Attachment A20

Desktop Geotechnical Assessment - 133-145 Castlereagh Street, Sydney

Douglas Partners
Geotechnics | Environment | Groundwater

Report on
Geotechnical Desktop Assessment

Proposed Commercial Development
133 Castlereagh Street, Sydney NSW 2000

Prepared for
Stockland

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The undersigned, on behalf of Douglas Partners Pty Ltd, confirm that this document and all attached drawings, logs and test results have been checked and reviewed for errors, omissions and inaccuracies.

	Signature	Date
Author		07/08/2020
Reviewer		07/08/2020

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Douglas Partners Pty Ltd
ABN 75 053 980 117
www.douglaspartners.com.au
96 Hermitage Road
West Ryde NSW 2114
PO Box 472
West Ryde NSW 1685
Phone (02) 9809 0666

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1. Introduction

This report presents the results of a geotechnical desktop assessment carried out for a proposed commercial development at 133-145 Castlereagh Street, Sydney. The investigation was commissioned by Huw Evans of Stockland and was carried out in accordance with Douglas Partners' (DP) proposal SYD191166.P.001.Rev0 dated 7 November 2019.

In the preparation of this report, findings and information from previous, nearby geotechnical investigations, as well as other available information (geological maps etc.) have been used. The report includes preliminary comments on expected ground conditions, groundwater and vibration. It will also provide initial design parameters for foundations and shoring walls.

It is understood that the development comprises a 37-storey commercial building with a lower ground level, together with basement car parking and associated facilities. Excavation at the site is understood to be limited to the Piccadilly Court Basement area in the southwest corner of the site where soil and rock will be removed down to approximately the existing basement level. The proposed development will lie in-between the Sydney Metro tunnels under Castlereagh Street and Pitt Street which are currently being constructed. The location of the tunnels is shown in Appendix B.

1.1 Overview

The following overview has been provided by Urbis. This Geotechnical Investigation Desktop Study has been prepared by Douglas Partner Pty Ltd on behalf of Stockland. It accompanies a planning proposal seeking to initiate the preparation of a Local Environmental Plan amendment for the land known as 'Stockland Piccadilly Complex' located at 133-145 Castlereagh Street, Sydney (the site) legally described as Lot 10 in DP828419.

The planning proposal seeks to amend the floor space ratio development standard applicable to the site, under the *Sydney Local Environmental Plan 2012* (the LEP), in accordance with Section 3.33 of the *Environmental Planning and Assessment Act 1979* (EP&A Act).

In accordance with Clause 7.20 of the LEP, this planning proposal also seeks amendments to the *Sydney Development Control Plan 2012* (the DCP) to establish site specific provisions to guide the future development, including establishing a building envelope for the site as well as other key assessment criteria.

The intended outcome of the proposed amendments to the LEP and DCP is to facilitate the redevelopment of the site for a commercial office tower development above a retail podium, including Wesley Mission facilities at lower ground level, together with basement car parking and associated facilities. Such a proposal aligns with the draft Central Sydney Planning Strategy to facilitate additional commercial floor space capacity in Central Sydney while also delivering improved public domain outcomes. Such outcomes will include a northerly aligned direct through-site link between Pitt and Castlereagh Street and enhanced pedestrian amenity and activation at the ground plane.

The planning proposal is supported by a conceptual reference design, but the final details of the development will be subject to a future design excellence process and a future detailed development application.

The purpose of this Geotechnical Investigation Desktop Study is to support a planning proposal submission to the City of Sydney Council.

2. Review of Previous Investigations

The following DP investigations were carried out in close proximity to the proposed development location;

- **194 – 204, Pitt Street, Sydney: City Tattersalls Club (DP Ref. 84482.02)** – Geotechnical Investigation carried out in 2016 comprising 3 boreholes drilled to depths of up to 14 m.
- **110-118 Bathurst Street, Sydney (DP Ref. 73410.02)** – Geotechnical Investigation comprising 5 boreholes drilled to depths of 24 m;
- **478 George Street, Sydney (DP Ref, 73065.03)** – Geotechnical Investigation comprising 1 borehole to a depth of 22 m;
- **163 Castlereagh Street, Sydney (DP Ref. 71782.00)** – Geotechnical Investigation carried out in 2010 comprising 8 boreholes drilled to RL[1] -13.
- **65 – 77 Market Street, Sydney (DP Ref. 85572.00)** – Geotechnical Investigation carried out in 2018 comprising 3 boreholes drilled to depths of up to 7 m.
- **Centrepoint Development, Pitt Street, Sydney (DP Ref. 43296)** – Geotechnical Investigation carried out in 2005 comprising 7 boreholes drilled to depths of up to 24 m.

3. Site Description

The proposed development is located at 133-145 Castlereagh Street, Sydney (see Figure 1). The site occupies an area of 4800 m^2 and is bounded by Pitt Street (~RL 19.5 m) to the west and Castlereagh Street (~RL 22.6 m) to the east. The northern and southern boundaries of the site are bounded by multistorey, commercial buildings. The site is currently occupied by a 31-storey high-rise building with a 4-level basement car park to RL 3.6 m.

[1] RL – Reduced Level in metres relative to Australian Height Datum

Figure 1: Location of site and lot boundary (Ref. sixmaps.nsw.gov.au)

The Sydney Metro tunnels run directly beneath Pitt Street to the west and Castlereagh Street to the east of the site. The Tunnel Boring Machines have already passed by the site on their way to Barangaroo.

4. Geological Profile

Reference to the Sydney 1:100 000 Geological Series Sheet indicates that the site is underlain by Triassic Age Hawkesbury Sandstone. This rock Formation typically comprises medium to coarse grained quartz sandstone with minor shale and laminite lenses.

In a fresh condition, Hawkesbury Sandstone is typically pale to mid-grey in colour, has massive and cross-bedded facies and strength properties typically in the medium to high strength range. The formation normally has near-horizontal bedding partings spaced from less than 1 m to well over 3 m in places, and is typically cut by the following two sets of steeply dipping joints:

- Set 1: Strike 020° to 035° / Dip 70° - 90° E and W
- Set 2: Strike 110° to 130° / Dip 70° - 90° N and S

The Hawkesbury Sandstone in the Sydney CBD is also characterised by “joint swarms/fault zones” that are extensive through the city. An extract of the mapping of these features by Pells, Braybrooke and Och is shown in Figure 2. The site location has been superimposed onto the map.

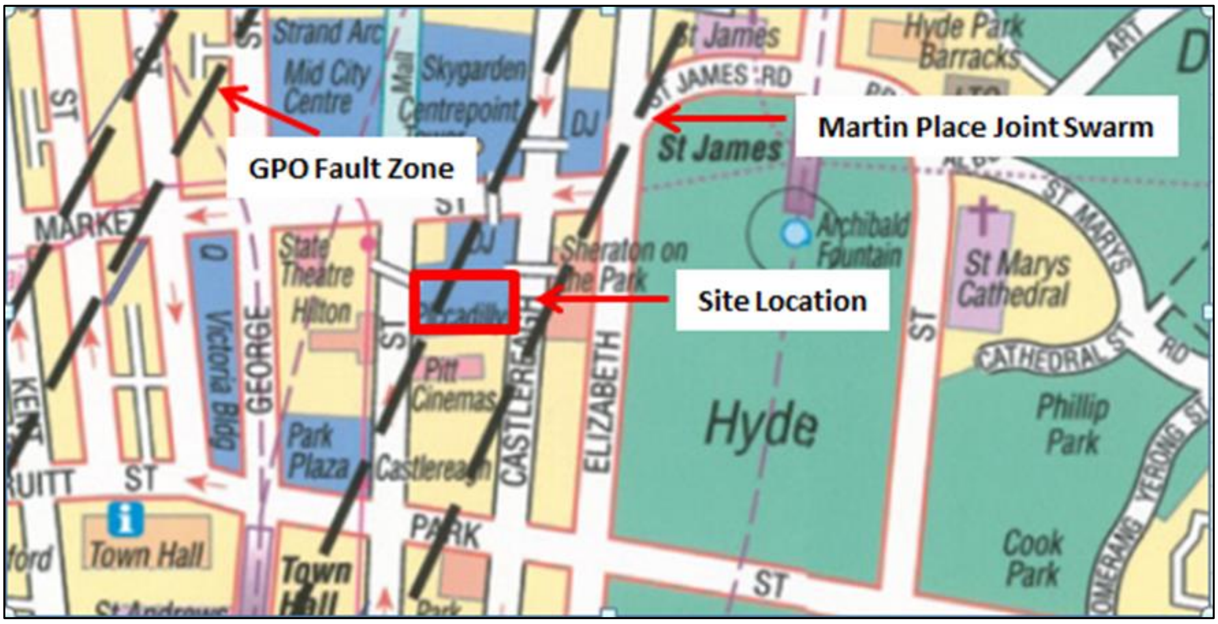


Figure 2: Near vertical structural features (adapted from Pells, Braybrooke & Och, 2004).

The site lies directly above the 'Martin Place Joint Swarm' and to the east of the GPO fault zone. Dashed black lines indicate the typical location and trend of the fault zones.

The map indicates that an interpreted joint swarm or "structural zone" oriented NE-SW (known as the Martin Place Joint Swarm) cuts through the majority of the site. Typically, this zone comprises a number of steeply dipping NNE oriented sheared zones with associated, closely spaced, steeply dipping joints (vertical to 75°from horizontal) to the east and west within otherwise medium to high strength rock.

Apart from near-vertical strike-slip faults, there are often also numerous low-angle (0° to 25°) thrust faults within the Hawkesbury Sandstone. These often manifest themselves as crushed or clayey bedding planes between individual sandstone beds or clayey zones ramping up along cross-beds. The thrust faults generally strike east-west and dip either north or south.

Hawkesbury Sandstone is also prone to weathering with red-brown or brown iron staining of the upper beds and with surface exposures often weathered to silty and sandy clays of medium plasticity.

The expected ground profile beneath the existing Piccadilly Court Basement is summarised in Table 1 below.

Table 1: Expected Ground Profile beneath Piccadilly Court Basement from RL 15 m

Geological Unit	Layer	Description[1]
1	Fill/Residual Soil	Fill - generally building rubble and gravelly sand over natural silty clay (residual) and sandy clay to depths of up to 1 m.
2	Weathered Rock	Extremely low to low strength, extremely to slightly weathered sandstone over medium strength sandstone with very low strength bands to depths of to depths of up to 3 – 4 m.
3	Sandstone	Medium strength, slightly weathered to fresh sandstone to depths of 6 to 7 m over high strength, fresh sandstone with occasional medium strength bands.

Note 1: Depths are approximate only

The groundwater level is expected to be lower than bulk excavation level. It is likely that nearby basement developments have lowered the groundwater level. Water seepage is still expected to occur along soil/rock interface, bedding planes, joints and faults, particularly after prolonged rainfall.

The ground profile presented above is preliminary only and will need to be confirmed by sub-surface investigation including coring of rock at several locations across the site and the installation of groundwater monitoring wells. These boreholes and monitoring wells should be drilled/installed to below the Sydney Metro tunnels.

5. Comments

It should be pointed out that the comments given below regarding excavation, excavation retention and foundations are of a preliminary nature. It is expected that a detailed geotechnical investigation, including the drilling of rock cored boreholes, will be carried out to confirm the ground conditions at the site and the preliminary comments given in this report will be reviewed/revised in light of the new information.

5.1 Proposed Development

It is understood that the development will comprise a 37-storey commercial building with retail passage on the ground and first floors as well as a five-level basement. The proposed development will lie directly between the Chatswood to Sydenham Sydney Metro tunnels which are currently being constructed under Castlereagh Street and Pitt Street. A Telstra tunnel, High Voltage cables and service pits run along Pitt Street adjacent to the site.

The Architects cross-section (see Appendix D) indicate the proposed basement structure extends to depths of about 18.5 m along Castlereagh Street side and about 16 m along Pitt Street. Lift shafts are shown to extend about 2.5 m below the lowest basement level.

The drawings for the existing basement by fitzpatrick + partners (see Appendix E) show the structure extends to RL 3.6 m across most of the site footprint except the Piccadilly Court Basement area in the southwest. In this area, the existing structure extends to the Lower Ground Floor level at about RL 16.5 m.

5.2 Existing Basements

The neighbouring building to the north along Castlereagh Street is the David Jones retailer. David Jones occupies 65 – 77 Market Street and is currently a 10-storey building with a 3 level basement to ~RL 9.1 m. It is understood that a Development Application (DA) has been approved by the City of Sydney Council for refurbishment of the David Jones building and the addition of a 22-storey residential tower on the current building. The works are understood to begin in March 2020. Although there will be no further bulk excavation in the basement, there will be detailed excavations and additional foundations.

To the north along Pitt Street is the City Tattersall Club at 194 and 196-204 Pitt Street. The building comprises 7 storeys with mostly a 1 level basement at RL 16.43 m and a 2nd basement level in the northwest corner of the building. It is understood that an envelope approval for the Stage 1 Concept Development Application has been recently awarded for a mixed-use tower, comprising indicative residential, retail, hotel and club land uses. The building envelope will have a maximum height of approximately 168 metres and 5 basement levels for bicycle parking, loading, storage and building services, accessed from Pitt Street.

To the south along Pitt Street, 226-230 Pitt Street comprises a 6 storey commercial building with a 1 level basement. It is understood that an approved DA exists for internal alterations and fit-out to part of the basement, ground, mezzanine and first floor.

The neighbouring building to the south along Castlereagh Street, 147-153 Castlereagh Street, is understood to comprise a 12-storey commercial building with a lower ground floor and basement.

5.3 Excavation

5.3.1 Excavation Conditions

Excavation to the proposed B5 level is expected beneath the Piccadilly Court Basement area. Excavation is also expected in the unexcavated area adjacent to the ramp in the southeast corner of the site.

Excavation is expected to encounter some sub-slab Fill (Unit 1) and weathered rock (Unit 2) down to about 4 to 5 m depth, with the remaining excavation being in medium and high strength sandstone (Unit 3) expected to be at about RL 12 to RL 14 m. Medium strength rock is expected to have an Unconfined Compressive Strength (UCS) of 6 to 20 MPa and high strength rock is expected to have a UCS of 20 to 60 MPa.

Excavation within the filling and the extremely low strength rock (Units 1 and partly Unit 2) should be readily achieved using conventional earthmoving equipment such as hydraulic excavators with bucket attachments. Excavation of the stronger rock will largely depend on rock strength and discontinuity spacing and will require medium to heavy ripping or rock breaking equipment (hydraulic hammers) aided by rock sawing. Rock breaking equipment will generally cause noise and vibration that could be disturbing to people in adjacent or nearby buildings (see Section 5.3.4). Monitoring of ground-borne vibration and control of the rock hammering is likely to be required. Rock sawing will probably be required to assist excavation and potentially reduce noise/vibration.

Excavation of the medium to high strength sandstone will cause some stress relief within the rock. Experience of stress relief at other sites in the Sydney CBD indicate horizontal stress relief movements vary from 0.5 to 2 mm/m depth of rock excavated. Most movement is expected at the midpoint of the top of an excavated face reducing to near zero moving to the corners and the base of the excavation. Stress relief movement decreases with distance away from the excavation and can be expected to occur to distances back from the excavation of up to the equivalent of 2 times the length of the excavated face. More stress relief movement is expected in the principal stress direction of north-south direction in the Hawkesbury Sandstone in Sydney.

The new structure should not be constructed in hard contact with the excavated rock faces. A minimum 25 mm gap should be left to allow for future stress relief from creep and/or potential neighbouring excavation works.

5.3.2 Disposal of Excavated Material

All surplus excavated materials will need to be disposed of in accordance with the Protection of the Environment Operations Act 1997 (POEO Act). All materials removed from the site are defined as waste under the POEO Act and must be disposed of in accordance with one of the following:

- Virgin Excavated Natural Materials (VENM) as defined under the POEO Act, permitting reuse on site; or,
- a waste category meeting the criteria set out in the NSW EPA Waste Classification Guidelines 2014, with the materials disposed to a landfill licenced to receive the waste under the assigned classification; or,
- material complying with a Resource Recovery Order (RRO) as defined under the Protection of the Environment Operations (Waste) Regulation 2014, with complying materials able to be reused under certain conditions.

5.3.3 Groundwater during Excavation and Construction

Although groundwater it not expected to be encountered during excavation, there is, however, likely to be minor, ephemeral seepage from along the top of the soil/rock interface and through the rock joints and bedding planes where exposed in the excavation following periods of heavy rainfall.

Seepage can be managed using temporary sumps and pumps with discharge into the stormwater system after any treatment required by EPA and council. Groundwater is likely to have significant concentrations of iron which will tend to precipitate on exposure to air giving rise to gelatinous masses of iron oxide/hydroxide sludge. This will need to be taken into account when designing permanent drainage lines and pump-out systems.

Monitoring seepage during excavation can provide an indication of long-term seepage for hydraulic design. It should be remembered, however, that groundwater levels and rainfall may change with time.

5.3.4 Ground-Borne Vibration

Excavation of the rock using hydraulic hammers will generate ground-borne vibration. It will be necessary during excavation to use appropriate methods and equipment to keep ground-borne vibration within acceptable limits. The standards listed below are considered appropriate documents on which to base the management of ground vibration:

- German Standard DIN4150-3-1999 “Structural vibration – effects of vibrations on structures”; and,
- Australian Standard AS2670.2-1990 “Evaluation of human exposure to whole-body vibrations – continuous and shock induced vibrations in buildings (1-80 Hz)”.

5.3.4.1 Provisional Allowed Vibration Limit

Based on the current information it is expected that the structures adjacent to the site can withstand vibration levels (up to 25 mm/s Vector Sum Peak Particle Velocity (VSPPV) for concrete framed structures) higher than those required to maintain the comfort of their occupants. A human comfort criterion is therefore required and the VSPPV is proposed as the control parameter. It is recommended that during normal working hours a Provisional Allowed Vibration Limit (PAVL) of 8.0 mm/s VSPPV be set at the foundation level of potentially affected buildings.

5.3.4.2 Excavation Plant

DP maintains a database of vibration trial results which can provide guidance for the selection of excavation plant. Trial data is dependent on site conditions and equipment, hence actual vibration levels may differ from predictions and a specific trial is recommended at the commencement of rock excavation. The database suggests buffer distance ranges, such as those shown for selected plant in Table 2, which should be maintained between excavation plant and adjacent buildings. These estimates should be examined in relation to the distances between adjacent buildings and the proposed excavation footprint, in order to select suitable plant.

Table 2: Approximate Buffer Distances for Selected Plant (PAVL 8 mm/s VSPPV)

Excavation Plant	Distance from plant by which vibration would attenuate to the Provisional Allowed Limit	
	From DP trial maxima [1]	From DP trial averages
Rock Saw on Excavator [2,3]	1.1 m	0.6 m
Ripper on 20t Excavator	3.4 m	1.2 m
Rock Hammer < 500 kg operating weight	7.4 m	3.0 m
Rock Hammer 501 - 1000 kg operating	7.5 m	3.3 m
Rock Hammer 1001 - 2000 kg operating	12.4 m	5.4 m
Rock Hammer > 2000 kg operating weight	7.4 m	4.9 m

Note:

1. Smaller distances can generally be determined from individual trials, as indicated by those from trial averages;
2. Buffer distances for rock hammers may be reduced by prior saw cutting along, or parallel to, excavation boundaries; and
3. Loading effects from adjacent buildings may reduce vibration levels, to enable boundary saw cuts with few exceedances;

5.3.4.3 Building Condition Surveys and Telstra Tunnel

It is recommended that dilapidation surveys (structural condition surveys) of adjacent buildings, pavements and any major services (e.g. Telstra Tunnel) be carried out before commencement of any excavation work and the building foundation types and conditions be determined, where possible, to allow further assessment of the maximum acceptable vibration levels and provide a record in the event of any damage claims. Follow up dilapidation surveys should also be carried out during and after excavation. It is also likely that Sydney Metro will require dilapidation surveys of their tunnels as part of their risk and impact assessments, although this may not be possible during construction of the tunnels.

5.3.5 Underpinning and Excavation Support

Careful consideration should be given to the planning and design of the excavation, excavation sequence and shoring system(s) to reduce the risk of destabilising or causing damage to the surrounding buildings, services and public footpaths/roads. A controlled, systematic approach based on investigation, underpinning of adjacent building footings (where required) and excavation should be adopted.

Excavation in the overburden materials and rock of less than medium strength will require both temporary and permanent lateral support. Based on the available information shoring may be required down to approximately RL 12 to 14 m (to expected top of medium strength sandstone). Final depth will be dependent on the depth to medium strength and stronger sandstone.

A number of options are possible for shoring wall construction including cantilevered piles or steel soldier piles with lagging or shotcrete infill panels depending on the depth of the soil and weathered rock across the site. Shoring should be designed to laterally support the soil/rock (including water pressures where applicable) and all surcharge loads, taking into account the allowable deformation limits for adjacent buildings and height and distance of surrounding services. Shoring (other than cantilevered systems) will require anchoring back into weathered rock or better.

Surcharge loads from building footings adjacent to the excavated area should be taken into account. It is recommended that as-built drawings of the neighbouring buildings are requested and additional investigation is carried out to determine the exact founding level and founding conditions of those footings.

5.3.5.1 Shoring Wall Design

It is suggested that the design of the shoring system is based on a triangular earth pressure distribution using the unit weights and earth pressure coefficients provided in Table 3. 'Active' lateral earth pressure coefficient (K_a) values may be used where some wall movement is acceptable. 'At rest' lateral earth pressure coefficient (K_o) values should be used where the wall movement needs to be limited.

Table 3: Recommended Design Parameters for Shoring Systems

Material	Unit Weight (kN/m^3)	Earth Pressure Coefficient		Effective Cohesion c' (kPa)	Effective Friction Angle (Degrees)
		Active (K_a)	At Rest (K_o)		
Clay and Sandy Clay	20	0.35	0.5	2	25
Extremely Low to Low Strength Sandstone	22	0.2	0.3	10	25
Medium Strength Sandstone	24	0	0	-	-

Notes: The values above assume a level surface behind the wall
It is assumed that the rock mass is free of adverse dipping joints and seams.
It should also be noted that the K_o design will not prevent stress relief movement.

The horizontal (lateral) earth pressures acting on the wall can be calculated based on the following:

$$H_z = K(\gamma z + p)$$

Where:
- H_z = horizontal pressure at depth z
- γ = unit weight of soil or rock
- K = earth pressure coefficient
- z = depth (m)
- p = vertical surcharge pressure

If more than 1 row of anchors is required, then a rectangular earth pressure distribution of 4H kPa (H = retained height in metres). This assumes that some minor lateral movement is acceptable (K_a conditions). Where adjoining building foundations and sensitive services are present it is recommended that the shoring be designed for at rest conditions (K_0 conditions), using a pressure of 8H kPa.

Care should be exercised to ensure that anchors are installed progressively during excavation and stressed prior to excavation of the next drop. It should be noted that stress relief (see Section 5.3.6) related movement may lead to an increase in the stress in anchors, which should be taken into account when designing the support.

Additional surcharge loads, such as new and existing footings, pavements and construction related activities must also be allowed for in the design as a rectangular earth pressure distribution, applied over the depth of influence.

The earth pressure loading described above does not include either earthquake loads or hydrostatic pressure due to the build-up of groundwater behind impermeable walls, both of which must be considered in the design. Unless positive drainage measures are incorporated to prevent water pressure build-up behind the walls, full hydrostatic head should be allowed for in design while, at the same time, allowing for the soil unit weight to reduce to the buoyant condition.

Beds of weathered or weaker rock within the medium strength sandstone may require protection with shotcrete to prevent degradation.

5.3.5.2 Anchor Design

The design of anchors and rockbolts should be based on the estimated bond strengths indicated in Table 4.

Table 4: Allowable Bond Stress

Material	Allowable Bond Stress
Low strength sandstone	100 kPa
Medium strength sandstone	350 kPa
Medium to high strength sandstone	600 kPa
High strength sandstone	1000 kPa

These values should be confirmed by pull-out tests prior to installation of anchors.

Ultimately, it is the contractor's responsibility to ensure that the correct design values (specific to the anchor system and method of installation) are used and that the anchor holes are carefully cleaned out prior to grouting. After anchors have been installed, it is recommended that they be tested to 125% of nominal working load and then locked-off at 80% of their working loads, with the lock-off load confirmed by a lift-off test. Checks should be carried out to ensure that the load is maintained in the anchors throughout the construction period and is not lost due to creep effects or to other causes.

It is anticipated that the proposed building will support the shoring wall over the long term and therefore the ground anchors are expected to be temporary only. The use of permanent anchors, if required, would require careful attention to corrosion protection for which further geotechnical advice should be sought.

It should be noted that permission will be required from adjacent property owners or City of Sydney Council prior to installing bolts/anchors below their land/footpath/road. Due consideration should also be given to buried services on footpaths and basements on surrounding properties.

5.3.5.3 Rock Discontinuities and Self-Supporting Rock Faces

Staged excavation and inspection by a suitably qualified geotechnical engineer will be required to confirm that excavated rock faces are not adversely affected by discontinuities.

The typical two major joint sets (NNE and ESE) are aligned approximately 20° off the north-south and east-west trending excavation faces, respectively. The east-west joints are typically strata bound and are widely spaced but generally not persistent. The E-W joints rarely affect stability but can act as a potential release planes for wedges.
The north-south trending joints, however, are very prominent and can dip up to 20° (off the vertical) to the east or west. Bedding planes and soft seams are common in the Hawkesbury Sandstone, even in high strength, fresh sandstone. These joints, bedding planes and seams can adversely affect the rock mass and form unstable rock slivers, blocks and wedges (see Figure 3).

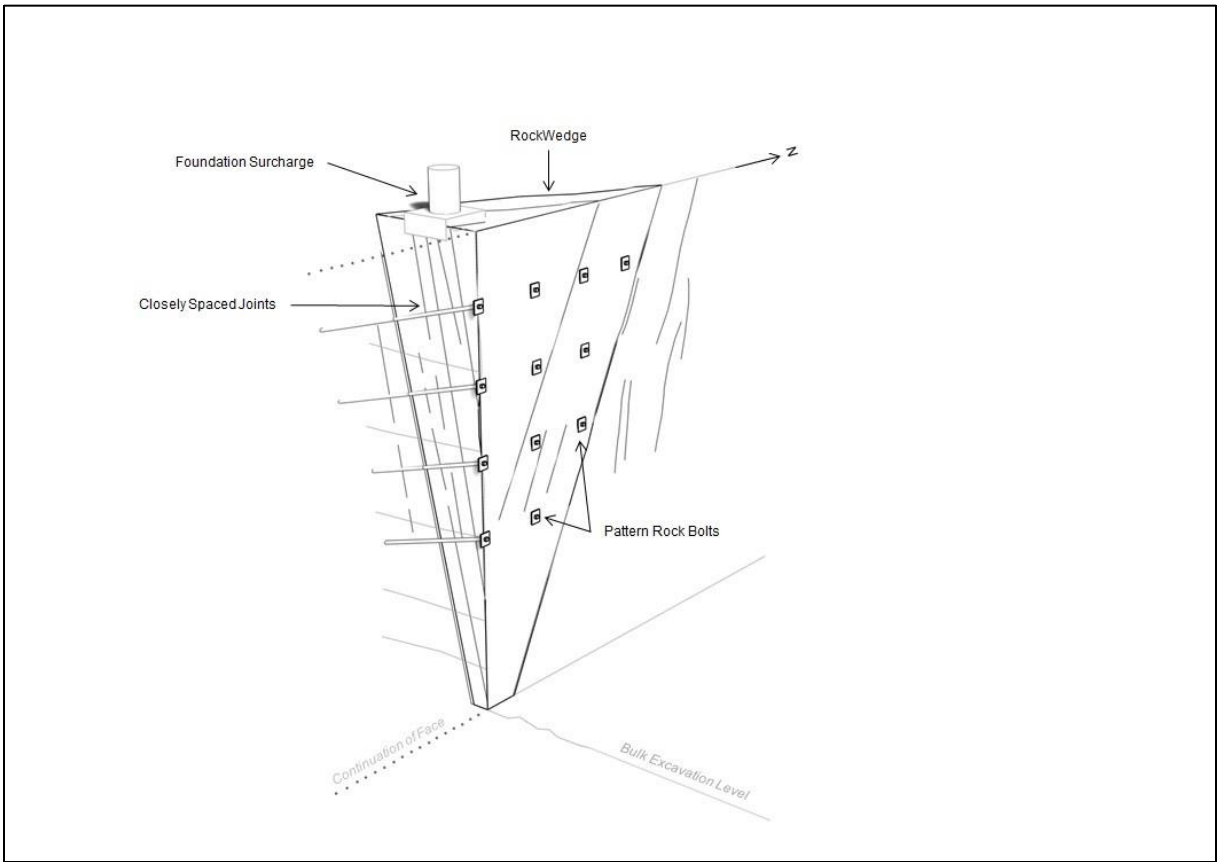


Figure 3: Example of jointed rock mass and rock wedge as well as rockbolt support

Excavated faces in medium strength or stronger sandstone can therefore only be considered self-supporting if they are not affected by adversely oriented joints. It should also be noted, that weak seams and beds can reduce the capacity of the rock to support load and result in renewed or increased settlement. The allowable bearing pressure of the rock may be required to be reduced as a result of these weak seams/beds.

It is noted that the site lies within the Martin Place Fault Zone. This zone is characterised by multiple, steeply dipping joints. Whilst these joints are expected to be not adverse in the south face of the excavation, they may adversely the affect the otherwise free-standing medium strength or stronger sandstone in the western face beneath Pitt Street.

Ground anchors and rockbolts may be required for the lateral restraint of unstable wedges within the excavated faces. Rock mass support can only be finalised once the actual joint location, dip and dip direction have been determined during excavation. It is therefore recommended that all rock faces be inspected by a suitably experienced geotechnical engineer/engineering geologist at 1.5 m drops during excavation to confirm that the site conditions are consistent with the geotechnical model, to verify the stability of the faces and advise on rockbolting/anchoring requirements.

5.3.6 Stress Relief

Locked-in stresses are present in the Triassic sedimentary rock underlying Sydney as a result of tectonic movements. Evidence from measurements in the greater Sydney region indicates that the primary compressive stress field is in the north-south direction. As the excavation depth increases, these stresses will be released, which will result in lateral movement of the rock. This lateral movement will increase the risk of cracking of the adjacent buildings or any part of a structure poured hard against the rock face. It may also increase the lock-off loads in anchors. The additional load on anchors is usually accommodated by providing at least 4 m free length and where possible, locking-off at 80% of the design load.

The magnitude of stress relief related movement is controlled by bedding and jointing as well as the magnitude of the locked-in stress and the length of the excavated face, making it difficult to predict the actual movement. Based on previous experience, lateral movement of the centre of the face of the excavation of the order of 0.5 – 2 mm per metre depth of rock (medium strength or stronger) excavation can be expected, decreasing towards corners. The movement generally decreases away from the excavated face but may continue for a considerable distance. Consideration should also be given to the locations of columns, connections with perimeter walls and other structural elements to ensure that future stress relief movements do not affect the structure.

5.4 Foundations

Based upon the preliminary geotechnical profile outlined in Section 4, building loads at the lowest basement level can be founded directly on the high strength sandstone expected at Basement 5 level, using shallow foundations (e.g. pad or strip footings).

Preliminary design of pad and strip foundations on medium strength or stronger sandstone may be carried out using the preliminary values given in Table 4. The higher allowable bearing pressures, however, will require additional investigation comprising drilling within the site and spoon testing of footings in order to confirm the rock quality below the proposed founding levels.

Table 4: Recommended Preliminary Design Parameters for Foundation Design

Foundation Material	Maximum Allowable Bearing Pressure (Serviceability)		Ultimate Bearing Pressure		Young's Modulus, E (MPa)
	End Bearing (kPa)	Shaft Adhesion (Compression) (kPa)	End Bearing (kPa)	Shaft Adhesion (Compression) (kPa)	
Medium strength sandstone	3,500	350	20,000	800	350
Medium to high strength sandstone	6,000	600	60,000	1,500	900
High strength sandstone	10,000	1,000	120,000	3,000	2,000

Note: Ultimate end bearing pressure values occur at large settlements typically > 5% of minimum footing dimension

Foundations proportioned on the basis of the allowable bearing pressures in Table 4 would be expected to experience total settlements of less than 1% of the minimum foundation width under the applied working load, with differential settlements between adjacent columns expected to be less than half of this value. Note that further site investigation drilling should be carried out to confirm the rock strength before the suggested bearing pressures can be adopted.

For design using the ultimate values provided in Table 4, a geotechnical strength reduction factor ($Ø_g$) should be determined by the designer in accordance with the piling code AS 2159-2009. Serviceability criteria will also need to be met when using ultimate design parameters.

Where footings are located in close proximity to rock faces comprising medium strength or stronger sandstone (adjacent to lift pits, service trenches or neighbouring basements) the allowable bearing pressures should be reduced or the footing relocated outside the zone of influence of the face (zone of influence defined as being an imaginary line drawn upwards at 45°from the base of the trench, pit or neighbouring basement).

All foundations should be inspected by a geotechnical engineer or engineering geologist to confirm that foundation conditions are suitable for the design parameters, and proof-drilled or spoon tested as appropriate. If weak seams or defects are encountered, footings may need to either be deepened until suitable foundation material is reached otherwise the class of rock, and in turn, the allowable bearing capacity of the rock will be reduced. Alternatively, the footing could be re-sized to reduce the bearing pressure to less than the allowable bearing pressure of the founding material.

Spoon testing requires a 50 mm diameter hole drilled below the base of the footing to a depth of 1.5 times the footing width, followed by testing to check for the presence of weak layers or clay bands.

If unfavourable conditions are identified by additional investigation, during footing inspection or spoon testing, then footings may need to be deepened, or redesigned based on a lower allowable end bearing pressure.

5.5 Ground Slabs

The floor at basement level can be designed as a slab on ground. Only suitable material should be used to backfill over-excavated areas, compacted to a minimum 98% standard maximum density prior to the casting of the slabs. In these areas CBR testing will be required for slab design, unless the slabs are suspended. Note that CBR testing can take up to a month to complete.

It will be necessary to provide under-floor drainage to safeguard against uplift pressures if the basement is designed as drained. This can comprise a 100 mm thick durable open graded crushed rock with subsoil drains and sumps.

5.6 Groundwater Post-Construction

It is assumed that the existing basement has an operating sub-floor drainage system comprising gravel-filled drainage runs transferring water inflow (seepage) into subsoil pumpstations fitted with submersible pumps discharging into the stormwater drainage system. If the existing system is to be overhauled or replaced, the capacity of the current system should be checked. A site test of the current inflow could be carried out to better inform the hydraulic design. This could involve fitting the pump outlet with flowmeters to record the discharge volumes before the water enters the stormwater system. Readings should be taken on a regular basis for a sufficient time to establish reliable information. Records of rainfall during testing should also be recorded.

The site test should provide actual inflow rates for the current situation. Note that inflow rates may vary as a result of changes in groundwater levels or rainfall from the current levels, due to future climate change. The hydraulic engineer should take this into account in his design.

Groundwater is likely to have significant concentrations of iron which will tend to precipitate on exposure to air giving rise to gelatinous masses of iron oxide/hydroxide sludge. This should be taken into account in the drainage design and a suitable number of rodding points and regular maintenance included. In addition, an in-line flocculation system to remove the iron precipitate before the water reaches the pumps should also be considered, together with provisions for de-sludging the tanks. Note that pumps should be positioned above the base of pumpout pits or deep sumps included in the pits as the iron precipitate will tend to accumulate at the base of the pit and will block the pump’s intake.

5.7 Seismic Design

The Site Subsoil Class, as defined in AS1170.4 – 2007, is ‘Class C_e – Shallow soil’.

5.8 Sydney Metro - Chatswood to Sydenham Tunnels

The 7 m diameter Sydney Metro tunnels run directly beneath Pitt Street to the west and Castlereagh Street to the east of the site. The Tunnel Boring Machines have already passed by the site and construction is underway.

The horizontal and vertical alignments are shown in the 'For Construction' drawings (provided by Sydney Metro) in Appendix B. It is noted that the tunnel alignment is closer to the site along Pitt Street than along Castlereagh Street, and is closest at the boundary with the City Tattersalls Club.

The tunnel crown and invert adjacent to the site are at about RL 5 m and RL -2 m respectively (about 14 and 17 m below road level in Pitt Street and Castlereagh Street respectively). The crown of the two tunnels are about 1.5 m above the level of the existing basement and the bulk level of the proposed excavation beneath the Piccadilly Court Basement area in the southwest corner of the site.

The 1st and 2nd Protection Reserves (refer to Sydney Metro Technical Guidelines in Appendix F) around the metro underground infrastructure will need to be established in order to determine the restrictions placed on construction and to ensure that the design and construction meet the stated requirements in the Guidelines. As built or survey drawings must be acquired from Sydney Metro in order to comment on the proximity of the development to the tunnels and their associated easements/reserves.

Of the construction activities expected as part of the redevelopment, the main geotechnical related activities that may affect the tunnels are:

- vibration as a result of demolition;
- relaxation of rock mass as a result of removal of building loads;
- ground movement as a result of excavation (expected to be limited to the unexcavated area beneath the Piccadilly Court Basement); and,
- increase in stress as a result of new building loads.

Without carrying out numerical modelling (part of the Engineering Impact Assessment required by Sydney Metro at the Development Application stage) it is not possible to provide predictions of the geotechnical impact of the various activities on the tunnels.

5.9 Further Geotechnical Work

The following geotechnical work is recommended for the Development Application stage:-

1) Geotechnical investigation of the site including:
   - on-site boreholes and in situ testing to develop a geological model, establish the likely in situ stress conditions and for foundation design. Boreholes to provide information to at least 1 m below the invert of the tunnels and to include observation wells for groundwater level monitoring;
   - test pits to investigate building footings and foundation conditions adjacent to the proposed excavation beneath the Piccadilly Court Basement; and,
   - inspection slots in existing basement walls to investigate the ground profile for shoring design.
2) Numerical modelling to predict ground movements in relation to the Sydney Metro tunnels and the Telstra tunnel/services along Pitt Street. It is likely that three-dimensional modelling will be required.
3) Geotechnical input into the engineering impact assessment report.
4) Geotechnical input into the risk assessment report.

5) Dilapidation survey of tunnels (subject to Sydney Metro access).

Note that the above list is not exhaustive and additional geotechnical input may also be required.

Further associated work for the Development Application would be a Waste Classification Assessment of material proposed to be transported off site in accordance with the appropriate guidelines.

6. Limitations

Douglas Partners (DP) has prepared this report for this project at 133 Castlereagh Street, Sydney in accordance with the email request from Huw Evans from Stockland and DP's proposal SYD191166.P.001.Rev0 dated 7 November 2019. This report is provided for the exclusive use of Stockland for this project only and for the purposes as described in the report. It should not be used for other projects 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 assessment provided in this report is based on sub-surface conditions presented in reports prepared by DP. Sub-surface conditions can change abruptly due to variable geological processes and also as a result of human influences. Such changes may occur after field testing has been completed. 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/or testing locations.

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 / environmental / groundwater) 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

About this Report

Douglas Partners

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.

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

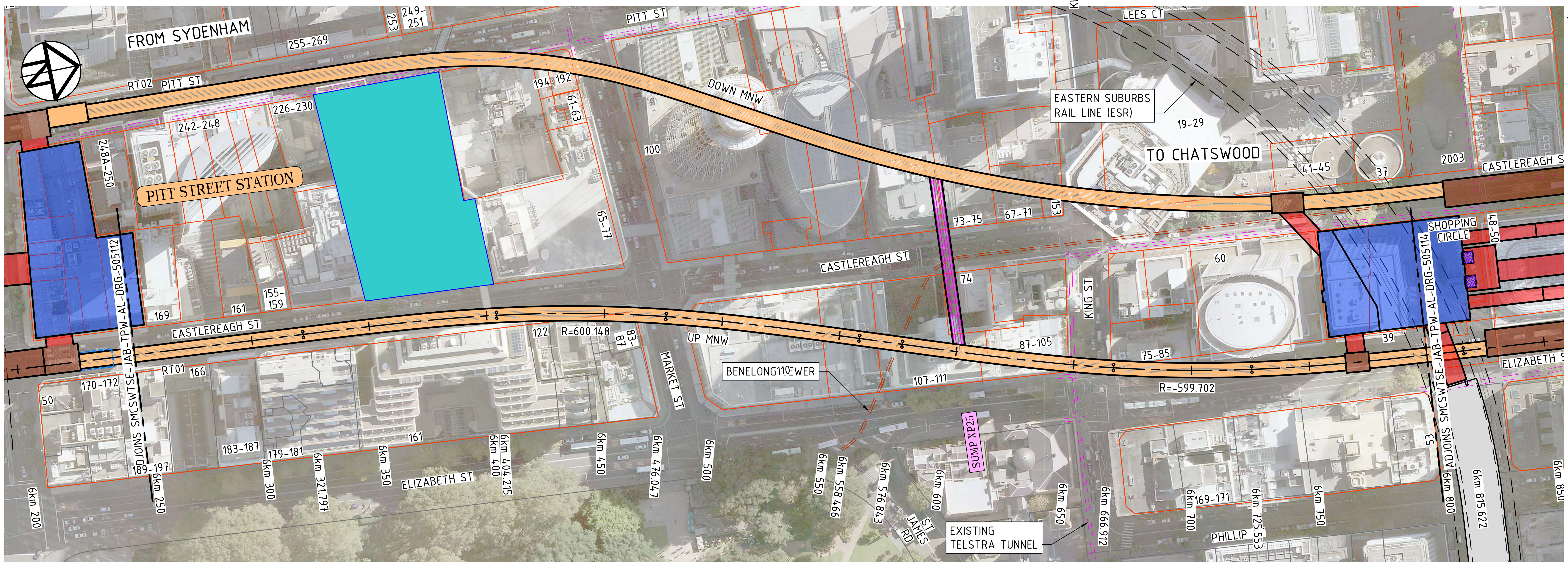
Where information obtained from this report is provided for tendering purposes, it is recommended that all information, including the written report and discussion, be made available. In circumstances where the discussion or comments section is not relevant to the contractual situation, it may be appropriate 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

Site Photographs



PLAN
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LEGEND

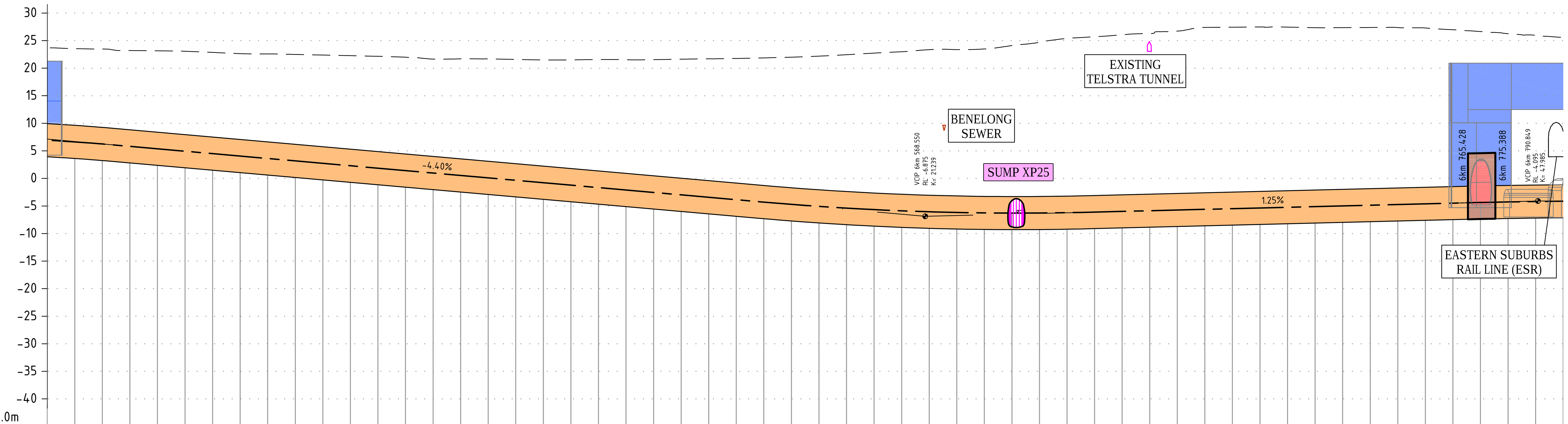
- TUNNEL ALIGNMENT CONTROL LINE
- RUNNING TUNNELS
- CROSS PASSAGES AND CROSS PASSAGES WITH SUMP
- STUB TUNNEL
- DIVE STRUCTURES
- STATION EXCAVATIONS
- NOZZLE ENLARGEMENTS
- CROSSOVER CAVERN
- STATION SHAFTS
- STATION CAVERNS
- STATION ADITS
- SHAFT
- LIFT SHAFTS

CADASTRAL MODEL (BASED ON PR124656-SACM-001-E)

- SURVEY ACCURATE CADASTRAL MODEL
- NEAR SURVEY ACCURATE CADASTRE
- DIGITAL CADASTRAL DATABASE

NOTE

1. FOR ALL ALIGNMENT NOTES REFER DRAWING NO. SMCSWTSE-JAB-TPW-AL-DRG-505005.



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6km 260.000	6.628	23.564
6km 270.000	6.254	23.474
6km 273.975	6.085	
6km 280.000	5.820	23.201
6km 290.000	5.380	23.167
6km 300.000	4.940	23.071
6km 310.000	4.500	22.878
6km 320.000	4.060	22.642
6km 321.797	3.981	
6km 330.000	3.620	22.592
6km 340.000	3.180	22.500
6km 350.000	2.740	22.387
6km 360.000	2.301	22.278
6km 370.000	1.861	22.163
6km 380.000	1.421	22.003
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6km 440.000	-1.219	21.509
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6km 460.000	-2.099	21.544
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6km 476.047	-2.805	
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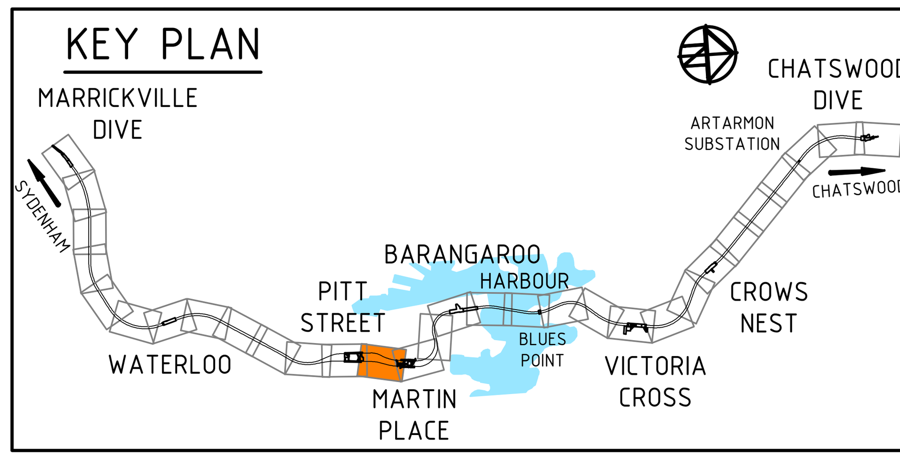

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CLIENT
NSW GOVERNMENT Transport for NSW

SERVICE PROVIDERS

DRAWN	L. AVUK	09.01.18
DESIGNED	TfNSW	-
DRG CHECK	J. MACADANGDANG	09.01.18
DESIGN CHECK	N/A	-
APPROVED	K. LIN	09.01.18

SYDNEY METRO CITY & SOUTHWEST
TSE PROJECT WIDE
ALIGNMENT
GA PLAN AND LONGITUDINAL SECTION
TUNNEL ALIGNMENT CONTROL LINE RT01 - SHEET 13

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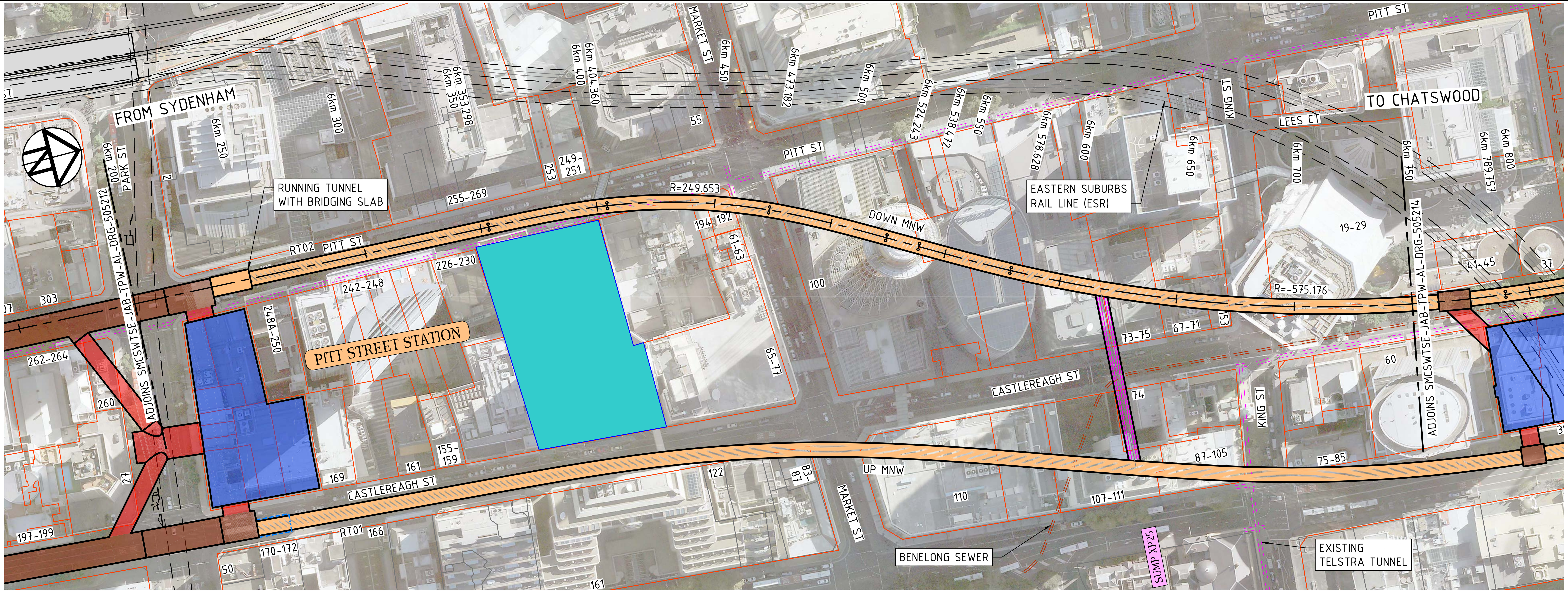

PLAN
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LEGEND

- TUNNEL ALIGNMENT CONTROL LINE
- RUNNING TUNNELS
- CROSS PASSAGES AND CROSS PASSAGES WITH SUMP
- STUB TUNNEL
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CADASTRAL MODEL (BASED ON PR124656-SACM-001-E)

- SURVEY ACCURATE CADASTRAL MODEL
- NEAR SURVEY ACCURATE CADASTRE
- DIGITAL CADASTRAL DATABASE

NOTE

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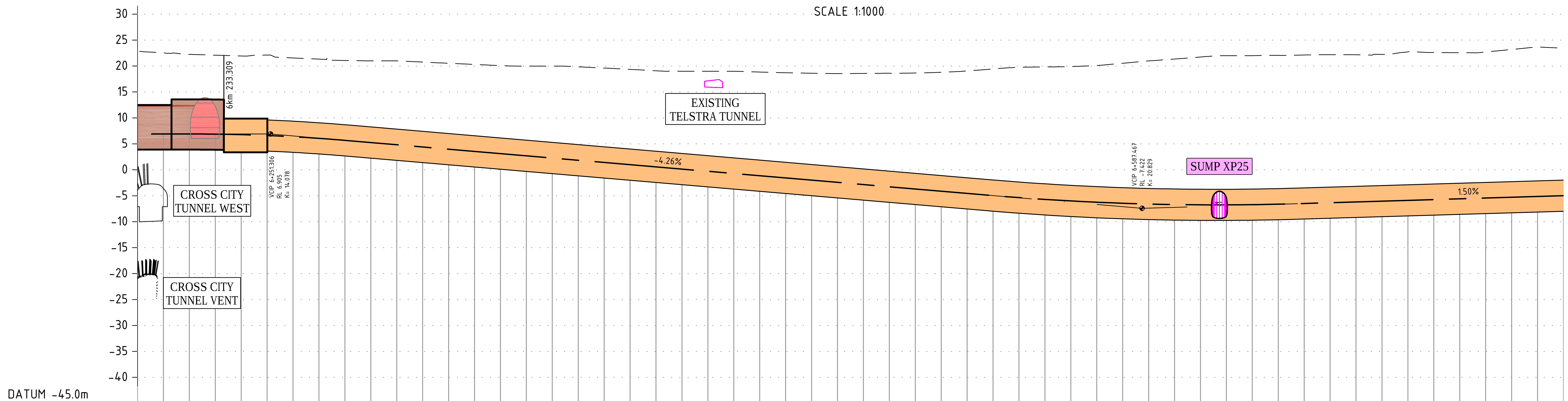

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6km 230.000	6.878	22.102
6km 240.000	6.781	21.947
6km 250.000	6.613	22.123
6km 260.000	6.373	21.562
6km 270.000	6.063	21.334
6km 280.000	5.681	21.073
6km 281.306	5.626	
6km 290.000	5.256	21.006
6km 300.000	4.830	20.991
6km 310.000	4.404	20.768
6km 320.000	3.977	20.533
6km 330.000	3.551	20.312
6km 340.000	3.125	20.095
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6km 353.298	2.558	
6km 360.000	2.273	20.000
6km 370.000	1.846	19.857
6km 380.000	1.420	19.612
6km 390.000	0.994	19.363
6km 400.000	0.568	19.087
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6km 410.000	0.142	19.005
6km 420.000	-0.284	19.000
6km 430.000	-0.711	18.989
6km 440.000	-1.137	18.846
6km 450.000	-1.563	18.712
6km 460.000	-1.989	18.619
6km 470.000	-2.415	18.547
6km 473.182	-2.551	
6km 480.000	-2.842	18.580
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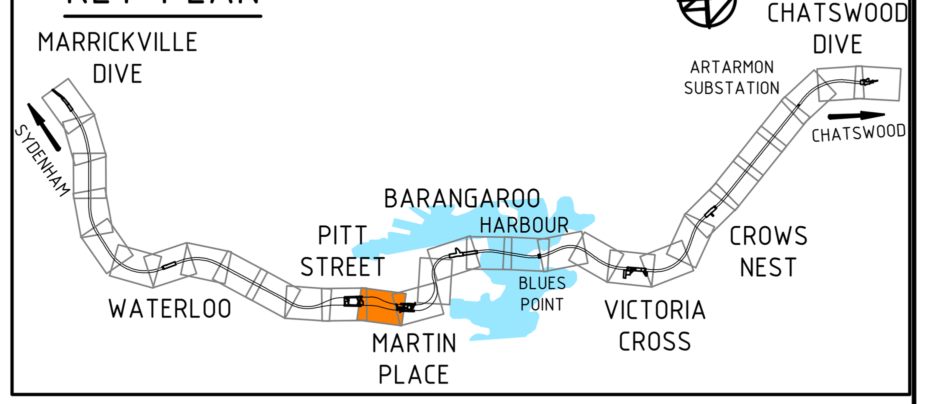

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SCALES
SCALE 1:1000 AT A1 SIZE
SCALE 1:500 AT A1 SIZE

IC CERTIFIED - IC CERTIFICATE SMCSWTSE-IC-CER-B2-008-A

CLIENT
NSW GOVERNMENT
Transport for NSW

SERVICE PROVIDERS
ARCADIS
HOCHTIEF
PSM
McMILLEN JACOBS ASSOCIATES

DRAWN: L. AVUK 09.01.18
DESIGNED: TINSW
DRG CHECK: J. MACADANGDANG 09.01.18
DESIGN CHECK: N/A
APPROVED: K. LIN 09.01.18

SYDNEY METRO CITY & SOUTHWEST

TSE PROJECT WIDE
ALIGNMENT
GA PLAN AND LONGITUDINAL SECTION
TUNNEL ALIGNMENT CONTROL LINE RT02 - SHEET 13

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Plotted by: JULIUS.MACADANGDANG
Plot Date & Time: 1/9/2018 2:22 PM
File Plotted: C:\SMCSW-TSE-Export\

643

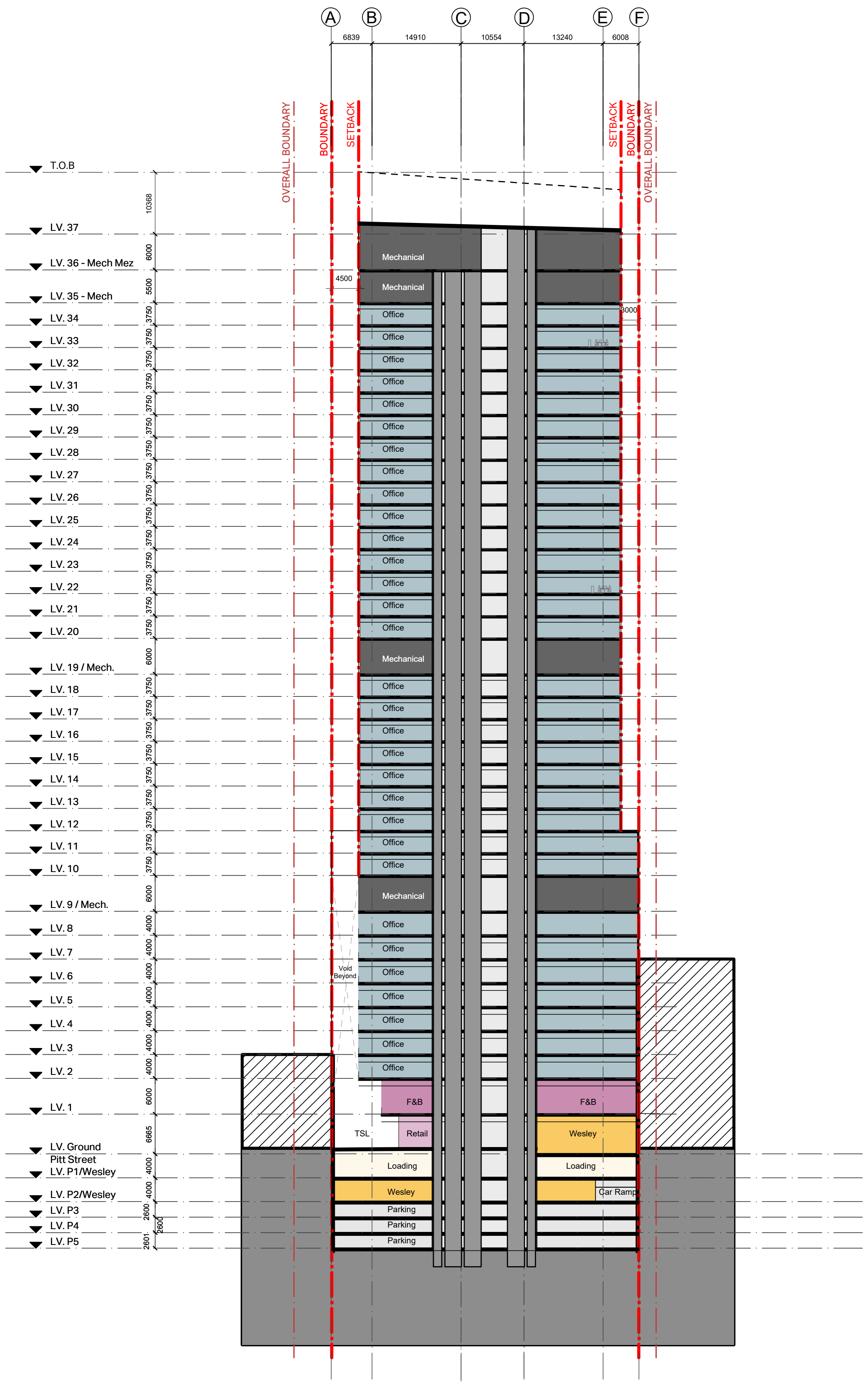
Appendix C

Drawings


BOUNDARY
EXISTING CITY
BH1
EXIST. WATER MAIN
EXISTING SERVICE PITS
ALIGN SOLDIERS EITHER SIDE OF PITS
EXIST GAS MAINS
BOUNDARY
TELECOM TUNNEL
PITT STREET
LINE OF KERB
EXIST. HIGH VOLT. CABLES
BH2
RL 16.46
RL 16.70
RL 17.074
TEMPORARY BATTER PROFILE

Appendix D

Architects Cross-Section



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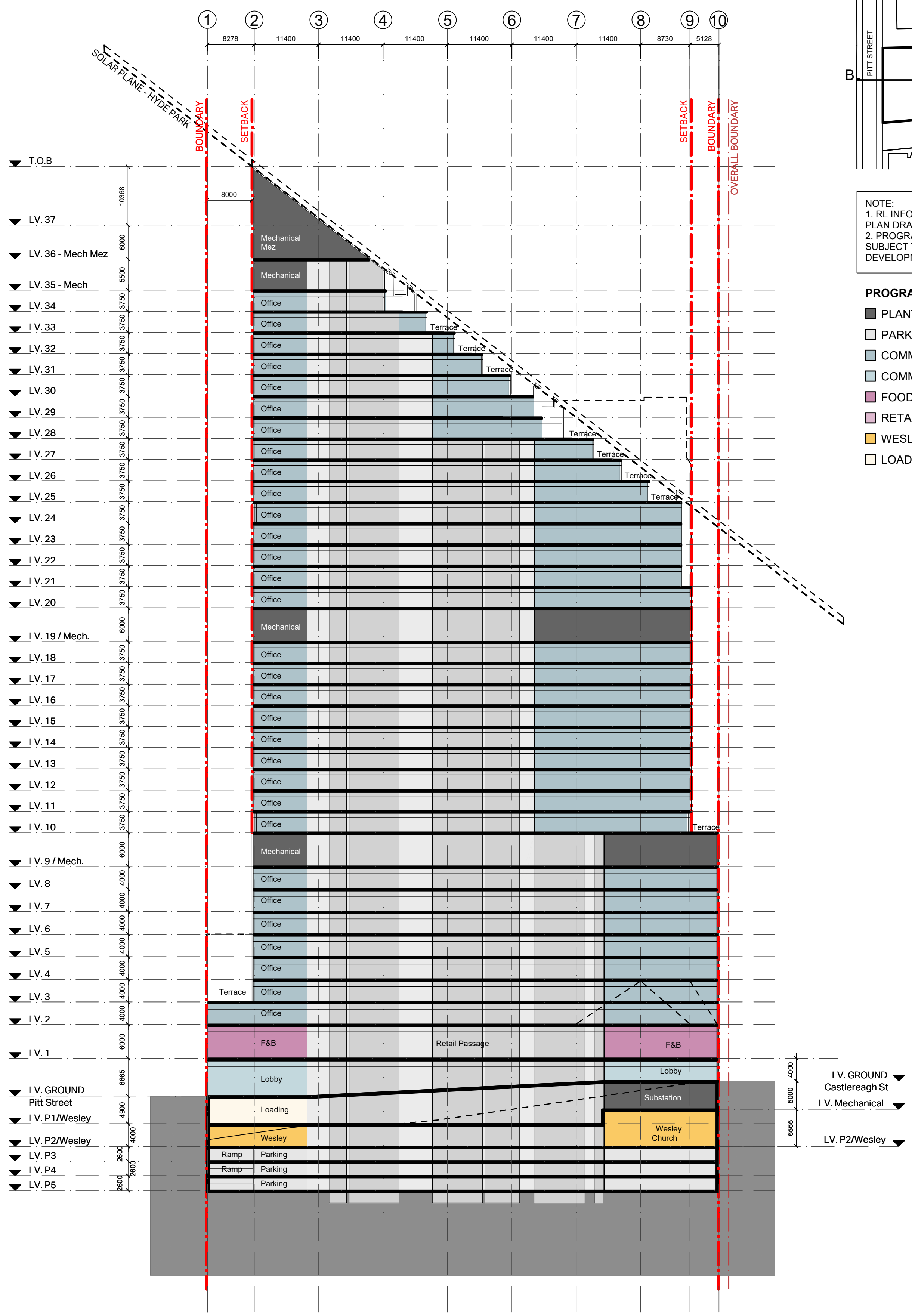

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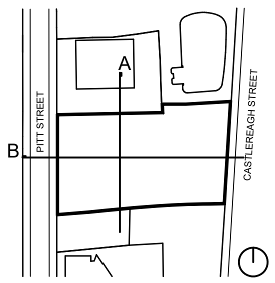

NOTE:
1. RL INFORMATION REFER TO PLAN DRAWINGS.
2. PROGRAMS INDICATIVE ONLY. SUBJECT TO FURTHER DESIGN DEVELOPMENT.

PROGRAM LEGEND
- PLANT
- PARKING
- COMMERCIAL OFFICE
- COMMERCIAL LOBBY
- FOOD & BEVERAGE
- RETAIL
- WESLEY MISSION
- LOADING

CLIENT
Stockland
STOCKLAND
LEVEL 25
133 CASTLEREAGH STREET
SYDNEY NSW 2000
W: STOCKLAND.COM.AU

PROJECT NAME
PICCADILLY DEVELOPMENT
133 - 145 CASTLEREAGH STREET
SYDNEY NSW 2000

DRAWING AUTHOR
3XN
3XN AUSTRALIA PTY LTD
SUITE 509
19A BOUNDARY STREET
DARLINGHURST NSW 2010
W: 3XN.COM

REVISION

ISSUE	DATE	DESCRIPTION
A	03/8/2020	ISSUE FOR PLANNING PROPOSAL

GENERAL NOTES
DRAWINGS ARE INDICATIVE AND SHOW ARCHITECTURAL DESIGN INTENT. DETAILING AND SIZING IS INDICATIVE AND PRELIMINARY ONLY. THE DESIGN IS TO BE VERIFIED BY THE SUBCONTRACTOR AT TENDER STAGE IN ACCORDANCE WITH THE PROJECT PERFORMANCE SPECIFICATIONS. ALL DRAWINGS MUST BE READ IN CONJUNCTION WITH THE REPORTS, SPECIFICATIONS AND SCHEDULE OF THE PROJECT TEAM.

DRAWING KEY

3XN PROJECT NUMBER
550001
TRUE NORTH (MGA) PROJECT NORTH
GRAPHIC SCALE
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1:1000
STATUS
PLANNING PROPOSAL

DRAWING
SECTIONS
DRAWING NUMBER
DA-02-001
ISSUE DATE
03/8/2020
ISSUE
A

Appendix E

Existing Site Drawings (fitzpatrick+partners)

NOTE:

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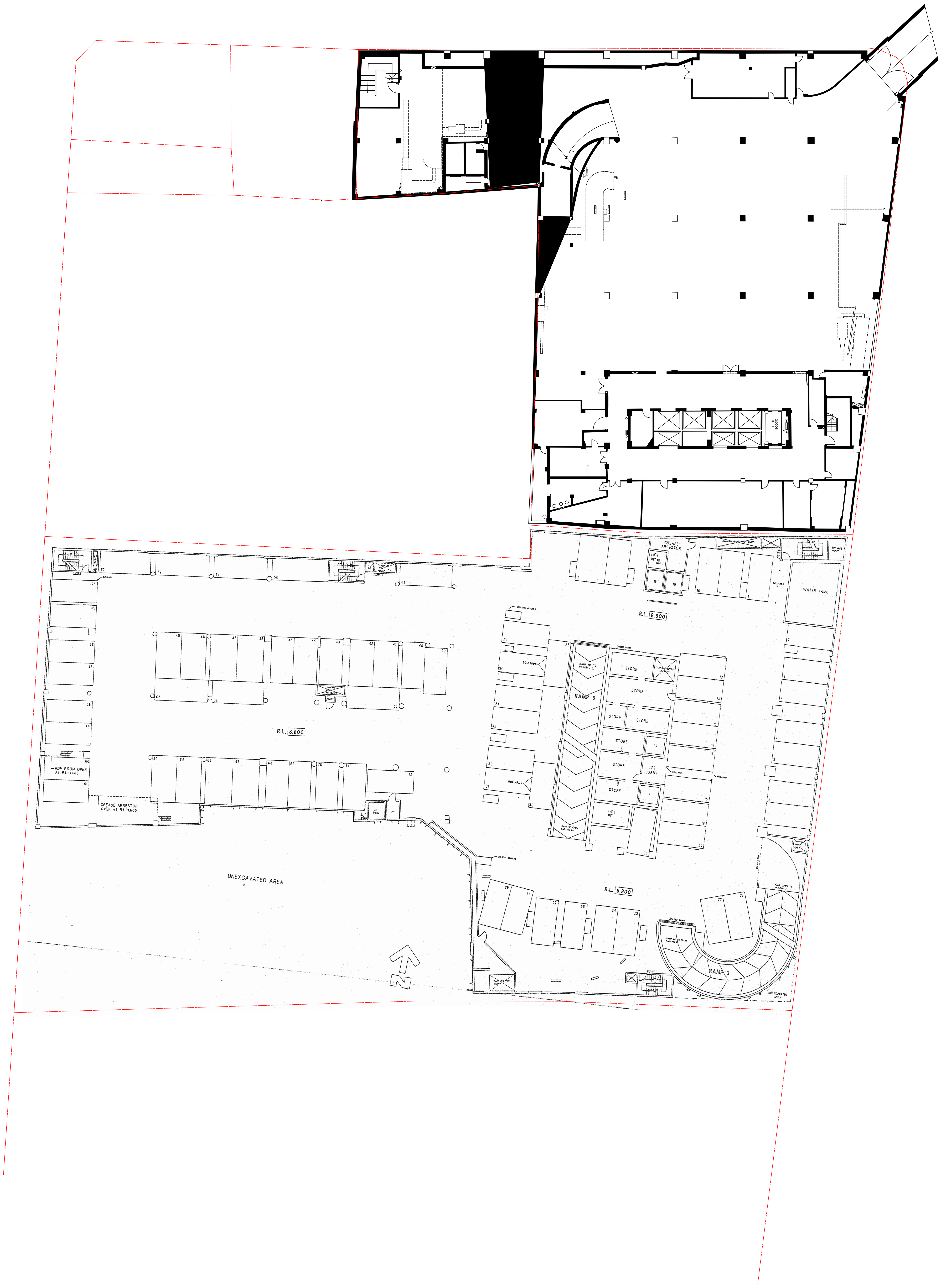

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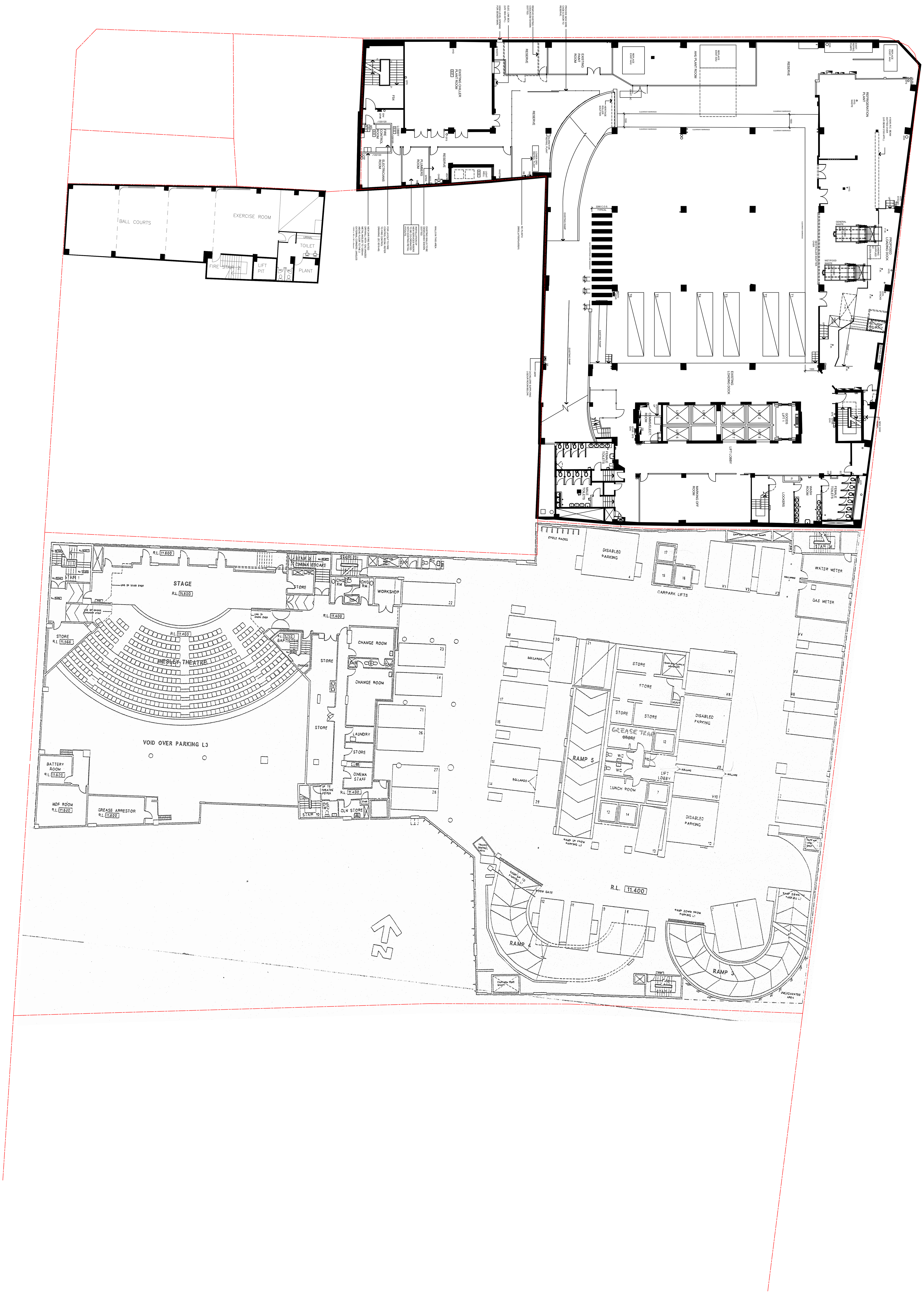

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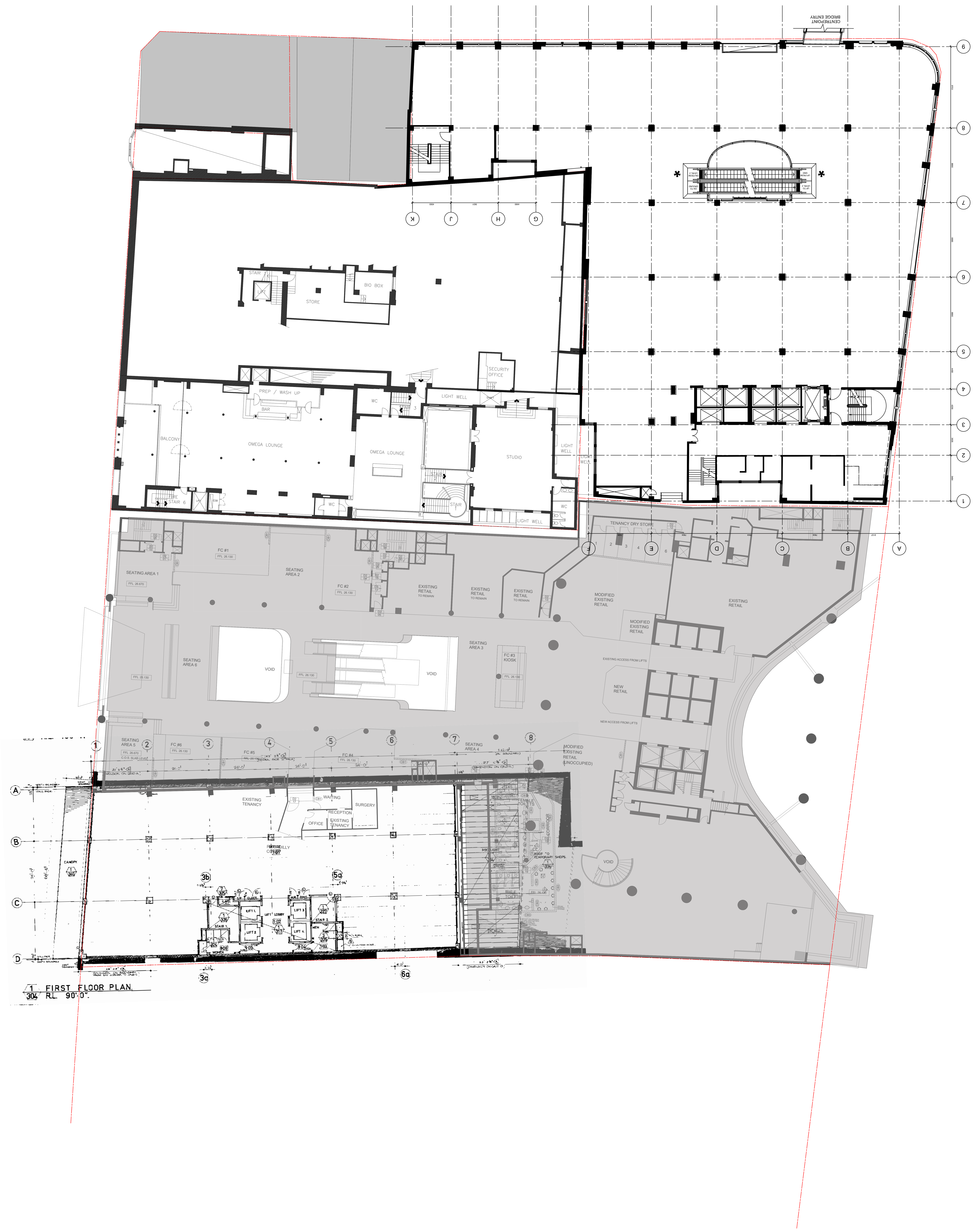

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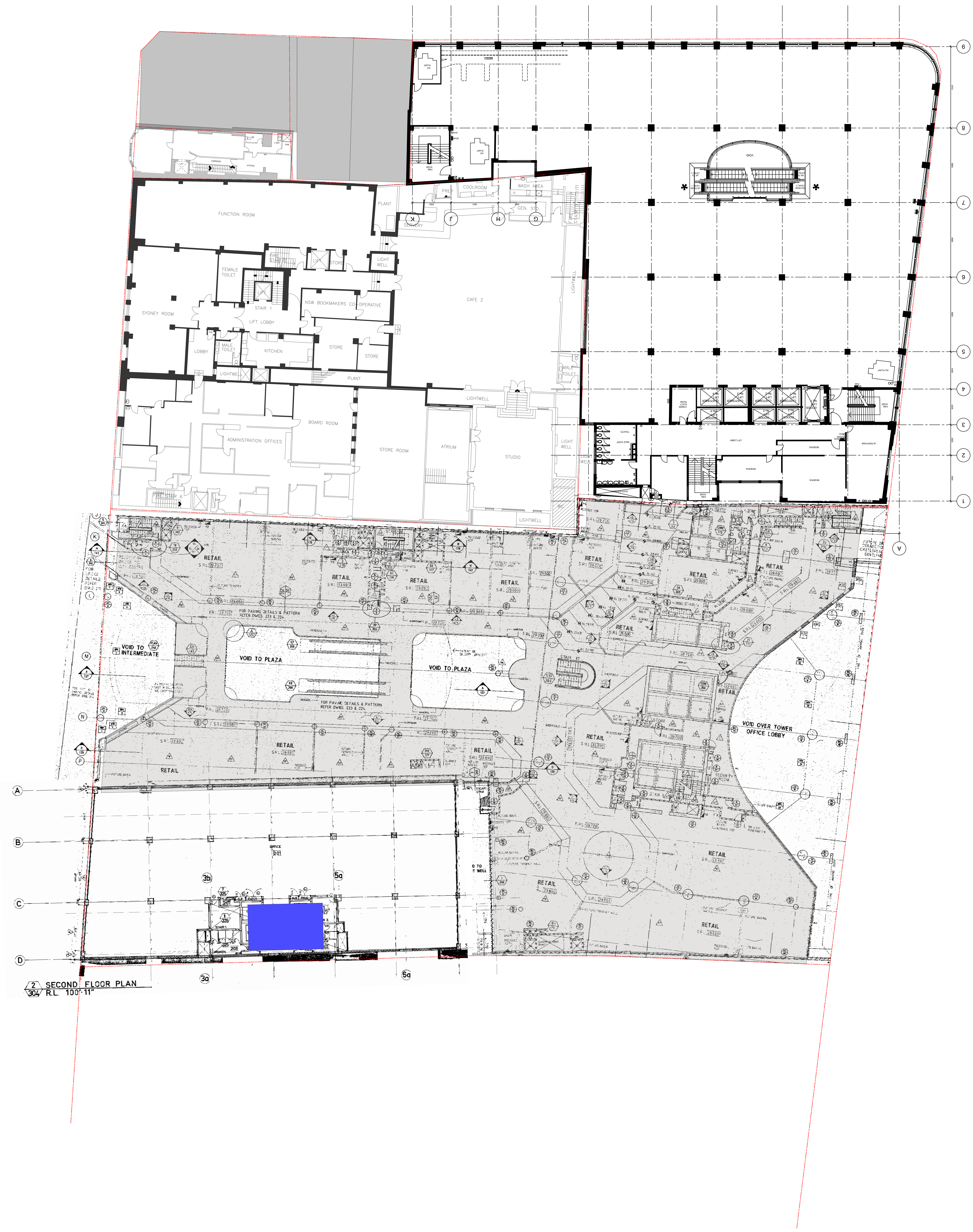

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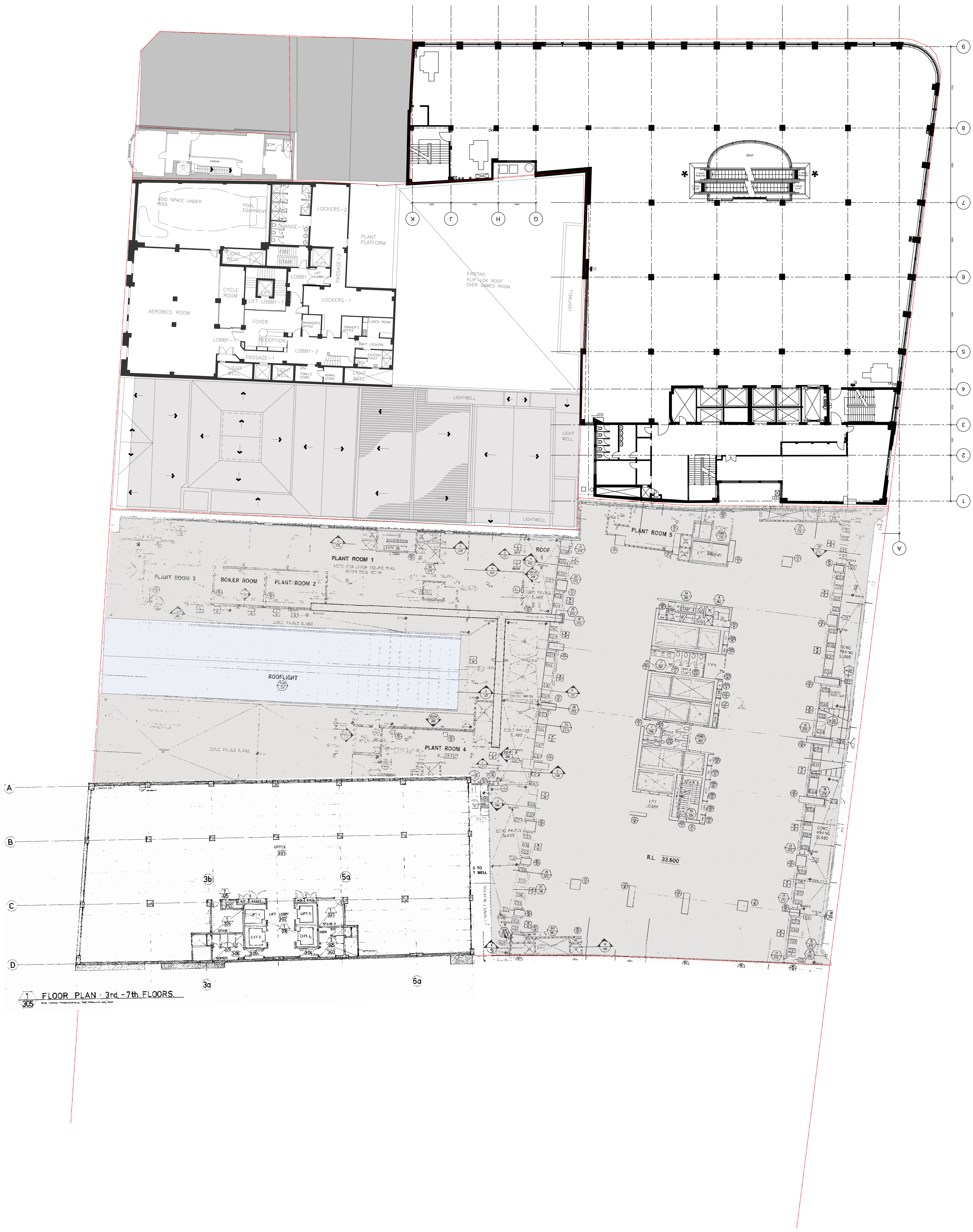

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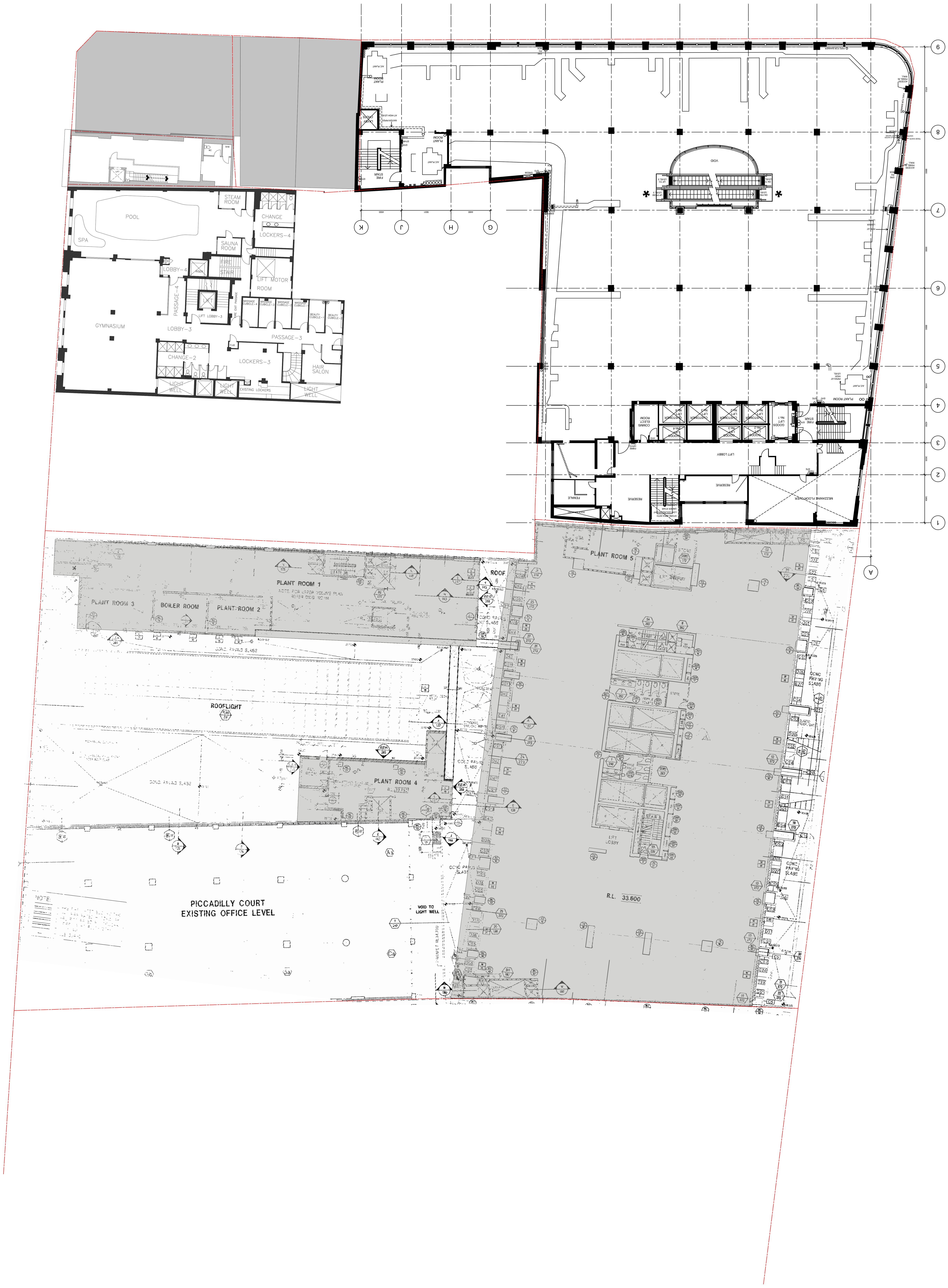

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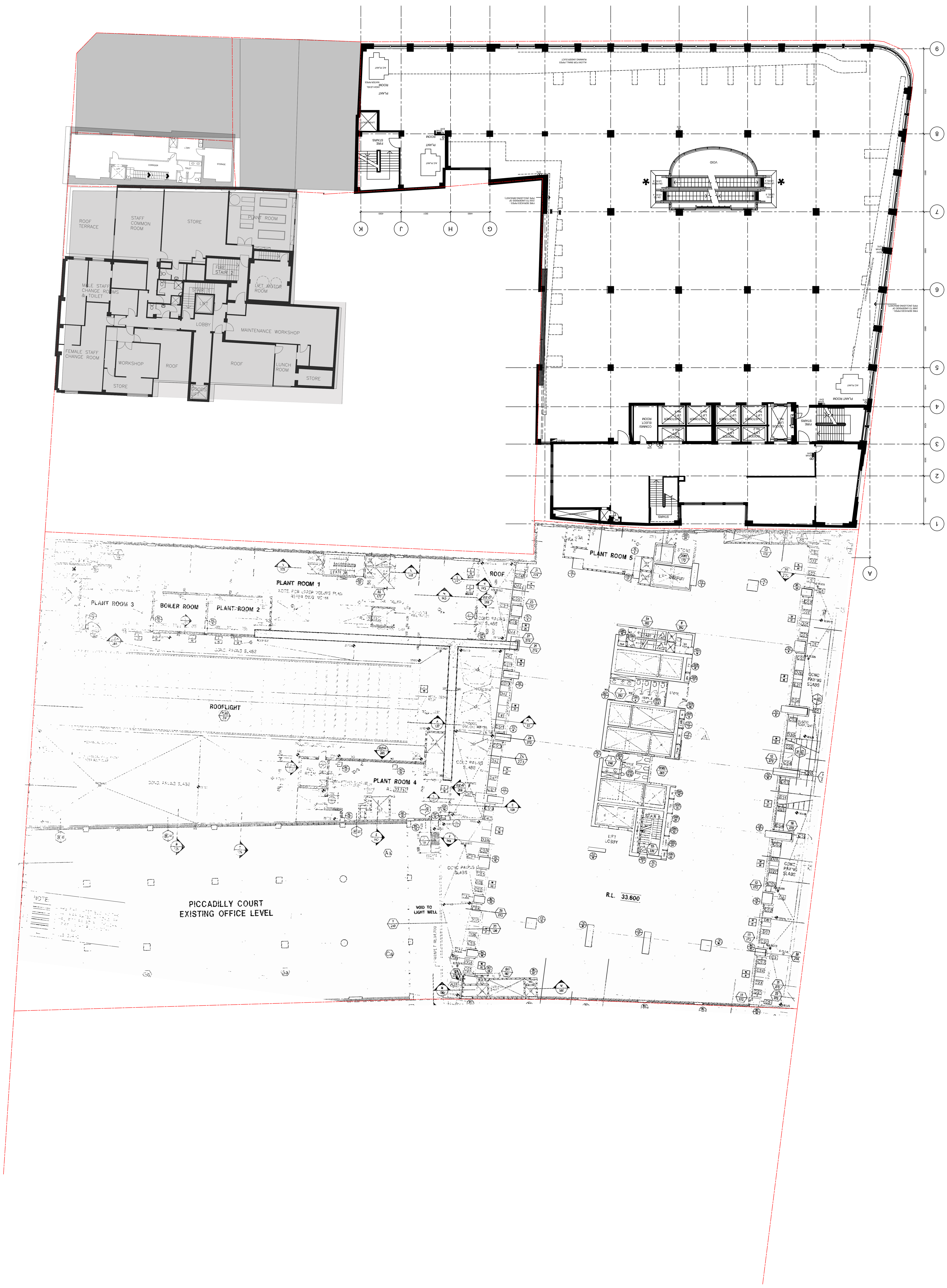

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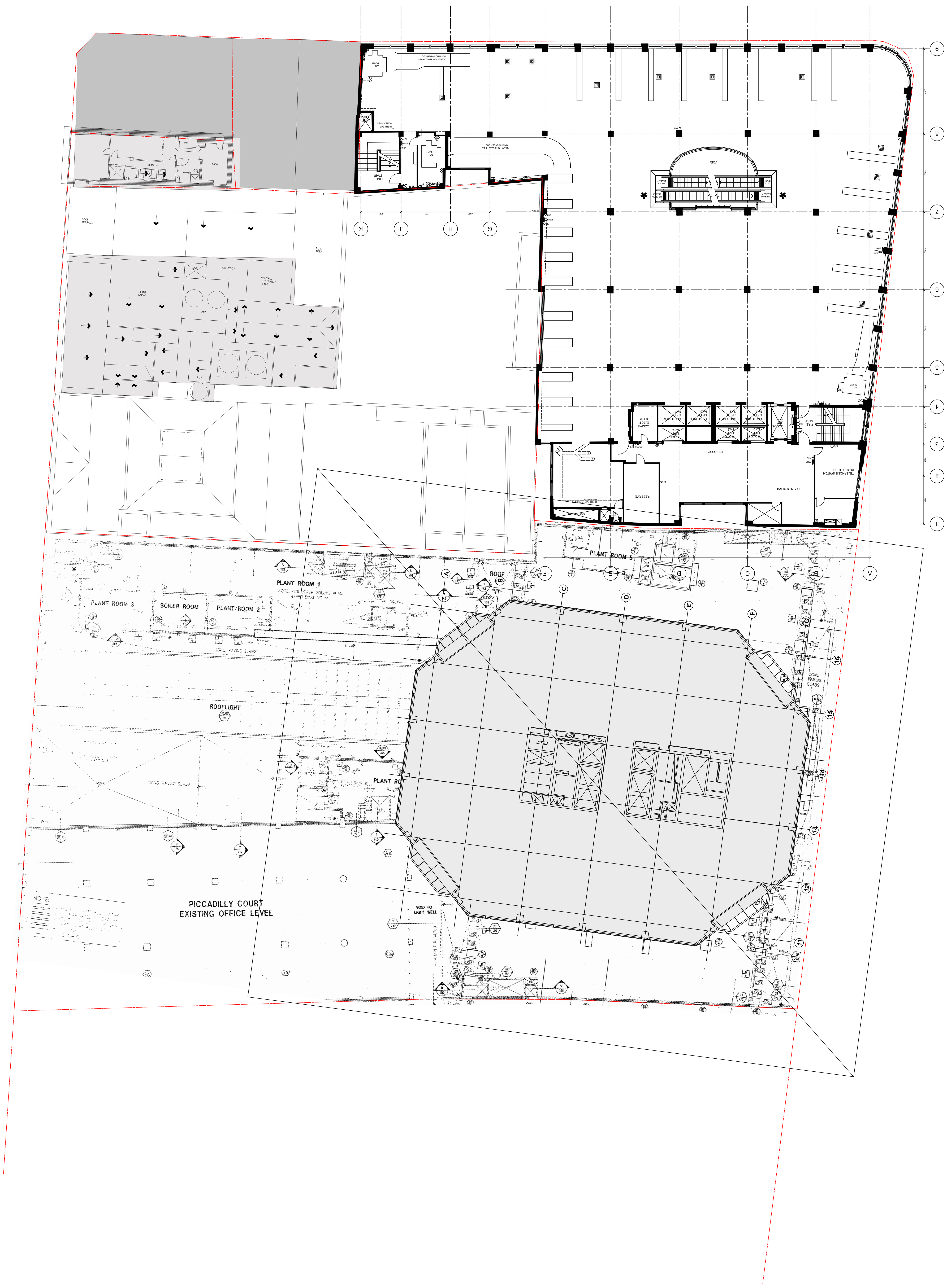

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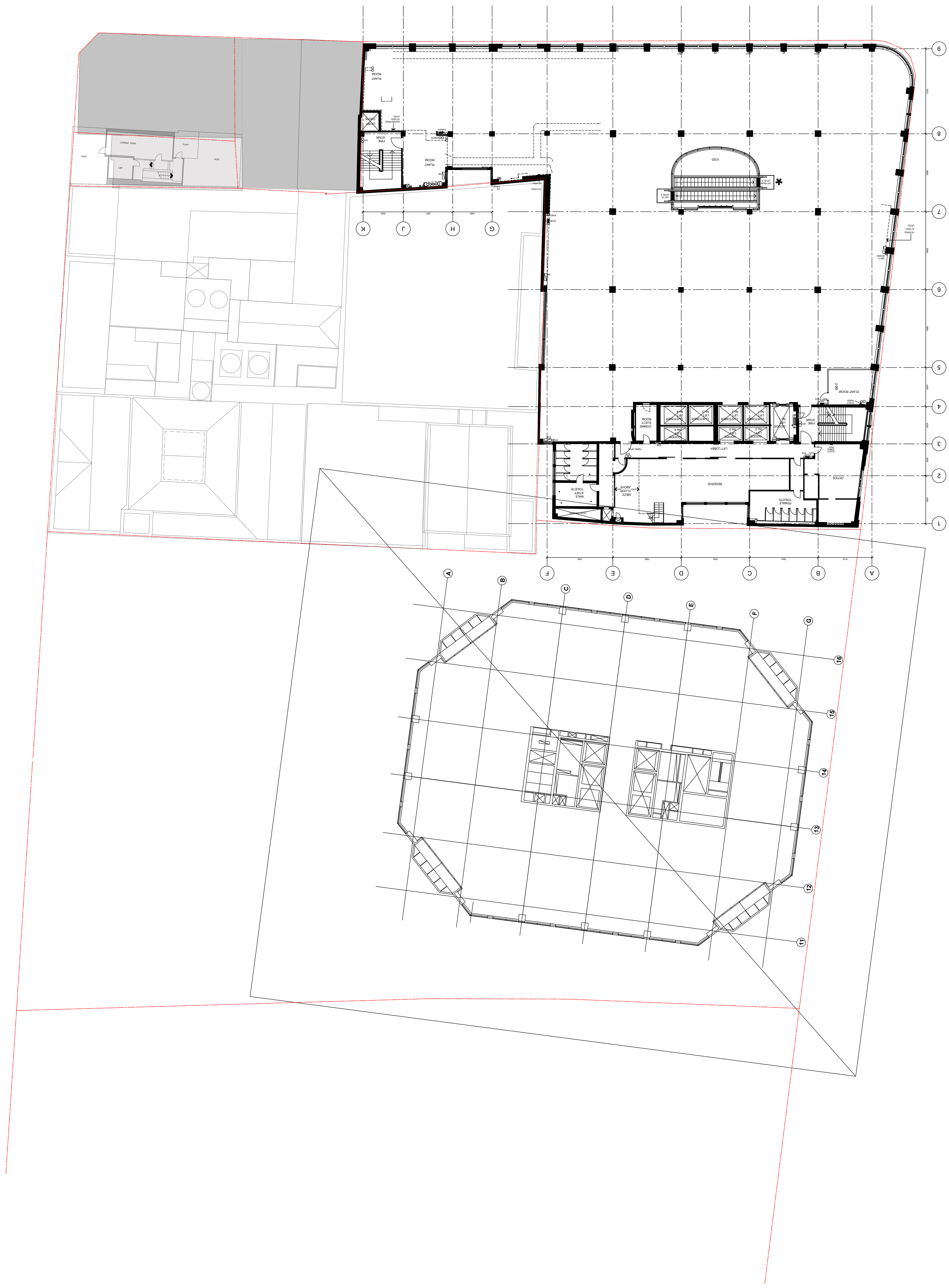

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Appendix F

Sydney Metro Underground Corridor Protection Guidelines Revision 1_0 (1)

Transport for NSW

Sydney Metro – Technical Services

Sydney Metro Underground Corridor Protection

Technical Guidelines

16 October 2017

Document No: NWRLSRT-PBA-SRT-TU-REP-000008

Revision No: 1

Document information
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B	31/07/2017	Draft – DRR comments incorporated
C	11/10/2017	Draft – Further DRR comments incorporated
1	16/10/2017	Final Issue

Author, Reviewer and Approver details				
Prepared by:	Antoni Kuras	Date: 16/10/2017	Signature:	
Reviewed by:	Nagen Loganathan/Jiping Pan	Date: 16/10/2017	Signature:	Pan Jiping
Approved by:	Ian M Whitton	Date: 16/10/2017	Signature:	

Distribution
Transport for NSW, Parsons Brinckerhoff file, Cox, Hassell, Rail Planning Services, AECOM

Document owner
AECOM Australia Pty Limited and Parsons Brinckerhoff Australia Pty Limited *ABN 31 763 921 748* Level 27 Ernst & Young Centre 680 George Street Sydney NSW 2000 GPO Box 5394 Sydney NSW 2001 Australia Tel: +61 2 9272 5100 Fax: +61 2 9272 5101

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Glossary

CBD	Central Business District
IV	Independent Verification
TfNSW	Transport for New South Wales
Developer	The person or organisation responsible for the new construction and/or alteration works
Easement	A right to use for a specific purpose land owned by others. The easement can be limited in either height or depth or width or all. This is also referred as easement land
Stratum	Land owned for the metro which is limited in either height or depth or width or all. This is also referred as stratum land
Substratum	Land owned for the metro which is below surface level.
Development	The term "Development" in this document means new construction and/or alteration works that change the existing asset configuration and could affect existing or future underground metro infrastructure. These works may include demolitions, alterations of existing structures, basements, foundations, anchors, temporary and permanent groundwater drawdown, pipe jacking, site investigations, tunnel and retaining wall constructions.
NSW	New South Wales
Qualified Person	A person who is registered as a professional engineer or an architect or a surveyor under any law relating to the registration of engineers or architects or surveyors, as the case may be, and who under law is allowed to practice or carry on the business of a professional engineer or an architect or a surveyor.
SEPP	State Environmental Planning Policy
Support Zone	Zone where tunnel supports are located. Tunnel support can comprise permanent concrete linings, rockbolts and anchors, ground improvement measures such as grouted zones, rock pillar stich bolts, steel sets, lattice girders, brick lining, cast-in-situ lining, shotcrete lining and waterproof membranes
TfNSW	Transport for New South Wales
Underground Structures	Any engineering works below the surface of the ground

1. Introduction

Developments near existing metro underground infrastructure, such as running tunnels, station caverns and shafts have the potential to have an adverse impact on the structural stability and operations of this infrastructure. Similarly, developments proposed near planned metro underground infrastructure have the potential to impact on the feasibility of future metro construction.

TfNSW has an obligation to review the development applications of projects near to underground metro infrastructure, both planned and existing, on a case-by-case basis to ensure that their consequential impacts are appropriately assessed and managed. This guideline document has been developed to provide the requirements and technical guidance to assist developers with their assessment of development induced effects and the associated risks.

2. Purpose of this document

This guideline document provides the technical requirements to assess and manage the risks associated with developments near existing and future underground metro infrastructure. This document is based and builds on the ASA Standard T HR CI 12051 ST Developments Near Rail Tunnels.

The purpose of this guideline document is to assist external developers in the planning, design and construction near underground metro rail infrastructure. This guideline supports the key objective of the *State Environmental Planning Policy (Infrastructure) 2007* (Infrastructure SEPP) to protect the safety and integrity of key transport infrastructure from adjacent developments.

2.1 Scope

This guideline document covers the specific requirements and provides guidelines to be followed for new developments near existing and future underground Sydney Metro rail infrastructure (termed 'metro underground infrastructure' throughout this document) during development planning, designing, constructing and operating stages. In the context of this guideline document, future infrastructure is defined as infrastructure that has yet to be constructed but has an established rail corridor in accordance with the Infrastructure SEPP.

This guideline document primarily covers the developments near the following existing, under construction and future metro lines:

- Sydney Metro Northwest
- Sydney Metro converted Epping to Chatswood Rail Line (ECRL) and
- Sydney Metro City & Southwest.

It applies to new developments near Sydney Metro running tunnels and other underground infrastructure such as: cross passages between running tunnels; station caverns and adits; crossover caverns; station boxes and shafts; nozzle enlargements; ventilation shafts and dive/portal structures. Information regarding existing and planned new metro infrastructure can be sourced from TfNSW.

3. Reference Documents

The following documents have been referenced to prepare this document:

Transport for NSW standards

- T HR CI 12051 ST Developments Near Rail Tunnels.
- TS 20001 System Safety for New or Altered Assets
- T HR CI 12070 ST Miscellaneous Structures
- T HR CI 12075 ST Airspace Developments
- T HR CI 12080 ST External Developments
- T HR EL 12002 GU Electrolysis from Stray DC Current

Legislation and guidelines

- The Environmental Planning and Assessment Act 1979
- The Heritage Act 1977
- State Environmental Planning Policy (Infrastructure) 2007 (Infrastructure SEPP)
- Development Near Rail Corridors and Busy Roads 2008 – Interim Guidelines – Department of Planning, NSW Government

Other reference documents

- CIRIA C580, Embedded Retaining Walls, Guidance for Design, 2003

4. Protection reserves

Protection reserves define the extent of zones that have been established to protect existing metro infrastructure and protect the feasibility of planned metro infrastructure from future adjacent development activities.

For the purpose of assessing the effects of adjacent developments, underground metro infrastructure includes, but is not limited to, the following:

- running tunnels and interconnecting cross passages
- station caverns and adits
- crossover caverns
- station boxes and shafts
- nozzle enlargements
- ventilation shafts and
- dive and portal structures.

Appendix A includes descriptions of Sydney Metro infrastructure for each of the existing and future metro lines. These descriptions provide an overview of the metro alignments and general location of the underground elements for each section.

Protection reserves are defined in this document. Developers must establish the reserve zones based on the requirements provided within this document and ensure that the design and construction meet the stated requirements.

4.1 Protection reserves

The protection reserves are categorised as either the 'first reserve' or 'second reserve'. Figure 4.1 and 4.2 represent the zones that form the first reserve and the second reserve around metro underground infrastructure.

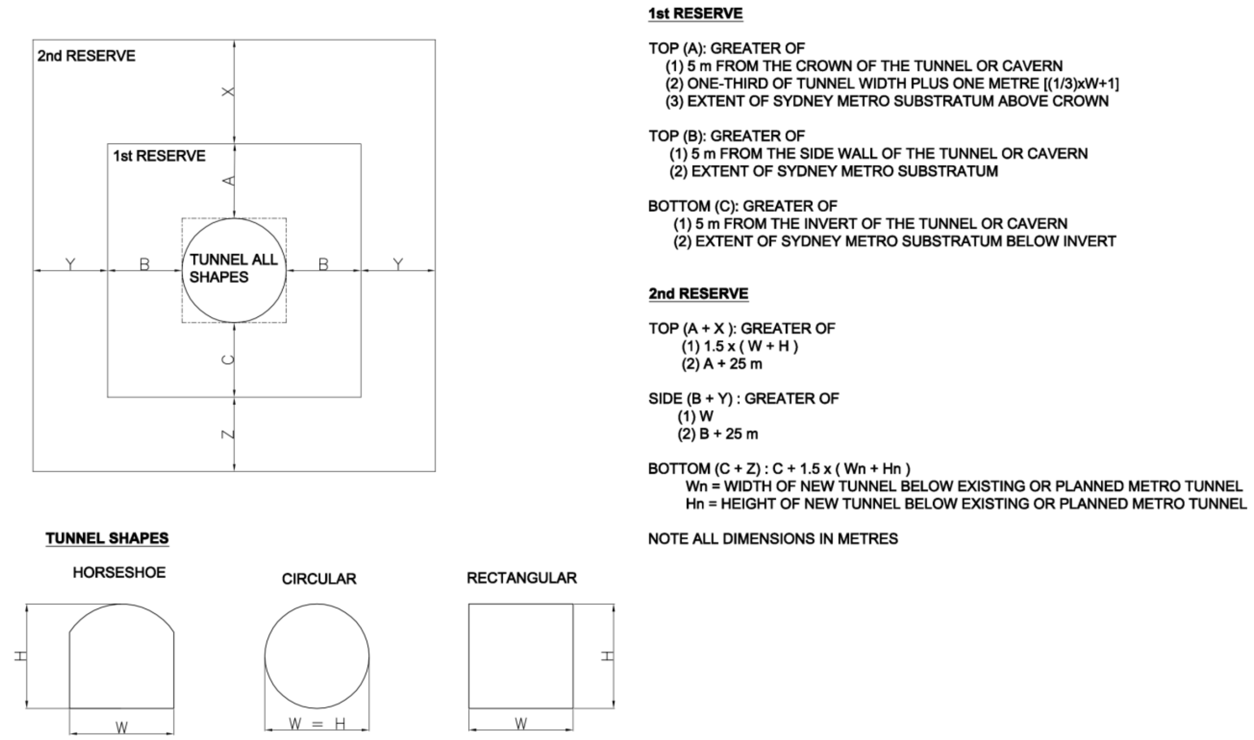

Figure 4.1 Protection reserves for metro tunnels and caverns

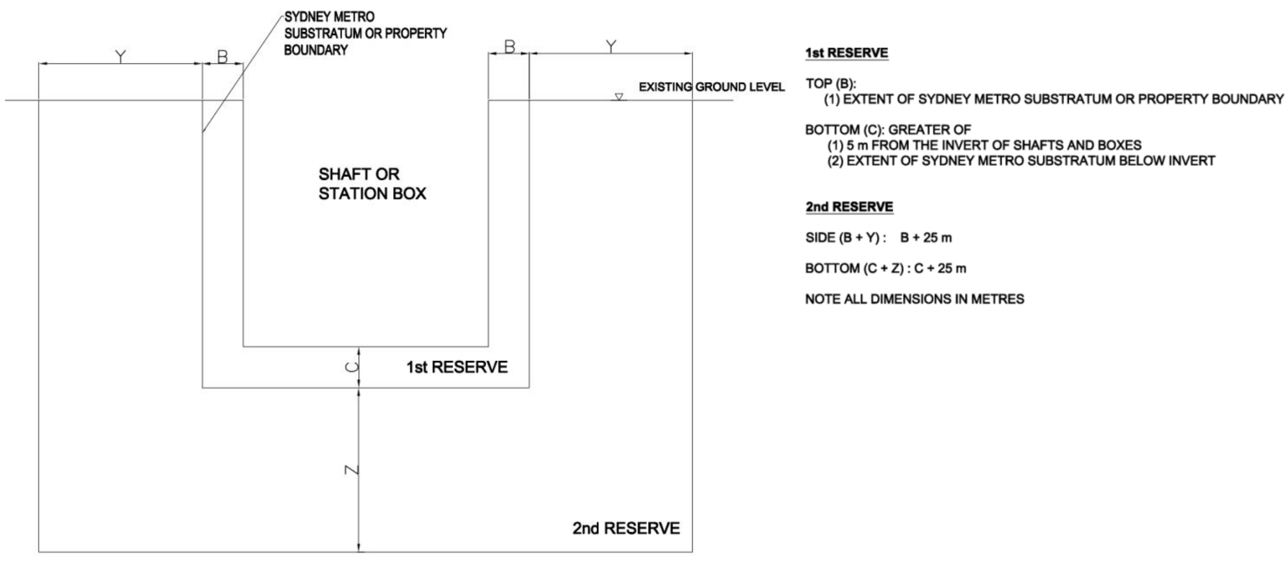

Figure 4.2 Protection reserves for shafts and station boxes

4.2 First Reserve

The first reserve encompasses the ground that immediately surrounds the underground metro infrastructure. This zone represents the area that must not be encroached upon by any future development and its construction.

The limits of this zone are indicated in Figure 4.1 and Figure 4.2. These limits are determined based on an appreciation of general ground support principles and the substratum acquired for the Sydney Metro.

Table 4.1 Definition of first reserve for tunnels and caverns

Boundary (Dimension Reference as shown in Figure 4.1)	Reserve dimensions (m)
Top (A)	The greater of the following: ▪ 5 m from the crown of tunnel or cavern ▪ Support zone based on 1/3*tunnel width plus 1 metre (1/3*W+1) ▪ Extent of Sydney Metro substratum above crown
Side (B)	The greater of the following: ▪ 5 m from side wall of tunnel or cavern ▪ Lateral extent of Sydney Metro substratum
Bottom (C)	The greater of the following: ▪ 5 m below the invert of the tunnel or cavern ▪ Extent of Sydney Metro substratum below invert

Table 4.2 Definition of first reserve for shafts and station boxes

Boundary (Dimension Reference as shown in Figure 4.2)	Reserve dimensions (m)
Side (B)	▪ Lateral extent of Sydney Metro substratum or property boundary
Bottom (C)	The greater of the following: ▪ 5 m below the invert of the shafts or boxes ▪ Extent of Sydney Metro substratum below invert

4.3 Second reserve

The second reserve zone surrounds the first reserve and covers the areas where development works have the potential to adversely impact on the performance of the support elements of underground infrastructure, metro operations or the feasibility of planned metro infrastructure.

Any developments that take place within the second reserve require an engineering assessment of the works to predict their effects on the underground rail infrastructure.

The limits that apply to the second reserve are summarised in Tables 4.3 and 4.4 below.

Table 4.3 Definition of second reserve for tunnels and caverns

Boundary (Dimension Reference as shown in Figure 4.1)	Reserve dimensions (m)
Top (A+X)	The greater of the following: ▪ 1.5 x (W+H) ▪ A+25 Where 'W' and 'H' are width and height of the existing rail tunnel
Side (B+Y)	The greater of the following: ▪ W ▪ B+25
Bottom (C+Z)	C + 1.5 x (W_n + H_n) Where, 'W_n' and 'H_n' are width and height of new tunnel under the existing metro tunnel or cavern

Table 4.4 Definition of second reserve for shafts and boxes

Boundary (Dimension Reference as shown in Figure 4.2)	Reserve dimensions (m)
Side (B+Y)	▪ B+25 m
Bottom (C+Z)	▪ C+25 m

The following factors have been considered to establish the extent of the second reserve:

- potential stress and displacement influence zones associated with external developments that consider the expected zone of negligible ground stress changes due to the construction
- extent of shear displacement of horizontal rock defect or bedding and joints during construction
- potential groundwater drawdown influence zone and
- vibration influence zone.

4.4 Construction restriction placed on protection reserves

Table 4.5 provides the construction restrictions that are applied to each reserve zone as shown in Figure 4.1 and Figure 4.2.

Table 4.5 Construction restrictions

Types of construction	First reserve	Second reserve
Excavation for basements, footings	Not allowed	▪ Excavations less than 2.0 m depth from surface level, assessment not required. ▪ Excavation greater than 2.0 m depth, assessment required.
Shallow footings or pile foundations	Not allowed	Allowed, subject to load restrictions. Assessment required.
Tunnels and underground excavations	Not allowed	Allowed, subject to assessment
Ground anchors	Not allowed	Allowed, subject to assessment
Demolition of existing subsurface structures	Not allowed	Allowed, subject to assessment
Penetrative subsurface investigations	Allowed away from support zone, Assessment required	Allowed, subject to assessment

5. Developments

5.1 General

Any new construction above, below or alongside the existing or future metro infrastructure, that is located within the protection reserves, are considered developments that fall within the scope of this guideline document. Any construction that is located outside these protection reserves, but still has the potential to cause construction-induced groundwater drawdown and vibration that will affect underground metro infrastructure are considered developments that fall within the scope of this guideline document.

Developments near metro infrastructure must be planned, designed, constructed and maintained to ensure the protection of existing and future metro infrastructure. These developments must not affect the metro operations including either the operational capacity or the efficiency of the network during any stage of the life cycle of that development.

Development related loads and ground displacements can cause deformation of existing tunnels and other associated structures and, in extreme situations, can cause structural failure and collapse. Deformation of the tunnel and cavern support elements and the surrounding ground is of concern as movement of structural lining can cause structural instability, groundwater ingress and encroachment of support into rail functional areas, such as rolling stock kinematic envelopes.

The following sections discuss those aspects of developments where construction restrictions are placed within the second reserve and includes safety and environmental considerations.

5.2 Construction restrictions

The following summarises key construction activities that are permitted, but have a potential to affect metro infrastructure, as such restrictions may apply to construction activity within the second reserve:

- Excavation for basements and shafts – above / beside or below
- Ground anchors – above / beside or below
- Shallow footing or pile foundation – above / beside or below
- Tunnels and underground excavations – above / beside or below
- Demolitions or existing structure – above or beside
- Geotechnical investigations / instrumentation – above / beside or below

Whilst these restrictions focus mainly on impacts to existing underground infrastructure, in many cases they are equally applicable to future metro infrastructure. In these cases the intent of the construction restrictions is to ensure the feasibility of future metro construction and operations is not adversely affected by new developments and their construction.

As a general note, the construction of new developments must take into account the construction constraints, particularly live road and rail operating conditions, noise and vibration restrictions and track possession constraints that are inherent to working near to an operating rail environment. Further consideration must be given to access requirements that may be necessary for inspection and maintenance purposes.

5.2.1 Open excavations

Open excavations can be above and/or to the side of underground metro infrastructure. Such excavations can alter the insitu stress regime in the ground that directly affects support elements of underground infrastructure and other sensitive infrastructure. The excavations can additionally reduce the structural support provided by the surrounding rock where the rock provides active support.

Temporary and permanent anchors can be part of the development to support open excavations, underground excavations and provide uplift resistance for construction cranes and basements. High stress concentrations around ground anchors can affect the surrounding ground locally and potentially impact on the stability of the rock and existing underground structures.

A range of excavation methods are available to excavate ground for new developments. Activities such as rock breaking, pile driving and rock drilling/cutting works have the potential to impose temporary loads and excessive noise and vibration on metro infrastructure. Vibration can dislodge rock wedges on existing metro tunnels and caverns, as well as impose additional non-uniform load patterns on the support of metro tunnels and caverns.

Ground improvement works such as grouting and ground freezing works can also affect existing metro tunnel and cavern structures. Grouting can block water drainage paths and impose excessive hydrostatic loads on tunnel and cavern support. Specialised techniques such as ground freezing can cause volume increase that can impose loads on nearby tunnel and cavern support.

In addition, excavation activities will induced ground borne vibration with the potential to affect metro infrastructure.

5.2.2 Foundations

Additional pressures from shallow spread footings and piled foundations designed to support new developments can increase the stresses in the permanent concrete structural linings of metro tunnels and caverns and the surrounding rock. The effects of the foundation loads must be considered, including opportunities to redistribute bearing pressures away from the protection reserves to minimise the impacts.

Of interest are the changes in stress distribution from foundations within the ground above or surrounding existing (or future metro) underground infrastructure as a consequence of development construction. Issues of potential concern relate to increase in vertical or horizontal pressures beneath foundation elements, increases in shear stress along known existing bedding planes in the rock mass and uplift pressures below the invert of metro underground infrastructure.

Ground borne vibration from activities such as pile driving or bored piles installation and sheet pile installation must be considered.

5.2.3 Underground excavation

Underground excavations include the construction of adjacent rail and road tunnels (above, to the side and below), utility tunnels, cable conduits, drainage pipes, and pedestrian walkways and underpasses. Such underground excavations can significantly alter the insitu stress field in the surrounding ground resulting in stress concentrations, stress relief and displacements. These changes can significantly affect the existing metro tunnel and cavern support elements.

In cases where underground excavations are designed to be drained structures (that is, the structural lining and ground support of tunnel and caverns are built to support the ground but permit groundwater to flow into the excavation) consideration must be given to the groundwater drawdown that this will cause and the impacts that this will have on nearby metro infrastructure.

Ground borne vibration caused by tunnelling must also be considered.

5.2.4 Demolition

The demolition of any existing buildings or basements has the potential to adversely affect existing metro underground infrastructure and cause disruption to metro operation. Where necessary, measures may be needed to protect metro assets during demolition works of existing buildings and structures as part of development construction.

5.2.5 Geotechnical investigations

Development activity requires geotechnical and subsurface investigations that can include drill holes, geophysical exploration, in-situ tests and permeability tests. During construction, instrumentation holes such as inclinometers, piezometers and extensometers can be drilled to measure the ground reaction and the impacts.

Importantly, the drilling of boreholes and installation of instrumentation must be planned to avoid existing metro infrastructure and avoid disruption to metro operations.

5.3 Safety

Developments near underground metro infrastructure must address the following aspects of safety in respect of the metro and its operation at any stage of the life cycle of that development:

- structural safety
- operational safety
- fire safety
- inspection and maintenance and
- floor protection.

Consideration must be given to maintenance and to future users of the development. Importantly, new development must not obstruct emergency access to metro infrastructure and any maintenance access requirements.

Approvals from TfNSW are required to enter into the metro assets for dilapidation survey, installation of instruments, monitoring and visual inspections. Persons carrying out these activities must be accompanied by safety personnel from TfNSW or from TfNSW approved organisations when entering metro tunnels.

5.4 Protection of environment

The developer must take into account the environmental impacts that can affect the metro with a view to minimising any effects during the whole life cycle of development. Typical considerations for developments in the urban environment are as follows:

- stormwater management
- noise and vibration
- air quality, particularly dust
- traffic impacts
- visual impact and amenity
- ability and ease to maintain and 'retro-fit' improvements over time
- disposal and re-use at life cycle end
- ecological impact due to draw-down

- groundwater contamination and
- construction materials to be as low toxicity as possible.

6. Development applications and construction

Proposed development which triggers the Infrastructure SEPP will require concurrence from TfNSW (or in some cases Sydney Trains). Different documentation is required at different stages to enable TfNSW to assess the potential impact on future corridors.

To assist TfNSW with their assessment, documentation must be provided at the planning stage and development application stages. Depending on the finding of the assessment by TfNSW documentation and supporting information may also need to be provided at the design, construction and operation stages of the development.

6.1 Planning stage

Where new developments are within the purview of the Infrastructure SEPP criteria it is recommended that the developer consult with Sydney metro and prepare the following documents during the planning stage (or pre-lodgement of DA stage) for preliminary comment and discussion purposes based on the development concept:

- location of site layout
- existing easements on land and for the metro underground infrastructure
- architectural layout showing the general arrangement of the development
- plans and drawings of existing metro infrastructure obtained from TfNSW that show protection reserve boundaries based on this guideline document
- section view and plan view of the proposed development (including the reduced level of basements) and protection reserves and
- site investigation plans (if they involve drilling within the protection reserves).

6.2 Development application (or concurrence) stage

The developer must submit the following documents to TfNSW as part of their development application:

- legal boundary alignment along the length of the proposed site identified by a NSW registered surveyor
- drawings showing the development in relation to the metro infrastructure in plan, elevation view and sectional view with dimensions and reduced levels
- easements (including right of ways) or stratums, covenants and caveats identified by a NSW registered surveyor, specifying the purpose of the easement and whom it is in favour of
- location of metro underground infrastructure and its dimensions, relative distances and reduced levels to the proposed excavation face and levels, foundations
- geotechnical investigation report with details in accordance with Section 7.1 of this guideline document
- impact assessment report with details in accordance with Section 7.2 of this guideline document and
- risk assessment report in accordance with Section 7.3 of this guideline document.

The following may also be requested by TfNSW based on the information provided at the planning stage:

- Detailed dilapidation survey report in accordance with section 7.4 of this guideline document.

6.3 Post development application

Based on the information provided to support the development application TfNSW may require the developer to provide the following information and documentation at the following stages of project development.

6.3.1 Prior to construction

The following documents may need to be submitted prior to construction commencement:

- detailed ground and vibration monitoring plan including trigger levels, action plans and remedial measures, details of the instrumentation and baseline monitoring readings (refer to Section 10)
- construction schedule, construction management plan including sequence plan identifying impacts
- construction layout of equipment relative to metro infrastructure
- final detailed work method statements (refer to Section 8)
- temporary safety plans and measures
- temporary works plan, temporary access, vehicle, plant and equipment such as cranes (including mobile cranes) and stockpiling
- noise, vibration and electrolysis studies and control measures
- a rail related risk assessment and management plan
- list of machinery to be used
- groundwater control plans, environmental aspects including contamination
- design loadings and certified drawings for construction related works that affect metro infrastructure
- agreed interface activities plan with TfNSW and
- condition and dilapidation survey reports of all metro infrastructure affected by the development (refer to Section 8.2).

6.3.2 During construction

The following documentation may need to be submitted to TfNSW at agreed intervals by the developer, during the development construction phase:

- monitoring report at agreed intervals, which includes monitoring results and assessment by the geotechnical or structural consultant
- notification of work progress at agreed intervals, which is applicable during excavations, foundations and support installations, superstructure construction up to the ground level
- interim dilapidation survey reports as appropriate
- any changes to the design and construction methods for approval by TfNSW and
- rock face mapping, inspection and assessment reports.

6.3.3 After construction completion and prior to issue of occupation certificate

TfNSW may request the following documentation from the developer, after completion of the construction:

- one set of as-built structural and foundation plans signed by qualified person
- one set of as-built drawings for ground anchors and other support details near the affected metro infrastructure
- monitoring summary report
- copy of the geotechnical mapping report carried out during excavation works
- dilapidation survey report conducted after construction completion (refer to Section 8.2)
- structural safety report
- operational safety report and
- current mitigation verification report, including maintenance base line measurements referenced to measured locations (refer to Section 9.4)

7. Engineering investigations and assessments

The developer must prepare the following documentation in support of their DA:

- geotechnical investigation report
- impact assessment report
- risk assessment report
- dilapidation survey report
- drainage report and
- a summary report that presents the main conclusion and results from the above reports.

This section of this guideline document provides an explanation of the information that needs to be included in these reports to enable TfNSW to ascertain the relative impact of the development on existing and future Sydney Metro underground infrastructure. In terms of the engineering investigations and assessments undertaken for future metro infrastructure, the intent of these is to ensure the feasibility of future metro construction is not adversely affected by new developments and their construction.

The main aim of these assessments and investigations is to demonstrate that there will be no adverse effects arising from the proposed development within the defined protection reserves. The acceptability of the effects predicted (as determined through investigation and assessment) must be viewed against the performance requirements described in section 9 of this guideline document, as well as compliance with relevant standards and codes.

The developer should approach TfNSW for information that defines the extent of existing and future metro infrastructure in order to undertake these investigations and assessments.

7.1 Geotechnical investigation

If required by TfNSW, the developer must carry out detailed geotechnical investigations of the soil or rock strata above, alongside and below existing and future Sydney Metro underground infrastructure, as appropriate, to establish the existing ground conditions within the area affected by the proposed development. Geotechnical investigations must be undertaken by suitably qualified and experienced consultant. The results of the investigation must be presented in a geotechnical investigation report.

The intent of these geotechnical investigations must be as follows:

- Provide information that enables a geological model to be developed. Based on this model sections should be able to be must be prepared that illustrate the ground conditions in and around the interface of the proposed development with the Sydney Metro underground infrastructure of concern.
- Establish the likely insitu stress conditions within the soils and underlying rockmass surrounding the interface.
- Define, if present, critical geological features such as bedding planes, joints and dykes.
- Present an interpretation of relevant rock and soil properties based on the results any insitu and laboratory testing that has been undertaken.
- Provide an interpretation of the existing groundwater regime within and surrounding the interface.
- Identify and describe the presence of any human-made features within the development site.

The scope of the geotechnical investigation undertaken to support the development application may comprise the following:

- drilled boreholes
- insitu testing
- geological mapping and
- geophysical exploration.

Whilst the installation of instrumentation and the drilling of investigation boreholes is permissible near to metro infrastructure, they should be located and orientated to avoid the supporting systems of existing metro underground infrastructure. This will require a detailed study of existing arrangements to demonstrate that risk to the underground infrastructure is appropriately managed for approval from TfNSW prior to the drilling of boreholes.

In some cases TfNSW may require that before drilling can take place a surveyor must establish the co-ordinates of the borehole at surface. In these cases drilling may only proceed after obtaining approval from TfNSW.

All boreholes must be carefully grouted to their full depth with a bentonite and cement grout mixture upon completion.

As a minimum the geotechnical investigation report will need to present the following information:

- borehole location plan, borehole logs, test results, geological mapping, photographic documentation and other relevant information
- description of the soil profile of the area
- critical geological features such as bedding planes, joints and dykes
- other relevant data from geotechnical investigation
- rock and soil properties, laboratory and insitu test results
- existing insitu stress states in soils and rocks
- groundwater levels and condition.
- detailed geotechnical model for the analysis including geotechnical design parameters
- recommended footing design, methods of shoring and excavation and
- a copy of all plans, geotechnical data, operations and maintenance records with any qualifications and limitations provided by TfNSW to the developer.

7.2 Engineering impact assessment

The developer must carry out an engineering analysis and impact assessment to demonstrate that the effects of the proposed development on tunnels and underground facilities will not cause unacceptable adverse impacts on future or existing Sydney Metro infrastructure. The engineering assessment must be carried out by suitably qualified persons with experience in tunnel design and analysis. In some cases TfNSW may request the developer to arrange independent verification of the engineering analysis and impact assessment based on the project complexity and the potential effects on metro infrastructure.

The results of the analysis and assessment must be presented in an engineering report. The engineering assessment report must be prepared and endorsed by a suitably qualified person and submitted to TfNSW.

The engineering analysis and impact assessment must take into account any other adjacent development activities planned for the future or that are taking place at the time of analysis. This information can be obtained from TfNSW.

Depending on the complexity of the development, a two-dimensional or three-dimensional numerical modelling (finite element [FE] or finite difference [FD]) may be requested by TfNSW to predict the effects on the underground construction at different stages of construction and the eventual or current operation of the metro. The modelling must also consider the effects of associated temporary works, such as construction loading (e.g. cranes and material stockpiling).

If undertaken, numerical modelling must fulfil the following requirements:

- be based on a realistic geological model derived from the subsurface information gathered through the geotechnical investigation
- must incorporate critical geological features that may be present, such as bedding planes, weak layers, joints and other discontinuities and
- take account of the existing condition of the tunnel lining including defects such as cracks, drainage conditions and support conditions as determined by dilapidation survey and insitu strength tests.

If necessary, the results from this numerical modelling may need to be validated during construction by comparison with the results from the field monitoring of installed instrumentation.

As a minimum the impact assessment report must include the following:

- Details of the scope of the development.
- Verified survey plans by a NSW registered surveyor that show the location of the proposed development in relation to the metro easements, protection reserves and the planned or existing metro alignment including track centre lines and details of the and underground structures.
- The metro underground infrastructure must be shown in plan and various sections with the inclusion of the protection reserves as defined in this guideline document to clearly illustrate the comparative position of the development in relation to the existing or planned metro infrastructure. They must also extend to the expected physical zone of influence, which is the extent to which the development is expected to affect the surrounding ground.
- Detailed drawings depicting structural layout, foundation layout, foundation loads, drainage plans, temporary works such as dewatering, shoring and anchoring and permanent works of the proposed development.
- Structural drawings that show the designs for shoring, as recommended by the developer's geotechnical consultant.
- Predicted displacements of existing or planned metro underground infrastructure (if constructed prior to the proposed development) due to proposed development at various stages, namely pre-construction (including demolition), excavation, development construction and post-construction.
- Predicted displacements, stresses and structural actions as imposed on the structural support of metro infrastructure structure at various stages of construction, namely pre-construction (including demolition), excavation, development construction and post-construction. In most cases this support will be in the form of watertight structural concrete linings.
- Structural assessments of these predicted effects on existing and planned metro infrastructure (if constructed prior to the proposed development). This must include as appropriate the structural integrity of underground support (such as structural linings), track beds, existing drainage structures, waterproofing measures and structural clearances.
- Appropriate sensitivity analysis to ensure that the predictions are not adversely affected by reasonable variations in input parameters and different conditions that can occur during all stages of development construction.
- Assessment of the effects of construction techniques and methodology on the underground metro infrastructure.

- Provide discussion on any design assumptions, qualifications or limitations that have been applied. This discussion must indicate how these have been considered as part of the sensitivity analysis and then integrated as identified risks as part of the risk assessment (as discussed below).
- Recommendations regarding any planned preventive or remedial action that may be required to limit development induced impacts on metro infrastructure.
- Noise and vibration assessment report (refer section 8.6).
- Stray currents report, including a risk assessment (refer to Section 9.4).
- Certification that the proposed development will not induce unacceptable adverse effects on metro infrastructure.

7.3 Risk assessment

The developer has a legal duty to eliminate risks to safe rail operations so far as is reasonably practicable (SFAIRP). As such the developer must identify all reasonably foreseeable safety risks and hazards to the metro or its operations and eliminate these risks where reasonably practicable and where it does not minimise each risk SFAIRP.

The identified risks and their SFAIRP demonstration must be documented in a manner that can be provided as assurance evidence to TfNSW. TS 20001 System Safety for New or Altered Assets describes the assurance for changes impacting rail or transport assets. Reference should also be made to T HR CI 12075 ST when preparing the risk assessment.

A rail related risk assessment report must be prepared and submitted for consideration and approval by TfNSW in accordance with the safety management system for TfNSW and address/include the following:

- safety in design that covers and the whole of asset life cycle, including all stages of construction
- identify all hazards and risks to the development and metro facilities including metro support elements and other infrastructure
- present the risk identification process that has been adopted which considers the entire asset life cycle of the metro infrastructure
- apply and present a risk ranking in accordance with the TfNSW safety management system
- confirm that all risk can and will be managed so far as is reasonably practicable (SFAIRP) and
- present the controls that are needed to manage risks from the development to metro infrastructure. These may include early warning criteria for monitoring.

7.4 Dilapidation survey

Dilapidation surveys of existing metro infrastructure may be requested by TfNSW during the planning stages and may need to be submitted as part of the development application. If required, the developer must arrange for a dilapidation survey to be undertaken of metro infrastructure in proximity to the development. The existing condition of the metro infrastructure must be established and considered as part of the risk assessment.

7.5 Drainage report

Where relevant TfNSW may request that a drainage report is prepared that details the proposed means of drainage that will be adopted to manage the collection of water, including groundwater, within basement levels of the proposed development.

7.6 Independent verification

Depending on the details of the proposed development and the proximity of planned or future metro infrastructure, TfNSW may request that an independent verification of the engineering analysis and impact assessment be carried out. If required, the independent verification must be arranged by the developer.

The independent verification must be carried out by an organisation that is independent of the organisation that prepared the engineering analysis. The independent verification organisation will be subject to the approval of TfNSW.

The independent verification must include detailed engineering proof checking of all aspects of the engineering analysis and impact assessment including any proposed temporary works.

The independent verification organisation must prepare a report that describes its verification activities and includes certification that the proposed development will produce no unacceptable adverse effects on existing metro infrastructure. The independent assessment report must be submitted to TfNSW with the engineering assessment report.

8. Construction requirements

8.1 General

All metro property must be fully protected during construction of the development and all site work (including clearances to metro tracks and protection reserves) must comply with the requirements outlined in this guideline document, as well as other relevant TfNSW standards relating to air space developments, external developments and tunnels, and safe working requirements.

All construction carried out on metro property must comply with the requirement of the relevant authorities and legislation including workplace health and safety (WHS) requirements and environmental requirements.

In the event that concurrence is provided by TfNSW the construction requirements described in this section apply.

8.2 Dilapidation survey

Before construction of the development can commence and an occupation certificate can be issued, a joint inspection of the existing metro near the proposed development may be requested by TfNSW. If requested the survey must be carried out by representatives of the developer and TfNSW. The existing condition of the metro infrastructure must be agreed and recorded. Additional joint inspections may be required during construction.

The extent of metro infrastructure that must be surveyed will be determined by TfNSW.

Detailed dilapidation reports must be submitted to TfNSW describing conditions before commencement of works and after completion of works.

The dilapidation report must include the following as a minimum:

- details of existing defects
- dimensions of existing cracks
- photos of defects with labels that indicate their locations and
- signs of wetness, staining and seepage from existing defects.

This inspection must establish the extent of any existing exposed cracks, such as those observed on the surface of concrete linings which support metro tunnels and caverns. These cracks must be suitably marked and identified to enable any deterioration to be monitored.

8.3 Risk assessments

Prior to commencing any works the risk assessment report issued in support of the DA must be updated based on the detailed design at construction. The updated risk assessment report must take into account any modifications to the design and the impact these may have on identified risks.

Safe work method statements must also be prepared that include, as a minimum, the following:

- detailed work methods including the incorporation of the controls as stated in the risk assessment plan and
- an emergency response plan.

The developer must submit the safe work method statements and updated risk assessment report to TfNSW for approval.

8.4 Demolition works and construction impacts

The demolition of any existing buildings or basements must be planned in such a way that no adverse risk is imposed on existing metro underground infrastructure. The developer is required to take every possible action to minimise imposed risks and is required to meet the costs of any protection of the metro infrastructure and any incurred disruption to metro rail operations.

The impact of any proposed underground demolition work (including de-stressing, unloading and resulting ground vibrations) must be assessed to ensure that there are no adverse effects on metro infrastructure. If large-scale demolition works are involved, then the developer is required to install a vibration monitoring system to monitor vibration levels near adjacent metro infrastructure.

Hydraulic rock breakers must not be used within five metres of any existing metro infrastructure.

The developer is required to arrange a structural investigation by appropriately qualified person to address the impacts.

Refer to T HR CI 12075 ST for further details.

8.5 Excavation works

The developer must submit the following for TfNSW's approval prior to commencing excavation for the development:

- An engineering assessment report which through the use of numerical modelling techniques (if required) demonstrates that the excavation will not cause any adverse effect on the underground metro infrastructure.
- Design reports that detail the shoring system that support excavations must be provided to TfNSW prior to construction and must include evidence of independent verification certification.
- A detailed monitoring plan for ground deformation, tunnel convergence, stress, crack width monitoring, vibration monitoring and reporting protocol for each party.
- Risk assessment and contingency plans.
- Detailed work method statements which include hold points at various stages of excavation and are linked to the acceptable monitoring results.

The following requirements apply to excavation and piling works at construction:

- The positon of underground metro infrastructure (outer walls) and protection reserves must be marked clearly on the ground for easy identification.
- All piling contractors must be made aware of the existing underground metro infrastructure adjacent to construction site.
- TfNSW must be informed of the progress of piling and excavation works on a daily basis.
- The results of field monitoring undertaken during excavation or piling works must be assessed by a suitably qualified person and reported to TfNSW at an agreed frequency.

Depending on the project complexity and potential impact on metro infrastructure, TfNSW can require the developer to engage a geotechnical consultant during the time of excavation process for visual verifications of substrata as identified during investigation, geological mapping where required and an assessment of monitoring results.

The developer must submit the monitoring results together with geotechnical consultant's assessment to TfNSW at agreed frequencies and stages of construction. A TfNSW nominated observer may be involved with the monitoring.

Monitoring must continue until construction of the building structure or superstructure is complete. With prior agreement with TfNSW, monitoring frequencies may be decreased when the basement construction is completed. Monitoring must continue after the completion of the construction activities until no changes occur in three consecutive monitoring cycles. TfNSW must be informed before termination of the monitoring activities.

8.6 Noise and vibration

The effects of noise and vibration on existing metro infrastructure and on the development must be considered as part of the design and construction of developments.

The construction of the development must be carried out such that the effects of noise and vibration on nearby metro structures and facilities are minimised. Prior to construction, an acoustic and vibration assessment report, including a vibration monitoring plan, must be prepared by a qualified person and submitted to TfNSW. This assessment must cover acoustic and vibration levels arising from the proposed development during construction and its operation after completion (including any machinery causing heavy vibration levels). The assessment must also determine the effects of noise and vibration on the metro infrastructure and its operations.

8.7 Contaminants and hazardous materials

The storage of potential contaminants and hazardous materials within the protection reserves will be subject to TfNSW approval. A risk assessment and appropriate safety precautions must be provided for storage of potential contaminants within any of the protection reserves, where there is potential for the contaminants to migrate to or come in contact with the metro underground infrastructure. This assessment must address the potential impact on the durability of concrete, grout, resin, steel, waterproofing gaskets and membranes and any other material forming the permanent works of the metro underground infrastructure.

The storage of potential contaminants and hazardous materials may be permitted if the results from the risk assessment demonstrate that the risk to the metro underground infrastructure can be appropriately managed.

9. Performance requirements

The design and construction of the development must be carried out with full recognition of the potential effects that could be imposed on the performance of the existing metro or the feasibility of the future metro. As an overarching principle the development must not affect the stability and integrity of the metro infrastructure and its safe operation. Broadly, the developer must ensure that the development and its construction do not adversely affect the performance of metro infrastructure in respect of the following:

- amenity
- aesthetics
- structural integrity
- durability
- function
- user/customer benefits
- safety during construction and operation and
- environmental performance.

It should be noted that throughout the developer's activities, the developer must monitor the actual effects of construction against design predictions and in accordance with the project-specific construction phase monitoring requirements.

Aspects of the development and its construction which could adversely affect the metro infrastructure include the following:

- loading or unloading from the development
- ground deformation resulting from excavations and external loading
- induced vibrations during construction and operation
- ground borne noise impacts
- electrolysis from earth leakage currents
- discharge of stormwater from the development
- changes to groundwater levels affecting design assumptions
- loss of support to any underground rail facility (including rockbolts and anchors)
- temporary structures and
- load from anchors

This section details the design and performance requirement that must be adhered to by the developer in order to address these issues.

9.1 Structural integrity

Development induced load and displacements must not have any adverse effects on the support structure or system of metro infrastructure in both the short and long term conditions.

Structures that are proposed to be constructed over and/or adjacent to metro underground structures must be suitably designed to take into account the presence of the existing metro infrastructure and future construction of metro infrastructure. Construction work methods must be developed as part of the design process.

The effects on metro support elements and other metro infrastructure at any stage of the whole life cycle of the development must be assessed to ensure that the works must remain compliant with relevant standards. These structural elements include, but not limited to, concrete (precast, insitu or sprayed) linings, load bearing columns, walls and roof beams, slabs, rock pillar supports, permanent rock anchors (or bolts), track slabs, drainage structure, shafts and underground stations.

Of particular interest is the possibility of increases in structural actions, such as axial loading and flexural bending, to support elements and structural linings of metro underground infrastructure, as a consequence of development loading.

9.1.1 Imposed loading

Any temporary or permanent works adjacent to the metro could be subject to the influence of train loading and as such will need to be assessed in accordance with AS 5100 for live load surcharge. Parts of the development that could be affected must be designed to comply with T HR CI 12070 ST Miscellaneous Structures, T HR CI 12075 ST Airspace Developments and T HR CI 12080 ST External Developments.

Permanent works adjacent to metro must take into account the design actions resulting from any proposed future metro construction. TfNSW will provide advice in relation to planned future metro infrastructure.

9.1.2 Induced movement

Displacement of metro infrastructure as induced by the development must not affect the operational functionality and durability of the affected infrastructure. Also, the developer must consider the possibility that future metro construction may induce movement on the development.

The following displacements limits apply:

- For metro cast insitu cavern and tunnel concrete linings, the allowable total movement in any direction is 10 mm and differential movement in any plane is 10 mm or 1:2000 whichever is less.
- For metro running tunnels that are supported by a precast concrete segmental lining, the allowable total movement in any direction is 10 mm and differential movement in any plane is 10 mm or 1:2000 whichever is less. The main purpose of these limits is to ensure that the watertightness of the lining through joints is not compromised as consequence of gasket decompression and/or damage.
- Shear movement across rock bedding as induced by the development activities must not exceed 10 mm where permanent rock bolts, installed as part of the metro infrastructure support system, intersect these bedding planes.

Any development activity, whether beneath or adjacent to contained metro tracks, that has the potential to cause track displacement must comply with the requirements of SPC 207 Track Monitoring Requirements for Undertrack Excavation. The track must be monitored and managed in accordance with the requirements stated in SPC 207 for monitoring, notification and intervention levels and emergency procedures.

9.1.3 Induced cracking

The extent of dilapidation surveys undertaken (and described previously in this document) of metro infrastructure must be determined based on predictions of deformation and the load influence zone imposed by the proposed development. The survey must establish the extent of any existing cracks. Where present these must be suitably marked and identified to enable any deterioration during and after the construction to be monitored.

The following technical criteria must be met regarding cracking, including the presence of pre-existing cracks on the face of metro concrete structures:

- No new cracking of metro concrete structures (both inside and outside of structures such as tunnel linings or other support elements) is allowed to be induced by the development and its construction. Compliance with this requirement must be confirmed by performing impact assessments during the design stage.
- Any existing cracks must not increase by more than 0.2 mm in width or increase in length by more than 300mm in total over the stages of development construction.
- The propagation of these existing cracks must comply with the following requirements:
  - The configuration of cracks must not result in concrete spalling or affect the safe operation of the metro system.
  - In the event that water seepage is observed (previously absent) through the cracks during development construction then TfNSW will on behalf of the developer seal the cracks by grouting the cracks until this seepage ceases.
- Engineering analysis and assessment undertaken for the development (as discussed within this guideline document) must take into account the presence of existing cracks of metro infrastructure.

The monitoring of existing cracks and critical structural elements during construction must form part of the overall monitoring plan.

9.2 Excavation and groundwater

Excavation for the development and all associated retaining works (along with other ground disturbance works associated with the proposed development) must not affect the safety and operational integrity of the metro or cause the destabilisation of metro infrastructure. The methods of excavation employed are of particular relevance in this regard, especially where methods employ chiselling, percussive pile driving or similar methods. Importantly, explosives must not be used for the splitting and removal of rock and excavation.

Typical issues associated with excavation works include slippage, slumping, creation of fissures or cracks, rock or earth falls, exacerbated ground movements, water inflows, cracking the supporting structural elements and in extreme cases structural failure. Excavation works must be undertaken in a manner that minimises the risk of such occurrences.

Sections of temporary shoring installed to support excavations for the development must have a minimum service life of 3 years, if their stability has the potential to affect metro infrastructure. Shoring systems must be designed by an approved design organisation and verified by an independent qualified person. Allowance should be provided for minimum unplanned excavation in accordance with CIRIA C580 Embedded Retaining Walls, Guidance for Design, 2003.

Ground anchors are not allowed within the first reserve zone. Any ground anchors within the second reserve must be assessed for their effect on metro underground infrastructure. Anchors must not be tested in cases where this testing could cause collapse or failure, or both, in the surround soil and rock structure.

Assessment of metro infrastructure from development excavation must also consider the loading that cranes (including their foundation anchorage) will impose within the excavation on metro infrastructure.

Construction near metro underground infrastructure can also impact the local groundwater regime. These impacts have the potential to cause adverse loading of the infrastructure, not contemplated and thus designed for over the design life of the metro. Critically, the watertightness and waterproofing must not be adversely affected or damaged.

The developer must carry out an engineering assessment of the impact of any changes to the groundwater regime that the development could cause. Issues of concern that have the potential to impact on metro infrastructure include the following:

- The development and its construction could create a water barrier that dams groundwater flow above the metro underground infrastructure.
- Groundwater ingress into excavations associated with the development can cause dewatering of the local water table. Importantly, dewatering must not commence without prior approval from TfNSW.

Consequently, the engineering assessment must address any temporary dewatering (at any stage of the development) to demonstrate that effects on underground metro infrastructure are acceptable.

9.3 Noise and vibration

The noise from construction and rail operation must be considered against statutory and project noise vibration limit requirements. TfNSW does not accept liability for the generation of noise and vibration from normal railway operations (including track maintenance), or for its transmission into developments above or adjacent to rail tunnels.

When designing developments above or adjacent to rail tunnels (existing or planned), consideration must be given to operational and construction vibration; as well as ground or structure borne noise emissions in accordance with Developments Near Rail Corridor and Busy Roads – Interim Guideline, Department of Planning, NSW Government 2008.

In planning development construction the following requirements apply.

Any development that occurs within a screening distance of 25 m horizontally from first reserve must consider the vibration on the metro infrastructure with the following assessment criteria of maximum peak particle velocity (PPV):

- 15 mm/s for tunnel and cavern cast insitu concrete linings that are in good condition.
- 20 mm/s at the running tunnels supported using a precast concrete segment lining.

It is important to note that more stringent limits may apply if rail equipment, that is sensitive to vibration, has the potential to be affected by the development and its construction.

During development construction vibration monitoring may be required of the underground metro support, such as concrete linings. This monitoring must be conducted based on the selection of appropriate trigger levels.

If the vibration levels exceed tolerable limits, then the developer must modify the construction methodology in such a way that the vibration limits are satisfied.

9.4 Stray currents and electrolysis

When designing developments above or adjacent to underground metro infrastructure consideration must be given to operational stray currents that may be present. The risk assessment must also consider the potential presence of stray currents.

TfNSW does not accept liability for the generation of stray currents from an operating electrified railway.

The potential effects of stray electrical currents and electrolysis in the electrified area of the metro network must be considered in accordance with T HR CI 12080 ST and T HR EL 12002 GU during the design of the development.

A suitable test program must be established during the early design phase to quantify a stray current signature for the development site prior to undertaking enabling works. Suitable stray current mitigation strategies must be integrated into the design of the development.

Following construction, stray current testing must be carried out to verify that electrolysis mitigation strategies are proven to be effective, which includes undertaking a comparison with the pre-development stray current signature. This information must also be used to establish maintenance baselines for the life of the development.

10. Monitoring

Monitoring provides a means of validating assumptions made to design the development and prove the acceptability of impacts that could affect metro performance.

The structural performance of the metro underground infrastructure must be monitored as necessary during construction of the development to verify predicted displacements, stress levels in structural elements and vibration levels. The monitoring regime must be developed by a qualified tunnel engineering consultant.

Where required, the developer must implement monitoring system that incorporates early warning criteria developed in agreement with TfNSW. The developer's geotechnical consultant must assess the monitoring results continually, and submit monitoring assessment reports to TfNSW for review.

The tables below indicate the circumstances where various types of monitoring are required. These requirements must be provided as a minimum. Figure 10.1 provides typical extents that monitoring must be provided in each case.

Table 10.1 Minimum monitoring requirement for development activities near rail tunnels - In ground

Type of instrument	Deep open excavations	Foundation works- shallow or deep	New underground excavation or new tunnel
Inclinometer	Yes	Yes	Yes
Water standpipe	If required by TfNSW	If required by TfNSW	If required by TfNSW
Piezometer	Yes	Yes	Yes
Extensometer	Yes	If required by TfNSW	Yes
Ground settlement markers	Yes	Yes	Yes
Building settlement markers	Yes	Yes	Yes

Table 10.2 Minimum monitoring requirement for development activities near rail tunnels – within existing rail tunnels

Type of instrument	Deep open excavations	Foundation works- shallow or deep	New underground excavation or new tunnel
Tunnel convergence	Yes	Yes	Yes
Tiltmeter	Yes	If required by TfNSW	Yes
Crack meter	Yes	Yes	Yes
Vibration sensor	Yes	Yes	Yes
Rail track monitoring (distortion)	Yes	If required by TfNSW	Yes
Strain gauges in lining	If required by TfNSW	If required by TfNSW	If required by TfNSW
Pressure cells in lining	If required by TfNSW	If required by TfNSW	If required by TfNSW
Real time monitoring such as EL beams, optical prism laser scanning	If required by TfNSW	If required by TfNSW	If required by TfNSW

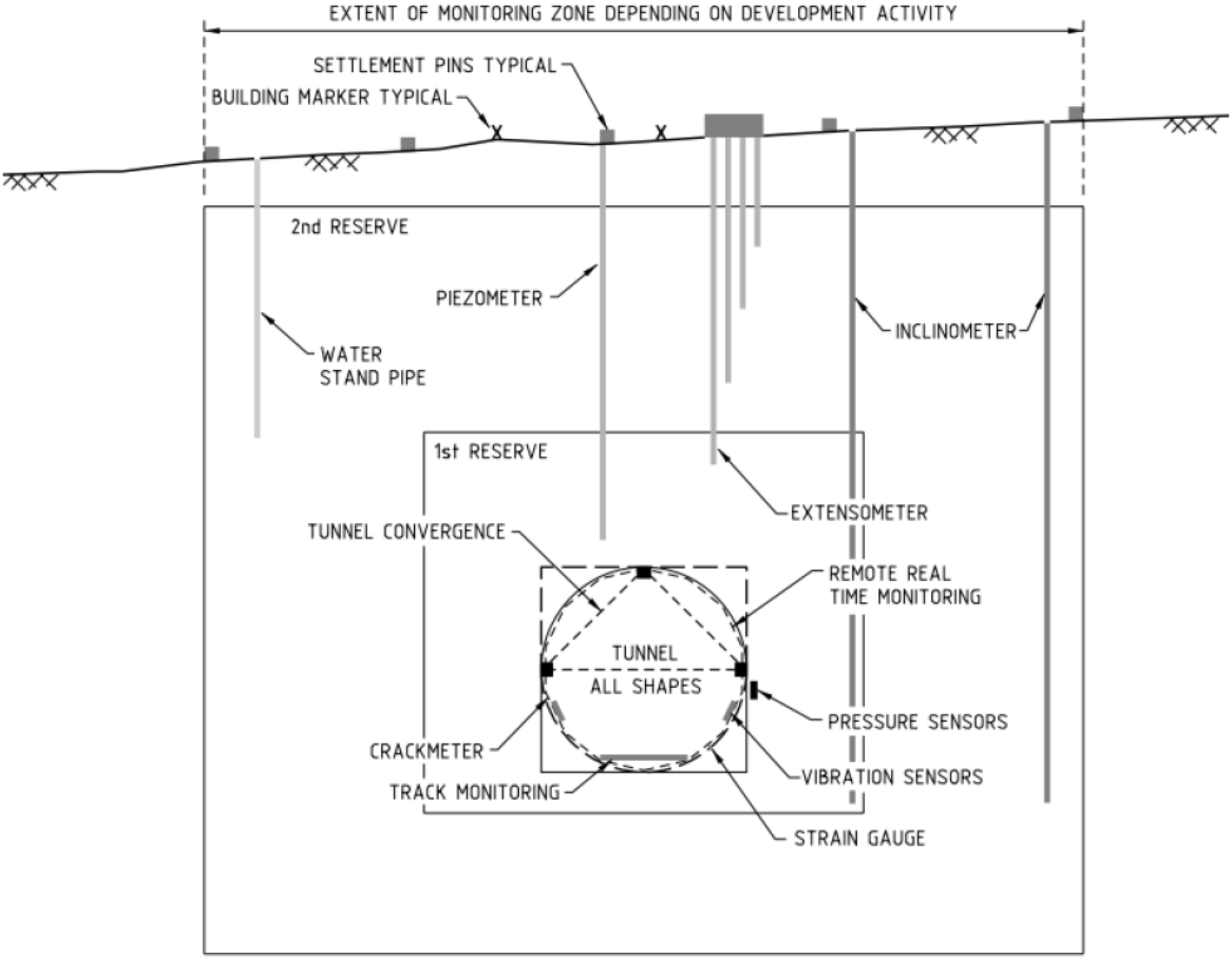

Figure 10.1 Typical instrumentation layout

Baseline data for each monitoring parameter must be established before commencement of development construction. The developer must provide as a minimum, three sets of monitoring data to establish a baseline prior to excavation.

The equipment that is used for remote monitoring (particularly for alarm or warning systems) must have proven reliability in similar applications.

Any alarm or warning system should have a visual and audible alarm system to activate and to stop all works as necessary and notify relevant personnel such as site manager, geotechnical consultant and nominated TfNSW representative.

Depending on the project complexity, physical inspections of existing metro infrastructure may be required on a regular basis during critical stages of construction. If necessary, these inspections should be undertaken jointly with the developer and TfNSW representative (including a representative from the metro operator as necessary).

Monitoring plans must be submitted to TfNSW for review and approval prior to the commencement of development construction. The monitoring plan must include a response regime and contingency plan. These must be agreed with TfNSW before work can commence.

Appendix A

Sydney Metro

Sydney Metro – Northwest

The Sydney Metro Northwest is the first dedicated metro line to be constructed for the metro and extends from Chatswood through to the Northwest. Sydney Metro Northwest incorporates 13 km of track and rail infrastructure between Epping and Chatswood that has been modified and segregated to form part of the Sydney Metro. The following are key features of the Sydney Metro Northwest.

Sydney Metro – Northwest Epping to Cudgegong Road

- 23 km of new track and rail infrastructure delivered through 15.5 km of twin tunnels and 4 km of elevated structure, with the remaining 3 km of rail infrastructure provided at-grade with some sections in cutting.
- Eight new stations are located at Cherrybrook, Castle Hill, Showground (to be known as Hills Showground), Norwest, Bella Vista, Kellyville, Rouse Hill and Cudgegong Road.
- The stations at Castle Hill, Showground and Norwest are contained within cut and cover concrete boxes, whilst stations Cherrybrook and Bella Vista follow an open cut station configuration. Stations at Kellyville and Rouse Hill are elevated. Cudgegong Road station is the only station that is at grade.
- The 15.5 km of twin running tunnels have an internal diameter of approximately 6.2 m and have been excavated predominantly through shale and sandstone using tunnel boring machines (TBMs). The tunnels are supported using a precast concrete segmental lining.
- There are 61 cross passages between running tunnels. These cross passages have been mined and are supported using a permanent cast insitu concrete lining.
- There are services shafts at Epping and Cheltenham area which are cut and cover structures. These shafts are supported using permanent cast insitu concrete lining.
- Other structures includes nozzle enlargement at the ends of stations at Castle Hill, Showground and Northwest. These have been mined and are supported using a permanent cast insitu concrete lining.
- A 159 m long mined crossover cavern is immediately east of Castle Hill Station. The cavern has a span of 21 m wide and has a height that varies from 14 m to 17 m. The cavern is supported by a permanent cast insitu concrete lining.

Sydney Metro – Northwest Epping to Chatswood (Existing ECRL)

- The 13 km length of existing track and rail infrastructure between Epping and Chatswood, which known as Epping to Chatswood Rail Link (ECRL), will be converted to form part of the Sydney Metro System.
- The underground infrastructure of ECRL comprises twin single track tunnels about 7 m in diameter and four underground stations completed in 2008. The depth of rail level varies from about 15 m at the portal to in excess of 60 m in other sections.
- The underground station structures at North Ryde, Macquarie Park and Macquarie University Stations consist of large span platform caverns typically of about 19 m in span and 13 m in height, together with concourse caverns, access tunnels, adits, shaft and associated plant and equipment rooms. The station caverns have been excavated in mainly competent, horizontally bedded sandstone and shales permanently supported using composite linings consisting of rock reinforcement in the form of rock bolts and shotcrete.
- Epping Station comprises two platform caverns connected by cross passages and accessed through escalator tunnels, lift shafts and two large plant room ventilation shafts. This station is located beneath the existing surface station.
- The running tunnels were excavated by rock tunnel boring machines (TBMs) and underground stations and associated structures were excavated using roadheaders, rock hammers and rock saws. The running tunnel support consists of temporary primary support using rock bolts and shotcrete, and final support using unreinforced cast-in-situ concrete lining, nominally 200 mm thick. A section of the running tunnels was lined with shotcrete for construction reasons. The invert of the tunnel consists of precast reinforced segments with a floating track slab.

Sydney Metro – City & Southwest

Sydney Metro City & Southwest will extend the metro rail under Sydney Harbour, through new stations in the lower North Shore, Sydney CBD and south west to Bankstown. This planned metro section will extend the network from Cudgegong Road through to Bankstown. The following are key features of this planned section of the metro system.

Sydney Metro - City

- The city section of the Sydney Metro will consist of underground infrastructure that extends from a dive and portal structure at Chatswood, under North Sydney and Sydney Harbour and then beneath the Sydney CBD to Central and through to Sydenham where the metro will daylight at a portal and dive structure at Marrickville.
- Seven new stations of varying configuration will be constructed at Crows Nest, Victoria Cross, Barangaroo, Martin Place, Pitt Street, Central and Waterloo.
- Twin running tunnels of approximately 14 km in length (portal to portal) will be excavated using TBMs and supported using a precast concrete segmental lining to create a watertight environment. The tunnels will predominantly align through siltstone and sandstone, except below the Sydney Harbour where TBM tunnelling will be required through marine ground sediments for a length of around 170 m.
- A total of 57 mined cross passages will be provided between running tunnels at regular intervals, with a maximum spacing of around 240 m. Of these cross passages eight will contain sumps at low points. The cross passages will be excavated using mechanical methods and supported using a watertight permanent lining, formed using cast insitu concrete. A services shaft will connect with a cross passage at Artarmon. The shaft will also be supported by permanent cast insitu concrete lining.
- Waterloo Station, Central Station, Barangaroo Station and Crows Nest Station will be constructed as cut and cover box structures that contain island platforms. The station will be typically 24 m in width and range from 200 m to 215 m in length. Pitt Street Station and Martin Place Station will have binocular platform caverns that connect with two entrance and services shaft structures, whilst Victoria Cross Station will have a single span cavern with an island platform, which also connects with two entrance and services shaft structures.
- At Martin Place Station and Pitt Street Station the platform caverns will range in length from 193 m to 246 m and have spans of approximately 12 m with an approximate height of 11 m. At the Victoria Cross the platform cavern will be approximately 174 m in length and have a span of 23 m with a height of 13 m. All the caverns and adits will be excavated using mechanical methods and supported using a watertight permanent lining, formed using cast insitu concrete.
- A mined cross over cavern which is 226 m in length will be constructed immediately north of Barangaroo Station. This cavern will have an internal span of 23 m wide and have a height that varies from 14 m to 17 m. The cavern will be supported using a watertight cast insitu concrete lining.
- Mined twin tunnel enlargements that are up to around 17 m in length will be provided to house tunnel ventilation fans at either end of the Victoria Cross Station caverns, the northern end of the rail crossover at Barangaroo, the southern end of Waterloo Station and at the northern end of Crows Nest Station. The nozzle enlargements will be excavated using mechanical methods and supported using a watertight permanent lining, formed using cast in-situ concrete.
- Dive structures and portal structures will be located at Marrickville and Chatswood. A stabling yard will be constructed at the Marrickville portal site.

Sydney Metro – Southwest

- This section of the metro is currently part of the Bankstown Line, but will be converted to form part of the metro system from Sydenham to Bankstown.
- The extension of the metro in the south west will be 13.4 km in length and will require existing rail track and stations to be upgraded.

- Eleven existing stations at Sydenham, Marrickville, Dulwich Hill, Hurlstone Park, Canterbury, Campsie, Belmore, Lakemba, Wiley Park, Punchbowl and Bankstown will be converted to the metro rail system.

Figure A.1 Sydney Metro