

**Lend Lease Development Pty Ltd**

**PROPOSED STUDENT ACCOMODATION TOWERS  
DARLING DRIVE, DARLING HARBOUR  
ASSESSMENT OF IMPACTS ON ADJACENT INFRASTRUCTURE**

**Report PSM1986-009R**

**March 2013**

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## **1. INTRODUCTION**

This report supports a State Significant Development Application (SSD 12\_5752) submitted to the Minister for Planning and Infrastructure pursuant to Part 4 of the *Environmental Planning and Assessment Act 1979* (EP&A Act).

The Application seeks approval for the establishment of building envelopes and design parameters for a new neighbourhood and a community hub (referred to as The Haymarket) as part of the Sydney international convention, exhibition and entertainment precinct (SICEEP) Project at Darling Harbour.

The project will develop The Haymarket into one of Sydney's most innovative residential and working districts. Through the delivery of the overall project, Darling Harbour will also become home to Australia's largest convention and exhibition facilities, Sydney's largest red carpet entertainment venue, and a hotel complex of up to 900 rooms. The SICEEP Project importantly forms a critical element of the NSW Government's aspiration to "make NSW number one again".

### **1.1. Overview of proposed development**

The proposal relates to a staged development application and seeks to establish concept plan details for The Haymarket, located within the southern part of the SICEEP Site.

The Haymarket will include student housing, public car parking, a commercial office building, and four mixed use development blocks (retail/commercial/residential podium with residential towers above) centred around a new public square to be named Haymarket Square.

More specifically concept approval is sought for the following:

- Demolition of existing site improvements, including the existing Sydney Entertainment centre (SEC), Entertainment car park, and part of the pedestrian footbridge connected to the Entertainment car park and associated tree removal;
- North-west block – construction of a part public car park and part commercial/office building;
- North-east block – construction of a mixed use podium (comprising retail, commercial, above ground parking, and residential) with three residential buildings above;
- South-east block - construction of a mixed use podium (comprising retail, commercial, above ground parking, and residential) with three residential buildings above;
- South-west block - construction of a mixed use podium (comprising retail, commercial, above ground parking, and residential) with three residential buildings above;
- North block – construction of a mixed use building comprising retail, commercial and residential;
- Student housing – construction of two buildings providing for up to 1,000 beds;

- Public domain improvements including a new square, water features, new pedestrian streets and laneways, streetscape embellishments, and associated landscaping. (It is intended that a Stage 2 DA seeking approval for parts of the public domain (The Boulevard and Haymarket Square) will be lodged with the first residential stage);
- Reconfiguration and upgrade of Darling Drive (part);
- Remediation strategy; and
- Car parking rates.

## 1.2. **Background**

The existing convention, exhibition and entertainment centre facilities at Darling Harbour were constructed in the 1980s and have provided an excellent service for Sydney and NSW.

The facilities however have limitations in their ability to service the contemporary exhibition and convention industry which has led to a loss in events being held in Sydney.

The NSW Government considers that a precinct-wide renewal and expansion is necessary and is accordingly committed to Sydney reclaiming its position on centre stage for hosting world-class events with the creation of the Sydney international convention, exhibition and entertainment precinct.

Following an extensive and rigorous Expressions of Interest and Request for Proposals process, Darling Harbour Live (formerly known as 'Destination Sydney'- a consortium comprising AEG Ogden, Lend Lease, Capella Capital and Spotless) was announced by the NSW Government in December 2012 as the preferred proponent to transform Darling Harbour and create the new Sydney international convention, exhibition and entertainment Precinct.

Key features of the Darling Harbour Live Preferred Master Plan include:

- Delivering world-class convention, exhibition and entertainment facilities, including:
  - Up to 40,000m<sup>2</sup> exhibition space;
  - Over 8,000m<sup>2</sup> of meeting rooms space, across 40 rooms;
  - Overall convention space capacity for more than 12,000 people;
  - A ballroom capable of accommodating 2,000 people; and
  - A premium, red-carpet entertainment facility with a capacity of 8,000 persons.
- Providing up to 900 hotel rooms in a hotel complex at the northern end of the precinct.
- A vibrant and authentic new neighbourhood at the southern end of the precinct, called 'The Haymarket', home to an IQ Hub focused on the creative industries and high-tech businesses, apartments, student accommodation, shops, cafes and restaurants.

- Renewed and upgraded public domain, including an outdoor event space for up to 25,000 people at an expanded Tumbalong Park.
- Improved pedestrian connections linking to the proposed Ultimo Pedestrian Network drawing people between Central, Chinatown and Cockle Bay Wharf as well as east-west between Ultimo/Pymont and the City.

### **1.3. Site Description**

The SICEEP Site is located within Darling Harbour. Darling Harbour is a 60 hectare waterfront precinct on the south-western edge of the Sydney Central Business District that provides a mix of functions including recreational, tourist, entertainment and business.

With an area of approximately 20 hectares, the SICEEP Site is generally bound by the Light Rail Line to the west, Harbourside shopping centre and Cockle Bay to the north, Darling Quarter, the Chinese Garden and Harbour Street to the east, and Hay Street to the south.

The SICEEP Site has been divided into three distinct redevelopment areas (from north to south) – Bayside, Darling Central and The Haymarket. The Application Site area relates to The Haymarket as shown in the figure below.

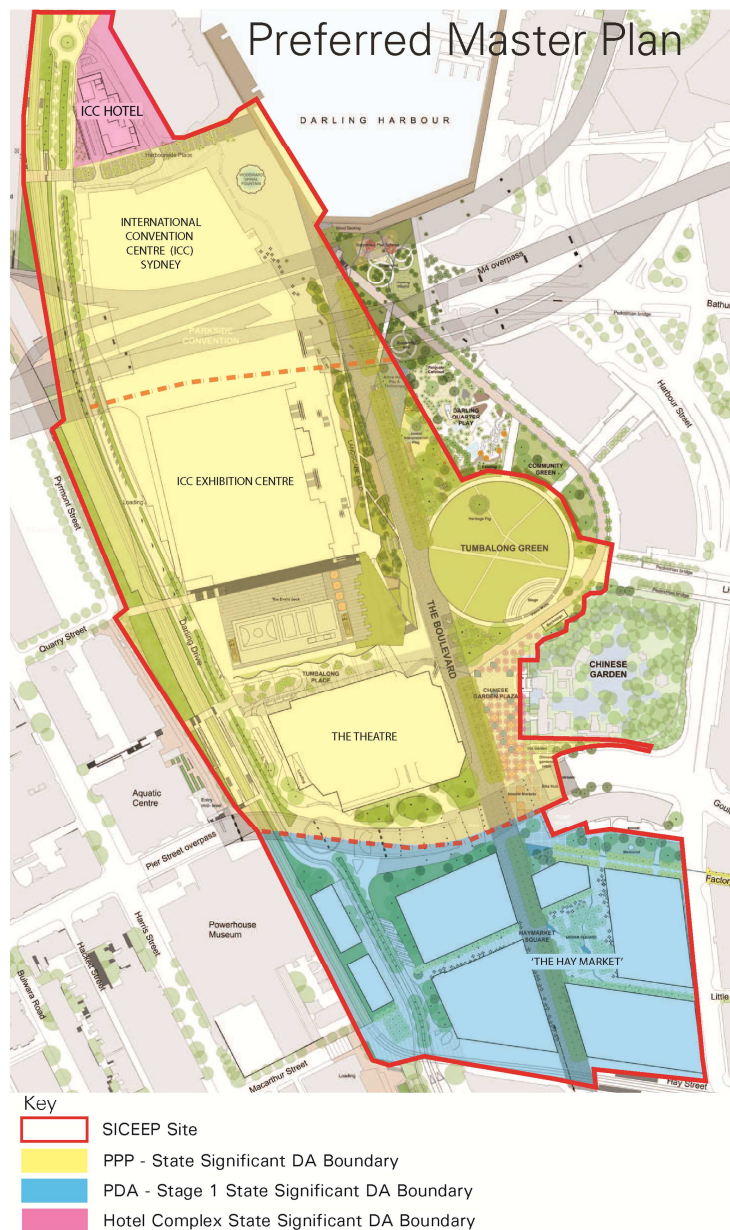


## 1.4. Planning Approvals Strategy

In response to separate contractual agreements with the NSW Government and staging requirements Lend Lease (Haymarket) Pty Ltd is proposing to submit a number of separate development applications for key elements of the overall Project.

This staged development application involves the establishment of building envelopes and design parameters for a new neighbourhood and a community hub (The Haymarket) within the southern part of the SICEEP Site. Detailed development applications will accordingly follow seeking approval for specific aspects of The Haymarket in accordance with the approved staged development application.

Separate development applications will be lodged for the PPP component of the SICEEP Project (comprising the convention centre, exhibition centre, entertainment facility and associated public domain upgrades) and Hotel complex.



## **2. SCOPE OF WORK**

This report has been prepared to support the State Significant Development Application (SSD 12\_5752) and presents a preliminary assessment of the impacts on the student accommodation buildings that are proposed along the western edge of The Haymarket on the following existing tunnel structures which underlie the proposed student accommodation site:

- Sydney Water Corporation (SWC) trunk sewer tunnel, and
- Energy Australia City West Cable Tunnel (CWCT).

This work was undertaken by Pells Sullivan Meynink (PSM) for Lend Lease Development Pty Ltd (Lend Lease) in accordance with a Professional Services Agreement executed on 21 February 2013 and our fee proposal dated 30 January 2013 (Ref. PSM1986-006L).

This work has been undertaken for the planning approval stage of the project, and follows a previous preliminary assessment of impacts on the cable tunnel undertaken by PSM in August 2012 (Ref. PSM1986-001L, dated 7 August 2012, and e-mail dated 10 August 2012).

Documents provided by Lend Lease and relied upon in undertaking this work are included in the appendices.

## **3. PROPOSED STUDENT ACCOMODATION BUILDINGS**

Lend Lease are redeveloping the southern portion (The Haymarket) of the Darling Harbour precinct, including the existing Entertainment Centre and surrounding area, as part of the Sydney International Convention, Exhibition and Entertainment Precinct (SICEEP) development.

Two student accommodation tower buildings are proposed to be constructed within two new englobo lots to the west of the existing Entertainment Centre multi-storey car park that are proposed to be created by the subdivision of the common boundary between Lot 800 DP1164281 (owned by SHFA), Lot 33 DP870306 (owned by Rail Corporation New South Wales) and Darling Drive (owned by SHFA). Commensurate with the subdivision, it has been assumed that INSW will provide for the timely extinguishment and/or relocation of existing easements.

The towers are currently proposed to be constructed within a rectangular area of approximately 90 m length and 18 m width, as shown in Figure 1. Existing ground surface levels within this area range from RL 3.5 m to RL 5.5 m (Ref. Survey plan included in Appendix A).

Pile working loads have been provided by the Robert Bird Group (under separate commission to Lend Lease) and are included in Appendix B. These loads are also summarised in Table 1 below, though it is noted that these details do not account for either the cable or sewer tunnels, and that we have adjusted some of the pile locations (and also loads) for the purposes of our analysis as discussed further below.

As part of the previous assessment in August 2012, Robert Bird Group indicated that a deflection limit of up to 20 mm is appropriate for the proposed buildings.

**TABLE 1  
ORIGINAL PILE LOADS  
PROVIDED BY ROBERT BIRD GROUP**

BUILDING	PILE LOCATION	APPROXIMATE WORKING LOADS PER PILE	
		VERTICAL (kN)	HORIZONTAL (kN)
North	Isolated columns	13,600	340
	Core pad with walls over	10,000	250
South	Isolated columns	12,240	306
	Core pad with walls over	7,500	250

#### **4. EXISTING TUNNEL INFRASTRUCTURE**

##### **4.1. City West Cable Tunnel**

The City West Cable Tunnel (CWCT) was constructed for Energy Australia in about 2008. It passes beneath Darling Drive and crosses under each of the two proposed buildings, as shown in Figure 1.

The tunnel was constructed using a tunnel boring machine, with an inside diameter of 3.0 m and is lined with precast concrete segments of 175 mm thickness. As noted above, PSM has previously undertaken an assessment of the potential impact upon the CWCT. PSM also undertook geotechnical investigations and provided tunnelling advice to Energy Australia as part of the CWCT project.

The tunnel is located beneath the groundwater table and the segmental lining has been designed to resist external hydrostatic pressures. The lining design is intended to result in very low leakage rates into the tunnel.

The tunnel easement has been registered (Ref Deposited Plans DP 1181007, DP 1181091 and DP 1181017). The terms of the easement are yet to be registered.

PSM has sought further tunnel details from Energy Australia (EA). EA has indicated a willingness to assist in this regard, though at the time of preparing this draft report, these details have not been received. It is not known whether Energy Australia have developed any specific criteria in regards to the degree of physical impacts (e.g. deformation) which are acceptable for the tunnel lining. Relevant tunnel drawings are included in Appendix C.

The CWCT plan location utilised for the purpose of this report has been based on the registered easement plans. The easement plans location coincides with CWCT design plans and alignments retained by PSM under a previous commission with Energy Australia. Information obtained by Rygate & Company Pty Ltd (project surveyors) from “dial before you dig” shows the tunnel located approximately 7 m to the east of the location nominated above and have not been utilised for the purpose of this report.

#### **4.2. Trunk sewer tunnel**

As shown in Figure 1, a SWC 1.0 m diameter trunk sewer runs from Hay Street through to William Henry Street, crossing beneath the location of the proposed northern most student accommodation tower. SWC provided as-built drawings of the sewer which are included in Appendix D. These indicate that the sewer was constructed by Leighton Contractors Pty Ltd for the New Darling Harbour Authority in about 1988.

It is understood from the documents provided that the sewer was constructed by tunnelling methods (i.e. rather than trenching).

The section of the sewer which passes beneath the proposed student accommodation building employed tunnelling cross section type ‘C’, which is described in the Leighton drawings as ‘tunnel in soil or faulty rock’. This involved excavation of a tunnel with a span of up to about 2.4 m, a height of about 2.4 m, and included temporary timber support.

The sewer itself comprises a 1.0 m diameter glass reinforced plastic liner embedded within a block of reinforced concrete of 1.6 m width and 1.6 m height. The reinforcement comprises a grillage of 16 mm diameter bars spaced at 200 mm centres in each direction. A concrete class of 400.45.25 is indicated in the drawings. This terminology is not in current use and its meaning is unclear. The voids between the reinforced concrete, tunnel walls and timbering were filled with grout.

The invert level of the sewer is at about RL -4.0 m AHD where it passes beneath the northern building. This corresponds to a depth from the existing surface to the crown of the tunnel of approximately 5.0 m to 7.5 m. The as-built plans also show an assumed rock line (based on four investigation boreholes drilled along the route of the tunnelled sewer) which suggests that the portion of the sewer beneath the northern building was excavated in rock.

Criteria in regards to the magnitude of physical impacts which are acceptable for the sewer tunnel have not been provided to PSM. For the purpose of this assessment report PSM have developed and nominated a suitable acceptance criteria.

### **5. GEOTECHNICAL CONDITIONS**

No geotechnical investigation has yet been undertaken specifically for the proposed student accommodation towers. Recent borehole investigations undertaken by others (including Coffey for INSW) have either been located at some distance from the site, or have terminated at shallow depth (i.e. above bedrock level).

A geotechnical model has been prepared for the site based on the results of two nearby boreholes drilled by PSM as part of the CWCT project, as well as from a range of geotechnical data provided by Lend Lease (sources by Lend Lease from INSW data room). The location of these boreholes is shown in Figure 1, and relevant borehole logs are included in Appendix E.

The geotechnical units, levels, and thicknesses are shown in Table 2 below.

**TABLE 2  
GEOTECHNICAL MODEL**

<b>GEOTECHNICAL UNIT</b>	<b>REDUCED LEVEL OF TOP OF UNIT</b> RL (m) AHD	<b>THICKNESS</b> (m)
FILL, ALLUVIUM	3.5 to 2.5	6.5 to 8.5
CLASS III SANDSTONE	-3 to -5	8 to 11
CLASS II SANDSTONE	-11 to -15	> 20

Note: 1. Rock classification is in accordance with Reference 1.

Inferred bedrock surface contours are shown in Figure 1. These show that the rock levels drop from the west to the east (i.e. towards the original harbour) by about 6 m over a distance of roughly 50 m.

It is noted that poorer conditions occur in the vicinity of the site due to the presence of intrusive volcanic dykes, as well as joint swarms. The model shown in Table 2 is considered to more closely represent geotechnical conditions in the area where the cable tunnel passes close to the proposed student accommodation building.

Groundwater levels encountered in the borehole investigations near the site were measured to be at about RL 0.8 m (AHD).

## **6. IMPACTS ON TRUNK SEWER**

### **6.1. Physical conflicts**

The indicative pile locations initially proposed by RBG (based on a conceptual student accommodation building design prepared by Lend Lease) are shown in the plan drawing in Figure 1. It can be seen that the sewer tunnel alignment has the potential to intersect in the order of four of the piles supporting the proposed northern building. As the piles need to be founded in bedrock, and the level of the sewer coincides with the bedrock level, these four piles have the potential to intersect the sewer tunnel if no alternate design solution was to be considered.

The pile locations therefore need to be adjusted to avoid the sewer. They also need to be positioned and detailed so as to prevent adverse impacts on the adjacent sewer structure. RBG and Lend Lease have advised that the pile locations can be sufficiently

co-ordinated between the student accommodation building and the tunnelled sewer through the introduction of suitable transfer structures below the student accommodation building, thereby allow the “offsetting” of paired piled foundations either side of the existing tunnelled sewer by a suitable distance acceptable to SWC.

## **6.2. Adjustment of pile locations**

Based on previous experience, the pile locations have been adjusted to provide a 1.5 m horizontal separation distance between the pile shaft and the 1.6 m wide reinforced concrete box in which the sewer is encased. The 1.5 m distance also includes allowances for:

- pile construction tolerance in plan,
- pile verticality tolerance, and
- possibility that the sewer tunnel may have been excavated larger than the 2.4 m span shown on the as-built drawings.

This separation distance results in a 4.6 m wide corridor centred on the sewer in which no piles can be located. While a 1.5 m offset has been utilised for the purposes of this assessment report, it is acknowledged that a reduction in offset may be acceptable to SWC and that the final offset arrangement would be subject to further detailed design and consultation between SWC and the proponent Lend Lease.

PSM has modified the original pile layout accordingly. Many of the original piles were replaced by two piles – one on either side of the sewer, as shown in Figure 1. Some type of structural bridging beam is likely to be required to transfer the column loads to the new pile locations. RBG and Lend Lease have advised that this represents a pragmatic approach acceptable to Lend Lease.

For two of the piles, the original position has been adjusted by less than 0.4 m, and no additional pile has been provided. It is assumed that the building structure can accommodate this adjustment without requiring an additional pile. Once again, RBG and Lend Lease have advised that this represents a pragmatic approach acceptable to Lend Lease.

This process has resulted in the total number of piles increasing from 75 to 80. Revised pile locations and loads are tabulated in Appendix F.

PSM note that the student accommodation design is yet to be finalised and that once a final design configuration is determined, further detailed analysis should be undertaken to verify the findings of this report.

## **6.3. Preliminary ‘bridging’ pile design**

### **6.3.1. Purpose**

The new piles located either side of the sewer (offset) have been termed ‘bridging’ piles in this report. A preliminary pile design has been undertaken to allow analysis of physical impacts on the sewer due to pile settlement under load, in particular to check the sewer deformation associated with the 1.5 m separation distance proposed above.

### 6.3.2. Pile loads

Loads for the new piles have been calculated based on the revised pile locations and the loads provided by RBG.

For the majority of the 'bridging' piles, it has been assumed that the original pile load is shared equally by each of the two new piles. However, for two of the core pad piles, the eccentricity of the load results in one of the new piles being subject to a vertical load of 17,000 kN, while the pile on the other side of the sewer only takes 3000 kN. The 17,000 kN load is significantly higher than any of the other pile loads proposed by RBG.

The revised pile loads were used to design pile embedment lengths, as discussed in the following section.

### 6.3.3. Preliminary pile design parameters

Table 3 below summarises pile design parameters which have been used to assess preliminary proportions for the proposed bored piles.

**TABLE 3  
PRELIMINARY PILE DESIGN PARAMETERS**

<b>GEOTECHNICAL UNIT</b>	<b>YOUNG'S MODULUS (MPa)</b>	<b>ALLOWABLE SHAFT ADHESION (MPa)</b>	<b>ALLOWABLE END BEARING PRESSURE (MPa)</b>
FILL, ALLUVIUM	5	0	0
CLASS III SANDSTONE	800	0.5	4.0
CLASS II SANDSTONE	1500	0.8	6.0
CLASS I SANDSTONE	2500	1.0	10.0

These parameters assume that the piles are constructed to a high standard, with a roughened shaft, and are cleaned and dewatered prior to the placement of concrete.

The simplified approach of using allowable shaft adhesion and end bearing pressure has been employed for simplicity and to achieve realistic pile embedment lengths. This methodology is considered appropriate for this stage of the project.

### 6.3.4. Pile proportions

A pile diameter of 1.2 m has been adopted for all the piles supporting the two tower buildings. This is intended to achieve relatively short piles, and thus reduce negative impacts on the underlying cable tunnel. Further refinement during detailed design may allow adoption of more economic pile diameters, in particular for those piles located further from the tunnels.

Embedment lengths have been calculated for the various pile loads as shown in Table 4 below.

The calculated toe level of the bridging piles has been adjusted where necessary so that it is no higher than RL -5.0 m. This level is about 1.0 m below the sewer invert level shown on the as-built drawings. This is because adoption of a higher level could potentially destabilise the sidewall of the sewer tunnel, especially where adverse defects (e.g. seams, joints) occur in the rock.

**TABLE 4  
PRELIMINARY PROPORTIONS OF BRIDGING PILES**

<b>PILE TYPE</b>	<b>WORKING LOAD (kN)</b>	<b>DIAMETER (m)</b>	<b>TOE LEVEL RL (m) AHD</b>
Isolated columns	6800	1.2	-5.0
Core pad with walls over	3000	1.2	-5.0
Core pad with walls over	17,000	1.2	-7.7

Note: 1. Pile toe levels assume a bedrock surface at RL -2.3 m AHD, and a sewer invert level at RL -4.0 m.

#### **6.4. Phase<sup>2</sup> analysis**

##### **6.4.1. Model details**

Settlement due to working loads was calculated via an axisymmetric analysis using the software Phase<sup>2</sup>, produce by Rocscience Inc. Graphical output from the analysis is presented in Appendix G.

Two analyses were undertaken, using the pile proportions listed in Table 4 above, and elastic geotechnical parameters as per Table 3. A Young's modulus for the concrete shaft of the pile of 20 GPa was adopted.

Run 1 corresponded to the 6800 kN load, and Run 2 to the 17,000 kN pile load.

##### **6.4.2. Analysis results**

For the pile loaded to 6800 kN, a pile head settlement of 4 mm was calculated. The pile toe settled about 2 mm, and the zone in the rock 1.5 m from the pile (i.e. representing the edge of the sewer) settled about 0.5 mm to 1 mm. The analysis also indicated that the stresses in the rock at the 1.5 m from the pile increased by about 100 kPa to 200 kPa.

For Run 2, in which the pile was loaded to 17,000 kN, the pile head settlement was about 8 mm and the pile toe about 2 mm. The zone 1.5 m from the pile moved about 2 mm. The stresses in the rock 1.5 m from the pile were assessed to increase by about 250 kPa to 300 kPa.

The Phase<sup>2</sup> analyses are discussed further in the following sections.

## **6.5. Tolerable deformation of sewer structure**

### **6.5.1. Adverse mechanisms**

Two main concerns have been identified in regards to the degree of deformation which the sewer structure can tolerate:

1. Bending deformation of the reinforced concrete box which encases the sewer sufficient to result in cracking of the concrete. Where the width of such cracks is excessive, this could compromise the durability of the structure.
2. Bending deformation leading to compressive or tensile failure of the glass fibre reinforced plastic sleeve which forms the sewer lining.

### **6.5.2. Reinforced concrete box**

For an assumed concrete strength of 32 MPa, a typical design flexural tensile strength is in the order of about 3.4 MPa. For a Young's modulus of concrete of 20 GPa (i.e. including an allowance for creep), this strength corresponds to a tensile strain of approximately 170  $\mu\epsilon$ . Therefore where the tensile strain exceeds this value, tensile failure of the concrete (i.e. cracking) would occur. Based on the size of the reinforced concrete box (i.e. side lengths of 1.6 m), a curvature of 0.0002  $m^{-1}$  is required to cause cracking.

Crack width has not been considered in this assessment. Crack widths are typically controlled by reinforcement details, and curvature in excess of that required to initiate tensile cracking of concrete is required to cause cracks of sufficient width to compromise durability. Therefore this type of assessment would probably result in a greater allowable curvature than that proposed above.

### **6.5.3. Glass fibre reinforced plastic sleeve**

Details of the glass fibre reinforced plastic (GRP) sleeve are not shown in the as-built drawings. Generic data on GRP pipe used for sewer applications has therefore been sought to permit assessment of the liner. A product data sheet from Ameron International for their Bondstrand series 2400 fibreglass pipe and fittings is included in Appendix H.

For filament wound pipe of 1000 mm diameter the following properties are given:

- Young's modulus 12.5 GPa
- Tensile strength (21°C) 80 MPa
- Minimum bending radius 405 m (i.e. maximum curvature 0.0025  $m^{-1}$ )

It is noted that the minimum bending radius corresponds to a tensile strain of about 1200  $\mu\epsilon$ . Based on the Young's modulus listed above, a tensile stress of 15 MPa is calculated, which is much lower than the stated tensile strength. The difference is likely to be associated with stress concentrations at pipe joints, and the adverse effects of internal and external pressures applied to the curved pipe.

## **6.6. Impact on sewer structure**

From the discussion above it is apparent that the cracking of the reinforced concrete box which encases the sewer is much more sensitive to deformation compared to the fibreglass pipe sleeve.

The deformations calculated by the Phase<sup>2</sup> analysis have been used to assess the resulting curvature along the centre of the sewer pipe. The results of this analysis are shown in Figure 3 and Figure 4. The top graph in each figure shows the deformation versus distance from the centre of the pile, while the lower graph shows the deformation and curvature calculated along a line representing the centre of the sewer.

Figure 3 shows results for the case with two 1.2 m diameter piles located either side of the sewer, with each loaded to 6800 kN. This indicates that the sewer would be subject to a settlement of about 1.2 mm, and that the maximum curvature would be in the order of  $0.00018 \text{ m}^{-1}$ , which is slightly less than the curvature calculated to result in initial cracking of the concrete.

Figure 4 represents the case where one pile is loaded to 17,000 kN, and the other to only 3000 kN. The sewer is calculated to settle by about 1.4 mm. Curvature is in the order of  $0.00019 \text{ m}^{-1}$ , which again is slightly less than the curvature calculated to result in initial cracking of the concrete.

This assessment suggests that the 1.5 m setback distance proposed previously is a reasonable value, and that adverse impacts on the sewer are unlikely. This conclusion is based on the preliminary pile design analysed, which corresponds to a calculated pile settlement in the order of a few millimetres at rock level. This pile detail is readily achieved using standard pile design and construction techniques.

## **7. IMPACTS ON CABLE TUNNEL**

### **7.1. Deformation criteria**

#### **7.1.1. General**

At present the easement for the cable tunnel has not yet been finalised, though it is understood that the easement will comprise a 10 m diameter zone centred on the tunnel axis. Energy Australia has not provided any criteria in regards to the degree of physical impacts (e.g. deformation) which are acceptable the tunnel. PSM has therefore undertaken a preliminary assessment of deformation criteria for the tunnel, as described below.

The analysis undertaken employs assumed tunnel lining details. These details are based on analysis of similar segmentally lined TBM tunnels and from tender design drawings of the CWCT retained by PSM (Ref. Appendix C). The key parameters employed in the analysis are listed below:

- Internal diameter of 3.0 m
- Segmental lining thickness of 175 mm
- Unreinforced segmental concrete lining

- Concrete lining compressive strength = 60 MPa
- Concrete lining flexural tensile strength = 5 MPa
- Six radial joints, each characterised by a joint normal stiffness of 100,000 MPa/m
- Grout compressive strength = 2 MPa

The analysis assumes that the existing tunnel lining is subject to a hydrostatic stress of 200 kPa due to a groundwater level at about RL 1 m.

Three modes of damage have been considered:

1. Cracking of the lining segments due to vertical convergence.
2. Spalling of lining segments due to increased compressive hoop stresses.
3. Leakage between joints in the lining due to horizontal divergence.

### 7.1.2. Phase<sup>2</sup> analysis

Finite element analysis of the tunnel lining was undertaken using the software Phase<sup>2</sup>, produce by Rocscience Inc. Graphical results are presented in Appendix I. The analysis was undertaken to investigate the sensitivity of the tunnel lining to induced vertical and lateral deformations, in particular to assess the onset of tensile cracking and/or spalling.

The analysis involved the application of a concentrated load above the centre of the tunnel to simulate the effect of multiple piles. The load was gradually increased, while the response of the tunnel lining was monitored. Figure 5 shows the calculated response of the tunnel lining as a function of vertical convergence.

The implications of this figure are described in the following sections.

### 7.1.3. Flexural cracking

The Phase<sup>2</sup> analysis results summarised in Figure 5 indicate that the onset of flexural tensile cracking is associated with vertical convergence in the order of 1.2 mm to 2 mm. The peak tensile stresses occur adjacent to the joints between lining segments, possibly as a result of indirect stresses caused by high localised bearing stresses across such joints.

This type of behaviour is likely to be dependent on the actual joint details used in the cable tunnel construction, and therefore further analysis may be required during detailed design once the as-built detail are known.

### 7.1.4. Spalling

Compressive stresses of up to 20 MPa were calculated for vertical convergence of about 2 mm. This value is much less than the assumed compressive strength of the lining of 60 MPa. These stresses typically occurred on the inside face of the lining at the level of the spring-line.

As per the previous section, the analysis undertaken does not account for joint details which may result in higher localised stresses.

### 7.1.5. Leakage

Waterproofing between the segments is likely to be achieved using proprietary rubber gaskets. The proposed deformation limit in extension is based on experience with a previous project, and assumes that the gasket is required to provide an effective seal against a differential pressure of 200 kPa.

### 7.1.6. Proposed deformation limits

Proposed acceptance criteria for the cable tunnel are listed in Table 5 below:

**TABLE 5  
PROPOSED DEFORMATION CRITERIA  
FOR CITY WEST CABLE TUNNEL**

DEFORMATION MECHANISM	PROPOSED DEFORMATION LIMIT (mm)
1. Cracking of the lining segments	1.5 (vertical convergence)
2. Spalling of lining segments due to increased compressive stresses	2.5 (vertical convergence)
3. Leakage between joints in the lining due to lateral extension	2 (horizontal extension)

## 7.2. FLAC3D analysis

### 7.2.1. Pile details

A preliminary footing design for the student accommodation towers has been undertaken based on the design parameters shown in Table 3, the bedrock contours in Figure 1, and the pile layout and loads listed in Appendix F.

All of the piles have been modelled with a diameter of 1.2 m. Calculated pile lengths vary from 8 m to 10.6 m, including a single pile loaded to 17 MN. The pile structural element formulation available in FLAC3D has been employed, with the ultimate shaft adhesion and end bearing values varied for each of the units intersected by the piles.

It is noted that further discussion with RBG following completing the FLAC3D analysis concluded that the single 17 MN pile would likely be replaced by two piles which would share the load.

### 7.2.2. Model geometry

The FLAC3D model encompasses both proposed buildings, and comprises a rectangle of plan dimensions 100 m by 150 m. The base of the model is at RL -50 m (AHD), and

the surface level roughly coincides with the existing surface levels as shown in the survey plan included in Appendix A.

The CWCT runs through the centre of the model, as shown in the graphical output included in Appendix J. The tunnel is modelled as an unlined excavation. The tunnel lining is not included in the analysis.

There are approximately a million elements within the model, with element sizes ranging from about 0.6 m to 3 m.

### **7.2.3. Analysis results**

Graphical output from the analysis is presented in Appendix J, and Figure 6 shows calculated deformations along the tunnel alignment.

The results indicate pile head settlement of between about 3 mm and 20 mm, which is broadly consistent with the Phase<sup>2</sup> axisymmetric analysis.

Tunnel settlement ranges from zero up to a maximum of about 3.5 mm. Vertical convergence of up to 1.3 mm is calculated beneath the core of the Northern building, while 1.1 mm convergence is assessed beneath the Southern building. Horizontal dilation of up to 0.3 mm is also calculated.

These calculated deformations are within the acceptable limits as summarised above in Table 5.

## **8. CONCLUSION AND RECOMMENDATIONS**

The assessment described in this report demonstrates that the proposed student accommodation buildings can be constructed so as to result in acceptable effects on the adjacent existing tunnel infrastructure, i.e.:

- Trunk sewer tunnel, and
- City West Cable Tunnel (CWCT)

The student buildings are to be supported on piled foundations which will be founded in Hawkesbury sandstone bedrock. Preliminary design indicates that pile lengths are likely to range from 8 m to 10.6 m. This is for a pile diameter of 1.2 m.

To protect the trunk sewer, the pile layout will firstly need to avoid the sewer alignment, and also provide a separation distance between the pile and the sewer. To avoid damaging the reinforced concrete box around the sewer the piles located adjacent to the sewer will need to extend below the sewer invert level and be proportioned so that settlement at the founding level is less than a few millimetres. This proposed settlement limit is for a separation distance of 1.5 m between the pile shaft and the reinforced concrete box in which the sewer is encased. Other separation distances may be feasible and these can be further tested at detailed design phase.

The cable tunnel is located about 20 m below the surface, and is overlain by approximately 13 m of bedrock. The preliminary pile design noted above results in pile

toe levels located about RL -7.6 m, which provides about 10 m of rock cover above the crown of the cable tunnel.

Analysis of the cable tunnel has been performed using assumed tunnel lining details. This analysis suggests that cracking of the lining would initially occur when the vertical convergence exceeds about 1.5 mm. Compressive spalling type failure requires at least several millimetres of convergence.

Three-dimension finite element analysis has been undertaken of the proposed building foundations. The analysis includes the tunnel alignment and the preliminary pile layout and loads noted above. The analysis calculates vertical convergence of the tunnel of less than 1.3 mm, which is less than the relevant adopted allowable deformation limit.

In summary, PSM is satisfied that the proposed student accommodation buildings as contemplated in Significant Development Application (SSD 12\_5752) can be developed over existing tunnelled infrastructure including SWC's trunk sewer tunnel, and Energy Australia's City West Cable Tunnel (CWCT).

Modelling undertaken by PSM has demonstrated that the proposed student accommodation building structures can be designed utilising industry standard design and construction techniques and practices such that impacts on the existing tunnelled infrastructure services below are retained within acceptable limits so as not to result in detrimental impacts on the existing infrastructure.

It is recommended that once design developed building designs are sufficiently progressed, such as at the respective Stage 2 DA stages, and subsequent to further consultation with the respective utility providers, that the modelling undertaken to date be further refined to confirm the conclusions of this report.

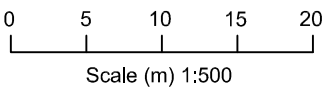
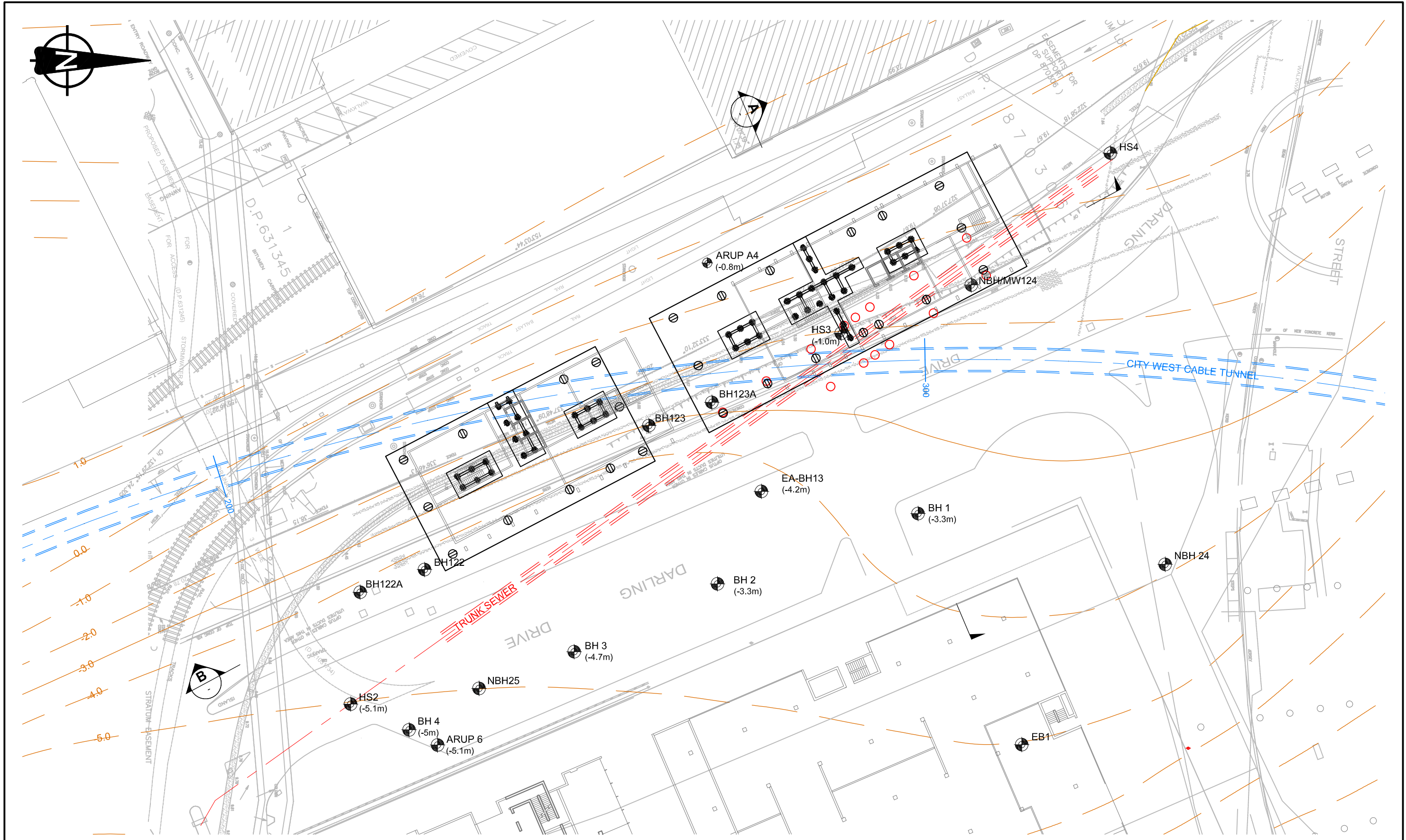
For and on behalf of  
PELLS SULLIVAN MEYNINK



STRATH CLARKE

## **REFERENCES**

1. Pells, P.J.N., and Mostyn, G., and Walker, B.F., 'Foundations on sandstone and shale in the Sydney Region', Australian Geomechanics Journal, 1998.

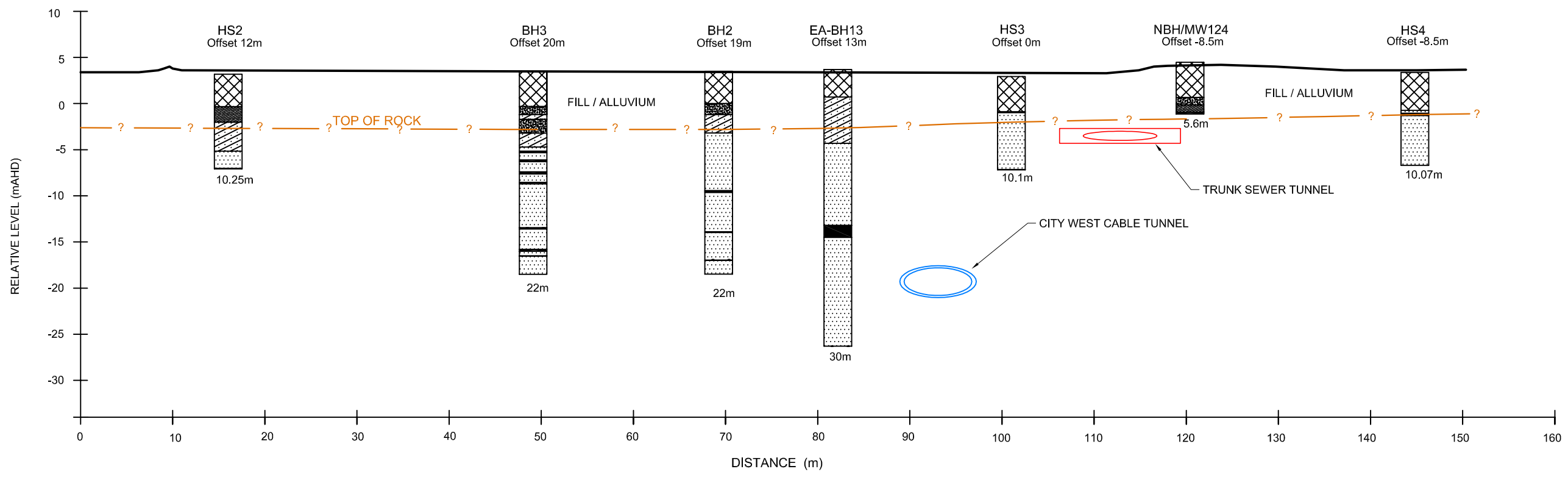


Pells Sullivan Meynink

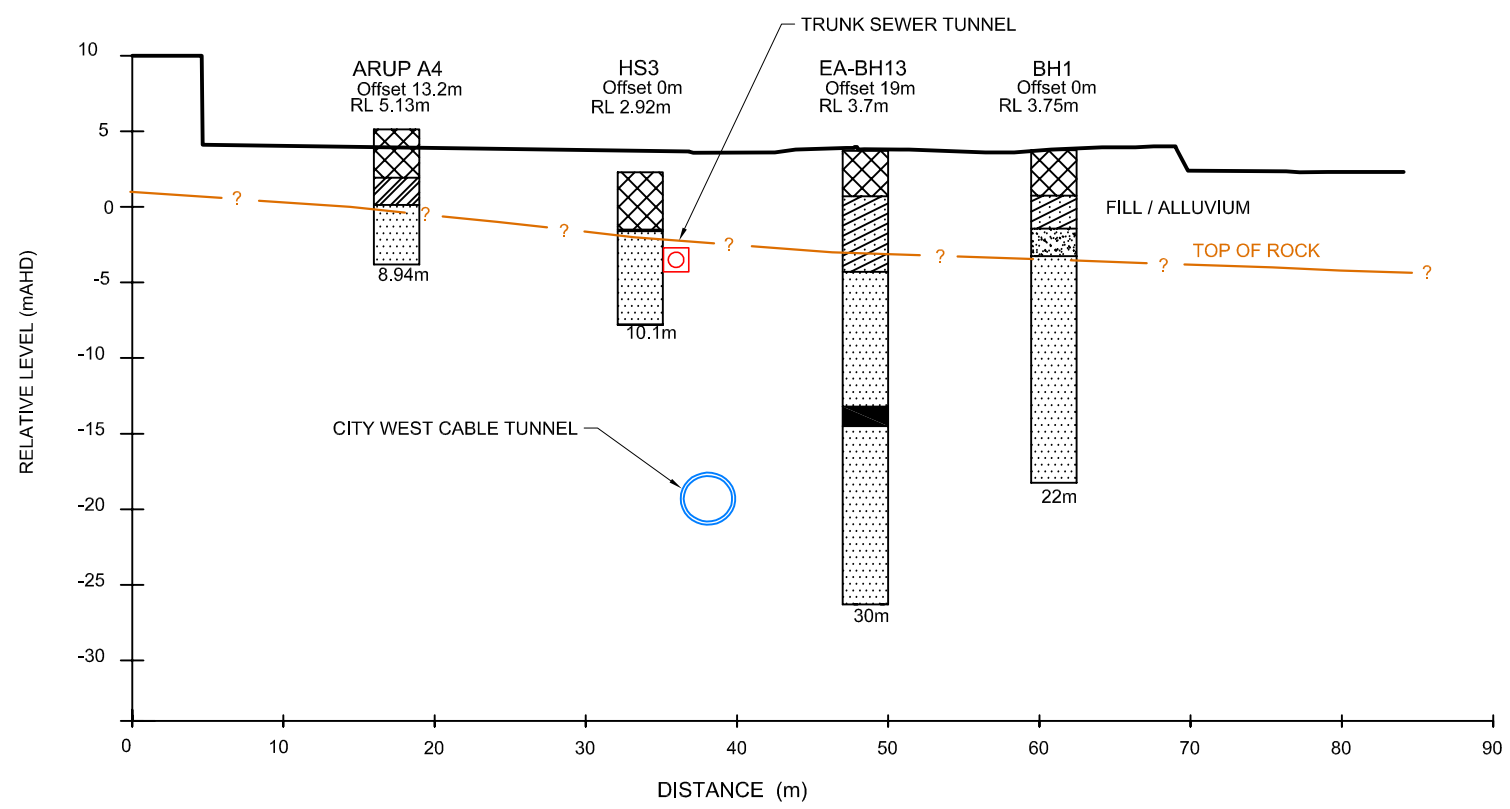
Lend Lease Development Pty Ltd  
 Darling Harbour Redevelopment  
 Proposed student accomodation towers  
 SITE PLAN

PSM1986-009R

FIGURE 1

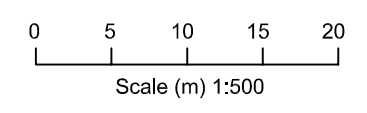


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SCALE 1:500



**A** SECTION  
SCALE 1:500

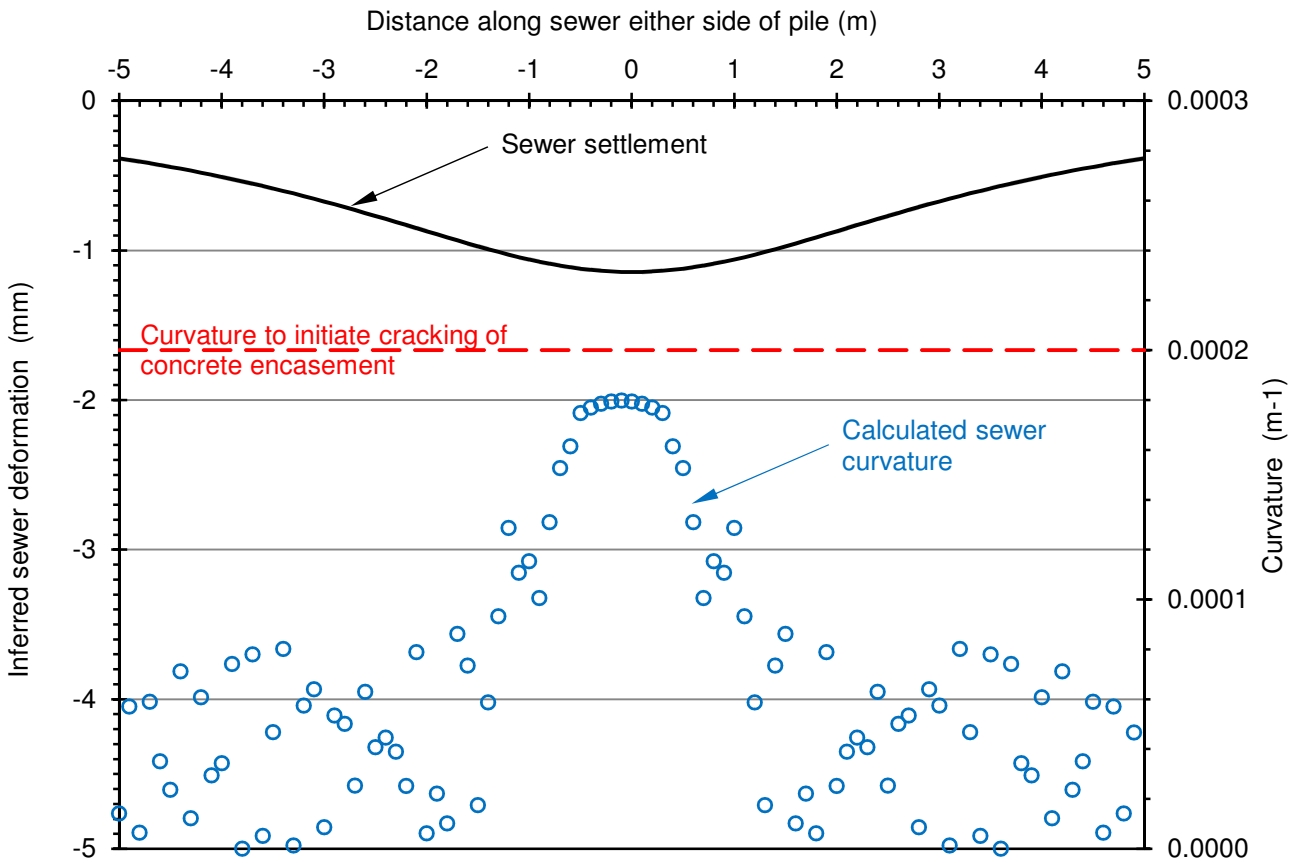
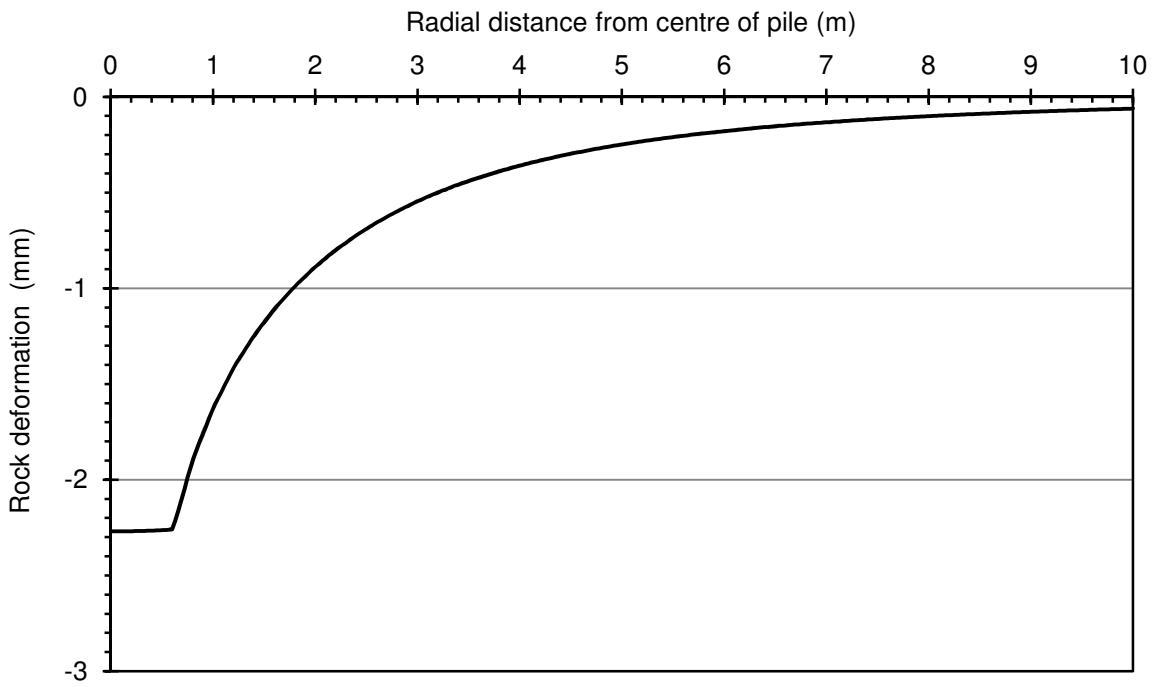
- LEGEND**
- Fill
  - Alluvium
  - Sand
  - Sandy Clay / Clayey Sand
  - Clay
  - Sandstone
  - Core Loss



**Pells Sullivan Meynink**

Lend Lease Development Pty Ltd  
Darling Harbour Redevelopment  
Proposed student accomodation towers  
**GEOTECHNICAL SECTIONS**

PSM1986-009R      FIGURE 2



Notes:

1. Sewer deformation assumes piles either side
2. Sewer located 2.9 m from centre of pile

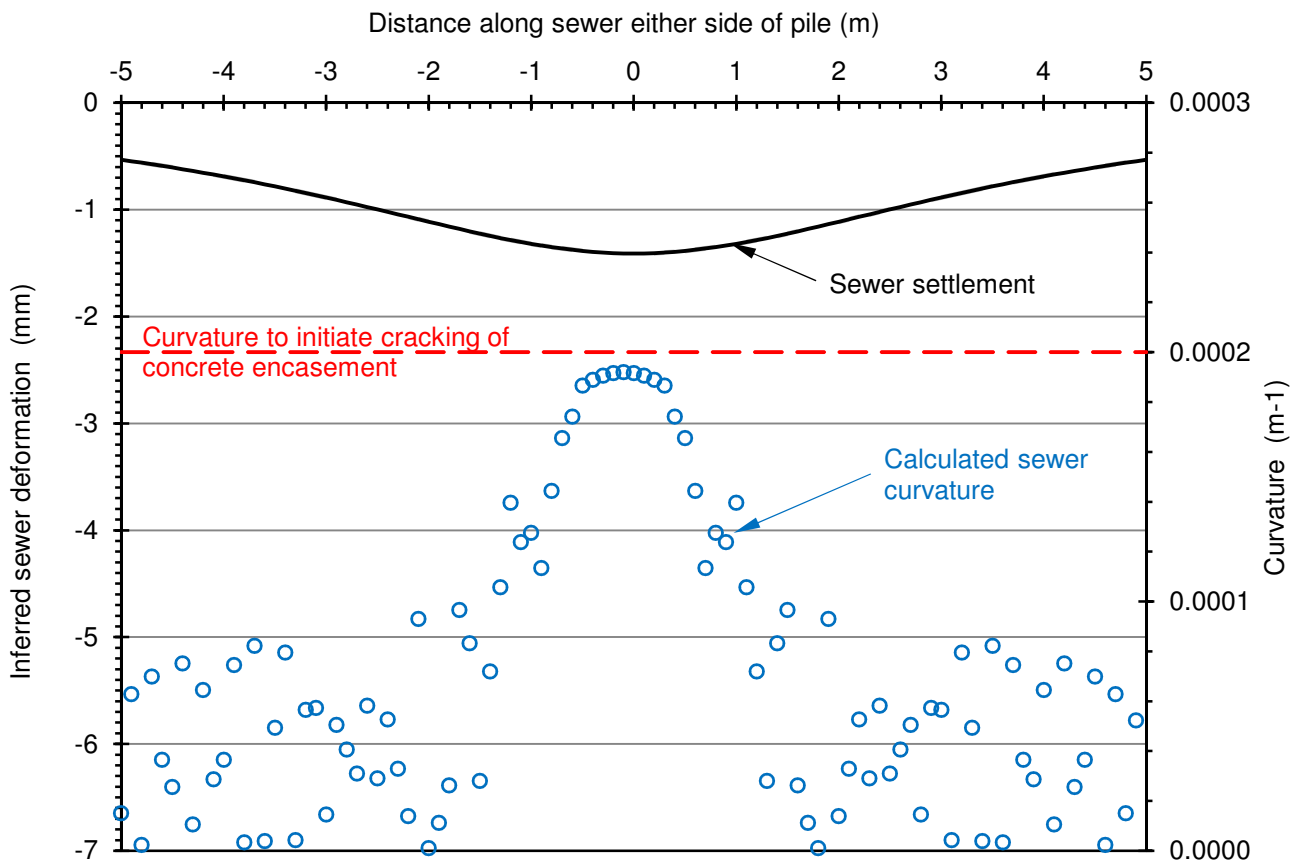
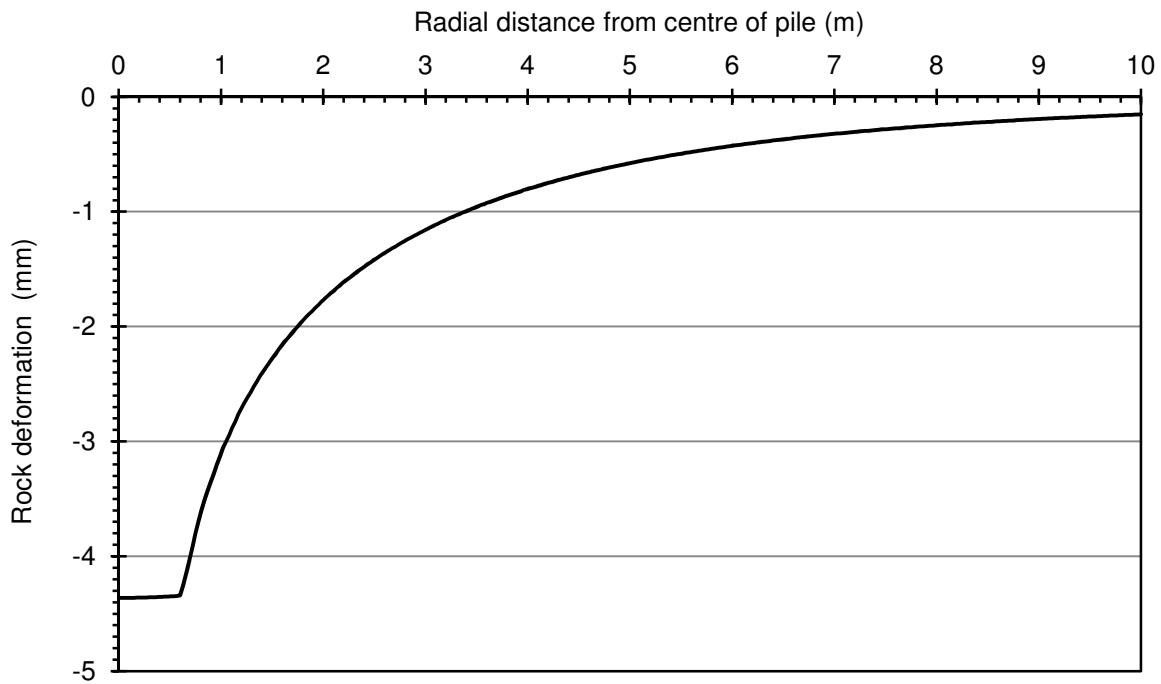


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 Darling Harbour Redevelopment  
 Proposed student accommodation towers  
 CURVATURE OF SEWER DUE TO ADJACENT  
 LOADED PILE (RUN 1 - 6800 kN)**

**PSM1986-009R**

**FIGURE 3**



Notes:

1. Sewer deformation assumes pile on opposite side of sewer loaded to only 3000 kN
2. Sewer located 2.9 m from centre of pile

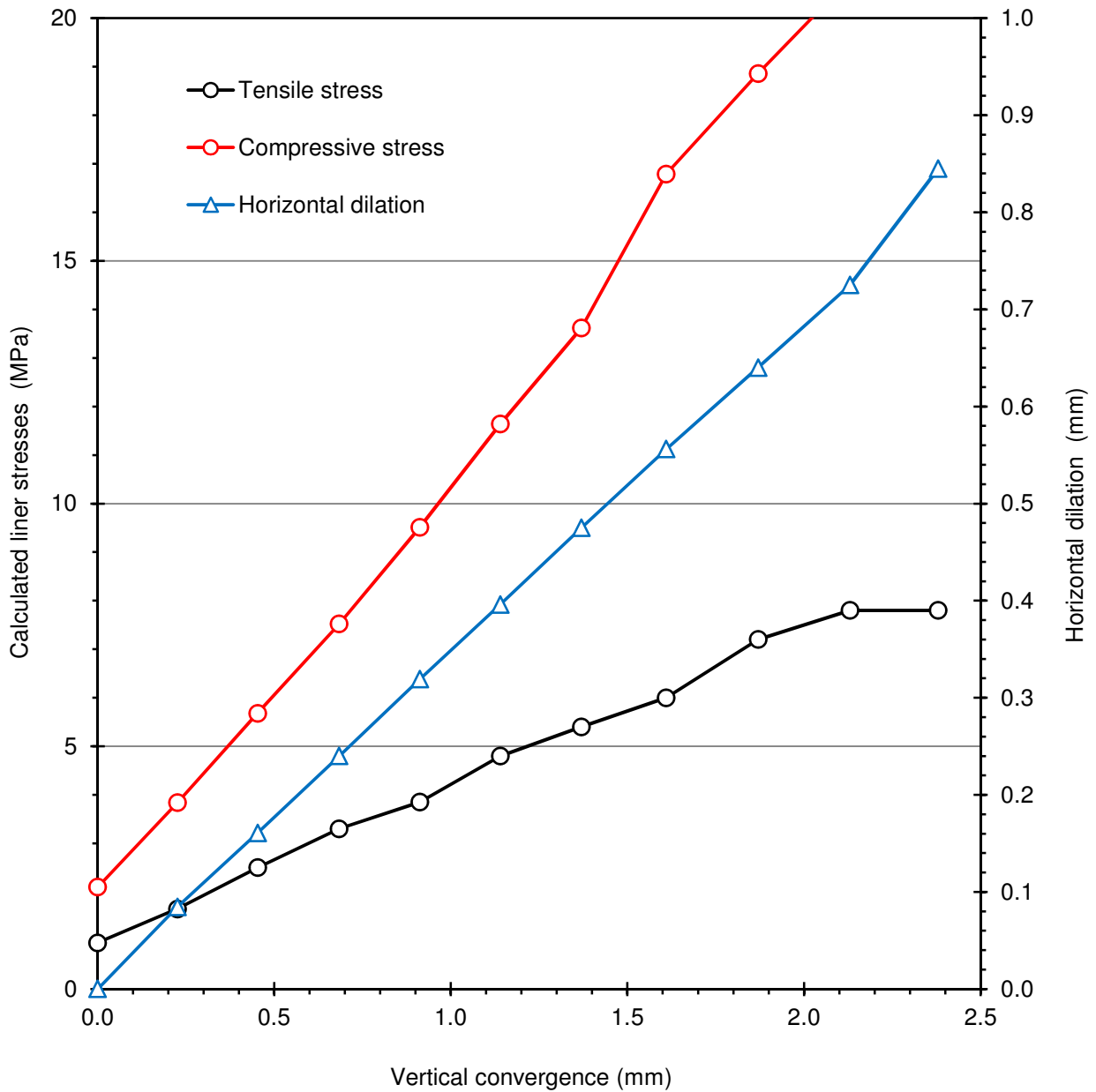


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Darling Harbour Redevelopment  
Proposed student accommodation towers  
CURVATURE OF SEWER DUE TO ADJACENT  
LOADED PILE (RUN 2 - 17,000 kN)**

**PSM1986-009R**

**FIGURE 4**



Notes:

1. Phase<sup>2</sup> analysis "CWCT - Run2.fez"

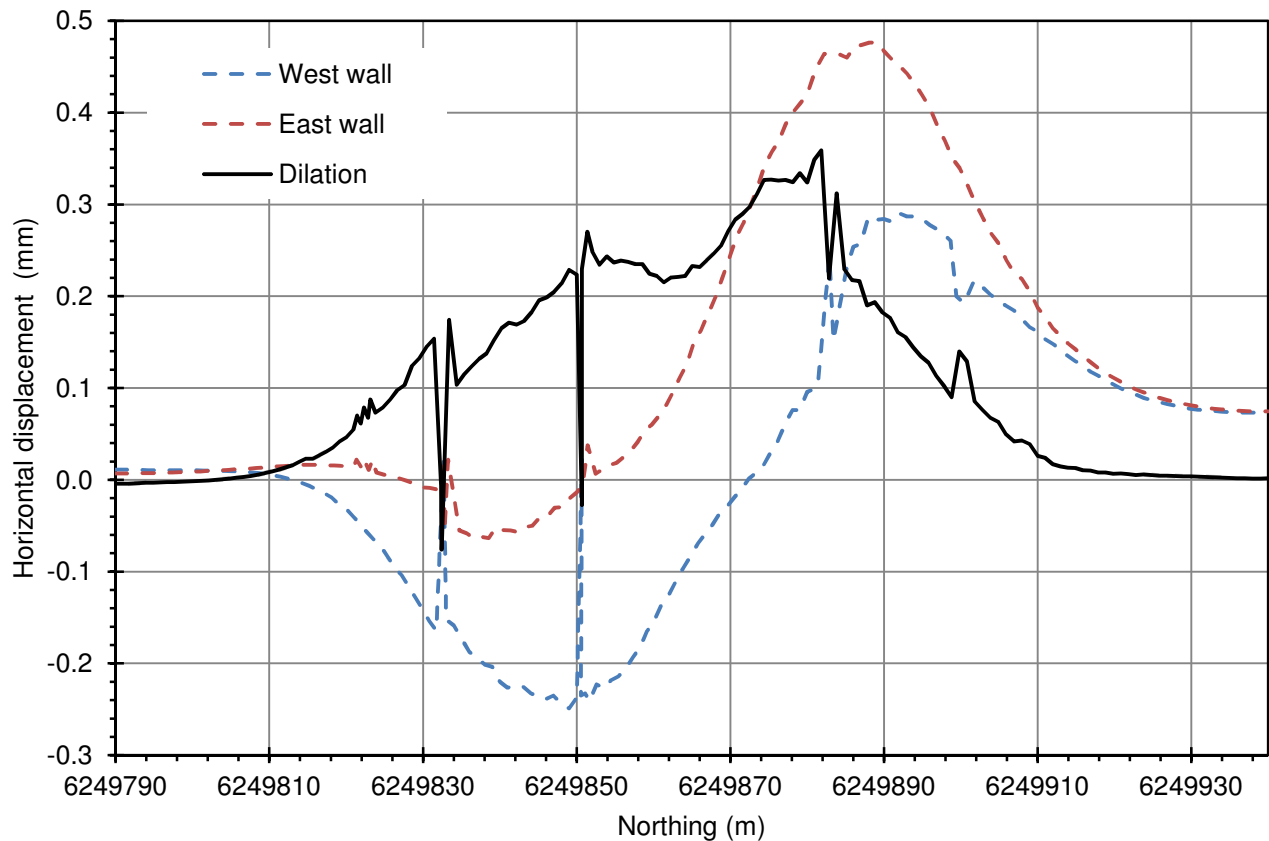
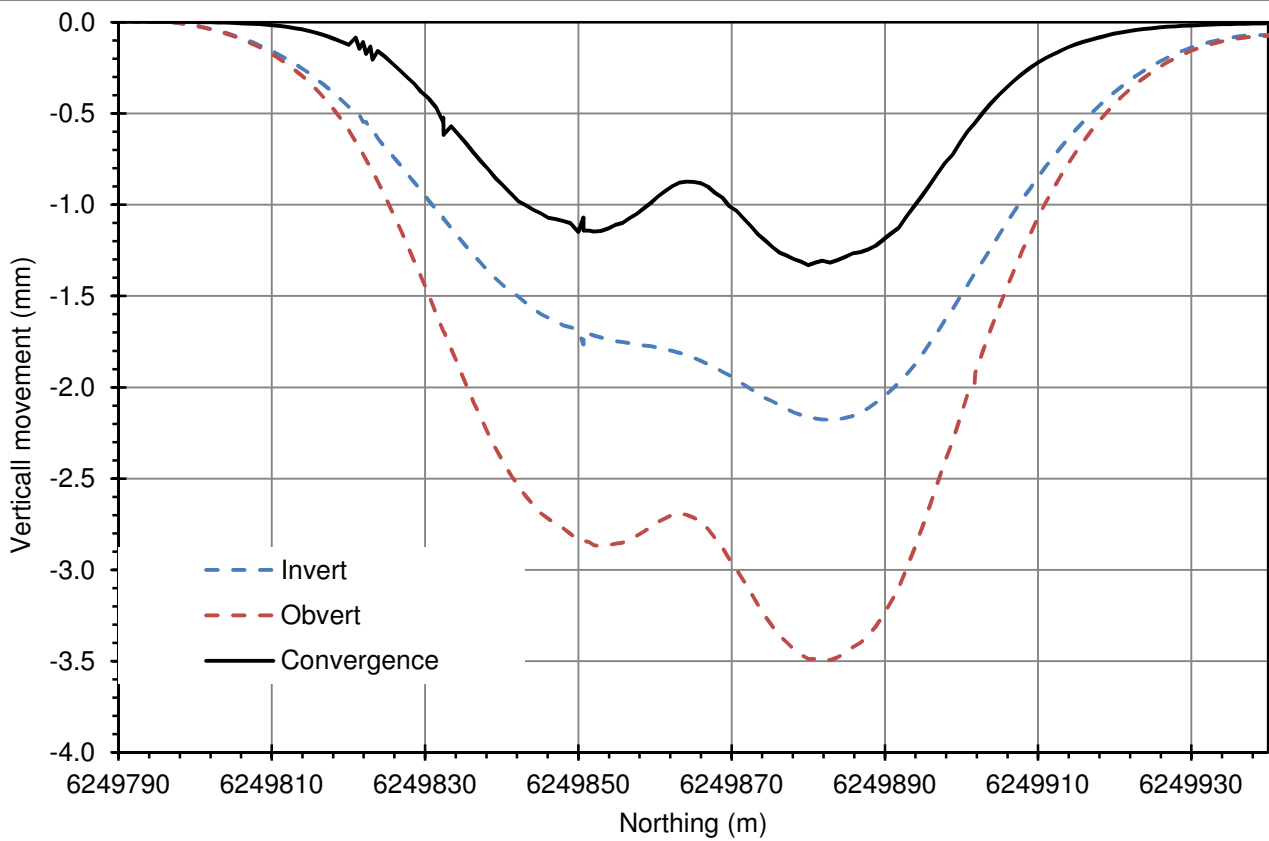


**Pells Sullivan Meynink**

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Darling Harbour Redevelopment  
Proposed student accomodation towers  
SUMMARY OF PHASE<sup>2</sup> ANALYSIS OF  
CWCT SEGMENTAL LINER**

**PSM1986-009R**

**FIGURE 5**



Notes:

1.



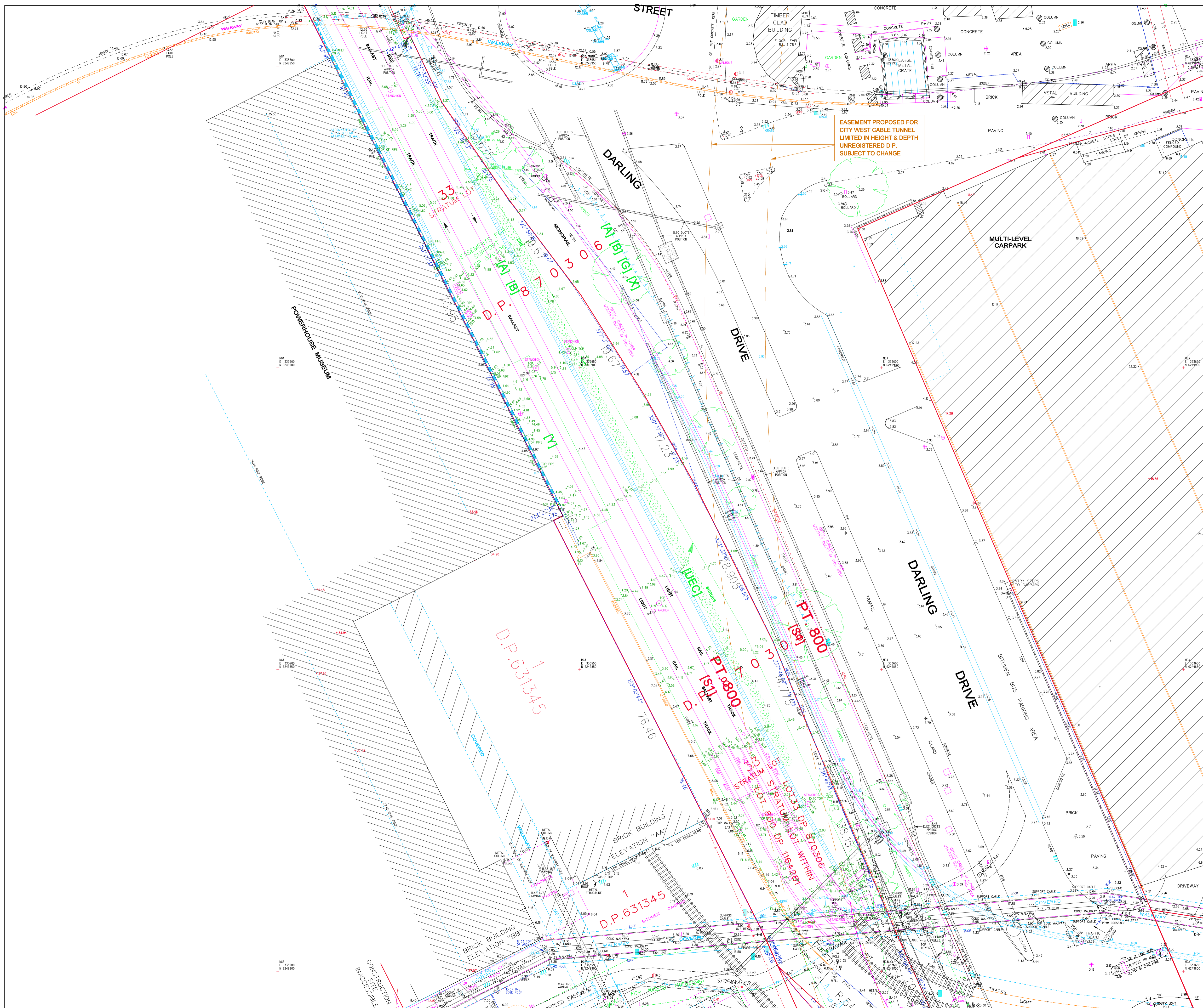
**Pells Sullivan Meynink**

**Lend Lease Developments Pty Ltd  
Darling Harbour Redevelopment  
Proposed student accomodation towers  
SUMMARY OF FLAC3D DEFORMATION  
ANALYSIS OF CWCT**

**PSM1986-009R**

**FIGURE 6**

**APPENDIX A**  
**SITE SURVEY PLAN**



EASEMENT PROPOSED FOR CITY WEST CABLE TUNNEL LIMITED IN HEIGHT & DEPTH UNREGISTERED D.P. SUBJECT TO CHANGE

**NOTES:**

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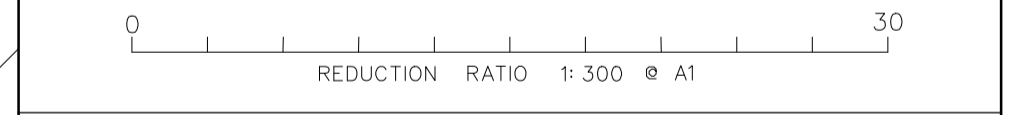
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P.W. Rygate & West  
ABN 61 001 204 897

Suite 904 Level 9, 89 York St  
Sydney NSW 2000  
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F +61 2 9262 6843  
E surveys@rygate.com.au  
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**SYDNEY**

**PLAN**  
PART OF OVERALL PLAN  
SHOWING DETAIL & LEVELS


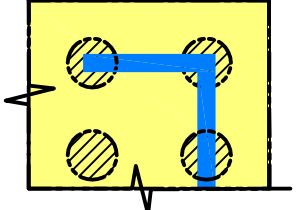

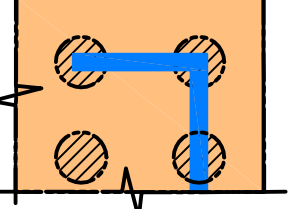
CAD REFERENCE 75660\_Student\_Housing\_survey

REFERENCE No.	PLAN No.	DATE	SHEET No. -
75660		7/2/2013	OF - SHEETS

**APPENDIX B**  
**PROPOSED BUILDING LAYOUT AND LOADS**

Robert Bird Group		
SICEEP DARLING HARBOUR		
STUDENT ACCOMMODATION		
CONCEPT FOOTING PLAN		
1:200 @A3	JL	12527
P1	11:02:13 AM	FOR INFO ONLY

\*PER PILE\*  
WORKING PILE LOADS  
(APPROXIMATE)

Legend	Vertical (kN)	Horizontal (kN)
 DENOTES NORTHERN BUILDING PILES/COLUMNS	13600	340
 DENOTES NORTHERN BUILDING CORE PAD WITH PILES UNDER AND WALLS OVER	10000	250
 DENOTES SOUTHERN BUILDING PILES/COLUMNS	12240	306
 DENOTES SOUTHERN BUILDING CORE PAD WITH PILES UNDER AND WALLS OVER	7500	250

NOTE: FOOTING, COLUMN, PILE + WALL LOCATIONS & LOADS ARE INDICATIVE ONLY, BASED ON PRELIMINARY ARCHITECTURAL PLANS BY ALLEN, JACK + COTTIER RECEIVED ON 7TH FEBRUARY, 2013




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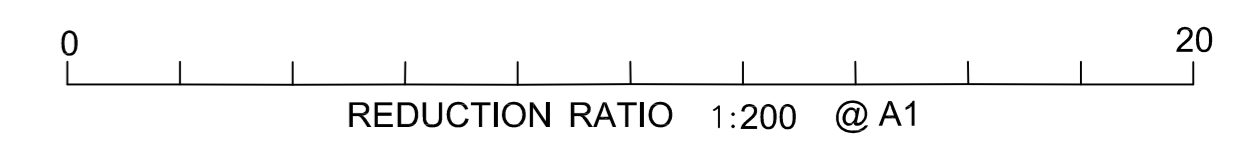
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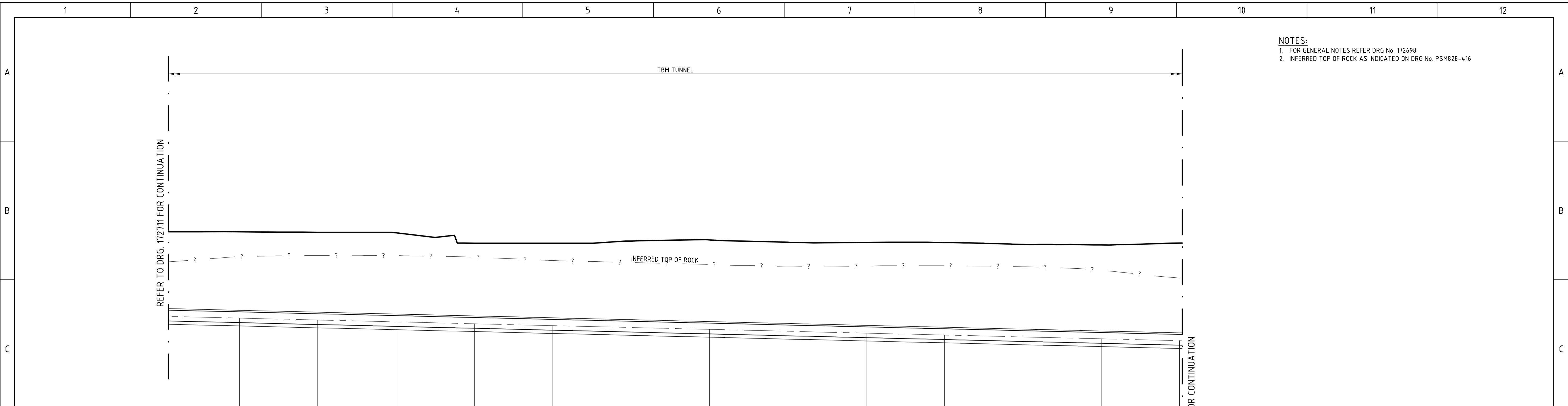
L.G.A.  
**SYDNEY**

**PLAN**  
SHOWING UNDERGROUND SERVICES LOCATIONS DERIVED FROM INFORMATION SUPPLIED BY DBYD, ULTIMO PYRMONT LIGHT RAIL NSW AND VERBAL ADVICE FROM POWERHOUSE MUSEUM PROPERTY SERVICES MANAGER WITHIN THE VICINITY OF PROPOSED STUDENT HOUSING.

CAD REFERENCE 75660\_Student Housing Services

REFERENCE No.	PLAN No.	DATE	SHEET No.
75660	75660	5.02.2013	1 OF 1 SHEETS

**APPENDIX C**  
**CITY WEST CABLE TUNNEL**  
**TENDER DRAWINGS**



**NOTES:**  
 1. FOR GENERAL NOTES REFER DRG No. 172698  
 2. INFERRED TOP OF ROCK AS INDICATED ON DRG No. PSM828-416

REFER TO DRG. 172711 FOR CONTINUATION

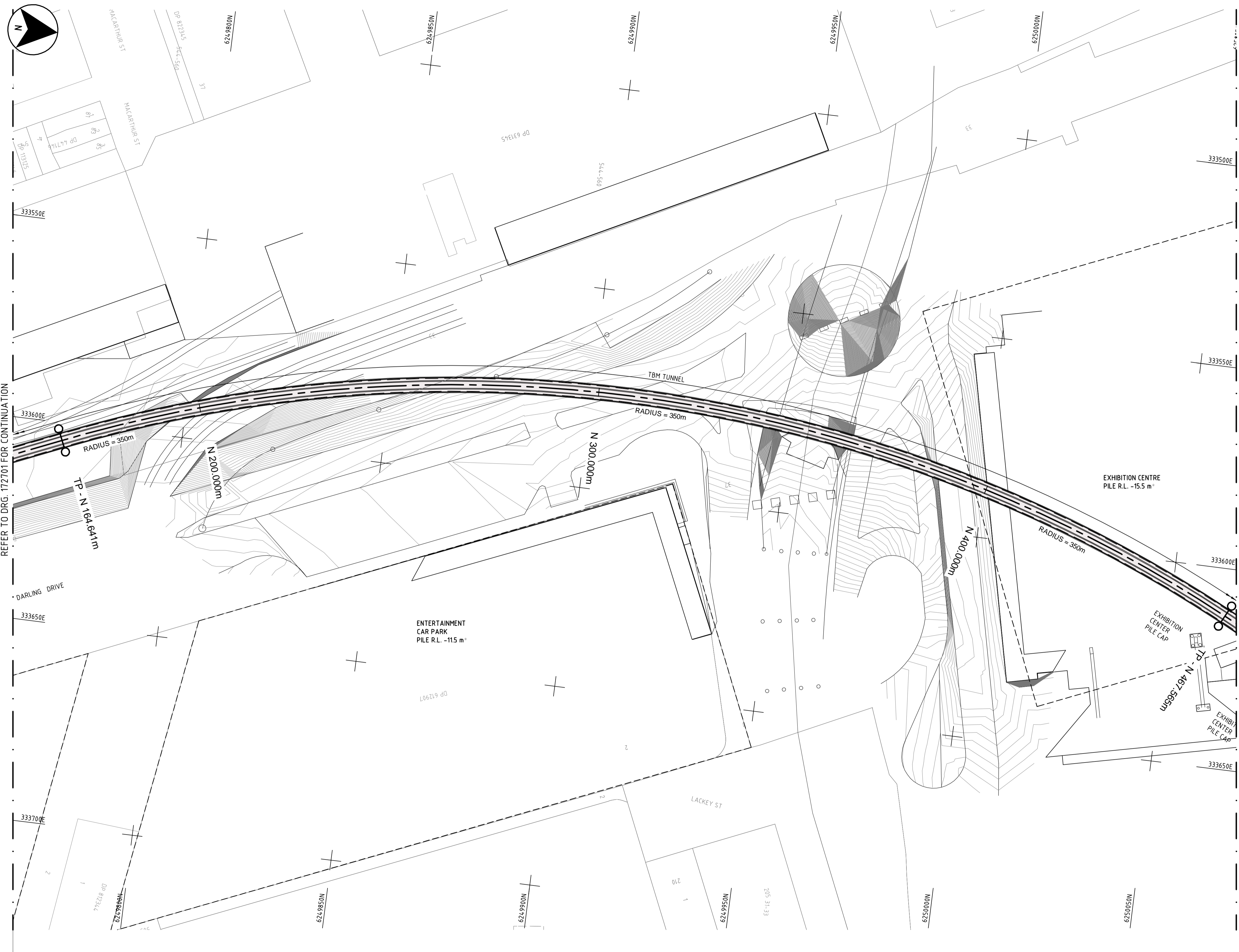
REFER TO DRG. 172713 FOR CONTINUATION

Datum -41	HORIZONTAL		VERTICAL	VC LENGTH
	VC LENGTH			
			-2.40%	350 R
TBM CONTROL LINE				
CWCT TOP OF INVERT SLAB				
METROWEST FLOOR				
CCT VENT FLOOR				
CCT FLOOR				
TOP OF ROCK				
EXIST SURFACE				
CHAINAGE				

**LONG SECTION - TBM TUNNEL**  
**MARY ANN ST. SHAFT TO CITY NORTH SUBSTATION**  
 SCALE 1:500

FOR TENDER

<p><b>CAD DRAWING</b> DO NOT MANUALLY AMEND</p> <p><b>AMENDMENTS</b></p> <table border="1"> <tr><td>A</td><td>PRELIMINARY</td><td>17.11.05</td></tr> <tr><td>B</td><td>PRELIMINARY</td><td>29.11.05</td></tr> <tr><td>C</td><td>ISSUED FOR 30% CONCEPT</td><td>19.12.05</td></tr> <tr><td>D</td><td>ISSUED FOR EA REVIEW</td><td>10.04.06</td></tr> <tr><td>E</td><td>ISSUED FOR TENDER</td><td>18.07.06</td></tr> </table>	A	PRELIMINARY	17.11.05	B	PRELIMINARY	29.11.05	C	ISSUED FOR 30% CONCEPT	19.12.05	D	ISSUED FOR EA REVIEW	10.04.06	E	ISSUED FOR TENDER	18.07.06		<p><b>MAUNSELL   AECOM</b></p> <p>Maunsell Australia Pty Ltd A.B.N. 20 093 846 925</p>	<p>MAJOR PROJECTS 138 HARRIS ST PYRMONT, NSW 2009 TEL: 02 9269 2954 FAX: 02 9269 2960</p>	<table border="1"> <tr><td>SCALE</td><td>AS SHOWN</td></tr> <tr><td>DESIGNED</td><td>J.A.</td></tr> <tr><td>DRAWN</td><td>M.N.</td></tr> <tr><td>CHECKED</td><td>W.J.</td></tr> <tr><td>APPROVED</td><td></td></tr> <tr><td>DATE</td><td>NOV.05</td></tr> <tr><td>PRJTRK No.</td><td></td></tr> <tr><td>PROJECT NUMBER</td><td>20026005.00</td></tr> </table>	SCALE	AS SHOWN	DESIGNED	J.A.	DRAWN	M.N.	CHECKED	W.J.	APPROVED		DATE	NOV.05	PRJTRK No.		PROJECT NUMBER	20026005.00	<p><b>CITY WEST CABLE TUNNEL</b> <b>GENERAL ARRANGEMENT</b> <b>VERTICAL ALIGNMENT</b></p>	<table border="1"> <tr><td>DRAWING No</td><td>172712</td></tr> <tr><td>SHEET 2 OF 7</td><td></td></tr> <tr><td>AMD</td><td>E</td></tr> <tr><td>SIZE</td><td>A1</td></tr> </table>	DRAWING No	172712	SHEET 2 OF 7		AMD	E	SIZE	A1
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B	PRELIMINARY	29.11.05																																											
C	ISSUED FOR 30% CONCEPT	19.12.05																																											
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E	ISSUED FOR TENDER	18.07.06																																											
SCALE	AS SHOWN																																												
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SIZE	A1																																												



**NOTES:**  
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 2. \* DENOTES BUILDING MAXIMUM STRUCTURAL DEPTH, RL ASSUMED TO BASE OF PILE.

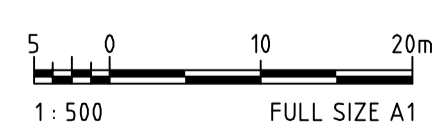
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**MAUNSELL | AECOM**

Maunsell Australia Pty Ltd  
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 138 HARRIS ST PYRMONT, NSW 2009  
 TEL: 02 9269 2954 FAX: 02 9269 2960

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DRAWN	W.J.
CHECKED	
APPROVED	
DATE	NOV.05
PRJTRK No.	
PROJECT NUMBER	20026005.00

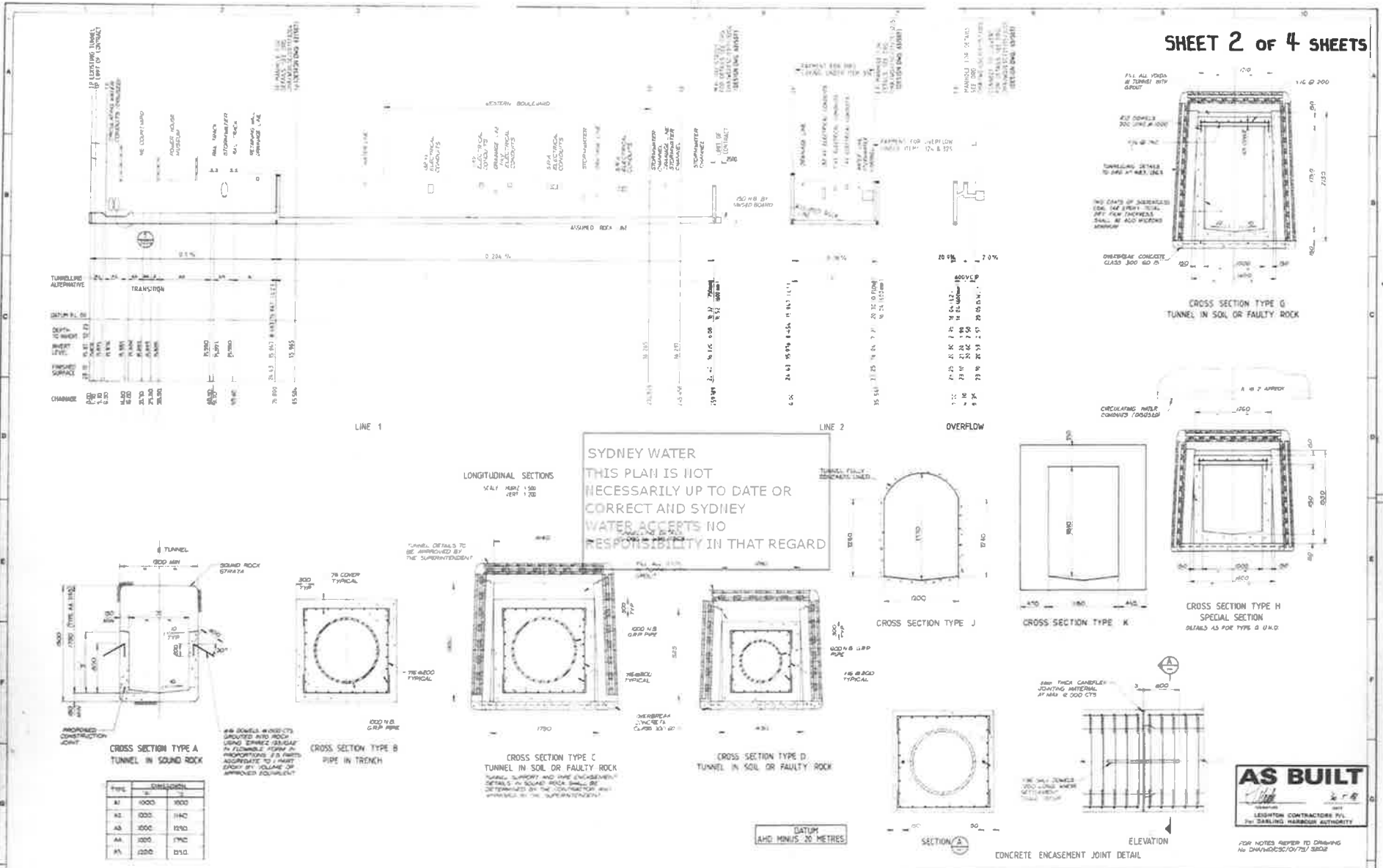
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 GENERAL ARRANGEMENT  
 HORIZONTAL ALIGNMENT**

DRAWING No	172702	SHEET 2 OF 7	AMD E	SIZE A1
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**APPENDIX D**  
**SEWER TUNNEL AS-BUILT DRAWINGS**





TUNNELLING ALTERNATIVE

DEPTH TO BENCH	DEPTH TO LEVEL	FINISHED SURFACE	CHAMBER
15.10	15.10	15.10	15.10
15.15	15.15	15.15	15.15
15.20	15.20	15.20	15.20
15.25	15.25	15.25	15.25
15.30	15.30	15.30	15.30
15.35	15.35	15.35	15.35
15.40	15.40	15.40	15.40
15.45	15.45	15.45	15.45
15.50	15.50	15.50	15.50
15.55	15.55	15.55	15.55
15.60	15.60	15.60	15.60
15.65	15.65	15.65	15.65
15.70	15.70	15.70	15.70
15.75	15.75	15.75	15.75
15.80	15.80	15.80	15.80
15.85	15.85	15.85	15.85
15.90	15.90	15.90	15.90
15.95	15.95	15.95	15.95
16.00	16.00	16.00	16.00
16.05	16.05	16.05	16.05
16.10	16.10	16.10	16.10
16.15	16.15	16.15	16.15
16.20	16.20	16.20	16.20
16.25	16.25	16.25	16.25
16.30	16.30	16.30	16.30
16.35	16.35	16.35	16.35
16.40	16.40	16.40	16.40
16.45	16.45	16.45	16.45
16.50	16.50	16.50	16.50
16.55	16.55	16.55	16.55
16.60	16.60	16.60	16.60
16.65	16.65	16.65	16.65
16.70	16.70	16.70	16.70
16.75	16.75	16.75	16.75
16.80	16.80	16.80	16.80
16.85	16.85	16.85	16.85
16.90	16.90	16.90	16.90
16.95	16.95	16.95	16.95
17.00	17.00	17.00	17.00

TYPE	DIAMETER
A1	1000
A2	1000
A3	1000
A4	1000
A5	1000

**AS BUILT**

LEIGHTON CONTRACTORS PTY LTD  
FOR DARLING HARBOUR AUTHORITY

<p>DATE: 15/05/2014</p> <p>APPROVED BY: [Signature]</p> <p>DATE: 15/05/2014</p> <p>APPROVED BY: [Signature]</p>	<p>DATE: 15/05/2014</p> <p>APPROVED BY: [Signature]</p> <p>DATE: 15/05/2014</p> <p>APPROVED BY: [Signature]</p>	<p>DATE: 15/05/2014</p> <p>APPROVED BY: [Signature]</p> <p>DATE: 15/05/2014</p> <p>APPROVED BY: [Signature]</p>	<p>DATE: 15/05/2014</p> <p>APPROVED BY: [Signature]</p> <p>DATE: 15/05/2014</p> <p>APPROVED BY: [Signature]</p>	<p>DATE: 15/05/2014</p> <p>APPROVED BY: [Signature]</p> <p>DATE: 15/05/2014</p> <p>APPROVED BY: [Signature]</p>	<p>DATE: 15/05/2014</p> <p>APPROVED BY: [Signature]</p> <p>DATE: 15/05/2014</p> <p>APPROVED BY: [Signature]</p>	<p>DATE: 15/05/2014</p> <p>APPROVED BY: [Signature]</p> <p>DATE: 15/05/2014</p> <p>APPROVED BY: [Signature]</p>	<p>DATE: 15/05/2014</p> <p>APPROVED BY: [Signature]</p> <p>DATE: 15/05/2014</p> <p>APPROVED BY: [Signature]</p>	<p>DATE: 15/05/2014</p> <p>APPROVED BY: [Signature]</p> <p>DATE: 15/05/2014</p> <p>APPROVED BY: [Signature]</p>	<p>DATE: 15/05/2014</p> <p>APPROVED BY: [Signature]</p> <p>DATE: 15/05/2014</p> <p>APPROVED BY: [Signature]</p>	<p>DATE: 15/05/2014</p> <p>APPROVED BY: [Signature]</p> <p>DATE: 15/05/2014</p> <p>APPROVED BY: [Signature]</p>	<p>DATE: 15/05/2014</p> <p>APPROVED BY: [Signature]</p> <p>DATE: 15/05/2014</p> <p>APPROVED BY: [Signature]</p>
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MAINWORKS CONTRACTOR  
**LEIGHTON**

CONTRACT NO: [Number]  
PROJECT: [Name]

**NEW DARLING HARBOUR AUTHORITY**

**DARLING HARBOUR DEVELOPMENT PROJECT**

W.N. 300418/5

**SITE SERVICES-SEWERAGE HAY STREET SUB-MAIN SECTIONS**

DATE: 15/05/2014  
DRAWN BY: [Name]  
CHECKED BY: [Name]  
DATE: 15/05/2014

**CMP8**

CONSTRUCTION MANAGEMENT PARTNERSHIP



