Pacific Highway / Italia Road Intersection

Geotechnical Desktop Assessment Report

Boral Resources (NSW) Pty Ltd

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1. Introduction

1.1 Overview

Boral Resources (NSW) Pty Ltd (Boral) is acting on behalf of Eagleton Rock Syndicate (ERS) and Australian Resource Development Group Pty Limited (ARDG) (collectively referred to as the ‘quarry operators’) in submitting a development application (DA) to Port Stephens Council (Council), pursuant to Part 4 of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act), for proposed upgrades to the Italia Road and Pacific Highway intersection (the proposed development).

The proposed development involves safety upgrades to the Italia Road and Pacific Highway intersection, including:

– Construction of a dedicated left-turn northbound acceleration lane from Italia Road onto the Pacific Highway.
– Widening of the existing bridge over the Balickera Canal (to accommodate the northbound acceleration lane).
– Lengthening of the northbound deceleration lane into Italia Road.

All works are proposed to be undertaken within the existing road reserve.

1.2 Project description

Transport for NSW (TfNSW) has identified the need for safety upgrades to the Italia Road and Pacific Highway intersection to meet the future predicted traffic growth of the area. The need to bring forward the safety upgrades to the intersection is in direct response to the vehicle movements predicted to be generated by the State Significant Development (SSD) applications submitted by Boral, ERS and ARDG. Consequently, the quarry operators have been working closely with TfNSW since 2020 to prepare a design for the intersection upgrades.

In principle, support was provided by TfNSW for a concept design in June 2022 on the basis that the quarry operators agreed to jointly fund all costs associated with the approval and construction of the required upgrades. A commercial agreement between the quarry operators is in place and (subject to approvals), construction of the intersection is expected to be finalised and operational within the last quarter of 2025.

The concept design has now been further developed to meet the requirements of TfNSW, Council and Hunter Water Corporation (HWC) and this refined design forms the basis of the DA.

GHD has been engaged by Boral to facilitate the DA submission. GHD’s general scope of work comprises:

– An updated concept road design
– Bridge and culvert extension concept designs
– Flood impact assessment
– Geotechnical desktop assessment
– Construction noise and vibration impact assessment
– Phase 1 preliminary contamination assessment
– Traffic impact assessment
– A road safety audit
– A detailed cost report

The existing concept design includes northbound widening of the Pacific Highway to facilitate deceleration and acceleration lanes connecting with new turn lanes into and out of Italia Road. Road widening associated with the deceleration lane is in the order of 250 m in length, while the widening associated with the acceleration lane is in the order of 650 m in length. The northbound acceleration lane will also require widening of the bridge over the Balickera Channel.

1.3 Purpose of this report

The purpose of this report is to present preliminary geotechnical assessment, describing geological and geotechnical characteristics and constraints relating to the proposed Italia Road and Pacific Highway intersection upgrade.

We understand that the preliminary assessment is required as input to the DA and future geotechnical investigation and assessment would be required to facilitate future design stages.

The report includes the results of a desktop study and site walkover, together with:

– Anticipated subsurface conditions.
– An assessment of the existing soil and geological characteristics of the site.
– Geotechnical characteristics and considerations for subsequent design stages, including recommendation for geotechnical investigation.

1.4 Assumptions and limitations

This report has been prepared by GHD for Boral Resources (NSW) Pty Ltd and may only be used and relied on by Boral Resources (NSW) Pty Ltd for the purpose agreed between GHD and Boral Resources (NSW) Pty Ltd as set out in Section 1 of this report.

GHD otherwise disclaims responsibility to any person other than Boral Resources (NSW) Pty Ltd arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on:

– Conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.
– Information obtained from visual inspection of select locations across the site. Site conditions at other parts of the site may be different from the site conditions observed.
– Assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

Observations undertaken in respect of this report are constrained by the particular site conditions, such as the location private property boundaries, vegetation and drainage lines. As a result, not all relevant site features and conditions may have been identified in this report.

GHD has prepared this report on the basis of information provided by Boral Resources (NSW) Pty Ltd, which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

The report should be read in conjunction with the Standard Sheets provided in Appendix A.

2. Site location and road network

2.1 Location

As shown in Figure 2.1, Boral's Seaham Quarry is located on the southern side of Italia Road in Balickera, NSW, approximately 1.5 km from the Pacific Highway intersection and about 10 km north-east of Raymond Terrace. The Seaham Quarry is a primary source of 'hard' rock for aggregate products used in the Hunter and Port Stephens regions of NSW.

Directly south of the Seaham Quarry, ERS propose to develop a separate independent quarry. While on the northern side of Italia Road, ARDG propose to develop a portion of the Wallaroo State Forest into another independent quarry. Access to the existing Seaham Quarry as well as the proposed ERS and ARDG quarries is via Italia Road from the Pacific Highway.

The existing site is immediately surrounded by a recreational motorway and a paintball facility (both located on the southern side of Italia Road between Seaham Quarry and the Pacific Highway). The nearest residential lots are located approximately 1 km north-west on Italia Road, as well as approximately 1.5 km south-east adjacent to the Pacific Highway. These lots are classified as low density and semi-rural.

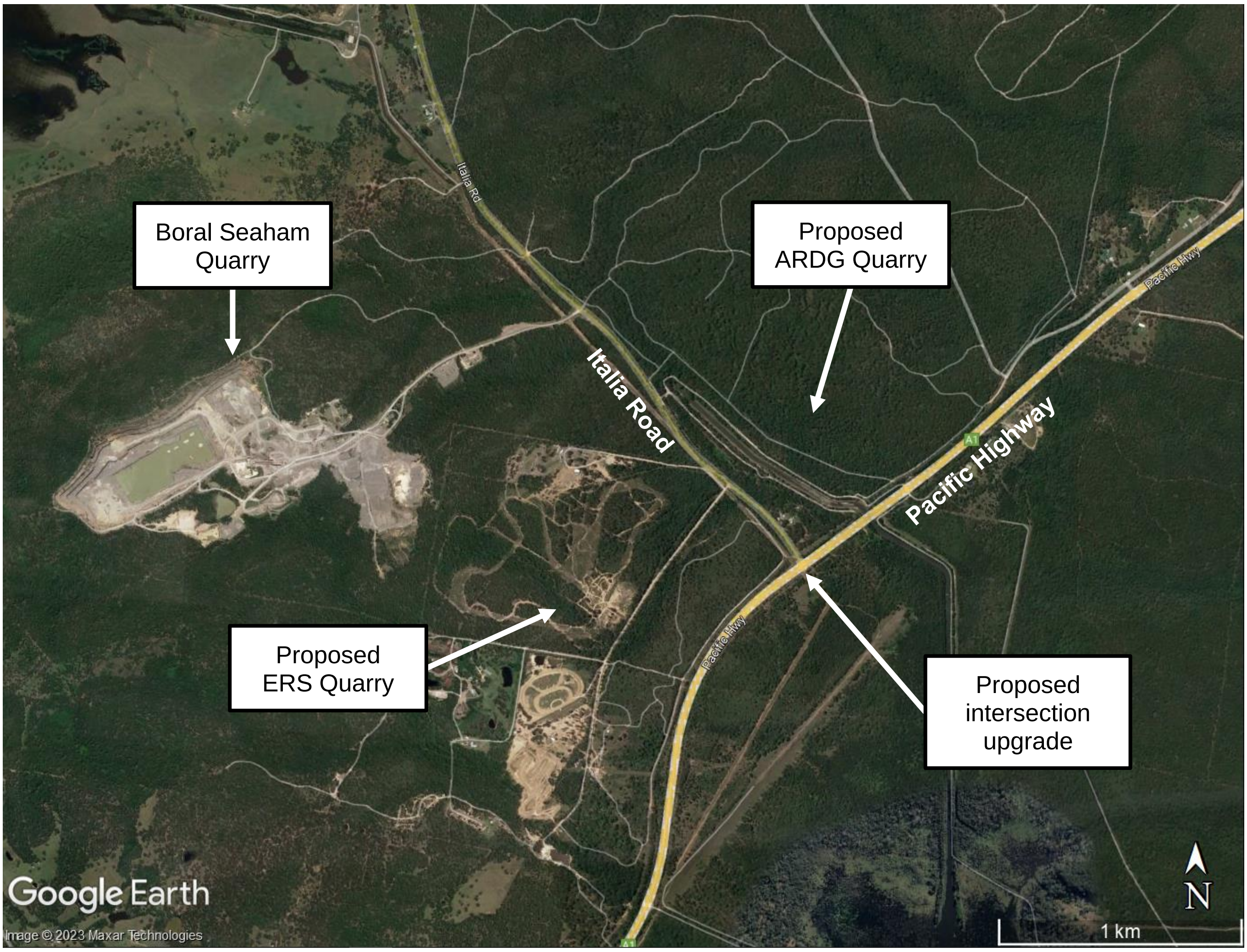

Figure 2.1 Site location map

2.2 Road network

2.2.1 Pacific Highway

The Pacific Highway is an arterial road generally aligned north-south, which runs along the east coast of Australia between Sydney and Brisbane. The Pacific Highway is a strategic freight corridor along the east coast and is accordingly approved for use by vehicles including 25/26 m B-doubles without specific permit conditions.

The Pacific Highway has an average daily traffic volume of approximately 15,000-16,000 vehicles based on actual peak hour traffic count data factored up to a daily estimate (two-way northbound and southbound combined) with around 2,000 of those being trucks.

The most recent 7-day traffic count data was in 2018 at the nearby Twelve Mile Creek (within 10 km of the site) which shows south-bound only traffic volumes of around 10,700 vehicles. At Taree (approximately 130 km north of the site), some 30,000 vehicles two way traffic per day was counted in 2023. Over the last seven years, the Pacific Highway traffic volumes have seen approximately 2-3% growth per annum based on historic traffic volume data published by TfNSW.

The Pacific Highway is a divided carriageway road with two to three lanes in each direction. In this regard, two lanes are provided in each direction adjacent to Italia Road, with the acceleration lane in the south-bound direction from Italia Road providing a third lane for approximately 1.2 km.

Sealed shoulders are provided on each side of the Pacific Highway with a typical width of 2.2 m to 2.5 m, allowing for vehicles to pull over if required. However, no car parking or bicycle lanes are provided along the Pacific Highway near the site.

A posted speed limit of 110 km/h applies in the vicinity of the site, reducing to 60 km/h through towns.

2.2.2 Italia Road

Italia Road is a local throughfare that generally runs north-west from the Pacific Highway for approximately 8.5 km to the intersection with East Seaham Road.

Italia Road is fully sealed and provides one traffic lane in each direction. No parking or bicycle lanes are provided.

A posted speed limit of 90 km/h applies to Italia Road, reducing to 60 km/h approximately 130 m from the Pacific Highway.

The intersection of Italia Road and Pacific Highway is shown below in Figure *2.2*.

2.2.3 Italia Road and Pacific Highway intersection

The existing intersection is a seagull type intersection as shown below in Figure *2.2*.

The intersection includes short right turn and left turn deceleration lanes to turn into Italia Road from the Pacific Highway.

The intersection features a long acceleration lane for south-bound vehicles turning right onto the Pacific Highway which forms a third lane on the Highway until it merges approximately 1.2 km south of the intersection. This allows right turning vehicles to enter Pacific Highway giving way to traffic in the north-bound and vehicles turning into Italia Road heading south-bound.

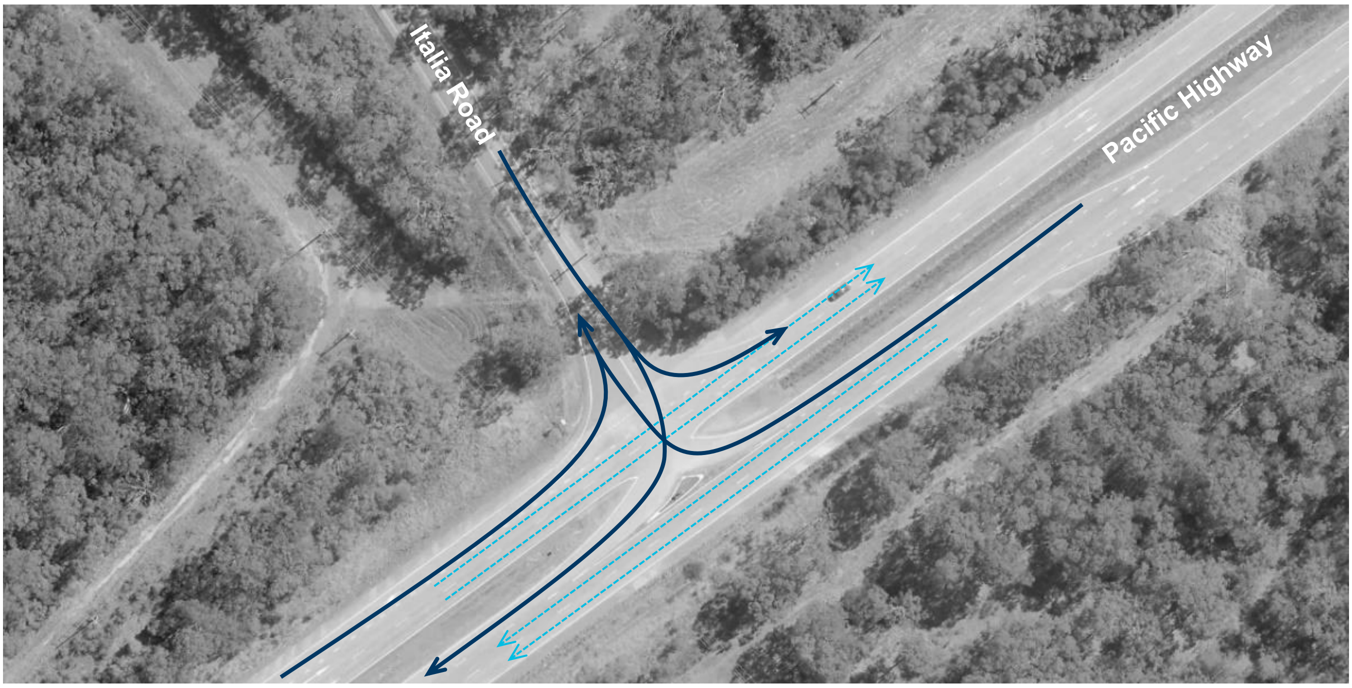

Figure 2.2 Current Italia Road / Pacific Highway intersection (source: MetroMap, accessed June 2022)

3. Geotechnical site setting and desktop review

A geotechnical desktop review was undertaken to develop our understanding of the anticipated subsurface conditions. The following sources were reviewed:

– eSPADE v2.2, 2023. State Government of NSW and Department of Planning and Environment 1998. Retrieved from https://www.environment.nsw.gov.au/eSpade2WebApp.
– MinView, 2023. Colquhoun G.P., Hughes K.S., Deyssing L., Ballard J.C., Folkes C.B, Phillips G., Troedson A.L. & Fitzherbert J.A., 2022. New South Wales Seamless Geology dataset, version 2.2 [Digital Dataset]. Geological Survey of New South Wales, Department of Regional NSW, Maitland.
– Previous reports from nearby projects:
  - "Strategic Concept Design Alternate Option 03" for ARDG, drawing number 22-19467-SK110, revision A, dated 17 April 2022.
  - "Stone Ridge Quarry – Geotechnical Stability Review" report by GHD for ARDG, revision 2, dated 10 November 2022.

A site walkover was undertaken by two experienced geotechnical engineers on 27 April 2023 to record site observations and develop our understanding of key geotechnical surface features.

The results of the desktop review and site walkover are presented in the following sub-sections.

3.1 Site description

Italia Road consists of a spray sealed wearing course dual carriageway, with narrow shoulders commonly less than 1 m wide. On approach to the Pacific Highway, the existing road formation is constructed over an embankment between approximately 1.5 m and 2 m high and generally increasing as the road surface level rises towards the intersection as shown in Figure 3.1.

A 400 mm diameter culvert approximately 130 m from the intersection connects to surface drainage channels running both parallel (i.e. at the toe of the embankment) and perpendicular (i.e. into private property adjacent) to Italia Road.

Common road surface defects were noted along Italia Road, including rutting, potholes, flushing, ravelling and edge drops. The surface deterioration increased on approach to the Pacific Highway as shown in Figure 3.2.

Figure 3.1 View along Italia Road looking south-east towards the intersection

Figure 3.2 Road surface defects on Italia Road near the intersection, looking south

The existing Pacific Highway pavement comprises a reinforced concrete wearing coarse in visibly good condition. In the vicinity of the intersection, the northbound carriageway comprises two lanes, with the addition of a left-hand turning lane into Italia Road that extends approximately 200 m.

Surface erosion and some minor slips (<0.2 m deep) were evident across the northbound embankment adjacent to the left-hand turning lane. Gravel had been placed seemingly recently along the verge at the crest of the embankment in this area.

The Pacific Highway surface level gently decreases at generally less than 5% past the intersection (to the north-east), reaching a low point near the existing bridge over Balickera Channel, located about 350 m north-east of the intersection.

The left-hand turning lane, gravel-surfaced verge and Pacific Highway longitudinal fall to the north-east are shown in Figure 3.3.

Figure 3.3 ***Looking north-east along the Pacific Highway towards the intersection***

In the area of proposed Pacific Highway widening (i.e. about 250 m south-west to 650 m north-east of the intersection), the existing road formation is constructed over embankments generally 1.5 m to 3 m high, but appearing to increase on approach to Balickera Channel where the road surface levels are in the order of 6 m to 8 m higher than channel floor.

The existing three-span reinforced concrete bridge over Balickera Channel is an approximate overall length of 35 m. A view of the bridge deck is shown in Figure 3.4. Scouring was observed in the spill-through batters adjacent to the bridge, with remediation provided in the form of ripped igneous boulders at the south-western end and a shotcrete/concrete surface lining that was ‘undermined’ at the north-eastern end.

Figure 3.4 ***Bridge substructure crossing Balickera Channel, looking north-east***

Drainage culverts under the Pacific Highway were observed in close proximity to the bridge, including two (about 60 m and 220 m) north-east of the bridge and one (about 50 m) south-west of the bridge. The culvert south-west of the bridge comprised a three-cell pre-cast concrete box structure approximately 10 m wide. Water was ponded at the presumed culvert inlet (on the north-western side of the Pacific Highway) as shown in Figure 3.5.

The drainage channel running towards the three-cell culvert inlet was observed to be full of water in places. Vegetation along the channel comprised juvenile to semi-mature trees and overgrown shrubs and grasses. The drainage channel extended along the toe of the northbound embankment from near the intersection. A sandstone block wall, typically around 2 m high, was observed retaining the road embankment between the box culvert and about 150 m north-east of the intersection. The drainage channel, sandstone block wall and embankment are shown in Figure 3.6.

Figure 3.5 Looking north-east to the three-cell box culvert and ponded water

Figure 3.6 Typical northbound embankment, sandstone block wall and chainage channel

North-east of the Balickera Channel, the existing Pacific Highway surface levels rise very gently. The rise in surface levels corresponds to a gradually decreasing embankment height, which reduces to about 1 m near the north-eastern limit of the proposed widening.

A sealed yet dilapidated road, bounded by overgrown vegetation, runs parallel to the Pacific Highway as shown below in Figure 3.7. The road is about 25 m from the northbound left-hand lane of the Pacific Highway and is accessed via a widened shoulder about 200 m north-east of the Balickera Channel bridge. The Pacific Highway and unnamed road are separated by mostly juvenile trees and dense shrubs with poor drainage apparent.

Figure 3.7 Looking south-west down an Unnamed road adjacent to the Pacific Highway

3.2 Soil landscape

Reference to the eSPADE (NSW Planning, Industry and Environment, v2.2) database shows that the site is largely located on the Ten Mile Road soil landscape, but mapped close to contact with the Nungra soil landscape near Balickera Channel and crosses into the Medowie soil landscape about 50 m north-east of Balickera Channel.

The Ten Mile Road soil landscape is characterised by undulating to gently undulating low hills on Carboniferous sediments and acid volcanics in the Medowie Lowlands and Clarencetown Hills regions. Slopes are typically between 5% and 10%, with elevations between 70 m and 150 m, and local relief between 40 m and 80 m. Vegetation through the landscape is described as uncleared open forest. Soil landscape limitations include high water erosion hazard, localised shallow soils, high run-on and seasonal waterlogging, and strongly to extremely acid soils of low fertility.

The Nungra soil landscape is characterised by widespread gently inclined footslopes and drainage plains of the Medowie Lowlands and Karuah Mountains physiographic ranges. The geology comprises Quaternary alluvium and deep silty footslope deposits eroded from surrounding hills and overlying Carboniferous rock strata. Slope gradients are typically less than 3%, with local relief less than 10 m and elevations up to 40 m. Vegetation through the landscape is described to comprise predominantly cleared tall open forest with woodlands on the lower slopes and plains. Soil landscape limitations include water erosion hazard, localised salinity, high run-on, seasonal waterlogging, localised flood hazard and foundation hazard.

The Medowie soil landscape is characterised by gently undulating low hills on relict sediments in the Medowie Lowlands region, with very broad, flat crests and long, gently inclined side slopes. Slopes are typically between 2% and 15%, with elevation between 30 m and 70 m and local relief to 30 m. Vegetation is described as partially cleared open forest. Soil landscape limitations include localised seasonal waterlogging on lower slopes, localised water erosion hazard, strongly acid soils with low inherent fertility and high potential aluminium toxicity.

3.3 Regional geology

Reference to the MinView Geological Survey of NSW seamless geology mapping shows that the site is primarily underlain by the Carboniferous aged Seaham Formation, lies close to the geological contact with the Carboniferous aged upper Mount Johnstone Formation and passes through Quaternary aged alluvial floodplain deposits in the vicinity of Balickera Channel.

The Seahman Formation is described to comprise “tillite, varved siltstone, tuff, red and green zeolitic mudstone with dropstones interbedded in thick-bedded lithic sandstone and conglomerate”.

The upper Mount Johnstone Formation is described to comprise “graded, massive, lithic arenite with interbeds of fine, laminated sandstone, shale, carbonaceous shale, poor coal and minor chert”.

The alluvial floodplain deposits are described to comprise “Silt, very fine to medium grained lithic to quartz-rich sand, clay”.

3.4 Groundwater bores

Reference to registered groundwater bores available on MinView shows the following in close proximity to the site:

– GW060853 – Located about 4 km north-west of the site; identifying 60 mm of topsoil overlying weathered conglomerate to 3.4 m depth, in turn overlying clayey sand to 11.2 m depth. The clayey sand was underlain by weathered sandstone to 12.4 m depth which was identified overlying dacite.
– GW060834 – Located about 4 km north-west of the site and about 500 m east of GW060853; identifying weathered conglomerate to 6.2 m depth overlying dacite.
– GW053074 – Located about 6 km north-east of the site and adjacent to the Pacific Highway; identifying clay to 6.7 m depth overlying sandstone to 15.5 m depth and, in turn, volcanic rock.
– GW051985 – Located about 5.5 km north-east of the site and adjacent to the Pacific Highway; identifying clay to 2.7 m depth overlying sandstone to 19.5 m depth and, in turn, volcanic rock.

3.5 Acid sulfate soils

Reference to the acid sulfate soil (ASS) probability map, accessed via eSPADE (NSW Planning, Industry and Environment, v2.2), shows that there are no mapped occurrences of ASS at the site.

The closest occurrence of ASS is a high probability mapped about 2 km north-west of the site associated with the Balickera Channel.

3.6 Nearby information

3.6.1 Balickera Tunnel

The Balickera Tunnel and associated canals/channels (including under the Pacific Highway at the site) were constructed between 1958 and 1964 as part of the Grahamstown Water Supply Scheme to allow fresh water to be transferred from the Williams River weir to Grahamstown Dam via the Balickera Pumping Station.

Balickera Tunnel is approximately 1.2 km long, with its nearest point about 1 km north-west of the Italia Road and Pacific Highway intersection. Mapped geology at the south-eastern end of the tunnel (nearest the site) comprises the Carboniferous aged upper Mount Johnstone Formation (sandstone), but lies close to the geological contact with the lower Mount Johnstone Formation (conglomerate).

3.6.2 Seaham Weir Modification

The Seaham Weir is located on the lower reaches of the Williams River, approximately 7.5 km west of the Italia Road and Pacific Highway intersection.

Site geology comprises Quaternary aged alluvial deposits. Subsurface conditions are understood to comprise alluvial clays and silts of variable consistency overlying residual soil and weathered rock.

3.6.3 Stone Ridge Quarry

GHD completed a desktop study and geotechnical stability review for ARDG's proposed Stone Ridge Quarry, located about 2 km north-west of the Italia Road and Pacific Highway intersection.

The desktop study findings noted that geology in the area comprised of a sequence of Carboniferous aged sedimentary and volcanic rocks, with a bedding sequence dipping in a south-easterly direction. A basal sequence of conglomerate, tuff and sandstone, overlain by volcanic lava flows was also noted. The volcanic rocks are overlain by a further sequence of basal conglomerate, sandstone and tuff, overlain by toscanitic lava, followed by interbedded conglomerate and indurated shales. These overlying units characterise the geology between the eastern end of the Balickera Tunnel and the Pacific Highway.

The desktop study also reported on geological and stratigraphic mapping conducted in 1966, as obtained from "The Balickera Section of the Carboniferous Kuttung Facies, New South Wales" (Royal Society of New South Wales, 1966). Based on this report, the Carboniferous stratigraphy was interpreted to dip 35° south-east. The geology to the north of the site was characterised by volcanic rocks assigned to the Mosman Swamp Andesites Formation of which is in the lower part of the Gilmore Volcanic Group. The document reported the Mosman Swamp Andesites Formation was overlain by the Eagleton Volcanics Formation (upper part of Gilmore Volcanic Group). Balickera Conglomerate was shown to overly the Eagleton Volcanics.

The MinView NSW Seamless Geology dataset presents a revised geological interpretation, with the geology previously assigned by Rattigan (1966) as the Mosman Swamp Andesites incorporated within the Eagleton Volcanics geology unit. The overlying geology previously mapped as Balickera Conglomerate has now been assigned to the Mount Johnstone Formation. The lower part of the Mount Johnstone Formation is dominated by conglomerate, whereas the upper part of the formation is characterised by sandstone, shale and carbonaceous shale.

4. Geotechnical characteristics and considerations

4.1 Site observations

General site observations were recorded, including:

- The existing road formation appears to have been constructed on embankments generally between 1.5 m and 3 m high, increasing in the vicinity of Balickera Channel.
- Natural surface levels adjacent to (and in the direction of) the Pacific Highway appear to:
  - Gently fall at around 5% past the Italia Road and Pacific Highway intersection to about 200 m south-west of Balickera Channel.
  - Be relatively level from the Balickera Channel bridge to about 200 m south-west.
  - Very gently rise at around 2% north-east of the Balickera Channel.
- Based on the natural surface levels and mapped soil/geology, materials underlying the embankments are anticipated to comprise residual soils in the vicinity of the intersection and alluvial soils around Balickera Channel.
- Surface drainage lines run parallel to both Italia Road and in the northbound verge of the Pacific Highway.
- Surface drainage lines run in the verges of both Italia Road and the northbound side of the Pacific Highway. The drainage line adjacent to the Pacific Highway held water, increasing in depth to a ‘pond’ at the inlet of a ‘bridge-sized’ culvert about 50 m south-west of the Balickera Channel.
- Localised ground surface softening was evident around the drainage path.
- A sandstone block wall up to approximately two metres in height retained the toe of the Pacific Highway embankment from about 150 m north-east of the intersection to the ‘bridge-sized’ culvert. The water-filled drainage line extended along the toe of the wall.
- A three-span reinforced concrete bridge crosses the Balickera Channel. The approaches to the bridge appeared to have been constructed with embankments in the order of 6 m to 8 m high. However, vegetated batter slopes prevented visual assessment to confirm the suspected embankment material. Thus, the embankment depth at the bridge and underlying material has not been confirmed.

4.2 Embankment widening

We understand that the concept design will include northbound widening of the Pacific Highway. Assuming road levels remain at the existing vertical alignment, embankment widening will be required.

It is anticipated that the embankment widening construction will be in accordance with Transport for NSW’s “QA Specification R44 Earthworks” (R44). R44 specifies embankment foundation (‘Type E’) treatments that are required to obtain adequate compaction of the overlying fill and pavement layers. In addition, cut floor treatments (‘Type C’) and special treatments comprising ‘Shallow Embankment’, ‘Cut/Fill Transition Zones’ and ‘Hillside Embankments’ are included in R44 but aren’t expected to be required.

Typical embankment foundation treatments which may be required (subject to geotechnical investigation results and design requirements) include:

- ‘Type E1 – Loosen and Recompact’ for embankment foundations. Unsuitable material should be removed prior to loosening the subgrade to a depth of 300 mm to 400 mm before re-compacting to a minimum 95% Standard maximum dry density ratio (SMDDR) as per R44.

- ‘Type E2 – Bridging Layer’ for embankment foundations affected by soft and/or wet foundations where it is impracticable to achieve the degree of compaction specified for the foundation. The bridging layer should consist of an 800 mm rock fill layer enclosed in geotextile (in accordance with R44 requirements). R44 indicates the distance between the top of the bridging layer and underside of the selected material zone (SMZ) should be 900 mm or more.
- ‘Type E5 – Drainage Layer’ for embankment foundations affected by groundwater. The drainage layer should consist of a 300 mm to 400 mm rock fill layer compacted in accordance with R44 and enclosed in geotextile (again as per R44 requirements). R44 indicates the distance between the top of the drainage layer and underside of the SMZ should be 900 mm or more. The drainage layer should be placed after appropriate stripping of unsuitable materials and shaping/trimming of the foundation to ensure that the water can drain properly.

Additional considerations such as embankment settlement and stability should be assessed following geotechnical investigation as subsequent design stages.

4.3 Culvert extensions and bridge widening

We understand that the Balickera Channel bridge and existing culverts will require widening to facilitate the proposed northbound acceleration lane. Culverts were identified about 50 m south-west of the Balickera Channel bridge, and about 60 m and 220 m north-east of the bridge.

Detailed geotechnical investigation will be required, along with development of geotechnical models to assess the anticipated founding conditions, footing options and potential geotechnical risks.

Consideration will need to be given to foundation preparation, settlement, modulus of subgrade reaction, vertical and lateral bearing capacity, footing soil and rock parameters and footing durability.

Based on site observations and experience on similar sites, it is expected that new bridge footings would comprise piled foundations. Support of new culvert widening would be expected to comprise concrete slabs over a foundation treatment that could include removal of unsuitable material and replacement with select fill.

4.4 Embankment retaining structure

At this stage, we understand that an embankment retaining structure to replace the existing Pacific Highway northbound verge wall is not proposed.

4.5 Recommended investigation

Geotechnical investigation should be undertaken in accordance with the minimum requirements outlined in:

- TfNSW “QA Specification PS231 – Geotechnical Investigation and Design” for concept design (PS231).
- TfNSW “QA Specification PS331 – Geotechnical Investigation and Design” for detailed design (PS331).

A detailed design scope of investigation in accordance with PS331 and subject to approval by TfNSW would generally comprise:

- Proposed embankment widening – test pits or boreholes every 50 m.
- Culvert extensions – one test pit or borehole at each proposed culvert extension and intermediate locations at no more than 30 m intervals along the length of the culvert as required.
- Bridge widening – one borehole drilled within 2 m from the centreline of each pier and abutment, and additional boreholes where the width of the pier or abutment exceeds 12 m.

Appendices

Appendix A

Standard Sheets

GENERAL NOTES

GHD
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The report contains the results of a geotechnical investigation or study conducted for a specific purpose and client. The results may not be used or relied on by other parties, or used 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.

To the maximum extent permitted by law, all implied warranties and conditions in relation to the services provided by GHD and the report are excluded unless they are expressly stated to apply in the report.

TEST HOLE LOGGING

The information on the test hole logs (boreholes, test pits, exposures etc.) is based on a visual and tactile assessment, except at the discrete locations where test information is available (field and/or laboratory results). The test hole logs include both factual data and inferred information. Moreover, the location of test holes should be considered approximate, unless noted otherwise (refer report). Reference should also be made to the relevant standard sheets for the explanation of logging procedures (Soil and Rock Descriptions, Core Log Sheet Notes etc.).

GROUNDWATER

Unless otherwise indicated, the water depths presented on the test hole logs are the depths of free water or seepage in the test hole recorded at the given time of measuring. The actual groundwater depth may differ from this recorded depth depending on material permeabilities (i.e. depending on response time of the measuring instrument). Further, variations of this depth could occur with time due to such effects as seasonal, environmental and tidal fluctuations or construction activities such as a change is ground surface level. Confirmation of groundwater levels, phreatic surfaces or piezometric pressures can only be made by appropriate surveys, instrumentation techniques and monitoring programmes.

INTERPRETATION OF RESULTS

The discussion or recommendations contained within this report normally are based on a site evaluation from discrete test hole data, often with only approximate locations (e.g. GPS). Generalised, idealised or inferred subsurface conditions (including any geotechnical cross-sections) have been assumed or prepared by interpolation and/or extrapolation of these data. As such these conditions are an interpretation and must be considered as a guide only.

CHANGE IN CONDITIONS

Local variations or anomalies in ground conditions do occur in the natural environment, particularly between discrete test hole locations or available observation sites. Additionally, certain design or construction procedures may have been assumed in assessing the soil-structure interaction behaviour of the site. Furthermore, conditions may change at the site from those encountered at the time of the geotechnical investigation through construction activities and constantly changing natural processes.

Any change in design, in construction methods, or in ground conditions as noted during construction, from those assumed or reported should be referred to GHD for appropriate assessment and comment.

GEOTECHNICAL VERIFICATION

Verification of the geotechnical assumptions and/or model is an integral part of the design process - investigation, construction verification, and performance monitoring. Variability is a feature of the natural environment and, in many instances, verification of soil or rock quality, or foundation levels, is required. There may be a requirement to extend foundation depths, to modify a foundation system and/or to conduct monitoring as a result of this natural variability. Allowance for verification by appropriate geotechnical personnel must be recognised and programmed for construction.

FOUNDATIONS

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

REPRODUCTION OF REPORTS

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Ref: DS5.5.1 Issue 0 Date: 05/10/2018

SOIL DESCRIPTION AND CLASSIFICATION

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Soil is described in general accordance with Australian Standard AS 1726-2017 (Geotechnical Site Investigations) in terms of visual and tactile properties, with potential refinement by laboratory testing. AS 1726 defines soil as particulate materials that occur in the ground and can be disaggregated or remoulded by hand in air or water without prior soaking. Classification of the soil is undertaken following description.

SOIL DESCRIPTION

The soil description includes a) Composition, b) Condition, c) Structure, d) Origin and e) Additional observations. 'FILL', 'TOPSOIL' or a 'MIXTURE OF SOIL AND COBBLES / BOULDERS' (with dominant fraction first) is denoted at the start of a soil description where applicable.

a) Soil Composition (soil name, colour, plasticity or particle characteristics, secondary and then minor components)

Soil Name: A soil is termed a *coarse grained soil* where the dry mass of sand and gravel particles exceeds 65% of the total. Soils with more than 35% fines (silt or clay particles) are termed *fine grained soils*. The soil name is made up of the primary soil component (in BLOCK letters), prefixed by applicable secondary component qualifiers. Minor components are applied as a qualifiers to the soil name (using the words 'with' or 'trace').

Particles are differentiated on the basis of size. 'Boulders' and 'cobbles' are outside the soil particle range, though their presence (and proportions) is noted. While individual particles may be designated as silt or clay based on grain size, fine grained soils are characterised as silt or clay based on tactile behaviour or Atterberg Limits, and not the relative composition of silt or clay sized particles.

Colour: The prominent colour is noted, followed by (spotted, mottled, streaked etc.) then secondary colours as applicable. Roughly equally proportioned colours are prefixed by (spotted, mottled, streaked etc.). Colour is described in its moist condition, though both wet and dry colours may also be provided if appropriate.

Plasticity: Fine grained soils are designated within standard ranges of plasticity based on tactile assessment or laboratory assessment of the Liquid Limit.

Particle Characteristics: The particle shape, particle distribution and particle size range within a coarse grained soil is described using standard terms. Particle composition may be described using rock or mineral names, with specific terms for carbonate soils.

Secondary and Minor Components: The primary soil is described and modified by secondary and minor components, with assessed ranges as tabulated.

Carbonate Soils: Carbonate content can be assessed by use of dilute '10%' HCl solution. Resulting clear sustained effervescence is interpreted as a *Carbonate soil* (approximately >50% carbonate), while weak or sporadic effervescence indicates *Calcareous soil* (< 50% carbonate). No effervescence is interpreted as a non-calcareous soil.

Organic and Peat Soils: Where identified, organic content is noted. *Organic soil* (2% to 25% organic matter) is usually identified by colour (usually dark grey/black) and odour (i.e. 'mouldy' or hydrogen sulphide odour). *Peat* (>25% organic matter) is identified by a spongy feel and fibrous texture. Peat soils' decomposition may be described as '*fibrous*' (little / no decomposition), '*pseudo-fibrous*' (moderate decomposition) or '*amorphous*' (full decomposition).

Fraction	Components		Particle Size (mm)
Oversize	BOULDERS		> 200
	COBBLES		63 - 200
Coarse grained soil particles	GRAVEL	Coarse	19 - 63
		Medium	6.7 -19
		Fine	2.36 - 6.7
	SAND	Coarse	0.6 - 2.36
		Medium	0.21 - 0.6
		Fine	0.075 - 0.21
Fine grained soil particles	SILT		0.002 - 0.075
	CLAY		< 0.002

Plasticity Terms (Fine Grained Soils)		Laboratory Liquid Limit Range
Silt	**Clay**	
N/A	N/A	(Non Plastic)
Low Plasticity	*Low Plasticity*	≤ 35%
	Medium Plasticity	> 35% and ≤ 50%
High Plasticity	*High Plasticity*	> 50%

Particle Distribution Terms (Coarse Grained Soils)	
Well graded	good representation of all particle sizes
Poorly graded	one or more intermediate sizes poorly represented
Gap graded	one or more intermediate sizes absent
Uniform	essentially of one size

Particle Shape Terms (Coarse Grained Soils)		
Rounded	*Sub-angular*	*Flaky or Platy*
Sub-rounded	*Angular*	*Elongated*

Secondary and Minor Components for Coarse Grained Soils			
Fines (%)	**Modifier** (as applicable)	**Accessory coarse (%)**	**Modifier** (as applicable)
≤ 5	*'trace silt / clay'*	≤ 15	*'trace sand / gravel'*
> 5, ≤ 12	*'with clay / silt'*	> 15, ≤ 30	*'with sand / gravel'*
> 12	*prefix 'silty / clayey'*	> 30	*prefix 'gravelly / sandy'*

Secondary and Minor Components for Fine Grained Soils	
% Coarse	**Modifier** (as applicable)
≤ 15	add *"trace sand / gravel"*
> 15, ≤ 30	add *"with sand / gravel"*
> 30	prefix soil *"sandy / gravelly"*

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b) Soil Condition (moisture, relative density or consistency)

Moisture: Fine grained soils are described relative to plastic or liquid limits, while coarse grained soils are assessed based on appearance and feel. The observation of seepage or free water is noted on the test hole logs.

Moisture - Coarse Grained Soils		
Term		**Tactile Properties**
Dry	*('D')*	Non-cohesive, free running
Moist	*('M')*	Feels cool, darkened colour, tends to stick together
Wet	*('W')*	Feels cool, darkened colour, tends to stick together, free water forms when handling

Moisture - Fine Grained Soils		
Term		**Tactile Properties**
Moist, dry of plastic limit	*('$w < PL$')*	Hard and friable or powdery
Moist, near plastic limit	*('$w \approx PL$')*	Can be moulded
Moist, wet of plastic limit	*('$w > PL$')*	Weakened, free water forms on hands with handling
Wet, near liquid limit	*('$w \approx LL$')*	Highly weakened, tends to flow when tapped
Wet, wet of liquid limit	*('$w > LL$')*	Liquid consistency, soil flows

Relative Density (Non Cohesive Soils): The Density Index is inherently difficult to assess by visual or tactile means, and is normally assessed by penetration testing (e.g. SPT, DCP, PSP or CPT) with published correlations. Assessment may be affected by moisture and *in situ* stress conditions. Density Index assessment may be refined by combination of *in situ* density testing and laboratory reference maximum and minimum density ranges.

Consistency (Cohesive Soils): May be assessed by direct measurement (shear vane, CPT etc.), or approximate tactile correlations. Cohesive soils include fine grained soils, and coarse grained soils with sufficient fine grained components to induce cohesive behaviour. A 'design shear strength' must consider the mode of testing, the *in situ* moisture content and potential for variations of moisture which may affect the shear strength.

Relative Density (Non-Cohesive Soils)		
Term and (Symbol)		**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

Consistency assessment can be influenced by moisture variation.

Consistency (Cohesive Soils)			
Term and (Symbol)		**Tactile Properties**	**Undrained Shear Strength**
Very Soft	*(VS)*	Extrudes between fingers when squeezed	< 12 kPa
Soft	*(S)*	Can be moulded by light finger pressure	12 - 25 kPa
Firm	*(F)*	Can be moulded by strong finger pressure	25 - 50 kPa
Stiff	*(St)*	Cannot be moulded by fingers	50 - 100 kPa
Very Stiff	*(VSt)*	Can be indented by thumb nail	100 - 200 kPa
Hard	*(H)*	Can be indented with difficulty by thumb nail	> 200 kPa
Friable	*(Fr)*	Easily crumbled or broken into small pieces by hand	-

c) Structure (zoning, defects, cementing)

Zoning: The *in situ* zoning is described using the terms below. *'Intermixed'* may be used for an irregular arrangement.

'layer' (a continuous zone across the exposed sample)

'lens' (a discontinuous layer with lenticular shape)

'pocket' (an irregular inclusion of different material).

'interbedded' or *"interlaminated'* (alternating soil types)

Defects: Described using terms below, with dimension orientation and spacing described where practical.

'parting' (an open or closed surface or crack sub parallel to layering with little / no tensile strength - open or closed)

'fissure' (as per a parting, though not parallel or sub parallel to layering – may include desiccation cracks)

'sheared seam' (zone of sub parallel near planar closely spaced intersecting smooth or slickensided fissures dividing the mass into lenticular or wedge shaped blocks)

'sheared surface' (a near planar, curved or undulating smooth, polished or slickensided surface, indicative of displacement)

'softened zone' (in clayey soils, usually adjacent to a defect with associated higher moisture content)

'tube' (tubular cavity, singly or one of a large number, often formed from root holes, animal burrows or tunnel erosion)

'tube cast' (an infilled tube – infill may vary from uncemented through to cemented or have rock properties)

'infilled seam' (sheet like soil body cutting through the soil mass, formed by infilling of open defects)

Cementation: Soils may be cemented by various substances (e.g. iron oxides and hydroxides, silica, calcium carbonate, gypsum), and the cementing agent shall be identified if practical. Cemented soils are described as:

'weakly cemented'	easily disaggregated by hand in air or water
'moderately cemented'	effort required to disaggregate the soil by hand in air or water

Materials extending beyond '*moderately cemented'* are encompassed within the rock strength range. Where consistent cementation throughout a soil mass is identified as a duricrust, it is described in accordance with duricrust rock descriptors. Where alternate descriptors of cementation development are applied for consistency with regional practices or geology, or client requirements, these are outlined separately.

Ref: DS6.5.1.1 Rev 0 Date: 2/03/2018

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d) Origin

An interpretation is provided based on observations of landform, geology and fabric, and may further include assignment of a stratigraphic unit. The use of terms 'possibly' or 'probably' indicates a higher degree of uncertainty regarding the assessed origin or stratigraphic unit. Typical origin descriptors include:

Residual	Formed directly from in situ weathering with no visible structure or fabric of the parent soil or rock.
Extremely weathered	Formed directly from in situ weathering, with remnant and/or fabric from the parent rock.
Alluvial	Deposited by streams and rivers (may be applied more generically as transported by water).
Estuarine	Deposited in coastal estuaries, including sediments from inflowing rivers, streams, and tidal currents.
Marine	Deposited in a marine environment.
Lacustrine	Deposited in freshwater lakes.
Aeolian	Transported by wind.
Colluvial and Slopewash	Soil and rock debris transported down slopes by gravity (with or without assistance of water). Colluvium is typically applied to thicker / localised deposits, and slopewash for thinner / widespread deposits.
TOPSOIL	Surficial soil, typically with high levels of organic material. Topsoils buried by other transported soils are termed *'remnant topsoil'*. Tree roots within otherwise unaltered soil does not characterise topsoil.
FILL	Any material which has been placed by anthropogenic processes (i.e. human activity).

e) Additional Observations

Additional observations may be included to supplement the soil description. Additional observations may consist of notations relating to soil characteristics (odour, contamination, colour changes with time), inferred geology (with delineation of soil horizons or geological time scale) or notes on sampling and testing application (including the reliability, recovery, representativeness, or condition of samples or test conditions and limitations). If the material is assessed to be not representative, terms such as 'poor recovery', 'non-intact', 'recovered as' or 'probably' are applied.

SOIL CLASSIFICATION

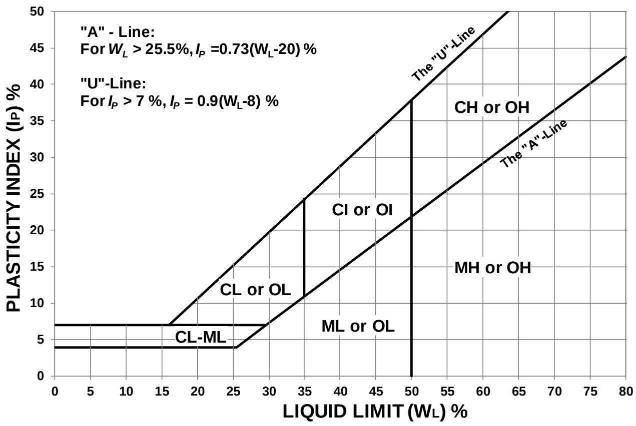
Classification allocates the material within distinct soil groups assigned a two character Group Symbol:

Coarse Grained Soils (sand and gravel: more than 65% of soil coarser than 0.075 mm)			**Fine Grained Soils** (silt and clay: more than 35% of soil finer than 0.075 mm)		
Major Division	**Group Symbol**	**Soil Group**	**Major division**	**Group Symbol**	**Soil Group**
GRAVEL (more than half of the coarse fraction is > 2.36 mm)	GW	GRAVEL, well graded	SILT and CLAY (low to medium plasticity)	ML	SILT, low plasticity
	GP	GRAVEL, poorly graded		CL	CLAY, low plasticity
	GM	Silty GRAVEL		CI	CLAY, medium plasticity
	GC	Clayey GRAVEL		OL	Organic SILT
SAND (more than half of the coarse fraction is < 2.36 mm)	SW	SAND, well graded	SILT and CLAY (high plasticity)	MH	SILT, high plasticity
	SP	SAND, poorly graded		CH	CLAY, high plasticity
	SM	Silty SAND		OH	Organic CLAY / SILT
	SC	Clayey SAND	Highly Organic	Pt	PEAT

Coarse grained soils with fines contents between 5% and 12% are provided a dual classification comprising the two group symbols separated by a dash, e.g. for a poorly graded gravel with between 5% and 12% silt fines (poorly graded 'GRAVEL with silt'), the classification is GP-GM.

For the purpose of classification, *poorly graded, uniform,* or *gap graded* soils are all designated as poorly graded. Soils that are dominated by boulders or cobbles are described separately and are not classified.

Classification is routinely undertaken based on tactile assessment with the soil description. Refinement of soil classification may be applied using laboratory assessment, including particle size distribution and Atterberg Limits. Atterberg Limits testing is applied to the sample portion finer than 0.425 mm. Fine grained soil components are assessed on the basis of regions defined within the Modified Casagrande Chart.



ROCK DESCRIPTION AND CLASSIFICATION

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Rock is described in general accordance with Australian Standard AS 1726-2017 (Geotechnical site investigations) in terms of visual and tactile properties, with potential refinement by laboratory testing. AS 1726 defines rock as any aggregate of minerals and/or organic materials that cannot be disaggregated by hand in air or water without prior soaking. The rock description and classification distinguishes between rock material, defects, structure and rock mass.

ROCK DESCRIPTION AND CLASSIFICATION

a) Description of rock material (rock name, grain size and type, colour, texture and fabric, inclusions or minor components, moisture content and durability)

Rock Name: Simple rock names are used to provide a reasonable engineering description rather than a precise geological classification. The rock name is chosen on the basis of origin, with common types summarised below. Additional, non-exhaustive, terminology is included in AS 1726. Rock names not described within AS 1726 may be adopted, with geological characteristics typically noted within accompanying text.

Grain Size (mm)	Sedimentary					Metamorphic		Igneous		
	Clastic or Detrital		Carbonate – Low Porosity	Carbonate – Porous	Pyroclastic	Foliated	Non-Foliated	Felsic	↔	Mafic
>2.0	CONGLOMERATE (rounded grains in a finer matrix) BRECCIA (angular or irregular fragments in a finer matrix)		LIMESTONE (Predominantly $CaCO_3$) or	CALCIRUDITE	AGGLOMERATE (rounded grains in a finer matrix) VOLCANIC BRECCIA (angular fragments in a finer matrix)	GNEISS	MARBLE (carbonate) QUARTZITE	GRANITE	DIORITE	GABBRO
2.0-0.06	SANDSTONE		DOLOMITE (Predominantly $CaMgCO_3$)	CALCARENITE	TUFF	SCHIST	SERPENTINITE	MICRO-GRANITE	MICRO-DIORITE	DOLERITE
0.06-0.002	MUDSTONE (silt and clay)	SILTSTONE (mostly silt)		CALCISILTITE	Fine grained TUFF	PHYLLITE or SLATE	HORNFELS	RHYOLITE	ANDESITE	BASALT
<0.002		CLAYSTONE (mostly clay)		CALCILUTITE						

Reproduced with modification from Tables 15, 16 and 17, Clause 6.2.3.1, AS 1726-2017, Geotechnical site investigations.

Grain size: For rocks with predominantly sand sized grains the dominant or average grain size is described as follows:

Rock type	Coarse grained	Medium grained	Fine grained
Sedimentary rocks	Mainly 0.6 mm to 2 mm	Mainly 0.2 mm to 0.6 mm	Mainly 0.06 mm (just visible) to 0.2 mm
Igneous and metamorphic rocks	Mainly >2 mm	Mainly 0.06 mm to 2 mm	Mainly <0.6 mm (just visible)

Colour assists in rock identification and interpolation. Rock colour is generally described in a *"moist"* condition, using simple terms (e.g. grey, brown, etc.) and modified as necessary by *"pale"*, *"dark"*, or *"mottled"*. Borderline colours may be described as a combination of these colours (e.g. red-brown).

Texture refers to the arrangement of, or the relationship between, the component grains or crystals (e.g. porphyritic, crystalline or amorphous).

Fabric refers to visible grain arrangement along a preferential orientation or a layering. Fabric may be noted as *"indistinct"* (little effect on strength) or *"distinct"* (rock breaks more easily parallel to the fabric). Common terms include *"massive"* or *"flow banding"* (igneous), *"foliation"* or *"cleavage"* (metamorphic). Sedimentary layering is described as *"bedding"* or (where thickness < 20 mm) *"lamination"*. The typical orientation, spacing or thickness of these structural features can be described directly in millimetres and metres. Further quantification of bedding thickness applied by GHD is as follows:

Bedding Term	Thickness
Very thickly bedded	>2 m
Thickly bedded	0.6 to 2 m
Medium bedded	0.2 to 0.6 m
Thinly bedded	60 to 200 mm
Very thinly bedded	20 to 60 mm
Laminated	6 to 20 mm
Thinly laminated	<6 mm

Features, Inclusions and Minor Components are typically only described when those features could influence the engineering behaviour of the rock. Described features may include: gas bubbles in igneous rocks; veins of quartz, calcite or other minerals; pyrite crystals and nodules or bands of ironstone or carbonate; cross bedding in sandstone; clast or matrix support in conglomerates and breccia.

Moisture content may be described by the feel and appearance of the rock, as follows: *"dry"* (looks and feels dry), *"moist"* (feels cool, darkened in colour, but no water is visible on the surface), or *"wet"* (feels cool, darkened in colour, water film or droplets visible on the surface). The moisture content of rock cored with water may not represent in situ conditions.

Durability of rock samples is noted where there is an observed tendency of samples to crack, breakdown in water or otherwise deteriorate with exposure.

Ref: DS6.5.2.1 Issue 2.0 Date: 01/08/2019

b) Classification of the rock material condition (strength, weathering and/or alteration)

Estimated Strength refers to the rock material and not the rock mass. The strength is defined in terms of uniaxial compressive strength (UCS), though is typically estimated by either tactile assessment or Point Load Strength Index ($Is_{(50)}$) (measured perpendicular to planar anisotropy). A correlation between $Is_{(50)}$ and UCS is adopted for classification, though is not intended for design purposes without appropriate supporting assessment. A field guide follows:

Term and (Symbol)		UCS (MPa)	$Is_{(50)}$ (MPa)	Field Guide
Very Low	*(VL)*	0.6 – 2	0.03 - 0.1	Material crumbles under firm blows with sharp end of geological pick; can be peeled with knife; too hard to cut a triaxial sample by hand. Pieces up to 30 mm thick can be broken by finger pressure.
Low	*(L)*	2 - 6	0.1 - 0.3	Easily scored with knife; indentations 1 to 3 mm show in the specimen with firm blows of a geological pick point; has dull sound under hammer. A piece of core 150 mm long by 50 mm diameter may be broken by hand. Sharp edges of core may be friable and break during handling.
Medium	*(M)*	6 - 20	0.3 - 1.0	Readily scored with a knife; a piece of core 150 mm long by 50 mm diameter can be broken by hand with difficulty.
High	*(H)*	20 - 60	1 - 3	A piece of core 150 mm long by 50 mm diameter cannot be broken by hand but can be broken by a geological pick with a single firm blow; rock rings under hammer.
Very High	*(VH)*	60 - 200	3 -10	Hand specimen breaks with geological pick after more than one blow; rock rings under hammer.
Extremely High	*(EH)*	>200	>10	Specimen requires many blows with geological pick to break through intact material; rock rings under hammer.

Based on Table 19, Clause 6.2.4.1, AS 1726-2017, Geotechnical site investigations. Refer to source document for further detail.

Material with strength less than *"very low"* is described using soil characteristics, with the presence of an original rock texture or fabric noted if relevant.

Weathering and Alteration: The process of weathering involves physical and chemical changes to the rock resulting from exposure near the earth's surface. A subjective scale for weathering is applied as follows:

Weathering Term and (Symbol)		Description
Residual Soil	*(RS)*	Material has weathered to such an extent that it has soil properties. Mass structure and material texture and fabric of original rock are no longer visible, but the soil has not been significantly transported.
Extremely Weathered	*(XW)*	Material has weathered to such an extent that it has soil properties. Mass structure, material texture and fabric of original rock are still visible.
Highly Weathered	*(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	*(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 partially discoloured with staining or bleaching along joints but shows little or no change of strength from fresh rock.
Fresh	*(Fr)*	Rock shows no sign of decomposition of individual minerals or colour changes.

Modified based on Table 20, Clause 6.2.4.2, AS 1726-2017, Geotechnical site investigations. Refer to source document for further detail.

Where physical and chemical changes to the rock are caused by hot gases or liquids at depth, the process is called alteration. Unlike weathering, the distribution of altered material may occur at any depth and show no relationship to topography. Where alteration minerals are identified the terms *"extremely altered" (XA)*, *"highly altered" (HA)*, *"moderately altered" (MA)* and *"slightly altered" (SA)* can be used to describe the physical and chemical changes described above.

Ref: DS6.5.2.1 Issue 2.0 Date: 01/08/2019

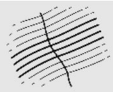
c) Description of defects (defect type, orientation, roughness and shape, coatings and composition of seams, spacing, length, openness and thickness, block shape)

Defects often control the overall engineering behaviour of a rock mass. AS 1726 defines a defect as “a discontinuity, fracture, break or void in the material or materials across which there is little or no tensile strength”. Describing the type, character and distribution of natural defects is an essential part of the description of many rock masses.

Commonly described characteristics of defects within a rock mass include type, orientation, roughness and shape, coatings and composition of seams, aperture, persistence, spacing and block shape.

The degree of detail required for defect descriptions depends on project requirements. All defects judged of engineering significance for the site and project are described individually. Where appropriate, generalised descriptions for less significant, or multiple similar, defects can be provided for delineated parts of rock core or exposures. A general description of delineated defect sets is provided when sufficient orientation data is available.

Defect Type is described using the terms summarised below. On core logs, only natural defects across which the core is discontinuous are described (i.e. inferred artificial fractures such as drill breaks are excluded). Incipient defects are described using the relevant texture or fabric terms. Healed defects (those that have been re-cemented by minerals such as chlorite or calcite) are described using the prefix “healed” (e.g. healed joint).

Type and (Symbol)		Description	Diagram
Parting	(Pt)	A surface or crack across which the rock has little or no tensile strength. Parallel or sub-parallel to layering (e.g. bedding) or a planar anisotropy in the rock material (e.g. cleavage). May be open or closed.	
Joint	(Jt)	A surface or crack with no apparent shear displacement and across which the rock has little or no tensile strength, but which is not parallel or subparallel to layering or to planar anisotropy in the rock material. May be open or closed.	
Sheared Surface	(SS)	A near planar, curved or undulating surface which is usually smooth, polished or slickensided and which shows evidence of shear displacement.	
Sheared Zone	(SZ)	Zone of rock material with roughly parallel near planar, curved or undulating boundaries cut by closely spaced joints, sheared surfaces or other defects. Some of the defects are usually curved and intersect to divide the mass into lenticular or wedge-shaped blocks.	
Sheared Seam	(SSm)	Seam of soil material with roughly parallel almost planar boundaries, composed of soil materials with roughly parallel near planar, curved or undulating boundaries cut by closely spaced joints, sheared surfaces or other defects. Some of the defects are usually curved and intersect to divide the mass into lenticular or wedge-shaped blocks.	
Crushed Seam	(CSm)	Seam of soil material with roughly parallel almost planar boundaries, composed of disoriented, usually angular fragments of the host rock material which may be more weathered than the host rock. The seam has soil properties.	
Infilled Seam	(ISm)	Seam of soil material usually with distinct roughly parallel boundaries formed by the migration of soil into an open cavity or joint, infilled seams less than 1 mm thick may be described as a veneer or coating on a joint surface.	
Extremely Weathered Seam	(WSm)	Seam of soil material, often with gradational boundaries. Formed by weathering of the rock material in place.	

Modified based on Table 22, Clause 6.2.5.2, AS 1726-2017, Geotechnical site investigations. Refer to source document for further detail.

Defect Orientation is recorded as the “dip” (maximum angle of the mean plane, measured from horizontal) and the “dip direction” (azimuth of the dip, measured clockwise from true north). Dip and dip direction is expressed in degrees, with two-digit and three-digit numbers respectively, separated by a slash (e.g. 45/090). For vertical boreholes, the defect dip is measured as the acute angle from horizontal. Rock core extracted from vertical boreholes is generally not oriented, so the dip direction cannot be directly measured. For non-oriented inclined boreholes, a defect “alpha” (α) angle is measured as the acute angle from the core axis. For vertical and non-oriented inclined boreholes, the dip direction can sometimes be estimated from the relationship of the defect to a well-defined site structure such as fabric. For oriented inclined boreholes, the measurement of the defect orientation is carried out and recorded in a form suited to the particular device being used and later processed to report true dip and dip direction.

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Roughness and Shape of the defect surface combine to have significant influence on shear strength. Standard descriptions and abbreviations include:

Roughness and (Symbol)		Description
Very Rough	(VR)	Many large surface irregularities (amplitude generally more than 1 mm). Feels like, or coarser than very coarse sand paper.
Rough	(Rf)	Many small surface irregularities (amplitude generally less than 1 mm). Feels like fine to coarse sand paper.
Smooth	(So)	Smooth to touch. Few or no surface irregularities.
Polished	(Pol)	Shiny smooth surface.
Slickensided	(Slk)	Grooved or striated surface, usually polished.

Shape and (Symbol)		Description
Planar	(Pln	The defect does not vary in orientation.
Curved	(Cu)	The defect has a gradual change in orientation.
Undulating	(Un)	The defect has a wavy surface.
Stepped	(St)	The defect has one or more well defined steps.
Irregular	(Ir)	The defect has many sharp changes of orientation.

Although the surface roughness of defects can be described at small (10-100 mm) scales of observation, the overall shape of the defect surface can usually be observed only at medium (0.1-1 m) and large (>1 m) scale.

Where it is necessary to assess the shear strength of a defect, observations are generally made at multiple scales. Surface roughness may also be characterised by using the joint roughness coefficient (JRC) profiles established by Barton and Choubey (1977). Where large-scale observations are possible, further measurement of defect "waviness" (angle of the asperities relative to the overall dip angle of the plane) is made.

Coatings and Composition of Seams: Many defects have surface coatings, which can affect their shear strength. Standard descriptions include:

Coating and (Symbol)		Description
Clean	(Cn)	No visible coating.
Stained	(Sn)	No visible coating but surfaces are discoloured.
Veneer	(Ve)	A visible coating of soil or mineral substance, but too thin to be measured may be patchy.
Coating	(Co)	A visible coating up to 1 mm thick. Soil material greater than 1 mm thick is described using defect terms (e.g. infilled seam). Rock material greater than 1 mm thick is described as a vein (Vn).

The composition of seams are described using soil description terms as given on the SOIL DESCRIPTION AND CLASSIFICATION Standard Sheet. Where possible the mineralogy of coatings is identified. Common mineral coatings include:

Common Minerals and (Symbol)	
Clay	(CLAY)
Calcite	(Ca)
Carbonaceous	(X)
Chlorite	(Kt)
Iron Oxide	(Fe)
Micaceous	(Mi)
Manganese	(Mn)
Pyrite	(Py)
Quartz	(Qz)

Aperture: Defects across which there is little or no tensile strength can be either *"open"* (*Op*) or *"closed"* (*Cl*). For rock core, the width of the "open" defect is measured whilst still in the core barrel splits. The descriptor *"tight"* (*Ti*) can only apply to healed or incipient defects (i.e. veins, foliation, etc.).

Persistence and Spacing of defects is described directly in millimetres and metres. If the measurement of defect persistence is limited by the extent of the exposure, the end conditions are noted (i.e. 0, 1 or 2 defect ends observed). The spacing between defects of similar orientation (i.e. within a specific defect set) is recorded when possible.

The frequency of defects within rock core can be measured as either: the spacing between successive defects; or the "Fracture Index", which is the number of defects per metre of core.

Spacing Term	Thickness
Very wide	>2 m
Wide	0.6 to 2 m
Medium	0.2 to 0.6 m
Closely	60 to 200 mm
Very closely	20 to 60 mm
Extremely closely	6 to 20 mm

Block Shape: Where it is considered significant, block shape can be described using the subjective terms as follows:

Block Shape	Description
Polyhedral	Irregular discontinuities without arrangement into distinct sets, and of small persistence.
Tabular	One dominant set of parallel discontinuities, for example bedding planes, with other non-continuous joints; thickness of blocks much less than length or width.
Prismatic	Two dominant sets of discontinuities, approximately orthogonal and parallel, with a third irregular set; thickness of blocks much less than length or width.
Equidimensional	Three dominant sets of discontinuities, approximately orthogonal, with occasional irregular joints, giving equidimensional blocks.
Rhomboidal	Three (or more) dominant, mutually oblique, sets of joints giving oblique-shaped, equidimensional blocks.
Columnar	Several, usually more than three sets of continuous, parallel joints usually crossed by irregular joints; lengths much greater than other dimensions.

Modified based on Table 23, Clause 6.2.5.7, AS 1726-2017, Geotechnical site investigations. Refer to source document for further detail.

Ref: DS6.5.2.1 Issue 2.0 Date: 01/08/2019

d) Interpreted stratigraphic unit

Stratigraphic units may be interpreted and reported, in accordance with The Australian Stratigraphic Units Database (ASUD). The terms *"possibly"* or *"probably"* indicate increased uncertainty in this interpretation.

e) Geological structure

After describing the rock material and defects, an interpretation of the nature and configuration of rock mass defects may be presented in logs, charts, 2D sections and 3D models (e.g. dipping strata, folds, unconformities, weathering profiles, defect sets, geological faults, etc.).

PARAMETERS RELATED TO CORE DRILLING

Drill Depth and Core Loss: Drilling intervals are shown on GHD Core Log Sheets by depth increments and horizontal marker lines.

"Core loss", or its inverse "total core recovery" (TCR), is measured as a percentage of the core run. If the location of the core loss is known, or strongly suspected, it is shown in a region of the column bounded by dashed horizontal lines. If unknown, core loss is assigned to the bottom of a core run.

Rock Quality Designation (RQD), described by Deere et al. (1989), may be recorded on GHD Core Log Sheets.

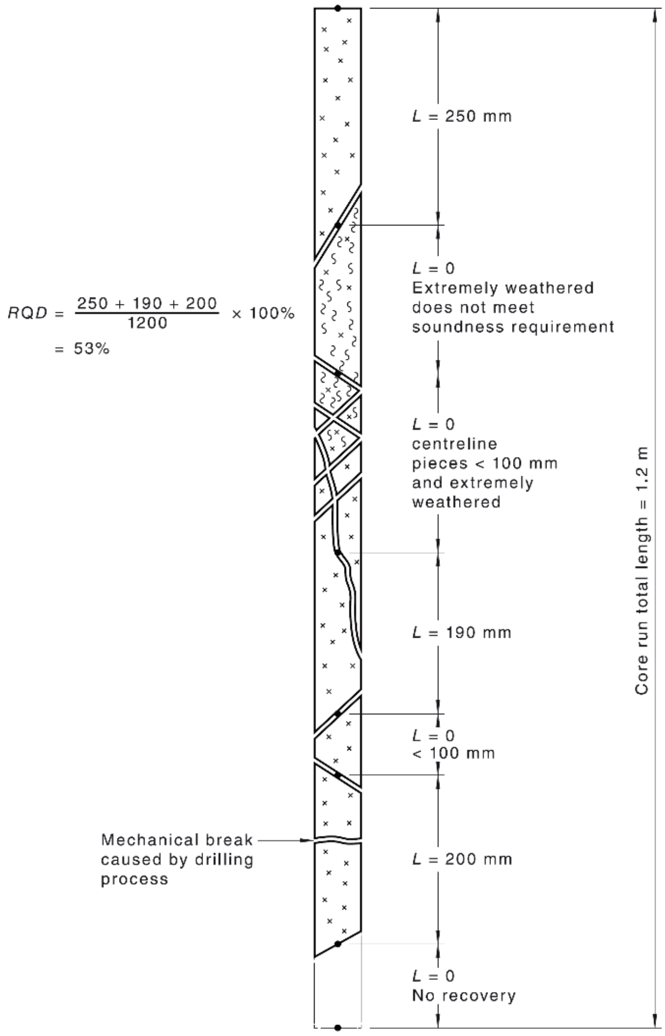
For certain projects, such as tunnelling or underground mining investigations, rock mass ratings or classifications can be required as part of the design process. The RQD forms a component of these rock mass ratings and provides a quantitative estimate of rock mass quality from rock core logs.

The rock core must be "N" sized (nominally 50 mm) or greater for derivation of RQD. The RQD is expressed as a percentage of intact rock core (excluding residual soil and extremely weathered rock) greater than 100 mm in length over the total selected core length.

Deere et al. (1989) recommends measuring lengths of core along the centreline, as shown right.

RQD is expressed as:

$$RQD = \frac{\sum Length\ of\ sound\ core\ pieces > 100\ mm\ in\ length}{Length\ of\ core\ run}\ x\ 100\%$$



RQD measurement procedure
(reproduced from Figure 13, Clause 6.2.9.4, AS 1726-2017, Geotechnical site investigations)

ROCK MASS CLASSIFICATION

Rock mass classification schemes may be used to represent the engineering characteristics of a rock mass. A large variety of classification schemes have been developed by various authors, ranging from simple to complex. All of the schemes are limited in their application and many rock mass classification systems assume that the rock mass is isotropic, which is rarely the case.

References

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