ST. PAUL'S CATHEDRAL AND MELBOURNE TOWN HALL GROUND MOVEMENT IMPACT ASSESSMENT

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Executive Summary

Cross Yarra Partnership (CYP) has been contracted by Melbourne Metro Rail Authority (MMRA) to design, build and maintain the tunnels and stations for the Metro Tunnel Project, (the Project). The project includes two nine-kilometre train tunnels and five new underground train stations, linking the north-west Sunbury rail corridor and the south-east Cranbourne/Pakenham rail corridor, unlocking additional capacity in the existing City Loop. The five new underground stations are located at Arden, Parkville, CBD North, CBD South and Domain.

This report details an Environmental Risk Assessment (ERA) of the additional Project Land proposed by CYP for Melbourne Metro. Effective environmental risk management is a continuous, collaborative and forward-looking process. It aims to anticipate potential impacts so that project related activities can be planned and managed, and were applicable, mitigate adverse impacts. Environmental risk is a function of the likelihood of an adverse event occurring and the consequence of the event. CYP will continue to apply a robust and transparent environmental risk assessment across all phases and components of the Project including construction and operational phases.

The project has already undergone an extensive and robust planning assessment process. As part of this, MMRA published an Environment Effects Statement (EES) and draft Planning Scheme Amendment that included an integrated assessment of the potential environmental, social, economic and planning impacts of the project, and the approach to managing these impacts.

In developing the EES, MMRA undertook a comprehensive engagement program to seek input from stakeholders and the community. This included stakeholders and the community having the opportunity to provide formal submissions during a public exhibition period, which were then presented to an Inquiry and Advisory Committee. The key focus of the Committee's review, findings and recommendations was the planning and environmental control framework for the Project, which resulted in a report prepared for the Minister for Planning.

In December 2016, the Minister for Planning released his Assessment of the environmental effects of the project. The Assessment was undertaken in line with the *Environment Effects Act 1978* and completed the EES process. The Minister's Assessment concludes that the environmental effects of the Project are acceptable, provided appropriate mitigation and management is implemented. The Minister subsequently approved a Planning Scheme Amendment (PSA) and Incorporated Document for the project. The Incorporated Document, under Section 4.7 Environmental Management Framework (EMF), required an EMF to be approved. The EMF ensured the inclusion of Environmental Performance Requirements (EPRs), which address sixteen environmental factors. This encompassing process will be referred throughout as the EES and PSA processes.

The EPR measurements ensure that there is a clear, unambiguous and transparent set of controls in place to guide the delivery of the Project. The EPRs define the project-wide environmental outcomes that must be achieved during design, construction and operation of Melbourne Metro, (regardless of the design solutions adopted). While it will not be possible to avoid all effects and impacts, the recommendations and outcomes of the public submission, Inquiry and Ministerial Assessment; found the EPRs should provide an effective way to manage potential risk.

It is therefore these EPRs that will be used to assess the ability for CYP to appropriately manage and mitigate the proposed changes outside of Project Land. As a consequence of this, an updated ERIA has been undertaken for the proposed changes to the Project Land.

Achieving these EPRs is a requirement of the Melbourne Metro Rail Project Incorporated Document contained in applicable planning schemes. From the initial environmental risk assessment, ground movement impacts for Melbourne Town Hall and St.Paul's Cathedral were found to have potentially greater impacts and are therefore the subject of this ground movement impact assessment. Although it is acknowledged there may be potential impacts to other sensitive receptors as a result of the Planning Scheme Amendment GC82, these will be appropriately managed and mitigated through the established EPRs.

The ground movement impact assessment methodology is based on an approach that has been implemented on large scale infrastructure projects across the world. The ground movement and potential subsequent building damage assessment has been carried out using the software programme Oasys XDisp. As the design process is ongoing, it has been necessary to make certain assumptions in terms of parameters adopted for the assessment, which has been built into the modelling parameters. Where assumptions have been made, they are considered to be reasonable and conservative.

The building damage assessment adopted is based upon classifications proposed by Burland (1995) where three levels of effects are considered, these being aesthetics (i.e. the appearance of the building), serviceability (i.e. the effect on the function of the building) and stability. Building assessment lines have been modelled around the building perimeter and across the building to capture a range of potential behaviours of the structure.

The initial ground movement risk assessment identified St.Paul's Cathedral and Melbourne Town Hall, which lay outside the approved Project Land, as requiring a detailed assessment due to the building damage assessment score as well as proximity to an excavation and/or basement depth. This impact assessment found the Melbourne Town Hall overall building damage score is 2, based on only one line (line 26) receiving a score of 2 and one line (line 29) receiving a score of 1. The majority of the building lines received a score of 0. The overall building damage score for St.Paul's

Cathedral is 1, represented by three lines (4, 12 and 26) receiving a score of 1. While the majority of the building lines have a score of 0.

In this instance, St.Paul's Cathedral and Melbourne Town Hall have been identified for a Phase 3 assessment. The Phase 3 assessments may identify buildings where specific attention is required, however the designation of any protection, mitigation or remediation works needs to consider the specific building form. Although a Phase 3 assessment is required, these are overall considered technically acceptable based on classifications proposed by Burland (1995).Burland (1995) is generally accepted as industry standard. In light of this, the established EPRs contain appropriate techniques to mitigate any possible adverse effects that could be experienced as a result of construction works.

Overall, based on available information the works to be completed by CYP at strata (below ground) under the Melbourne Town Hall and St. Paul's Cathedral are considered manageable and can be mitigated by the current EPRs. As part of the CBD South Station works, it is noted an inspection and monitoring will be undertaken during the design phases as outlined by the EPRs GM4 and GM 5. Furthermore, isolated locations of repair work may be required, but will be adequately managed through GM5.

1 Introduction

Cross Yarra Partnership (CYP) has been contracted by Melbourne Metro Rail Authority (MMRA) to design, build and maintain the tunnels and stations for the Metro Tunnel Project (the project). The project includes two nine-kilometre train tunnels and five new underground train stations, linking the north-west Sunbury rail corridor and the south-east Cranbourne/Pakenham rail corridor, unlocking additional capacity in the existing City Loop. The five new underground stations are located at Arden, Parkville, CBD North, CBD South and Domain.

The project has undergone an extensive and robust planning and environmental assessment. In 2016 MMRA exhibited and received public comment on:

- An Environment Effects Statement (EES) that presented an integrated assessment of the potential environmental, social, economic and planning impacts of the project, and the proposed approach to managing these impacts.
- A Draft Planning Scheme Amendment (PSA) to facilitate the use and development of the project, as well as, establishing a mechanism to protect the tunnels, stations and associated infrastructure from potential adverse effects of development in their vicinity.

In December 2016, the Minister for Planning released his assessment of the environmental effects of the project. The Minister subsequently approved a PSA (GC45) for the project which, among other things, inserted the *Melbourne Metro Rail Project Incorporated Document (December 2016)* into the Melbourne, Port Phillip, Stonnington and Maribyrnong Planning Schemes and gave legal effect to the Incorporated Document through Clause 52.02 of each of these Schemes. The project's Incorporated Document was subsequently amended by PSA GC67 to facilitate the Park Street, South Melbourne tram stop. The latest Incorporated Document is *Melbourne Metro Rail Project Incorporated Document (May 2017)*.

The EES and PSA processes assessed a Concept Design and indicative construction methodology for that project that was prepared by MMRA. This was described in some detail in Chapter 6 of the EES. The impacts from the construction and operation of Melbourne Metro are subject to the approved Environmental Performance Requirements (EPRs) determined by the Minister for Planning as part of the planning approvals for the Project. The EPRs define the project-wide environmental outcomes that must be achieved during design, construction and operation of Melbourne Metro.

CYP proposes a series of enhancements and changes to the Concept Design as exhibited in the EES and PSA processes that will deliver improvements in accessibility and construction and operational efficiencies.

Some of these CYP enhancements necessitate a need to change the boundary of the approved Project Land, which can only be done by a planning scheme amendment (PSA) to vary the plans appended to the Incorporated Document. The CYP changes predominately relate to the provision of underground support structures, additional station connections and temporary road occupations that affect surface land. Additionally, these changes are required to be in accordance with the approved environmental performance requirements.

A PSA to amend the Incorporated Document is an appropriate planning response, as the alternative would be to seek piecemeal planning permits or planning scheme amendments for the additional Project Land, as required.

1.1 Purpose of this Report

The purpose of this report is to assess the potential positive and adverse ground movement impacts, associated with the additional Project Land required for the Metro Tunnel project.

A ground movement assessment for the project was prepared as part of the EES and PSA processes previously submitted to Government. This report builds on the previous work by providing an assessment of the ground movement impacts related to the construction and operation of the project in CBD South where additional project land is proposed. The specific focus of this report is the potential ground movement impacts on St. Paul's Cathedral and Melbourne Town Hall. This assessment considers both direct and indirect impacts and identifies measures to manage adverse impacts and potential opportunities.

1.2 Project Description

The infrastructure proposed to be constructed as part of Melbourne Metro, as assessed in the EES and PSA processes, broadly comprises:

- Twin nine-kilometre rail tunnels from Kensington to South Yarra connecting the Sunbury and Cranbourne/ Pakenham railway lines to form the new Sunshine-Dandenong Line (with the tunnels to be used by electric trains)
- Rail tunnel portals (entrances) at Kensington and South Yarra

- New underground stations at Arden, Parkville, CBD North, CBD South and Domain with longer platforms to accommodate longer High Capacity Metro Trains (HCMTs). The stations at CBD North and CBD South would feature direct interchange with the existing Melbourne Central and Flinders Street Stations respectively
- Train/tram interchange at Domain station.

The changes, or project components that require additional Project Land relate to works at Parkville Station, CBD North Station and CBD South Station. This report only concerns works at CBD South Station and their potential impacts to St. Paul's Cathedral and Melbourne Town Hall. Works at CBD South Station include the following:

- Rail alignment: The modified rail alignment represents a change in horizontal or vertical alignment (i.e. change in track geometry).
- Underground support structures: Underground support structures are ancillary structures that are used for stabilisation of a primary structure such as a shaft, station box or tunnel:
  - Usually rock bolts are shorter in length and used predominantly along the rail tunnels.
  - Rock anchors are longer in length and can be used to support shafts at the stations.

  In both instances, each stabiliser can sit 1.5 to 2 metres apart and protrude at an angle.
  CYP to provide ground support during the construction phase and then will remain in situ pending removal or modification as part of any future redevelopment by others.
  Note: The underground support structures will be used temporarily by CYP to provide ground support during the construction phase and then will remain in situ pending removal or modification as part of any future redevelopment by others.
- Pedestrian adits: A pedestrian adit is a permanent underground passage that connects the tunnel or station to a ground level access point and has a primary purpose of facilitating passenger movements.
- Construction adits: A construction adit is an underground passage that will connect the station to a ground level access point. It is typically used for the movement of equipment, materials and excavated material. It can also be used for storage purposes.
- Flinders Street Station platform works: Additional lifts connecting the station platforms to the Degraves Street/Campbell Arcade underpass.
- Additional road areas: Additional road areas are road reserves required for construction management, together with temporary and legacy road requirements. TMPs will be prepared and implemented in accordance with the approved EPRs, for each area, setting out specific traffic management activities and legacy roadworks. Generally, temporary traffic management will involve signs, workers and possible signage line marking adjustments. Legacy roadworks will generally involve the re-surfacing of road, kerb and channels, road works, pedestrian/cycle crossings, and hard and soft landscaping.

1.2.1 CBD South Station

Table 1 provides a breakdown of the location of proposed CYP changes to the approved Project Land including CBD South Station.

As a result of CYP's design modifications, the car parking area located at Chapter House Lane, adjoining St.Paul's Cathedral, can be omitted from the Project Land.

TABLE 1: CBD SOUTH STATION CHANGES TO PROJECT LAND

Element	Location of change to approved Project Land
Rail tunnel alignment	Excursion outside of the approved Project Land are as follows: ▪ between Collins Street and Flinders Lane (west side of alignment) ▪ between the southern side of Collins Street and the northern side of Flinders Lane (west side of alignment) ▪ south Flinders Lane to north Flinders Street (east side of alignment) ▪ a small section of the Federation Square forecourt (east side of alignment).
Additional underground support structures	Excursion outside of the approved Project Land are as follows: ▪ between south Bourke Street and the north Collins Street ▪ between south of Collins Street and the north Flinders Lane (west side of alignment only) ▪ between south Flinders Lane and north Flinders Street (east side of alignment only)
Pedestrian adit	A pedestrian adit will be required to link CBD South Station with Federation Square. This will sit parallel to St.Paul's Cathedral footprint and Swanston Street, between south of Flinders Lane and north of Flinders Street. Another pedestrian adit will be required to provide an emergency egress from the tunnel to City Square. This will sit under Melbourne Town Hall footprint and the footpath at the corner of Collins Street and Swanston Street.

Construction adit	A construction adit extending diagonally south from Flinders Lane towards Swanston Street, under the north western corner of St.Paul's Cathedral
Flinders Street Station platform works	The CYP design changes at Flinders Street Station will require an extension to the approved Project Land to include the middle section of Flinders Street Station Platforms. Some works will occur at Degraves Street Underpass/Campbell Arcade

1.3 Study Area

The study area for the ground movement impact assessment is shown on Figure 1 and Figure 2. As this assessment focuses on Melbourne Town Hall and St. Paul's Cathedral, the land affected is located within the City of Melbourne.

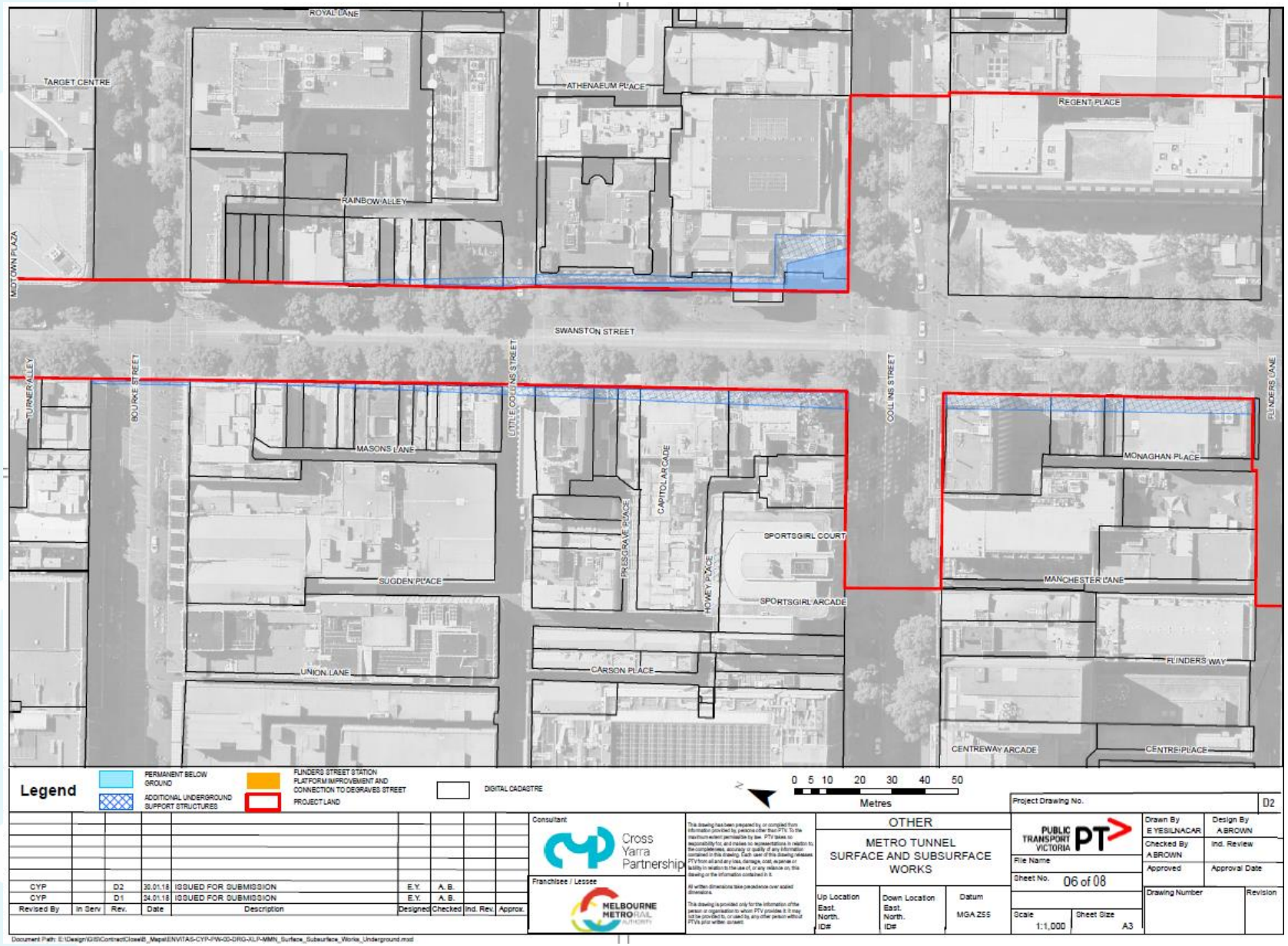

FIGURE 1: ADDITIONAL PROJECT LAND REQUIRED FOR PERMANENT BELOWGROUND AND UNDERGROUND SUPPORT STRUCTURES AT CBD SOUTH STATION

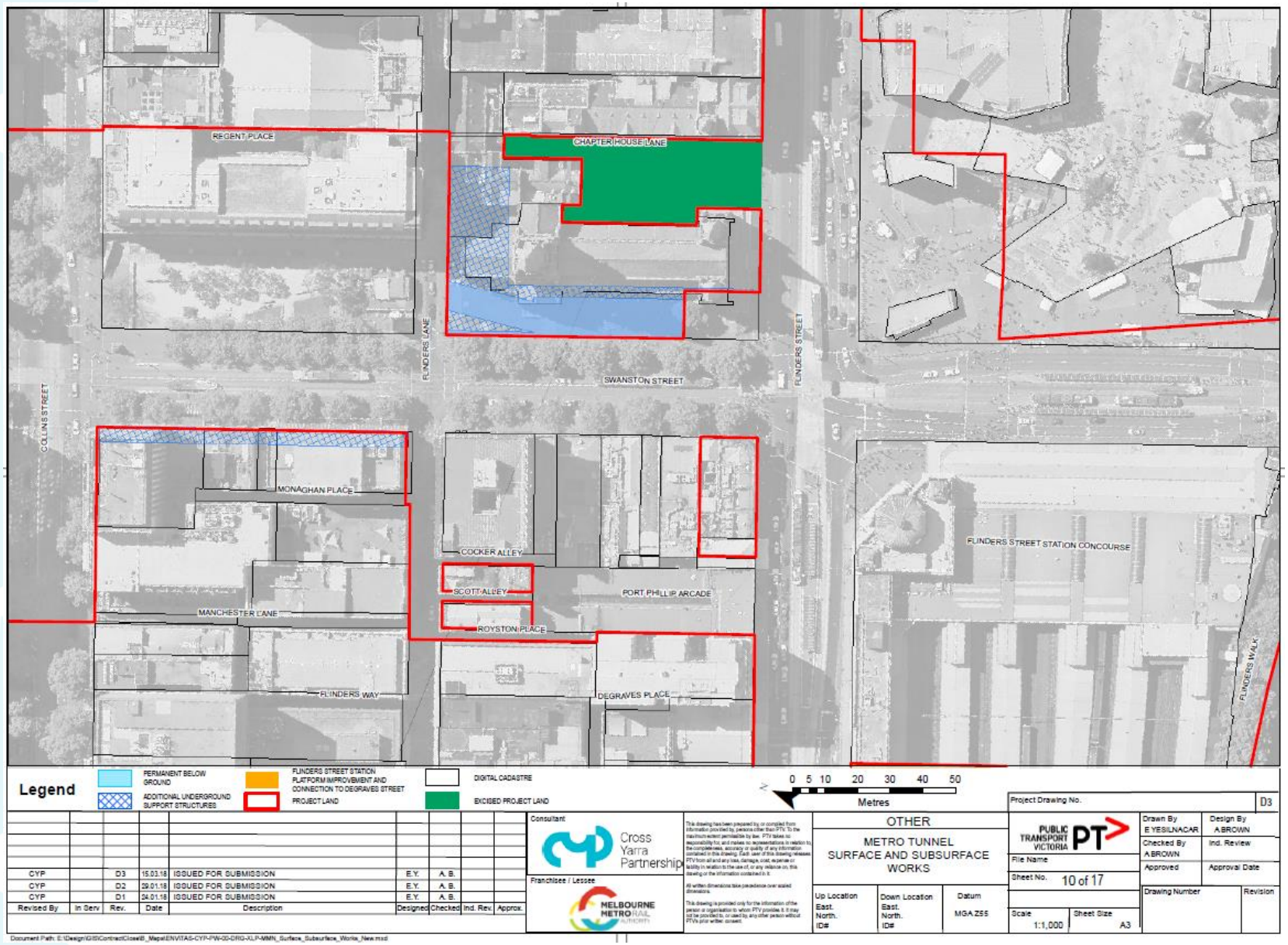

FIGURE 2 ADDITIONAL PROJECT LAND REQUIRED FOR PERMANENT BELOWGROUND, UNDERGROUND SUPPORT STRUCTURES AT CBD SOUTH STATIONAND EXCISED LAND

2 Methodology

2.1 Environmental Risk Assessment

s part of the EES and PSA processes undertaken in 2016, MMRA completed a detailed environmental risk assessment (ERA) based on the Concept Design. Through this process an approved set of Environmental Performance Requirements were defined. The EPRs define the project-wide environmental outcomes that must be achieved during design, construction and operation of Melbourne Metro, (regardless of the design solutions adopted). As stated previously, CYP has proposed enhancements and changes to the Concept Design, and as a consequence, have undertaken an updated desktop environmental risk assessment to determine the impacts of the proposed changes on the required additional Project Land.

CYP have continued to apply a robust and transparent environmental risk assessment process to the project, based on the requirements of Risk Management Standards AS/NZS ISO 31000:2009, as depicted in Figure 3 below. ISO 31000:2009 provides principles and generic guidelines on risk management and represents a standardised risk management approach. It provides a structured approach for the risk assessment and is widely used for EESs and EIAs.

The environmental risk assessment initially involved the definition of the context and scope of the additional Project Land required for the additional works. This entailed the preparation of an updated Project Description for buildings and works located outside of the approved Project Land. Following this, an initial environmental risk screening using the EPRs was undertaken. The approach followed by CYP involved the application of the EPRs as an assessment tool, an approach that accords with the framework established during the EES and PSA processes for the Project.

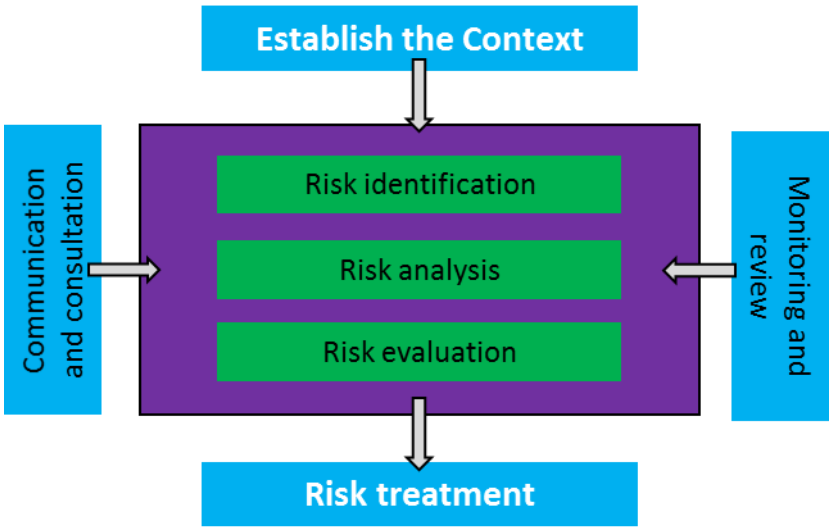

FIGURE 3: RISK ASSESSMENT PROCESS

The initial ground movement and noise and vibration environmental risk assessment undertaken by CYP was based on design information and construction methodology. This risk assessment determined that the changes to the Project Land resulting from CYP design changes required assessment of the potential ground movement impacts at St. Paul's Cathedral and Melbourne Town Hall at CDB South Station. The potential impact of project works at other locations along the alignment and within CBD South are deemed to be low and do not require specific assessment.

The primary areas of risk are the two new adits in proximity to St Pauls Cathedral and the Melbourne Town Hall shown on Figure 1 and 2 as permanent below ground infrastructure and additional underground support structures. This is further illustrated on Figure 4, which shows the relationship and connectivity of the new adits and the City Square, Flinders Street and Federation Square shafts.

2.2 Ground Movement Impact Assessment

An assessment of ground movement and potential impacts on structures has been completed at CBD South Station.

The ground movement impact assessment has been completed in three stages which is consistent with EPR GM3:

- An assessment of total ground movements from the combined construction of the station caverns, cut and cover shafts and adits;
- A simplified assessment of building behaviour assuming a simplified elastic deep beam model based on empirical methods and adopting moderately conservative parameters; and

- Specific consideration of interaction of the calculated ground movement and the structural form (eg high arched masonry for the cathedral) and sensitivity of heritage features.

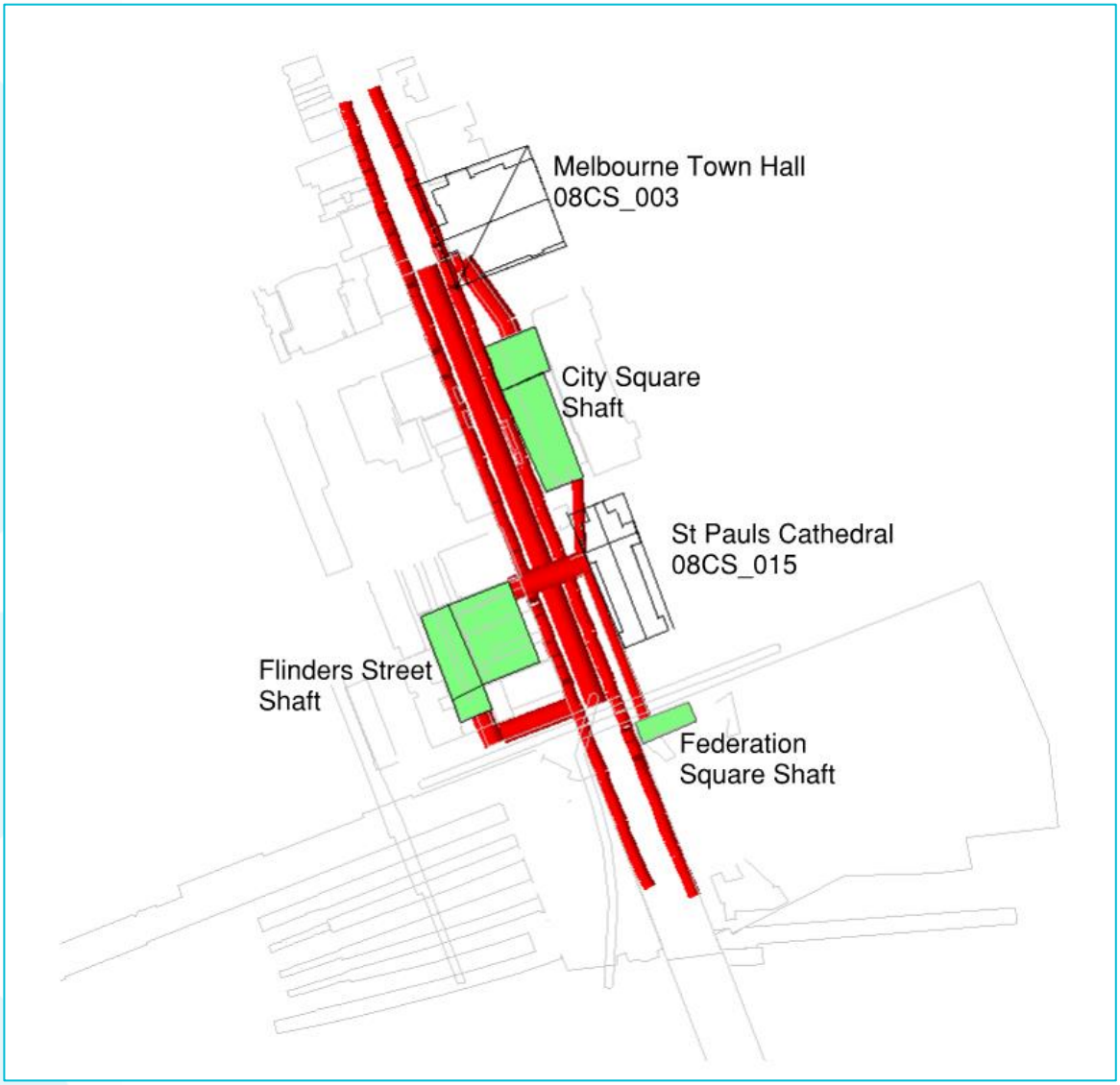

FIGURE 4: XDISP MODEL OF CBD SOUTH STATION SHAFTS, CAVERNS, TUNNELS AND ADITS USED FOR CALCULATING GROUND MOVEMENTS. THE DARK OUTLINES FOR TOWN HALL AND ST PAULS CATHEDRAL ARE THE LINES USED FOR ASSESSMENTS OF BULDING DAMAGE.

Within the context of the Project wide ground movement impact approach (TAS-D-CGM-1010-0244), the above assessment is effectively equivalent to a Phase 2 assessment which adopts several reasonably conservative assumptions. The figures are based on the ground movement assessment undertaken as part of the EES and PSA processes and further assessment since that time and industry standards set by Burland (1995). If the resulting conclusions from the Phase 2 assessment are not acceptable in terms of ground movement measures, a more detailed Phase 3 assessment can be completed adopting 'best estimate' parameters and/or more sophisticated analysis methods if required.

The software programme Oasys XDisp has been used to undertake the ground movement impact assessment and subsequent Phase 2 building impact assessment. Oasys XDisp has been specifically designed to predict ground movements due to excavations, including tunnels, basements, mines and embedded walls. The ground movement assessment considers the combined effects of all proposed works at CBD South Station.

2.2.1 Assessment of Ground Movements

Ground movements have been assessed based on station shaft cut and cover structures, mined caverns and adits. Ground movements have been assessed in accordance with the EPR GM2; which ensures the design works limit ground movements (e.g. through the use of anchors and propped excavations) to within an appropriate acceptability criteria, which will be determined with appropriate stakeholders throughout the design and construction process. To begin,

stakeholder meetings and discussions occurred with St. Paul's Cathedral with City of Melbourne. The criteria is based on The Burland Damage Assessment and stakeholder engagement outcomes.

Ground Movements from cut and cover station shafts.

Ground movements associated with station shafts have been developed by taking calculated ground movements from 2D retention models and applying them into XDisp as ground movement curves.

Ground movement curves describe the horizontal and vertical movement of a point adjacent to the side of an embedded wall excavation. A surface ground movement curve is a function of the distance from the wall/excavation, depth below top of wall/excavation and wall/excavation depth. XDisp takes the data points, and fits a polynomial curve which is used in the calculations.

At the time of the assessment, the geotechnical design of the stations was still underway, and therefore limited data available in relation to predicted ground movement profiles as a result of station construction. At this stage, preliminary data output from 2D finite element software has been adopted. The assessment will be required to be updated following updated design information and to comply with the EPRs.

Ground movement curves are considered to represent 100% of the ground movement profile, however in reality there is increased stiffness at the corner of excavations. From reported case studies, it has been observed that this increase in stiffness results in smaller ground movements. Oasys XDisp considers these effects and adjusts the ground movement curve based upon the methodology in industry standard methodology (Fuentes and Devriendt 2010).

Ground movements from dewatering local to the shaft cut and cover excavations are included in the predicted ground movements from the excavation modelling. Regional scale dewatering within the Melbourne Formation rock below the cathedral will result in relatively uniform ground settlement which are not typically associated with building damage and secondary in magnitude to the excavation settlements and have not been considered in the assessment.

Ground Movements from mined caverns and adits

Surface ground movements have been calculated based from empirical methods where the magnitude and profile of settlement at the ground surface is function of the cross-sectional area of the excavation and some simplified ground condition parameters. The following parameters have been applied to tunnels, cross passages and adits for the ground movement assessment. The figures are based on the Melbourne Metro Rail Project established through the EES and PSA processes ground movement assessment and further assessment since that time. Based on experience and preliminary modelling these values are considered conservative (although reasonable for a preliminary assessment) and will be updated for detailed impact assessments for the relevant packages. The ground loss percentage effects the magnitude of the surface settlement, while the through width parameter controls the profile of the settlement trough.

TABLE 2 TUNNELLING PARAMETERS USED IN GROUND MOVEMENT ASSESSMENT

Tunnelling Method	Ground Type	Ground Loss (%)	Trough Width Parameter k
Mined	Rock	0.5	0.6
TBM	Rock	0.5	0.6
TBM	Soil	1	0.4

2.2.2 Building Damage Assessment

The ground movement impact assessment has been based on an approach that has been implemented on other large scale infrastructure projects (Crossrail, UK and High Speed 2, UK) and consists of a three phase approach as detailed below.

The Phase 1 assessment is primarily a screening assessment, which identified that St Paul's Cathedral and the Town Hall required further assessment.

The Phase 2 assessment consists of an empirical assessment of structural behaviour based on a simple elastic deep beam model following the approach adopted in (Burland, 1995). The Phase 2 assessment assumes the building is weightless and fully flexible and follows the greenfield displacements exactly. This is conservative as it ignores the soil structure interaction effects associated with building stiffness and weight, which can be considerable. The assessment considers the settlement trough profile, identifying zones of hogging (extension or tension) and sagging (compression) which will induce axial strains in the structure. The curvature of the settlement profile is also considered which has the potential to induce shear and/or flexural tensile strains within the structure.

The assessment criteria is based on classifications proposed by Burland (1995) where the building damage is considered that affects 1. Aesthetics (i.e the appearance of the building), 2. Serviceability, (i.e the effect on the function of the building), and 3. Stability. The categories are related to the tensile strain that the building will experience. Table 3 below presents the damage categories that have been adopted in this assessment. The Burland assessment is conservatively based on a masonry building with an E/G ration of 2.6 and possions ratio of 0.3.

TABLE 3 DAMAGE CATEGORIES (BURLAND, 1995)

Category of Damage	Limiting Tensile Strain (%)	Normal degree of severity
0	0 to 0.05	Negligible - hairline cracks less than 0.1mm.
1	0.05 to 0.075	Very Slight – fine cracks which are easily treated during normal decoration. Typical crack widths up to 1mm.
2	0.075 to 0.15	Slight – cracks are easily filled although redecoration is normally required. Some repointing may be required. Crack widths up to 5mm.
3	0.15 to 0.3	Moderate – cracks require some opening up and can be patched by a mason. Repointing of external brickwork and the possibility of a small amount of brickwork replaced. Typical crack widths are 5 to 15mm or several up to 3mm.
4	>0.3	Severe – extensive repair work. Typical crack widths are 15-25mm.

2.2.3 Building Impact Assessment

The assessment of effects on the building is developed from the results of the ground movement prediction and Phase 2 building impact assessment, combined with an assessment of the buildings structural form and sensitive heritage features.

3 Impact Assessment

3.1 Risk Assessment

The risk assessment identified the following:

- Ground movement effects around CBD South Station show movement >5mm extends beyond the excavation footprint and beyond the project land precinct.
- The adit from Federation Square at CBD South extends outside of the approved Project Land and below the western edge of St Paul's Cathedral. There is another pedestrian adit from CBD South under Collins Street and the Melbourne Town Hall.
- Sensitive features inside St Paul's Cathedral include imported marble finishes, patterned tiles, glass mosaics and stained glass windows.
- The proposed EPR's will mitigate risk of ground movement effects on the structures, through designing the works to mitigate ground movements (GM2), complete a detailed assessment of movements and mitigation measures (GM3), confirm the condition of the structure (GM4), careful construction practices (GM5) and complete any required remedial work (GM6).
- The residual assessed risk from a ground movement perspective (prior to this assessment) was medium.

3.2 Impact Assessment

Ground movement impact assessments for Melbourne Town Hall and St Paul's Cathedral are described below.

3.2.1 Melbourne Town Hall

Combined ground movements and assessed building damage from XDISP are shown in Figure 5 based on conservative ground movement predictions. The empirical assessment indicates that the building will typically experience negligible damage as a result of the excavations. While some settlement may occur to the southern corner of the building, the over-all building slope is shallower than 1:1000 (ie less than 1mm over 1m) and considered technically acceptable for ground movement.

One building damage line along the western boundary has been assessed as having damage category 1 (very slight), however the building only extends along part of this boundary and the risk for damage is considered low. One building damage line has been assessed as being damage category 2, slight damage. Considering the overall building behaviour, the conservative ground movement predictions and simplified modelling assumptions, the assessed level of damage is considered acceptable as it is in line with technical standards. As part of the CBD South Station works we recommend that a condition inspection (GM4) and monitoring (GM3) is included as part of the design. Isolated locations of repair work may be required (GM5).

Based on the Phase 2 damage assessment, the residual risk is assessed as Moderate consequence, Unlikely likelihood, giving a ground movement risk of Low (Table 4).

In this instance, Melbourne Town Hall have been identified for a Phase 3 assessment. A Phase 3 assessment is a structure specific assessment with an iteratively refined assessment of ground behaviour, structural form, soil/structure interaction, condition surveys and mitigation works until the assessed damage risk is considered acceptable given technical standards and measures. Examples of considerations would include:

- additional information on the structural form above and below ground;
- soil structure interaction effects;
- subsurface displacements as opposed to the Phase 2 greenfield surface displacements;
- specific consideration of structure loading on ground movements.

The Phase 3 assessment identify buildings where specific attention is required, however the designation of any protection, mitigation or remediation works needs to consider the specific building form. Although a Phase 3 assessment is required, these are overall considered technically acceptable based on classifications proposed by Burland (1995).Burland (1995) is generally accepted as industry standard. In light of this, the established EPRs contain appropriate techniques to mitigate any possible adverse effects that could be experienced as a result of construction works.

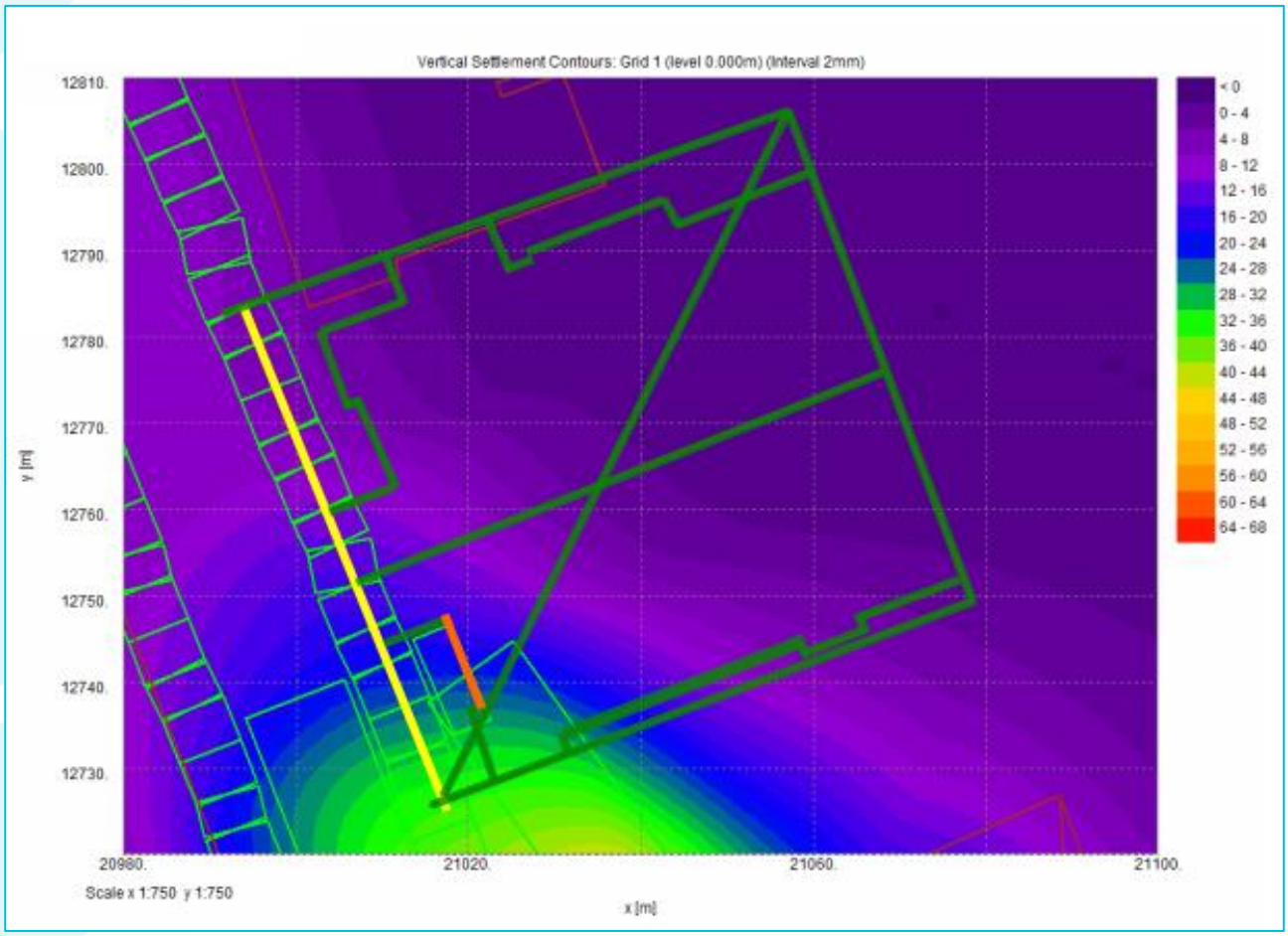

FIGURE 5: CALCAULTED GROUND SETTLEMENT CONTOURS AND XDISP BUILDING DAMAGE ASSESSMENT FOR THE TOWN HALL. BUILDING DAMAGE CATEGORIES ARE GREEN LINES = 0 (NEGLIGIBLE), YELLOW = 1 (VERY SLIGHT) AND ORANGE = 2 (SLIGHT).

3.2.2 St Pauls Cathedral

Combined ground movements and assessed building damage from XDISP are shown in Figure 6 based on conservative ground movement predictions. The empirical assessment indicates that the building will typically experience negligible damage as a result of the excavations. While some settlement may occur to the western extent of the building, the over-all building slope is in the order of 1:1000 (ie approximately 1mm over 1m) and considered acceptable given established ground movement classifications.

Two building lines across the church have been assessed as having very slight damage (damage category 1). The ground movement assessments have been overlain in sketch TAS-CYP-CBS-ZWD-SKT-CGM-TSC-C0001 for a section along Flinders Street, and an internal section through the choir.

The assessed building line along the Finders Street elevation indicated that only one segment is anticipated to experience damage score of one. Closer review of the results shows that the maximum tensile strain occurs on the eastern side of the cathedral (away from the main excavations) as a result of longitudinal strain (as opposed to flexural or shear strain). A reduced level of building strain would be expected if more accurate ground movement calculations ('best estimate') were completed along with more sophisticated soil structures interaction, which would decouple the behaviour of the building from the simplified behaviour of the ground.

The assessed building line through the choir indicates that the main source of tensile strain is due to longitudinal strain as opposed to flexural or shear strain. A reduced level of building strain would be expected if more accurate ground movement calculations ('best estimate') were completed along with more sophisticated soil structures interaction, which would decouple the behaviour of the building from the simplified behaviour of the ground.

In this instance, St.Paul's Cathedral have been identified for a Phase 3 assessment. A Phase 3 assessment is a structure specific assessment with an iteratively refined assessment of ground behaviour, structural form, soil/structure interaction, condition surveys and mitigation works until the assessed damage risk is considered acceptable given established ground movement classifications. Examples of considerations would include:

- additional information on the structural form above and below ground;

- soil structure interaction effects;
- subsurface displacements as opposed to the Phase 2 greenfield surface displacements;
- specific consideration of structure loading on ground movements.

The Phase 3 assessment identify buildings where specific attention is required, however the designation of any protection, mitigation or remediation works needs to consider the specific building form. Although a Phase 3 assessment is required, these are overall considered technically acceptable based on classifications proposed by Burland (1995).Burland (1995) is generally accepted as industry standard. In light of this, the established EPRs contain appropriate techniques to mitigate any possible adverse effects that could be experienced as a result of construction works.

St Pauls Cathedral Structural Specific Considerations

Structural specific considerations in relation to the ground movement assessment need to be finalised.

St Pauls Cathedral Heritage Specific Considerations

Heritage specific considerations in relation to the ground movement assessment need to be finalised.

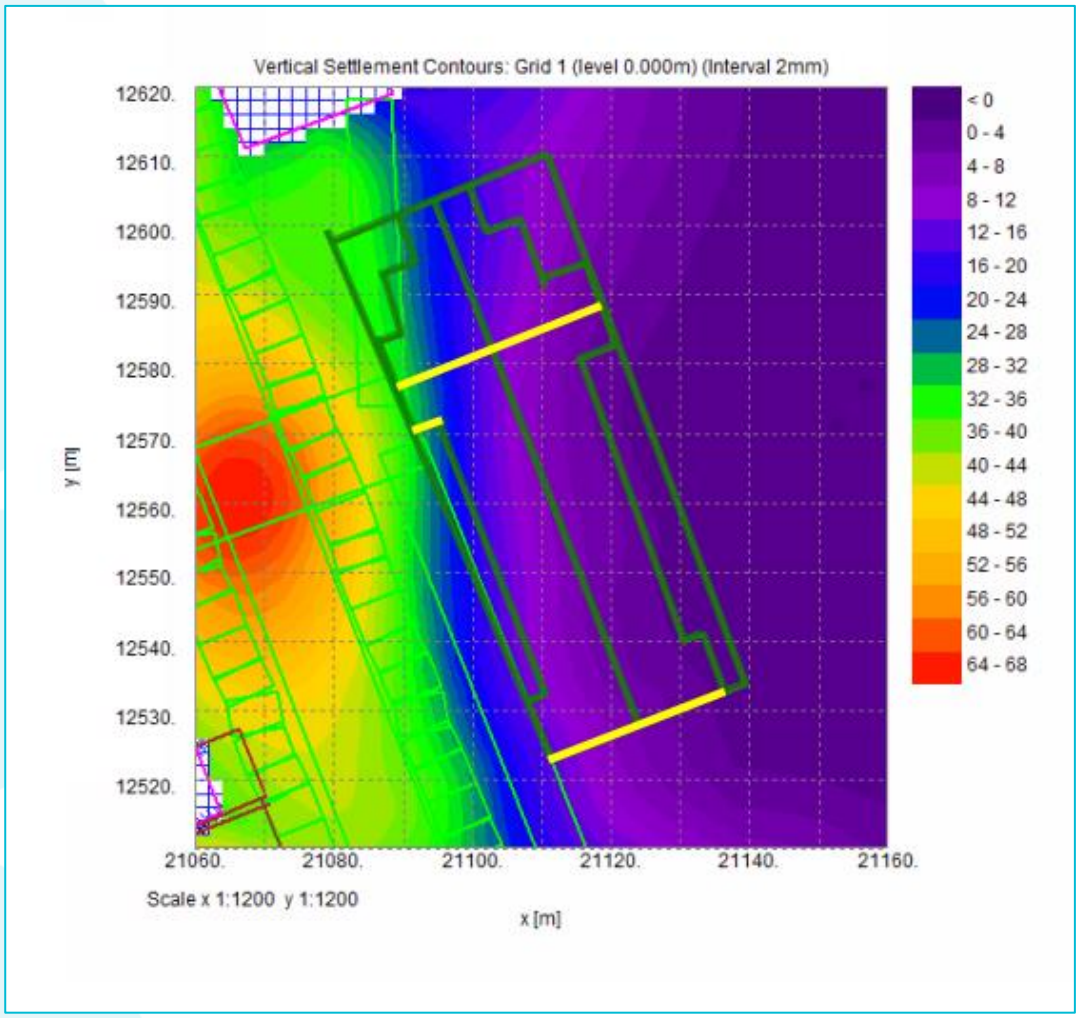

FIGURE 6: CALCAULTED GROUND SETTLEMENT CONTOURS AND XDISP BUILDING DAMAGE ASSESSMENT FOR ST PAUL'S CATHEDRAL. BUILDING DAMAGE CATEGORIES ARE GREEN LINES = 0 (NEGLIGIBLE) AND YELLOW LINES = 1 (VERY SLIGHT).

Based on the Phase 2 damage assessment, the potential for a moderate impact on the St. Paul's Cathedral is low (refer Table 4) and is considered satisfactory with the project EPRs. The risk assessment specifically considering structural sensitivity and heritage sensitivity needs to be confirmed.

TABLE 4 ENVIRONMENTAL RISK ASSESSMENT FOR GROUND MOVEMENT EFFECTS ON ST PAULS CATHEDRAL AND THE MELBOURNE TOWN HALL.

Assessment Component	Phase 2 Empirical	Specific Structural consideration	Specific heritage consideration	Residual risk assessment
Consequence	Moderate	Moderate	Moderate	Moderate
Likelihood	Unlikely	TBC	TBC	TBC
Risk	Low	TBC	TBC	TBC

As part of the CBD South Station works, it is noted an inspection and monitoring will be undertaken during the design phases as outlined by the EPRs GM4 and GM 5. Furthermore, isolated locations of repair work may be required, but will be adequately managed through GM5.

3.2.3 Stakeholders

MMRA, with the assistance of CYP, will be undertaking stakeholder engagement in relation to draft Planning Scheme Amendment GC82, as well as some consultation with Councils and key landowner. In recognition that project progress and decisions can be enhanced through dialogue with the community and relevant stakeholders, MMRA has developed core principles and goals for the planning and construction of the project. These are summarised in Table 5. CYP shares these principles and goals. Furthermore, the findings from the impact assessments will inform refinement of the Communication and Stakeholder Engagement Strategy.

TABLE 5: PRINCIPAL AND GOALS OF THE STAKEHOLDER AND ENGAGEMENT STRATEGY

Principle	Goal
Effective	Engagement is open, consistent, inclusive, accessible and transparent throughout planning and delivery of the project
Timely	Engagement spans all stages of the project, ensuring information is provided to stakeholders as the project develop and feedback is responded to and incorporated in the project's development
Meaningful	Engagement is clear on the elements of this project that can be influenced by the community and stakeholders, how the feedback will be used and is explicitly on which elements of the project are fixed and the reason for this
No surprises	Engage early to gain understanding of interests, concerns, requirements and preferred outcomes. Close the loop to determine how feedback has been considered

A three phase approach has been developed. Phase 1 – Early Engagement, Phase 2 - Engagement to support public display of draft PSA and Phase 3: Engagement post PSA. The Consultation and Summary Report provides further detail of the process and outcomes and next steps.

Phase 1: Early Engagement

Key stakeholders –government agencies / entities /precinct based

Engagement was focused on briefing key stakeholders particularly government departments and agencies, and Councils on the proposed changes to the Project Land. MMRA and CYP held stakeholder meetings to outline the PSA process and to obtain feedback leading up to submission of the draft PSA to the Minister for Planning. Where possible, MMRA and CYP used existing stakeholder meetings to discuss the PSA. Key messages were high level with the provision of information tailored to the specific needs of the stakeholder.

CYP and MMRA held meetings with each of the following stakeholder stakeholders as part of the ongoing stakeholder engagement strategy:

- City of Maribyrnong
- City of Melbourne
- City of Port Phillip
- City of Stonnington
- DELWP
- EPA
- Heritage Victoria
- Melbourne Water
- Parkville Precinct Reference Group
- Public Transport Victoria (PTV)/TfV
- State Library
- Transport for Victoria (TfV)
- VicRoads.

Landowner/Tenant Engagement

Strata divestment will be required for the proposed CYP design and construction changes to Project Land. Further, temporary occupation may also be required for the Project Land changes at 2 and 2A Chambers Street, South Yarra, for the purposes of the Rail Infrastructure Alliance (RIA), which is yet to be appointed.

MMRA commenced early engagement with the impacted property owners and tenants as part of PSA GC82 and will continue to do so throughout the PSA process.

Letters were sent to landowners and tenants about the proposed changes to Project Land in PSA GC82. The letters outlined the impact to their property, the planning process, how to be involved and how to contact the project for assistance or support.

MMRA and CYP held meetings with each of the following stakeholders as part of the ongoing stakeholder engagement strategy:

- Capitol Theatre
- Federation Square
- MATC
- Melbourne Central
- Manchester Unity
- QV Building
- RMIT University
- University of Melbourne.

Road Surface Works

A number of roads will be included in the draft PSA to enable construction management and some legacy roadworks. Engagement with stakeholders will occur before these permanent changes are undertaken. The nature of the road surface works and the broad timelines (where available) was provided in letters to relevant stakeholders.

Phase 2: Engagement to support public display of draft PSA

The PSA will be on display for 30 calendar days with the following proposed communications tools.

Targeted Letters

Information packs were provided to landowners and tenants, tailored to whether the proposed impact on the property is as follows:

- newly within the Project Land
- newly within the DDO
- an increase in the Project Land
- an increase in the DDO
- adjacent to the road surface works

Strata divestment and DDO-related change information packs included:

- Letters to landowners advising of the proposed changes to the PSA and potential strata divestment / a potential Design and Development Overlay (DDO) on their property
- Maps relevant to the property
- Invitation to provide feedback online or contact the project team
- The information packs will outline the time frames for the PSA process, opportunity to provide feedback, the strata divestment process (if relevant) and address any immediate questions.

The draft PSA and supporting documents will be published on the Metro Tunnel website for 30 calendar days. An online feedback form will also be made available for the duration of the draft PSA public display period for landowners and tenants to provide feedback on the PSA process and potential impacts on their property. These comments will be responded to, as outlined in Phase 3 of the consultation process. A consultation summary report will be produced to support formal submission of draft Amendment GC82.

Phase 3: Engagement post PSA

CYP will provide a response and update on the issues raised to prescribed stakeholders, key stakeholders, Reference Groups, and the community. Prescribed stakeholders will receive a response on their feedback including through comprehensive briefings.

Key stakeholders will be responded to formally in writing, and in stakeholder meetings. CYP will include presentations on the feedback received to the Parkville Precinct Reference Group and Community Reference Groups. Organisations and members of the community who provide feedback either online through the survey or in writing will be responded to, where email or address details are provided.

In accordance with the existing approved Environmental Performance Requirements and the project's contractual Project Scope & Technical Requirements, further detailed technical assessments are being undertaken including of building and asset condition, ground movement, groundwater, noise and vibration, and Electro Magnetic Interference (EMI). These assessments variously involve stakeholder consultation, and are used to inform design and construction of the project

3.2.4 Environmental Performance Requirements

The works being undertaken at strata (below ground) at St. Paul's Cathedral and Melbourne Town Hall are overall considered acceptable given established ground movement classifications. As part of the CBD South Station works, it is noted an inspection and monitoring will be undertaken during the design phases as outlined by the EPRs GM4 and GM 5. Furthermore, isolated locations of repair work may be required, but will be adequately managed through GM5.

For those sensitive receivers, particularly buildings, located within the additional Project Land that have not been included in this assessment will be addressed through the EES and PSA processes requirements and in particular EPRs.

3.2.5 Assumption and Limitations

This assessment is based upon information that has been available at the time of writing. In lieu of available information it has been necessary to make some assumptions. Where appropriate, this assessment will be revised to incorporate additional and updated information when it is available.

- The assessment is based on predicted greenfield settlement at ground surface.
- Building extents, building heights and the number of basement levels have been provided by CYP. These have only been independently verified as far as a virtual external walkover using publicly available satellite imagery (Google Earth). The building condition has not been considered.
- This assessment has considered specific buildings only. No assessment has been carried out in relation to utilities and other structures (such as bridges, rail lines, tram lines) at this time.

Overall, these assumptions are considered appropriate and conservative, and will be supported through the requirements of the EPRs.

4 Conclusion

The ground movement impact assessment that has been carried out by CYP for the CBD South station component. The intention of this assessment is to report the predicted ground movement and associated building damage assessment for two specific buildings; St Pauls Cathedral and Melbourne Town Hall.

The assessment criteria are based on classifications proposed by Burland (1995), which is the internationally accepted standard for Ground Movement. According to Burland (1995) the building damage is considered that affects 1. Aesthetics (i.e. the appearance of the building), 2. Serviceability, (i.e. the effect on the function of the building), and 3. Stability. The categories are related to the tensile strain that the building will experience.

The Melbourne Town Hall overall building damage score is 2, based on only one line (line 26) is indicating this score, and one line (line 29) indicating a score of 1. The majority of the building lines have a score of 0. The overall building damage score for St.Paul's Cathedral is 1, represented by three lines (4, 12 and 26) are indicating this score, the majority of the building lines have a score of 0.

In this instance, the results from a Phase 1 and Phase 2 assessment indicate a Phase 3 assessment is required for St.Paul's Cathedral and Melbourne Town Hall. This will provide CYP with the data required to ensure effective management and mitigation of potential damages as a result of the changes to the approved design.

Although a Phase 3 assessment is required, the findings are overall considered acceptable and manageable based on classifications proposed by Burland (1995). Specifically with regards to the Melbourne Town Hall with its portico and clock tower, and the complex structure of the Cathedral, further analysis may be warranted to confirm the assessments based on Burland and the requirements of GM3. The data base developed as part of GM4 will ensure as-built and pre-construction condition information for each potentially affected structures identified as susceptible to damage will assist in acquiring and maintaining data of both the Cathedral and Melbourne Town Hall to accurately record and monitor any changes that may result from the Metro tunnel works.

As required, this will be undertaken with Heritage Victoria, as outlined in GM6. Additional modelling is proposed as part of the design refinement and if the assessed impact is considered unacceptable more complex modelling (eg 3D structural FEM) may be considered and completed. If limited adverse effects on these structures are assessed as part of the design refinement, then more complex modelling (which includes its own assumptions and simplifications) may provide minimal benefit and focusing on mitigation approaches (e.g. construction staged monitoring, trigger levels and inspections) may prove to be more effective mitigation measures as proposed under GM3.

Based on available information, the above findings are considered acceptable given established ground movement classifications and they comply with the rigorous EPR requirements. As part of the CBD South Station works, it is noted an inspection and monitoring will be undertaken during the design phases as outlined by the EPRs GM4 and GM 5. Furthermore, isolated locations of repair work may be required, but will be adequately managed through GM5. The requirement of GM1 and GM2 should ensure ground movement is limited and a Phase 3 assessment will further ensure any potential impacts as a result of ground behaviour, structural form, soil/structure interaction, condition surveys and mitigation works until the assessed damage risk is considered acceptable in terms of ground movement.