Building around existing tunnels

Seminar

Barangaroo South
protecting a future rail corridor

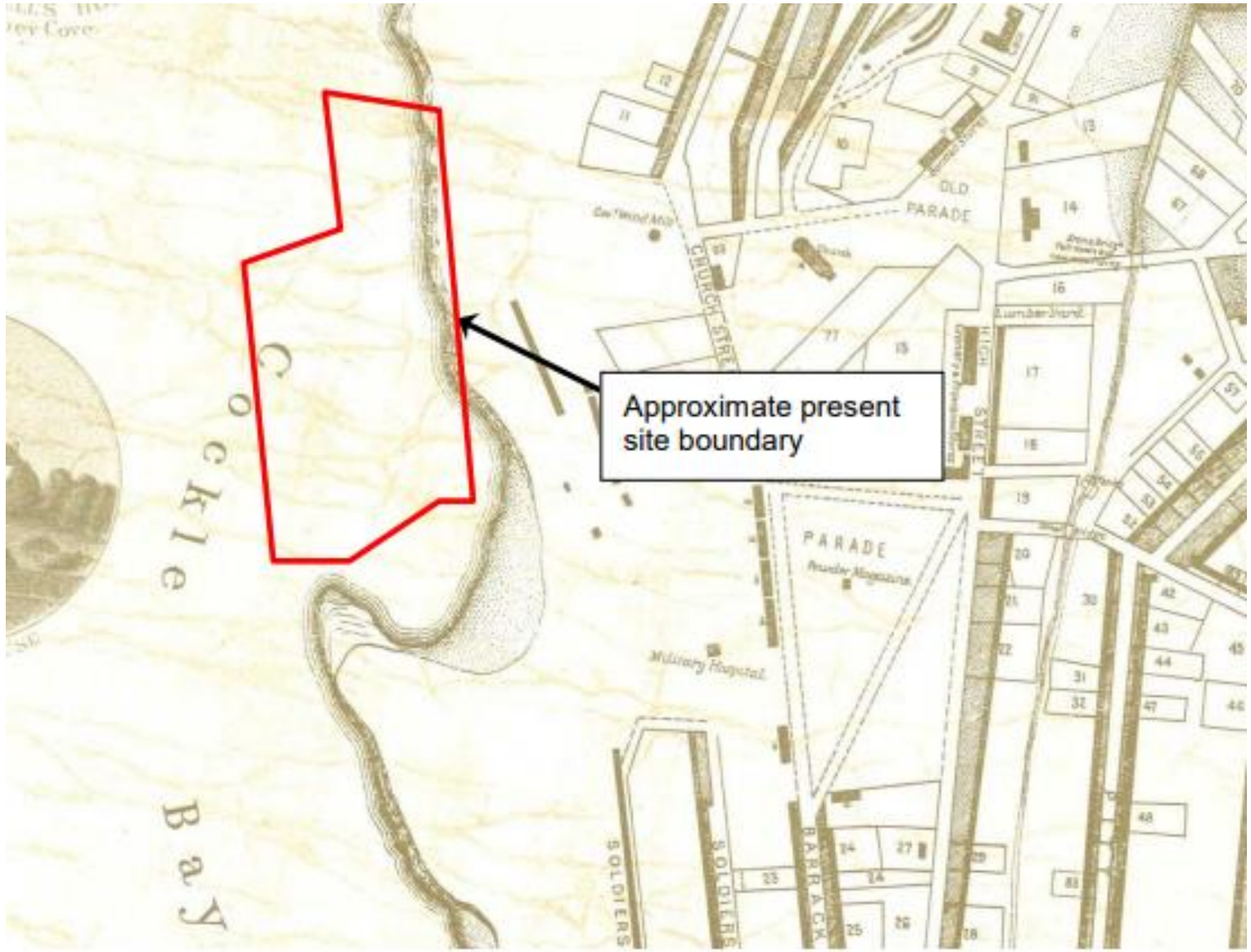
Ted Nye

E J Nye & Associates Pty Ltd

Sydney, 27 April 2023

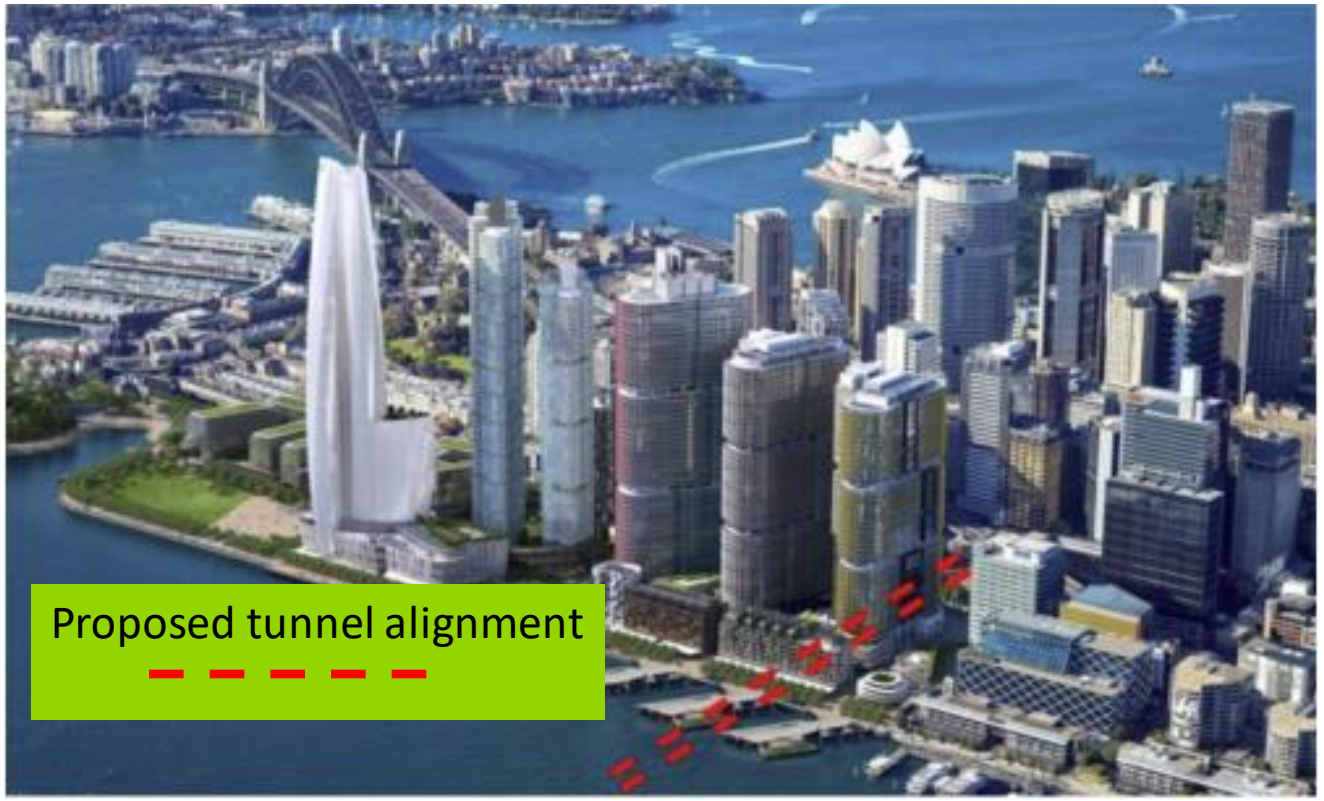
ENGINEERS AUSTRALIA | AUSTRALIAN TUNNELLING SOCIETY | 50 years 1972 - 2022 | AUSTRALIAN GEOMECHANICS SOCIETY

1. Introduction
2. Site description
3. Geological profile
4. Pile case studies
5. Basement/tunnel configuration
6. Tunnel Excavation method (TBM)
7. Risk matrix/assessment
8. Engineering assessment



Original harbour shoreline

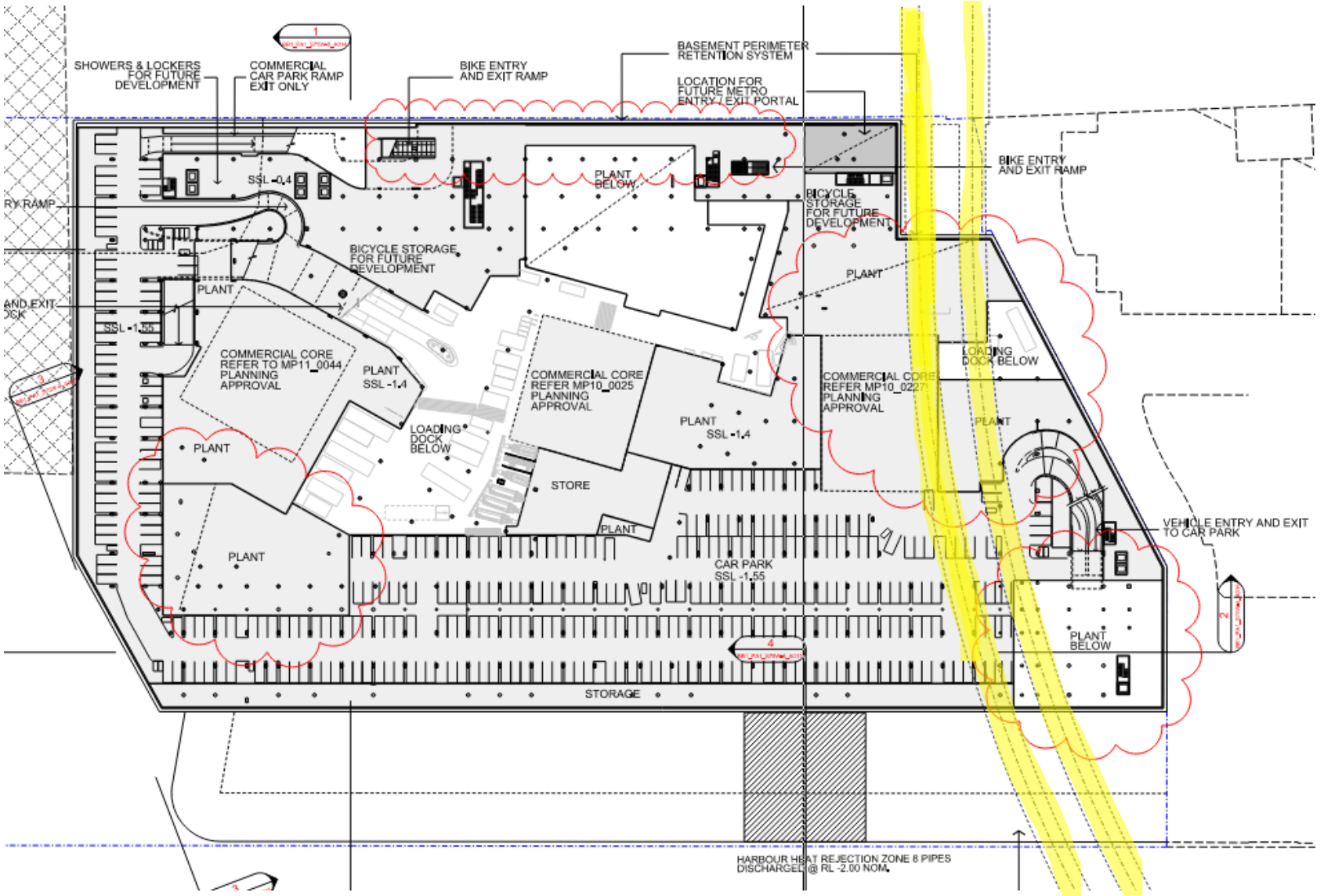
The 1930s



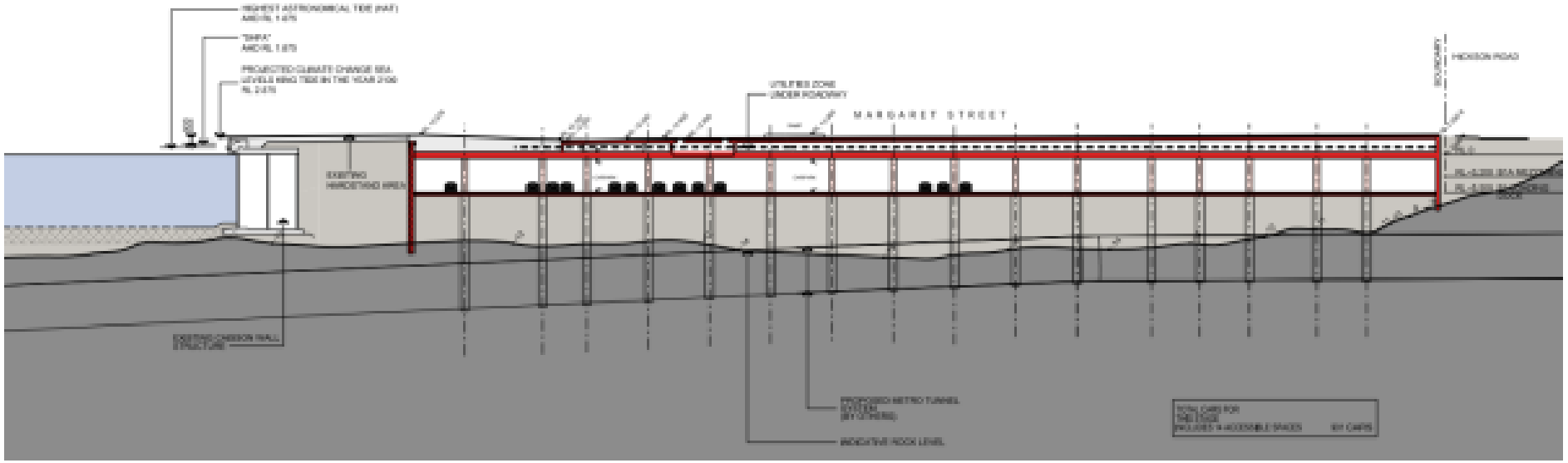
A few years ago

Development of Darling Harbour over time
(a creep foreshore into the harbour)

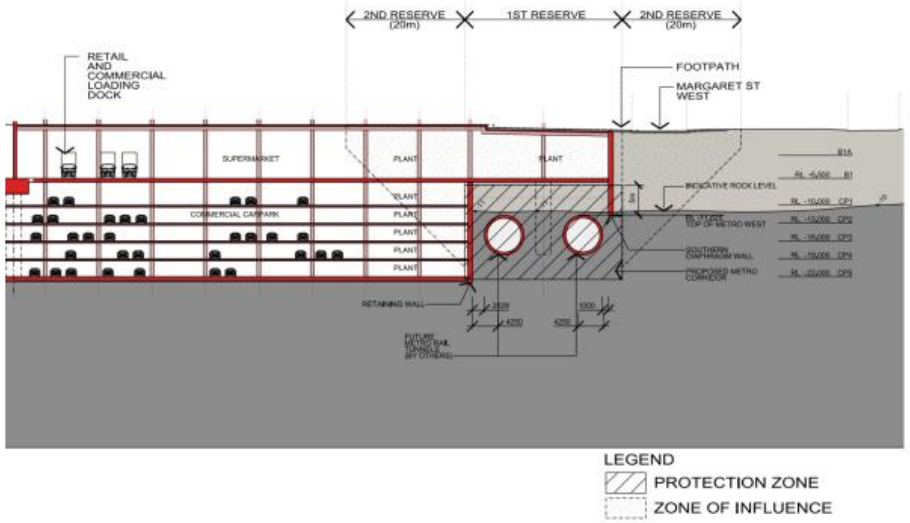
The now abandoned Sydney Metro alignment under the Barangaroo site



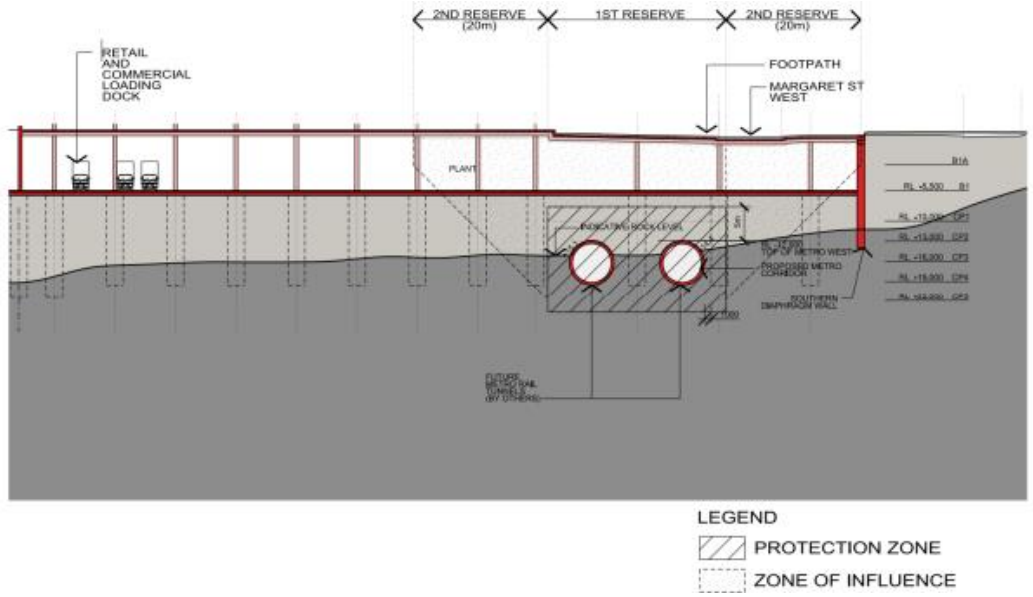
Plan view of tunnel alignment along the south boundary of the site



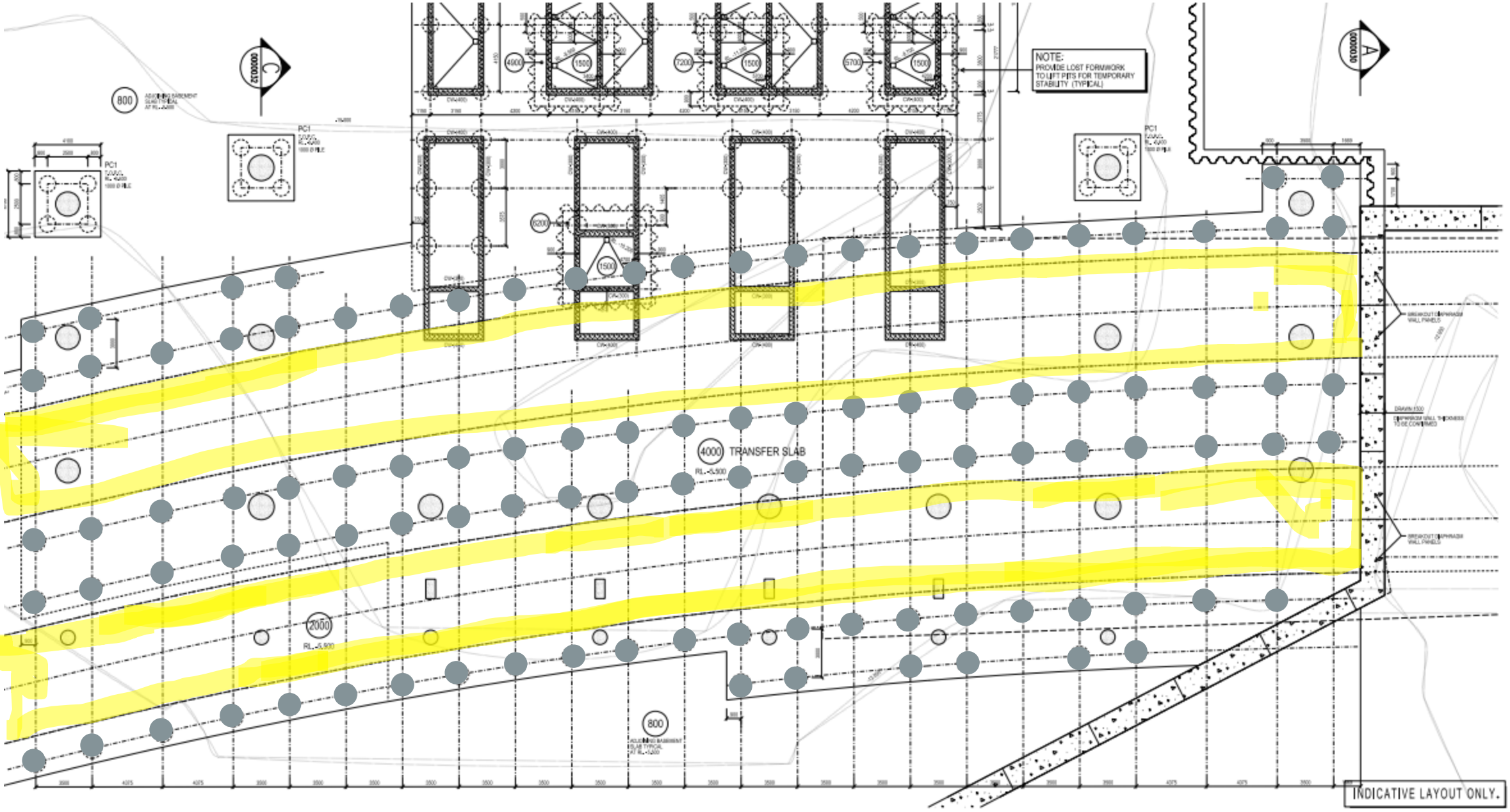
Long Section



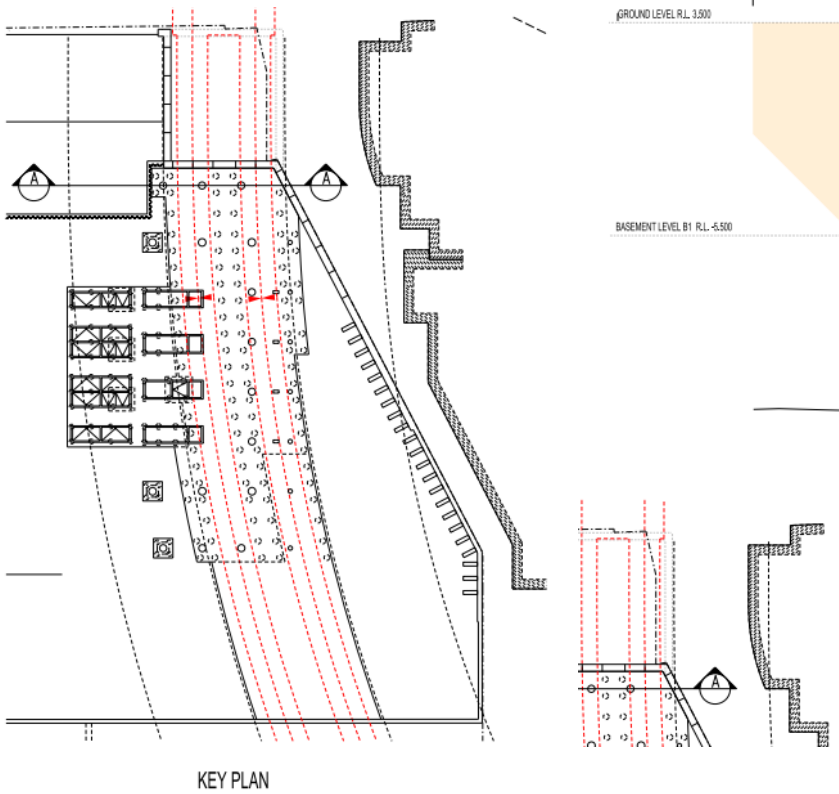
Cross section deep basement

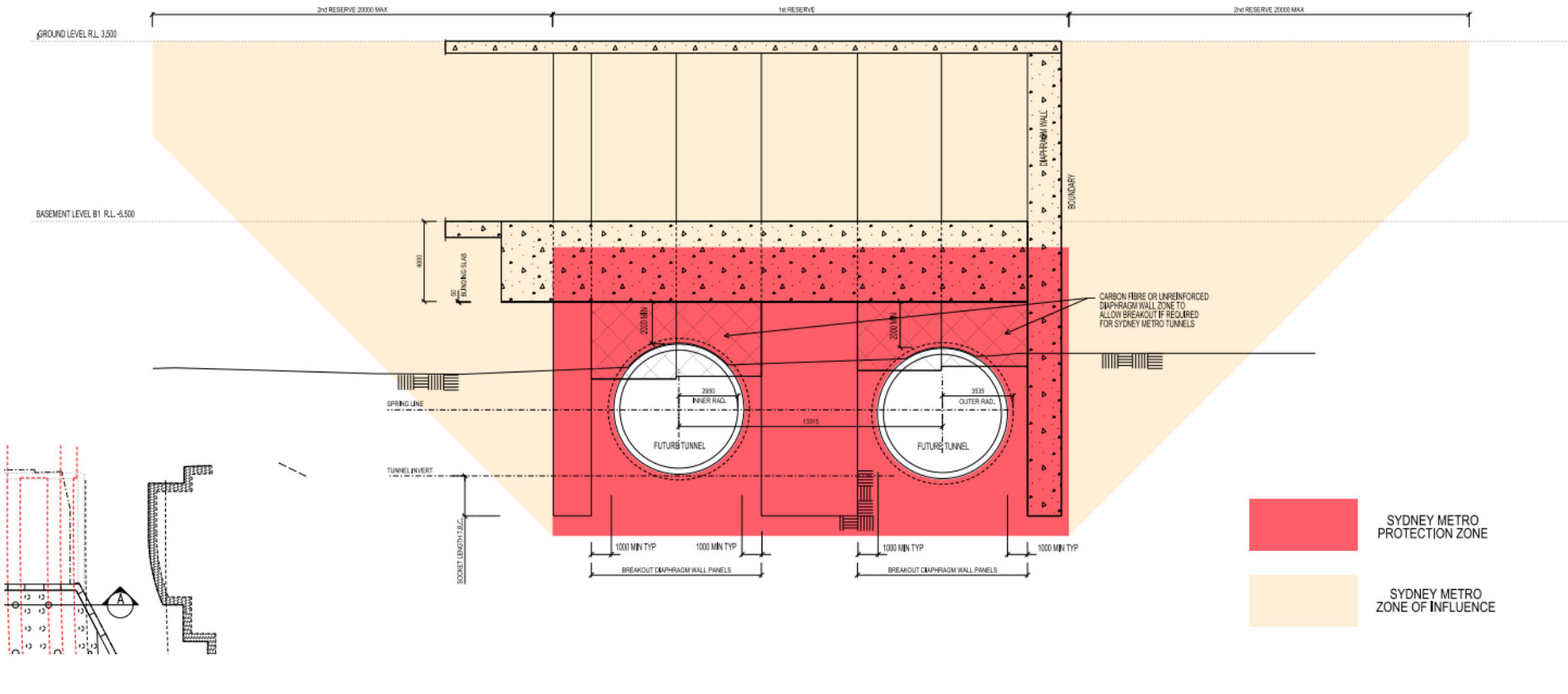


Other cross section

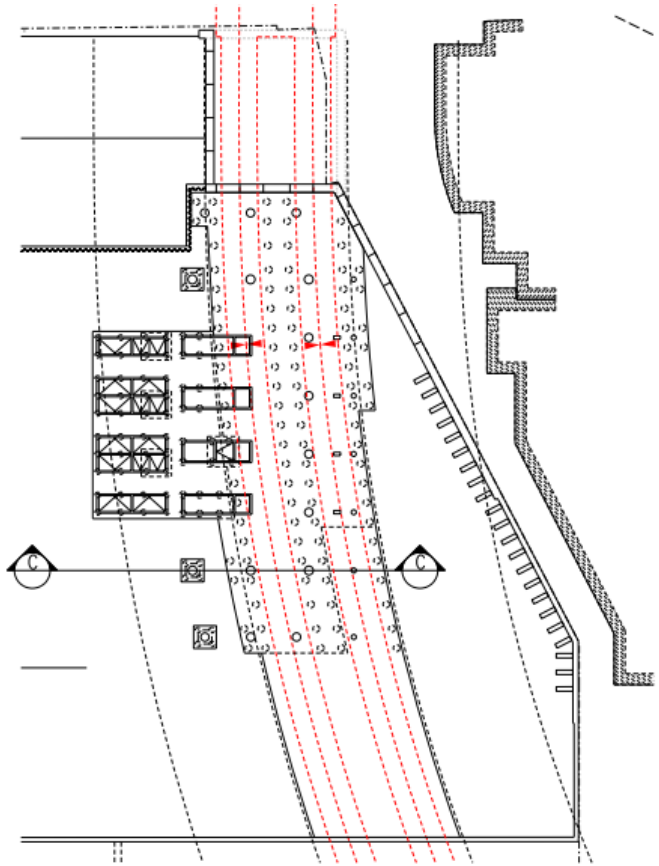


Plan layout of piles


KEY PLAN


2nd RESERVE 20000 MAX
1st RESERVE
2nd RESERVE 20000 MAX
GROUND LEVEL R.L. 3.500
BASEMENT LEVEL B1 R.L. -5.500
DIAPHRAGM WALL
BOUNDARY
BUILDING SLAB
CARBON FIBRE OR UNREINFORCED DIAPHRAGM WALL ZONE TO ALLOW BREAKOUT IF REQUIRED FOR SYDNEY METRO TUNNELS
2000 MIN
2990
INNER RAD.
3535
OUTER RAD.
13315
SPRING LINE
FUTURE TUNNEL
FUTURE TUNNEL
TUNNEL INVERT
SOCKET LENGTH T.B.C.
1000 MIN TYP
1000 MIN TYP
1000 MIN TYP
1000 MIN TYP
BREAKOUT DIAPHRAGM WALL PANELS
BREAKOUT DIAPHRAGM WALL PANELS
SYDNEY METRO PROTECTION ZONE
SYDNEY METRO ZONE OF INFLUENCE

Section A - A



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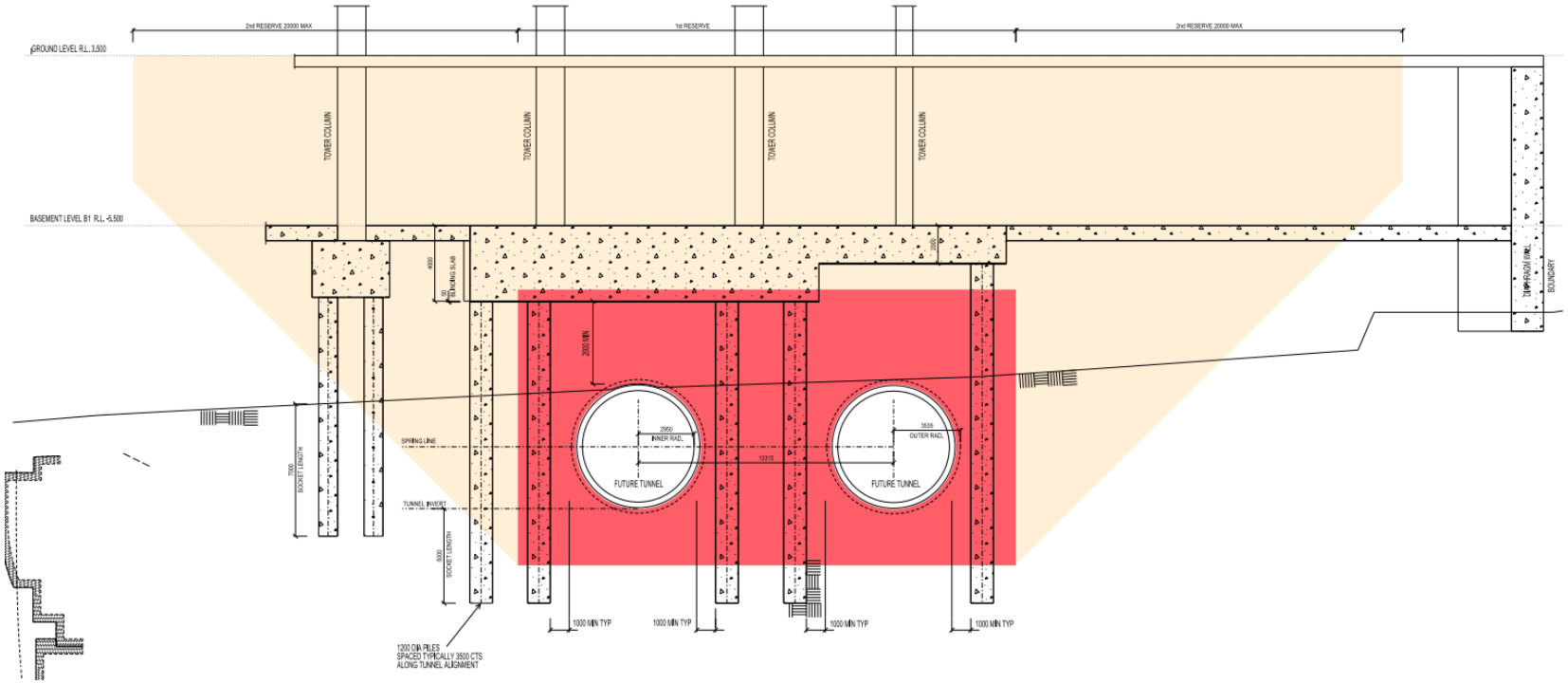


Section C - C

Tunnelling Under Existing Buildings – Using a slurry or EPB TBM						
#	Project	Description	Ground Conditions	Tunnelling Method	Building foundation description	Reference Source
1	Airport Line - Sydney Airport (1995 – 2000)	Domestic Terminal, tunnelling under existing 5-storey car park and also under a new car park designed to accommodate the new tunnel to traverse beneath.	Saturated sands with a near surface water table.	A 10m diameter slurry TBM with 450mm a thick concrete segmental liner. The ground cover to the crown of the tunnel was 12m along this section of tunnel.	8m long friction piles in sand. Multiple piles under each building column. The TBM passed below the piles with a 4m vertical clearance. The old car park has five floors and the new car park was initially built with five floors with four floors added around 2005.	Experience on the project. Also refer to paper published in 1999 regarding tunnelling under airport airside. Appendix E
2	Taipei Metro-Jonghe Line 1994-95	Twin metro tunnels under various buildings of 4 to 6 storeys	Mixed ground of clay/sand and gravel	Tunnels were built using a 6.3m diameter EPB TBM	Shallow friction piles were used under these buildings.	Experience on the project.
3	Bangkok Metro – Initial project 1999	Twin metro tunnels under road bridges along the alignment under Thanon Asoke	Soft to stiff clay	Bridges were on friction piles founded below the tunnel. Piles in alignment were removed after the bridge had been underpinned. Tunnels were built using a 6.3m diameter EPB TBM	Deep friction piles were used under these bridges.	Experience on the project
4	Lisbon Metro-Rossio – Cais do Sodre metro extension	Metro tunnels passing at low cover under a 19th century masonry building that had been underpinned	Mixed face of clay and granular fill	Tunnels were built using an EPB TBM	Building was on pads and short piles,	Lisbon Metro – Strengthening of buildings above the tunnels in the city center. J. Moreira and A. Floor - Proceedings ITA World Tunnel Conference 1998,

Tunnelling Under Existing Buildings – Using a slurry or EPB TBM						
#	Project	Description	Ground Conditions	Tunnelling Method	Building foundation description	Reference Source
5	Circle Line 5 – Singapore 2009	Twin metro tunnels under a 15 storey building	Weathered to completely weathered mudstones and fill (mixed)	Building was on piles, it was underpinned so that the piles in the tunnel alignment could be disconnected. Clearances to new piles were less than 1m for the tunnel drives, that were built using a 6.2m diameter EPB TBM	1.5m bored piles were in place. The underpinning used barrettes to support the transfer structure. Existing piles and barrettes were founded below tunnel spring line, and imposed no loads on the tunnel lining	Experience on the project.

Building Excavation Around Existing Tunnels						
#	Project	Description	Ground Conditions	Tunnelling Method	Building foundation description	Reference Source
1	ANA Hotel – "The Rocks" Sydney. Now called the Shangri La Hotel.	35 storey hotel with deep basement constructed over and adjacent to the twin track rail tunnel between Wynyard and Circular Quay.	Class I and II Sydney Sandstone	Tunnel constructed in the 1930s, probably drill and blast with unreinforced concrete arch over crown and un-support vertical rock side walls.	Seven bored piers drilled down both sides of tunnel 1.5m from rock face of inside wall of tunnel. Largest bored pier 2m in diameter and 18m in depth. All founded below rail level in rock sockets. Excavation within 3m of the tunnel crown. 2.5m deep concrete transfer slab over the tunnel.	Experience on project. Paper published 1990. Appendix E

Reviewed numerous case studies

Piling case study 1

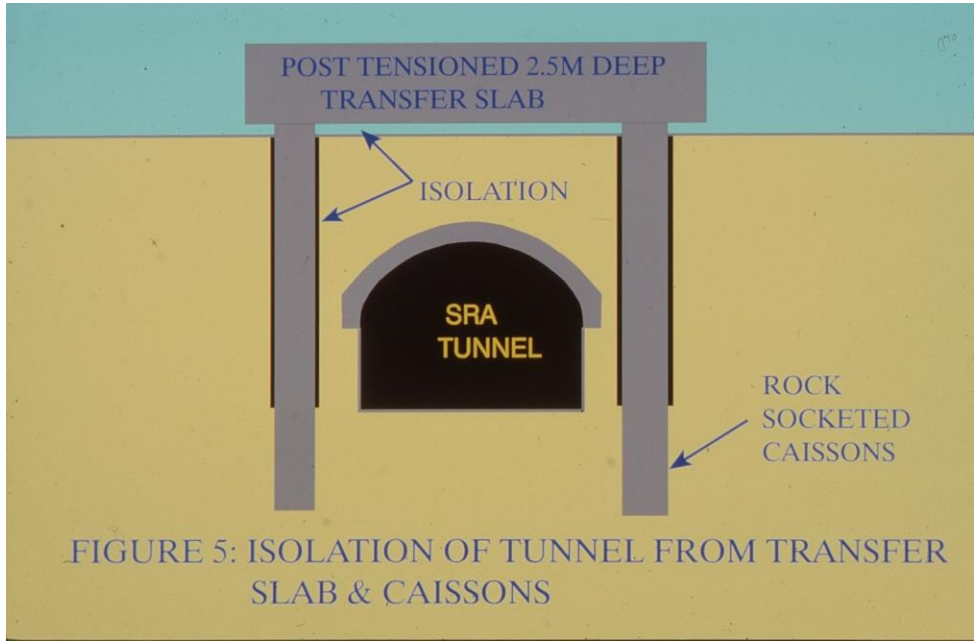
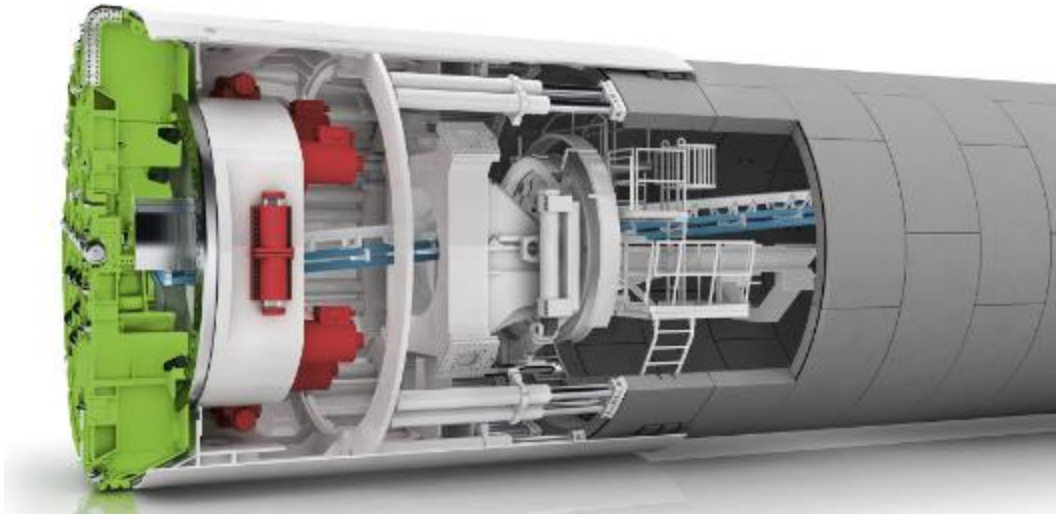
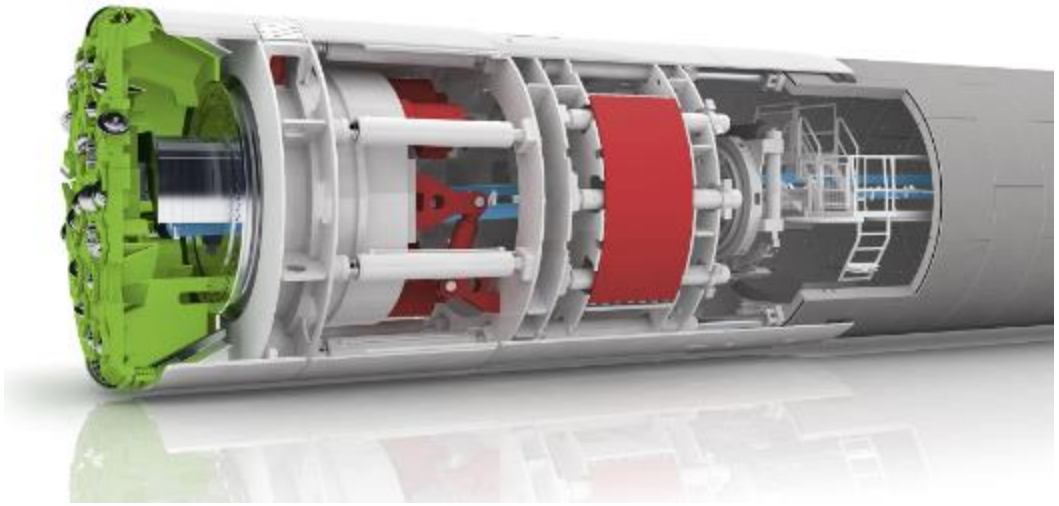


FIGURE 5: ISOLATION OF TUNNEL FROM TRANSFER SLAB & CAISSONS

Piling – Shangri La Hotel – The Rocks - 1988



Pushes off tunnel lining segments



Would not want to use side gripers

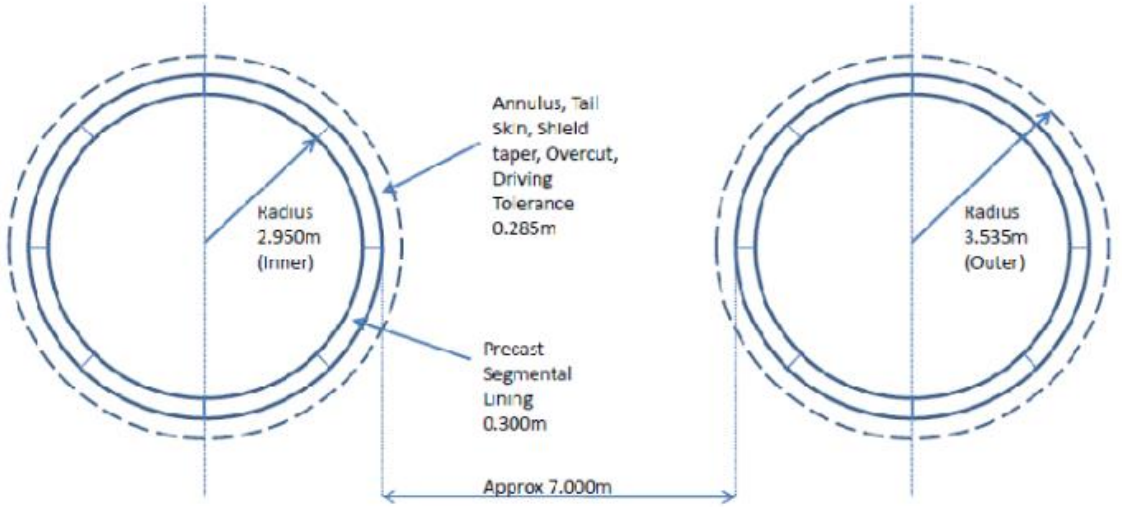
There are many types of TBMs

(has to be able to transition under the site and under Darling Harbour)

Protection Zone		Construction Activities	Conditions Guidelines
1st Reserve	Inside Protection Zone		Construction not permitted to directly encroach upon Protection Zone ***except where it can be demonstrated to the satisfaction of Sydney Metro that the encroachment will not have unacceptable structural or operational impacts on the metro corridor***.
	Outside Protection Zone	Surface excavation	Engineering assessment required from developer where surface excavations are proposed directly above station caverns and crossover caverns.
2nd Reserve		Surface excavation	
		Foundations	Engineering assessment is not required if calculated bearing pressures are less than 150KPa for shallow footings and strip footings are less than 3m by 3m in plan. For all other shallow foundations an engineering assessment is required of the developer. Engineering assessment is not required from developer if loading from deep foundations (including shaft friction) is transferred to below the boundary of the influence zone. Engineering assessment required from developer where the above condition is not satisfied for deep foundations.
		Underground Excavation (e.g. tunnel/cavern construction), ground anchors and demolition activities.	Developers must demonstrate through an engineering assessment that loading from shallow foundations will not adversely impact the future Line 1 MetroC.
		Geotechnical investigation and directional drilling	Assessment not required.

Running Tunnels internal radius	2.950m
Segmental lining	0.300m
Annulus between the inside of the tail-skin and the segments	0.100m
Tail skin thickness	0.030m
Shield Taper	0.030m
Overcut (including allowance for cutter wear)	0.025m
Driving tolerance (as specified)	0.100m
TOTAL TUNNEL RADIUS	**3.535m**
TOTAL TUNNEL DIAMETER (EXTENT OF TBM CUT PROFILE)	**7.070m**

Twin Tunnel (bored)



Sydney Metro Criteria

Likelihood Ratings

Likelihood	Category	Description
Almost Certain	A	The event is expected to occur in most circumstances
Likely	B	The event will probably occur in most circumstances
Possible	C	The event should occur at some time
Unlikely	D	The event could occur at some time
Rare	E	The event could occur only in exceptional circumstances

Risk Consequence Descriptors

Consequences	Category	Description
Catastrophic	5	The consequences would threaten the event and the event organisation. e.g. death, huge financial loss
Major	4	The consequence would threaten the continued effective functioning of the event organisation and therefore the event e.g. major financial loss, important external resources required.
Moderate	3	The consequences would not threaten the event, but would mean that the event would be subject to manageable changes e.g. high financial loss, medical treatment required.
Minor	2	The consequences would not threaten the efficiency or effectiveness of some aspects of the event, but would be dealt with internally e.g. medium financial loss, first aid treatment.
Insignificant	1	Consequences would be dealt with by routine operations, e.g. no injuries, no financial loss.

Level of Risk Martrix

Likelihood	Consequence				
	1 Insignificant	2 Minor	3 Moderate	4 Major	5 Catastrophic
A Almost Certain	Moderate	High	High	Extreme	Extreme
B Likely	Moderate	Moderate	High	High	Extreme
C Possible	Low	Moderate	High	High	High
D Unlikely	Low	Low	Moderate	Moderate	High
E Rare	Low	Low	Moderate	Moderate	High

Risk assessment – AS/NZ 4360:2004 – Likelihood, Risk Consequence and Matrix Tables

#	Description	Likelihood	Category	Risk (L,M,H,E)	Mitigation	Likelihood	Category	Risk (L,M,H,E)	Comments
1	Potential for bulk excavation to adversely impact on surrounding rock mass due to changes in the in-situ stresses.	B	1	M	It is highly unlikely that any changes in ground stress or displacement caused by the excavations will have any impact whatsoever on the future tunnelling works (in fact the basement excavation will decrease the potentially high theoretically existing predicted horizontal ground stresses). Any movements due to the Barangaroo basement excavations will occur at the time of those excavations and prior to the commencement of the Sydney Metro tunnelling works. Sydney sandstone is classed in tunnelling terms as a soft rock(UCS < 100MPa) and a TBM would have no difficulty cutting this rock either in a highly fractured state or in the form of massive rock mass without defects or displacements across these defects. Coffey has demonstrated through theoretical modelling that the changes in in-situ rock stress distribution are largely independent of the proximity of the Lend Lease basement wall to the tunnel.	E	1	L	Negligible risk to future tunnel. Refer also to Coffey Geotechnics memo report and analysis.
2	Temporary ground anchors supporting retention walls or retention piles intersect the tunnel alignment.	C	3	H	Design temporary ground anchors that are required as part of the Lend Lease basement perimeter ground water control and retention system works so that they do not intersect the future running tunnels. Modern anchor design permits a wide variety of anchor lengths, configurations and	E	2	L	Negligible risk

#	Description	Likelihood	Category	Risk (L,M,H,E)	Mitigation	Likelihood	Category	Risk (L,M,H,E)	Comments
					orientations. Accurately survey the drilled position of the ground anchor hole using down-hole survey instrument before placing ground anchor and grouting. The accurate positioning of ground anchors is considered standard practice using proven industry techniques.				
3	Potential for the basement perimeter ground water control and retention walls (diaphragm walls or equivalent) required to retain soft material overlying the sandstone rock to impact (intrude into) upon the path of the TBM	D	2	L	There is one instance where the Lend Lease basement perimeter ground water control and retention wall (diaphragm wall or equivalent) has the potential to intersect the tunnel alignment. This may occur where the wall passes perpendicular and over the CBD metro corridor. If applicable, the basement perimeter ground water control and retention wall will be designed to incorporate mass concrete wall panels within to the extent required to enable the TBM to pass through. The use of unreinforced diaphragm wall panels such as around station boxes which are subsequently penetrated by TBMs is standard practice.	D	2	L	Refer to Appendix C location and sections including diaphragm walls.
4	Adverse effect of the Lend Lease basement works on the existing permanent ground water table.	D	2	L	The Lend Lease basement perimeter ground water control and retention wall (diaphragm wall or equivalent) will control ground water ingress so that the existing long term water	D	2	L	The position of the ground water table whether retained or amended through the retaining works will not

#	Description	Likelihood	Category	Risk (L,M,H,E)	Mitigation	Likelihood	Category	Risk (L,M,H,E)	Comments
					level will be largely unchanged. The construction of perimeter retention systems to control groundwater inflow is conventional engineering practice.				significantly change the already existing risk with respect to ground water.
5	Loss of surcharge above the tunnel due to basement excavation.	C	3	H	The Lend Lease prepared Generic Structural Foundation Concepts propose the retention of a minimum of 2m above the tunnels in all cases which will provide sufficient surcharge for the TBM construction.	E	1	L	The ground above the tunnel is also confined by the overlying transfer structure.
6	Ravelling of ground (soft or rock) at the TBM face.	C	2	M	A Slurry or EPB TBM is designed specifically to prevent ravelling in front of the TBM face. In the unlikely event that ravelling occurs the TBM will traverse through that area of ground and any subsequent void remaining behind the segmental lining will be filled.	C	2	M	This risk remains regardless of whether the Barangaroo development is there or not.

#	Description	Likelihood	Category	Risk (L,M,H,E)	Mitigation	Likelihood	Category	Risk (L,M,H,E)	Comments
7	Risk of TBM departing from the design alignment such that there is the potential to conflict with Building C5 or the basement walls and foundations.	D	4	M	Allow a 1m clearance in addition to tunnel and Lend Lease's structural tolerances. Industry standard tolerances on metro tunnel construction range from + or - 50mm in Singapore up to + or – 70mm used in Bangkok. Therefore the 100mm tolerance allowed in the Metro specification is considered readily achievable. Modern TBMs use computerised guidance systems that give very clear indications of where the TBM is in relation to the design alignment. These systems can be set up to sound alarms both on the TBM and in the supervision (Contractor and Owner) offices if the TBM deviates from the required alignment or is likely to deviate so that the TBM alignment can be corrected. The control and management of the tunnel alignment to maintain design tolerances using conventional TBM technology is considered standard industry practice.	E	4	L	Risk reduced because of mitigation measures described. Advance rate of TBM relatively slow so that the mitigation measures described in the construction phase would be effective.

#	Description	Likelihood	Category	Risk (L,M,H,E)	Mitigation	Likelihood	Category	Risk (L,M,H,E)	Comments
8	Risk of Lend Lease's Building C5 or the basement foundations including the perimeter ground water control and retention walls being constructed outside the design tolerances (that have been agreed with Sydney Metro).	D	4	M	Coordinate the Sydney Metro and Barangaroo survey grids and certify survey set out by registered surveyor. Utilise modern three dimensional CAD software for the design and coordination of the Lend Lease basement foundations including the perimeter ground water control and retention walls and the CBD Metro tunnel alignment. This software is considered standard practice for modern major infrastructure and development projects. Require Australian Standard construction tolerances for the piling works (as a minimum). Ensure during construction of the basement foundations including the perimeter ground water control and retention walls that they are constructed within the specified tolerances. Before lowering steel reinforcement cages and backfilling with concrete have independent check of pile/diaphragm wall vertical alignment and depth. This is managed through suitable quality control processes. Mark the tunnel outline on the ground surface.	E	4	L	Risk reduced because of mitigation measures described.

#	Description	Likelihood	Category	Risk (L,M,H,E)	Mitigation	Likelihood	Category	Risk (L,M,H,E)	Comments
					When working within the vicinity of the CBD Metro alignment, workers should be inducted to ensure awareness. Produce three dimensional 'Works as Executed' drawings to Sydney Metro for future tunnel design and construction coordination.				
9	Stresses induced by the Barangaroo basement foundations including the perimeter ground water control and retention walls, and Building C5 structures adversely affect the Metro tunnels, as foundation elements cause localised high stresses that exceed the capacity of the tunnel linings.	C	4	H	Ensure that all foundations transfer the building loads to such a depth that any future tunnel is not affected. The use of modern three dimensional CAD software for the design and coordination of the Lend Lease basement foundations including the perimeter ground water control and retention walls and Building C5 and the CBD Metro tunnel alignment will ensure that foundations are located at appropriate depths. This software is considered standard practice for modern major infrastructure and development projects. Pile liners can be used to manage the extent of pile skin friction or otherwise. Pile liners considered standard industry practice for	E	1	L	Risk is actually removed because of mitigation measures described.

#	Description	Likelihood	Category	Risk (L,M,H,E)	Mitigation	Likelihood	Category	Risk (L,M,H,E)	Comments
					piling in water charged ground. Ensure during construction of the basement foundations including the perimeter ground water control and retention walls that they are constructed to and beyond the specified depths. Before lowering steel reinforcement cages and backfilling with concrete have independent check of pile/diaphragm wall depths. This is managed through suitable quality control processes. Produce three dimensional 'Works as Executed' drawings to Sydney Metro for future tunnel design and construction coordination.				
10	Elastic movements of the Barangaroo structures causes instability in the tunnel walls when the tunnels are driven past the walls at less than earth pressure balance pressures. (This is generally only a significant risk when going past particularly flexible structures in soft ground)	D	2	L	It is not a significant risk in the sandstone rock or soft ground for the type of TBM assumed and for a segmental concrete lining as described. However, the rigid retaining structures adjacent to the tunnel alignment will not move or the movements will be so small they will be insignificant.	E	1	L	Refer to drawings provided in Appendix D.
11	TBM breaks down under the Barangaroo structures and needs to be repaired or	D	3	M	Use a TBM that can have component parts (in particular, the main bearing) replaced from within the completed tunnel. TBMs of this	E	1	L	Risk reduced by using appropriate TBM design.

#	Description	Likelihood	Category	Risk (L,M,H,E)	Mitigation	Likelihood	Category	Risk (L,M,H,E)	Comments
	recovered.				design feature are readily available from reputable TBM manufacturers. Use a TBM that can have component parts that can be fully recovered if required from within the completed tunnel.				
12	Loss of overlying soft ground at the tunnel face that cannot be managed due to the presence of the surrounding Barangaroo structure.	D	2	L	Use a TBM capable of operating in a pressurised mode to provide the required face support to the soft ground. If there is for some reason excessive face loss at the tunnel face the TBM should be run through this ground and the void grouted once the TBM has cleared the area. Grouting will not be affected by any surrounding structures. The TBM is run through with grouting to follow so that the TBM is not accidently grouting into the ground itself.	E	1	L	The piled foundations supporting Building C5 will actually improve the ground conditions surrounding the tunnels. In one of the Lend Lease Generic Structural Foundation Concepts the 1.2m diameter steel reinforced concrete piles spaced at 3m centres along both sides of each tunnel will act as ground reinforcement in both the sandstone and soft ground above the rock horizon both vertically and horizontally.
13	Change in groundwater regime due to Barangaroo Development adversely affects the Metro project	E	1	L	It is unlikely that the Barangaroo development will either significantly raise or lower the existing tidal groundwater table in the longer term, therefore no no adverse impact for the Sydney Metro project is expected.	E	1	L	An EPM TBM can operate effectively both above and below the ground water table.
14	Loss of the overlying soft	D	3	M	The structural concept for the Barangaroo	E	1	L	Risk removed because of

#	Description	Likelihood	Category	Risk (L,M,H,E)	Mitigation	Likelihood	Category	Risk (L,M,H,E)	Comments
	ground at the tunnel face to such an extent that a large void is formed that migrates to the surface causing traffic disruption or damage to surface structures.				basement and Building C5over the future tunnels is for a suspended structural element on piles with a minimum clearance of 2m. The suspended structure would eliminate this risk of a void migrating to the surface and would be unaffected by voiding over the tunnel. The structural design and construct criteria for the suspended structural elements above the CBD Metro tunnel and their support piles can be the subject of ongoing design approvals with Sydney Metro as part of the design review process.				mitigation measures described.
15	Flotation of the tunnel lining if there is insufficient surface ground cover above the tunnel together with a high water table.	D	4	M	Where the ground cover is less than approximately 10m a calculation check must be carried out to confirm that the tunnel lining will not be subject to excessive flotation uplift forces. This is particularly relevant where there is open ground above the tunnel. In contrast under the C5 building the proposed 4m thick suspended slab and building load above will confine the ground under the slab and prevent flotation of the tunnel.	E	4	M	The risk under the building does not exist in this particular situation, in open ground within the Barangaroo site boundary, design measures may have to be taken if calculations demonstrate that without them there is a risk of flotation of the tunnel lining.

#	The Engineering Assessment should address the following	Comments	Further reference in this report and risk table
1	Changes in stress distribution within the ground above or surrounding planned metro underground infrastructure as a consequence of development construction. Of particular interest is the increase in vertical and horizontal pressures beneath foundation elements and increase in shear along existing bedding planes in the rock mass.	The current sequence of development at Barangaroo contemplates the construction of the Sydney Metro station and tunnels after the construction of the critical foundation elements of the Bulk Excavation and C5 Building works at Barangaroo South. Bulk excavation has the greatest potential to change the existing surround stress distribution in the rock mass, however, with Bulk Earthworks being undertaken prior to the development of the Sydney Metro as part of MP 10 0023, no changes of stress conditions subsequent to the development of the Sydney Metro arising from the development of Barangaroo South are expected. Bulk Earthworks undertaken as part of MP 10 0023 and Building works associated with C5 are proposed to utilise standard engineering and construction methodologies and equipment. Bulk Earthworks undertaken as part of MP 10 0023 and Building works associated with C5 will therefore not affect the ability of the TBM to excavate tunnel in sandstone rock and mixed face. Basement perimeter groundwater control and retention wall and C5 Building loads will not be imposed on the future	Risk item 1 Risk item 10.

#	The Engineering Assessment should address the following	Comments	Further reference in this report and risk table
		tunnel lining and will generally be designed to be founded below the tunnel	
2	Changes to the groundwater regime, including dewatering works or the installation of barriers to groundwater flow that may dam groundwater above the underground infrastructure.	The current sequence of development at Barangaroo contemplates the construction of the Sydney Metro station and tunnels after the construction of the critical foundation elements of the Bulk Excavation and C5 Building works at Barangaroo South. The Lend Lease basement perimeter ground water control and retention wall will use industry standard wall types such as diaphragm wall or equivalent and will control ground water ingress so that the existing long term tidal water level will be largely unchanged. It is unlikely that the Barangaroo development will either significantly raise or lower the existing tidal groundwater table in the longer term, therefore no adverse impact for the Sydney Metro project is expected.	Risk item 4.
3	Increase in structural actions, such as axial loading and flexural bending, to support elements and structural linings of the metro underground infrastructure, as a consequence of development loading.	The current sequence of development at Barangaroo contemplates the construction of the Sydney Metro station and tunnels after the construction of the critical foundation elements of the Bulk Excavation and C5 Building works at Barangaroo South. The likelihood of increase in structural actions, such as axial loading and flexural bending, to support elements and structural linings of the metro underground infrastructure, as a consequence of development loading is negligible. Where required, structural elements of the Barangaroo	Refer to Generic Structural Foundation Concepts in Appendix C. Risk item 2 and item 3. Risk item 9.

#	The Engineering Assessment should address the following	Comments	Further reference in this report and risk table
		South development will be designed using industry standard techniques and design practices to appropriately transfer loads either into the rock mass or past the tunnel. The development of design and construct criteria and design guidelines to be agreed between Sydney Metro and Lend Lease will be used to manage risks of tunnel construction subsequent to development of Barangaroo South.	
4	Deformation of the tunnel and cavern support elements and the surrounding ground. Of particular interest is the potential for encroachment of the structural lining into the contained envelopes (e.g. structure gauge etc), as well as predicted movement along existing bedding planes and their consequent effect on the support elements (e.g. rock bolts).	The current sequence of development at Barangaroo contemplates the construction of the Sydney Metro station and tunnels after the construction of the critical foundation elements of the Bulk Excavation and C5 Building works at Barangaroo South. Where required, structural elements of the Barangaroo South development will be designed using industry standard techniques and design practices to appropriately transfer loads either into the rock mass or past the tunnel such that deformation of the tunnel and cavern support elements and the surrounding ground is unlikely during the Metro works subsequent to the Barangaroo South development. The development of design and construct criteria and design guidelines to be agreed between Sydney Metro and Lend Lease will be used to manage risks of tunnel construction subsequent to development of Barangaroo South. A pattern of bored piers along and adjacent to the tunnels will in effect reinforce the rock mass. Above the rock profile	Risk items 7 and 8.

#	The Engineering Assessment should address the following	Comments	Further reference in this report and risk table
		similarly the piles will be of benefit, though this is difficult to quantify.	
5	Associated excavation methodology, especially where methods employ rock blasting, chiselling, percussive piles driving or similar methods are proposed.	The current sequence of development at Barangaroo contemplates the construction of the Sydney Metro station and tunnels after the construction of the critical foundation elements of the Bulk Excavation and C5 Building works at Barangaroo South, therefore impacts on Sydney metro arising from excavation methodology, especially where methods employ chiselling, percussive piles driving or similar methods are proposed are not relevant. Blasting is not to be used.	N/A
6	In circumstances where developments are likely to have a significant impact on the future construction of the SMN-Line 1 Metro a comprehensive assessment is needed that should involve the use of numerical modelling to accurately predict imposed actions to the support elements of the metro infrastructure. These types of assessment will generally be required for development in the First (1st) Reserve where excavation, or pile driving, will be relatively deep and close to the metro infrastructure and/or foundation loading from the development is significant.	The current sequence of development at Barangaroo contemplates the construction of the Sydney Metro station and tunnels after the construction of the critical foundation elements of the Bulk Excavation and C5 Building works at Barangaroo South. Barangaroo South will not impact on the future construction of the Sydney Metro tunnels. Any imposed loadings will be at the agreement of Sydney metro as part of the approvals process. All piles with transfer load past the tunnel. The development of design and construct criteria and design guidelines to be agreed between Sydney Metro and Lend Lease will be used to manage risks of tunnel construction subsequent to development of Barangaroo South.	Refer to Generic Structural Foundation Concepts in Appendix C. Construction clearances and hence construction tolerance are regarded as the most likely risk for the Sydney Metro tunnels. This is has been addressed by providing adequate clearance as referred to in other sections.

#	The Engineering Assessment should address the following	Comments	Further reference in this report and risk table
7	Where developments are expected to be of less concern, such as the case of construction only within the Second (2nd) Reserve, engineering assessments need not be as detailed. These types of assessment might only involve estimation of indicators such as stress changes and deformation within the ground from construction. These types of assessment may involve the use of less rigorous modelling techniques.	The development of design and construct criteria and design guidelines to be agreed between Sydney Metro and Lend Lease will be used to manage risks of tunnel construction subsequent to development of Barangaroo South. Refer above.	Refer above.

1. An integrated survey grid between the development and the Sydney Metro alignment must be established.

2. A 1 metre clearance between the Sydney Metro tunnels and walls, columns or foundation elements of the development is required. And add appropriate construction tolerance.

3. Where required found all vertical loads at a level below the zone of influence of the CBD Metro tunnels (or as agreed).

4. Upon completion of the Barangroo South development, retain a minimum of 2m of material over the crown of the future metro tunnels under the slab spanning between piles supporting the building piles.

5. It will be important to ensure that a detailed design and construction methodology are closely coordinated in an ongoing manner. It is recommend that an appropriate approvals regimes are established between builder and and Sydney Metro.

Final recommendations