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Report on Geotechnical Investigation

Proposed Culvert Modification
Condamine Street
Brookvale

Prepared for
Westfield Design and Construction Pty Ltd

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1. Introduction

This report presents the results of a geotechnical investigation undertaken by Douglas Partners Pty Ltd (DP) for a proposed modification of the culvert below Condamine Street, Brookvale. The investigation was commissioned by Westfield Design and Construction Pty Ltd (Westfield), in accordance with Westfield Consultant Services Contract D11753 dated 8 April 2013. The work was undertaken in consultation with the structural engineers for the project, Cardno (NSW) Pty Ltd (Cardno).

The proposed culvert modification forms part of a broader scope of works that will augment the existing stormwater system below the Warringah Mall site. This system also serves Brookvale Creek, which is culverted under the Warringah Mall site.

It is understood that the proposed modification of the culvert under Condamine Street is intended to provide additional hydraulic capacity to the stormwater and Brookvale Creek drainage system. The modification includes lowering the invert of the central two (of four) culvert cells below Condamine Street by 1.0 m, and associated local lowering of the downstream apron floor.

The geotechnical investigation within the culvert included dynamic cone penetrometer tests (DCPs) and hand augered boreholes, to provide information on subsurface conditions below the culvert. The results of the investigation are given in this report, together with comments relating to site stability, and design and construction practice.

2. Background

Geotechnical and environmental investigations within the Warringah Mall site have been separately reported in DP Report No. 71015.17 dated July 2013 and the No. 71015.18 report series, dated December 2013.

An Acid Sulphate Soil Management Plan has also been previously prepared for the works (Report No. 71015.20 dated December 2013).

Documents provided to DP for information include:

- *Proposed Enlargement of Existing Culverts under Condamine Street* Drawing ST2-STR-SK21, issue 1, showing construction staging for the lowering of the culvert floor.
- *Stormwater Management Plan and Stormwater Report* by Cardno (Job W4548, dated January 2014)
- *Structural Report for Section 96 Application* by Cardno (Job 89914004, dated January 2014)

- Drawings from the Department of Main Roads, NSW (now Roads and Maritime Service, RMS) of the culvert and downstream erosion control (Drawings 164 479 BC 0151, Sheets 1 to 7, January 1972)
- Survey drawings of ground surface levels by RPS Australia East Pty Ltd (Job PR116997, Sheets 1 to 5, dated 1/7/13)

3. Site Description

The existing stormwater culvert is located approximately 100 m south of the intersection of Condamine Street and Pittwater Road. It extends from the existing culvert system at Warringah Mall at its (upstream) north-western end to the Warringah Golf Club site at the (downstream) south-eastern end, onto a concrete apron and the open channel of Brookvale Creek.

The culvert is a reinforced concrete box culvert with an approximate length of 10 m, and total width of approximately 12 m. It is divided into four separate cells, each with an internal height of 1.8 m and width of 2.8 m. The RMS drawings indicate that the culvert is divided into four sections along its length, with two central sections under Condamine Street approximately 13 m long, and two shorter sections at each end, approximately 3 m long. No foundation details are shown for the culvert, suggesting that it is founded at shallow depth. From the more recent Cardno drawings, invert levels fall from approximately RL 6.0 m at the upstream end to RL 5.5 m at the downstream concrete apron. Figure 1 shows a view of the culvert from the apron at the time of the investigation.

Figure 1: Culvert as viewed from the downstream apron.

The investigation was undertaken following several weeks of no or only minor rain, with flows through only the northernmost culvert cell during the fieldwork. Water flow through the two northernmost cells was visible during earlier inspections. Beyond the culvert apron, water levels within Brookvale Creek were approximately 0.5 m to 1.0 m below the apron level (i.e. RL 4.4 m to RL 4.9 m).

The overlying, six lane Condamine Street has ground levels between RL 9.1 m to RL 9.7 m. It is understood that the road is of rigid (concrete) pavement construction.

At the Warringah Mall site, the culvert commences at an existing, concrete stormwater chamber identified as "Junction Pit C6". The chamber is currently buried below grassed landscaping and asphaltic concrete surfaced car parking areas. Ground levels in this area are gently sloping.

At its south-eastern end, the culvert emerges at the concrete apron at the Warringah Golf Course site. The apron is approximately 4 m to 8 m long and approximately 12 m wide. Apron surface levels are approximately RL 5.5 m to RL 5.4 m. The RMS drawings appear to suggest that the concrete apron is underlain by some kind of working platform. Through the Warringah Golf Course flows continue within Brookvale Creek, which is an unlined stream.

Ground levels slope down from the surrounding Warringah Golf Course (approximately RL 9 m) to the concrete apron (approximately RL 5.5 m) and to Brookvale Creek. It is understood that these slopes result in the Council classification of this part of the site as "Landslip Risk Class B". For the purpose of this report, the slopes adjacent to the apron are identified as the "northern slope" and "southern slope" as shown in Drawing No. 1 in Appendix B. Both slopes have a total height of approximately 3.5 m.

The northern slope is supported by a 600 mm high gabion retaining system wall to a distance of approximately 9.0 m from the culvert opening. Behind the gabion retaining wall, the ground slopes up at approximately 20° to at least 3 m from the apron. Slopes then locally steepen up to approximately 40° towards the access path over the culvert, or become more gently sloping towards the vehicle access road for the Brookvale Creek gross pollutant trap. The sloping ground in this area is vegetated with mature trees and some low shrubs. Topsoil is present at ground surface.

A photograph of the northern slope is provided in Figure 2, below.

Figure 2: Northern slope to apron

The southern slope is also supported by a 600 mm high gabion wall. The gabion retaining system is overlain by large, well-placed sandstone blocks stepping back to a height of approximately 2 m above apron level at approximately 30°. The slope then continues at approximately 20°, vegetated by grasses, low shrubs and small trees. A photograph of the southern slope is provided in Figure 3, below.

Figure 3: Southern slope to apron

There were no signs of existing slope instability at the northern and southern slope, with the exception of some minor creep of topsoil.

Based on the RMS drawings provided, it is understood that the gabion walls are founded 1 m below the concrete apron surface level.

4. Geology

Reference to the Sydney 1:100 000 Geological Series Sheet indicates that the site is mainly underlain by stream alluvium and estuarine deposits comprising silty to peaty quartz sands, silt and clay with ferruginous and humic cementation in places and common sea shells.

The regional geological mapping at the Warringah Mall site is shown in Figure 4, below, which indicates mapping of stream alluvial and estuarine deposits in yellow, and Hawkesbury Sandstone in green.

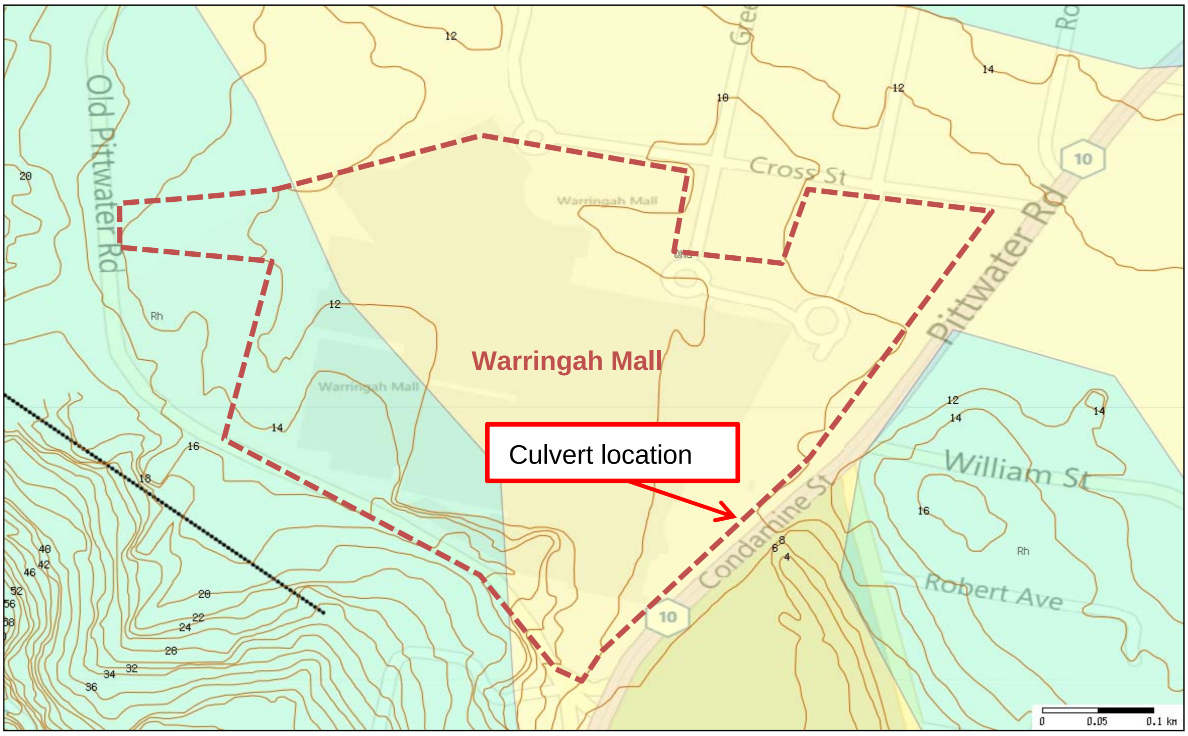


Figure 4: Extract of regional geology mapping and regional 2 m topographic contours at Warringah Mall

The mapping is consistent with previous geotechnical investigation at the Warringah Mall site, which has identified alluvial and estuarine sediments underlain by Hawkesbury Sandstone.

5. Field Work Method

Field work for the geotechnical investigation was undertaken on 4 February 2014. All personnel entering the culvert, and an external spotter had an accredited Sydney Water Confined Spaces Certificate. Confined space equipment comprising gas detectors and two-way radios were used.

The field work for the investigation included four shallow boreholes (BH 1 to BH 4) and four dynamic cone penetrometer tests (DCP 1 to DCP 4), undertaken at borehole locations. Test locations are shown in Drawing No. 1 in Appendix B. The location of tests was based on achieving a reasonable spread of test locations along the culvert, but with locations limited by minimum offsets required from a Southern Cross fibre optic underbore. This service is understood to underlie the culvert near the eastern kerb of Condamine Street. The locations of the tests were set-out by tape measurement from the culvert entrance. Approximate eastings and northings were then estimated from geo-referenced CAD drawings.

At each test location, the following process was followed:

- Concrete coring was undertaken through the concrete floor slabs, to depths of 0.3 m to 0.35 m.
- Dynamic cone penetrometer (DCP) tests were performed to refusal in the underlying soil to depths of 1.2 m to 5.4 m. DCP tests involve driving a steel rod into the ground using a 9kg hammer dropping 510 mm, with the number of blows required to penetrate successive 150 mm depth increments recorded. These blow counts can be correlated to the density or consistency of the soils.
- The boreholes were then advanced by hand auger to a depth of approximately 1.1 m, except at BH 4 where the borehole was continued to 2.5 m. Regular disturbed soil samples were collected from the auger blade for visual and tactile assessment.

At the completion of testing the boreholes were backfilled with drilling spoil and the concrete slab reinstated with quick-set concrete.

Ground surface levels at test locations were interpolated from the Cardno design drawings (Drawings CAR-060140 and CAR-060141).

6. Field Work Results

The detailed results of the field work, including borehole logs and DCP results are included in Appendix C of this report.

The subsurface conditions based on test results may be generally summarised as follows:

- **CONCRETE:** to depths of between 0.3 m and 0.35 m, including 10 mm diameter steel reinforcement; underlain by
- **SANDY CLAY:** soft, dark brown, possible filling, to depths of 0.2 m to 0.5 m, where present; underlain by,
- **ORGANIC CLAYEY SILT:** very soft and soft to 0.6 m to 0.8 m, then firm to approximately 1.8 m, then stiff to the limit of augering (2.5 m), includes rootlets and roots.

The deeper results obtained by DCP 1 suggest that very stiff clay or medium dense and possibly dense sand may be present below 3.6 m. It is noted, however, that the boreholes did not extend to this depth, and that significant side friction may develop on the rods as the DCP extends to greater depth, potentially causing artificially elevated test results.

The results at BH 3 suggest that DCP 3 encountered sudden refusal at 1.05 m depth due to tree roots below the culvert. It is considered likely that this is also the cause of the sudden refusal at DCP 2 and DCP 4.

Groundwater was observed from 0.5 m (RL 5.4 m) during augering of BH1, only. Groundwater observations may be influenced by the use of water during concrete coring or limited by slow infiltration through fine grained soils.

7. Comments

7.1 Proposed Development

It is understood that the proposed culvert modification below Condamine Street will involve the lowering of the invert level of the two central cells of the culvert by 1.0 m, and lowering of the apron in front of the subject cells by 1.0 m.

It is understood that a preliminary work method has been developed by Cardno for the lowering of the central cells of the culvert, in consultation with Westfield and RMS, as shown in Drawing ST2-STR-SK21, Issue 1, by Cardno. The drawing indicates that excavation is to proceed in 2 m to 3 m long sections, subject to ground conditions, in a stepwise process that includes:

- Temporary propping of the roof and possibly floor slab, as required; followed by,
- Removal of one cell floor, excavation to 1.3 m below existing floor level with batters in the underlying soil (i.e. partly undermining the remaining culvert slab); followed by
- Construction of one wall and half of the new culvert floor, using cast-in-situ concrete against the battered soil face; followed by,
- Installation or movement of additional props as required, removal of the second cell slab, excavation with batters as above; followed by,
- Construction of the new, central slab and column; followed by,
- Widening of the excavation to allow construction of the second wall of the lowered floor, by cast-in-situ concrete against the soil batter face.

The drawing indicating the above process has been reproduced in Appendix D, for reference.

It is understood from Cardno's *Structural Report for Section 96 - Application*, that full height diversion walls will be constructed both upstream and downstream in advance of the culvert and apron lowering to prevent water flows into the area during the works. These walls will be demolished after the completion of lowering operations.

7.2 Geotechnical Model

Based on the results of the current investigation and considering the results of previous investigation within the (upstream) Warringah Mall site, the geotechnical model developed for the Condamine Street Culvert is summarised in Table 1.

Table 1: Geotechnical Model

Unit	Material	Approximate Top of Unit (RL m)	Comment
1	Filling	9.1 to 9.7	From ground surface, above and adjacent to the existing culvert. Of unknown, but likely variable composition and consistency.
2	Sandy clay	5.2 to 5.7	Soft, possible filling, from the base of the culvert
3a	Organic Clayey Silt (soft)	5.4	Includes rootlets and roots. Apparently consistent below the culvert based on the results of recent investigation (refer note, below)
3b	Organic Clayey Silt (firm)	5.1 to 5.4	
3c	Organic Clayey Silt (stiff)	3.7 to 4.2	
4	Alluvial/Estuarine Soils (Sand, Clay & Silt)	2.5	Variable alluvial soils, largely below the depth of the current investigation. Based on investigation north-west of the culvert, these soils are likely to include very loose to medium dense sand layers interbedded with loose to dense clayey sand, dense sand and firm clayey silt, but may also contain weak clay layers.
5	Hawkesbury Sandstone	unknown	Likely present at significant depth, and in an area in which the depth to sandstone changes rapidly, based on the results of testing at Warringah Mall.

The current investigation suggests that relatively consistent ground conditions are present below the culvert, alluvial soils are often highly variable, and conditions may vary from those at the test locations. In particular, different ground conditions may be present towards and beyond the south-eastern end of the culvert, further from the available investigation information and where different construction methods may have been used during installation of the apron, gabion walls and erosion protection.

Groundwater readings taken during fieldwork in the vicinity of the culvert have indicated groundwater levels of approximately RL 5.5 m to RL 6.0 m (10 m to 20 m upstream of the culvert) and RL 5.4 m (at BH 1). Groundwater levels taken during fieldwork, however, may be affected by the rate of infiltration into the borehole and would be expected to fluctuate over time. Nonetheless, these results suggest that groundwater levels are currently at approximately RL 5.5 m below the culvert and within the depth of proposed excavation.

7.3 Excavation

Excavation to at least 1.3 m below the existing slab level is required to lower the invert by 1.0 m, allowing for a 0.3 m concrete base slab and no working platform. Based on the results of the investigation, the excavation will be through very soft, soft and firm sandy clay and organic clayey silt, at least partly below the groundwater table.

While the clay and clayey silt are expected to have a relatively low permeability, the presence of soft and very soft clay, and possible presence of lenses of sand or silt soils may result in significant groundwater ingress into the excavation and instability of the excavation floor and sidewalls. Within the soft and very soft clay and silt, very low safe batter slope are likely to apply - no steeper than 1V:3H - even once dewatering has been undertaken. Although the clay content may allow the walls to be temporarily excavated to a steeper angle, the resulting slope would be eventually unstable. If dewatering is not undertaken (or if dewatering failure occurs during the works), a significantly flatter slope is likely to develop, but with potential for significant further flattening if erosion and/or piping occurs. Should piping occur, the soil may simply flow. If permitted to develop, these yielding batter slopes could largely undermine the existing culvert, and may extend beyond the edges of the culvert.

The following measures are therefore considered appropriate during excavation:

- Underpinning of the existing culvert to below the depth of excavation, to improve bearing conditions, and to limit instability of the excavation sideslopes;
- Dewatering around the excavation, to intercept water flows through sand and silt lenses that may otherwise result in significant inflows and possible slope or floor instability; and
- Careful excavation in hit and miss panels (as per the preliminary Cardno methodology) to limit the extent of exposed ground.

Firm and wet organic clayey silt is expected at the base of the excavation. This material is expected to be readily susceptible to disturbance, and to be impractical to compact. The material is also likely to weaken readily with exposure to surface water, and may be highly erodible. In practice therefore, a working platform may be required at the base of the excavation, to reduce disturbance of the organic clayey silt and to provide a consistent bearing surface for the new culvert slab. A nominal working platform may be sufficient if only personnel are expected within the excavation (e.g. a 100 mm thick gravel layer). A geofabric separator would be required at the base of the excavation and transverse cut-offs (e.g. impermeable membranes) would be appropriate to reduce the risk of groundwater flow along the working platform into subsequent excavations. Compaction of the working platform is unlikely to be practical given the small work area, underlying organic clayey silt, and high groundwater table. A more substantial working platform such as lean mix concrete may be appropriate, especially if any equipment is to bear upon the subgrade.

Even after dewatering, the excavated material is expected to be weak, with a high interstitial water content and very high slump. In addition, interstitial water may be freed during handling of the material. Handling and transport of the material will need to consider these material properties. Reference should also be made to Section 7.7 (Acid Sulphate Soils) in this regard.

7.3.1 Underpinning

Underpinning will be required in advance of excavation for the following purposes:

- To obtain an adequate foundation bearing stratum for the culvert
- To limit the potential for progressive failure of the excavated sideslopes to extend beyond the culvert.

This underpinning is additional to and separate from the proposed modified culvert construction. For the purpose of this report, 'underpinning' refers only to the temporary underpinning necessary to facilitate construction of the lowered culvert, whereas the lowered culvert construction is referred to as 'underpinning' in the Cardno construction staging drawing.

Options for underpinning include:

- **Jet Grouting** – involving the use of high pressures to inject a fluid grout into the soil and mix it into the subject layer, forming a composite cement-soil structure. The presence of the existing culvert slab and depth of the culvert could permit relatively high pressures to be used. The presence of organic soils may, however, influence curing time and grout strength, and careful consideration should be given to possible uplift of the culvert floor.
- **Compaction Grouting** – using low slump concrete injected at intervals below the culvert to underpin down to a stronger stratum.
- **Mini-piles** – involving the construction of small-diameter piles through the culvert slab and into the underlying soil, and connections between the piles and culvert. The practical excavation of mini-piles is likely to be limited by the available headroom, and potential for excavations to be unstable if uncased due to the weak soils and high groundwater table.
- **Ground freezing** – using liquid nitrogen injected into the grout at closely spaced intervals to (temporarily) freeze water within the soil. This method is relatively infrequently used in Australia.

On site trials would be appropriate to assess the performance of the preferred underpinning method in the subject ground conditions.

Various options also exist in relation to the extent of underpinning proposed, with the use of more significant underpinning potentially significantly reducing excavation-stage risk. The following primary options are available:

- **Extensive underpinning of the culvert** by jet grouting, including continuous grouting below the outer cells to significant depth, plus continuous jet grouting at and below the floor of the proposed excavation below the inner cells. This could provide a barrier to groundwater inflow and significantly reduce (or possibly eliminate) dewatering requirements, improve conditions for working and founding the new structure and significantly reduce risks associated with changes in ground conditions. Consideration could also be given to grouting the volume to be excavated, with removal of the resulting low strength grout by jack hammers or similar. This underpinning would also effectively underpin the whole culvert, and potentially reduce the temporary loading on the structure.
- **Underpinning with continuous walls** below the outer cells, formed jet grouting or ground freezing. Continuous walls may reduce dewatering requirements and effectively contain side slope failures of the excavation, if designed for that purpose.

- **Discontinuous underpinning** by compaction grouting, mini-piles or by selective jet grouting or ground freezing. This could provide suitable improvement of bearing capacity, however it would have more limited benefit in controlling groundwater and slope movement, and place significantly greater reliance on the satisfactory performance of the dewatering system during the works

The difference between the extent of the above underpinning in section is illustrated in Figure 5, below.

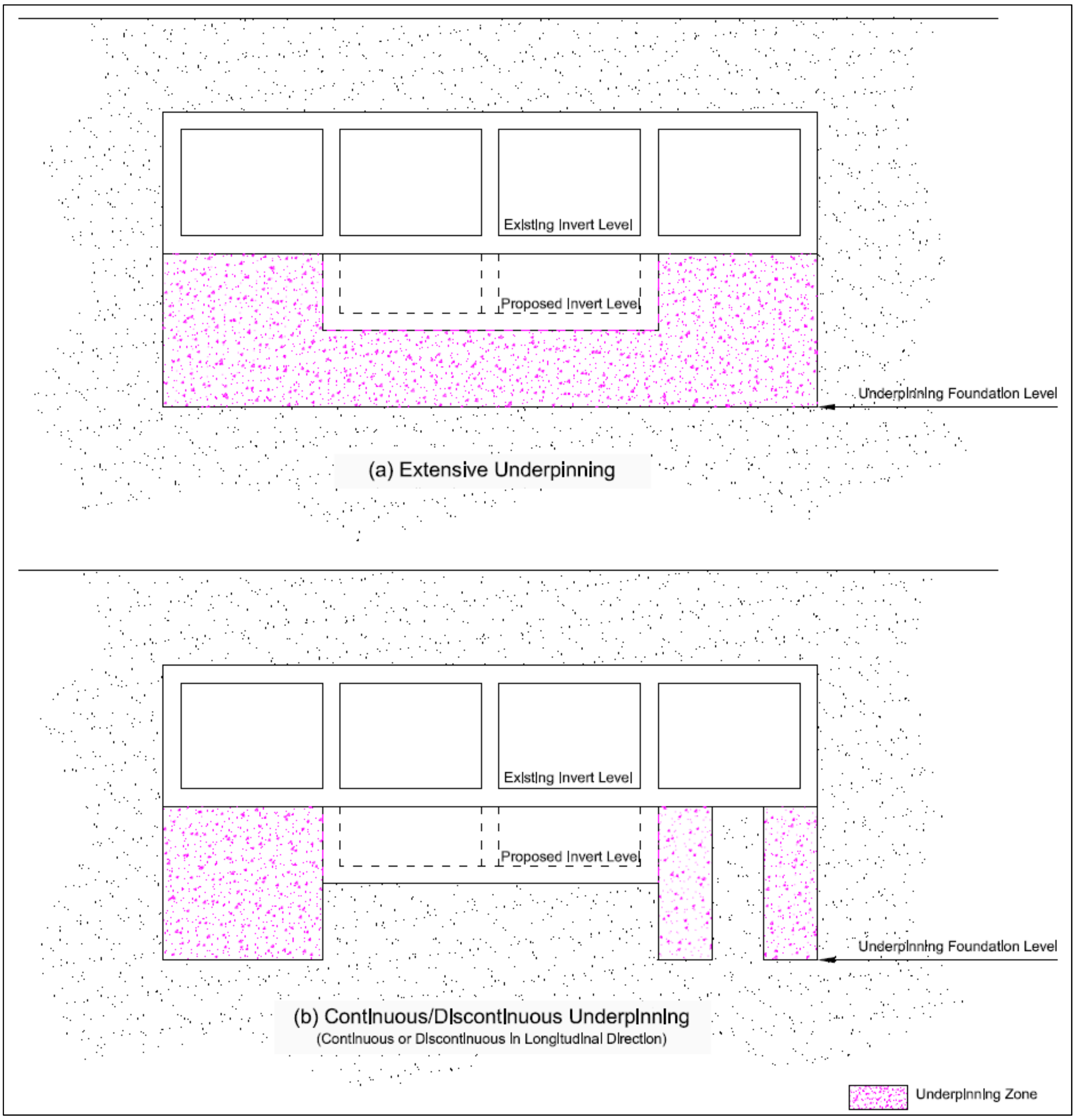


Figure 5: Section illustration of (a) Extensive Underpinning, and (b) Continuous / Discontinuous Underpinning showing bulk underpinning or column underpinning (not to scale)

There are many options for the detailed underpinning geometry, Figure 5(b) illustrates bulk underpinning (at left) and column type underpinning (at right), for example only.

The selection of underpinning should also consider possible interaction with services that may be present below the culvert. It is understood from Optus that a Southern Cross fibre-optic cable may be present below the culvert, towards the south-eastern end of the culvert, however the precise location and depth of the service is not yet known.

7.3.2 Dewatering

Dewatering will be required around the excavation in order to control slope and floor stability, unless extensive underpinning is used to wholly cut-off the excavation from the surrounding groundwater.

The clayey silt soils will be of low permeability and dewatering is likely to be quite difficult. Greater volumes of water may be removed if lenses of sand or silt are present within the soil. Such watercharged layers would be of particular concern for stability. It would generally be appropriate to keep groundwater levels approximately 0.5 m below the excavation.

Where the proposed underpinning will also act as a barrier to lateral water flow (e.g. continuous jet grouting or ground freezing), then dewatering may be limited to the floor of the dewatered excavation. Where underpinning is discontinuous (e.g. mini-piles, compaction grouting, or where gaps are present with jet grouting or ground freezing), then dewatering points are expected to be required beyond the proposed excavation, in order to dewater the sideslopes of the excavation. This more extensive dewatering will present more challenging dewatering conditions.

If extensive underpinning is undertaken, some provision for local dewatering may still be required in case insufficient contact/cut-off is achieved between adjacent jet grout volumes.

With the exception of an extensively underpinned excavation, safety mechanisms will need to be developed in the event of dewatering failure, or of possible surface inundation in a flood event that exceeds the (temporarily reduced) capacity of the culvert. Within the organic clayey silt soils this could result in rapid erosion and/or excavation instability, particularly if sand or silt lenses are present within the soil. Immediate backfilling of the excavation is likely to be the main means of providing stability in such an event. Such measures would be particularly critical if non-continuous underpinning is adopted.

7.4 Retention

The existing culvert will operate as a multi-propped structure. While the nature of the existing backfill around the culvert is unknown, it is likely that the filling will be variable, and potentially relatively poor, particularly towards the base of the culvert, above the existing soft soils.

A rectangular pressure distribution is therefore recommended for estimating the pressure on the sidewalls of the existing culvert and on the proposed culvert with lowered sidewalls. The pressure may be estimated by the following equation:

Pressure (in kPa) = 6H, where H is the total retained height in metres.

As the proposed culvert lowering will effectively increase the retained height, additional lateral pressures will be imposed on the existing structure.

Additional allowance should be made for surcharges and for hydrostatic loading. An estimated 'at rest' earth coefficient, K_0, of 0.6 is considered appropriate for quantifying the influence of surcharges. The use of lower, 'active' earth coefficients is considered inappropriate as the structure is not free to move.

7.5 Foundations

7.5.1 Bearing Capacity

During construction, significant additional loads are expected on the soils underlying the culvert. Vertical loads currently distributed across the base of the culvert will be re-distributed to the outer cells only, while the floors of the inner cells are removed, and the current bearing area (floor) of the outer cells significantly reduced by the batter slopes of the excavation.

Given that the existing culvert is founded on very soft and soft clayey sandy clay and organic clayey silt, excessive displacement would be expected to occur if underpinning is not undertaken. Underpinning of the outer cells will be required to effectively transfer the loads to a stronger, underlying bearing stratum below the base of excavation. The bearing capacity of the underpinning is therefore likely to be critical to design.

The bearing capacity will vary depending on the depth, type, dimensions and spacing of the proposed underpinning. As a preliminary guide, foundations within at least stiff clay or silt soils could be designed based on a maximum allowable bearing pressure of 100 kPa. Significantly higher bearing pressures may be achievable in the deeper sediments, particularly if granular soils are present, e.g. for foundations in medium dense sands 3 m below the base of excavation (subject to confirmation by testing), an allowable bearing pressure in the order of 500 kPa may be achievable.

As the bearing capacity is dependent on the dimensions and construction of any foundation, the bearing capacity should be reviewed during the underpinning design.

7.5.2 Settlement

Settlement of the final, constructed structure is not expected to be a significant issue. The 'lowered' floor is expected to place less load on the underlying soil than is currently present, and would therefore experience only minor settlements under the 'reload' curve.

In practice therefore, settlements are expected to be governed by the temporary case, when higher loads are to be transmitted via underpinning to a deeper soil stratum. The resulting settlements will vary depending on the design of the underpinning, including the underpinning dimensions, depth, spacing and bearing strata and extent of proposed dewatering, and cannot be assessed at this stage.

7.5.3 Uplift

The proposed culvert floor will be below the groundwater table and permanent dewatering is unlikely to be practical due to the presence of acid sulphate soils, the downstream Brookvale Creek and absence of existing drainage provisions. Possible uplift pressures should be assessed for any undrained structure.

The highest uplift pressures are likely to occur after high rainfall or flood events when high water flows have receded but elevated groundwater pressures are still present in the surrounding and underlying soils. No groundwater levels are available corresponding to flood events. Based on the existing groundwater levels and given that ground surface levels are relatively level in this area, it is estimated that the corresponding groundwater levels will be approximately 0.5 m to 1 m above flood water levels.

Any uplift at the culvert may be largely counteracted by the weight of soil above the culvert. A maximum bulk unit weight of 18 kN/m^3 should be adopted for soil above the culvert in assessing uplift, and the presence of any existing excavations (e.g. services trenches) considered.

Below the culvert apron, uplift pressures may be alleviated by the use of an underlying, free-draining working platform (e.g. single-size gravel). Uplift pressures can then be estimated as dropping linearly between the culvert and the end of the apron.

7.6 Slope Stability

7.6.1 Culvert

For excavation below the culvert, the use of relatively short intervals (e.g. 2 m to 3 m, as suggested by the preliminary Cardno drawings) is considered appropriate to limit the risk of slope instability, which will also be influenced by the underpinning method adopted, and by the effectiveness and continuity of dewatering activities. The excavation interval may be reassessed once the detailed work methodology is available, and subject to structural assessment of the culvert for each construction stage. Initial underpinning and dewatering trials should be considered to assess whether the proposed methodology is effective in the site conditions and further reassessment during the works is likely to be appropriate.

As stated above, options for immediate backfilling and protection of the excavation may need to be considered prior to the work for the event of potential external flooding, or failure of the dewatering system, particularly if a non-continuous underpinning option is adopted.

7.6.2 Apron

Excavation for the proposed apron will be temporary, to an approximate depth of 1.5 m at 3 m from the toe of these slopes. No significant impact is expected on slope stability due to the proposed temporary excavation and permanent, locally lowered, apron, provided that an appropriate work method is adopted.

Based on the organic clayey silts encountered below the culvert, it would still be considered appropriate to excavate the soils below the apron in a dewatered state. This is to reduce the risk of very flat slopes under the remaining slab (and resulting backfilling) and the more challenging excavation and construction conditions. The continuation of underpinning below the apron should be considered in order to facilitate and limit dewatering, particularly given its proximity to Brookvale Creek, and to control possible settlement or movement of the apron slab, particularly if surcharges will be present on the slab. The risk of slope instability could be further reduced by continuing with hit and miss panels under the apron.

Geotechnical review of the detailed work methodology at the apron would be appropriate to confirm that no significant impact on slope stability is expected.

7.6.3 Slope Risk Analysis

Slope instability during the works have been assessed for risk to property and life using the general methodology outlined by the Australian Geomechanics Society (Landslide Risk Management AGS Subcommittee 2007 Reference).

Identified hazards within the site are summarised in Table 2, together with qualitative assessment of likelihood, consequence and slope instability risk after completion of construction including appropriate engineering design and construction works.

Table 2: Qualitative Property Slope Instability Risk Assessment for Proposed Development

Hazard		Likelihood	Consequence[1]	Risk
1	Moderate erosion/slumping of slope above apron due to surface water flows	Unlikely – provided slope and upslope drainage is suitably maintained. No signs of past instability,	Insignificant – possible slope rectification and removal of spoil	Very Low
2	Very rapid movement of sandstone blocks above apron, blocks roll down slope onto apron	Unlikely – sandstone blocks well placed and interlocked with no evidence of past movement	Minor – local damage, some reinstatement stabilisation works	Low
3	Deterioration of gabion mesh next to apron, causing rockfill to migrate out of gabion, rapid fall of overlying sandstone blocks	Unlikely – for engineer designed, inspected, constructed and maintained gabion wall	Minor – local damage, some reinstatement stabilisation works	Low
4	Very slow creep of topsoil above apron	Almost certain	Insignificant – garden maintenance	Low
5	Rapid global slope instability at apron	Unlikely[2] – for existing slope. No evidence of past recent gross instability	Medium – Moderate damage and large stabilisation works	Low
5a		Possible to unlikely[2] – for excavation with no underpinning, hit and miss panels	Medium – Moderate damage and large stabilisation works	Low to Moderate
5b		Unlikely[2] – for excavation with underpinning to confine extent of excavation, possible hit and miss panels. Only local excavation proposed.	Medium – Moderate damage and large stabilisation works	Low
5c		Rare[2] – for excavation with extensive underpinning below the apron.	Medium – Moderate damage and large stabilisation works	Low

Hazard		Likelihood	Consequence[1]	Risk
6a	Rapid slope or floor instability during excavation in temporary batter below culvert, extending beyond culvert to road or footpath[4]	Possible – for engineer designed and constructed discontinuous underpinning, with continuous monitoring and inspection. Slope or floor instability possible	Medium –Moderate damage to the road or footpath, possibly requiring significant stabilisation works.	Moderate
6b		Unlikely – for engineer designed and continuous underpinning designed to retain the excavation, with continuous monitoring and inspection. Floor instability possible, or local slope instability if unexpected gaps in underpinning	Minor to Medium– limited damage to part of road and/or culvert, requiring some reinstatement stabilisation works.	Low
6c		Unlikely – for engineer designed and constructed extensive underpinning, with continuous monitoring and inspection. Local instability possible at unexpected gaps in underpinning.	Minor – limited damage to part of road, requiring some reinstatement stabilisation works.	Low

Notes:
1. For assessment of indicative damage as a proportion of property value, only that property within close proximity to the proposed culvert has been considered (i.e. land and structures within approximately 10 m to 20 m of the culvert). This is to avoid inappropriate assessment of consequences, given that the culvert works are local works within the significantly larger Condamine Street and Warringah Golf Course sites.
2. No investigation or analysis has been undertaken of ground conditions at the downstream slopes. Assessment of likelihood is therefore based on the observed condition, engineered construction of the apron and stabilisation measures and the general geometry of the existing slopes.
3. Reflects assessment of existing global slope conditions
4. Temporary risk during construction only

It should be noted that Hazards 1 to 5 (but excluding 5a to 5c) as given in Table 2 are unchanged by the proposed works, and reflect both the existing and future risk. The qualitative risk to property assessment indicates that risks are generally low or very low, but increasing to moderate for the specific cases of:

- Hazard 5a – Global slope instability at apron with no underpinning, using hit and miss panels;
- Hazard 6a – Rapid slope instability below the culvert in the temporary excavation case, with discontinuous underpinning of the culvert.

The AGS Practice note guidelines indicate that a low risk level is usually acceptable to regulators. Medium risk may be tolerated in certain circumstances, but is likely to require additional investigation, planning and implementation of treatment options to reduce the risk to low. For Hazard 5a, this is likely to require further investigation and assessment of the slope (or selecting construction methods reflected by Hazard 5b or 5c). For Hazard 6a, this would either require acceptance of a higher-than-usually accepted risk by the regulators, or adoption of the lower risk construction methods reflected by Hazard 6b and 6c.

For loss of life, the individual risk can be calculated from:

$$R_{(LoL)} = P_{(H)} \times P_{(S:H)} \times P_{(T:S)} \times V_{(D:T)}$$

where:

$R_{(LoL)}$	is the risk (annual probability of loss of life (death) of an individual)
$P_{(H)}$	is the annual probability of the hazardous event (erosion/ wall failure)
$P_{(S:H)}$	is the probability of spatial impact by the hazard (e.g. of the failure reaching the individual, taking into account the distance for a given event)
$P_{(T:S)}$	is the temporal probability (e.g. of the adjacent area being occupied by the individual) given the spatial impact
$V_{(D:T)}$	is the vulnerability of the individual (probability of loss of life of the individual given the impact).

The assessed individual risk to life (person most at risk) resulting from slope instability is summarised in Table 3.

Table 3: Quantitative Life Risk Assessment for Proposed Development

	Hazard[1]	$P_{(H)}$	$P_{(S:H)}$	$P_{(T:S)}$	$V_{(D:T)}$	Risk $R_{(LoL)}$
1	Moderate erosion/slumping due to surface water flows	1×10^{-4}	0.05	0.001[#]	0.05	2.5×10^{-10}
2	Very rapid movement of sandstone blocks above apron,	1×10^{-4}	0.1	0.01[#]	0.5	5×10^{-8}
3	Deterioration of gabion mesh next to apron, leading to rapid fall of overlying sandstone blocks	1×10^{-4}	0.1	0.005[#]	0.5	2.5×10^{-8}
4	Very slow creep of topsoil above apron	1×10^{-1}	0.001	0.001[#]	0.01	1×10^{-9}
5	Rapid global slope instability at apron – existing slope	1×10^{-4}	0.5	0.01[#]	0.1	2.5×10^{-7}
5a	Rapid global slope instability at apron – apron excavation, no underpinning	5×10^{-4}	0.5	0.01[#]	0.1	1.25×10^{-6}
5b	Rapid global slope instability at apron – apron excavation, underpinning	1×10^{-4}	0.5	0.01[#]	0.1	2.5×10^{-7}
5c	Rapid global slope instability at apron – apron excavation, extensive underpinning	1×10^{-5}	0.5	0.01[#]	0.1	2.5×10^{-8}
6a	Rapid slope or floor instability during excavation in temporary batter below culvert – discontinuous underpinning	1×10^{-3}	0.5	1	0.1	5×10^{-5}
6b	Rapid slope or floor instability during excavation in temporary batter below culvert –continuous underpinning	1×10^{-4}	0.1	1	0.1	1×10^{-6}
6c	Rapid slope or floor instability during excavation in temporary batter below culvert– extensive underpinning	1×10^{-4}	0.05	1	0.1	5×10^{-7}

Notes: 1 Summary description. Hazards further defined in Table 2.

This temporal, annual probability considers an elevated risk of a person being present on the apron or slopes during the year of construction works (based on an assumed 4 week duration, 12 hour work day, with someone working on the apron or slopes 25% of the time). A lower temporal probability would therefore be expected to apply in subsequent years.

Generally, the above annual risk of loss of life are within the acceptable risk levels suggested for new developments by the AGS. The exceptions are:

- Hazard 5a, for the option of excavation without underpinning below the apron, which marginally exceeds the suggested acceptable risk but is within the tolerable risk; and,
- Hazard 6a, for the option of discontinuous underpinning below the culvert, which exceeds the tolerable risk for a new development, but is less than the tolerable risk for an existing development. It is noted, however, that this hazard applies only during construction. Acceptable risk levels were obtained for both alternative options of continuous or extensive underpinning.

The probability assessment of Hazards 1 to 5 has generally assumed appropriate inspection and maintenance of the culvert and apron structures, and of existing slopes, drainage and stabilisation measures by the relevant parties. This would generally include regular visual inspections (e.g. annual and/or following heavy rainfall events) of the slopes and site developments, with regular maintenance and prompt rectification of any deterioration, including drainage and stabilisation measures. Similarly assessments of Hazards 5a, 5b and 6a to 6c assume an appropriate detailed work methodology will be adopted during the temporary culvert modification works, with appropriate monitoring, inspection and testing. The methodology and monitoring will depend on the specific construction and underpinning option selected for the works, and requirements of the regulators. In addition, the assessments presume that design and construction is undertaken in accordance with the recommendations contained in this report.

The above risk assessment indicates that the proposed development can be undertaken while meeting the usually accepted criteria of risk to life and risk to property. Additional construction options may be available if the regulators are willing to accept an elevated risk profile, particularly in the short term (i.e. during construction). In all cases, the risk assessment assumes construction is undertaken in accordance with the recommendations contained in this report

7.7 Acid Sulphate Soils

Specific testing for acid sulphate soils was outside of the scope of the current testing. It is noted, however, that previous testing of these alluvial/estuarine materials has indicated that acid sulphate soils are broadly present, and acid sulphate soils are expected to be present within the excavation. Reference should be made to DP's Acid Sulphate Management Plan dated December 2013, in relation to management of acid sulphate soils during the works.

The potential presence of hydrogen sulphide gas within the excavation due to the exposure of actual or potential acid sulphate soils should also be considered by the work methodology.

7.8 Monitoring

The use of detailed instrumentation to monitor culvert movement will be important for this project, to allow early identification of movements and assessment of possible causes. Precise survey points should be established within the culvert with at least weekly monitoring, increasing to daily during excavation and culvert construction.

Monitoring and assessment of the effectiveness of underpinning and dewatering will also be critical throughout the works. A detailed monitoring and assessment plan should be developed in conjunction with their detailed design.

Regular geotechnical inspections to confirm that subsurface conditions are consistent with those assumed by design would be appropriate as the work proceeds.

Additional monitoring requirements are likely to be implemented by RMS.

7.9 Further Investigation

Further investigation may be appropriate for the detailed design and assessment of underpinning, particularly for assessment of foundation conditions and settlements. Given the conditions encountered, investigation using cone penetrometer tests (CPTs) is likely to be the preferred approach to future investigation below the culvert. The appropriate detailed scope for further investigation may vary depending on the proposed method of underpinning at the site and accepted design uncertainty for that method.

Given the low headroom, any such investigation from within the culvert will require the development of site-specific equipment.

8. Limitations

Douglas Partners (DP) has prepared this report for this project at Warringah Mall, Condamine Street, Brookvale in accordance with the Westfield Consultant Services Contracts D11753 dated 8 April 2013. This report is provided for the exclusive use of Westfield Design and Construction Pty Ltd for this project only and for the purposes as described in the report. It should not be used by or relied upon for other projects or purposes on the same or other site or by a third party. Any party so relying upon this report beyond its exclusive use and purpose as stated above, and without the express written consent of DP, does so entirely at its own risk and without recourse to DP for any loss or damage. In preparing this report DP has necessarily relied upon information provided by the client and/or their agents.

The results provided in the report are indicative of the sub-surface conditions on the site only at the specific sampling and testing locations, and then only to the depths investigated and at the time the work was carried out. Sub-surface conditions can change abruptly due to variable geological processes and also as a result of human influences. Such changes may occur after DP's field testing has been completed.

DP's advice is based upon the conditions encountered during this investigation. The accuracy of the advice provided by DP in this report may be affected by undetected variations in ground conditions across the site between and beyond the sampling and testing locations. The advice may also be limited by budget constraints imposed by others or by site accessibility.

This report must be read in conjunction with all of the attached and should be kept in its entirety without separation of individual pages or sections. DP cannot be held responsible for interpretations or conclusions made by others unless they are supported by an expressed statement, interpretation, outcome or conclusion stated in this report.

This report, or sections from this report, should not be used as part of a specification for a project, without review and agreement by DP. This is because this report has been written as advice and opinion rather than instructions for construction.

The contents of this report do not constitute formal design components such as are required, by the Health and Safety Legislation and Regulations, to be included in a Safety Report specifying the hazards likely to be encountered during construction and the controls required to mitigate risk. This design process requires risk assessment to be undertaken, with such assessment being dependent upon factors relating to likelihood of occurrence and consequences of damage to property and to life. This, in turn, requires project data and analysis presently beyond the knowledge and project role respectively of DP. DP may be able, however, to assist the client in carrying out a risk assessment of potential hazards contained in the Comments section of this report, as an extension to the current scope of works, if so requested, and provided that suitable additional information is made available to DP. Any such risk assessment would, however, be necessarily restricted to the geotechnical components set out in this report and to their application by the project designers to project design, construction, maintenance and demolition.

Douglas Partners Pty Ltd

Appendix A

About this Report

Introduction

These notes have been provided to amplify DP's report in regard to classification methods, field procedures and the comments section. Not all are necessarily relevant to all reports.

DP's reports are based on information gained from limited subsurface excavations and sampling, supplemented by knowledge of local geology and experience. For this reason, they must be regarded as interpretive rather than factual documents, limited to some extent by the scope of information on which they rely.

Copyright

This report is the property of Douglas Partners Pty Ltd. The report may only be used for the purpose for which it was commissioned and in accordance with the Conditions of Engagement for the commission supplied at the time of proposal. Unauthorised use of this report in any form whatsoever is prohibited.

Borehole and Test Pit Logs

The borehole and test pit logs presented in this report are an engineering and/or geological interpretation of the subsurface conditions, and their reliability will depend to some extent on frequency of sampling and the method of drilling or excavation. Ideally, continuous undisturbed sampling or core drilling will provide the most reliable assessment, but this is not always practicable or possible to justify on economic grounds. In any case the boreholes and test pits represent only a very small sample of the total subsurface profile.

Interpretation of the information and its application to design and construction should therefore take into account the spacing of boreholes or pits, the frequency of sampling, and the possibility of other than 'straight line' variations between the test locations.

Groundwater

Where groundwater levels are measured in boreholes there are several potential problems, namely:

- In low permeability soils groundwater may enter the hole very slowly or perhaps not at all during the time the hole is left open;
- A localised, perched water table may lead to an erroneous indication of the true water table;
- Water table levels will vary from time to time with seasons or recent weather changes. They may not be the same at the time of construction as are indicated in the report; and
- The use of water or mud as a drilling fluid will mask any groundwater inflow. Water has to be blown out of the hole and drilling mud must first be washed out of the hole if water measurements are to be made.

More reliable measurements can be made by installing standpipes which are read at intervals over several days, or perhaps weeks for low permeability soils. Piezometers, sealed in a particular stratum, may be advisable in low permeability soils or where there may be interference from a perched water table.

Reports

The report has been prepared by qualified personnel, is based on the information obtained from field and laboratory testing, and has been undertaken to current engineering standards of interpretation and analysis. Where the report has been prepared for a specific design proposal, the information and interpretation may not be relevant if the design proposal is changed. If this happens, DP will be pleased to review the report and the sufficiency of the investigation work.

Every care is taken with the report as it relates to interpretation of subsurface conditions, discussion of geotechnical and environmental aspects, and recommendations or suggestions for design and construction. However, DP cannot always anticipate or assume responsibility for:

- Unexpected variations in ground conditions. The potential for this will depend partly on borehole or pit spacing and sampling frequency;
- Changes in policy or interpretations of policy by statutory authorities; or
- The actions of contractors responding to commercial pressures.

If these occur, DP will be pleased to assist with investigations or advice to resolve the matter.

About this Report

Site Anomalies

In the event that conditions encountered on site during construction appear to vary from those which were expected from the information contained in the report, DP requests that it be immediately notified. Most problems are much more readily resolved when conditions are exposed rather than at some later stage, well after the event.

Information for Contractual Purposes

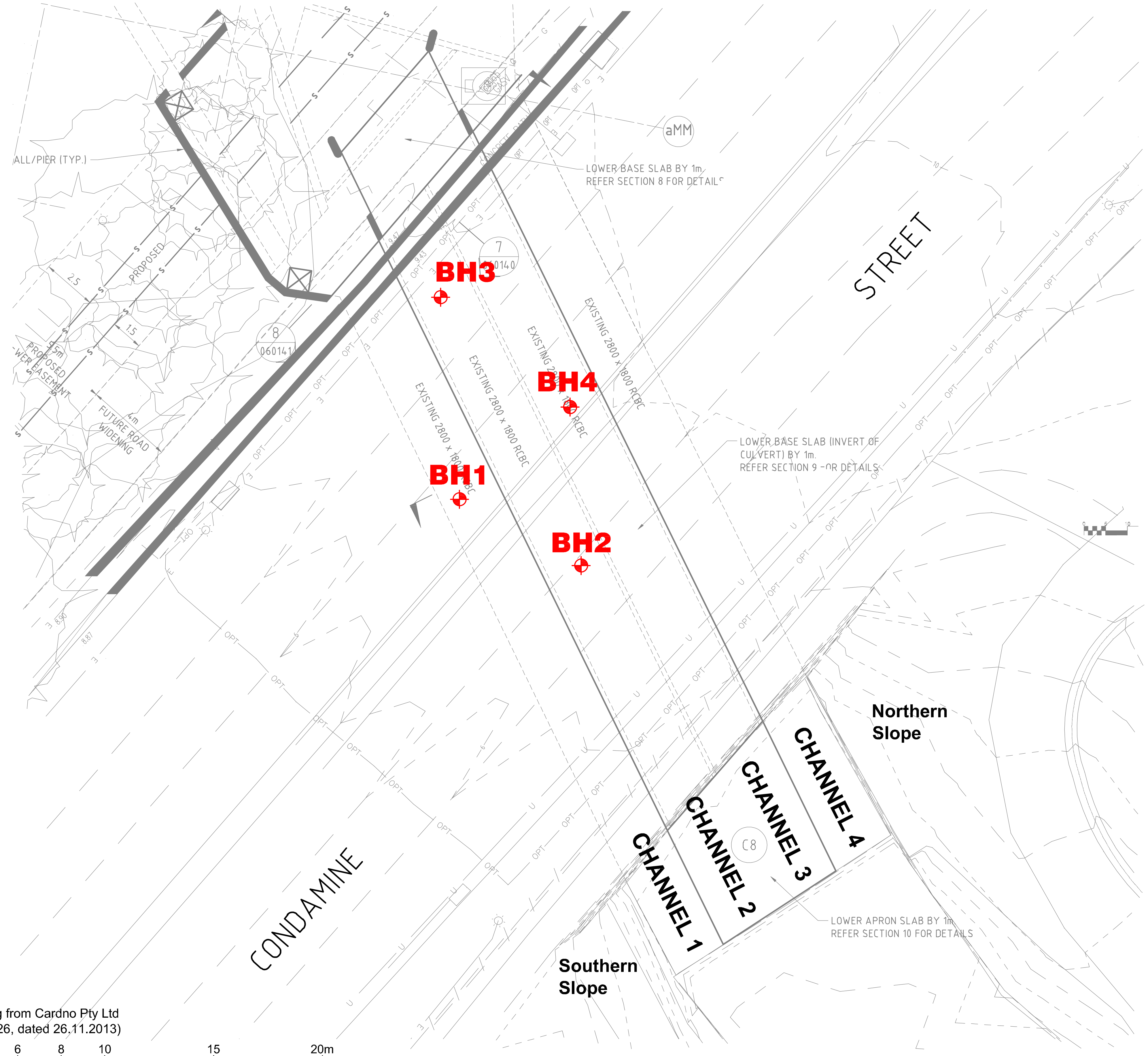
Where information obtained from this report is provided for tendering purposes, it is recommended that all information, including the written report and discussion, be made available. In circumstances where the discussion or comments section is not relevant to the contractual situation, it may be appropriate to prepare a specially edited document. DP would be pleased to assist in this regard and/or to make additional report copies available for contract purposes at a nominal charge.

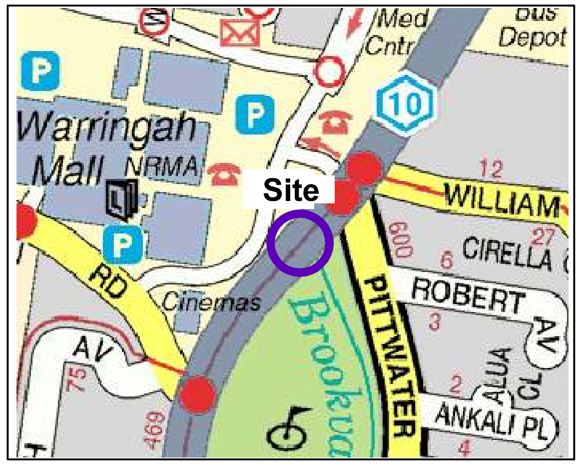
Site Inspection

The company will always be pleased to provide engineering inspection services for geotechnical and environmental aspects of work to which this report is related. This could range from a site visit to confirm that conditions exposed are as expected, to full time engineering presence on site.

Appendix B

Drawing No. 1 – Location of Tests





Locality Plan

NOTE: Base drawing from Cardno Pty Ltd
(Drawing CAR-110126, dated 26.11.2013)

0 1 2 3 4 6 8 10 15 20m

1:200 @ A3

LEGEND

Borehole and Dynamic Cone Penetrometer Test Location

Douglas Partners
Geotechnics | Environment | Groundwater

CLIENT: Westfield Design & Construction		TITLE: **Location of Tests** **Culvert Lowering** **Condamine Street, BROOKVALE**	PROJECT No: 71015.22
OFFICE: Sydney	DRAWN BY: PSCH		DRAWING No: 1
SCALE: 1:200 @ A3 approx.	DATE: 5.2.2014		REVISION: 0

Appendix C

Results of Field Work

Sampling

Sampling is carried out during drilling or test pitting to allow engineering examination (and laboratory testing where required) of the soil or rock.

Disturbed samples taken during drilling provide information on colour, type, inclusions and, depending upon the degree of disturbance, some information on strength and structure.

Undisturbed samples are taken by pushing a thin-walled sample tube into the soil and withdrawing it to obtain a sample of the soil in a relatively undisturbed state. Such samples yield information on structure and strength, and are necessary for laboratory determination of shear strength and compressibility. Undisturbed sampling is generally effective only in cohesive soils.

Test Pits

Test pits are usually excavated with a backhoe or an excavator, allowing close examination of the in-situ soil if it is safe to enter into the pit. The depth of excavation is limited to about 3 m for a backhoe and up to 6 m for a large excavator. A potential disadvantage of this investigation method is the larger area of disturbance to the site.

Large Diameter Augers

Boreholes can be drilled using a rotating plate or short spiral auger, generally 300 mm or larger in diameter commonly mounted on a standard piling rig. The cuttings are returned to the surface at intervals (generally not more than 0.5 m) and are disturbed but usually unchanged in moisture content. Identification of soil strata is generally much more reliable than with continuous spiral flight augers, and is usually supplemented by occasional undisturbed tube samples.

Continuous Spiral Flight Augers

The borehole is advanced using 90-115 mm diameter continuous spiral flight augers which are withdrawn at intervals to allow sampling or in-situ testing. This is a relatively economical means of drilling in clays and sands above the water table. Samples are returned to the surface, or may be collected after withdrawal of the auger flights, but they are disturbed and may be mixed with soils from the sides of the hole. Information from the drilling (as distinct from specific sampling by SPTs or undisturbed samples) is of relatively low reliability, due to the remoulding, possible mixing or softening of samples by groundwater.

Non-core Rotary Drilling

The borehole is advanced using a rotary bit, with water or drilling mud being pumped down the drill rods and returned up the annulus, carrying the drill cuttings. Only major changes in stratification can be determined from the cuttings, together with some information from the rate of penetration. Where drilling mud is used this can mask the cuttings and reliable identification is only possible from separate sampling such as SPTs.

Continuous Core Drilling

A continuous core sample can be obtained using a diamond tipped core barrel, usually with a 50 mm internal diameter. Provided full core recovery is achieved (which is not always possible in weak rocks and granular soils), this technique provides a very reliable method of investigation.

Standard Penetration Tests

Standard penetration tests (SPT) are used as a means of estimating the density or strength of soils and also of obtaining a relatively undisturbed sample. The test procedure is described in Australian Standard 1289, Methods of Testing Soils for Engineering Purposes - Test 6.3.1.

The test is carried out in a borehole by driving a 50 mm diameter split sample tube under the impact of a 63 kg hammer with a free fall of 760 mm. It is normal for the tube to be driven in three successive 150 mm increments and the 'N' value is taken as the number of blows for the last 300 mm. In dense sands, very hard clays or weak rock, the full 450 mm penetration may not be practicable and the test is discontinued.

The test results are reported in the following form.

- In the case where full penetration is obtained with successive blow counts for each 150 mm of, say, 4, 6 and 7 as:

  4,6,7
  N=13

- In the case where the test is discontinued before the full penetration depth, say after 15 blows for the first 150 mm and 30 blows for the next 40 mm as:

  15, 30/40 mm

The results of the SPT tests can be related empirically to the engineering properties of the soils.

Dynamic Cone Penetrometer Tests / Perth Sand Penetrometer Tests

Dynamic penetrometer tests (DCP or PSP) are carried out by driving a steel rod into the ground using a standard weight of hammer falling a specified distance. As the rod penetrates the soil the number of blows required to penetrate each successive 150 mm depth are recorded. Normally there is a depth limitation of 1.2 m, but this may be extended in certain conditions by the use of extension rods. Two types of penetrometer are commonly used.

- Perth sand penetrometer - a 16 mm diameter flat ended rod is driven using a 9 kg hammer dropping 600 mm (AS 1289, Test 6.3.3). This test was developed for testing the density of sands and is mainly used in granular soils and filling.
- Cone penetrometer - a 16 mm diameter rod with a 20 mm diameter cone end is driven using a 9 kg hammer dropping 510 mm (AS 1289, Test 6.3.2). This test was developed initially for pavement subgrade investigations, and correlations of the test results with California Bearing Ratio have been published by various road authorities.

Soil Descriptions

Douglas Partners

Description and Classification Methods

The methods of description and classification of soils and rocks used in this report are based on Australian Standard AS 1726, Geotechnical Site Investigations Code. In general, the descriptions include strength or density, colour, structure, soil or rock type and inclusions.

Soil Types

Soil types are described according to the predominant particle size, qualified by the grading of other particles present:

Type	Particle size (mm)
Boulder	>200
Cobble	63 - 200
Gravel	2.36 - 63
Sand	0.075 - 2.36
Silt	0.002 - 0.075
Clay	<0.002

The sand and gravel sizes can be further subdivided as follows:

Type	Particle size (mm)
Coarse gravel	20 - 63
Medium gravel	6 - 20
Fine gravel	2.36 - 6
Coarse sand	0.6 - 2.36
Medium sand	0.2 - 0.6
Fine sand	0.075 - 0.2

The proportions of secondary constituents of soils are described as:

Term	Proportion	Example
And	Specify	Clay (60%) and Sand (40%)
Adjective	20 - 35%	Sandy Clay
Slightly	12 - 20%	Slightly Sandy Clay
With some	5 - 12%	Clay with some sand
With a trace of	0 - 5%	Clay with a trace of sand

Definitions of grading terms used are:

- Well graded - a good representation of all particle sizes
- Poorly graded - an excess or deficiency of particular sizes within the specified range
- Uniformly graded - an excess of a particular particle size
- Gap graded - a deficiency of a particular particle size with the range

Cohesive Soils

Cohesive soils, such as clays, are classified on the basis of undrained shear strength. The strength may be measured by laboratory testing, or estimated by field tests or engineering examination. The strength terms are defined as follows:

Description	Abbreviation	Undrained shear strength (kPa)
Very soft	vs	<12
Soft	s	12 - 25
Firm	f	25 - 50
Stiff	st	50 - 100
Very stiff	vst	100 - 200
Hard	h	>200

Cohesionless Soils

Cohesionless soils, such as clean sands, are classified on the basis of relative density, generally from the results of standard penetration tests (SPT), cone penetration tests (CPT) or dynamic penetrometers (PSP). The relative density terms are given below:

Relative Density	Abbreviation	SPT N value	CPT qc value (MPa)
Very loose	vl	<4	<2
Loose	l	4 - 10	2 -5
Medium dense	md	10 - 30	5 - 15
Dense	d	30 - 50	15 - 25
Very dense	vd	>50	>25

Soil Descriptions

Soil Origin

It is often difficult to accurately determine the origin of a soil. Soils can generally be classified as:

- Residual soil - derived from in-situ weathering of the underlying rock;
- Transported soils - formed somewhere else and transported by nature to the site; or
- Filling - moved by man.

Transported soils may be further subdivided into:

- Alluvium - river deposits
- Lacustrine - lake deposits
- Aeolian - wind deposits
- Littoral - beach deposits
- Estuarine - tidal river deposits
- Talus - scree or coarse colluvium
- Slopewash or Colluvium - transported downslope by gravity assisted by water. Often includes angular rock fragments and boulders.

Symbols & Abbreviations

Douglas Partners

Introduction

These notes summarise abbreviations commonly used on borehole logs and test pit reports.

Drilling or Excavation Methods

C	Core Drilling
R	Rotary drilling
SFA	Spiral flight augers
NMLC	Diamond core - 52 mm dia
NQ	Diamond core - 47 mm dia
HQ	Diamond core - 63 mm dia
PQ	Diamond core - 81 mm dia

Water

▷	Water seep
▽	Water level

Sampling and Testing

A	Auger sample
B	Bulk sample
D	Disturbed sample
E	Environmental sample
U_{50}	Undisturbed tube sample (50mm)
W	Water sample
pp	pocket penetrometer (kPa)
PID	Photo ionisation detector
PL	Point load strength Is(50) MPa
S	Standard Penetration Test
V	Shear vane (kPa)

Description of Defects in Rock

The abbreviated descriptions of the defects should be in the following order: Depth, Type, Orientation, Coating, Shape, Roughness and Other. Drilling and handling breaks are not usually included on the logs.

Defect Type

B	Bedding plane
Cs	Clay seam
Cv	Cleavage
Cz	Crushed zone
Ds	Decomposed seam
F	Fault
J	Joint
Lam	lamination
Pt	Parting
Sz	Sheared Zone
V	Vein

Orientation

The inclination of defects is always measured from the perpendicular to the core axis.

h	horizontal
v	vertical
sh	sub-horizontal
sv	sub-vertical

Coating or Infilling Term

cln	clean
co	coating
he	healed
inf	infilled
stn	stained
ti	tight
vn	veneer

Coating Descriptor

ca	calcite
cbs	carbonaceous
cly	clay
fe	iron oxide
mn	manganese
slt	silty

Shape

cu	curved
ir	irregular
pl	planar
st	stepped
un	undulating

Roughness

po	polished
ro	rough
sl	slickensided
sm	smooth
vr	very rough

Other

fg	fragmented
bnd	band
qtz	quartz

Symbols & Abbreviations

Graphic Symbols for Soil and Rock

General

 Asphalt

 Road base

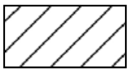
 Concrete

 Filling

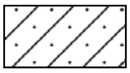
Soils

 Topsoil

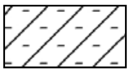
 Peat

 Clay

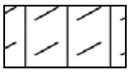
 Silty clay

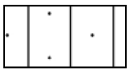
 Sandy clay

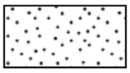
 Gravelly clay

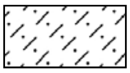
 Shaly clay

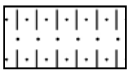
 Silt

 Clayey silt

 Sandy silt

 Sand

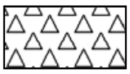
 Clayey sand

 Silty sand

 Gravel

 Sandy gravel

 Cobbles, boulders

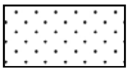
 Talus

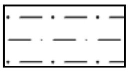
Sedimentary Rocks

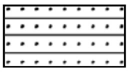
 Boulder conglomerate

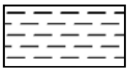
 Conglomerate

 Conglomeratic sandstone

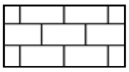
 Sandstone

 Siltstone

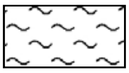
 Laminite

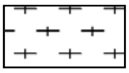
 Mudstone, claystone, shale

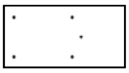
 Coal

 Limestone

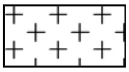
Metamorphic Rocks

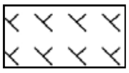
 Slate, phyllite, schist

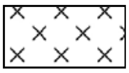
 Gneiss

 Quartzite

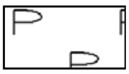
Igneous Rocks

 Granite

 Dolerite, basalt, andesite

 Dacite, epidote

 Tuff, breccia

 Porphyry

BOREHOLE LOG

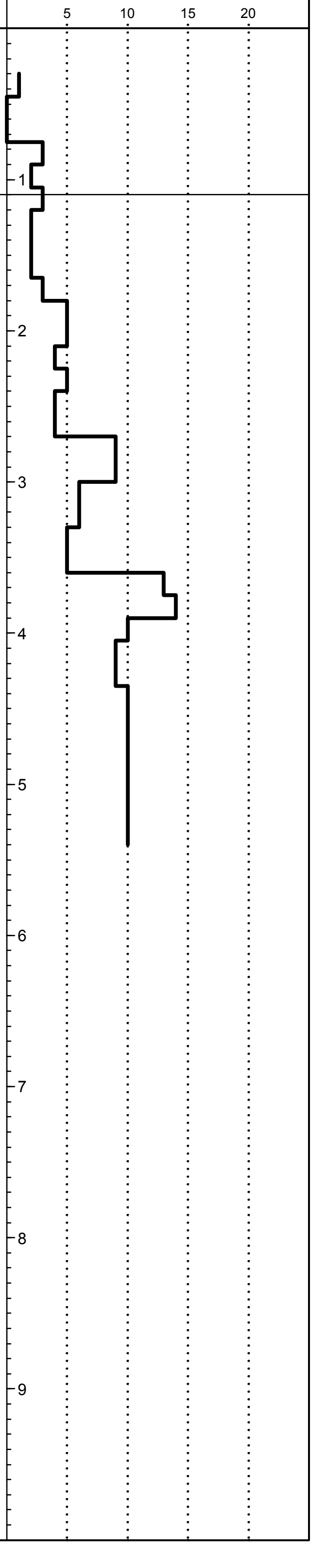
CLIENT: Westfield Design & Construction Pty Ltd
PROJECT: Proposed Culvert Modification
LOCATION: Condamine Street, Brookvale

SURFACE LEVEL: 5.9 AHD*
EASTING: 339548
NORTHING: 6262139
DIP/AZIMUTH: 90°/--

BORE No: 1
PROJECT No: 71015.22
DATE: 4/2/2014
SHEET 1 OF 1

RL	Depth (m)	Description of Strata	Sampling & In Situ Testing: Type	Depth	Sample	Results & Comments	Water
	0.3	CONCRETE - 300mm thick with 10mm diameter reinforcement					
	0.5	SANDY CLAY - soft, dark brown, fine sandy clay with rootlets, moist (possibly filling)	A	0.4			▼
5	1.1	ORGANIC CLAYEY SILT - soft then firm, dark brown, organic clayey silt, moist to wet	A	1.0			
		Bore discontinued at 1.1m - maximum depth possible due to height restrictions					

Dynamic Penetrometer Test (blows per 150mm)



RIG: Hand tools **DRILLER:** PGH **LOGGED:** PGH **CASING:** Uncased

TYPE OF BORING: Hand auger

WATER OBSERVATIONS: Initially moist then wet from 0.5m

REMARKS: *Reduced level (RL) approximate only. Interpolated from Cardno Design Drawing No: CAR-060140 and CAR-060141

☐ Sand Penetrometer AS1289.6.3.3
☒ Cone Penetrometer AS1289.6.3.2

SAMPLING & IN SITU TESTING LEGEND

A	Auger sample	G	Gas sample	PID	Photo ionisation detector (ppm)
B	Bulk sample	P	Piston sample	PL(A)	Point load axial test Is(50) (MPa)
BLK	Block sample	U_x	Tube sample (x mm dia.)	PL(D)	Point load diametral test Is(50) (MPa)
C	Core drilling	W	Water sample	pp	Pocket penetrometer (kPa)
D	Disturbed sample	▷	Water seep	S	Standard penetration test
E	Environmental sample	▼	Water level	V	Shear vane (kPa)

Douglas Partners
Geotechnics / Environment / Groundwater

BOREHOLE LOG

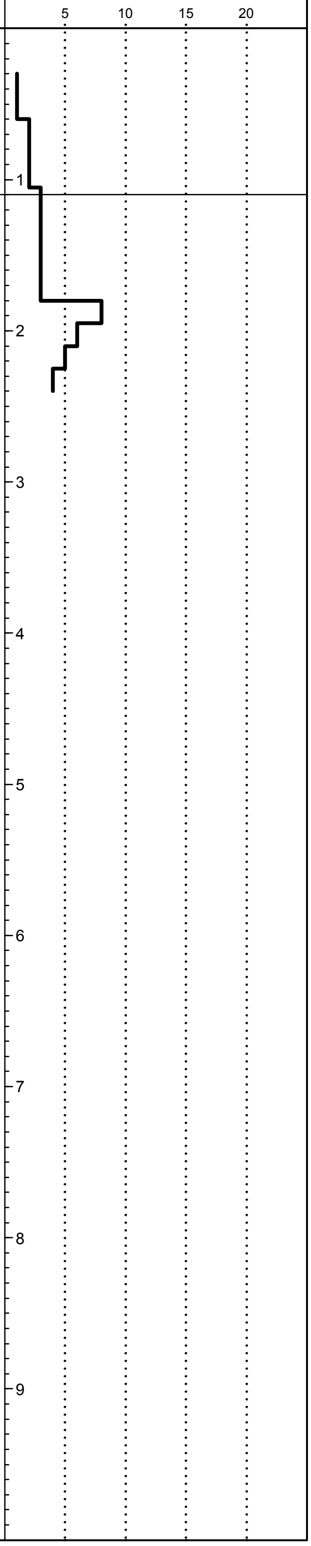
CLIENT: Westfield Design & Construction Pty Ltd
PROJECT: Proposed Culvert Modification
LOCATION: Condamine Street, Brookvale

SURFACE LEVEL: 5.8 AHD*
EASTING: 339554
NORTHING: 6262131
DIP/AZIMUTH: 90°/--

BORE No: 2
PROJECT No: 71015.22
DATE: 4/2/2014
SHEET 1 OF 1

Depth (m)	Description of Strata	Sampling & In Situ Testing: Type	Depth	Sample	Results & Comments	Water
0.3	CONCRETE - 300mm thick with 10mm steel reinforcement					
0.4	SANDY CLAY - soft, black, fine sandy clay, moist (possibly filling)	A	0.5			
1.1	ORGANIC CLAYEY SILT - soft then firm, black, organic clayey silt with some sand and rootlets, moist	A	1.0			
	Bore discontinued at 1.1m - maximum depth possible due to height restrictions					

Dynamic Penetrometer Test (blows per 150mm)



RIG: Hand tools **DRILLER:** PGH **LOGGED:** PGH **CASING:** Uncased
TYPE OF BORING: Hand auger
WATER OBSERVATIONS: Moist from 0.3m
REMARKS: *Reduced level (RL) approximate only. Interpolated from Cardno Design Drawing No: CAR-060140 and CAR-060141

☐ Sand Penetrometer AS1289.6.3.3
☒ Cone Penetrometer AS1289.6.3.2

SAMPLING & IN SITU TESTING LEGEND

A	Auger sample	G	Gas sample	PID	Photo ionisation detector (ppm)
B	Bulk sample	P	Piston sample	PL(A)	Point load axial test Is(50) (MPa)
BLK	Block sample	U_x	Tube sample (x mm dia.)	PL(D)	Point load diametral test Is(50) (MPa)
C	Core drilling	W	Water sample	pp	Pocket penetrometer (kPa)
D	Disturbed sample	▷	Water seep	S	Standard penetration test
E	Environmental sample	▼	Water level	V	Shear vane (kPa)

Douglas Partners
Geotechnics / Environment / Groundwater

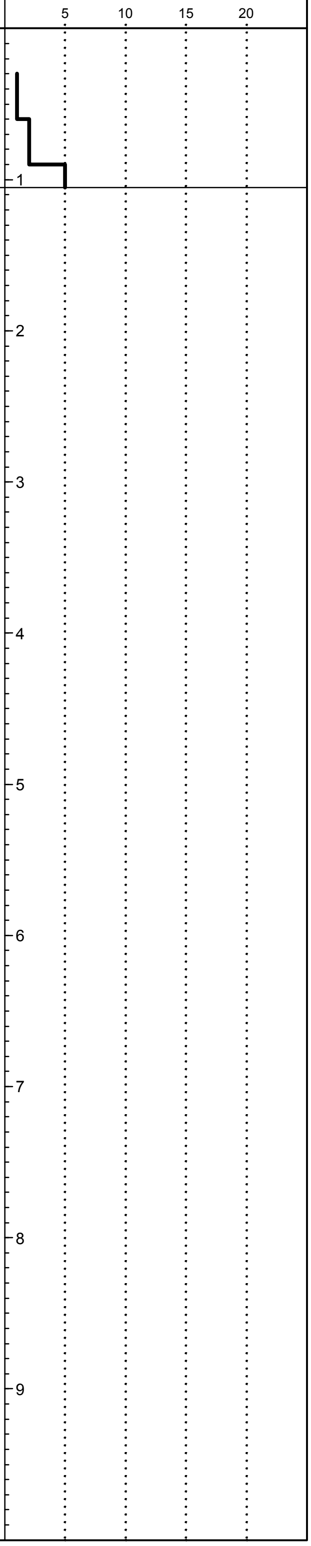
BOREHOLE LOG

CLIENT: Westfield Design & Construction Pty Ltd
PROJECT: Proposed Culvert Modification
LOCATION: Condamine Street, Brookvale

SURFACE LEVEL: 6.0 AHD*
EASTING: 339548
NORTHING: 6262143
DIP/AZIMUTH: 90°/--

BORE No: 3
PROJECT No: 71015.22
DATE: 4/2/2014
SHEET 1 OF 1

RL	Depth (m)	Description of Strata	Graphic Log	Type	Depth	Sample	Results & Comments	Water	Dynamic Penetrometer Test (blows per 150mm)
6		CONCRETE - 350mm thick with 10mm reinforcement							
	0.35	ORGANIC SILTY CLAY - soft then firm, black, organic silty clay, moist		A	0.5				
5	1.05			A	0.9				
		Bore discontinued at 1.05m - refusal on tree root							



RIG: Hand tools **DRILLER:** PGH **LOGGED:** PGH **CASING:** Uncased
TYPE OF BORING: Hand auger
WATER OBSERVATIONS: Moist from 0.35m
REMARKS: *Reduced level (RL) approximate only. Interpolated from Cardno Design Drawing No: CAR-060140 and CAR-060141

☐ Sand Penetrometer AS1289.6.3.3
☒ Cone Penetrometer AS1289.6.3.2

SAMPLING & IN SITU TESTING LEGEND

A	Auger sample	G	Gas sample	PID	Photo ionisation detector (ppm)
B	Bulk sample	P	Piston sample	PL(A)	Point load axial test Is(50) (MPa)
BLK	Block sample	U_x	Tube sample (x mm dia.)	PL(D)	Point load diametral test Is(50) (MPa)
C	Core drilling	W	Water sample	pp	Pocket penetrometer (kPa)
D	Disturbed sample	▷	Water seep	S	Standard penetration test
E	Environmental sample	▼	Water level	V	Shear vane (kPa)

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BOREHOLE LOG

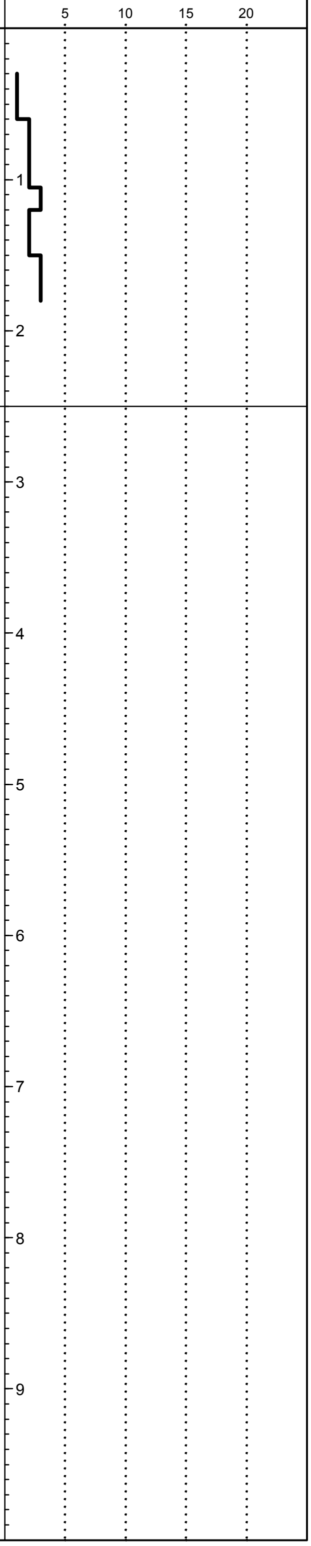
CLIENT: Westfield Design & Construction Pty Ltd
PROJECT: Proposed Culvert Modification
LOCATION: Condamine Street, Brookvale

SURFACE LEVEL: 5.9 AHD*
EASTING: 339553
NORTHING: 6262139
DIP/AZIMUTH: 90°/--

BORE No: 4
PROJECT No: 71015.22
DATE: 4/2/2014
SHEET 1 OF 1

RL	Depth (m)	Description of Strata	Graphic Log	Sampling & In Situ Testing: Type	Depth	Sample	Results & Comments	Water
		CONCRETE - 300mm thick with 10mm steel reinforcement						
	0.3	ORGANIC CLAYEY SILT - soft then firm, black, organic clayey silt, moist		A	0.6			
				A	2.1			
	2.5	Bore discontinued at 2.5m						

Dynamic Penetrometer Test (blows per 150mm)



RIG: Hand tools **DRILLER:** PGH **LOGGED:** PGH **CASING:** Uncased
TYPE OF BORING: Hand auger
WATER OBSERVATIONS: Moist from 0.3m
REMARKS: *Reduced level (RL) approximate only. Interpolated from Cardno Design Drawing No: CAR-060140 and CAR-060141

☐ Sand Penetrometer AS1289.6.3.3
☒ Cone Penetrometer AS1289.6.3.2

SAMPLING & IN SITU TESTING LEGEND

A	Auger sample	G	Gas sample	PID	Photo ionisation detector (ppm)
B	Bulk sample	P	Piston sample	PL(A)	Point load axial test Is(50) (MPa)
BLK	Block sample	U_x	Tube sample (x mm dia.)	PL(D)	Point load diametral test Is(50) (MPa)
C	Core drilling	W	Water sample	pp	Pocket penetrometer (kPa)
D	Disturbed sample	▷	Water seep	S	Standard penetration test
E	Environmental sample	▼	Water level	V	Shear vane (kPa)

Douglas Partners
Geotechnics / Environment / Groundwater

Douglas Partners
Geotechnics / Environment / Groundwater

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West Ryde NSW 1685
Phone (02) 9809 0666
Fax (02) 9809 4095

Results of Dynamic Penetrometer Tests

Client	Westfield Design & Construction	**Project No.**	71015.22
Project	Culvert Lowering	**Date**	5/02/14
Location	Condamine Street, Brookvale	**Page No.**	1 of 2

Test Locations	1	2	3	4						
RL of Test (AHD)	5.9	5.8	6.0	5.9						
Depth (m)	Penetration Resistance Blows/150 mm									
0.00 – 0.15	SLAB	SLAB	SLAB	SLAB						
0.15 – 0.30										
0.30 – 0.45	1	1	1	1						
0.45 – 0.60	0	1	1	1						
0.60 – 0.75	0	2	2	2						
0.75 – 0.90	3	2	2	2						
0.90 – 1.05	2	2	5	2						
1.05 – 1.20	3	3	R	3						
1.20 – 1.35	2	3		2						
1.35 – 1.50	2	3		2						
1.50 – 1.65	2	3		3						
1.65 – 1.80	3	3		3						
1.80 – 1.95	5	8		R						
1.95 – 2.10	5	6								
2.10 – 2.25	4	5								
2.25 – 2.40	5	4								
2.40 – 2.55	4	R								
2.55 – 2.70	4									
2.70 – 2.85	9									
2.85 – 3.00	9									

Test Method AS 1289.6.3.2, Cone Penetrometer ☑
AS 1289.6.3.3, Sand Penetrometer ☐

Tested By PGH
Checked By **SCP**

Remarks 1) R = Refusal

2) Reduced Level (RL) approximate only. Interpolsted from Cardno Design Drawing No: CAR-060140 and CAR-060141

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Fax (02) 9809 4095

Results of Dynamic Penetrometer Tests

Client Westfield Design & Construction
Project Culvert Lowering
Location Condamine Street, Brookvale

Project No. 71015.22
Date 5/02/14
Page No. 2 of 2

Test Locations	1									
RL of Test (AHD)	5.9 Con't									
Depth (m)	**Penetration Resistance** Blows/150 mm									
3.00 – 3.15	6									
3.15 – 3.30	6									
3.30 – 3.45	5									
3.45 – 3.60	5									
3.60 – 3.75	13									
3.75 – 3.90	14									
3.90 – 4.05	10									
4.05 – 4.20	9									
4.20 – 4.35	9									
4.35 – 4.50	10									
4.50 – 4.65	10									
4.65 – 4.80	10									
4.80 – 4.95	10									
4.95 – 5.10	10									
5.10 – 5.25	10									
5.25 – 5.40	10									
5.40 – 5.55										
5.55 – 5.70										
5.70 – 5.85										
5.85 – 6.00										

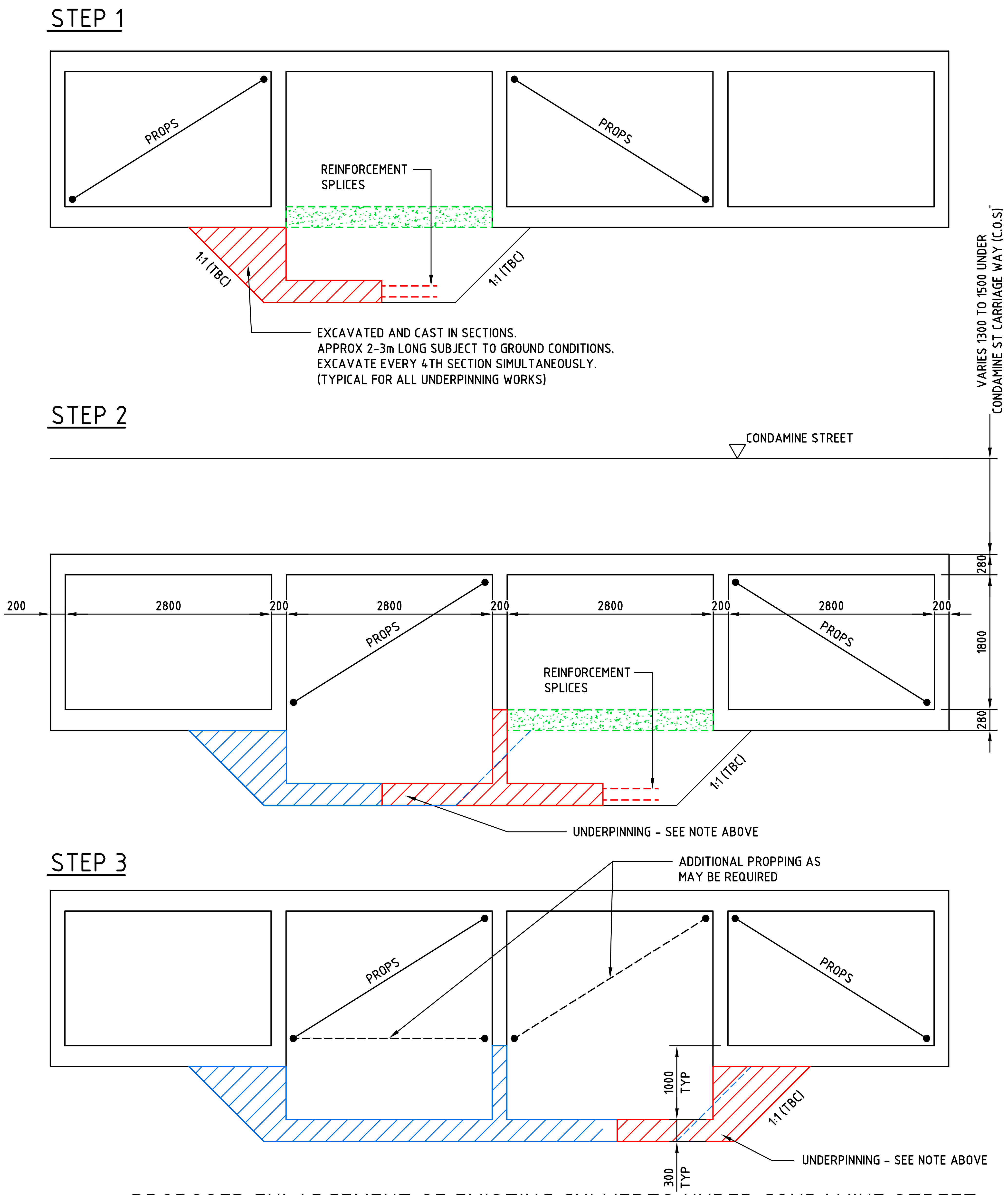
Test Method AS 1289.6.3.2, Cone Penetrometer ☑
AS 1289.6.3.3, Sand Penetrometer ☐

Tested By PGH
Checked By **SCP**

Remarks REDUCED LEVEL (RL) APPROXIMATE ONLY. INTERPOLSTED FROM CARDNO DESIGN DRAWING NO: CAR-060140 AND CAR-060141

Appendix D

Copy of Cardno Drawing ST2-STR-SK21



PROPOSED ENLARGEMENT OF EXISTING CULVERTS UNDER CONDAMINE STREET

SCALE 1:50

LEGEND

- DEMOLITION
- CONCRETING
- WORKS COMPLETED IN PREVIOUS STEPS

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Fax: 61 2 9439 5170
www.cardno.com.au

Project: WARRINGAH MALL STORMWATER UPGRADE CULVERT STAGE 2	Job No: NA89914004 Sheet Size: A3 FULL SIZE
Drawing: PROPOSED ENLARGEMENT OF EXISTING CULVERTS UNDER CONDAMINE STREET	Drawing No: ST2-STR-SK21 — Issue No: 1