DESCRIPTION

All natural defects are marked on the core using an 'X'.

Defect Type

Symbol	Description
BP	Bedding plane parting - arrangement in layers of mineral grains of similar sizes, near parallel to surface of deposition along which a continuous observable parting occurs. Generally no microfractures.
JT	Joint - a fracture across which rock has little or no tensile strength and is not obviously related to rock fabric.
SZ	Sheared Zone - zone of multiple closely spaced fracture planes with roughly parallel planar boundaries, usually forming blocks of lenticular or wedge-shaped intact material. Fractures are typically smooth, polished or slickensided; and curved.
FL	Foliation Parting – As for bedding plane parting except discontinuous microfractures may be present near parallel to the layering.
CR	Crushed Seam - zone with roughly parallel, planar boundaries (commonly slickensided) containing disoriented usually angular rock fragments of variable size often in a soil matrix.
WE	Weathered Zone - zone of any shape but commonly with parallel planar boundaries containing moderately to gradational boundaries into fresher rock.
DB	Drilling Break
DL	Drilling Lift
HB	Handling Break
SM	Infilled seam – Seam of soil material usually with distinct roughly parallel boundaries formed by the migration of soil into an open cavity or joint, infilled seam less than 1mm thick may be described as a veneer or coating on a joint surface.
SS	Sheared Surface – A near planar, curved or undulating surface which is usually smooth, polished or slickensided and which shows evidence of shear displacement.
VN	Vein
CL	Cleavage

Inclination

For specific defects, the orientation of each individual defect is noted in degrees from core normal. If the orientation cannot be measured, a dash (-) is used.

Defect Spacing

Defect Spacing, as per BS5930:2015		
Spacing/Width (mm)	**Descriptor**	**Symbol**
<20	Extremely Close	EC
20-60	Very Close	VC
60-200	Close	C
200-600	Medium	M
600-2000	Wide	W
2000-6000	Very Wide	VW
>6000	Extremely Wide	EW

Block Shape Terms (AS1726)	
Term	**Description**
Blocky	Equidimensional
Tabular	Thickness much less than length or width
Columnar	Height much greater than cross section

Shape	
Symbol	**Description**
PR	Planar – the defect does not vary in orientation
IR	Irregular – the defect has many sharp changes of orientation
CU	Curved – the defect has a gradual change in orientation
UN	Undulating – the defect has a wavy surface shape
ST	Stepped – the defect has one or more well-defined steps
DIS	Discontinuous defect

Infill Type			
Symbol	**Description**	**Symbol**	**Description**
CA	Calcite	MS	Secondary Mineral
X	Carbonaceous material	MU	Unidentified Mineral
KT	Chlorite	Clay	Clay
CT	Carbonate	QZ	Quartz
FE	Iron oxide	MN	Manganese

Roughness	
POL	Polished - shiny smooth surface
SL	Slickensided - grooved or striated surface, usually polished
S	Smooth – smooth to touch. Few or no surface irregularities
RF	Rough – many small surface irregularities (amplitude generally less than 1mm). Feels like fine to coarse sand paper.
VR	Very rough – Many large surface irregularities (amplitude generally more than 1mm). Feels like coarse than very coarse sand paper

Coating	
CN	Clean – no visible coating
SN	Stained – no visible coating but surfaces are discoloured
VNR	Veneer – a visible coating of soil or mineral, too thin to measure; may be patchy
CO	Coating – a visible coating up to 1mm thick. Thicker soil material shall be described using defect terms (e.g. infilled seam). Thicker rock strength material shall be described as a vein.

CORE RECOVERY DEFINITIONS

Total core recovery (TCR) is defined as the ratio of total length of core recovered to length of core run drilled (expressed as a percentage).

$$\text{TCR}= \frac{L_{\text{core recovered}}}{L_{\text{core run}}}$$

Solid core recovered (SCR) is defined as the ratio of the sum of length of solid core pieces recovered at full diameter to length of core run drilled (expressed as a percentage).

$$\text{SCR}= \frac{L_{\text{solid core recovered}}}{L_{\text{core run}}}$$

Rock quality designation (RQD) is defined as the ratio of length of solid core recovered in pieces 100mm or longer to length of core run drilled (expressed as a percentage).

$$\text{RQD}= \frac{L_{\text{solid core >100mm}}}{L_{\text{core run}}}$$

STANDARD PENETRATION TEST (SPT) REPORTING

The results of SPTs are reported on borehole logs. Typically the test is reported as the number of blows for the seating drive followed by a semi colon (;) and the number of blows of the two increments of the main drive e.g., 5; 10, 15. The N value is reported as the sum of the two values of the main drive, e.g., N= 25.

For a test which is terminated during the main drive, the blows for the seating drive are reported followed by the total number of blows and the total distance driven (mm) e.g., 15; 50/250.

For a test which is terminated during the seating drive, the total number of blows and the distance driven (mm) is reported and the result is suffixed with an “s” to designate the test was terminated during the seating drive e.g., 50/75s.

For a test that is terminated before achieving the full main drive penetration, the N values is determined by extrapolation of the penetration and number of blows recorded and is denoted with "*".

For a test that is terminated within the seating drive the N value is determined by extrapolation of the penetration and number of blows recorded and is denoted with "**".

SYMBOLS & ABBREVIATIONS

Drilling

Method	
AD	Auger drilling (bit unspecified)
AD/V	Auger drilling – Steel 'V' bit
AD/TC	Auger drilling – Tungsten carbide bit
RR	Tricone (rock roller) bit
WB	Washboring
NMLC, BMLC	Triple tube rotary core drilling (52mm, 35mm diameter)
NH, HQ	Wireline core drilling
D	Diatube coring

Support	
W	Water
M	Mud
C	Casing
T	Timbering
U	Unsupported

Field Testing

PL	Point load test (A – axial, D – diametral test)
Is(50)	Point load strength index (MPa)
q_c	Cone resistance (from CPT)
CPT	Cone penetration test
SPT	Standard penetration test
N	SPT blow count (blows/300 mm)
R	SPT refusal
RW	SPT rod weight only causing penetration
HW	SPT hammer and rod weight causing penetration
HB	SPT hammer double bouncing
PT	Pressuremeter test
PP	Pocket penetrometer, undrained shear strength (kPa)
V	In situ vane test, peak/residual value (kPa)

----▶-----	Inflow
----◀-----	Outflow (loss)
----▼-----	Level (date)
----◁-----	Partial loss

Soil Properties

CBR	California Bearing Ratio
NMC	Natural moisture content
OMC	Optimum moisture content from compaction test
LI	Liquidity index
LL	Liquidity limit
LS	Linear shrinkage
PI	Plasticity index
PL	Plastic limit
q_u, UCS	Unconfined compressive strength
w	Moisture content (% of dry weight)

Water – Moisture

W	Wet
M	Moist
D	Dry
S	Standpipe installed to depth shown
P	Piezometer installed at depth shown

Sample Codes

C	Core Sample
B	Bulk Sample
D	Disturbed Sample
AMAL	Amalgamated sample
B	Bulk disturbed
BLK	Block
CBR	CBR mould
CD	Plastic tub for chemical analysis
D	Small disturbed
DEN	Denison sample
DENm	Denison Sampler (modified)
E	Environmental
G	Gas

J	Jar
K	Amber chemical jar
LB	Large bulk disturbed
LDS	Large disturbed
M	Mazier type
P	Piston
TW	Thin walled push-in
U	Undisturbed – open drive
U100	100mm diameter undisturbed
U63	63mm diameter undisturbed
U76	76mm diameter undisturbed
W	Water

Appendix B

Borehole Logs

ARUP	NON-CORED BOREHOLE RECORD	BH1	SHEET 1 OF 2

CLIENT	Central Coast Council	LOGGED BY	RS
PROJECT	Terrigal Board walk	CHECKED BY	AC
		DRILLED DATE	22-May-18

CONTRACTOR	Rockwell	ANGLE	Vertical	GROUND LEVEL	RL 0.70m
DRILL MODEL	Track-mounted	BEARING	-	LOCATION	355738.0 E 6297959.7 N
DRILLER	KM	HOLE DIAMETER	110mm	ELEVATION DATUM	Australian Height Datum (AHD)
LOCATION	Haven Beach, Terrigal	MOUNT	BIT	COORDINATE SYSTEM	MGA94

DRILLING				STRATA					MATERIAL DESCRIPTION	CONDITION		OBSERVATION
DRILLING & CASING	WATER	DRILLING PENETRATION	GROUNDWATER LEVELS	SAMPLES	FIELD TESTS	DEPTH (R.L.) m (m)	GROUP SYMBOL	GRAPHIC LOG	SOIL TYPE Plasticity / Grain Size, Colour, Minor Components	WATER / MOISTURE	CONSISTENCY	Comments / Penetration Rate
AD/T HW casing		E	▽	SPT 0.00m 0.45m 0.50m SPT 0.65m 0.85m	SPT 1, 0, 1 N=1 SPT 4/150s	0.85	SW		SAND: fine to coarse, rounded, orange brown, with shell fragments	M W	VL	MAR
						1 2 3 4 5 6 7 8 9 10			Continued as cored borehole			

NOTES

See explanatory notes for details of abbreviations and basis of descriptions

JOB
261648

ARUP

CORED BOREHOLE RECORD

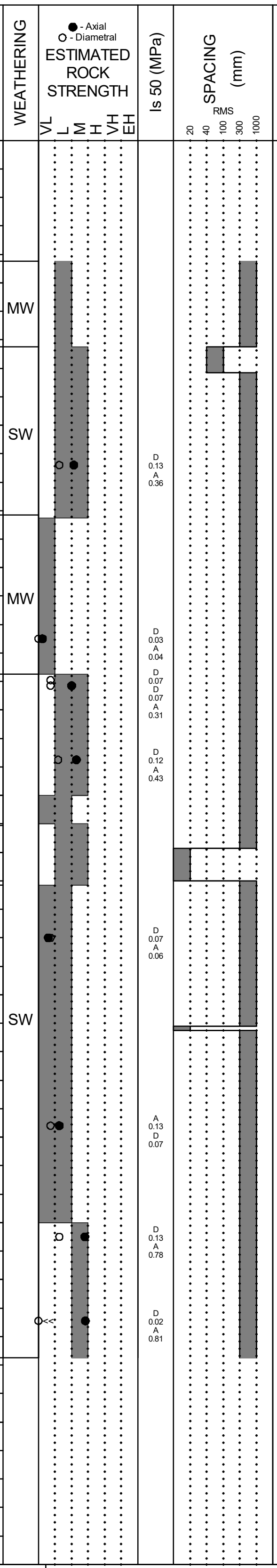
BH1

SHEET 2

OF 2

CLIENT	Central Coast Council	LOGGED BY	RS
PROJECT	Terrigal Board walk	CHECKED BY	AC
		DRILLED DATE	22-May-18
CONTRACTOR	Rockwell	GROUND LEVEL	RL 0.70m
DRILL MODEL	Track-mounted	LOCATION	355738.0 E 6297959.7 N
DRILLER	KM	ELEVATION DATUM	Australian Height Datum (AHD)
LOCATION	Haven Beach, Terrigal	COORDINATE SYSTEM	MGA94
ANGLE	Vertical		
BEARING	-		
HOLE DIAMETER	110mm		
MOUNT	BIT		

DRILLING & CASING	CORE LOSS %	TCR % (Drill rate)	SCR % / (RQD %)	FLUSH RETURN % (TYPE)
NMLC; HW casing (0.85–8.55)		100	100/(100)	100% Return
		100	95/(92)	80% Return
		100	100/(100)	20% Return



DEPTH m (R.L.) (m)	GRAPHIC LOG	ROCK TYPE Grain Size, Texture/Fabric, Colour, Minor Components	WEATHERING	Is 50 (MPa)	DISCONTINUITIES GENERAL DESCRIPTION Angle, Shape, Roughness, Infill, Thickness
0.85 (-0.15)		Continued from borehole			
	× ×	SILTSTONE, grey, thinly laminated	MW		
1.45 (-0.75)	· · ·	SANDSTONE, fine to medium grained, grey	SW	D 0.13 A 0.36	JT 70-80° PL VR BP 15° ST PL S
2.63 (-1.93)	× ×	SILTSTONE, grey	MW	D 0.03 A 0.04	BP 10° PL S
3.75 (-3.05)	· · ·	SANDSTONE, fine grained, grey		D 0.07 D 0.07 A 0.31 D 0.12 A 0.43	BP 15° CN PL S Cr 0-5° UN RF 20mm Rock Fragments
4.60 (-3.90)	× ×	SILTSTONE, grey			
4.81 (-4.11)	· · ·	SANDSTONE, fine grained, grey			JT 85° VN UN RF CR 0° 100mm Rock Fragments BP 0-5° UN S JT 85° PL RF BP 0° UN S Cr 0° IR VR 10mm
5.23 (-4.53)	× ×	SILTSTONE, grey, with fine grained sand	SW	D 0.07 A 0.06 A 0.13 D 0.07	SM 0° Clay 30mm
7.60 (-6.90)	· · ·	SANDSTONE, fine grained, grey		D 0.13 A 0.78 D 0.02 A 0.81	
8.55 (-7.85)		End of borehole at 8.55m Termination: Groundwater:			

NOTES

See explanatory notes for details of abbreviations and basis of descriptions

JOB 261648

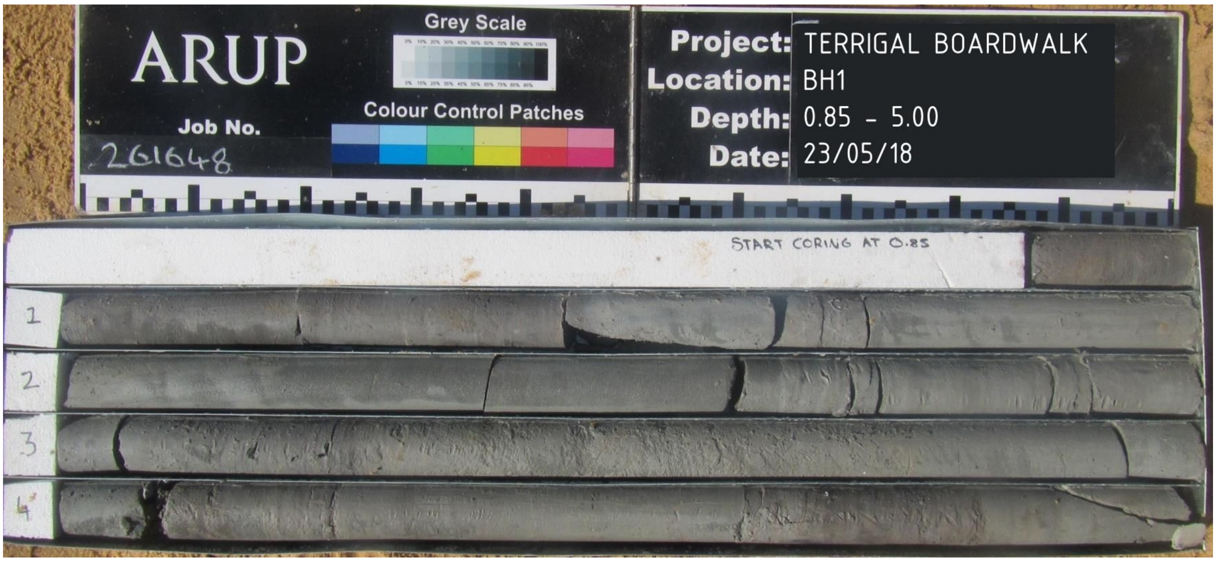
BOREHOLE PHOTO RECORD

BH1

SHEET 1

OF 1

CLIENT	Central Coast Council
PROJECT	Terrigal Board walk
LOGGED BY	RS
CHECKED BY	AC
DRILLED DATE	22-May-18
CONTRACTOR	Rockwell
DRILL MODEL	Track-mounted
DRILLER	KM
LOCATION	Haven Beach,
ANGLE	Vertical
BEARING	-
HOLE DIAMETER	110mm (Diamond)
GROUND LEVEL	RL 0.70mmAHD
LOCATION	355738.0 E 6297959.7 N
ELEVATION DATUM	Australian Height Datum (AHD)
COORDINATE SYSTEM	Map Grid of Australia (MGA)



BH1: 00.85m to 05.00m

BH1: 05.00m to 08.55m

NOTES

JOB

261648

ARUP

NON-CORED BOREHOLE RECORD

BH2

SHEET 1 OF 2

CLIENT	Central Coast Council	LOGGED BY	RS
PROJECT	Terrigal Board walk	CHECKED BY	AC
		DRILLED DATE	23-May-18 to 23-May-19

CONTRACTOR	Rockwell Drilling	ANGLE	Vertical	GROUND LEVEL	RL 0.95m
DRILL MODEL	Track-mounted	BEARING	-	LOCATION	355768.4 E 6297958.5 N
DRILLER	KM	HOLE DIAMETER	110mm	ELEVATION DATUM	Australian Height Datum (AHD)
LOCATION	Haven Beach, Terrigal	MOUNT	BIT	COORDINATE SYSTEM	MGA94

DRILLING				STRATA					MATERIAL DESCRIPTION	CONDITION		OBSERVATION
DRILLING & CASING	WATER	DRILLING PENETRATION	GROUNDWATER LEVELS	SAMPLES	FIELD TESTS	DEPTH (R.L.) m (m)	GROUP SYMBOL	GRAPHIC LOG	SOIL TYPE Plasticity / Grain Size, Colour, Minor Components	WATER / MOISTURE	CONSISTENCY	Comments / Penetration Rate
AD/T HW casing			▽ 1 ▽	SPT 0.00m 0.50m SPT 0.96m	SPT 1, 0, 2 N=2 SPT 2, 14, 20 N=34	1.00 (-0.05)	SW	⁘	SAND: fine to coarse, orange brown, trace shell fragments	M W	VL MD	MAR
				SPT 1.14m 1.30m	SPT 25/140s	1.30	CH	▨	SANDSTONE: fine to medium grained, pale grey. Recovered as CLAY, high plasticity	w < PL	St	BRK
									Continued as cored borehole			

Depth scale: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10

NOTES

See explanatory notes for details of abbreviations and basis of descriptions

JOB 261648

ARUP

CORED BOREHOLE RECORD

BH2

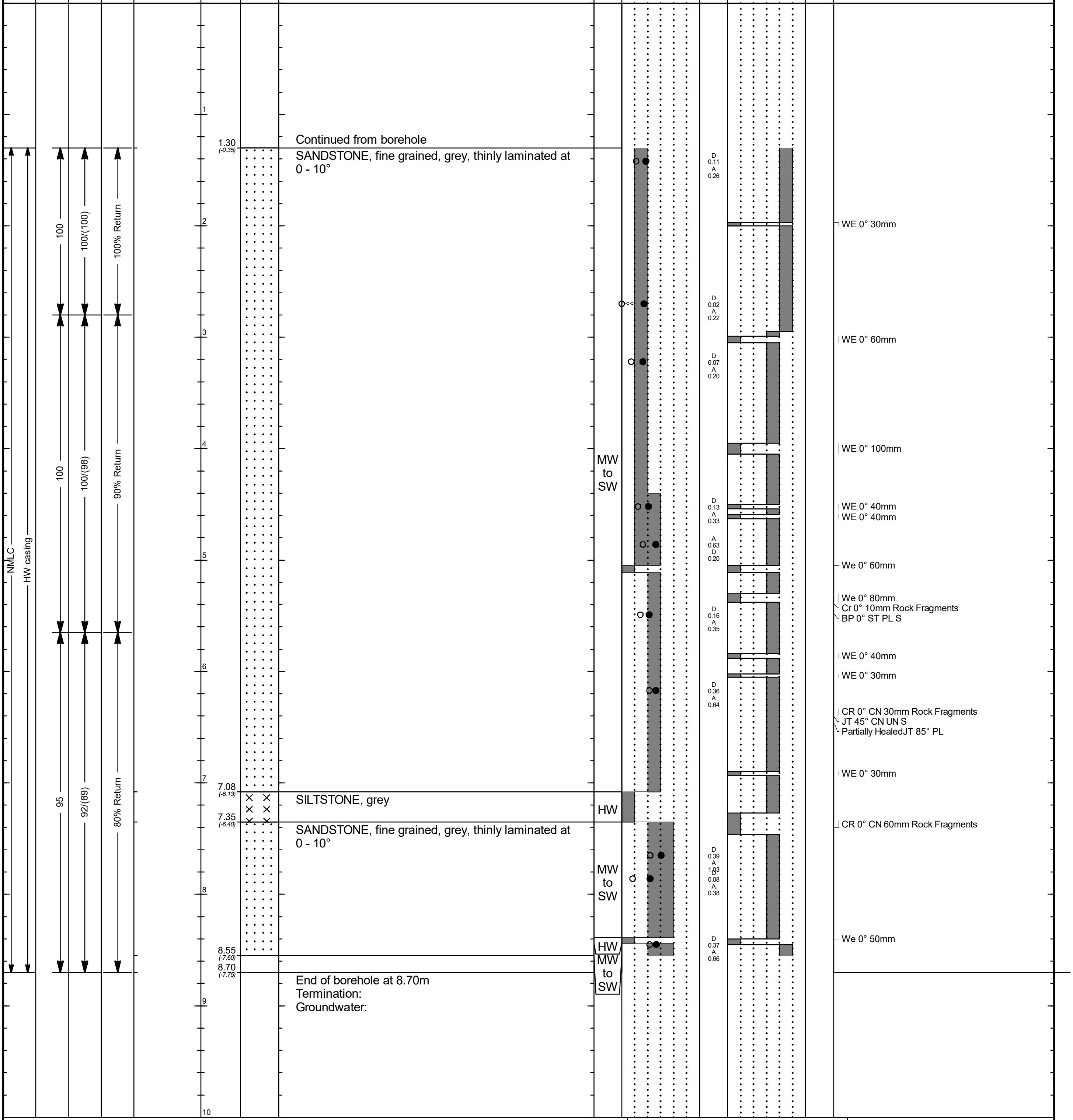
SHEET 2 OF 2

CLIENT	Central Coast Council	LOGGED BY	RS
PROJECT	Terrigal Board walk	CHECKED BY	AC
		DRILLED DATE	23-May-18 to 23-May-19

CONTRACTOR	Rockwell Drilling	ANGLE	Vertical	GROUND LEVEL	RL 0.95m
DRILL MODEL	Track-mounted	BEARING	-	LOCATION	355768.4 E 6297958.5 N
DRILLER	KM	HOLE DIAMETER	110mm	ELEVATION DATUM	Australian Height Datum (AHD)
LOCATION	Haven Beach, Terrigal	MOUNT	BIT	COORDINATE SYSTEM	MGA94

DRILLING | STRATA | MATERIAL DESCRIPTION | DISCONTINUITIES

DRILLING & CASING | CORE LOSS % | TCR % (Drill rate) | SCR % / (RQD %) | FLUSH RETURN % (TYPE) | SAMPLES & FIELD TESTS | DEPTH (R.L.) m (m) | GRAPHIC LOG | ROCK TYPE Grain Size, Texture/Fabric, Colour, Minor Components | WEATHERING | ● - Axial ○ - Diametral ESTIMATED ROCK STRENGTH VL L M H VH EH | Is 50 (MPa) | SPACING (mm) RMS 20 40 100 300 1000 | VISUAL LOG | GENERAL DESCRIPTION Angle, Shape, Roughness, Infill, Thickness



1.30 (-0.35) Continued from borehole

SANDSTONE, fine grained, grey, thinly laminated at 0 - 10°

7.08 (-6.13) SILTSTONE, grey

7.35 (-6.40) SANDSTONE, fine grained, grey, thinly laminated at 0 - 10°

8.55 (-7.60)

8.70 (-7.75) End of borehole at 8.70m
Termination:
Groundwater:

Is 50 (MPa):
D 0.11 A 0.26
D 0.02 A 0.22
D 0.07 A 0.20
D 0.13 A 0.33
A 0.63 D 0.20
D 0.16 A 0.35
D 0.36 A 0.64
D 0.39 A 1.03
D 0.08 A 0.38
D 0.37 A 0.66

General description:
WE 0° 30mm
WE 0° 60mm
WE 0° 100mm
WE 0° 40mm
WE 0° 40mm
We 0° 60mm
We 0° 80mm
Cr 0° 10mm Rock Fragments
BP 0° ST PL S
WE 0° 40mm
WE 0° 30mm
CR 0° CN 30mm Rock Fragments
JT 45° CN UN S
Partially HealedJT 85° PL
WE 0° 30mm
CR 0° CN 60mm Rock Fragments
We 0° 50mm

NOTES

See explanatory notes for details of abbreviations and basis of descriptions

JOB 261648

© Arup Pty Ltd 2018
1.0.2.2 AUS CORED CORE LOGS (AS1726)
\\GLOBAL.ARUP.COM\AUSTRALASIA\SYD\PROJECTS\261000\261648-00 TERRIGAL BOARDWALK\WORK\INTERNAL\261648 TERRIGAL\GEOTECH\02 SITE\04 GINT\02_DATA\03_DATABASE\GINT STD AGS 3_1_V0_0-2 - IN PROGRESS.GLB

ARUP

BOREHOLE PHOTO RECORD

BH2

SHEET 1

OF 1

CLIENT	Central Coast Council
PROJECT	Terrigal Board walk

LOGGED BY	RS
CHECKED BY	AC
DRILLED DATE	23-May-18 to 23-May-19

CONTRACTOR	Rockwell Drilling	ANGLE	Vertical
DRILL MODEL	Track-mounted	BEARING	-
DRILLER	KM	HOLE DIAMETER	110mm (Diamond)
LOCATION	Haven Beach,		

GROUND LEVEL	RL 0.95mmAHD
LOCATION	355768.4 E 6297958.5 N
ELEVATION DATUM	Australian Height Datum (AHD)
COORDINATE SYSTEM	Map Grid of Australia (MGA)

BH2: 01.30m to 06.00m

BH2: 06.00m to 08.70m

NOTES

JOB

261648

ARUP	# NON-CORED BOREHOLE RECORD	BH3	SHEET 1 OF 2

CLIENT	Central Coast Council	LOGGED BY	RS
PROJECT	Terrigal Board walk	CHECKED BY	AC
		DRILLED DATE	22-May-18

CONTRACTOR	Rockwell	ANGLE	Vertical	GROUND LEVEL	RL 2.20m
DRILL MODEL	Track-mounted	BEARING	-	LOCATION	355787.1 E 6297946.0 N
DRILLER	KM	HOLE DIAMETER	110mm	ELEVATION DATUM	Australian Height Datum (AHD)
LOCATION	Haven Beach, Terrigal	MOUNT	BIT	COORDINATE SYSTEM	MGA94

DRILLING				STRATA					MATERIAL DESCRIPTION	CONDITION		OBSERVATION
DRILLING & CASING	WATER	DRILLING PENETRATION	GROUNDWATER LEVELS	SAMPLES	FIELD TESTS	DEPTH (R.L.) m (m)	GROUP SYMBOL	GRAPHIC LOG	SOIL TYPE Plasticity / Grain Size, Colour, Minor Components	WATER / MOISTURE	CONSISTENCY	Comments / Penetration Rate
AD/T NW casing		E		0.01m SPT 450mm 0.46m 0.50m SPT	SPT 0, 1, 1 N=2 SPT 1, 2, 3 N=5	0.90 (1.30)	SW	⁘	SAND: fine to coarse, well graded, orange brown, trace shell fragments	M	VL	MAR Becoming dark grey
				0.96m 1.00m SPT 1.10m		1.10	CH	▨	SANDSTONE: fine to medium grained, pale grey. Recovered as CLAY, high plasticity	w < PL	D	BRK
									Continued as cored borehole			

Depth scale: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10

NOTES	See explanatory notes for details of abbreviations and basis of descriptions	JOB 261648

ARUP

CORED BOREHOLE RECORD

BH3

SHEET 2
OF 2

CLIENT	Central Coast Council	LOGGED BY	RS
PROJECT	Terrigal Board walk	CHECKED BY	AC
		DRILLED DATE	22-May-18

CONTRACTOR	Rockwell	ANGLE	Vertical	GROUND LEVEL	RL 2.20m
DRILL MODEL	Track-mounted	BEARING	-	LOCATION	355787.1 E 6297946.0 N
DRILLER	KM	HOLE DIAMETER	110mm	ELEVATION DATUM	Australian Height Datum (AHD)
LOCATION	Haven Beach, Terrigal	MOUNT	BIT	COORDINATE SYSTEM	MGA94

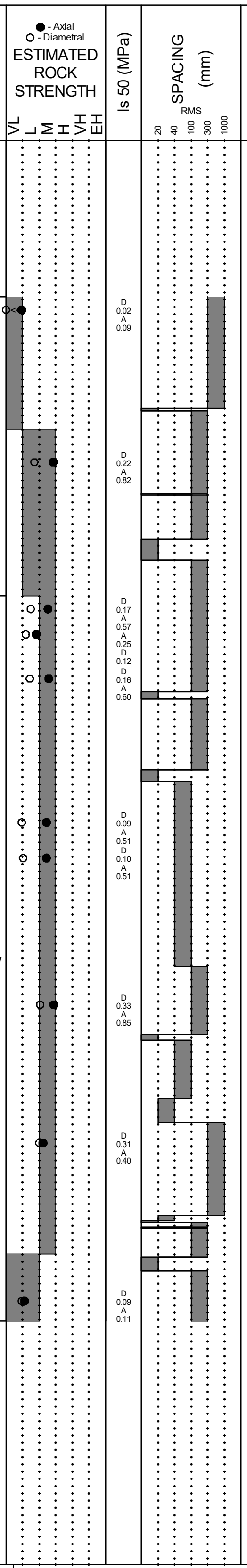
DRILLING | STRATA | MATERIAL DESCRIPTION | DISCONTINUITIES

DRILLING & CASING: NMLC; HW casing (1.10 to 8.29)

CORE LOSS % TCR % (Drill rate)	SCR % / (RQD %)	FLUSH RETURN % (TYPE)
100	100/(100)	100% Return 22/05/2018
100	99/(100)	100% Return
100	100/(90)	100% Return

SAMPLES & FIELD TESTS: SPT (at 1.10)

DEPTH m (R.L.) (m)	GRAPHIC LOG	ROCK TYPE Grain Size, Texture/Fabric, Colour, Minor Components	WEATHERING
		Continued from borehole	
1.10 (1.10)	× ×	SILTSTONE, grey, thinly laminated at 0-5°	SW
3.20 (-1.00)	∴	SANDSTONE, fine to medium grained, grey	MW
7.82 (-5.62)	× ×	SILTSTONE, grey, porphyritic, thinly laminated at 0-5°	
8.29 (-6.09)		End of borehole at 8.29m Termination: Groundwater:	



Is 50 (MPa):

D 0.02 A 0.09
D 0.22 A 0.82
D 0.17 A 0.57 A 0.25 D 0.12 D 0.16 A 0.60
D 0.09 A 0.51 D 0.10 A 0.51
D 0.33 A 0.85
D 0.31 A 0.40
D 0.09 A 0.11

VISUAL LOG

GENERAL DESCRIPTION
Angle, Shape, Roughness, Infill, Thickness

- We 0° 20mm
- WE 0° 10mm
- We 0° 150mm
- We 0-10° 50mm
- We 0° 30mm
- CR 0° 20mm Rock Fragments
- HealedJT 50° IR
- CR 0° 20mm Rock Fragments and Clay
- We 0° 40mm
- BP 0° ST PL S 3mm
- CR 0° VR 5mm Rock Fragments
- JT 85° IR VR
- JT 40° UN S
- BP 0° PL S Sand Infill
- WE 0° 10mm
- WE 0° 10mm
- SM 0° Clay 30mm
- We 0° 100mm

NOTES

See explanatory notes for details of abbreviations and basis of descriptions

JOB
261648

ARUP	# BOREHOLE PHOTO RECORD	BH3	SHEET 1 OF 1

CLIENT	Central Coast Council	LOGGED BY	RS
		CHECKED BY	AC
PROJECT	Terrigal Board walk	DRILLED DATE	22-May-18

CONTRACTOR	Rockwell	ANGLE	Vertical	GROUND LEVEL	RL 2.20mmAHD
DRILL MODEL	Track-mounted	BEARING	-	LOCATION	355787.1 E 6297946.0 N
DRILLER	KM	HOLE DIAMETER	110mm (Diamond)	ELEVATION DATUM	Australian Height Datum (AHD)
LOCATION	Haven Beach,			COORDINATE SYSTEM	Map Grid of Australia (MGA)

BH3: 01.10m to 08.39m

NOTES

JOB
261648

© Arup Pty Ltd 2018
SS_1.0.5.1 AUS BH PHOTO LOG (AS1726)
\\GLOBAL.ARUP.COM\AUSTRALASIA\SYD\PROJECTS\261000\261648-00 TERRIGAL BOARDWALK\WORK\INTERNAL\261648 TERRIGAL\GEOTECH\02 SITE\04 GINT\02_DATA\03_DATABASE\GINT STD AGS 3_1_V0_0-2 - IN PROGRESS.GLB

ARUP

NON-CORED BOREHOLE RECORD

BH4

SHEET 1 OF 2

CLIENT	Central Coast Council	LOGGED BY	RS
PROJECT	Terrigal Board walk	CHECKED BY	AC
		DRILLED DATE	24-May-18

CONTRACTOR	Rockwell	ANGLE	Vertical	GROUND LEVEL	RL 1.10m
DRILL MODEL	Track-mounted	BEARING	-	LOCATION	355748.0 E 6297957.9 N
DRILLER	KM	HOLE DIAMETER	110mm	ELEVATION DATUM	Australian Height Datum (AHD)
LOCATION	Haven Beach, Terrigal	MOUNT	BIT	COORDINATE SYSTEM	MGA94

DRILLING				STRATA					MATERIAL DESCRIPTION	CONDITION		OBSERVATION
DRILLING & CASING	WATER	DRILLING PENETRATION	GROUNDWATER LEVELS	SAMPLES	FIELD TESTS	DEPTH (R.L.) m (m)	GROUP SYMBOL	GRAPHIC LOG	SOIL TYPE Plasticity / Grain Size, Colour, Minor Components	WATER / MOISTURE	CONSISTENCY	Comments / Penetration Rate
AD/T HW casing		E		0.00m SPT 0.50m	SPT 1, 0, 2 N=2		SW		SAND: fine to coarse, orange BROWN, with shell fragments	M W	VL	MAR
				SPT 0.71m	SPT 3, 7/60s	0.65 (0.45)						
				1.05m		1 1.05	CH		SANDSTONE: fine to medium grained, pale grey. Recovered as CLAY, high plasticity	w < PL	St	BRK
						2			Continued as cored borehole			
						3						
						4						
						5						
						6						
						7						
						8						
						9						
						10						

NOTES

See explanatory notes for details of abbreviations and basis of descriptions

JOB 261648

ARUP

CORED BOREHOLE RECORD

BH4

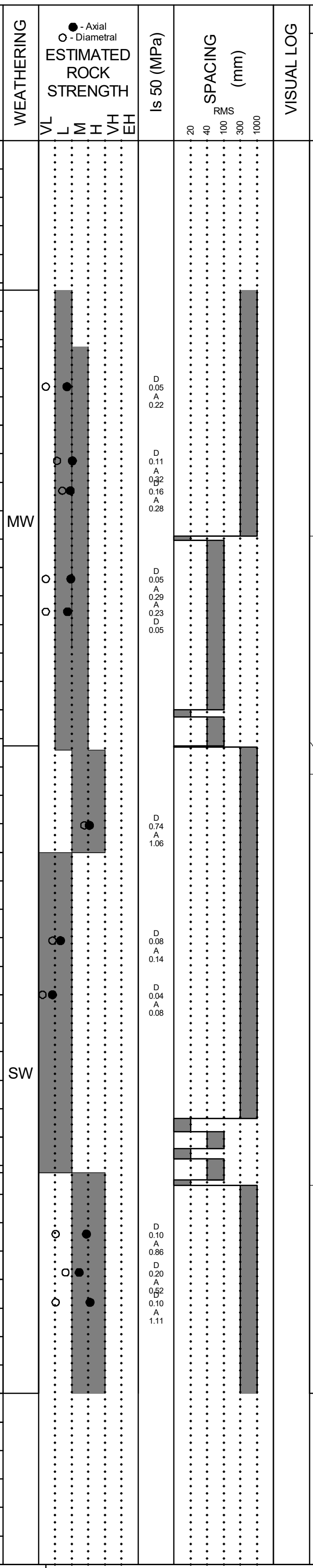
SHEET 2
OF 2

CLIENT	Central Coast Council	LOGGED BY	RS
PROJECT	Terrigal Board walk	CHECKED BY	AC
		DRILLED DATE	24-May-18

CONTRACTOR	Rockwell	ANGLE	Vertical	GROUND LEVEL	RL 1.10m
DRILL MODEL	Track-mounted	BEARING	-	LOCATION	355748.0 E 6297957.9 N
DRILLER	KM	HOLE DIAMETER	110mm	ELEVATION DATUM	Australian Height Datum (AHD)
LOCATION	Haven Beach, Terrigal	MOUNT	BIT	COORDINATE SYSTEM	MGA94

DRILLING | STRATA | MATERIAL DESCRIPTION | DISCONTINUITIES

DRILLING & CASING	CORE LOSS % TCR % (Drill rate)	SCR % / (RQD %)	FLUSH RETURN % (TYPE)	SAMPLES & FIELD TESTS	DEPTH (R.L.) m (m)	ROCK TYPE Grain Size, Texture/Fabric, Colour, Minor Components	WEATHERING	Is 50 (MPa)	GENERAL DESCRIPTION Angle, Shape, Roughness, Infill, Thickness
NMLC HW casing	100	100/(100)	100% Return		1.05 (0.05)	Continued from borehole SILTSTONE, grey, thinly laminated	MW		
					1.45 (-0.35)	SANDSTONE, fine grained, grey		D 0.05 A 0.22 D 0.11 A 0.32 D 0.16 A 0.28	
	100	98/(98)	100% Return					D 0.05 A 0.29 A 0.23 D 0.05	WE 0° 30mm
									WE 0° 50mm CR 0° 20mm Rock Fragments HealedJT 80° PL WE 0° 10mm BP 10-15° Clay IR S 5mm
							SW	D 0.74 A 1.06	
					5.00 (-3.90)	SILTSTONE, grey, thinly laminated		D 0.08 A 0.14	
	100	100/(100)	100% Return					D 0.04 A 0.08	WE 5-10° 90mm WE 15° 70mm WE 5° 40mm
					7.25 (-6.15)	SANDSTONE, fine grained, grey, thinly laminated		D 0.10 A 0.86 D 0.20 A 0.52 D 0.10 A 1.11	
					8.80 (-7.70)	End of borehole at 8.80m Termination: Groundwater:			



NOTES

See explanatory notes for details of abbreviations and basis of descriptions

JOB
261648

ARUP

BOREHOLE PHOTO RECORD

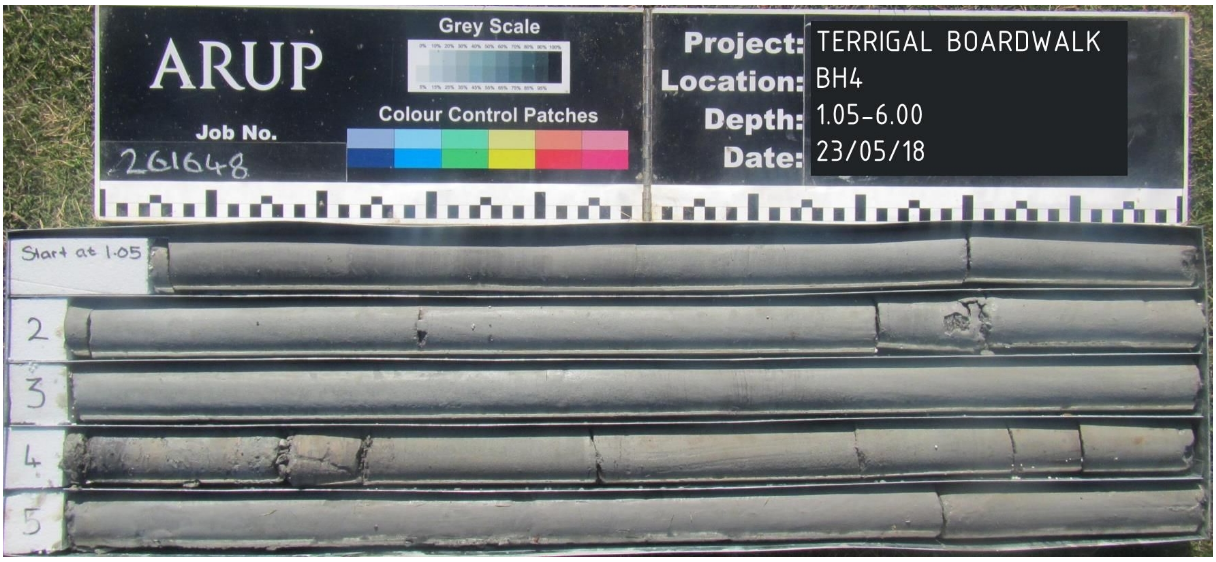
BH4

SHEET 1

OF 1

CLIENT	Central Coast Council	LOGGED BY	RS
PROJECT	Terrigal Board walk	CHECKED BY	AC
		DRILLED DATE	24-May-18

CONTRACTOR	Rockwell	ANGLE	Vertical	GROUND LEVEL	RL 1.10mmAHD
DRILL MODEL	Track-mounted	BEARING	-	LOCATION	355748.0 E 6297957.9 N
DRILLER	KM	HOLE DIAMETER	110mm (Diamond)	ELEVATION DATUM	Australian Height Datum (AHD)
LOCATION	Haven Beach,			COORDINATE SYSTEM	Map Grid of Australia (MGA)



BH4: 01.05m to 06.00m

BH4: 06.00m to 08.80m

NOTES

JOB

261648

Appendix C

DCP Test Results

ARUP

DYNAMIC CONE PENETROMETER TEST RESULTS

Date: 22/05/2018

Sheet 1 of

Project Name: Terrigal Boardwalk

Job No.: 261648

Made by: RS

Comments:

Test No.	**DCP 1**	**DCP 2**	**DCP 6**	**DCP 7**	**DCP 8**	**DCP 9**	**DCP 3**	**DCP 5**	**DCP 4**
Surface RL	0.75	1.3	1.3	1.45	1.3	1.3	0.25	0.85	1.3
Depth below surface (m)	**Blows/ 100mm (n)**								
0.0 - 0.1	1	1	1	1	1	1	2	1	0
0.1 - 0.2	↓	↓	↓	2	1	↓	2	1	1
0.2 - 0.3	1	1	2	2	1	2	3	2	1
0.3 - 0.4	4	3	4	5	2	2	17/40mm	4	2
0.4 - 0.5	7	4	5	5	20/50mm	5	refusal	9	2
0.5 - 0.6	12	6	5	25/50mm	refusal	4		14	5
0.6 - 0.7	23	12	12	End		6		10/0mm	11/70mm
0.7 - 0.8	30/50mm	23	22/50mm			8/8mm		refusal	refusal
0.8 - 0.9	End	12/20mm	End			Refusal			
0.9 - 1.0		bouncing							
1.0 - 1.1									
1.1 - 1.2									
1.2 - 1.3									
1.3 - 1.4									
1.4 - 1.5									
1.5 - 1.6									
1.6 - 1.7									
1.7 - 1.8									
1.8 - 1.9									
1.9 - 2.0									

Remarks:

1. The procedure used for this test is in accordance with AS1289.6.3.2-1997
2. 8 blows per 20mm is taken as refusal
3. Datum is AHD

Appendix D

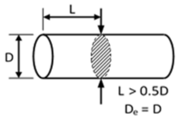
Point Load Strength Index Test Results

POINT LOAD STRENGTH INDEX TEST RESULTS

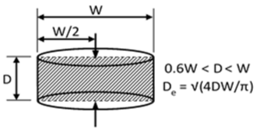
SHEET 1 **OF** 1

PROJECT NAME: Terrigal Boardwalk

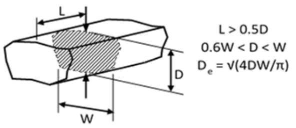
LOCATION			TEST DATA										RESULTS	
TEST No.	LOCATION ID	Depth (m)	SAMPLE DESCRIPTION	MOISTURE CONDITION	TEST TYPE	L (mm)	D (mm)	W (mm)	GAUGE FACTOR, f	SIZE CORRECTION FACTOR, K	FAILURE LOAD, P (kN)	FAILURE DESCRIPTION	Is (50) MPa	STRENGTH CLASSIFICATION
1	BH1	2.28	Sandstone	F	D	44	51		1.00	1.01	0.33	2	0.13	L
2	BH1	2.28	Sandstone	F	A		44	51	1.00	1.03	1.00	1	0.36	M
3	BH1	3.79	Sandstone	F	D	40	51		1.00	1.01	0.19	1	0.07	VL
4	BH1	3.83	Sandstone	F	A		44	51	1.00	1.03	0.86	1	0.31	M
5	BH1	4.35	Sandstone	F	D	32	51		1.00	1.01	0.30	1	0.12	L
6	BH1	4.35	Sandstone	F	A		32	51	1.00	0.96	0.93	1	0.43	M
7	BH1	5.60	Siltstone	F	D	30	51		1.00	1.01	0.17	1	0.07	VL
8	BH1	5.60	Siltstone	F	A		30	51	1.00	0.95	0.13	1	0.06	VL
9	BH1	6.92	Siltstone	F	D	42	51		1.00	1.01	0.18	1	0.07	VL
10	BH1	6.92	Siltstone	F	A		42	51	1.00	1.02	0.36	4	0.13	L
11	BH1	7.70	Sandstone	F	D	32	51		1.00	1.01	0.34	1	0.13	L
12	BH1	7.70	Sandstone	F	A		32	51	1.00	0.96	1.68	1	0.78	M
13	BH1	8.29	Sandstone	F	D	42	51		1.00	1.01	0.04	3	0.02	EL
14	BH1	8.29	Sandstone	F	A		42	51	1.00	1.02	2.16	4	0.81	M
15	BH1	3.50	Sandstone	F	D	40	51		1.00	1.01	0.09	3	0.03	VL
16	BH1	3.50	Sandstone	F	A		40	51	1.00	1.01	0.11	1	0.04	VL
17														
18														
19														
20														
21														
22														
23														
24														
25														
26														
27														
28														
29														
30														
31														
32														
33														
34														



Diametral (D)



Axial (A)



Irregular Lump (L)

Is (50) = 1000 x fKP / De^2 (MPa)
P = Failure Load (kN)
De = Equivalent core diameter(mm)
K = Size Correction Factor
f = Gauge Factor

FAILURE DESCRIPTION:
1. Fracture through fabric of specimen not influenced by weak planes.
2. Fracture along bedding.
3. Fracture influenced by pre-existing plane (J), microfracture (M), vein (V), chemical alteration (C)
4. Chip or Partial Fracture

POINT LOAD TESTER SERIAL No: 6510-0617 DATE OF CALIBRATION: 17/10/2016

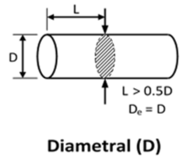
MADE BY: JW
CHECKED BY: AC
DATE: 22/05/2018
JOB No: 261648
VERIFIED BY:
DATE VERIFIED:

POINT LOAD STRENGTH INDEX
TEST RESULTS

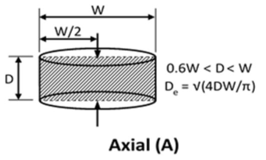
SHEET 1
OF 1

PROJECT NAME: Terrigal Boardwalk

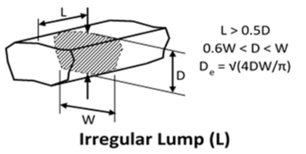
LOCATION			TEST DATA										RESULTS	
TEST No.	LOCATION ID	Depth (m)	SAMPLE DESCRIPTION	MOISTURE CONDITION	TEST TYPE	L (mm)	D (mm)	W (mm)	GAUGE FACTOR, f	SIZE CORRECTION FACTOR, K	FAILURE LOAD, P (kN)	FAILURE DESCRIPTION	Is (50) MPa	STRENGTH CLASSIFICATION
1	BH2	1.42	Sandstone	F	D	32	51		1.00	1.01	0.28	1	0.11	L
2	BH2	1.42	Sandstone	F	A		32	51	1.00	0.96	0.56	4	0.26	L
3	BH2	2.70	Sandstone	F	D	34	51		1.00	1.01	0.05	3	0.02	EL
4	BH2	2.70	Sandstone	F	A		34	51	1.00	0.97	0.50	1	0.22	L
5	BH2	3.22	Sandstone	F	D	36	51		1.00	1.01	0.17	1	0.07	VL
6	BH2	3.22	Sandstone	F	A		36	51	1.00	0.99	0.48	1	0.20	L
7	BH2	4.52	Sandstone	F	D	30	51		1.00	1.01	0.33	1	0.13	L
8	BH2	4.52	Sandstone	F	A		30	51	1.00	0.95	0.69	4	0.33	M
9	BH2	4.86	Sandstone	F	D	30	51		1.00	1.01	0.51	1	0.20	L
10	BH2	4.86	Sandstone	F	A		30	51	1.00	0.95	1.30	1	0.63	M
11	BH2	5.49	Sandstone	F	D	34	51		1.00	1.01	0.40	1	0.16	L
12	BH2	5.49	Sandstone	F	A		34	51	1.00	0.97	0.79	1	0.35	M
13	BH2	6.17	Sandstone	F	D	35	51		1.00	1.01	0.94	1	0.36	M
14	BH2	6.17	Sandstone	F	A		35	51	1.00	0.98	1.48	1	0.64	M
15	BH2	7.65	Sandstone	F	D	42	51		1.00	1.01	1.01	1	0.39	M
16	BH2	7.65	Sandstone	F	A		42	51	0.99	1.02	2.77	1	1.03	H
17	BH2	7.86	Sandstone	F	D	33	51		1.00	1.01	0.20	3	0.08	VL
18	BH2	7.86	Sandstone	F	A		33	51	1.00	0.97	0.85	1	0.38	M
19	BH2	8.45	Sandstone	F	D	34	51		1.00	1.01	0.95	1	0.37	M
20	BH2	8.45	Sandstone	F	A		34	51	1.00	0.97	1.50	1	0.66	M
21														
22														
23														
24														
25														
26														
27														
28														
29														
30														
31														
32														
33														
34														



Diametral (D)



Axial (A)



Irregular Lump (L)

Is (50) = 1000 x fKP / De^2 (MPa)
P = Failure Load (kN)
De = Equivalent core diameter(mm)
K = Size Correction Factor
f = Gauge Factor

FAILURE DESCRIPTION:
1. Fracture through fabric of specimen not influenced by weak planes.
2. Fracture along bedding.
3. Fracture influenced by pre-existing plane (J), microfracture (M), vein (V), chemical alteration (C)
4. Chip or Partial Fracture

POINT LOAD TESTER SERIAL No: 6510-0617 DATE OF CALIBRATION: 17/10/2016

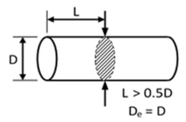
MADE BY: JW
CHECKED BY: AC
DATE: 23/05/2018
JOB No: 261648
VERIFIED BY:
DATE VERIFIED:

POINT LOAD STRENGTH INDEX TEST RESULTS

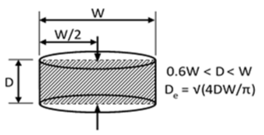
SHEET **1**
OF **1**

PROJECT NAME: Terrigal Boardwalk BH3

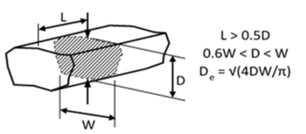
LOCATION			TEST DATA										RESULTS	
TEST No.	LOCATION ID	Depth (m)	SAMPLE DESCRIPTION	MOISTURE CONDITION	TEST TYPE	L (mm)	D (mm)	W (mm)	GAUGE FACTOR, f	SIZE CORRECTION FACTOR, K	FAILURE LOAD, P (kN)	FAILURE DESCRIPTION	Is (50) MPa	STRENGTH CLASSIFICATION
1	BH3	1.19	Siltstone	F	D	35	51		1.00	1.01	0.05	3	0.02	EL
2	BH3	1.19	Siltstone	F	A		35	51	1.00	0.98	0.22	4	0.09	VL
3	BH3	2.26	Siltstone	F	D	37	51		1.00	1.01	0.58	1	0.22	L
4	BH3	2.26	Siltstone	F	A		37	51	1.00	0.99	1.99	1	0.82	M
5	BH3	3.29	Sandstone	F	D	42	51		1.00	1.01	0.45	1	0.17	L
6	BH3	3.29	Sandstone	F	A		42	51	1.00	1.02	1.52	1	0.57	M
7	BH3	4.79	Sandstone	F	D	38	51		1.00	1.01	0.24	1	0.09	VL
8	BH3	4.79	Sandstone	F	A		38	51	1.00	1.00	1.27	1	0.51	M
9	BH3	3.47	Sandstone	F	D	42	51		1.00	1.01	0.31	1	0.12	L
10	BH3	3.47	Sandstone	F	A		42	51	1.00	1.02	0.68	4	0.25	L
11	BH3	3.78	Sandstone	F	D	41	51		1.00	1.01	0.41	1	0.16	L
12	BH3	3.78	Sandstone	F	A		41	51	1.00	1.01	1.58	1	0.60	M
13	BH3	5.04	Sandstone	F	D	32	51		1.00	1.01	0.25	1	0.10	VL
14	BH3	5.04	Sandstone	F	A		32	51	1.00	0.96	1.11	1	0.51	M
15	BH3	6.07	Sandstone	F	D	41	51		1.00	1.01	0.84	1	0.33	M
16	BH3	6.07	Sandstone	F	A		41	51	1.00	1.01	2.24	1	0.85	M
17	BH3	7.04	Sandstone	F	D	36	51		1.00	1.01	0.81	1	0.31	M
18	BH3	7.04	Sandstone	F	A		36	51	1.00	0.99	0.95	1	0.40	M
19	BH3	8.15	Siltstone	F	D	31	51		1.00	1.01	0.24	1	0.09	VL
20	BH3	8.15	Siltstone	F	A		31	51	1.00	0.95	0.24	4	0.11	L
21														
22														
23														
24														
25														
26														
27														
28														
29														
30														
31														
32														
33														
34														



Diametral (D)



Axial (A)



Irregular Lump (L)

Is (50) = 1000 x fKP / De^2 (MPa)
P = Failure Load (kN)
De = Equivalent core diameter(mm)
K = Size Correction Factor
f = Gauge Factor

FAILURE DESCRIPTION:
1. Fracture through fabric of specimen not influenced by weak planes.
2. Fracture along bedding.
3. Fracture influenced by pre-existing plane (J), microfracture (M), vein (V), chemical alteration (C)
4. Chip or Partial Fracture

POINT LOAD TESTER SERIAL No: 6510-0617 DATE OF CALIBRATION: 17/10/2016

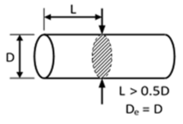
MADE BY: JW
CHECKED BY: AC
DATE: 22/05/2018
JOB No: 261648
VERIFIED BY:
DATE VERIFIED:

POINT LOAD STRENGTH INDEX
TEST RESULTS

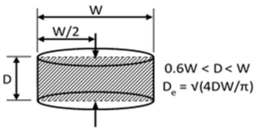
SHEET 1
OF 1

PROJECT NAME: Terrigal Boardwalk

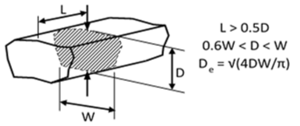
LOCATION			TEST DATA										RESULTS	
TEST No.	LOCATION ID	Depth (m)	SAMPLE DESCRIPTION	MOISTURE CONDITION	TEST TYPE	L (mm)	D (mm)	W (mm)	GAUGE FACTOR, f	SIZE CORRECTION FACTOR, K	FAILURE LOAD, P (kN)	FAILURE DESCRIPTION	Is (50) MPa	STRENGTH CLASSIFICATION
1	BH4	1.73	Sandstone	F	D	34	51		1.00	1.01	0.12	1	0.05	VL
2	BH4	1.73	Sandstone	F	A		34	51	1.00	0.97	0.50	1	0.22	L
3	BH4	2.25	Sandstone	F	D	37	51		1.00	1.01	0.28	1	0.11	L
4	BH4	2.25	Sandstone	F	A		37	51	1.00	0.99	0.78	1	0.32	M
5	BH4	2.46	Sandstone	F	D	43	51		1.00	1.01	0.42	1	0.16	L
6	BH4	2.46	Sandstone	F	A		43	51	1.00	1.03	0.77	1	0.28	L
7	BH4	3.08	Sandstone	F	D	39	51		1.00	1.01	0.12	3	0.05	VL
8	BH4	3.08	Sandstone	F	A		39	51	1.00	1.00	0.73	4	0.29	L
9	BH4	3.31	Sandstone	F	D	39	51		1.00	1.01	0.13	1	0.05	VL
10	BH4	3.31	Sandstone	F	A		39	51	1.00	1.00	0.58	4	0.23	L
11	BH4	4.81	Sandstone	F	D	39	51		1.00	1.01	1.92	1	0.74	M
12	BH4	4.81	Sandstone	F	A		39	51	0.99	1.00	2.70	1	1.06	H
13	BH4	5.62	Siltstone	F	D	38	51		1.00	1.01	0.20	3	0.08	VL
14	BH4	5.62	Siltstone	F	A		38	51	1.00	1.00	0.34	4	0.14	L
15	BH4	6.00	Siltstone	F	D	47	51		1.00	1.01	0.11	1	0.04	VL
16	BH4	6.00	Siltstone	F	A		47	51	1.00	1.05	0.22	4	0.08	VL
17	BH4	7.68	Sandstone	F	D	36	51		1.00	1.01	0.26	1	0.10	L
18	BH4	7.68	Sandstone	F	A		36	51	1.00	0.99	2.04	1	0.86	M
19	BH4	8.16	Sandstone	F	D	38	51		1.00	1.01	0.26	1	0.10	L
20	BH4	8.16	Sandstone	F	A		38	51	0.99	1.00	2.78	1	1.11	H
21	BH4	7.95	Sandstone	F	D	26	51		1.00	1.01	0.52	1	0.20	L
22	BH4	7.95	Sandstone	F	A		26	51	1.00	0.92	0.96	1	0.52	M
23														
24														
25														
26														
27														
28														
29														
30														
31														
32														
33														
34														



Diametral (D)



Axial (A)



Irregular Lump (L)

Is (50) = 1000 x fKP / De^2 (MPa)
P = Failure Load (kN)
De = Equivalent core diameter(mm)
K = Size Correction Factor
f = Gauge Factor

FAILURE DESCRIPTION:
1. Fracture through fabric of specimen not influenced by weak planes.
2. Fracture along bedding.
3. Fracture influenced by pre-existing plane (J), microfracture (M), vein (V), chemical alteration (C)
4. Chip or Partial Fracture

POINT LOAD TESTER SERIAL No: 6510-0617 DATE OF CALIBRATION: 17/10/2016

MADE BY: JW
CHECKED BY: AC
DATE: 24/05/2018
JOB No: 261648
VERIFIED BY:
DATE VERIFIED:

Appendix E

Laboratory Test Result Certificates

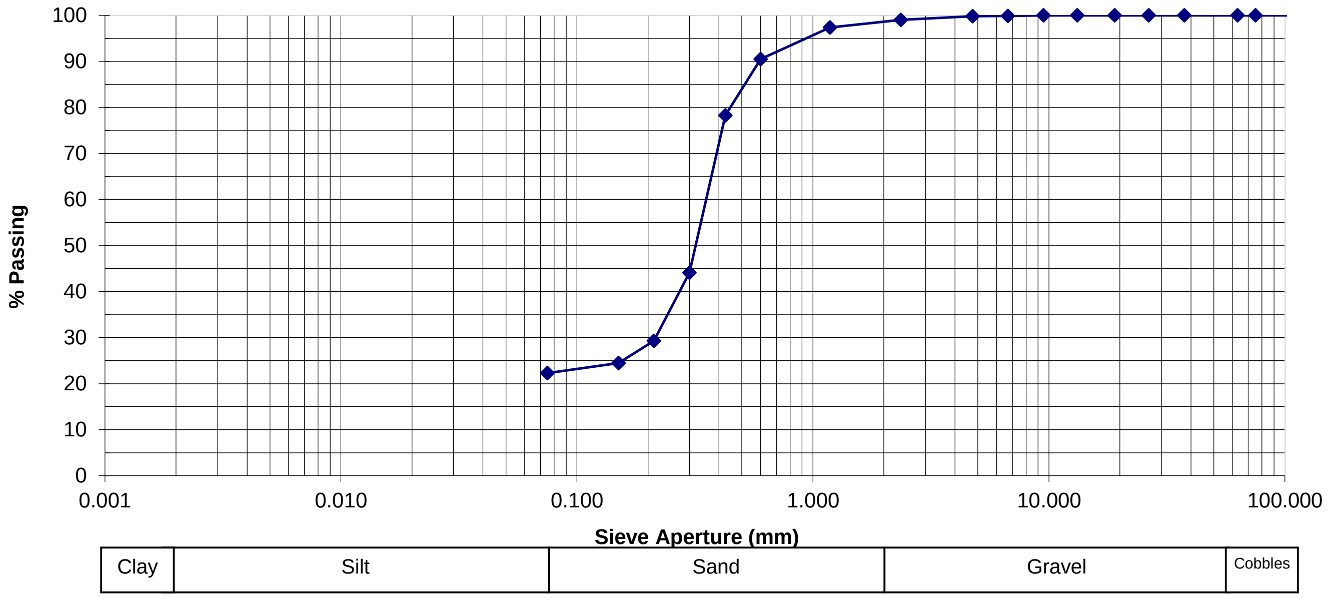
PARTICLE SIZE DISTRIBUTION REPORT

Client:	Arup	**Source:**	BH1-01 0.5-0.65m
Address:	Level 10, 201 Kent Street, Sydney 2000 Australia	**Sample Description:**	Clayey SAND trace of Gravel
Project:	Terrigal Boardwalk (261648)	**Report No.:**	S33957-PSD
Job No.:	S18220	**Lab No.:**	S33957

Test Procedure: ☑ AS1289.3.6.1 Soil classification tests - Determination of the particle size distribution of a soil - Standard method of analysis by sieving

Sampling: Sampled by Client | Date Sampled: 23/05/2018

Preparation: Prepared in accordance with the test method



Sieve Apperture: (mm)	% Passing	Specification (..) Envelope	Sieve Aperture: (mm)	% Passing	Specification (..) Envelope
200	100		4.75	100	
75	100		2.36	99	
63	100		1.18	97	
37.5	100		0.600	90	
26.5	100		0.425	78	
19	100		0.300	44	
13.2	100		0.212	29	
9.5	100		0.150	24	
6.7	100		0.075	22	

NATA

The results of the tests, calibrations and/or measurements included in this document are traceable to Australian/national standards. Accredited for compliance with ISO/IEC 17025. This document shall not be reproduced, except in full.

NATA Accredited Laboratory Number: 14874

Authorised Signatory:

Chris Lloyd

7/06/2018

Date:

MACQUARIE GEOTECH

Macquarie Geotechnical
U8 10 Bradford Street
Alexandria NSW 2015

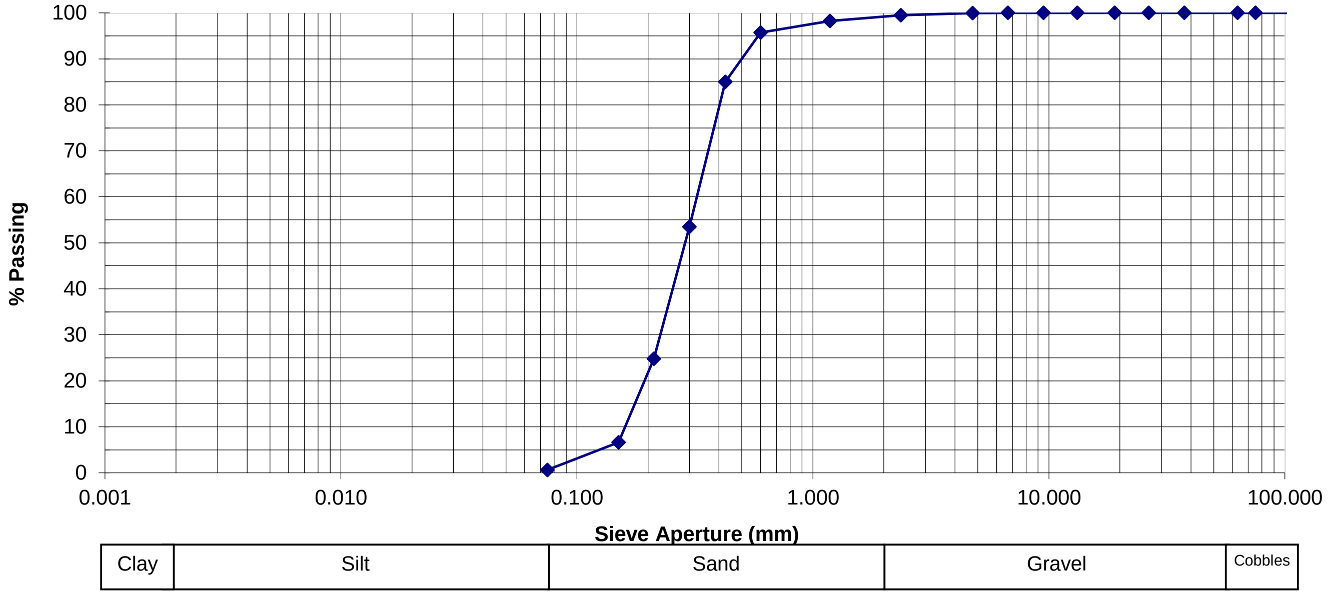
PARTICLE SIZE DISTRIBUTION REPORT

Client:	Arup	**Source:**	BH3-01 0.5-0.9m
Address:	Level 10, 201 Kent Street, Sydney 2000 Australia	**Sample Description:**	SAND trace of Clay and Gravel
Project:	Terrigal Boardwalk (261648)	**Report No.:**	S33963-PSD
Job No.:	S18220	**Lab No.:**	S33963

Test Procedure: ☑ AS1289.3.6.1 Soil classification tests - Determination of the particle size distribution of a soil - Standard method of analysis by sieving

Sampling: Sampled by Client | Date Sampled: 23/05/2018

Preparation: Prepared in accordance with the test method



Sieve Apperture: (mm)	% Passing	Specification (..) Envelope	Sieve Aperture: (mm)	% Passing	Specification (..) Envelope
200	100		4.75	100	
75	100		2.36	99	
63	100		1.18	98	
37.5	100		0.600	96	
26.5	100		0.425	85	
19	100		0.300	53	
13.2	100		0.212	25	
9.5	100		0.150	7	
6.7	100		0.075	1	

NATA

The results of the tests, calibrations and/or measurements included in this document are traceable to Australian/national standards. Accredited for compliance with ISO/IEC 17025. This document shall not be reproduced, except in full.

NATA Accredited Laboratory Number: 14874

Authorised Signatory:

Chris Lloyd

7/06/2018

Date:

MACQUARIE GEOTECH

Macquarie Geotechnical
U8 10 Bradford Street
Alexandria NSW 2015

Uniaxial Compressive Strength

Client:	Arup	**Sample Source:**	BH1-02 2.14-2.28m
Address:	Level 10, 201 Kent Street, Sydney 2000 Australia	**Sample Description:**	Sandstone
Project:	Terrigal Boardwalk (261648)	**Report No.:**	S33958-UCS
Job No.:	S18220	**Lab No.:**	S33958
Test Procedure:	AS 4133.4.2.2 Determination of uniaxial compressive strength-Rock strength less than 50 MPa		
Testing Machine:	Matest 2000 kN Compression Machine	**Sample Curing:**	-
Sampling Method:	Sampled by Client	**Date Sampled:**	23/05/2018
Storage History:	Core Box	**Storage Environment:**	Sealed at as received moisture condition

Uniaxial Compressive Strength 10 MPa

Date Tested:	5/06/2018		Moisture Content:	6.8	%
Specimen Height:	123.0	mm	Duration of Test:	634	seconds
Average Specimen Diameter:	52.0	mm	Rate of Displacement:	< 0.1	mm/min

Failure Type: Mixed mode

Other Pertinent Observations:

Deviation from Standard: Test specimen length to diameter ratio falls outside of standard limitations of 2.5-3.0.

The results of the tests, calibrations and/or measurements included in this document are traceable to Australian/national standards. Accredited for compliance with ISO/IEC 17025 - Testing. This document shall not be reproduced, except in full.

NATA Accredited Laboratory Number: 14874

Authorised Signatory:

Jacob Lloyd

Date: 7/06/2018

Macquarie Geotechnical

U8 10 Bradford Street
Alexandria NSW 2015

Uniaxial Compressive Strength

Client:	Arup	**Sample Source:**	BH1-04 8.37-8.55m
Address:	Level 10, 201 Kent Street, Sydney 2000 Australia	**Sample Description:**	Sandstone
Project:	Terrigal Boardwalk (261648)	**Report No.:**	S33960-UCS
Job No.:	S18220	**Lab No.:**	S33960
Test Procedure:	AS 4133.4.2.2 Determination of uniaxial compressive strength-Rock strength less than 50 MPa		
Testing Machine:	Matest 2000 kN Compression Machine	**Sample Curing:**	-
Sampling Method:	Sampled by Client	**Date Sampled:**	23/05/2018
Storage History:	Core Box	**Storage Environment:**	Sealed at as received moisture condition

Uniaxial Compressive Strength 13 MPa

Date Tested:	5/06/2018	Moisture Content:	4.3 %
Specimen Height:	110.4 mm	Duration of Test:	642 seconds
Average Specimen Diameter:	51.7 mm	Rate of Displacement:	< 0.1 mm/min
Failure Type:	Single shear plane		
Other Pertinent Observations:			
Deviation from Standard:	Test specimen length to diameter ratio falls outside of standard limitations of 2.5-3.0.		

The results of the tests, calibrations and/or measurements included in this document are traceable to Australian/national standards. Accredited for compliance with ISO/IEC 17025 - Testing. This document shall not be reproduced, except in full.

Authorised Signatory:

Jacob Lloyd

NATA Accredited Laboratory Number: 14874

Date: 7/06/2018

Macquarie Geotechnical

U8 10 Bradford Street
Alexandria NSW 2015

Uniaxial Compressive Strength

Client:	Arup	**Sample Source:**	BH2-01 3.06-3.23m
Address:	Level 10, 201 Kent Street, Sydney 2000 Australia	**Sample Description:**	Sandstone
Project:	Terrigal Boardwalk (261648)	**Report No.:**	S33961-UCS
Job No.:	S18220	**Lab No.:**	S33961
Test Procedure:	AS 4133.4.2.2 Determination of uniaxial compressive strength-Rock strength less than 50 MPa		
Testing Machine:	Matest 2000 kN Compression Machine	**Sample Curing:**	-
Sampling Method:	Sampled by Client	**Date Sampled:**	23/05/2018
Storage History:	Core Box	**Storage Environment:**	Sealed at as received moisture condition

Uniaxial Compressive Strength 7.6 MPa

Date Tested:	5/06/2018		Moisture Content:	7.5	%
Specimen Height:	133.6	mm	Duration of Test:	624	seconds
Average Specimen Diameter:	51.7	mm	Rate of Displacement:	< 0.1	mm/min
Failure Type:	Single shear plane				
Other Pertinent Observations:					

NATA

The results of the tests, calibrations and/or measurements included in this document are traceable to Australian/national standards. Accredited for compliance with ISO/IEC 17025 - Testing. This document shall not be reproduced, except in full.

NATA Accredited Laboratory Number: 14874

Authorised Signatory:

Jacob Lloyd

Date: 7/06/2018

MACQUARIE GEOTECH

Macquarie Geotechnical

U8 10 Bradford Street
Alexandria NSW 2015

Uniaxial Compressive Strength

Client:	Arup	**Sample Source:**	BH2-02 7.7-7.86m
Address:	Level 10, 201 Kent Street, Sydney 2000 Australia	**Sample Description:**	Siltstone
Project:	Terrigal Boardwalk (261648)	**Report No.:**	S33962-UCS
Job No.:	S18220	**Lab No.:**	S33962
Test Procedure:	AS 4133.4.2.2 Determination of uniaxial compressive strength-Rock strength less than 50 MPa		
Testing Machine:	Matest 2000 kN Compression Machine	**Sample Curing:**	-
Sampling Method:	Sampled by Client	**Date Sampled:**	23/05/2018
Storage History:	Core Box	**Storage Environment:**	Sealed at as received moisture condition

Uniaxial Compressive Strength 7.7 MPa

Date Tested:	5/06/2018		Moisture Content:	5.6	%
Specimen Height:	126.5	mm	Duration of Test:	621	seconds
Average Specimen Diameter:	50.2	mm	Rate of Displacement:	< 0.1	mm/min
Failure Type:	Mixed mode				
Other Pertinent Observations:					

NATA

The results of the tests, calibrations and/or measurements included in this document are traceable to Australian/national standards. Accredited for compliance with ISO/IEC 17025 - Testing. This document shall not be reproduced, except in full.

NATA Accredited Laboratory Number: 14874

Authorised Signatory:

Jacob Lloyd

Date: 7/06/2018

MACQUARIE GEOTECH

Macquarie Geotechnical

U8 10 Bradford Street
Alexandria NSW 2015

Uniaxial Compressive Strength

Client:	Arup	**Sample Source:**	BH3-02 1.75-1.88m
Address:	Level 10, 201 Kent Street, Sydney 2000 Australia	**Sample Description:**	Siltstone
Project:	Terrigal Boardwalk (261648)	**Report No.:**	S33964-UCS
Job No.:	S18220	**Lab No.:**	S33964
Test Procedure:	AS 4133.4.2.2 Determination of uniaxial compressive strength-Rock strength less than 50 MPa		
Testing Machine:	Matest 2000 kN Compression Machine	**Sample Curing:**	-
Sampling Method:	Sampled by Client	**Date Sampled:**	23/05/2018
Storage History:	Core Box	**Storage Environment:**	Sealed at as received moisture condition

Uniaxial Compressive Strength 1.9 MPa

Date Tested:	5/06/2018		Moisture Content:	11.3	%
Specimen Height:	103.5	mm	Duration of Test:	646	seconds
Average Specimen Diameter:	52.6	mm	Rate of Displacement:	< 0.1	mm/min
Failure Type:	Mixed mode				
Other Pertinent Observations:					
Deviation from Standard:	Test specimen length to diameter ratio falls outside of standard limitations of 2.5-3.0.				

Authorised Signatory:

Jacob Lloyd

NATA Accredited Laboratory Number: 14874

Date: 7/06/2018

Macquarie Geotechnical

U8 10 Bradford Street
Alexandria NSW 2015

Uniaxial Compressive Strength

Client:	Arup	**Sample Source:**	BH3-04 6.81-7m
Address:	Level 10, 201 Kent Street, Sydney 2000 Australia	**Sample Description:**	Siltstone
Project:	Terrigal Boardwalk (261648)	**Report No.:**	S33966-UCS
Job No.:	S18220	**Lab No.:**	S33966
Test Procedure:	AS 4133.4.2.2 Determination of uniaxial compressive strength-Rock strength less than 50 MPa		
Testing Machine:	Matest 2000 kN Compression Machine	**Sample Curing:**	-
Sampling Method:	Sampled by Client	**Date Sampled:**	23/05/2018
Storage History:	Core Box	**Storage Environment:**	Sealed at as received moisture condition

Uniaxial Compressive Strength 9.9 MPa

Date Tested:	5/06/2018		Moisture Content:	6.6	%
Specimen Height:	131.6	mm	Duration of Test:	606	seconds
Average Specimen Diameter:	51.8	mm	Rate of Displacement:	< 0.1	mm/min
Failure Type:	Mixed mode				
Other Pertinent Observations:					

NATA Accredited Laboratory Number: 14874

Authorised Signatory:

Jacob Lloyd

Date: 7/06/2018

Macquarie Geotechnical

U8 10 Bradford Street
Alexandria NSW 2015

Uniaxial Compressive Strength

Client:	Arup	**Sample Source:**	BH4-01 2.31-2.47m
Address:	Level 10, 201 Kent Street, Sydney 2000 Australia	**Sample Description:**	Siltstone
Project:	Terrigal Boardwalk (261648)	**Report No.:**	S33967-UCS
Job No.:	S18220	**Lab No.:**	S33967
Test Procedure:	AS 4133.4.2.2 Determination of uniaxial compressive strength-Rock strength less than 50 MPa		
Testing Machine:	Matest 2000 kN Compression Machine	**Sample Curing:**	-
Sampling Method:	Sampled by Client	**Date Sampled:**	23/05/2018
Storage History:	Core Box	**Storage Environment:**	Sealed at as received moisture condition

Uniaxial Compressive Strength 9.9 MPa

Date Tested:	5/06/2018		Moisture Content:	6.6	%
Specimen Height:	131.6	mm	Duration of Test:	606	seconds
Average Specimen Diameter:	51.8	mm	Rate of Displacement:	< 0.1	mm/min

Failure Type: Mixed mode

Other Pertinent Observations:

NATA

The results of the tests, calibrations and/or measurements included in this document are traceable to Australian/national standards. Accredited for compliance with ISO/IEC 17025 - Testing. This document shall not be reproduced, except in full.

Authorised Signatory:

Jacob Lloyd

NATA Accredited Laboratory Number: 14874

Date: 7/06/2018

MACQUARIE GEOTECH

Macquarie Geotechnical

U8 10 Bradford Street
Alexandria NSW 2015

Uniaxial Compressive Strength

Client:	Arup	**Sample Source:**	BH4-03 8-8.17m
Address:	Level 10, 201 Kent Street, Sydney 2000 Australia	**Sample Description:**	Siltstone
Project:	Terrigal Boardwalk (261648)	**Report No.:**	S33969-UCS
Job No.:	S18220	**Lab No.:**	S33969
Test Procedure:	AS 4133.4.2.2 Determination of uniaxial compressive strength-Rock strength less than 50 MPa		
Testing Machine:	Matest 2000 kN Compression Machine	**Sample Curing:**	-
Sampling Method:	Sampled by Client	**Date Sampled:**	23/05/2018
Storage History:	Core Box	**Storage Environment:**	Sealed at as received moisture condition

Uniaxial Compressive Strength 9.1 MPa

Date Tested:	5/06/2018	Moisture Content:	5.0 %
Specimen Height:	125.1 mm	Duration of Test:	640 seconds
Average Specimen Diameter:	51.9 mm	Rate of Displacement:	< 0.1 mm/min
Failure Type:	Mixed mode		
Other Pertinent Observations:			
Deviation from Standard:	Test specimen length to diameter ratio falls outside of standard limitations of 2.5-3.0.		

NATA

Authorised Signatory:

Jacob Lloyd

NATA Accredited Laboratory Number: 14874

Date: 7/06/2018

MACQUARIE GEOTECH

Macquarie Geotechnical

U8 10 Bradford Street
Alexandria NSW 2015

SOIL CHEMICAL PROPERTIES REPORT

Client:	Arup	**Source:**	BH1 - 03 6-6.1m
Address:	Level 10, 201 Kent Street, Sydney 2000 Australia	**Sample Description:**	Silty CLAY with sand
Project:	Terrigal Boardwalk (261648)	**Report No:**	B48632-SCP
Job No:	S18220	**Lab No:**	B48632 (S33959)

Test Procedure:

☑	AS1289 4.2.1	Soil Chemical Tests - Determination of a sulfate content of a natural soil and the sulfate content of the groundwater - Normal Method
☑	AS1289 4.3.1	Soil Chemical Tests - Determination of the pH value of a soil - Electrometric method
☐	AS 1289 4.4.1	Soil Chemical Tests - Determination of the electrical resistivity of a soil - Method for sands and granular material
☐	AS 1012.20	Chloride and sulphate
☐	RMS T123	pH value of a soil (electrometric method)
☐	RMS T185	Resistivity of sands and granular road construction materials
☐	RMS T200	Chloride content of roadbase
☑	RMS T1010	Quantitative determination of chlorides in soil
☐	RMS T1011	Quantitative determination of sulphates in soil
☐	BS1377(1990 pt.3)	Water soluble sulphate content
☐	APHA 4500 H+B	pH
☐	APHA 4500 SO4 2-B	Sulphate
☐	APHA 4500 Cl-B	Chloride
☐	APHA 2510 & 2520-B	Electrical Conductivity
☐	TAI B117	Sulphides Present (This service Not Covered by NATA Accreditation)

Sampling:	Sampled by Client	**Date Sampled:**	23/05/2018
Preparation:	Prepared in accordance with the test method		

Sulphides Present	-
Sulphur Peroxide (%)	-
Sulphate content (ppm)	12.4
Sulphate content (%)	0.00
Chloride ion content (ppm)	327.9
Chloride ion content (%)	0.03
pH	6.1
Electrical Conductivity (uS/cm)	-
Mean Resistivity Ω.m	-
(Resisitivity) Density ratio (R_D)	-
(Resisitivity) Density index (I_D)	-

NATA

The results of the tests, calibrations and/or measurements included in this document are traceable to Australian/national standards. Accredited for compliance with ISO/IEC 17025. This document shall not be reproduced, except in full.

NATA Accredited Laboratory Number: 14874

Authorised Signatory:

Brad Morris

13/06/2018

Date:

MACQUARIE GEOTECH

Macquarie Geotechnical
3 Watt Drive
Bathurst NSW 2795

SOIL CHEMICAL PROPERTIES REPORT

Client:	Arup	**Source:**	BH2 - 01 3.06-3.23m
Address:	Level 10, 201 Kent Street, Sydney 2000 Australia	**Sample Description:**	Sandy GRAVEL with silt
Project:	Terrigal Boardwalk (261648)	**Report No:**	B48633-SCP
Job No:	S18220	**Lab No:**	B48633 (S33961)

Test Procedure:

☑	AS1289 4.2.1	Soil Chemical Tests - Determination of a sulfate content of a natural soil and the sulfate content of the groundwater - Normal Method
☑	AS1289 4.3.1	Soil Chemical Tests - Determination of the pH value of a soil - Electrometric method
☐	AS 1289 4.4.1	Soil Chemical Tests - Determination of the electrical resistivity of a soil - Method for sands and granular material
☐	AS 1012.20	Chloride and sulphate
☐	RMS T123	pH value of a soil (electrometric method)
☐	RMS T185	Resistivity of sands and granular road construction materials
☐	RMS T200	Chloride content of roadbase
☑	RMS T1010	Quantitative determination of chlorides in soil
☐	RMS T1011	Quantitative determination of sulphates in soil
☐	BS1377(1990 pt.3)	Water soluble sulphate content
☐	APHA 4500 H+B	pH
☐	APHA 4500 SO4 2-B	Sulphate
☐	APHA 4500 CI-B	Chloride
☐	APHA 2510 & 2520-B	Electrical Conductivity
☐	TAI B117	Sulphides Present (This service Not Covered by NATA Accreditation)

Sampling:	Sampled by Client	**Date Sampled:**	23/05/2018
Preparation:	Prepared in accordance with the test method		

Sulphides Present	-
Sulphur Peroxide (%)	-
Sulphate content (ppm)	10.3
Sulphate content (%)	0.00
Chloride ion content (ppm)	673.6
Chloride ion content (%)	0.07
pH	6.0
Electrical Conductivity (uS/cm)	-
Mean Resistivity Ω.m	-
(Resisitivity) Density ratio (R_D)	-
(Resisitivity) Density index (I_D)	-

NATA

The results of the tests, calibrations and/or measurements included in this document are traceable to Australian/national standards. Accredited for compliance with ISO/IEC 17025. This document shall not be reproduced, except in full.

NATA Accredited Laboratory Number: 14874

Authorised Signatory:

Brad Morris

13/06/2018

Date:

MACQUARIE GEOTECH

Macquarie Geotechnical
3 Watt Drive
Bathurst NSW 2795

SOIL CHEMICAL PROPERTIES REPORT

Client:	Arup	**Source:**	BH3 - 03 2.5-2.6m
Address:	Level 10, 201 Kent Street, Sydney 2000 Australia	**Sample Description:**	Silty CLAY with sand
Project:	Terrigal Boardwalk (261648)	**Report No:**	B48634-SCP
Job No:	S18220	**Lab No:**	B48634 (S33965)

Test Procedure:

☑	AS1289 4.2.1	Soil Chemical Tests - Determination of a sulfate content of a natural soil and the sulfate content of the groundwater - Normal Method
☑	AS1289 4.3.1	Soil Chemical Tests - Determination of the pH value of a soil - Electrometric method
☐	AS 1289 4.4.1	Soil Chemical Tests - Determination of the electrical resistivity of a soil - Method for sands and granular material
☐	AS 1012.20	Chloride and sulphate
☐	RMS T123	pH value of a soil (electrometric method)
☐	RMS T185	Resistivity of sands and granular road construction materials
☐	RMS T200	Chloride content of roadbase
☑	RMS T1010	Quantitative determination of chlorides in soil
☐	RMS T1011	Quantitative determination of sulphates in soil
☐	BS1377(1990 pt.3)	Water soluble sulphate content
☐	APHA 4500 H+B	pH
☐	APHA 4500 SO4 2-B	Sulphate
☐	APHA 4500 CI-B	Chloride
☐	APHA 2510 & 2520-B	Electrical Conductivity
☐	TAI B117	Sulphides Present (This service Not Covered by NATA Accreditation)

Sampling:	Sampled by Client	**Date Sampled:**	23/05/2018
Preparation:	Prepared in accordance with the test method		

Sulphides Present	-
Sulphur Peroxide (%)	-
Sulphate content (ppm)	16.5
Sulphate content (%)	0.00
Chloride ion content (ppm)	124.1
Chloride ion content (%)	0.01
pH	6.9
Electrical Conductivity (uS/cm)	-
Mean Resistivity Ω.m	-
(Resisitivity) Density ratio (R_D)	-
(Resisitivity) Density index (I_D)	-

The results of the tests, calibrations and/or measurements included in this document are traceable to Australian/national standards. Accredited for compliance with ISO/IEC 17025. This document shall not be reproduced, except in full.

NATA Accredited Laboratory Number: 14874

Authorised Signatory:

Brad Morris

13/06/2018

Date:

Macquarie Geotechnical
3 Watt Drive
Bathurst NSW 2795

SOIL CHEMICAL PROPERTIES REPORT

Client:	Arup	**Source:**	BH4 - 02 6-6.1m
Address:	Level 10, 201 Kent Street, Sydney 2000 Australia	**Sample Description:**	Silty CLAY with sand
Project:	Terrigal Boardwalk (261648)	**Report No:**	B48635-SCP
Job No:	S18220	**Lab No:**	B48635 (S33968)

Test Procedure:

☑	AS1289 4.2.1	Soil Chemical Tests - Determination of a sulfate content of a natural soil and the sulfate content of the groundwater - Normal Method
☑	AS1289 4.3.1	Soil Chemical Tests - Determination of the pH value of a soil - Electrometric method
☐	AS 1289 4.4.1	Soil Chemical Tests - Determination of the electrical resistivity of a soil - Method for sands and granular material
☐	AS 1012.20	Chloride and sulphate
☐	RMS T123	pH value of a soil (electrometric method)
☐	RMS T185	Resistivity of sands and granular road construction materials
☐	RMS T200	Chloride content of roadbase
☑	RMS T1010	Quantitative determination of chlorides in soil
☐	RMS T1011	Quantitative determination of sulphates in soil
☐	BS1377(1990 pt.3)	Water soluble sulphate content
☐	APHA 4500 H+B	pH
☐	APHA 4500 SO4 2-B	Sulphate
☐	APHA 4500 CI-B	Chloride
☐	APHA 2510 & 2520-B	Electrical Conductivity
☐	TAI B117	Sulphides Present (This service Not Covered by NATA Accreditation)

Sampling: Sampled by Client **Date Sampled:** 23/05/2018

Preparation: Prepared in accordance with the test method

Sulphides Present	-
Sulphur Peroxide (%)	-
Sulphate content (ppm)	14.4
Sulphate content (%)	0.00
Chloride ion content (ppm)	195.0
Chloride ion content (%)	0.02
pH	6.7
Electrical Conductivity (uS/cm)	-
Mean Resistivity Ω.m	-
(Resisitivity) Density ratio (R_D)	-
(Resisitivity) Density index (I_D)	-

NATA

The results of the tests, calibrations and/or measurements included in this document are traceable to Australian/national standards. Accredited for compliance with ISO/IEC 17025. This document shall not be reproduced, except in full.

NATA Accredited Laboratory Number: 14874

Authorised Signatory:

Brad Morris

13/06/2018

Date:

MACQUARIE GEOTECH

Macquarie Geotechnical
3 Watt Drive
Bathurst NSW 2795

SOIL CHEMICAL PROPERTIES REPORT

Client:	Arup	**Source:**	BH4 - 03 8-8.17m
Address:	Level 10, 201 Kent Street, Sydney 2000 Australia	**Sample Description:**	Sandy GRAVEL with silt
Project:	Terrigal Boardwalk (261648)	**Report No:**	B48636-SCP
Job No:	S18220	**Lab No:**	B48636 (S33969)

Test Procedure:

☑	AS1289 4.2.1	Soil Chemical Tests - Determination of a sulfate content of a natural soil and the sulfate content of the groundwater - Normal Method
☑	AS1289 4.3.1	Soil Chemical Tests - Determination of the pH value of a soil - Electrometric method
☐	AS 1289 4.4.1	Soil Chemical Tests - Determination of the electrical resistivity of a soil - Method for sands and granular material
☐	AS 1012.20	Chloride and sulphate
☐	RMS T123	pH value of a soil (electrometric method)
☐	RMS T185	Resistivity of sands and granular road construction materials
☐	RMS T200	Chloride content of roadbase
☑	RMS T1010	Quantitative determination of chlorides in soil
☐	RMS T1011	Quantitative determination of sulphates in soil
☐	BS1377(1990 pt.3)	Water soluble sulphate content
☐	APHA 4500 H+B	pH
☐	APHA 4500 SO4 2-B	Sulphate
☐	APHA 4500 CI-B	Chloride
☐	APHA 2510 & 2520-B	Electrical Conductivity
☐	TAI B117	Sulphides Present (This service Not Covered by NATA Accreditation)

Sampling:	Sampled by Client	**Date Sampled:**	23/05/2018
Preparation:	Prepared in accordance with the test method		

Sulphides Present	-
Sulphur Peroxide (%)	-
Sulphate content (ppm)	10.3
Sulphate content (%)	0.00
Chloride ion content (ppm)	31.0
Chloride ion content (%)	0.00
pH	6.9
Electrical Conductivity (uS/cm)	-
Mean Resistivity Ω.m	-
(Resisitivity) Density ratio (R_D)	-
(Resisitivity) Density index (I_D)	-

The results of the tests, calibrations and/or measurements included in this document are traceable to Australian/national standards. Accredited for compliance with ISO/IEC 17025. This document shall not be reproduced, except in full.

NATA Accredited Laboratory Number: 14874

Authorised Signatory:

Brad Morris

13/06/2018

Date:

Macquarie Geotechnical
3 Watt Drive
Bathurst NSW 2795