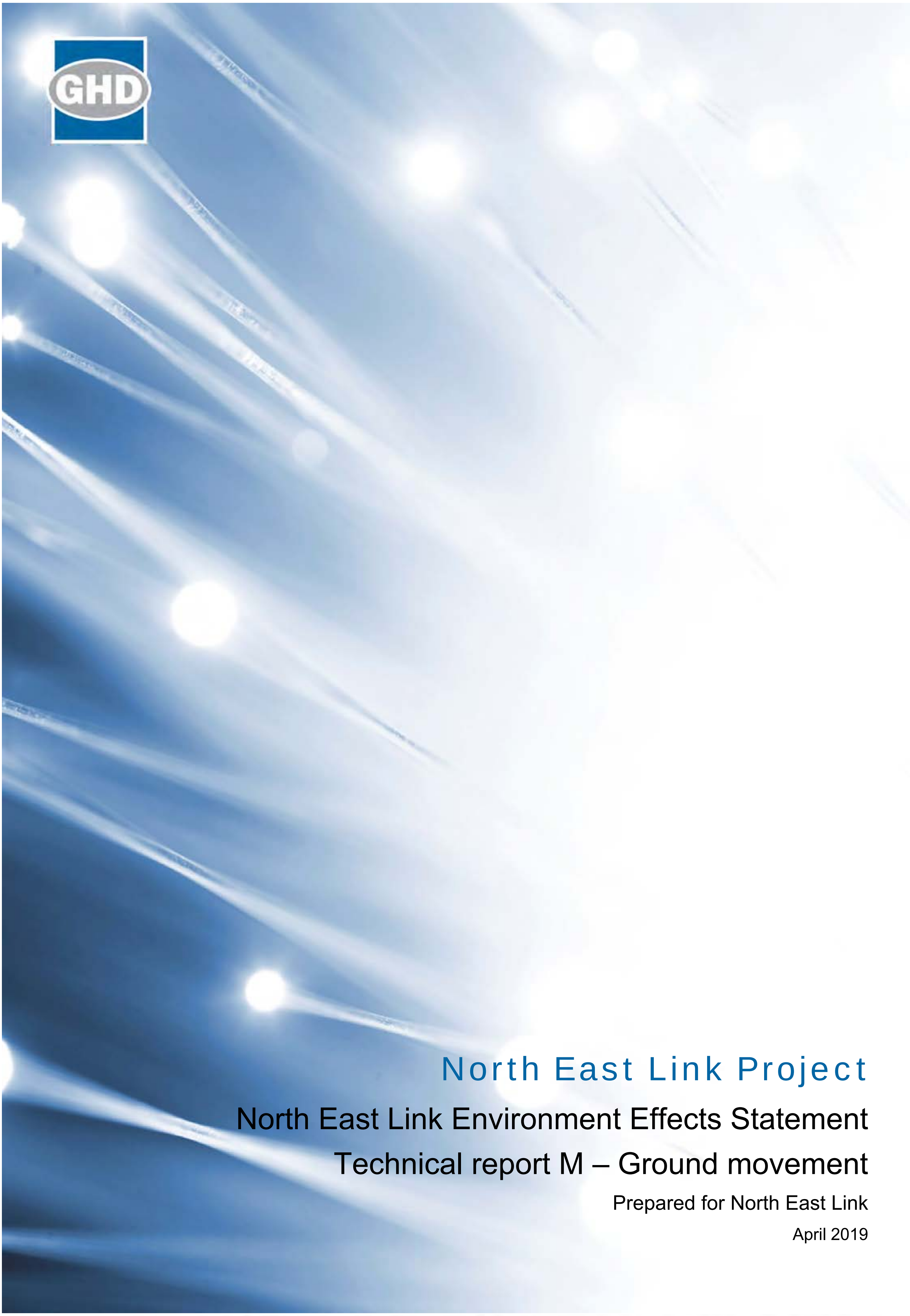
Environment
Effects Statement

Technical Report M
Ground movement



North East Link Project

North East Link Environment Effects Statement

Technical report M – Ground movement

Prepared for North East Link

April 2019

WATER | ENERGY & RESOURCES | ENVIRONMENT | PROPERTY & BUILDINGS | TRANSPORTATION

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Executive summary

This technical report is an attachment to the North East Link Environment Effects Statement (EES). It has been used to inform the EES and *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth) assessments required for the project and defines the Environmental Performance Requirements (EPRs) necessary to meet the EES objectives.

Overview

North East Link is a proposed new freeway-standard road connection that would complete the missing link in Melbourne's ring road, giving the city a fully completed orbital connection for the first time. North East Link would connect the M80 Ring Road (otherwise known as the Metropolitan Ring Road) to the Eastern Freeway and includes works along the Eastern Freeway from near Hoddle Street to Springvale Road.

The Major Transport Infrastructure Authority (MTIA) is the proponent for North East Link. The MTIA is an administrative office within the Victorian Department of Transport with responsibility for overseeing major transport projects.

North East Link Project (NELP) is an organisation within MTIA that is responsible for developing and delivering North East Link. NELP is responsible for developing the reference project and coordinating development of the technical reports, engaging and informing stakeholders and the wider community, obtaining key planning and environmental approvals and coordinating procurement for construction and operation.

On 2 February 2018, the Minister for Planning declared North East Link to be 'public works' under Section 3(1) of the *Environment Effects Act 1978*, which was published in the *Victorian Government Gazette* on 6 February 2018 (No. S 38 Tuesday 6 February 2018). This declaration triggered the requirement for the preparation of an EES to inform the Minister's assessment of the project and the subsequent determinations of other decision-makers.

The EES was developed in consultation with the community and stakeholders and in parallel with the reference project development. The reference project has been assessed in this EES. The EES allows stakeholders to understand the potential environmental impacts of North East Link and how they are proposed to be managed.

GHD was commissioned to undertake a ground movement impact assessment to inform the EES.

Ground movement context

The scoping requirements for the EES issued by the Minister for Planning set out the specific environmental matters to be investigated and documented in the project's EES, which informs the scope of the EES technical studies. The scoping requirements include a set of evaluation objectives. These objectives identify the desired outcomes to be achieved in managing the potential impacts of constructing and operating the project.

The assessment is to include (among other things) '...*the potential for ground movement or other geophysical conditions including risks related to land and river bank or bed stability*...'.

The evaluation objective relevant to ground movement thus falls under the heading 'Land Stability'. The evaluation objective is:

> *To avoid or minimise adverse effects on land stability from project activities, including tunnel construction and river and creek crossings.*

A summary of the key assets, values or uses potentially affected by the project and an assessment of the project's impacts on those assets, values and uses is set out below.

This report addresses the risks to existing buildings, structures, utilities or land areas arising from ground movements caused by construction of the project.

Environmental Performance Requirements (EPRs) are assigned where potentially adverse effects have been identified. The EPRs specify the limits and processes that must be followed so that appropriate monitoring and remedial measures are put in place to manage risk and ensure that ground movements are kept to acceptable levels.

Key findings

This report has assessed the potential ground movement effects caused by: tunnelling undertaken by tunnel boring machines (TBM), open-face tunnelling using sequential excavation methods (SEM), construction of new embankment structures, the excavation of retained cuttings and cut-and-cover structures and groundwater pressure changes in soils due to construction de-watering.

In addressing the EES scoping requirements, the following methodology was adopted:

- The study area was divided into three planning elements: the M80 Ring Road to northern portal, the northern portal to the southern portal, and the Eastern Freeway.
  These elements were further sub-divided into 11 'reaches' on the basis of geotechnical conditions and anticipated construction method.
- The existing conditions for each project element were established to:
  - Provide a baseline for the ground and groundwater conditions
  - Identify any significant buildings, structures, utilities or land areas considered sensitive to ground movement
  - Identify any ground movement hazards in the existing built environment and natural landscape.

This was achieved by a review of in-house and published geotechnical, geological and hydrogeological information, inter-disciplinary reports, aerial photography and utilities information. Walkover surveys were also conducted in June 2018 and November 2018.

The identified features were assessed for ground movement risk using an internationally recognised three-stage approach (Mair et al., 1996) to provide a shortlist requiring specific EPRs: a preliminary assessment; second stage assessment (for those features at 'Slight' risk); and detailed evaluation (for those features identified at 'Moderate' risk in the second stage assessment).

The risk of damage to the majority of buildings, structures, utilities or land areas within the zone of influence (ZoI) of the works was found to be 'Slight' or less. Nonetheless, for those receptors considered particularly 'sensitive', EPRs have been proposed. However the detailed evaluation for 'Helmet', a sculptural artwork owned by Manningham City Council located close to the temporary southern portal at Banksia Street, indicates an unacceptable level of risk of damage to the structure. Temporary relocation of this artwork may be required during construction.

The relocation of the water pressure-reducing station on the northern side of Drysdale Street, including the downstream and upstream water mains referred to as the Lower Plenty Road water main, would be subject to further assessment at the detailed design stage.

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4. EES assessment framework
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IV. Stakeholder consultation report
V. Draft Planning Scheme Amendment
VI. Works Approval Application

EES Map Book

Abbreviations

Abbreviation	Definition
με	Micro-strain – ratio of change in dimension to original dimension
CEMP	Construction Environmental Management Plan
CCM	Confinement Convergence Method
CH	Chainage
EES	Environment Effects Statement
EPR	Environmental Performance Requirement
FEA	Finite element analysis
GFRP	Glass fibre reinforced plastic
GIS	Geographic information system
GSI	Geological Strength Index
HV	High voltage
MTIA	Major Transport Infrastructure Authority
NB	Northbound
NELP	North East Link Project
OEMP	Operations Environmental Management Plan
PFAS	Perfluorooctanesulfonic acid
SB	Southbound
SEM	Sequential Excavation Method (mined tunnelling)
SPT	Standard penetration test
TBM	Tunnel boring machine
V_L%	Volume loss
ZoI	Zone of influence of ground movements (5mm vertical settlement or greater)

Glossary

Term	Definition
CLS pipe	Concrete-lined steel pipe – typically used for potable water conveyance
Cover	The lesser of the depth of ground from the surface to the crown of the tunnel or pipeline or the depth of competent ground to the crown of a tunnel or pipeline,
Crown	The highest point of the external curved surface of a tunnel or pipeline cross section
Department of Transport	The Victorian Department of Transport is responsible for delivering the government's transport infrastructure agenda. It was formed on 1 January 2019 when the former Victorian Department of Economic Development, Jobs, Transport and Resources transitioned into the Department of Transport and the Department of Jobs, Precincts and Regions.
EPR GM1	Suggested action to manage environmental effects with identification number 1
Hogging	Areas of upward curvature in the settlement profile
Invert	Interior bottom elevation of a tunnel pipe
LIDAR	A survey method that uses pulsed laser light to map surface topography in 3D
Major Transport Infrastructure Authority	The Major Transport Infrastructure Authority is the proponent for the North East Link project. The MTIA is an administrative office within the Victorian Department of Transport with responsibility for overseeing major transport projects.
North East Link Project	North East Link Project is an organisation within MTIA that is responsible for developing and delivering North East Link. NELP was formerly known as the North East Link Authority prior to 1 January 2019. NELP is responsible for developing the reference project and coordinating development of the technical reports, engaging and informing stakeholders and the wider community, obtaining key planning and environmental approvals and coordinating procurement for construction and operation.
Obvert	Interior top elevation of a tunnel pipe
$Phase^2$	A 2D finite element numerical modelling program used for geotechnical analysis in soil and rock.
Risk GM01	An identified potential hazard and effect on the environment with identification number 01
Sagging	Areas of downward curvature in the settlement profile
Settlement	Downward movement of ground material
VC pipe	Vitrified clay pipe – typically used for reticulation/sub-main sewers
Volume loss	Ratio of over-excavated ground to theoretical excavated volume
XDisp	A program used to estimate the potential ground settlement due to tunnelling and excavation activities

1. Introduction

1.1 Purpose of this report

North East Link is a proposed new freeway-standard road connection that would complete the missing link in Melbourne's ring road, giving the city a fully completed orbital connection for the first time. North East Link would connect the M80 Ring Road (otherwise known as the Metropolitan Ring Road) to the Eastern Freeway and include works along the Eastern Freeway from near Hoddle Street to Springvale Road.

The Major Transport Infrastructure Authority (MTIA) is the proponent for North East Link. The MTIA is an administrative office within the Victorian Department of Transport with responsibility for overseeing major transport projects.

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On 2 February 2018, the Minister declared the works proposed for North East Link as Public Works and issued a decision confirming that an Environment Effects Statement (EES) is required for the project due to the potential for significant environmental effects.

Similarly, the project was referred to the Australian Government's Department of the Environment and Energy on 17 January 2018. On 13 April 2018 the project was declared a 'controlled action', requiring assessment and approval under the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth) ('EPBC Act'). Separate to this EES, a Public Environment Report (PER) is required to be prepared to satisfy the EPBC Act requirements, and assess the impacts of the project on Commonwealth land and matters of national environmental significance (MNES).

The purpose of this report is to assess the potential ground movement impacts associated with North East Link and to define the Environmental Performance Requirements (EPRs) necessary to meet the EES objectives

This report comprises one of the technical appendices to the EES. Ground movements arising from tunnelling undertaken using open-face mining techniques or by tunnel boring machine (TBM) are considered, along with ground movements due to new embankment structures, excavations for retained cuttings and cut-and-cover structures and groundwater pressure changes in compressible soils.

The scope of this technical report is to:

- Describe the geological, geotechnical and hydro-geological conditions that constrain the reference project alignment and have a bearing on the magnitude and extent of ground movements arising from construction.
- Identify the existing surface and below ground structures and utilities (within the zone of influence of construction) that may be affected by excavation induced ground movements.
- Understand the potential magnitude and distribution of ground movement at each structure or asset assessed, to determine the risks to the structure or asset.
- For those structures deemed to be at a significant risk of adverse effects, develop environmental performance requirements (EPRs) for ground movement that specify the limits and processes that must be followed to achieve an acceptable outcome.

This report focuses on ground movements and their potential effects, and takes due cognisance of anticipated groundwater drawdown or 'mounding' effects described in Technical report N – Groundwater. The effects of excavation-induced vibration are considered separately in Technical report D – Tunnel vibration and will not be discussed here.

1.2 Why understanding ground movement is important

Ground movement describes the horizontal or vertical movements associated with deep excavations and tunnel construction. The magnitude and extent of these movements and the potential for adverse effects largely depends on the ground conditions, the construction method and the quality of 'workmanship' employed in construction. For this assessment, 'good workmanship[1]' is assumed.

To avoid unacceptable environmental effects, it is important to undertake ground movement calculations at the early stages of a project. These calculations may also influence design decisions, such as the final vertical tunnel alignment or proximity of a retained excavation to existing services and structures.

Risks associated with ground movement are primarily assessed by determining the potential strains when structures or utilities are subjected to ground movement. Maximum vertical displacement and ground slope are often used in preliminary assessments as 'proxies' for strains that may be induced in a structure. The maximum vertical displacement is the maximum extent the ground surface moves in the vertical direction, while the maximum ground slope refers to the maximum change in slope of the ground from the horizontal.

These simple criteria enable a rapid elimination of those structures within the zone of influence that are unlikely to be at risk of adverse ground movement effects. Efforts can then be focused on those structures that remain at risk and thus require more detailed assessment.

In the context of assessing the ground movements arising from tunnelling or deep excavations the term 'settlement' is typically used in the technical literature. The term 'subsidence' is usually reserved for regional aquifer de-pressurisation effects or due to instability of deep mine workings. The term 'settlement' will be adopted here.

[1] 'Good workmanship' is defined as the standard of workmanship as reasonably expected of a competent contractor in performing the works.

2. Scoping requirements

2.1 EES evaluation objectives

The scoping requirements for the EES, released by the Minister for Planning set out the specific environmental matters to be investigated and documented in the project's EES, which then informs the scope of the EES technical studies. The scoping requirements include a set of evaluation objectives. These objectives identify the desired outcomes to be achieved in managing the potential impacts of constructing and operating the project.

The assessment is to include (among other things) '...*the potential for ground movement or other geophysical conditions including risks related to land and river bank or bed stability...*'.

The evaluation objective relevant to ground movement thus falls under the heading 'Land Stability'. The evaluation objective is:

> *To avoid or minimise adverse effects on land stability from project activities, including tunnel construction and river and creek crossings.*

2.2 EES scoping requirements

Scoping requirements relevant to the ground movement evaluation objective are listed in Table 2-2 (next page), as well as the location where these items have been addressed in this report.

2.3 Linkages to other technical reports

This report relies on or informs the technical assessments as listed in Table 2-1.

Table 2-1 Linkages to other technical reports

Technical report	Relevance to this impact assessment
Technical report N – Groundwater	Groundwater numerical modelling provides an estimate of the predicted change in water levels from construction dewatering, which results in a change in effective stress within the affected areas and in turn consolidation of any compressible soils.
Technical report Q – Ecology	Ground movement assessments provides an indication of the movements that may affect ecologically sensitive features.
Technical report K – Historical heritage	Identifies the presence of heritage listed features which are of significant community, architectural or historical value. This informs the identification of sensitive receptors that may require ground movement EPRs.
Technical report O – Contamination and soil	Identifies the location of historical landfills or other contaminated sites that may be disturbed by ground movements.
Technical report L – Aboriginal cultural heritage	Identifies the location of cultural heritage sites and provides an indication of the potential effects of ground movement on sensitive features.
Technical report P – Surface water	Identifies hydrological or geomorphic conditions that may contribute to susceptibility to erosion eg steep slopes, channels.

Table 2-2 Scoping requirements relevant to ground movement

Aspect	Scoping requirement	Section addressed
Key issues	Potential for project works to cause or lead to land subsidence or erosion that could adversely affect properties, structures, infrastructure, drainage, river health or other values including under future climate change scenarios.	Risk assessment: Section 7 Technical report P – Surface water
Priorities for characterising the existing environment	Identify and map ground conditions along the project corridor including geology, hydrogeology and drainage. Identify ground conditions that may be susceptible to subsidence from proposed project activities (eg tunnelling, deep excavation, dewatering) and direct and indirect changes to vegetative cover (such as from increased shading by elevated structures).	Existing conditions: Section 6 Vegetation assessed in Technical report Q – Ecology.
	Identify properties, structures and infrastructure that may be susceptible to subsidence.	Existing conditions: Section 6
	Identify hydrological or geomorphic conditions that may contribute to susceptibility to erosion (eg steep slopes, channels).	Existing conditions: Section 6 Technical report P – Surface water
Design and mitigation measures	Identify design and construction management measures to maintain ground stability and prevent erosion where risks of potential instability due to the project have been identified.	Environmental Performance Requirements: Section 9 Technical report P – Surface water
Assessment of effects	Predict subsidence and erosion due to project works and assess residual effects on assets and values.	Impact assessment: Section 8 Technical report P – Surface water
Approach to manage performance	Describe the environmental performance requirements to set subsidence and erosion outcomes that the project must achieve.	Environmental Performance Requirements: Section 9 Technical report P – Surface water

3. Project description

3.1 Overview

The North East Link alignment and its key elements assessed in the Environment Effects Statement (EES) include:

- **M80 Ring Road to the northern portal** – from the M80 Ring Road at Plenty Road, and the Greensborough Bypass at Plenty River Drive, North East Link would extend to a northern portal near Blamey Road utilising a mixture of above, below and at surface road sections. This would include new road interchanges at the M80 Ring Road and Grimshaw Street.
- **Northern portal to southern portal** – from the northern portal the road would transition into twin tunnels that would connect to Lower Plenty Road via a new interchange, before travelling under residential areas, Banyule Flats and the Yarra River to a new interchange at Manningham Road. The tunnels would then continue to a southern portal located south of the Veneto Club.
- **Eastern Freeway** – from around Hoddle Street in the west through to Springvale Road in the east, modifications to the Eastern Freeway would include widening to accommodate future traffic volumes and new dedicated bus lanes for the Doncaster Busway.
  There would also be a new interchange at Bulleen Road to connect North East Link to the Eastern Freeway.

These elements are illustrated in Figure 3-1.

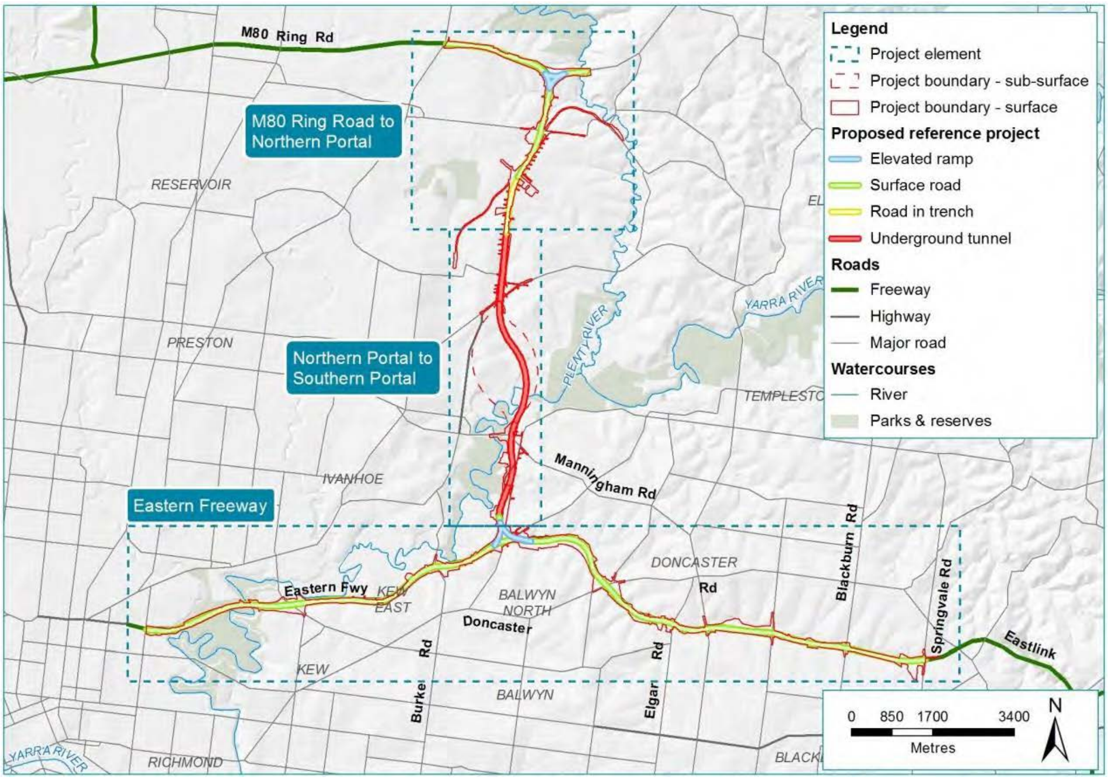


Figure 3-1 Overview of North East Link

The project would also improve existing bus services from Doncaster Road to Hoddle Street through the Doncaster Busway as well as pedestrian connections and the bicycle network with connected walking and cycling paths from the M80 Ring Road to the Eastern Freeway.

For a detailed description of the project, refer to EES Chapter 8 – Project description.

3.2 Activities and design considerations relevant to ground movement

3.2.1 M80 Ring Road to the northern portal

A new interchange would connect the M80 Ring Road and Greensborough Bypass to North East Link. This would include modifying the M80 Ring Road from Plenty Road to provide two three-lane carriageways connecting to North East Link. These carriageways would widen between the western end of Worcester Crescent and Waterford Place to accommodate four lanes for westbound traffic and five lanes for eastbound traffic. A separate two-lane ramp would accommodate westbound traffic to Plenty Road. The widening of the carriageway is anticipated to result in an increase in vertical loading on underground services.

The North East Link carriageways would begin to descend in elevation adjacent to the Watsonia railway station car park. Five new land bridges 60 metres in length would be constructed between Watsonia Road and Blamey Road, with the northern-most providing a road connection for Watsonia Road.

The North East Link carriageways would remain in an open ‘trench’ until Blamey Road where they would transition into a cut-and-cover tunnel. This section of work includes modifying Lower Plenty Road to allow connections to Greensborough Road and to North East Link’s inner north and southbound carriageways.

The construction of the trench and cut-and-cover sections is anticipated to give rise to ground movement. The potential for these movements to affect adjacent surface structures and underground services and utilities is assessed in this report.

3.2.2 Northern portal to southern portal

The North East Link tunnel start approximately 1.3 kilometres north of Lower Plenty Road at a portal formed where the trench structure becomes a cut-and-cover structure at Blamey Road. The North East Link would extend to 400 metres south of Veneto Club on Bulleen Road, where the cut-and-cover structure would emerge in an open trench structure opposite Bulleen oval.

Within this element, twin TBM tunnels would extend from Lower Plenty Road to Bridge Street to connect with the Manningham Road interchange. The tunnels would provide three traffic lanes in each direction. The excavated diameter of each TBM tunnel would be approximately 15.7 metres. The length of TBM tunnelling would be approximately 3.0 kilometres between Lower Plenty Road and Bridge Street.

The Manningham Road interchange is a combination of underground and surface road construction extending from Bridge Street in Bulleen to Golden Way in Bulleen. The design consists of cut-and-cover tunnels with three lanes for traffic in both north and south directions. Manningham Road would be modified to maintain access to Bridge Street and provide new ramp access to North East Link.

Twin tunnels with up to four lanes of traffic in each direction would continue from the Manningham Road interchange near Avon Street in Bulleen to Rocklea Road in Bulleen. These tunnels would be constructed as mined tunnels (SEM – sequential excavation method). The length of mined tunnelling would be approximately 400 metres.

From Rocklea Road, the tunnels would continue in cut-and-cover to emerge at a southern portal on the west side of Bulleen Road adjacent to Bulleen Oval. The road would then ascend to entry and exit ramps for traffic to the Eastern Freeway in both directions.

For the TBM and mined tunnel sections the potential for tunnelling induced 'settlement' of the ground to affect overlying surface structures and sub-surface infrastructure is assessed. For the cut-and-cover sections, risks from ground movement are assessed in the same way as the retained structures north of Lower Plenty Road. However for this element of the project, groundwater drawdown due to temporary de-watering during construction may also contribute to ground movements associated with 'consolidation settlement' in soils, such as are found in the Yarra Valley. These effects are considered in this ground movement assessment.

3.2.3 Bulleen Road to Eastern Freeway

Bulleen Road would be modified to construct new surface grade and viaduct structures adjacent to the Veneto Club and continuing to the Eastern Freeway. This would require the diversion of an existing 1750-millimetre diameter sewer beneath Bulleen Road and construction of a new sewer to the east of Bulleen road, by 'pipe-jacking' tunnelling and trenching methods.

Eastern Freeway upgrades would occur from Hoddle Street, Abbotsford in the west to Springvale Road, Nunawading in the east including widening of the freeway and new dedicated bus lanes between Doncaster Road and Hoddle Street (the 'Doncaster Busway').

3.3 Construction

Key construction activities for North East Link would include:

- General earthworks including topsoil removal, clearing and grubbing vegetation
- Relocation, adjustment or installation of new utility services
- Construction of retaining walls and diaphragm walls including piling
- Ground treatment to stabilise soils
- Tunnel portal and dive shaft construction
- Storage and removal of spoil
- Construction of cross passages, ventilation structures and access shafts
- Installation of drainage and water quality treatment facilities
- Installation of a Freeway Management System
- Tunnel construction using tunnel boring machines (TBMs), mining and cut-and-cover techniques
- Installation of noise barriers
- Restoration of surface areas.

3.3.1 Construction methods

To widen the M80 Ring Road, it is envisaged that motorway embankment structures would require modification. This may increase or decrease the vertical loading on the ground and structures beneath.

For the open trench and cut-and-cover tunnelled sections, retaining walls are anticipated for the deeper sections where battered cuttings are not feasible due to space constraints.
Small deflections of the wall during excavation of the ground in front of the wall would translate into vertical settlement and horizontal ground strain behind the wall.

The magnitude and extent of this settlement would depend on the excavation and support sequence and the permanent structural support required for the specific ground and groundwater conditions (such as drained versus watertight or 'tanked' design solutions).

The reference project proposes diaphragm walls for the tanked cut-and-cover sections, and contiguous bored pile walls for the drained retaining wall sections. Other wall construction types that may be considered by the contractor include sprayed concrete, sheet pile walls or kingpost and lagging walls, depending on the geology, retained height and the degree of watertightness required. Figure 3-2 illustrates a bored pile wall supported by walling beams and ground anchors, as used on the 2011 Airport Link project in Brisbane.

Figure 3-2 Anchored and braced bored pile retaining walls (Airport Link, Brisbane, 2011)

The tunnelled sections of North East Link between the northern and southern portals would be constructed using three different techniques:

1. Cut-and-cover between each portal and the start of bored tunnelling at Lower Plenty Road (northern temporary portal) and Rocklea Road (southern temporary portal) and for the Manningham Road Interchange between Banksia Street and Avon Street, Bulleen.
2. Twin tunnel boring machine (TBM) tunnels between Lower Plenty Road and Banksia Street.
3. Open face mining twin tunnels between Avon Street and Rocklea Road, Bulleen

In addition, the Bulleen Road sewer diversion is expected to be constructed using trenching and pipe-jacking techniques.

The reference project assumes the TBM tunnels would be constructed using two TBMs. One tunnel would be operated some distance in advance of the other (assumed to be approximately 350 metres) to minimise possible adverse 'interaction effects' and facilitate the construction program. If 'soft ground' (soil) or high groundwater ingress is encountered during tunnelling, it is anticipated the TBMs would operate in 'closed mode', applying a support pressure to the excavated ground as they advance. This would minimise ground movements and excessive groundwater drawdown.

In competent ground (such as sparsely fractured rock, little water) the TBMs may be operated in 'open mode' to increase advance rates. Figure 3-3 illustrates an example of a large diameter TBM used for the 2012 Legacy Way project in Brisbane.

Figure 3-3 Large diameter TBM (Legacy Way, Brisbane, 2012)

The TBMs would install a precast segmental concrete lining as they advance. The segments are fitted with water-proofing gaskets and subsequently grouted into position to provide a watertight lining. Figure 3-4 shows an example of these segments (with water-proofing gaskets attached) that form a complete ring of the segmental tunnel lining.

This method of tunnelling has the advantage of being able to install the permanent watertight lining in a single stage; that is, as a 'one-pass' lining. This prevents significant volumes of groundwater from entering the tunnel excavation during construction.

Figure 3-4 TBM tunnel lining segment with gasket

Due to the relatively short length of bored tunnels required between Avon Street and Rocklea Road, the reference project assumes these would be constructed most economically by sequential excavation method (SEM) techniques. This process is typically undertaken in a series of stages (such as upper section or 'top heading', followed by a middle section or 'bench' and finally the bottom section or 'invert') and sprayed concrete is applied after each stage. This is why it is called 'sequential excavation method' tunnelling. At some distance behind the face, a secondary or final lining would be placed, often using formwork and cast-in situ reinforced concrete. It is again assumed the first tunnel would be driven some distance in advance of the second to minimise interaction effects.

Precedent for this SEM tunnelling in Melbourne can be found in the construction of the Eastlink tunnels. The Eastlink tunnels were excavated using track-mounted 'road-headers' which excavated the rock using a boom mounted rotary milling tool, followed by the installation of a temporary lining of sprayed concrete. Similarly, Figure 3-5 shows a photograph of SEM tunnelling works with a roadheader for the Airport Link in Brisbane in 2010.

Other excavation methods include standard mechanical excavators, high-energy hydraulic hammers ('rock-breakers'), non-explosive expansive chemicals and drill-and-blast. The final choice of tunnelling method would be partly governed by the contractor, the geotechnical properties of the ground, groundwater conditions, programme constraints and proximity to vibration sensitive receptors.

Unlike the TBM tunnels, which install the lining in 'one-pass', SEM tunnelling installs a tanked lining only in the second stage. Because of this, there is a period of time where groundwater can enter the tunnel excavation prior to casting the final lining.

The diversion of the Bulleen Road sewer to avoid a clash with the North East Link works would require pipe-jack installation in conjunction with standard open trenching techniques. Typically, launch and reception shafts (and trenched sections) would be formed using temporary sheet piles, although other methods such as concrete bored piles or grouted columns may be employed. The tunnelled sections are often formed using pipe-jacking techniques (for diameters in excess of 600 millimetres typically) which rely on a small-diameter TBM thrust ahead of a series of pre-cast concrete, steel, or glass fibre reinforced plastic (GFRP) pipes.

Figure 3-5 SEM tunnelling with roadheader (Airport Link, Brisbane, 2010)

As for larger diameter TBM or mined tunnels, there would be an inevitable volume loss around the pipe-jack tunnels which may cause local ground movement effects. Figure 3-6 illustrates a pipe jack in progress, with hydraulic rams providing the forward thrust for the TBM and subsequent pipes.

3.3.2 Construction program

While the specific program of construction would vary according to the contractor's preferences, for the purposes of the ground movement assessment the following assumptions have been made:

- The TBMs may be able to advance at an overall average rate of around 5 to 15 metres per day, with the advance rate dependent on factors including the geotechnical conditions, learning curves of the construction crew or maintenance activities.
- Utilities diversions, such as the Bulleen Road sewer (and other utilities such as a 450-millimetre diameter gas main in Bulleen Road and a 300-millimetre diameter water transfer work near Drysdale Street) would be undertaken early in the project, while the TBMs are on order and other enabling works are underway.
- Because it is anticipated the Manningham Road interchange excavations would take some time to construct, it is anticipated it may be over three years before casting the final base slabs (and temporary dewatering pumps are switched off).

- Similarly, the SEM tunnels would be constructed as 'drained' structures in the temporary condition. It is assumed this condition would remain for at least 18 months to two years after the start of construction of these tunnels, until casting of the permanent inner lining is completed.
- The deep trench and cut-and-cover excavations would typically be undertaken at the same time as other construction activities. However, to provide construction access for the tunnel launch and retrieval activities, it is expected these excavations would start nine to 12 months ahead of tunnelling works.
- The reference project assumes the southern section of the trench would be completed as a water-tight structure, whereas north of Blamey Road the trench may remain as a drained structure. Consolidation settlement is not considered a significant risk because the ground predominantly comprises weathered rock in this reach.

Figure 3-6 Pipe-jacking for a new sewer (Christchurch, 2011)

3.4 Operation

Following construction of North East Link, the key operation phase activities would include:

- Operation and maintenance of new road infrastructure
- Operation and maintenance of Freeway Management System
- Operation of North East Link motorway control centre
- Operation and maintenance of the tunnel ventilation system
- Operation and maintenance of water treatment facilities
- Operation and maintenance of the motorways power supply (substations)
- Maintenance of landscaping and Water Sensitive Urban Design (WSUD) features.

Although no significant ground movement effects associated with the operation of North East Link are anticipated, it is inevitable that movements would occur as a result of long-term changes to the groundwater level. That is, where groundwater drawdown or ‘mounding’ occurs, long-term consolidation settlements or ground heave due to expansive soils may result.
In general, these effects result in modest differential movements and occur over decades (in the ground conditions anticipated for North East Link) and therefore present little risk of damage to surface structures or utilities.

It is assumed that a permanent lining that is nearly impermeable would be adopted and any drawdown would have negligible ground movement effects. Conversely, these linings can have the opposite effect and result in a rise in groundwater where the natural groundwater flow is impeded.

It is further assumed that long-term groundwater control to avoid consolidation settlement (such as the groundwater re-charge system required for the City Link Burnley Tunnel) would not be adopted by the contractor because of the considerable cost and maintenance requirements.

Further detail on operational and construction groundwater control and drawdowns is provided in Technical report N – Groundwater.

4. Legislation, policy, guidelines and criteria

No specific legislation or policy guidelines apply to the assessment of ground movement. Instead, specific assessments of structures are undertaken using established engineering principles and methods that consider the particular construction details and condition of the effected structures or utilities.

Relevant legislation, policy, guidelines and standards include, but may not be limited to:

- Burland JB, Standing J and Jardine R, eds. (2001), *Building Response to Tunnelling. Volume 1: Projects and Methods* and *Volume 2: Case studies*, Construction Industry Research and Information Association (CIRIA) – Special Publication 200, UK
- Attewell PB and Taylor RK, eds. (1984), *Ground Movements and their effects on structures*, Surrey University Press
- Preene M, Roberts TOL and Powrie W (2016), *Groundwater control design and practice* (2nd ed.), Construction Industry Research and Information Association UK (CIRIA) – report C750
- Gaba A, Hardy S, Doughty L, Powrie W and Selemetas D (2017), *Guidance on embedded retaining wall design,* Construction Industry Research and Information Association UK (CIRIA) – report C760.

In addition, reference to the technical literature is made to inform the assessment process; see Section 11 of this report.

Limited design guidance relating to ground movement may also found within the following publications:

- British Tunnelling Society (2011), Monitoring Underground Construction – a Best Practice Guide, ICE publishing
- Code of Practice for the Risk Management of Tunnel Works (ITIG 2012)
- Austroads (2010), Publication *ARGT01/10 Guide to Road Tunnels* (Parts 1: Introduction to Road Tunnels and Part 2: Planning, Design and Commissioning)
- Australian Standard AS 2870 – 2011 Residential slabs and footings
- British Tunnelling Society/Institution of Civil Engineers (2010), *Specification for Tunnelling*, third edition, Thomas Telford
- Australian Standard AS 1726 – Geotechnical Site Investigations
- Australian Standard AS 2566.2 – 2002 Buried Flexible Pipelines.

5. Method

5.1 Overview

This section describes the method used to assess the potential impacts of North East Link. A risk-based approach was applied to prioritise the key issues for assessment and inform measures to avoid, minimise and offset potential effects. Figure 5-1 shows an overview of the assessment method.

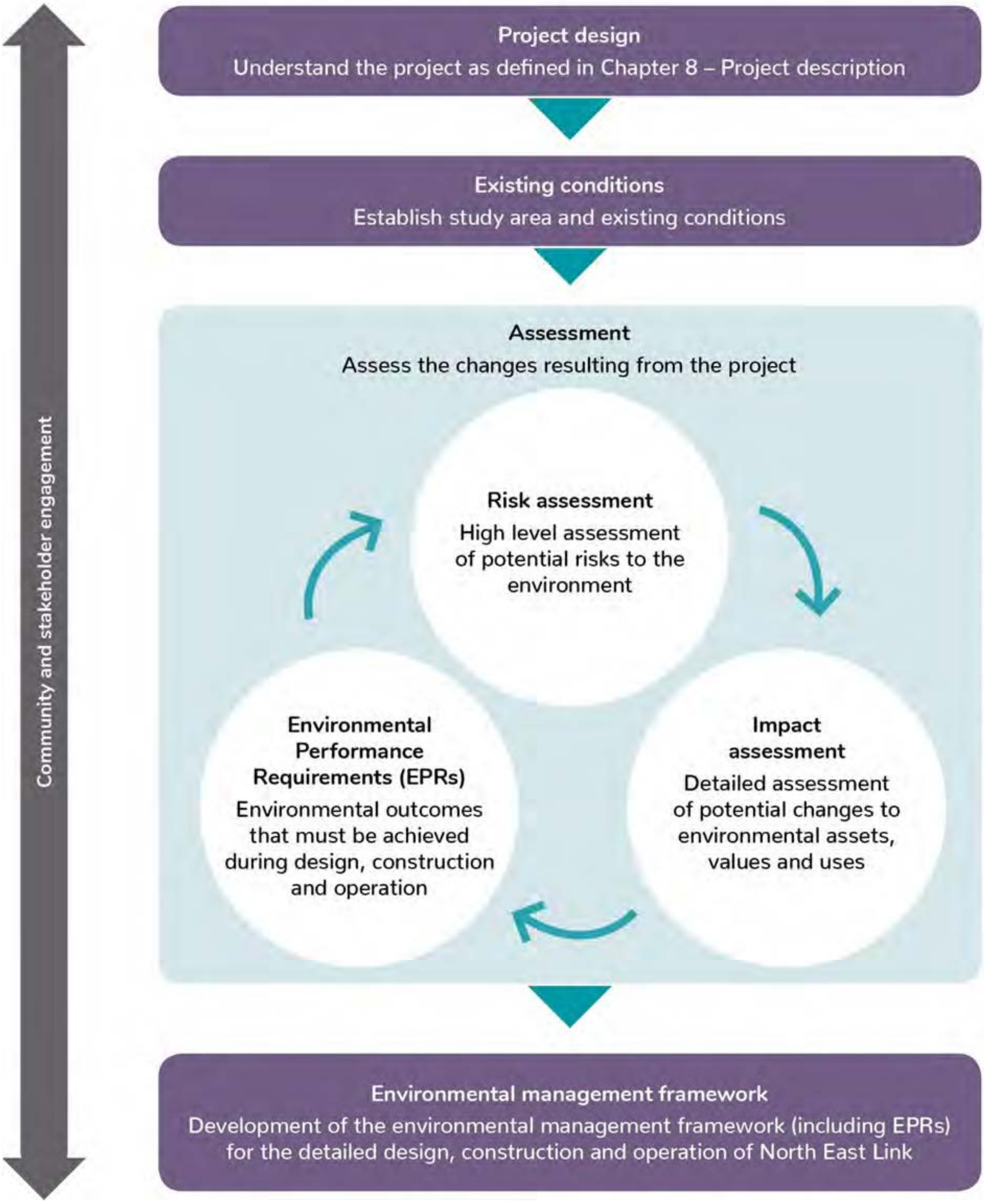


Figure 5-1 Overview of assessment method

The following sections outline the method adopted for the ground movement impact assessment.

5.2 Identification of sensitive receptors

To undertake this assessment, it was first necessary to identify a short list of potential sensitive receptors within the project boundary, which is largely occupied by residential areas, community facilities, public open space and areas of environmental sensitivity. Based on a desktop study, any structures of heritage or community significance and any critical pieces of infrastructure were identified, in addition to residential areas that might be affected by ground movement. Small utilities of less than 400-millimetre diameter were not explicitly considered in the assessment, unless deemed to be particularly sensitive[2]. Sensitive receptors are listed and briefly described in Section 8.

The shortlist of sensitive receptors was further narrowed by considering the zone of influence of the excavation works where significant ground movements could occur. The zone of influence may be estimated to be around 1.5 to 2 times the tunnel or excavation depth, or alternatively the extent of the five-millimetre settlement contour – whichever is the greater.
Preliminary calculations were undertaken to confirm the zone of influence to eliminate those receptors unlikely to be affected by the reference project at an early stage. A staged risk assessment was then undertaken for the remaining structures as described in Section 5.6.1.

5.3 Study area

The North East Link alignment is described in terms of three elements: the M80 Ring Road to the northern portal section; the northern portal to southern portal section; and the Eastern Freeway works.

The differences in geology and construction methods have been used to further sub-divide these elements into 'reaches' for the purposes of ground movement assessment.

M80 Ring Road to the northern portal

- Reach 1 – M80 Ring Road to Watsonia railway station (surface works)
- Reach 2 – Watsonia railway station to northern portal (open cut excavations).

Northern portal to southern portal tunnels

- Reach 3 – Northern portal to Lower Plenty Road (cut-and-cover)
- Reach 4 – Lower Plenty Road to Banyule Flats (TBM)
- Reach 5 – Banyule Flats to Manningham Road Interchange Box (TBM)
- Reach 6 – Manningham Road interchange (cut-and-cover)
- Reach 7 – Avon Street to Rocklea Road (SEM mined tunnels)
- Reach 8 – Rocklea Road to Bulleen Oval (cut-and-cover).

Eastern Freeway

- Reach 9 – Bulleen Oval to Eastern Freeway (surface works)
- Reach 10 – Eastern Freeway West (surface works)
- Reach 11 – Eastern Freeway East (surface works).

[2] This is because the smaller diameter utilities are typically much more 'relatively flexible' than the larger diameter utilities assessed. Discussed in Section 5.7.4.

5.4 Existing conditions

The objectives of the existing conditions assessment were to: establish a baseline for the ground and groundwater conditions for each project element and reach; identify any significant buildings, structures, utilities or land areas that may be sensitive to the impacts of ground movement; and, identify any ground movement hazards inherent in the existing built environment and natural landscape.

The approach adopted for this aspect of the work comprised a review of in-house and published geotechnical, geological and hydrogeological information relevant to the study area; a review of inter-disciplinary reports on land usage, heritage places, aerial photography and utilities; and, collection of available information relevant to any sensitive receptors within the 'zone of influence' of the project works.

The following sources of information were reviewed:

- In-house inter-disciplinary information and research including the results of groundwater drawdown modelling undertaken for the groundwater assessment (Refer Technical report N – Groundwater)
- The Victorian Heritage Database and Planning Schemes Online were consulted to identify relevant heritage places and their relevant listing under the Victorian Heritage Register (VHR), the Victorian Heritage Inventory (VHI) or a council Heritage Overlay (HO)
- Historic land use data from council libraries (City of Banyule, City of Manningham and City of Boroondara) (web based), historical societies (web based), Land Channel Photo Mosaics Series (Victorian Government)
- Historical Melbourne aerial photographs from 1945 were obtained from the University of Melbourne's map collection
- Landfill data was obtained from National Waste Management Database, EPA Victoria Publication 1270 (EPA Victoria, 2009) and council reports
- Current land use data was obtained from Planning Maps online (Victorian Government, Department of Environment, Land, Water and Planning)
- Utility information obtained from the Dial-Before-You-Dig website, Yarra Valley Water Asset database, Melbourne Water Asset Database and asset owner correspondence
- Factual geotechnical data collected by NELP specifically for the development of the reference project
- Additional geotechnical and geological data was obtained from the Vic Roads Geotechnical Assessment North East Link Transport Corridor including:
  - Planning Investigation Department, Report No. MW-91-01-15-01, 25 June 2010
  - Vic Roads M80 Upgrade Project, Plenty Road to Greensborough Highway, Report No. GR153-05.04.SCI.Rev0, 14 July 2015.

5.5 Risk assessment

An environmental risk assessment has been completed to identify environmental risks associated with construction and operation of North East Link. The risk-based approach is integral to the EES as required by section 3.1 of the Scoping Requirements and the *Ministerial guidelines for assessment of the environmental effects under the Environment Effects Act 1978*.

Specifically the EES risk assessment aimed to:

- Systematically identify the interactions between project elements and activities and assets, values and uses
- Focus the impact assessment and enable differentiation of significant and high risks and impacts from lower risks and impacts
- Inform development of the reference project to avoid, mitigate and manage environmental impacts
- Inform development of EPRs that set the minimum outcomes necessary to avoid, mitigate or manage environmental impacts and reduce environmental risks during delivery of the project.

This section presents an overview of the EES risk assessment process. EES Attachment III – Environmental risk report describes each step in the risk assessment process in more detail and contains a consolidated risk register.

This technical report describes the risks associated with the project for ground movement. Wherever risks relating to this study are referred to, the terminology 'risk XX01' is used. Wherever EPRs relating to this study are referred to, the terminology 'EPR XX1' is used. The risk assessment completed for this study is provided as Appendix A.

5.5.1 Risk assessment process

The risk assessment process adopted for North East Link is consistent with AS/NZS ISO 31000:2009 Risk Management Process. The following tasks were undertaken to identify, analyse and evaluate risks:

- Use existing conditions and identify applicable legislation and policy to establish the context for the risk assessment
- Develop likelihood and consequence criteria and a risk matrix
- Consider construction and operational activities in the context of existing conditions to determine risk pathways
- Identify standard controls and requirements (Environmental Performance Requirements (EPRs) to mitigate identified risks
- Assign likelihood and consequence ratings for each risk to determine risk ratings considering design, proposed activities and standard EPRs.

While there are clear steps in the risk process, it does not follow a linear progression and requires multiple iterations of risk ratings, pathways and EPRs as the technical assessments progress. Demonstrating this evolution, a set of initial and residual risk ratings and EPRs are produced for all technical reports. Figure 5-2 shows this process.

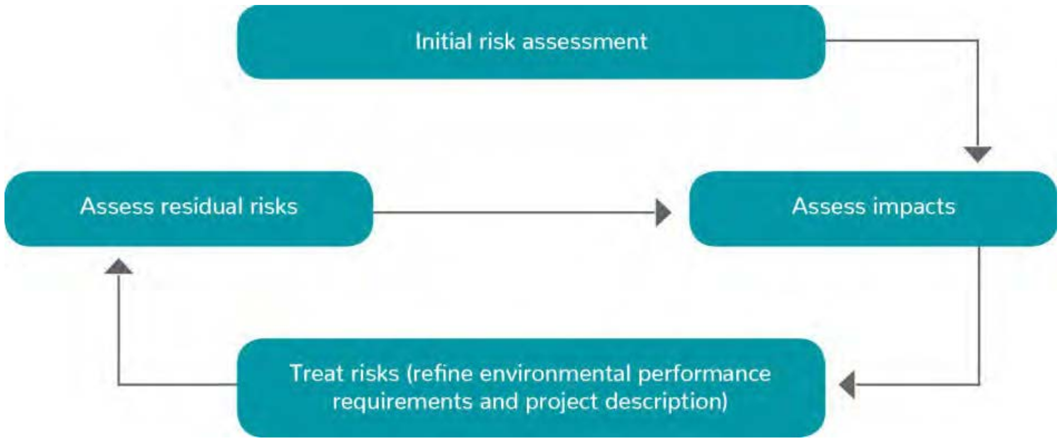


Figure 5-2 Risk analysis process

5.5.2 Risk rating

Risk ratings were assessed by considering the consequence and likelihood of an event occurring. In assessing the consequence, the extent, severity and duration of the risks were considered. These are discussed below.

5.5.3 Assigning the consequences of risks

'Consequence' refers to the maximum credible outcome of an event affecting an asset, value or use. Consequence criteria as presented in Chapter 4 – EES assessment framework, were developed for the North East Link EES to enable a consistent assessment of consequence across the range of potential environmental effects. Consequence criteria were assigned based on the maximum credible consequence of the risk pathway occurring. Where there was uncertainty or incomplete information, a conservative assessment was made on the basis of the maximum credible consequence.

Consequence criteria have been developed to consider the following characteristics:

- Extent of impact
- Severity of impact
- Duration of threat.

Severity has been assigned a greater weighting than extent and duration as this is considered the most important characteristic.

Each risk pathway was assigned a value for each of the three characteristics, which were added together to provide an overall consequence rating.

Further detail on the consequence criteria are provided in Chapter 4 – EES assessment framework.

5.5.4 Assigning the likelihood of risks

'Likelihood' refers to the chance of an event happening and the maximum credible consequence occurring from that event. The likelihood criteria are presented in Table 5-1.

Table 5-1 Likelihood of an event occurring

Planned	The event is certain to occur
Almost certain	The event is almost certain to occur one or more times a year
Likely	The event is likely to occur several times within a five-year timeframe
Possible	The event may occur once within a five-year timeframe
Unlikely	The event may occur under unusual circumstances but is not expected (ie once within a 20-year timeframe)
Rare	The event is very unlikely to occur but may occur in exceptional circumstances (ie once within a 100-year timeframe)

5.5.5 Risk matrix and risk rating

Risk levels were assessed using the matrix presented in Table 5-2.

Table 5-2 Risk matrix

Likelihood	Consequence				
	Negligible	Minor	Moderate	Major	Severe
Rare	Very low	Very low	Low	Medium	Medium
Unlikely	Very low	Low	Low	Medium	High
Possible	Low	Low	Medium	High	High
Likely	Low	Medium	Medium	High	Very high
Almost certain	Low	Medium	High	Very high	Very high
Planned	Planned (negligible consequence)	Planned (minor consequence)	Planned (moderate consequence)	Planned (major consequence)	Planned (severe consequence)

5.5.6 Planned events

North East Link would result in some planned events, being events with outcomes that are certain to occur (ie planned impacts such as land acquisition), as distinct from risk events where the chance of the event occurring and its consequence is uncertain. Although planned events are not risks, these were still documented in the risk register as part of Attachment III – Risk report for completeness and assigned a consequence level in order to enable issues requiring further assessment or treatment to be prioritised.

These planned events were assessed further through the impact assessment process.

5.5.7 Risk evaluation and treatment

The risk assessment process was used as a screening tool to prioritise potential impacts and the subsequent level of assessment undertaken as part of the impact assessment. For example, an issue that was given a risk level of medium or above, or was identified as a planned event with a consequence of minor or above, would go through a more thorough impact assessment process than a low risk.

Where initial risk ratings were found to be 'medium' or higher, or were planned events with a consequence of 'minor' or higher, options for additional or modified EPRs or design changes were considered where practicable. It should be noted that the consequence ratings presented in the risk register are solely based on the consequence criteria presented in Attachment III – Risk report. Further analysis and evaluation of the impacts potentially arising from both risks and planned events and information on how these would be managed is provided in Section 8.

5.6 Impact assessment

5.6.1 Overview of ground movement assessment approach

Sources of ground movement

For the assessment of potential ground movement effects on existing surface structures and below ground utilities and services, three sources of movement have been considered:

- Inward ground movements due to 'volume loss' as a result of tunnel excavation (refer to discussion in Section 5.7.1 and Appendix D.1)
- Horizontal and vertical movements that occur behind retaining structures as the excavation proceeds
- Consolidation of compressible soil due to groundwater drawdown caused by construction dewatering required for excavation below the water table.

Other sources of movement such as liquefaction, vibration-induced compaction, thermal effects or 'reactive/expansive' soils that result in seasonal ground movement are not considered to present significant risks to the overall project.

In addition, one instance of possible ground movement due to slope instability was identified where the tunnels would pass underneath a steep slope in the Yarra Valley area. This is assessed in Section 8.2.5.

Volume loss movement is traditionally associated with ground movements around tunnels excavated in soft ground such as firm to stiff cohesive soils (see Section 5.7.1). For stronger or stiffer ground such as rock or hard and dense soils, movements at typical civil engineering depths can often be characterised by 'elastic' movements or movements associated with the displacement of discrete fracture bounded blocks of rock.

In soft-ground tunnelling, a common empirical approach to assess ground movement is to use the 'Gaussian method' proposed by Peck (1969).

In rock, this method can be applied with care. Difficulties can arise due to the influence of discrete fractures and features in the rock that result in non-uniform behaviour. However, when the fracturing is particularly closely spaced relative to the size of the excavation, a better fit with the Gaussian model can be obtained as the rock behaves in a more uniform manner. Typically, for detailed assessments, numerical methods may be employed to simulate the effects of particular fractures or feature networks in the rock.

For retaining wall structures, the same considerations regarding uniform behaviour versus non-uniform behaviour apply. In addition, groundwater pressure would also play an important part in the magnitude of any wall deflection, which translates to horizontal and vertical movement of the ground behind the wall. A number of empirical curves to estimate ground movements (depending on ground and wall type) are available in the literature and, where detailed analysis is required, numerical methods may be employed.

The potential ground movement effects associated with lowering the water table during de-watering of an excavation are well understood. Sometimes termed ‘effective stress settlement’ this effect is largely restricted to soft, compressible soils. Dense, free-draining granular soil, stiff to hard clays and rock are far less susceptible to this phenomenon. Analytical methods based on idealised solutions are available to estimate the magnitude of these movements. Again, for structures and utilities requiring detailed assessment, numerical methods may be employed to capture non-uniform effects such as complicated geometry or variable ground conditions.

Zone of influence

Having ascertained the problem geometry and ground conditions, calculations are made to determine the lateral extent of potential ground movements. For tunnel volume loss, the effects are typically limited to a surface area within a distance of around 1.5 times the depth of an individual tunnel. For retaining structures, the extent of significant ground movements may be limited to a distance of twice the depth of the excavation. These extents can be used as preliminary indicators of the ‘expected zone of influence’.

However, for effective stress settlement, the zone of influence can reach significantly greater distances from the excavation depending on the magnitude and duration of dewatering and the particular ground conditions. This is because in many cases, the conductivity of the ground to groundwater flow is substantially higher in the horizontal direction than the vertical. In rock, water will often preferentially flow through an interconnected fracture network leading to a widespread zone of influence.

Typically, a settlement magnitude threshold will be set to define the zone of influence for the particular project circumstances. For practical purposes this may be set at the limit of meaningful surveying accuracy (that is, one to two millimetres of vertical movement) or may be set at a value that reflects a negligible likelihood of perceptible damage to existing structures (such as two to 10 millimetres of vertical movement as per Rankin, 1988). In this assessment, five millimetres of settlement is used to define the zone of influence on the basis of being half of the lowest damage category as defined by Rankin. This provides a conservative limit within which to conduct the assessments.

In any decision regarding an appropriate zone of influence the sensitivity of potential ‘receptors’ of high community value or heritage significance may require a more flexible approach to determining the extent of the assessment undertaken.

Oasys Xdisp, a commercially-available tunnel and excavation settlement analysis software has been used to determine the settlement and horizontal displacement contours around the North East Link excavations. Damage risk indicators such as ground slope and horizontal strain were derived from this data. In addition, effective stress settlement due to groundwater drawdown was integrated with the Xdisp settlement to produce a combined set of resultant settlement contours.

Basis for assessment of risk

Having assessed the potential extent and magnitude of vertical ground movement in the zone of influence around the proposed works, a staged approach to the assessment of risk to existing structures has been adopted in line with international practice.

This comprises a three-stage assessment process as defined by Burland et al (2001) and Mair, Taylor & Burland (1996), the results of which are compared against six categories of damage risk. However for the EES, qualitative ‘consequence criteria’ are also applied. Table 5-3 shows an approximate equivalence between the five consequence descriptors adopted for the EES and the six descriptors recommended by Burland et al. For the purposes of this EES assessment the more detailed classification has been adopted.

A general description of the three-stage approach is as follows:

- **Preliminary assessment** – A simplified approach based on the maximum estimated vertical settlement and ground slope. The assessment assumes that surface structures follow the settlement trough shape, with no beneficial interaction effects between the soil and structural foundations. For those structures that fall into the 'slight' risk category or above (Rankin, 1988), further assessment would be undertaken. Rankin's classification also provides some guidance with regards to the risk of damage to buried utilities and services. However, an additional check may be made after O'Rourke and Trautmann (1982), who suggest that a ground slope limit steeper than 1:140 may result in damage to relatively rigid pipelines greater than 200 millimetres in diameter; for relatively flexible pipelines slopes between 1:40 to 1:140 may be acceptable. See Section 5.7.4 for a more detailed explanation on the assessment of utilities.
- **Second stage assessment** – The specific influence of the geometry (section properties) and stiffness of the structure are considered. For example, an equivalent simply supported elastic beam analogy is used to assess possibly damaging ('limiting') tensile strains (ε_{lim}%) in a building when subjected to the Greenfield (Gaussian) displacement profile. For utilities and buried structures, an assessment of the tolerable joint rotations, bending and extensional strains, is undertaken on a case-by-case basis. Construction sequence should be taken into account. A review of the existing condition may indicate the structure may have historically experienced some damage and this should be taken into account. Those structures that fall into the 'moderate' risk category or above (as defined in Table 5-3) are subject to a detailed evaluation.
- **Detailed evaluation** – This level of assessment considers additional factors that will have a bearing on the risk (or consequence) classification. This may include specific details of the building construction (and structural condition), the relative stiffness of the structure and the ground, the 3D position of the structure relative to the settlement profile, self-weight of the structure and the development of settlement and strains with construction sequence. While this level of analysis typically 'downgrades' the risk category, in instances where a moderate risk or greater remains, consideration of mitigation measures are required.

In addition to the engineering assessment of the risk of damage to structures affected by ground movement, any structures of heritage value, or of particular community value that fall within the zone of influence of the works, would be subject to a second stage assessment. This approach has been adopted for this assessment.

Table 5-3 Damage risk (and consequence) classification as applied to buildings

Building damage classification (limiting tensile strain)					Equivalent EES qualitative descriptor (approx.)
Risk category	Normal degree of severity	Description of typical and likely forms of repair for typical masonry buildings	Approx. crack width (mm)	Limiting tensile strain ε_{lim} (%)	Consequence – general guiding description
0	Negligible	Hairline cracks.	< 0.1	< 0.05	**Insignificant** – ground movement below background levels causes no measurable damage
1	Very slight	Fine cracks easily treated during normal redecoration. Close inspection may reveal some cracks in external brickwork or masonry.	0.1 – 1.0	0.05 – 0.075	**Minor** – settlement causes slight damage; does not affect serviceability; easily repaired.
2	Slight	Cracks easily filled. Redecoration probably required. Doors and windows may stick slightly.	1 – 5	0.075 – 0.15	
3	Moderate	Cracks may require cutting out and patching. Re-pointing of external brickwork and possibly a small amount of brickwork to be replaced. Doors and windows sticking. Service pipes may fracture. Weather tightness often impaired.	5 – 15 or several > 3 mm	0.15 – 0.3	**Moderate** – settlement causes some damage to building or infrastructure assets; minor or temporary loss of function; readily repaired.
4	Severe	Extensive repair involving removal and replacement of sections of walls especially over door and windows. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Service pipes disrupted.	15 – 25 depends on number of cracks	> 0.3	**Major** – settlement causes partial loss of function; repair may require some replacement and/or structural reinforcement.
5	Very severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and required shoring. Windows broken by distortion. Danger of instability.	> 25 depends on number of cracks	> 0.3	**Critical** – settlement causes complete loss of function; large-scale damage requiring extensive rectification or reconstruction.

For those structures at a ‘moderate’ risk of damage after detailed evaluation, EPRs would be assigned. In addition, structures of heritage or community value at risk of damage would also be assigned EPRs.

Figure 5-3 illustrates the phased approach adopted for the assessment of ground movement effects.

5.7 Input assumptions and validation

5.7.1 Tunnelling ground movement

The process of tunnelling causes ground movements ahead of the tunnel face, so an inevitable ‘convergence of the ground’ and an excavated volume of ground slightly greater than the theoretical volume of the tunnel will be excavated (ie “volume loss”).

The shape of the transverse surface settlement profile (or ‘trough’) caused by TBM tunnelling can be closely approximated by the equation for an inverted normal probability bell curve (or Gaussian function) (Peck, 1969). The volume of this settlement trough is taken to be equivalent to the volume loss caused during tunnelling. Volume loss is defined as the ratio of over-excavated material to the theoretical excavated volume and is often expressed as a percentage of the theoretical excavated face area of the tunnel.

In order to apply the Gaussian approach, an estimate of the volume loss caused by the tunnelling process is required. This defines the maximum settlement above the tunnel. The width of the trough is defined by a ‘trough width parameter’ (equivalent to one standard deviation on the bell curve) which is typically taken as a simple proportion of the depth to the axis of the tunnel based on empirical precedent.

In soft ground, volume loss may typically be estimated with reference to published empirical data, by application of plasticity theory or by ground relaxation analysis (ie ‘confinement-convergence’ method, or CCM). Less commonly, 3-D modelling may be applied to simulate the interaction between excavation, ground convergence and lining installation explicitly.

For rock, ground movement effects may be determined using the CCM, where the tunnelling excavation process is simulated in two dimensions by a ‘relaxation factor’ and the movements cease when the lining is ‘installed’ after an appropriate degree of relaxation has occurred. Typically, the CCM is used to determine the loading applied to the lining (such as Hoek et al., 2008) however the degree of relaxation will give rise to an estimate of the radial displacement around the tunnel (or ‘convergence’) which can be directly related to a volume loss.

The degree of relaxation is thus the key parameter required. Based on empirical data from the construction of large diameter TBM tunnels, the degree of convergence can be estimated from an assessment of the delay in installing the pre-cast segmental lining with distance behind the tunnel face. The effect of yield of the ground around the tunnel heading is also taken into account. This is directly related to the quality of the ground (weathering, strength and fracturing) which can be quantified using rock mass quality indices such as the Geological Strength Index (or GSI, Hoek et al., 1999).

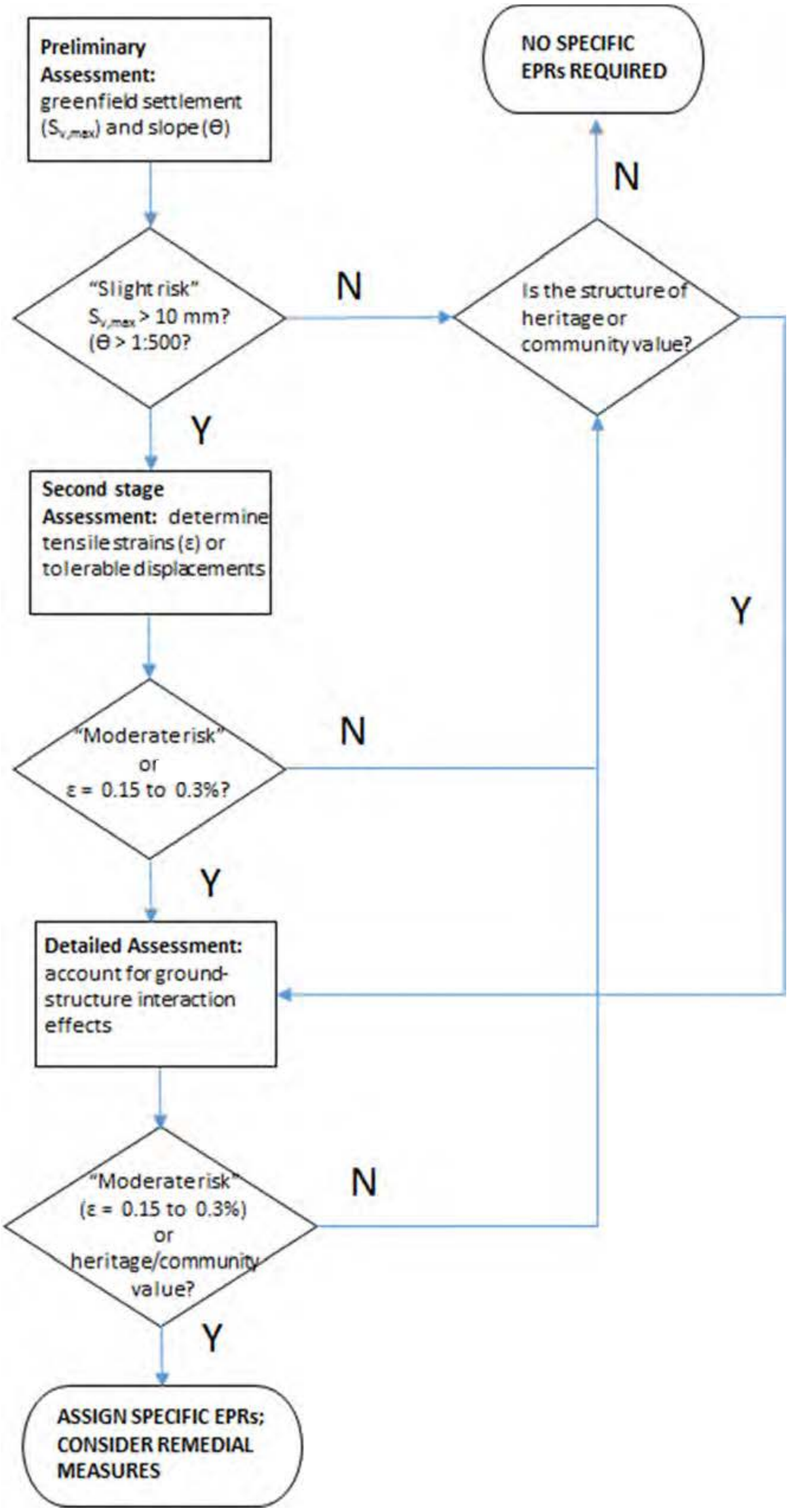


Figure 5-3 Ground movement assessment process

Having assessed the degree of convergence expected around the tunnel excavation, the volume loss can then be estimated as:

$$V_L\% = \frac{4\delta}{D} * 100$$

where δ can be taken as the average radial convergence around the tunnel and D is the excavated tunnel diameter (after Dimmock & Mair, 2007). Estimates of the rock mass quality in faulted rock (as expected to be encountered in some sections of the TBM drives) suggest that a GSI value of 25 would be appropriate in association with a medium strength rock substance when the rock is 'moderately weathered'. The CCM analysis for a 15.7-metre diameter tunnel then suggests that an average radial convergence of 30 millimetres is appropriate, which implies a volume loss of approximately 0.8 per cent (Appendix D.1).

Similar calculations for faulted rock that is only 'slightly weathered' implies a volume loss of approximately 0.4 per cent. For fractured (not faulted) rock with moderate substance strength, lower volume losses of as little as 0.1 per cent may be determined (that is, an essentially 'elastic' ground response).

It has thus been assumed the TBM drives would give rise to volume losses of 0.2 per cent to 0.8 per cent depending on the quality of the ground encountered. In the case of the SEM drives, an estimated volume loss of 0.3 per cent was adopted based on the ground condition expected to be encountered there. It is considered these are conservative estimates and appropriate for the purposes of this assessment.

Table 5-4 summarises where these volume losses have been applied along the reference project alignment with reasoning. It must nonetheless be recognised that actual ground conditions encountered may vary from those assumed for this EES assessment.

5.7.2 Retaining wall excavation induced ground movement

Ground movement associated with the construction of retaining structures for the 'open trench' sections of the alignment and the cut-and-cover sections is also feasible. Ground movement in these circumstances would be a function of the ground conditions, depth of excavation, relative stiffness of the wall and the propping/excavation sequence. For the purposes of this assessment, published empirical ground movement curves have been used as the basis for analysis of each section. A ground movement curve describes the relationship between ground movement and distance from an excavation. Selection of a suitable ground movement curve primarily involves comparing the in-situ ground conditions and proposed wall design and construction methods (that is, propped or cantilevered, sequential excavation, stiff or flexible), against published empirical data.

The current proposed retaining wall design indicates that generally the retaining walls would have a relatively high stiffness compared with the surrounding ground for each section along the alignment. The variation in ground conditions would therefore be the key input into the selection of an appropriate ground movement curve. For trough excavations in stiffer ground, such as highly weathered siltstone and residual soils in the vicinity of the northern portal or at Manningham Road interchange, an empirical curve published by Clough & O'Rourke (1990) for displacements adjacent to excavations in stiff to very hard clay (assumed to be equivalent to highly weathered and residual soil conditions) will be used as the basis for assessment.

Table 5-4 Volume loss parameters for preliminary settlement analysis

Location	Volume loss – V_L%	Reasoning
Lower Plenty Road to Leura Avenue (TBM)	0.8	Faulted zones have been detected near the temporary portal in the vicinity of Lower Plenty Rd. Reduced ground cover above the tunnel, with some superficial soil.
Leura Avenue to Banyule Flats (TBM)	0.2	Greater than one-tunnel diameter of cover above the tunnel crown and ground is believed to be mainly competent siltstone.
Banyule flats northern valley interface (TBM)	0.8	Reduced ground cover above the tunnel crown beneath the Yarra Valley. The ground cover consists of a thick layer of geologically 'recent' alluvial soils and highly fractured rock; potential 'mixed ground' conditions in TBM face.
Banyule flats (TBM)	0.4	Ground cover above tunnel crown increases as the alignment continues under the Yarra Valley. Siltstone in this location is of lower GSI as rock fracturing is more prominent and fault zones are possible.
Banyule flats southern valley interface (TBM)	0.8	Ground cover of material above tunnel crown decreases as the alignment rises to meet the Manningham Road interchange box. Surface material comprises weathered siltstone with some fault zones expected. Mixed face conditions comprising rock and alluvium anticipated.
Mined (SEM) tunnels	0.3	Moderately weathered, moderate strength fractured rock is anticipated in this section of the alignment.

To validate and refine the ground movement curve, the geotechnical modelling software *Plaxis 2D* was used to model ground movements in highly weathered rock to residual soil for several retaining wall sections along the alignment. The results suggested the Clough & O'Rourke (1990) displacement profile is a reasonable if slightly conservative assumption.

For the trough excavations in the clay alluvium in the vicinity of the Bulleen Road portal, an empirical curve published by Gaba et al. (2017) (the CIRIA C760 report) for stiff clays was selected as appropriate. This ground movement profile shows a lower magnitude of settlement closer to the excavation wall but higher magnitudes at greater distances from the excavation wall compared to the Clough & O'Rourke (1990) curve.

Appendix D.2 describes the assumptions and numerical validation conducted for the selection of an appropriate ground movement curve for the retaining wall excavations.

5.7.3 Consolidation settlement

Groundwater drawdown associated with de-watering excavations during construction can lead to the consolidation settlement of compressible soils due to the changes in pore pressures. The magnitude of this settlement is a function of the change in the groundwater level, depth of the compressible layer and the elasticity of the material. This assessment adopted a 1D consolidation theory approach to estimate the magnitude of consolidation settlement.

To estimate the consolidation settlement at each assessed location, the depth of the affected layer[3] was assumed to be equivalent to the estimated thickness of the Alluvium deposits within the Yarra River Valley, less the depth to the estimated pre-construction groundwater level. This assumption is considered to be conservative, given that the Alluvium deposits are not all expected to consist of soft or compressible soils.

[3] The thickness of the compressible soil layer that experiences a change in groundwater level.

5.7.4 Utility assessments

A key factor in the method of utility assessment is the relative stiffness of the utility compared with the surrounding soil. If the utility is considered to be relatively rigid, such as a reinforced concrete or vitreous clay pipe, strains would be concentrated at the pipe joints with acceptable limits being governed by tolerable rotation and 'pull-out' for the joints. For relatively flexible utilities (such as 'continuous' smaller diameter pipelines or brick lined drains) strains would develop along the length of the utility with acceptable limits being governed by the strain limits of the utility materials. For example, a perfectly flexible pipeline is defined by O'Rourke & Trautmann (1982) as one which deforms such that the strain in the pipe directly reflects the ground strains with no relative rotation at joints. Deformation in flexible pipelines is therefore concentrated in the form of bending (or flexural) strain.

Given the large number of utilities that could be subject to ground movement along the alignment, pipe relative stiffness has been used as a first pass check of risk of damage. Pipes with low relative stiffness will be assumed to behave as 'infinitely flexible' in response to ground movements, whereby the extreme fibre bending strain, ε_b, can be calculated using the following equation:

$$\varepsilon_b = \frac{external\ radius}{radius\ of\ curvature}$$

where the radius of curvature is a direct function of ground displacements. For a given radius of curvature, pipes with a smaller diameter will therefore inherently have smaller bending strains and hence a lower risk of damage. Generally, a diameter of 400 millimetres or smaller meant that the pipeline has a low enough relative stiffness to be considered as flexible and can be assumed to be at a lower risk of damage compared with other nearby larger diameter pipelines, as it will be subject to lower bending strains.

The approach for the assessment of utilities has therefore involved the assessment of pipelines greater than 400 millimetres in diameter and considered this assessment to be representative of other nearby smaller flexible pipelines. In the case where pipe material was deemed to have a high relative stiffness and the relationship between pipe diameters and bending strains cannot be directly applied, a case-specific assessment has been undertaken and allowable rotation and pull-out at the pipe joints was assessed.

5.8 Rationale

The staged assessment of settlement damage risk (after Burland et al., 1995, Mair et al., 1996 and Rankin, 1988) has been adopted here as it is a well-established approach used on major infrastructure projects in Australia and the United Kingdom. The 'Burland method' is well suited to the 'risk-based' approach required for the EES studies and provides a rigorous and transparent means of assessment.

5.9 Limitations, uncertainties and assumptions

The following limitations apply to the information in this report:

- The desktop study is based on a snapshot of conditions that existed at the time of the assessment.
- The alignment model used for the ground movement assessment was the reference project. Minor shallow excavations such as on and off ramps were not included in the ground movement assessment.

- Information obtained from Technical report N – Groundwater and Technical report O – Contamination and soil are constrained by the limitations, uncertainties and assumptions of those reports.
- Consolidation settlement calculations were undertaken using the groundwater drawdown contours for the Reference Project.
- The on-going geotechnical ground investigations means this assessment is based on a potentially incomplete or partial dataset. Nonetheless, given the geological understanding gained through the broader project investigation activities to date, our assessment of the prevailing ground conditions within the study area is considered suitable for the assessment undertaken.
- Site walkovers were completed in June 2018 and November 2018, where at-risk structures or features were inspected from the surrounding roads and public area to classify the typical types of structures that may be impacted by ground movement. The assessment required assumptions about the footing details and building geometry, as access to each property was not possible.
- Details about utility information were largely obtained from publicly available sources considered suitably accurate for this assessment. No intrusive investigations ('pot-holing') or internal inspections/surveys have been undertaken to confirm these details.
- In the case of a secondary assessment on a utility, the information provided from asset owners took precedence over publicly available sources. Where gaps in the information existed, assumptions were adopted to complete the assessments.

The opinions, conclusions and any recommendations in this report are based on information obtained from, and testing undertaken at or in connection with, specific sample points. Site conditions at other parts of the site may be different from the site conditions found at the specific sample points.

Investigations undertaken in respect of this report are constrained by the particular site conditions, such as the location of buildings, services and vegetation. As a result, not all relevant site features and conditions may have been identified in this report.

Site conditions (including the presence of hazardous substances and/or site contamination) may change after the date of this report. GHD does not accept responsibility arising from, or in connection with, any change to the site conditions. GHD is also not responsible for updating this report if the site conditions change.

5.10 Stakeholder engagement

Stakeholders and the community were consulted to support the preparation of the North East Link EES and to inform the development of the project and understanding of its potential impacts. Table 5-5 lists the specific engagement activities that have occurred in relation to ground movement, with more general engagement activities occurring at all stages of the project. Feedback received during community consultation sessions is summarised in Section 5.11.

Table 5-5 Stakeholder engagement undertaken for ground movement

Activity	When	Matters discussed	Outcome
Consultation with Melbourne Water	Ongoing	Existing condition for the Maroondah aqueduct (M80 to Northern portal element); the Yan Yean – Surrey Hills water main under Greensborough Road (Tunnels element), the Mitcham – Surrey Hills – Preston water main under the Eastern Freeway, East Yarra Main Sewer near Bulleen Road and the Koonung Creek conduit (Eastern Freeway element).	Details adequate for a preliminary assessment obtained. Various details will be assumed.
Walkover at Heide Museum of Modern Art	21 June 2018	Sculptural installations in the grounds of the Sculpture Park	Walkover complete. Details adequate for a preliminary assessment obtained.
Yarra Valley Water	Ongoing	As built condition of the Banyule Creek sewer, a 450-millimetre diameter reticulation sewer for the North Yarra Main.	Details adequate for a preliminary assessment obtained. Various details will be assumed.
Manningham City Council	28 June 2018	Sculptural installation 'Helmet'	Detailed construction drawings obtained.
Veneto Club	21 June 2018	Construction drawings detailing the portico arch structure.	Detailed construction drawings obtained.
Walkover at Simpson Barracks	20 November 2018	Visual inspection of the Simpson Barracks buildings	Confirmation of construction details relevant to the impact assessments.

5.11 Community feedback

In addition to consultation undertaken with specific stakeholders, consultation has been ongoing with the community throughout the design development and the EES process. Feedback relevant to the ground movement assessment for the EES is summarised in Table 5-6, along with where and how topics were addressed for this report.

Table 5-6 Community consultation feedback addressed by ground movement

Feedback	How it's been addressed
Concerns about damage to residential properties (including swimming pools) and other buildings located above the tunnel alignment.	The assessment of ground movement impacts has considered the potential for tunnelling and retained excavations to cause settlement and affect nearby buildings and structures, as described in Section 8 of this report. A number of EPRs have been established to minimise risk of adverse effects, including establishing a model to predict impacts (EPR GM1), completing condition surveys for potentially affected assets (EPR GM3) and establishing monitoring requirements (EPR GM2).
Concerns about damage to homes with deep foundations on Rocklea Road.	As described in Section 8 of this report, the most critical case at this location is considered to result in a 'Very Slight' damage risk category. While not requiring further detailed assessment, the following EPRs have nonetheless been proposed including establishing a model to predict impacts (EPR GM1), completing condition surveys for potentially affected assets (EPR GM3) and establishing monitoring requirements (EPR GM2). In addition, given the tunnel alignments lie to the west of the former brick quarry, it is not anticipated that any piled buildings on the former quarry site lie within the zone of influence of ground movement.
Concerns about repair of any property damage related to tunnelling during construction.	An EPR has been established to specify the requirements for repairing damage (EPR GM4).

6. Existing conditions

The existing conditions of the assets, values and uses being considered throughout this assessment are described in the following sections.

6.1 Overview

6.1.1 Geology

The geology underlying the study area is relatively complex. It encompasses a sequence of marine, alluvial, sedimentary and volcanic soils and rock laid down over a time interval of more than 400 million years. Prolonged periods of erosion have repeatedly modified the landscape.

The project alignment from the M80 Ring Road to the Eastern Freeway, and from Hoddle Street to the Ringwood bypass spans the transition between the Silurian Anderson Creek and Melbourne Formations at depth. These rocks comprise rhythmically interbedded siltstone and fine sandstone. They have been folded on a north to north-east trending axis, faulted and intruded by dykes over geological time.

The Silurian rocks have typically been weathered to a maximum of approximately 30 metre depth; however beneath the Yarra Valley erosion by the 'proto-Yarra' river has removed much of the weathered rock. In its place is a thick sequence of geologically-young Quaternary sediments including clay, sand, organic soils and gravel, immediately overlying slightly weathered to fresh rock. Nonetheless, project drilling has shown that beneath the valley sediments there are a number of potentially thick, high persistence faults comprising crushed rock, sand and clay derived from the 'parent' rock.

To the west, close to the Hoddle Street end of the Eastern Freeway works, Neogene period basalt lavas (called the 'Newer Volcanics') are encountered, such as can be seen in Merri Creek. These rocks are also encountered north of the M80 Ring Road and Greensborough Bypass intersection within the Janefield Wetlands area.

In addition, deposits of mottled grey to red-brown, very stiff to hard clay and medium dense to very dense sands and silts have been encountered to a depth of up to around 14 metres beneath the elevated areas around Manningham Road, on the east side of the Yarra Valley. These deposits are inferred to represent formerly east-west draining alluvial paleo-channels subsequently stranded by down-cutting of the proto-Yarra River. These deposits are considered to belong to the Red Bluff Sandstone member of the Neogene, Brighton Group. South of Manningham Road in the vicinity of Ilma Court in Bulleen, an infilled channel of Miocene age alluvium occurs above the tunnel crown.

A simplified geological long section is shown in Figure 6-1.

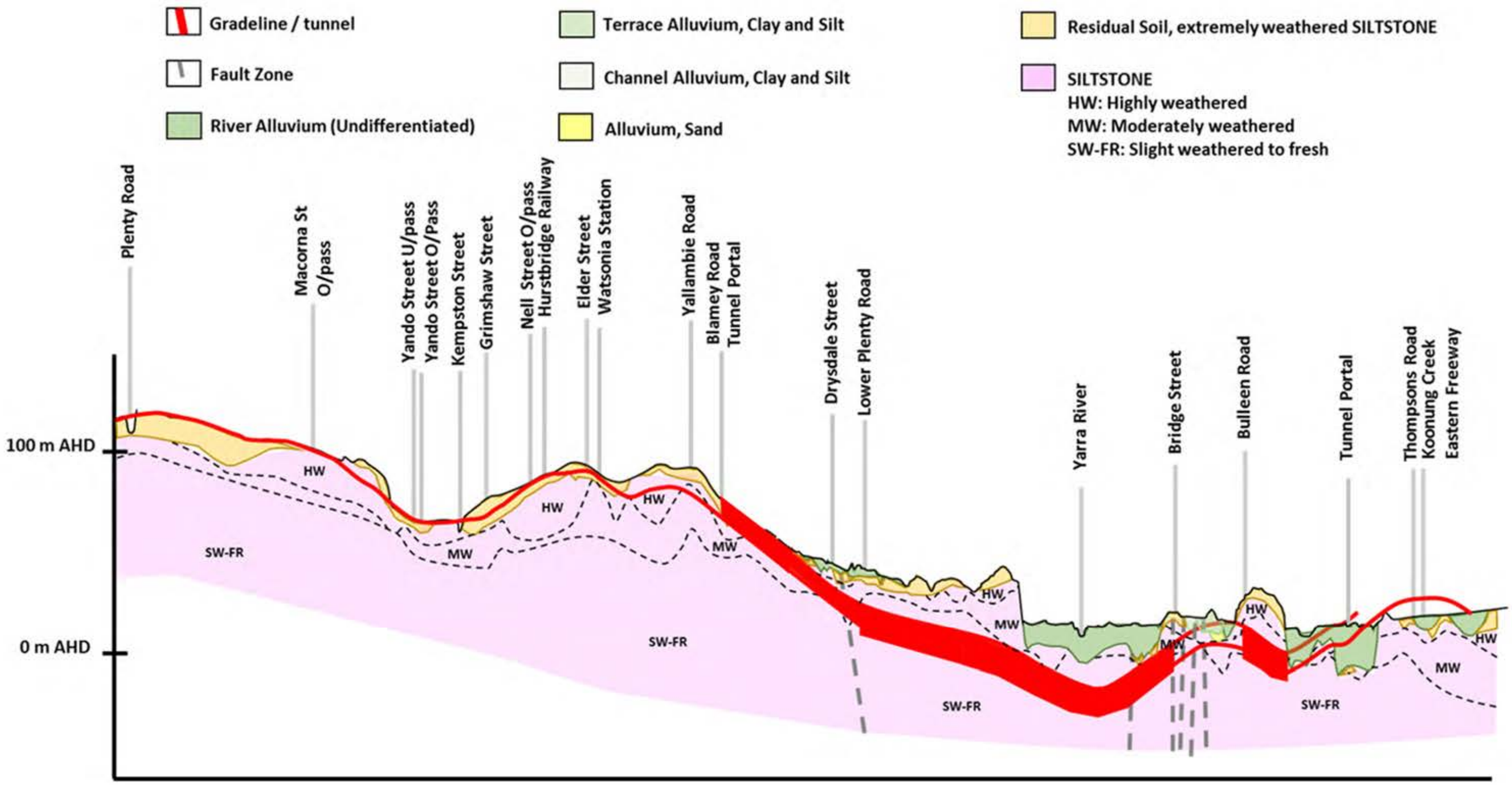


Figure 6-1 Simplified geological long section

6.1.2 Hydrogeology

A comprehensive description of the project-specific hydrogeology for the North East Link is provided in Technical report N – Groundwater. A summary is provided below.

The hydrogeology along the project alignment can be broadly categorised as an alluvial aquifer and a bedrock aquifer system. These systems are expected to be connected where alluvium overlies the bedrock, with contrasting aquifer hydraulic properties. Existing groundwater abstraction in the study area is limited. This is partly due to the urbanised setting, but low bore yields (generally <1 L/s) and saline groundwater tend to reduce abstractive potential.

The bedrock aquifer groundwater quality is saline with salinities averaging 5,700 mg/L total dissolved solids (TDS). As such, groundwater is too saline for irrigation and potable applications without treatment. While groundwater could be used for stock and industrial applications, much of the study area is within residential zoning.

The alluvial aquifer has a lower groundwater salinity of 2,658 mg/L TDS which reflects interaction with surface water and direct rainfall recharge (much of the floodplain is zoned public open space).

Water levels within the study area are variable. Shallower water levels (generally within 6 metres of the surface) are identified within the floodplains and alluvial sediments. The deeper water levels occur within the bedrock aquifer, in the topographically elevated parts of the study area, and is generally 10 metres or greater below the ground surface.

Long term groundwater level behaviour and seasonal fluctuations are not well understood due to an absence of historical data for the catchments within the study area. Ongoing monitoring is underway to better establish the level of seasonal variability. Available monitoring data indicates that seasonal fluctuations of around one metre in the bedrock aquifer may occur.

6.1.3 Historical land use

The study area is historically named Keelbundoora, an Aboriginal word translating to ‘round, brackish swamp’, which reflected the frequent flooding of the area. Evidence of Indigenous land use dating to several thousand years before European settlement has been found in the area (Banyule City Council, 2018).

Good pastures in the valleys initially attracted pastoral ‘squatters’ as early settlers of the district. By the 1850s much of the area was cleared for farmland with villages established to serve farming communities.

Discovery of gold in the early 1850s saw a substantial influx of people and while local villages grew significantly; mining activity was most prominent in Plenty Gorge, just north of the M80 Ring Road and Greensborough Bypass (Victorian Places, 2015).

Today, the area is urbanised and consists of several highly populated suburbs surrounding the Yarra Valley and Banyule Flats parklands.

6.2 M80 Ring Road to the northern portal

Items deemed to be sensitive receptors as per the existing conditions are indicated by bold text in the next Sections 6.2, 6.3 and 6.4.

6.2.1 Reach 1 – M80 Ring Road to Watsonia railway station (surface works)

General description

This reach encompasses the residential suburbs of Bundoora, Watsonia North, Watsonia and Greensborough. This section of the alignment predominantly consists of surface road works with some cuttings and above ground structures and viaducts. As the alignment approaches Watsonia railway station, the carriageways would descend in elevation into a retained cut adjacent to Nepean Street, Greensborough, until the northern portal. The M80 Ring Road and Greensborough Bypass were significant road infrastructure projects completed in the late 1990s. Existing earth embankments constructed to support these roads would continue to serve as the foundation for the proposed surface works. Changes in loads associated with the modification of the surface road may cause ground movement on underlying utilities and services.

The geology of this reach is dominated by the Silurian bedrock. The rock exhibits a deeply weathered profile, with highly weathered rock extending approximately 15 to 25 metres below surface level. The rock becomes fresh to slightly weathered at a depth of 25 to 45 metres below surface.

Some minor alluvial deposits are expected in the small creeks and beneath any superficial basalt deposits. Sub-basaltic sediments are also expected just north of the M80 Ring Road and Greensborough Bypass intersection in the Janefield Wetlands area. Though these sediments are reactive clays, the work in this reach would not cause significant changes in the water table and so ground movement due to drawdown effects is not anticipated to be significant.

The VicRoads M80 upgrade project Report No. GR153-05.04.SCI.Rev0 identified a former quarry site which was backfilled with waste fill at the M80 Ring Road and Greensborough Bypass intersection. Investigation data from geotechnical boreholes NEL-BH008 and NEL-BH098 identifies the fill as sandy clay with brick fragments, while test pit logs from the VicRoads report GR153-05 04 indicated that the fill consisted of solid inert material (glass bottles, bricks, scrap metal) at depths up to seven metres below ground level. The 1956 aerial photograph shows the former quarry site at the intersection. The time of quarry backfilling is unknown. This fill has served as the foundation for the existing road for several years and will now be compacted. It is not expected to result in any ongoing settlement induced by North East Link works provided the changes in surface load are small.

Banyule City Council Contaminated Land Register indicates that AK Lines Reserve in Watsonia was a former landfill site. Historical aerial photographs confirm that filling started in the late 1950s and ceased in the mid-1960s. The reserve is currently a sporting oval.

Potential sensitive receptors

As works in this reach consists of surface road works largely on already existing road embankments the risk of damage related to ground movement is considered to be very low. Sensitive receptors that may be adversely affected by ground movement are limited to existing road infrastructure or locations where the alignment intersects features such as utilities or waterways.

A section of the **Maroondah aqueduct** runs beneath the M80 Ring Road just west of the M80 Ring Road and Greensborough Bypass intersection. In the late 1970s, the original aqueduct was decommissioned and replaced by a 2.16-metre diameter concrete-lined steel (CLS) pipe currently used as a water supply main. Depth to the top of the pipe ranges from 1.1 to 1.4 metres. The pipeline was installed in a trenched excavation and encased in concrete. Changes to the existing M80 Ring Road embankment may affect the integrity of this utility.

6.2.2 Reach 2 – Watsonia railway station to northern portal (open cut)

General description

This reach encompasses the suburbs of Yallambie and Macleod. This section of the alignment would primarily be constructed in a retained cut reaching a maximum depth of 13 metres. The open cut section would have several viaduct structures bridging over the road.

The geological conditions expected to be encountered within this reach comprise predominantly extremely weathered to highly weathered Silurian siltstone and sandstone.

There are four 220 KV transmission towers associated with the nearby Watsonia electrical substation adjacent to Greensborough Road. Of these, two would require relocation. The other two towers are located approximately 100 metres from the North East Link alignment and are unlikely to be influenced by ground movements due to works within this reach.

Potential sensitive receptors

The retaining wall excavations would generate ground movements due to wall construction and ground relaxation as the excavation proceed.

A section of the **Hurstbridge rail line** runs longitudinal to shallow trenched excavations just north of Watsonia railway station. The rail line gets within approximately 30 metres of the trench excavation and may be subject to ground movements.

Simpson Barracks is located on the eastern side of Greensborough Road, extending from Yallambie Street through to Drysdale Street. This section of the alignment would pass through the western boundary of the Simpson Barracks land area. An L-shaped structure and an associated outbuilding within the Simpson Barracks, located near the open cut section of the alignment, would be sensitive to ground movement due to their proximity to the works. These two structures are referred to as the **Simpson Barracks buildings** in this report.

A section of the Dandenong – west Melbourne ring gas transmission main transects the proposed surface road works near Watsonia railway station. In the late 1970s, this pipeline was relocated 10 metres beneath Greensborough Road and encased in a 600-millimetre diameter steel conduit as part of an upgrade to the Hurstbridge rail line. This relocated section of this pipeline is not expected to be subject to significant ground movements related to the project's surface works.

At the eastern end of the relocated section of the gas main, the original pipeline remains at approximately 1 to 2 metres below ground surface and runs parallel to Greensborough Road. Additional surface loads due to the proposed lane widening of Greensborough Road in conjunction with ground movements associated with shallow trough excavations along the alignment may affect this pipeline. This section of the utility consists of a 450-millimetre diameter continuously-welded steel high-pressure gas transmission line, owned by APA. This utility is referred to as the **Elder Street gas main** in this report.

6.3 Northern portal to southern portal

6.3.1 Reach 3 – Northern portal to Lower Plenty Road (cut-and-cover)

General description

This reach contains approximately 1.4 kilometres of cut-and-cover tunnel, south of the northern portal, as the alignment approaches Lower Plenty Road. The depth of the cut would reach approximately 35 metres below ground level at Lower Plenty Road to facilitate TBM tunnelling further south.

Similar to Reach 2, the ground conditions expected to be encountered include extremely weathered to highly weathered siltstone and sandstone. As the cut-and-cover excavation becomes deeper to form the temporary TBM tunnel portal at Lower Plenty Road, some slightly weathered to fresh siltstone is encountered at depth as well as alluvial terrace deposits at ground surface. A steeply dipping fault zone is expected to be encountered north of Lower Plenty Road. It is anticipated the fault zone will have soil-like geotechnical properties.

In proximity to the temporary Lower Plenty Road portal, the ground movement induced by the TBM excavations would be superimposed on the ground movement caused by the retaining wall excavations. The siltstone in this area may be sensitive to larger-scale instabilities along persistent defects and bedding planes, as well as faulted rock near the portal.

VicRoads Report No. 91-01-15-01 and historic aerial photographs identified a former landfill site at Borlase Reserve, Yallambie. A 1966 aerial photograph suggests that earthworks occurred at the southern end of the reserve. From the 1972 aerial photograph, the earthworks had ceased and the area was revegetated. Investigation data from nearby geotechnical boreholes indicate fill material up to 5 metres deep, comprising sandy clay, with trace sandstone cobbles, brick and wood fragments. SPT test results from these boreholes indicate the fill material can be described as ‘very dense’. The underlying alluvium exhibits a stiff consistency.

Potential sensitive receptors

The St Martin of Tours School on Lower Plenty Road comprises a large multi storey structure including a church. The school site is approximately 200 metres from the North East Link cut-and-cover section and therefore unlikely to be influenced by significant ground movements and is ruled out of further assessment.

The following features have been identified for further assessment in this report:

- All **residential properties** that fall within the zone of influence of the cut-and-cover excavations. Those in proximity to the temporary portal may be at greater risk of ground movement (see Appendix B).
- **Strathalan** is an aged care facility that contains three heritage places subject to a council heritage overlay (Banyule Planning Scheme – HO164). A masonry house built in 1906 and the associated mature pine trees and red gum near the property entrance are of local historic and aesthetic significance. These heritage places as well as some of the Strathalan aged care housing units adjacent to Greensborough Road are likely to fall within the anticipated zone of influence and will require further assessment.
- The Yan Yean – Surrey Hills water main is a 600 to 900-millimetre diameter pipe that runs parallel to the open cut and cut-and-cover sections near Greensborough Road. The asset is owned by Melbourne Water. Pipe details were obtained from as-built drawing set M104/C/243 – 260, issued by Melbourne Water. In 2009, a section of the pipe from Yallambie Road to Drysdale Street was replaced with a 600-millimetre diameter CLS pipe as part of the M104B Morang Outlet Main Replacement Stage 6 Project.

This section of the pipe will be the most critical for this assessment as it is adjacent to the deepest sections of the cut-and-cover excavations. To the south, the length of the pipe from Drysdale Street to Station Road, the pipe was filled with grout and abandoned. Pipe segment lengths are not shown on drawings provided, so a length of 4.5 metres is assumed based on precedent. This utility is referred to as the **Greensborough Road water main** in this report. While this utility is also present in Reach 2, it would be subject to greater ground movements within Reach 3.

- The pressure reducing station located on the northern side of Drysdale Street currently lies within the excavation footprint of the reference project and would require re-location as part of any enabling works. A conceptual plan to relocate this station to the east of the reference project alignment requires that the three CSL water mains (of 375 millimetres, 600 millimetres and 1,350 millimetres diameter) currently associated with this station be re-aligned. The concept suggests the water mains be re-aligned from the Drysdale-Borlase Street intersection heading south along the western edge of Borlase Street to Lower Plenty Road, then in a south-westerly direction along the northern side of Lower Plenty Road to the intersection with Greensborough Road; then finally north along the eastern side of Greensborough Rd to re-connect with the existing mains at the Drysdale-Greensborough Rd intersection. The conceptual alignment of these three water mains is referred to as the **Lower Plenty Road Water Main** in this report.

6.3.2 Reach 4 – Lower Plenty Road to Banyule Flats (TBM)

General description

This section of the alignment consists of twin TBM tunnels excavated beneath residential areas in the suburbs of Viewbank, Rosanna and Heidelberg. The tunnels would be approximately 15.7-metres diameter, with a wall-to-wall separation of approximately 16 metres. The tunnels would be up to 42 metres below ground level. Emergency evacuation cross passages would be excavated between the twin tunnels at 120-metre intervals.

This tunnelled section is expected to be almost completely constructed through slightly weathered to fresh siltstone and sandstone bedrock interspersed with minor dykes and significant fault zones with soil-like properties.

Potential sensitive receptors

The Novitiate of the Sisters of Mercy is subject to a council heritage overlay (Banyule Planning Scheme – HO53) and is of local architectural and historical significance. It is considered a landmark in the local vicinity and contains a large multi storey masonry structure. Adjacent houses are subject to a council heritage overlay, at 206–230 Rosanna Road (Banyule Planning Scheme – HO54) and 234 Rosanna Road (Banyule Planning Scheme – HO55). These heritage places are approximately 300 metres from the North East Link alignment and so damage induced by ground movement is unlikely and these structures are not considered for further assessment. Banyule Primary School is over 100 metres from the North East Link TBM alignment, so damage induced by ground movement is unlikely and this structure is not considered for further assessment.

The sensitive receptors within this reach that will be assessed include:

- All **residential properties** overlying the TBM alignment within the zone of influence as highlighted in Appendix B.

- **Viewbank House aged care** and **Goodstart Early Learning Kindergarten** as socially and commercially-sensitive structures. These two structures are both directly overlying the North East Link TBM alignment, and will be assessed in conjunction with the residential properties in the vicinity.
- A 375 to 450-millimetre diameter vitreous clay sewer pipe runs along the Banyule Creek in proximity to the TBM tunnel alignment. No detailed construction drawings of this sewer have been acquired to date with the available information limited to that obtained from the Yarra Valley Water asset map. Constructed in 1963, a pipe length of 0.6 metres is assumed for this assessment. Pipe jointing is of spigot and socket. A section of the 450-millimetre diameter sewer runs transverse to the TBM tunnels alignment near Buckingham Drive, with a clearance of 0.5 to 1.5 metres. It is a branch of the North Yarra Main Sewer. This utility is referred to as the **Banyule Creek sewer** in this report.

6.3.3 Reach 5 – Banyule Flats to Manningham Road interchange (TBMs)

General description

In this reach the TBMs would excavate beneath the sensitive Banyule Flats, Banksia Park and the Yarra River in the suburbs of Heidelberg and Bulleen. As the alignment approaches Manningham Road, where the Manningham Road interchange would be constructed using cut-and-cover methods, the depth becomes significantly shallower. The TBMs would be driven north from a temporary portal at Banksia Street.

The TBM tunnels would primarily be excavated through slightly weathered to fresh siltstone and in some cases moderately weathered siltstone at the tunnel crown. There is a possibility the crown of the tunnel may intersect the base of the alluvial sediments in the valley as the alignment approaches Manningham Road intersection. It may thus encounter mixed face conditions comprising saturated sands, soft to stiff clays and organic materials in the upper part of the face. Combined with reduced ground cover, this presents an escalated risk of ground movement at this location.

The alluvial sediments reach a depth of approximately 15 metres within the valley. These sediments may be subject to time-dependent consolidation. A number of faults have been identified in the underlying bedrock with soil-like geotechnical properties.

Potential sensitive receptors

Arthur Hogue's house is a heritage inventory listed site (VHI H7822-0492) of archaeological significance. The North East Link TBM alignment would pass directly beneath this site. There are no remaining structural elements so the environmental effects will not be assessed in this report. The same is true for the Banyule Flats, which is of indigenous significance. The Banyule Flats is classified under **Parkland and landscapes** in this report.

The Yarra Valley Country Club consists of a club house located approximately 150 metres from the TBM alignment, outside of the anticipated zone of influence. The Yarra Valley Country Club golf course spans a large area within the Banyule Flats, and is classified under **Parkland and landscapes** in this report. The golf course contains a shed that directly overlies the proposed TBM alignment. The shed is of a flexible steel-framed structure and therefore deemed to have minimal susceptibility to ground movement, and is ruled out of further impact assessment.

The following features will be considered for assessment:

- **Banyule Homestead** is a heritage place on the Victorian Heritage Register (VHR H0926) and is also subject to a council heritage overlay (Banyule Planning Scheme – HO13), valued for its Elizabethan-style architecture and its historical significance. Built in 1846, it is a two storey structure of rendered brick on sandstone footings and a small underground wine cellar. Located on 60 Buckingham Drive, Heidelberg, it sits on top of a slope which dips steeply into the Banyule Flats (Yarra Valley).
- The tunnel alignment passes under the edge of the escarpment at the margins of the Banyule Flats with slopes of approximately 36°. This slope has been considered for land stability risks. The slope is referred to as the **Banyule Flats north slope** in this report.
- **Banyule Swamp** is a small 7 hectare pond within Banyule Flats adjacent to the TBM alignment. Ground movement induced by the nearby TBM alignment may modify embankment heights.
- **Heide Museum of Modern Art** is an art gallery and sculpture park, which contains two heritage places on the Victorian Heritage Register; Heide I (VHR H0687) and Heide II (VHR H1494). The museum is valued for its association with the notable art patrons and collectors John and Sunday Reed, who purchased the house and grounds in 1943. The TBM alignment would pass directly under a number of 'contemporary' listed artistic sculptures, such as *'Crescent House'* and *'Theoretical Matter'*.
- **'Helmet'** by Tanya Court and Cassandra Chilton (2007) is a Ned Kelly-inspired painted corten steel sculpture located in Banksia Park near Manningham Road and Bridge Street and is owned by Manningham Council. Being close to the Manningham Road interchange cut-and-cover and overlying the proposed TBM alignment, it is potentially subject to significant ground movement risk.
- **'Journeys End'** is a residence subject to a council heritage overlay (Manningham Council – HO26) and is of local architectural and historical significance. It is a timber double storey 'craftsman bungalow' located approximately 80 metres east of the TBM tunnels, in proximity to the southern TBM launch site. Cypress trees subject to a council heritage overlay (HO25) are located adjacent to Journeys End along the Bridge Road Property boundary.
- A **residential house** located on Bridge Street, which neighbours Journeys End, is located approximately 40 metres from the alignment. May be subject to further risk from the design alternative involving the excavation of two separate TBM retrieval shafts on the north side of Bridge Street within the Banksia Park area (see Section 8.5.2).
- An **HV power transmission tower** located approximately 43 metres to the west of the North East Link TBM alignment in proximity to Heide sculpture park. The tower is of a trussed steel frame construction.

6.3.4 Reach 6 – Manningham Road interchange (cut-and-cover)

General description

This reach is within the suburb of Bulleen and involves cut-and-cover tunnel construction methods, with several surface road connections that would form a large interchange box at a maximum depth of approximately 22 metres. Given the requirements for cut-and-cover and the extents of the connecting surface roads, much of the surrounding land would be acquired for the project. This land includes the large industrial and commercial area surrounding the Manningham Road intersection.

On the western boundary of the industrial area the course of the Yarra River has eroded the toe of the elevated plateau bounded approximately by the Yarra River in the west and Bulleen Road and Manningham Road in the east. The slope reaches a maximum angle of approximately 20° over a height of approximately 10 metres.

The relatively complex geology in this reach includes moderately to extremely weathered Silurian rock overlain by a layer of Pleistocene alluvial soils with significant variations in thickness across the width of the study area. Deposits of alluvium consisting of clay and silt, are inferred to represent formerly east-west draining alluvial paleo-channels (broadly beneath Manningham Road). Subsequently stranded by down-cutting of the proto-Yarra River, these deposits are inferred to belong to the Red Bluff Sandstone member of the Brighton Group.

Potential sensitive receptors

This reach is bounded to the west by the Yarra Flats, which is a heritage place subject to a council heritage overlay (Banyule Planning Scheme – HO134) and is of local and indigenous significance. The alluvial soils in this area may be subject to time-dependent consolidation resulting from the groundwater drawdown arising from the cut-and-cover excavations. The former Bulleen Drive-in is subject to a council heritage overlay (Manningham Planning Scheme – HO72) and may also require acquirement for construction. The former Bulleen Drive-in and surrounding open space is classified under **Parkland and landscapes** in this report. These areas do not contain buildings or other structures and therefore do not require further assessment for ground movement.

The potential sensitive receptors requiring further assessment identified within this reach include:

- **Banksia Street Pipe Bridge**, located approximately 330 metres west of the Manningham Road interchange on Banksia Street, is a heritage place on the Victorian Heritage Inventory (VHI H7922-0210). It connects the surface works west of the Manningham Road interchange to Banksia Street. This location may be subject to the time-dependent consolidation resulting from the groundwater drawdown required for the cut-and-cover excavations.
- A **River Red Gum** tree located on the corner of Manningham Road and Bridge Road is subject to a council heritage overlay (Manningham Planning Scheme – HO24) and is of indigenous significance. The removal of the tree is required as part of the Manningham Road interchange design, and is therefore not further assessed in this report.
- A section of the Yarra East Main Sewer runs longitudinal to the North East Link cut-and-cover alignment along Bulleen Road. It is a 1.75-metre internal diameter reinforced concrete sewer pipe owned by Melbourne Water. A section of the sewer further south on Bulleen Road would undergo relocation works before construction started (is referred to as the Bulleen Road Sewer diversion in this report). The remaining pipe that is not undergoing relocation falls within 70 metres from the cut-and-cover section. This sewer is referred to as the **Bulleen Road sewer** in this report.
- A steep slope to the west of the Manningham Road interchange has been considered for slope stability risk. This slope is referred to as the **Manningham Interchange slope** in this report.

6.3.5 Reach 7 – Avon Street to Rocklea Road (SEM tunnels)

General description

This section of the alignment is proposed to be mined through extremely to highly weathered siltstone rock at a maximum depth of cover of approximately 35 metres beneath the suburb of Bulleen. Larger caverns would have to be mined in the vicinity of Golden Way to allow for the merge of the on and off ramps. These caverns would extend for approximately 100 metres. Once the merge is completed, the mined tunnels would maintain approximate internal dimensions of 14 metres across and 12.5 metres high. Mined tunnelling also poses greater complexities compared with TBM tunnelling in terms of support and ground disturbance.
The mined tunnel construction method involves a drained primary lining, followed by a 'tanked' secondary concrete lining. This means that some groundwater drawdown would occur during construction.

An infilled channel of Miocene-Pliocene alluvium (possibly Brighton Group) occurs above the tunnel crown in the vicinity of Ilma Court. To the west of the alignment, the thickness of this alluvium is approximately 8 metres.

To the east, a former brick clay quarry centred on Yarraleen Reserve in the vicinity of Rocklea Road is now occupied by residential properties. Anecdotal evidence suggests there may be some deep pile foundations for some of the residential properties within this area. The current alignment is located centrally between the quarry and the alluvium so they are not expected to be affected by the tunnelling process. Faults and weathered dykes may also be present, which could deteriorate upon exposure.

Potential sensitive receptors

Bolin Bolin Billabong is subject to a council heritage overlay (Manningham Planning Scheme – HO30) and is a site of significance to the indigenous community. It is a culturally important site serving as a meeting place for indigenous people. Groundwater drawdown during construction may adversely affect water levels in this feature. Bolin Bolin Billabong is classified under **Parkland and Landscapes** in this report. A heritage listed Moreton Bay fig tree (Manningham Planning Scheme – HO147) is located in nearby Robb Close. There are no buildings or other structures at these sites, and so no further assessment in relation to ground movement is required.

The sensitive receptors identified within this reach include:

- **Clarendon Eyre House** is subject to a council heritage overlay (Manningham Planning Scheme – HO147) and is of local architectural significance. It is a large Italianate double storey white brick house, located approximately 180 metres from the North East Link mined tunnel alignment.
- The **residential properties** that overlie the mined tunnels. Structures in proximity to the transition between the cut-and-cover sections and mined tunnels would have greatest sensitivity.

6.3.6 Reach 8 – Rocklea Road to Bulleen Oval (cut-and-cover)

General description

This reach would comprise a cut-and-cover section that would connect the mined tunnels to Bulleen Road via a ramp. The remaining cut-and-cover section would be sufficiently shallow to give a minimal zone of influence at these locations. Groundwater drawdown caused by construction dewatering is expected to subject the local soils to consolidation settlement. The Bulleen Road sewer that runs along Bulleen Road is proposed to be diverted using pipe-jacking and trenched techniques through the Trinity Grammar playing fields.

This section of the alignment is dominated by a deep layer of alluvial sediment (nearby boreholes indicate alluvials up to 21 metres deep) comprising soft to stiff clay soils and loose to medium dense sandy soils. Significant faulting has also been encountered in the slightly weathered to fresh siltstone beneath the alluvium.

During geotechnical field investigations, uncontrolled fill (including some asbestos sheeting) was observed within Bulleen Park off Bulleen Road (NEL-BH039). Historical aerial photographs taken from 1931 to 2015 indicate landfilling operations around the location of Bulleen Park in the 1960s. A 1963 aerial photograph indicates the landfill area covered the current day football oval extending to the Yarra River in the west, the current day Veneto Club in the north and to the Bulleen Park entrance road in the south.

Potential sensitive receptors

The Templestowe Football Club clubhouse is located approximately 90 metres from the cut-and-cover trenched excavation which is at a depth of approximately 6 metres. This structure is planned to be acquired for North East Link.

The sensitive receptors identified for further assessment within this reach are therefore those that are close to the deeper sections of the trenched excavations or within the influence of the mined excavations, including:

- The **Bolin Bolin Integrated Water Facility** is a wetland storage lake adjacent to Bolin Bolin Billabong. The facility was constructed in 2017 as part of the Bolin Bolin Integrated Water Management Project. The lake is approximately 50 metres west of the cut-and-cover section on Bulleen Road.
- The **Veneto Club** is an Italian social club built in the 1960s. The building is located over 100 metres from the cut-and-cover section and is likely to be outside the anticipated zone of influence given the adjacent proposed trenched excavation is relatively shallow. However, there is a large portico archway structure at the building entrance, which may be within the anticipated zone of influence. The arch consists of three closed steel box arched sections each with large concrete plinth footings. There is a water feature next to the arch, with a lion sculpture perched atop a column at the centre. Concrete slabs near the arch and water feature show evidence of historic cracking.
- **Trinity Grammar Sporting Complex** is located to the east of the cut-and-cover excavations within this reach. This area would be subject to ground movements as a result of the Bulleen Road sewer diversion works. The reference project alignment proposes that a portion of this land would require temporary occupation, including modification of a large water storage lake within the playing fields adjacent to Bulleen Road. Considering this, and because there are no structural elements in this area, no further assessment of ground movement for the water storage is required.

Ground surface displacements along with other risks associated with sewer pipe-jacking may affect the ground surface of the playing fields. Marcellin College Sporting Complex is located to the south of Trinity Grammar Sporting Complex, further from the cut-and-cover.

6.4 Eastern Freeway

6.4.1 Reach 9 – Bulleen Oval to Eastern Freeway (surface works)

Traffic lanes would be widened along Bulleen Road from the Manningham Road intersection to the Eastern Freeway. A viaduct ramp would be constructed to elevate Bulleen Road above the cut-and-cover section. A new road would be constructed on the ground surface parallel to Bulleen Road, which would connect the cut-and-cover section to the Eastern Freeway. This new road would be constructed within Bulleen Park and Carey Grammar Sports Complex. Bulleen Swim Centre and the Boroondara Tennis Centre are located on Bulleen Road adjacent to the North East Link surface works. These structures are planned to be acquired and so will not be assessed further. The road embankments would overly surface geology comprising undifferentiated river alluvium, highly weathered siltstone and residual soils.

Two sewers exist at a location just north of the Eastern Freeway adjacent to the Bulleen Swim Centre which would connect to the relocated Yarra East Main Sewer (or Bulleen Road Sewer). A 2.25-metre diameter reinforced concrete pipe branches off toward the west beneath the Carey Grammar Sporting Complex and a 1.5-metre diameter reinforced concrete pipe branches off toward the east.

The 2.25-metre pipe, owned by Melbourne Water, would be subject to the additional loads applied from the North East Link road embankment construction above, as well as the ground movement effects induced by the shaft excavations for relocating the East Yarra Main Sewer. This sewer ranges in depth (to axis) from five to seven metres below ground surface. This sewer is referred to as the **Bullen Road west sewer** in this report.

6.4.2 Reach 10 – Eastern Freeway West (surface works)

This reach would undergo modifications to the surface road and a bus transit lane would be constructed. No substantial road widening would occur so additional surface loads are expected to be insignificant. While no sensitive receptors to ground movement have been identified, some key features within this reach are noted below. The surface works here overly undifferentiated river alluvium associated with the Yarra Valley, transitioning to basalt lavas (Newer Volcanics) such as can be seen in Merri Creek.

The alignment would pass through Yarra Bend Park, which is on the Victorian Heritage inventory (VHI H7922-0142). Historical Melway maps indicate the Camberwell municipal landfill operated from 1966 to 1977. A review of historical aerial photographs indicated the landfill occupied the area where the Musca Reserve and Freeway Public Golf Course are now located. It is likely that a section of the Eastern Freeway was built over the former landfill when it was constructed in 1977.

6.4.3 Reach 11 – Eastern Freeway East (surface works)

This reach would be subject to significant surface road works along the Eastern Freeway. The most significant road widening works would take place immediately east of where Bulleen Road meets the Eastern Freeway. Given the nature of the works within this reach, the influence of ground movement would be restricted to existing road infrastructure or any utilities beneath the widened motorway. The surface works here would span transitions between Silurian siltstone and sandstone of the Anderson Creek and Melbourne Formations, with some superficial river alluvium such as that associated with Koonung Creek.

Potential sensitive receptors

Glenfern House is an early farmhouse subject to a council heritage overlay (Manningham Planning Scheme – HO3) at 10 Amberly Court in Bulleen. GHD's internal database identified a landfill as operating for a year around 1977 at the intersection of Doncaster Road and the Eastern Freeway in Balwyn North. While no aerial photography could be obtained for 1977, an aerial photograph for 1978 shows an area where earthworks have occurred, which is inferred to be the former landfill site.

Any utilities underlying the sections where lane widening is proposed may be most sensitive to ground movement. Two major utilities have been identified as requiring further assessment:

- **Koonung Creek conduit** is a tributary of the Yarra River that would intersect the Eastern Freeway surface works within this reach several times as an underground conduit. The Bulleen Road to Doncaster Road section of the Eastern Freeway was completed in 1982 and as part of that work the Koonung Creek was diverted into a below-ground conduit structure over approximately three kilometres long. The conduit comprises a 'three-pin' reinforced concrete arch structure measuring 6.6 metres wide and 4 metres high, founded on a reinforced concrete slab. The reference project proposes the conduit is 'bridged over' at the locations where it passes beneath or near the Eastern Freeway, with a concrete slab installed above the existing conduit to protect it from the additional loads generated by road widening.
- A 1.15-metre diameter enamel-lined steel water pipeline, part of the Mitcham – Surrey Hills – Preston main, transects the Eastern Freeway near Kenneth Street in Bulleen. This asset is owned by Melbourne Water and was installed in 1957. Upgrade works at this location would consist of significant lane widening from 10 to 22 lanes. Limited construction details of this water main are available. This water main is referred to as the **Kenneth Street water main** in this report.

7. Risk assessment

A risk assessment of project activities was performed in accordance with the methodology described in Section 5.5. The risk assessment has been used as a screening tool to prioritise the impact assessments and development of EPRs. The risk pathways link project activities (causes) to their potential effects on the environmental assets, values or uses that are considered in more detail in the impact assessment. Risks were assessed for the construction and operation phases of the project.

The identified risks and associated residual risk ratings are listed in Table 7-1. The likelihood and consequence ratings determined during the risk assessment process and the adopted EPRs are presented in Appendix A. There were found to be no planned events for ground movement.

Table 7-1 Ground movement risks

Risk ID	Potential threat and effect on the environment	Residual risk rating
Risk GM01	Upgrade works to M80 pavement/subgrade cause ground movements that lead to damage to the Maroondah aqueduct.	Low
Risk GM02	Open cut and cut-and-cover excavations between Watsonia Station and Lower Plenty Road causing ground movement leading to damage to nearby residential properties, infrastructure and utilities adjacent to Greensborough Road.	Very low
Risk GM03	Construction of the northern portal (TBM) temporary retention structures causing ground movement leading to damage to adjacent residential properties (and minor utilities).	Very low
Risk GM04	Construction of the trench south of Yallambie Road causing ground movement leading to damage to buildings in Simpson Barracks.	Low
Risk GM05	TBM tunnelling between Lower Plenty Road and Banyule Flats may cause ground movement leading to damage to residential, sensitive or heritage buildings (for example Banyule Homestead, Viewbank house, Goodstart Early Learning).	Very low
Risk GM06	TBM tunnelling between Banyule Flats and Banksia Street causing ground movement leading to damage to residential, sensitive or heritage buildings (for example Banyule flats, Heide Sculpture Park).	Very low
Risk GM07	TBM tunnelling between northern edge of Banyule Flats and Banksia Street causing localised heave or settlement leading to permanent visible changes to landforms.	Very low
Risk GM09	Groundwater drawdown associated with temporary dewatering of Manningham Road Interchange excavations may cause drawdown settlement related ground movements, adversely affecting parklands and landscape areas including Bolin Bolin Billabong and Manningham Interchange Slope.	Low
Risk GM10	Groundwater 'mounding' associated with Manningham Road Interchange retention structures may cause swelling or compaction related ground movements, adversely affecting adjacent utilities, Bulleen Road, commercial and residential buildings.	Low
Risk GM11	Sequential Excavation Method (SEM) mined tunnelling beneath the area between Bulleen Road and Rocklea Road, causing ground movement leading to damage to adjacent utilities, Bulleen Rd, and residential buildings.	Low
Risk GM12	Sequential Excavation Method (SEM) mined tunnels may cause unacceptable strains on Historic Clarendon Eyre House (6 Robb Close) if variable ground conditions (deep weathering, paleo-channel deposits) are encountered.	Very low

Risk ID	Potential threat and effect on the environment	Residual risk rating
Risk GM13	Construction of the cut-and-cover/retained excavations south of Rocklea Road causing ground movement leading to damage to adjacent residential properties and minor utilities.	Low
Risk GM14	Construction of the cut-and-cover/retained excavations south of Rocklea Road causing ground movement leading to damage to the Veneto Club and the Bolin Bolin Integrated Water Facility.	Low
Risk GM16	Eastern Freeway upgrade works parallel to/and above the Koonung Creek Culvert causing ground movements leading to damage of the concrete (BEBO) arch structure in areas where it is not bridged over.	Low
Risk GM17	Trenched excavations and de-watering associated with the Bulleen Road cut-and-cover section as well as pipe jacking associated with the Bulleen Road sewer diversion works causing ground movement leading to permanent surface settlement/depressions and water ponding in playing fields.	Low
Risk GM18	Pipe-jacking for Bulleen Road sewer diversion works in shallow cover beneath Trinity Grammar Sporting Complex causing ground movement leading to localised 'sinkholes' or surface 'blowout' and damage to fields.	Low
Risk GM19	Tunnelling between Lower Plenty Road and edge of Banyule Flats may cause ground movement leading to damage to Banyule Creek sewer.	Low
Risk GM20	Tunnelling beneath Banksia Park at Banksia St portal in addition to the Manningham Road Interchange cut-and-cover excavation may cause ground movement leading to damage to 'Helmet', a sculptural installation owned by Manningham Council.	Medium
Risk GM21	Tunnelling beneath Banksia Park at Banksia St portal in addition to the cut-and-cover excavation may cause ground movement leading to damage to 'Journey's End' heritage building (and adjacent property).	Very low
Risk GM22	Upgrade works to Eastern Freeway pavement/subgrade causes ground movements that leads to damage to the 1.15 metre diameter pipeline near Kenneth Street (Kenneth Street water main).	Very low
Risk GM23	Construction of the road embankment between Bulleen Oval and the Eastern Freeway causes ground movement leading to damage to the 2.25 metre diameter North Yarra Main Branch sewers (Bullen Road west sewer).	Low
Risk GM24	Upgrade works to Greensborough Road causing ground movements that lead to damage to the Dandenong – Melbourne ring main (Elder Street gas main).	Very low
Risk GM25	Tunnelling beneath Banyule Flats may cause ground movement leading to damage to parklands and landscape areas, including the Banyule Swamp.	Low
Risk GM26	Lower Plenty Rd water mains (conceptual re-alignment) adversely affected by the TBM launch/reception in potentially faulted ground (high V_L%)	Low
Risk GM27	Excavation of TBM retrieval shafts at the southern end of the TBM tunnels adversely impacting residential properties on Bridge Street.	Low

8. Impact assessment

8.1 Overview

The assessment of risk of adverse effects on existing surface and below ground structures has been informed by a desktop review of the existing geology and potentially affected structures (Section 6) and an appreciation of the construction methods expected to build the reference project (Section 3.3). The staged approach to the assessment of ground movement risk is described briefly in Section 5.6. As mentioned in Section 3.4, minor ground movement effects associated with the operation of North East Link are anticipated as a result of ground water mounding to the east of the Manningham Road Interchange.

The structures (or groups of structures) or assets listed below were identified from the existing conditions desktop study as being of potential interest for the ground movement assessment. An overview map of their locations with respect to the reference project is presented in Appendix B, with more detailed maps in Appendix E. Structures identified for acquisition are not considered. While a number of the structures lie outside the zone of influence of ground movement for the reference project alignment, the potential for alignment changes by the contractor may require re-consideration of these sensitive structures under EPR GM1 and any potential impacts managed under EPRs GM2-4:

8.1.1 Reach 1

- **Maroondah aqueduct** – a 2.16-metre diameter CLS water supply pipeline passing beneath the M80 Ring Road near Chappell Drive in Greensborough would be subject to differential vertical loads induced by the surface road works in this location (risk GM01).

8.1.2 Reach 2

- **Hurstbridge rail line** – a section of railway track runs longitudinal to shallow trough excavations just north of Watsonia railway station, coming within 30 metres of the reference project alignment (risk GM02).
- **Elder Street gas main** – a 0.45 metre welded steel high pressure gas transmission pipeline running longitudinal to the shallow trough excavation along Greensborough Road (risk GM24).
- **Simpson Barracks buildings** – an L-shaped building and associated outbuilding located at the corner of Yallambie Road and Greensborough Road (risk GM04).

8.1.3 Reach 3

- **Greensborough Road water main** – a 0.6 metre diameter water main beneath the Greensborough Road on the west side of the proposed cut-and-cover tunnel/trench north of Lower Plenty Road (risk GM02).
- **Strathalan** aged care facilities – contains three heritage overlay listed features and several aged care units on Greensborough Road (risk GM03).
- **Residential properties** – in proximity to the cut-and-cover excavations and the northern portal (on Greensborough Road and Borlase Street) largely comprise one and two-storey brick veneer housing (risk GM02 and risk GM03).
- **Lower Plenty Road water main** – conceptual alignment of three CLS water mains (with diameters of 375 millimetres, 600 millimetres and 1,350 millimetres running parallel and transecting the reference project alignment at Lower Plenty Road (risk GM26).

8.1.4 Reach 4

- **Residential properties, kindergarten and aged care facility** – largely comprise one and two-storey brick clad and weatherboard structures lying directly over the TBM tunnel alignment, south of Lower Plenty Road on the west side of the Banyule Creek Reserve, Rosanna/Viewbank (risk GM05).
- **Banyule Creek sewer** – a 0.45 metre diameter vitreous clay bell-and-spigot sewer at shallow depth, passing above the proposed TBM tunnels in the Banyule Flats (risk GM19).

8.1.5 Reach 5

- **Banyule Homestead** – a multi-storey masonry structure on the Victorian Heritage Register built in 1846 in the Elizabethan Gothic Revival style (risk GM05).
- **Banyule Flats north slope** – an east facing steep slope dipping at an angle of 26° to 36° toward the Banyule Flats, overlying the TBM tunnels and near Banyule Homestead (risk GM25).
- **Banyule Swamp** – this approximately 7-hectare swamp lies in the Yarra floodplain opposite the Banyule Homestead. An outfall structure located on the western bank regulates the water level and may be subject to settlement that would modify the outfall flow regime (risk GM25).
- **Heide sculpture park** – much of the sculpture park directly overlies the proposed TBM alignment. There are a small number of sculptural installations (such as 'Crescent House' and 'Theoretical Matter') deemed to be at higher sensitivity to ground movement due to their proximity to the alignment (risk GM06).
- **Transmission tower** –A transmission towers located near the Heide sculpture park is anticipated to be tolerant to the relatively small differential ground movements due to tunnelling settlement anticipated at their location (risk GM06).
- **'Helmet'** – constructed in Banksia Park in 2007, this installation is owned by Manningham Council and lies close to and above the TBM tunnels at the intersection of Manningham Road and Bridge Street, Bulleen. The structure is built on a concrete slab, with steel I-section beams supporting painted steel panelling (risk GM20).
- **Journey's End** – a heritage overlay double storey timber-framed residential structure (including a row of mature cypress trees) is located at 22–40 Bridge Street, Bulleen (risk GM21).
- **Bridge Street Residential** – Residential property located on Bridge Street Bulleen adjacent to Banksia Park (risk GM21 and risk GM27).

8.1.6 Reach 6

- **River red gum** – a mature river red gum tree (*Eucalyptus camaldulensis*) is situated near the corner of Bridge Street and Manningham Road, Bulleen. Removal of the tree is required for the Manningham Road interchange. No further ground movement assessment has been undertaken.
- **Bulleen Road sewer** – comprising a 1.75-metre diameter reinforced concrete sewer, this Yarra Valley Water asset lies outside the immediate ground movement zone of influence.

- **Banksia Street Pipe Bridge** – located adjacent to the Manningham Road Bridge (constructed over the Yarra River in the 1960s), the Banksia Street Pipe Bridge was built in 1891 as part of a secondary water distribution system for the Yan Yean water supply system. Known as a ‘Warren Truss’ structure, it is founded on brick and wrought iron piers with riveted joints and supports a 32-inch wrought iron water main (risk GM09).
- **Manningham interchange slope** – lies approximately 35 metres west of the closest cut-and-cover structure, with a maximum west facing slope angle of approximately 20° (risk GM09).

8.1.7 Reach 7

- **Residential properties** – located in St Andrews Crescent, Golden Way, Claremont Avenue, Rocklea Road and Killara Mews (Bulleen), these structures comprise one to two-storey brick clad and weatherboard houses (risks GM09, GM11 and GM13).
- **Clarendon Eyre** House and the nearby **Moreton Bay fig tree** – located in Robb Close in Bulleen. The house comprises a two to three-story masonry structure in an ‘Italianate’ architectural style, adjacent to a single storey building which may be an earlier cottage (risk GM12).

8.1.8 Reach 8

- **Trinity Grammar Sporting Complex** – located to the east of Bulleen Road, the sporting complex may be subject to the effects of ground movement from North East Link cut-and-cover works as well as the Bulleen Road sewer diversion works. While there are no structural elements to this site, the formation of settlement troughs at the ground surface may compromise drainage of the playing fields in extreme weather. Marcelin College Sporting Complex is assessed in conjunction (risk GM17 and risk GM18).
- The **Bolin Bolin Integrated Water Facility** – in 2017, Manningham Council commissioned a 1.5 ML combined wetland and storage lake adjacent to the Bolin Bolin Billabong, in conjunction with storage tanks within Bulleen Park and a secondary 3.33 ML (minimum) storage within the Freeway Public Golf Course, connected by a distribution pipeline (risk GM14).
- **Veneto Club** – located at 191 Bulleen Road, this structure comprises a 1970s three-storey reinforced concrete framed structure in a ‘brutalist’ architectural style. Proposed land acquisition for North East Link results in the removal of most of the existing front wall (concrete pillars with metal railings) as well as the ornamental reinforced concrete arched entrance gates. A portico arch and column out the front of the building are of higher sensitivity (risk GM14).

8.1.9 Reach 9

- **Bulleen Road west sewer** – Branches off from the East Yarra Main Sewer at a location adjacent to the Bulleen Swim Centre on Bulleen Road. It is a 2.25-metre diameter reinforced concrete sewer installed in 1966 (risk GM23).

8.1.10 Reach 11

- **Koonung Creek culvert** – the Eastern Freeway from Bulleen Road to Doncaster Road was completed in 1982. As part of this work Koonung Creek was diverted into a below ground conduit structure, approximately three kilometres in length. The conduit comprises a ‘three-pin’ reinforced concrete (BEBO) arch structure measuring 6.6 metres wide and 4 metres high, and is founded on a reinforced concrete slab (risk GM16).

- **Kenneth Street water main** – a section of the Mitcham – Surrey Hills – Preston water main transects the Eastern Freeway near Kenneth Street, Bulleen. It is a 1.15-metre diameter steel enamel lined water main owned by Melbourne Water. The surface works at this location would consist of significant lane widening, which would create additional loads on the pipeline (risk GM22).

8.1.11 Project wide

- **Parklands and landscapes** – includes the wider Banyule Flats area, Yarra Valley Country Club, Yarra Flats and Bolin Bolin Billabong. These features have no structural elements present so no impact assessment can be undertaken. Appendix B2 and Appendix B3 shows the settlement contours at these locations to give an indication of the magnitude of settlement expected within these areas (risk GM07 and risk GM09).

The above mentioned sensitive receptors were subject to a Preliminary Assessment (Section 8.2) and where necessary a Second Stage Assessment (Section 8.3) and a Detailed Assessment (Section 8.4). A detailed description of the risk assessment for each of these locations that are identified as requiring consideration is described in Appendix A. A series of EPRs (EPRs GM1, GM2, GM3 and GM4) have been defined as summarised in Table 9-1 and allocated to the sensitive receptors. The EPRs apply constraints to the contractor so that structures at risk of adverse effects due to ground movement are adequately assessed and, where necessary, appropriate mitigation measures are implemented to keep risks at acceptable levels.

It is recommended that for residential properties subject to a preliminary assessment (that is, within the zone of influence as described in Section 8.2) the following EPR is applied by default:

- EPR GM3 – **Condition surveys (property and infrastructure)**

8.2 Preliminary assessments

8.2.1 Reach 1

Given the nature of the construction works within this reach, the ground movement zone of influence is minimal and sensitive receptors were restricted to underlying sensitive utilities subject to changes in surface loads. This comprises the Maroondah aqueduct and the Dandenong – West Melbourne ring main.

The surface works at the location of the Maroondah aqueduct consist of road widening from 6 to 19 lanes. During construction of the M80 Ring Road in 1992, allowance was made for the construction of future carriageways by constructing road embankments on either side of the M80 Ring Road. Lane widening for North East Link would modify these embankments, and therefore the additional loading applied to the underlying Maroondah aqueduct is minimised.

The deflection under these loads were modelled in industry standard software '*Settle3D'*. Geological and geotechnical information was obtained from the nearest North East Link site investigation borehole (NEL-BH115). The model consisted of sections of unloading and sections of loading on the Maroondah aqueduct, depending on whether the existing road embankments were being removed or extended to meet the design requirements of North East Link.

Preliminary calculations indicate the maximum ground displacement from the road widening would be approximately 16 millimetres, with an associated ground slope of 1:824. According to Rankin (1988) this places the aqueduct into the 'Slight' risk category thus a second stage assessment was conducted as discussed in Section 8.3.1.

8.2.2 Reach 2

Appendix B1 shows the ground movement zone of influence for Reach 2, as defined by a five-millimetre vertical displacement (settlement) contour. The zone of influence reaches a maximum of 20 metres from the North East Link alignment.

The Hurstbridge rail line falls outside the zone of influence therefore does not require further assessment.

Preliminary assessment of the **Simpson Barracks buildings** indicates that the L-shaped main building would be subjected to an estimated two millimetres of settlement with a negligible ground slope, placing it in the 'Negligible' risk category (Rankin, 1988). The outbuilding sited much closer to the open trench excavation would experience an estimated maximum settlement of approximately 19 millimetres, with an associated maximum ground slope of 1:400, placing it in the 'Slight' risk category. Due to the possible sensitivity of these buildings, a second stage assessment was conducted as discussed in Section 8.3.3.

The Elder Street gas main runs beneath the proposed lane widening along Greensborough Road in a longitudinal direction. The gas main would also be subject to horizontal and vertical ground movements from the shallow trough excavation on Greensborough Road. It is a welded steel 450-millimetre diameter high-pressure gas pipeline approximately two metres below ground surface. Geological and geotechnical information obtained from nearby boreholes NEL-BH007 and NEL-BH191 indicate the gas pipeline is within stiff sandy clay, underlain by highly weathered siltstone around 2.5 metres below ground surface.

Ground movements from the lane widening at the location of the Elder Street gas main were modelled in industry standard 'finite element' software *RS2*. The ground movements induced by the nearby 4 metre deep trough excavation along Greensborough Road were calculated using Xdisp and superimposed on the lane widening induced settlement, giving rise to a maximum settlement of 18 millimetres and a ground slope of 1:998. Given the sensitive nature of this utility, a second stage assessment was conducted as discussed in Section 8.3.2.

8.2.3 Reach 3

Appendix B1 shows the ground movement zone of influence for Reach 3, as defined by a five-millimetre vertical displacement (settlement) contour. The zone of influence ranges from 10 to 45 metres from the cut-and-cover excavation wall. The largest zone of influence is seen close to the northern portal, where the ground movement induced by the TBM tunnels is superimposed on the ground movement induced by the retaining wall excavations.

The Strathalan heritage places lie outside the zone of influence so no further assessment of these structures is necessary. No residential properties fall within zone of influence for this reach.

The Greensborough Road water main comprises a 0.6-metre internal diameter CLS water main, located beneath the Greensborough Road on the west side of the proposed cut-and-cover tunnel/trench north of Lower Plenty Road. A staged excavation sequence was modelled so that the critical scenarios affecting this utility could be assessed. 'Stage 1' modelled the critical strains and curvature experienced by the pipe by placing the advancing face 45 metres from the end of the pipe. 'Stage 2' modelled the maximum horizontal and vertical settlement after completion of the entire length of the cut-and-cover.

It was assumed that the pipeline follows the 'greenfield' settlement profile in a flexible manner and that welding of the pipe sections has resulted in an effectively 'continuous' pipeline. No beneficial effects of the inner concrete lining nor the backfill surrounding the pipeline are considered.

A maximum vertical displacement of seven millimetres with a negligible ground slope was estimated, indicating that a second stage assessment is not necessary.

The proposed trenching and TBM tunnel portal works are expected to require the exhumation and reinstatement of the Lower Plenty Road water main A conceptual design for the re-alignment of this utility comprises three individual CLS pipes of diameters ranging from 375 to 1.35 metres. Following the methodology described in Section 5.7.4, the largest diameter pipe of 1.35 metres represents the most critical pipe of the three. For the purposes of the assessment, the largest diameter pipe is therefore taken to represent the most vulnerable utility of this conceptual re-alignment.

Preliminary assessment results indicate that the 1.35 metre diameter pipeline may be subject to a maximum of 76 millimetres of settlement and a maximum ground slope of 1:480, indicating that a second stage assessment is required. However, given the re-alignment is at the conceptual stage of design, details necessary for a second stage assessment are not available. It is recommended the following EPRs are assigned to these utilities in lieu of a second stage assessment:

- EPR GM1 – **Geotechnical model and assessment**
- EPR GM2 – **Ground Movement Plan**
- EPR GM4 – **Properties and assets impacted by ground movement and settlement.**

8.2.4 Reach 4

Appendix B2 shows the ground movement zone of influence for Reach 4, as defined by the five millimetre settlement contour line. The zone of influence is typically 25 metres from the tunnel alignment centreline in this area.

Residential houses within the zone of influence have been grouped as follows to simplify the damage assessment approach:

- LP2: Lower Plenty Road 2 – residential houses in proximity to the Lower Plenty Road portal cut-and-cover and TBM tunnel interface
- BC1: Banyule Creek 1 – group 1 of residential houses overlying the TBM alignment, including the Viewbank aged care facility
- BC2: Banyule Creek 2 – group 2 of residential houses overlying the TBM alignment, including a kindergarten.

The preliminary assessment results presented for the above groups of residential houses represent the maximum settlement and ground slope calculated for the entire structure grouping.

Table 8-1 summarises the outcome of the preliminary assessment for Reach 4. This indicates that residential structures in areas LP2, BC1 and BC2 within the 10-millimetre settlement contour, (Section 8.3.4) and the vitreous clay Banyule Creek sewer (Section 8.3.5), require a second stage assessment. Structures excluded from further assessment include residential structures outside the 10-millimetre contour.

Table 8-1 Reach 4 preliminary assessment summary

Name	Preliminary assessment		Second stage assessment required?
BC1/BC2 (Banyule Creek) residential	Settlement	12 mm	Yes
	Ground slope	1:3800	
	Rankin risk category	2 – *Slight*	
LP2 residential	Settlement	51 mm	Yes
	Ground slope	1:385	
	Rankin risk category	3 – *Moderate*	
Banyule Creek sewer	Max. vertical displacement	36 mm	Yes
	Max. slope	1:1016	
	Rankin risk category	2 – *Slight*	

8.2.5 Reach 5

Appendix B2 shows the ground movement zone of influence for Reach 5, as defined by the five-millimetre contour line. The zone of influence is typically 38 metres from the tunnel centreline.

The heritage structures Banyule Homestead and Journey's End fall outside the zone of influence and have estimated settlements of less than one millimetre so no further assessment has been undertaken for these structures. The residential house neighbouring Journey's End also falls outside the zone of influence, however it has been considered for assessment as part of the design alternative involving the excavation of two separate TBM retrieval shafts on the north side of Bridge Street within the Banksia Park area (Section 8.5.2)

Preliminary geological mapping of the Silurian rock outcropping at the base of the Banyule Flats north slope (below Banyule Homestead) measured in-situ bedding dipping into the slope at approximately 65°, with planar jointing approximately orthogonal to the bedding (dipping out of the slope) forming a blocky rock mass. Figure 8-1 shows a photograph of bedrock exposures below Banyule Homestead. There is evidence the current slope angle is controlled by the observed jointing, which has formed blocks that have dislodged over geological time. The observed slope face angle of 26° to 36° closely matches the jointing that dips out of the face at approximately 25° to 30°.

Preliminary FEA modelling in *RS2* suggests the strains caused by the TBM drives beneath this slope would have minimal impact on stability. On the basis of the field observations and preliminary modelling, the risk of the proposed project works leading to slope instability is considered negligible and so will not be further assessed.

Figure 8-1 Bedrock exposure below Banyule Homestead (looking south), outcrop is approximately 1.5 metres in height

Heide sculptures were identified to fall within the zone of influence. These include:

- 'Theoretical matter' – Neil Taylor (1999): a welded reinforcing steel geometric structure founded on a 100-millimetre thick reinforced concrete slab\
- 'Crescent House' – Andrew Burns (2013): a curved one-storey timber structure founded on piers/pads
- 'Nereus' – Erwin Fabian (2003): a welded steel structure founded on a 250-millimetre thick reinforced concrete pad
- 'Basket and Wave' – Dennis Oppenheim (1984): powder coated tubular steel geometric structures, founded on two separate concrete pads
- 'Scales' – Peter Rosman (1987): concrete box and pipe structures founded on separate pad footings.

Observations made during a Heide sculpture park site walkover on 21 June 2018 concluded the sculptures 'Nereus', 'Basket and Wave' and 'Scales' are of low sensitivity due to their observed structural form. 'Theoretical Matter' and 'Crescent House', were however considered appropriate for a second stage assessment.

For 'Helmet', the estimated settlement and ground slopes suggest there is a significant risk of damage to the structure.

A small industrial shed associated with the Yarra Valley Country Club has been ruled out of the impact assessment given its structure was deemed to have minimal susceptibility to ground movement and is of low architectural or community value. Other non-structural sensitive receptors, such as the surrounding landscape and the Banyule Flats have been ruled out of further assessment.

The south-western corner of the Banyule Swamp pond lies immediately east of the proposed tunnel alignment. The south western bank and associated outfall structure that regulate the water level may experience settlement (risk GM25). Given the shallow depth of the pond, relatively small changes in the embankment height may change its water level.

Considering the sensitivity of the Banyule Swamp water level and the potential for modification as a result of ground movement, the following EPRs are recommended:

- EPR GM1 – **Geotechnical model and assessment**
- EPR GM2 – **Ground Movement Plan**
- EPR GM3 – **Condition surveys (property and infrastructure)**
- EPR GM4 – **Properties and assets impacted by ground movement and settlement.**

A high voltage transmission tower is located close to the reference project alignment as noted in Section 6.3.3. However, it is outside of the five millimetre settlement limit zone of influence and therefore not anticipated to be subject to adverse settlement effects.

Table 8-2 summarises the outcome of the preliminary assessment in Reach 5. This indicates that a second level assessment is required for 'Theoretical Matter', 'Crescent House' and 'Helmet' (see Sections 8.3.6 and 8.3.7).

Table 8-2 Reach 5 preliminary assessment summary

Name	Preliminary assessment		Second stage assessment required?
'Theoretical Matter'	Settlement	24 mm	Yes
	Ground slope	<1:10000	
	Rankin risk category	2 – *Slight*	
'Crescent House'	Settlement	18 mm	Yes
	Ground slope	1:1000	
	Rankin risk category	2 – *Slight*	
'Helmet'	Max settlement	93 mm	Yes
	Max slope	1:541	
	Rankin risk category	4 – *High*	
Banyule Swamp (south western bank)	Max settlement	35 mm	No, Rankin categories not applicable
HV transmission tower	Settlement	1 mm	No
	Ground slope	<1:10000	
	Rankin risk category	1 – *Negligible*	

8.2.6 Reach 6

Appendix B3 shows the ground movement zone of influence for Reach 6, as defined by the five-millimetre settlement contour line reflecting ground movements associated with tunnel volume loss, the installation and excavation of the cut-and-cover structures and consolidation settlement due to temporary construction groundwater drawdown.

The **Manningham Interchange slope** identified at the edge of the Yarra River lies approximately 35 metres west of the closest cut-and-cover structure. Analysis of the available LIDAR survey data suggests a maximum slope angle of approximately 20°, with a height of approximately 10 metres. Geotechnical investigations immediately south of the area in question suggest the in-situ ground conditions may comprise highly weathered to moderately weathered siltstone overlain by approximately 6 to 7 metres of alluvium. Preliminary slope stability analysis suggests the factor of safety of the slope is high. Considering the distance of the reference project excavation from the crest of the slope, no further assessment is warranted as the risk of excavation induced instability within this slope is considered negligible.

The heritage Banksia Street Pipe Bridge structure lies outside the zone of influence of the cut-and-cover excavations and so requires no further assessment.

Groundwater 'mounding' associated with Manningham Interchange retention structures is estimated to increase the local water table by up to 6 metres to the east of the structure (refer to Technical report N – Groundwater). As described in Section 6.3.4, the ground conditions to the east of the interchange are inferred to comprise ferruginised Pliocene to Miocene clay alluvium associated with ancient paleo-channel and river terrace deposits. Preliminary calculations suggest that some widespread ground heave is possible due to swelling of the clay alluvium at depth, however the movement is estimated to occur over a period spanning decades. Given the widespread nature of the movement, it is anticipated that the ground damage risks will be low.

Nonetheless, the following EPR is recommended to monitor condition and control impacts associated with groundwater mounding effects to the east of the Manningham Road interchange.

- EPR GM1 – **Geotechnical model and assessment**

8.2.7 Reach 7

Appendix B3 shows the ground movement influence zone for Reach 7, as defined by the five-millimetre settlement contour line. The zone of influence is generally around 25 metres from the tunnel centreline.

The identified sensitive receptors Clarendon Eyre House and the Moreton Bay fig tree lie outside the zone of influence and so no further assessment is necessary.

The residential houses near Bulleen Road within the zone of influence will be assessed collectively as 'BR residential'. The settlement and ground slope of a selected structure that represents the worst case was assessed to determine if a second stage assessment is required for any or all of the houses within that group. The maximum settlement experienced by the selected structure is 26 millimetres, with a ground slope of 1/1207. This places this group of residential structures in the Rankin (1988) risk category 2 – *Slight,* indicating that a second stage assessment is required (Section 8.3.4).

Sensitive receptors included in the Stage 1 assessment that have subsequently been excluded from Stage 2 assessment are the residential properties that fall within the five-millimetre settlement contour but outside the 10-millimetre contour, along with Clarendon Eyre House and the Moreton Bay fig tree.

8.2.8 Reach 8

Appendix B3 shows the ground movement influence zone for Reach 8, as defined by the five millimetre contour line reflecting ground movements associated with tunnel volume loss, the excavation of the cut-and-cover structure and consolidation settlement due to temporary construction groundwater drawdown. The zone of influence is generally around 80 metres from the alignment centreline. The influence of the Bulleen Road sewer diversion works increases the zone of influence up to approximately 110 metres from the alignment centreline.

The Bulleen Road sewer realignment would cause ground movement affecting the playing fields of Trinity Grammar Sporting Complex and Marcellin College Sporting Complex. The proposed diverted sewer alignment generally avoids significant impact on the playing fields, with the shaft excavations located outside of the playing fields designated perimeter. The pipe-jack alignment does pass directly underneath two cricket pitches however, subjecting the ground surface to a maximum settlement of approximately 8 mm. Though there is potential for ground slopes to form at the playing fields surface, these are not expected to be noticeable or to affect the use of either of the sporting complexes. For example, the critical slope identified in the area is formed by a change in surface elevation of approximately 10 mm over 10 metres (a slope of 1:1000) in an isolated area located on the boundary of Trinity Grammar Sporting Complex. No further assessment of the playing fields will therefore be conducted.

The Bolin Bolin integrated water facility is estimated to experience settlement in the region of five millimetres or less, which is not expected to compromise the facility. Appendix B3 shows the settlement contours at this location.

Veneto Club and the Bolin Bolin integrated water facility would be subject to ground movement induced by the cut-and-cover excavation near Bulleen Road. The preliminary assessment results for these receptors are presented in Table 8-3.

Table 8-3 Reach 8 preliminary assessment summary

Name	Preliminary assessment		Second stage assessment required?
Bolin Bolin integrated water facility	Settlement	5 mm	No
	Ground slope	1:3700	
	Rankin risk category	1 – *Negligible*	
Veneto Club	Settlement	6 mm	Yes, due to communal value
	Ground slope	1:3200	
	Rankin risk category	1 – *Negligible*	

8.2.9 Reach 9

The nature of construction works within this reach consists of surface road works comprising road embankment and road viaduct construction. Potentially sensitive receptors therefore included underlying utilities subject to additional surface loads, such as the Bulleen Road west sewer, a 2.25-metre diameter reinforced concrete pipe owned by Melbourne Water, which would be subject to ground movement induced by an increase in surface loads and a shaft excavation required for the relocation of the East Yarra Main Sewer.

The change in surface loads induced by the North East Link road embankments at this location was modelled using the 2D FEA analysis software *RS2*, and the resulting displacement profile at the depth of the pipe was assessed. This was superimposed on the shaft excavation settlement and the combined ground movement was assessed. Ground conditions in the vicinity of the pipe comprise clayey silt of low plasticity and sand to depths of greater than nine metres.

Preliminary calculations indicate that the maximum ground displacement due to the surface loading is in the order of 27 millimetres, with an associated maximum ground slope of around 1:560. This is within the limits proposed by O'Rourke and Trautmann (1982), who suggest a limiting 1:140 ground slope for relatively rigid pipelines. However, according to Rankin (1988), the high magnitude of settlement here places the pipeline into a *'Slight'* risk category. As a result, this asset will require a second stage assessment (Section 8.3.10).

8.2.10 Reach 10

No sensitive receptors were identified within this reach.

8.2.11 Reach 11

The nature of construction works within this reach is primarily lane widening. Therefore the ground movement zone of influence is minimal and sensitive receptors were restricted to underlying sensitive utilities subject to additional surface loads.

The Kenneth Street water main is a 1.1-metre diameter steel enamel-lined pipe owned by Melbourne Water that transects the Eastern Freeway in the vicinity of Kenneth Street, Bulleen. The geology at this location comprises clay alluvium up to 18 metres deep. While construction drawings of this pipe have not been examined, a ground cover of 3.2 metres over the pipe obvert has been determined from information obtained from Melbourne Water.

A preliminary assessment of the additional surface loads induced by lane widening at this location were modelled in *RS2* and the resulting displacement profile at the depth of the pipe was assessed. Preliminary calculations indicate that the maximum ground displacement is in the order of seven millimetres, with an associated maximum ground slope of 1:2400. According to Rankin (1988), this places the pipeline into the 'Negligible' risk category, so this asset will not be subject to further assessment. This ground slope is also well within the limits proposed by O'Rourke and Trautmann (1982).

The Koonung Creek conduit comprises a 'three-pin' reinforced concrete (BEBO) arch structure measuring 6.6 metres wide by 4 metres high, founded on a reinforced concrete slab. The reference project proposes the conduit is 'built over' where it passes underneath the Eastern Freeway. Under this scenario, a concrete slab would be installed above the existing conduit to protect it from the additional loads from road widening. No further assessment has thus been undertaken for this structure.

8.3 Second stage assessments

8.3.1 Maroondah aqueduct

This assessment has considered the potential for the M80 Ring Road pavement/subgrade upgrade works at Greensborough to cause ground movement damage to the Maroondah aqueduct (risk GM01).

Comprising a 2.16-metre internal diameter CLS steel pipeline, this utility passes beneath the M80 Ring Road near Chappell Drive, Greensborough. The proposed modifications to the existing M80 Ring Road are expected to subject sections of the pipeline to both loading and unloading. Because the pipeline was re-constructed in the 1970s and the M80 Ring Road was constructed in the 1990s, the cumulative ground movements induced by the original freeway works along with the proposed North East Link works will be considered as a conservative measure.

The second stage assessment estimated the magnitude of the changes in vertical displacement, based on an estimate of the modulus of the ground beneath the new structures as well as the dissipation of stress change with depth. The ground conditions are assumed to comprise thin (< three metres) residual soils formed on highly weathered Silurian siltstone (Melbourne Formation) based on nearby borehole NEL-BH115. A conservative value of Youngs Modulus of 100 MPa has been assumed for the ground around the aqueduct.

The implied curvatures in the pipeline due to vertical variation in stress were then used as the basis for this assessment. No horizontal ground strains were considered given the predominantly vertical nature of ground loading and displacement.

The degree of interaction between the ground movements and the pipeline was assessed by considering the relative stiffness of the pipeline. For the CLS pipeline the typical construction requires double welding of the joints between pipes; as such it can be assumed to be continuous. The flexural rigidity of the pipe can thus be estimated from the Youngs Modulus for mild steel, the pipe wall thickness and the diameter of the pipe. When compared with the modulus of the ground and the estimated ground heave/settlement curves, the CLS pipeline is considered to be 'relatively flexible'.

For the calculation of longitudinal curvature and pipe strains, any beneficial stiffening effect of the concrete backfill around the pipeline, or the cement lining inside the pipeline, was ignored. In the areas where a reduction in ground loading occurs, the pipeline can be expected to 'hog' (arch upwards) with the result that tensile strains would reach a maximum in the obvert of the pipe. Conversely, increases in load would result in 'sagging' (downward curvature) and tensile strains concentrating in the pipe invert. Compressive strains in the opposite locations in each case (potentially leading to 'buckling') are assumed to be very small and non-critical.

The results of this analysis are summarised in Appendix C1. Typical elastic strain limits for mild steel would be of the order of 450 to 660 micro-strain (με). In bending, the pipe strain can be calculated directly from the radius of the pipe and the radius of curvature. The tightest radius of curvature caused by the cumulative effects of the M80 works is of the order of 5.4 kilometres, with an associated bending strain of 197 με. Based on an acceptable strain in the steel of no more than 400 με, an allowable radius of curvature would be of the order of 2.65 kilometres. This indicates that the pipeline would not be subject to strains in excess of those within the capacity of the pipe, assuming it is in good condition.

For the potential transverse distortion of the pipeline ('squat') it is considered reasonable to include the beneficial effects of the lightly reinforced concrete backfill around the pipeline. By inspection, the potential for unacceptable distortion of the pipe is thus considered negligible.

No further assessment for this utility is considered necessary for the purposes of the EES. However the following EPRs are recommended to monitor condition and control impacts based on the final design (see Table 9-1):

- EPR GM1 – **Geotechnical model and assessment**
- EPR GM2 – **Ground Movement Plan.**

8.3.2 Elder Street gas main

This assessment has considered the potential for the construction of the trenched excavation in the vicinity of Watsonia railway station, along with the proposed lane widening along Greensborough Road, to cause ground movement leading to damage to the Elder Street gas main (risk GM24).

The gas pipeline is a 0.45 metre internal diameter steel high pressure gas main that runs longitudinally on the east side of Greensborough Road near Watsonia railway station. The gas main transects Greensborough Road adjacent to Elder Street. The pipeline was relocated to 10 metres below ground surface and encased in a 600 millimetre conduit in the 1970s where it passes beneath Greensborough Road. This section of the pipeline will not be assessed, as it is deep enough to avoid any significant ground movement effects induced by the proposed 4 metre deep trench excavation nearby.

The section of pipeline that was assessed runs longitudinal to Greensborough Road and is at a depth of approximately 1 to 2 metres below ground surface. It is assumed the pipeline follows the 'greenfield' settlement profile in a flexible manner and that welding of the pipe sections has resulted in an effectively 'continuous' pipeline. No beneficial effects of the inner concrete lining nor the backfill surrounding the pipeline are considered.

The second stage assessment has adopted a check of the pipe curvature and tensile strains along the pipe length. The minimum radius of curvature due to the local ground movement was in the order of 4.31 kilometres. For the pipe dimensions, this equates to a bending strain of approximately 53 με, which is well below typical strains at the elastic limit of between 450 to 660 με for steel. No further assessment for this structure is considered necessary. Nonetheless, the following EPRs are recommended to monitor condition and control impacts based on the final design:

- EPR GM1 – **Geotechnical model and assessment**
- EPR GM2 – **Ground Movement Plan.**

Appendix C2 summarises the results of this second stage assessment.

8.3.3 Simpson Barracks buildings

This assessment considered the potential for the construction of the trench south of Yallambie Road to cause ground movement leading to damage to sensitive buildings in Simpson Barracks (risk GM04).

Main building

The L-shaped main building structure within the Simpson Barracks defence area could not be inspected nor were any structural details made available for this assessment. It has been assumed the structure comprises two contiguous double-storey buildings on shallow footings.

The preliminary assessment assumes 'greenfield' or fully flexible behaviour for this structure. While this is considered to be a conservative assumption, it is not unreasonable for typical framed low-rise structures on shallow footings. While the resulting risk categories suggest this structure is at low risk of damage, it is recommended the following EPRs are applied to this structure to monitor condition and predict impacts based on the final design.

- EPR GM1 – **Geotechnical model and assessment**
- EPR GM2 – **Ground Movement Plan**
- EPR GM3 – **Condition surveys (property and infrastructure).**

Outbuilding

The outbuilding adjacent to the main building structure within the Simpson Barracks area is situated approximately 7.5 metres east of the reference project trench, aligned in a north to south orientation.

Visual inspection of the structure revealed it to consist of a steel (portal) frame structure clad in corrugated galvanised steel sheet. The floor of the structure comprised flexible asphalt paving, with vertical columns assumed to be founded on circular concrete piers. Connections between the columns and the rafter beams are bolted, with web stiffeners located within the rafter beams.

The bolted portal frame structure is considered to be tolerant to ground movement, given its relative flexibility. The critical section of the building was found to be located at the base of a storage room sited approximately in the centre of the outbuilding. The storage room portal frame is founded on a raised concrete wall approximately 750 millimetres high. Because as-built construction details were not available, the base has been assumed to comprise a 200-millimetre thick reinforced concrete wall founded on a strip footing at a depth of 600 millimetres.

The second stage assessment for the outbuilding is included in Appendix C3. The results of the assessment indicate that the structure lies within the 'Moderate' damage risk category, suggesting that some cracking may occur within the reinforced concrete structure.
However, considering the relative axial stiffness of the structure as proposed by Franzius et al. (2006) suggests that the damage risk category could be modified by reducing the effect of the horizontal ground strain. It is therefore anticipated that this structure would not experience damage in excess of the 'Slight' category.

It is recommended that the following EPRs are applied to this structure to monitor condition and predict impacts based on the final design:

- EPR GM1 – **Geotechnical model and assessment**
- EPR GM2 – **Ground Movement Plan**
- EPR GM3 – **Condition surveys (property and infrastructure).**

8.3.4 Residential housing

Lower Plenty Road portal (LP2)

This assessment considered the potential for the construction of the northern portal retention structures to cause ground movement that damages adjacent residential properties and minor utilities (risk GM03).

Identified as properties within areas LP2, south of Lower Plenty Road on the west side of Banyule Creek in Rosanna and Viewbank, these buildings comprise low-rise residential properties. The properties are primarily made up of one and two-storey brick clad and weatherboard timber framed structures, situated in close proximity to the TBM tunnel alignment. Appendix C4 summarises the assessment for a typical property in this area.

For the purposes of this assessment, the more critical case of a representative structure lying within the area of hogging curvature was assessed. For this scenario settlements range from 5 to 29 millimetres, with a deflection ratio of 0.02 per cent. It is feasible some structures in the LP2 areas could suffer effects in the 'Slight' damage risk category.

The actual degree of damage to these structures would depend on the location and orientation of individual buildings relative to the TBM alignment, the TBM construction sequence and the existing condition of the building.

While the damage risk category does not imply that a detailed assessment will be necessary for these structures, it is recommended the following EPRs are applied:

- EPR GM1 – **Geotechnical model and assessment**
- EPR GM2 – **Ground Movement Plan**
- EPR GM3 – **Condition surveys (property and infrastructure).**

Banyule Creek area (BC1 and BC2)

This assessment considered the potential for tunnelling between Lower Plenty Road and the edge of the Yarra Valley to cause ground movement that damages residential buildings (risk GM05).

Buildings in these areas comprise low-rise one and two-storey brick clad and weatherboard timber framed residential properties, lying in close proximity to the TBM tunnel alignment. Goodstart Early Learning and Viewbank House are located within this region and have been assessed in conjunction with these residential properties. For the purposes of this assessment, the more critical case of a representative structure lying within the area of hogging curvature was assessed. For this scenario settlements range from 2 to 12 millimetres, with a deflection ratio of 0.001 per cent. It is anticipated that structures in this area would not experience effects in excess of the 'Negligible' damage risk category.

Appendix C5 summarises the assessment for a typical property in this area. Nonetheless, due to the proximity of these structures to the reference project alignment, it is recommended that the following EPRs are applied to monitor condition and predict impacts based on the final design:

- EPR GM1 – **Geotechnical model and assessment**
- EPR GM2 – **Ground Movement Plan**
- EPR GM3 – **Condition surveys (property and infrastructure).**

Bulleen area (BR residential)

This assessment considered the potential for construction associated with the Manningham Road Interchange and the mined tunnels to cause ground movement that damages adjacent residential buildings (risks GM09, GM10, GM11 and GM13).

Buildings in this area comprise residential properties located in St Andrews Crescent, Golden Way, Claremont Avenue, Rocklea Road and Killara Mews. The building stock is composed of one to two-storey brick clad and weatherboard houses in close proximity to the (SEM) mined tunnels and the temporary portal near Rocklea Road.

For the purposes of this assessment, three analyses have been undertaken representing critical locations on the east and west sides of the mined tunnels. Appendix C9.A, C9.B and C9.C summarise the assessments which indicate that settlements range from 7 to 26 millimetres, with deflection ratios of 0.007 per cent and 0.008 per cent. The most critical assessment results (Appendix C9.C) suggest that residential structures located above the mined tunnels in proximity to the cut-and-cover sections may fall within the 'Very Slight' damage risk category. While the damage risk category does not imply that a Detailed Assessment will be necessary for these structures, it is recommended the following EPRs are applied to monitor condition and predict impacts based on the final design:

- EPR GM1 – **Geotechnical model and assessment**
- EPR GM2 – **Ground Movement Plan**
- EPR GM3 – **Condition surveys (property and infrastructure).**

Given the tunnel alignment lies to the west of the former brick quarry, it is not anticipated that any piled buildings lie within the zone of influence of ground movement.

8.3.5 Banyule Creek sewer

This assessment has considered the potential for the TBM excavations in the proximity of the Banyule Drain causing ground movements leading to damage to the Banyule Creek sewer (risk GM02).

Comprising a 0.45-metre internal diameter vitreous clay bell-and-spigot sewer, this utility passes at shallow depth above the proposed TBM tunnels in the Banyule Flats. While no construction drawings for the sewer have been obtained, this second stage assessment is based on the assumption that typically VC pipes of this size have a short length relative to their diameter. For the purposes of this assessment it was assumed that each pipe is of the order of 0.6 metres long with a wall thickness of 30 millimetres.

For the relatively short lengths of pipe and stiffness of the VC pipe material, it is assumed that each pipe will behave relatively rigidly, such that all movements occur at the pipe joints. The second stage assessment may thus be undertaken by considering the potential for loss of 'serviceability' due to joint rotation and 'pull-out' caused by flexural and axial strains.

Bracegirdle et al. (1996) quotes a range of allowable joint rotations and pull-out displacement for lead-yarn caulked bell-and-spigot joints in cast iron pipes. These range from 1 to 2.5 degrees rotation and 10 to 25-millimetre pull-out. This range of allowable rotation values are similar to typical modern specifications for rubber ring jointed bell and spigot concrete pipes which range between 0.5 to 2 degrees, the allowable rotation generally increasing with decreasing diameter. For the purposes of this assessment, an allowable rotation of 0.5 degrees and pull-out displacement of 7.5 millimetres is assumed. It is recognised that actual tolerable values would depend on the existing condition of the pipeline and the geometry and caulking details for the joints, which is not currently known.

Appendix C6 summarises the results of the ground movement assessment and indicates that a maximum settlement of approximately 36 millimetres occurs close to the northbound TBM tunnel location. This coincides with the maximum radius of curvature which would govern the joint rotation.

In the sagging zone, the radius of curvature has been estimated at 18 kilometres which, for the assumed 0.6-metre length of pipe indicates an angular rotation of 0.002 degrees. This is well within the assumed 0.5-degree tolerance so damage due to rotation is not expected.

The calculated maximum horizontal tensile strain is approximately 50 $\mu\varepsilon$. When combined with the lateral component of the joint rotations at that location, this equates to an estimated pull-out of 0.25 millimetres which is well below the assumed tolerance for the joints.

The calculated joint movements are well below assumed tolerances. The assessment has also ignored any beneficial pipe-soil interactions. Despite the lack of knowledge about the current condition of the pipe, it is considered this second stage assessment indicates that a detailed evaluation is not warranted for this utility. Nonetheless, the following EPRs are recommended to monitor condition and control impacts based on the final design:

- EPR GM1 – **Geotechnical model and assessment**
- EPR GM2 – **Ground Movement Plan.**

8.3.6 Crescent House

This assessment considered the potential for TBM tunnelling between the northern edge of the Yarra Valley and the North East Link southern portal to cause ground movement that damages sensitive features in the Heide Sculpture Park, including Crescent House (risk GM06).

Constructed in 2013, the Crescent House artwork comprises a small timber-framed pavilion structure, clad with 'yakisugi' cedar wood panelling. An aluminium panel painted in micaceous iron oxide forms the east-facing wall of the structure. Figure 8-2 is a photograph of Crescent House.

Appendix C7 summarises the results of the second stage assessment for this structure.

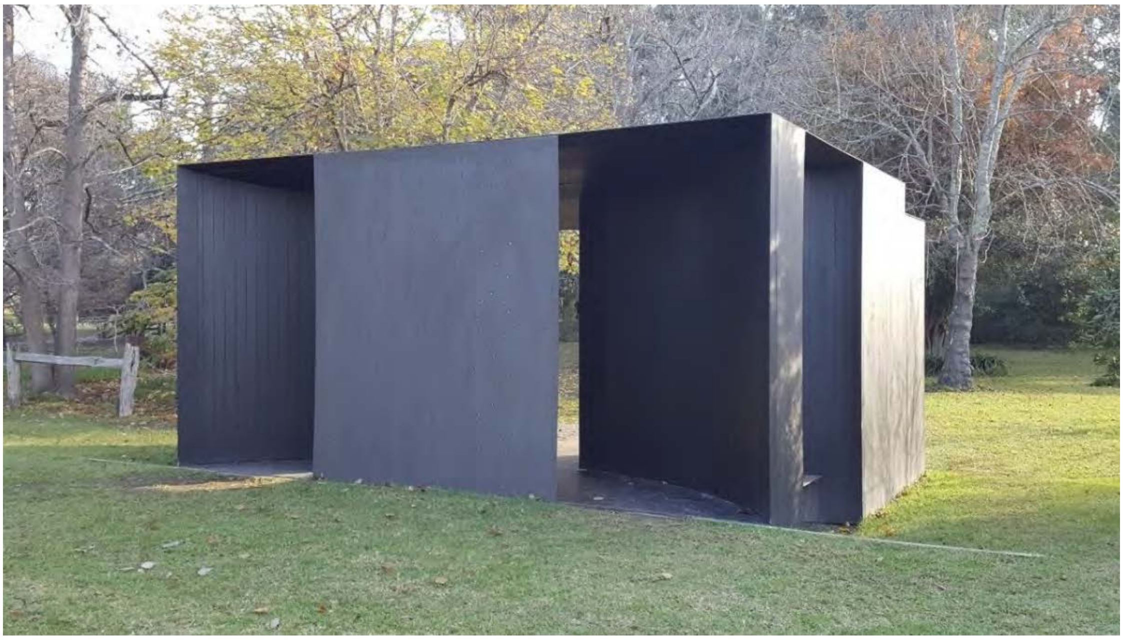


Figure 8-2 Crescent House (viewed from the north-east)

From the available information on the structural arrangement of the piece, the floor sub-frame consists of a joist and bearer arrangement with bearers supported by metal stirrups affixed to concrete blocks or pad footings. The structure is approximately 5 x 4 metres in plan.
The north-south orientation of the long axis places the structure approximately parallel to the TBM drive direction.

The structure is located close to the inflection point of the settlement profile above the northbound TBM tunnel. Settlements range from 13 to 18 millimetres, suggesting very low deformations for the structure. The calculated deflection ratio (Δ/L) and horizontal ground strain places the pavilion in the 'Negligible to Slight' risk category after Burland (1995).

Visual inspection of the structure suggests that it is in relatively good condition. In addition, when the timber frame and isolated pad foundation design is taken into account, it is considered the structure would offer negligible resistance to ground movements in terms of bending or axial stiffness. Similarly, the lightweight materials used would impose very low vertical stresses on the ground, further minimising interaction. As such, the structure is assumed to be highly 'flexible' with a high degree of tolerance to differential movement.

For these reasons, further assessment of the structure (a detailed assessment) is not considered warranted. Nonetheless, because of the artistic and community value of the structure, it is recommended the following EPRs are applied:

- EPR GM1 – **Geotechnical model and assessment**
- EPR GM2 – **Ground Movement Plan**
- EPR GM3 – **Condition surveys (property and infrastructure)**.

8.3.7 Theoretical Matter

This assessment considered the potential for TBM tunnelling to cause ground movement that damages the artwork 'Theoretical Matter' located within the Heide Sculpture Park (risk GM06).

Figure 8-3 is a photograph of the artwork. The primary structural arrangement of this artwork consists of a steel reinforcing bar welded into a three-dimensional grid, effectively forming a (non-tetrahedral) space frame. The structure is supported on a rectangular concrete slab footing, assumed to be nominally reinforced with a single layer of SL62 mesh or equivalent, with an average slab thickness of approximately 100 millimetres[4].

The dimensions of the slab were measured to be approximately 5 by 3.2 metres in plan. The structure appears to be resting on the footing slab with no visible fixing, and therefore is assumed to have little interaction with the foundation.

The orientation of the structure is such that the long axis lies approximately parallel to the underlying TBM drive direction and is situated between the northbound and southbound drives. Preliminary calculations considering the relative bending and axial stiffness of the slab footing using the modified approach suggested by Franzius et al. (2006) indicated the footing is 'flexible' and would follow the greenfield settlement trough.

While the final settlement profile below the structure imposes a negligible deflection ratio on the footing due to a favourable interaction between the TBM drives, the sequence of drive construction could potentially impose a much greater deflection ratio on the footing.

Considering the case of the southbound TBM drive being driven ahead of the northbound drive, the foundation would be located in the 'hogging zone', just beyond the point of inflection. While this temporary case would impose the greatest amount of tensile strain within the foundation slab, the resultant deflection ratio is still relatively small. As the slab 'beam' is very shallow in the bending axis, the induced tensile strain would be negligible.

Appendix C7 summarises the results of the second stage assessment for this structure. From the analysis work conducted, it can be summarised that the damage risk from ground movement is considered 'Negligible' and a detailed assessment is not warranted. Nonetheless, because of the artistic and community value of the structure, it is recommended the following EPRs are applied:

- EPR GM1 – **Geotechnical model and assessment**
- EPR GM2 – **Ground Movement Plan**
- EPR GM3 – **Condition surveys (property and infrastructure)**.

[4] These eestimates were based on observations made during the field inspection.

Figure 8-3 Theoretical Matter (viewed from the north-west)

8.3.8 Helmet

This assessment considered the potential for the excavation of the Manningham Road interchange and adjoining TBM tunnels to cause ground movement to the sculpture (risk GM20).

Located in Banksia Park just above the temporary TBM tunnel portal at Banksia Street, this installation is owned by Manningham City Council. Figure 8-4 is a photograph of the artwork. Appendix C8 summarises the results of the second stage assessment for this structure.

Constructed in 2007, the sculpture comprises approximately 100-millimetre thick reinforced concrete slabs covered with rubberised asphalt sheeting and low height retaining walls, to create an apron around the main vertical component of the structure. Plan dimensions are approximately 15 x 30 metres.

The main part of the sculpture (which is a representation of Ned Kelly’s helmet) comprises four vertical steel I-beam stanchions, bolted to concrete filled bored pier foundations, installed to a minimum depth of 2.7 metres below the natural ground surface. The frame for the vertical structure is comprised of a truss made of steel members of various sizes and is clad with black, powder coated ‘corten’ steel panels (3 millimetres thick) ‘spot’ welded and bolted to the frame.

The preliminary assessment indicates over 92 millimetres of maximum settlement and ground slopes of the order of 1:540 are feasible. This second stage assessment considered staged tunnel excavations, whereby the ground movement induced by a single tunnel was modelled. The results indicate the worst case arises when the northbound tunnel has been fully excavated beneath the structure such that the degree of differential settlement is at its highest. Appendix C8 presents the worst case deflection ratio and horizontal ground strain across the various stages.

The highly non-uniform geometry of this structure suggests it should be considered in two parts: firstly, the response of the concrete retaining walls and slabs to differential movement and secondly, the response of the vertical steel structure.

The large span and relatively thin concrete slabs suggests that a flexible response can be assumed. This could result in cracking of the concrete due to bending moments from differential settlement. Direct extensional ground strains may further add to this risk. This cracking is however considered mainly a risk for the durability of the concrete, as it can expose reinforcing steel leading to corrosion of the steel and discolouration and spalling of the concrete.
The rubberised asphalt sheets would, to some extent, mask these effects in the slabs but the low retaining walls may exhibit visible signs of cracking.

The I-beam and panel structure may also suffer significant differential movements leading to torsion and buckling of the panels and failure of fixings. This may adversely affect the appearance of the sculpture.

Due to the highly non-uniform geometry of this structure and its value as a public work of art, it will be subject to a detailed assessment.

Figure 8-4 Helmet (viewed from the south-west)

8.3.9 Veneto Club

This assessment considered the potential for the construction of the cut-and-cover/retained excavations south of Rocklea Road to cause ground movement that damages the Veneto Club (risk GM14).

Located at 191 Bulleen Road, this structure comprises a 1970s three-storey reinforced concrete-framed structure in a ‘brutalist’ architectural style. A box girder arched portico, polished concrete column and concrete slabs at the entrance to the main building fall within the zone of influence and are subject to a second stage assessment.

These structures lie on the alluvial soils in the Yarra Valley so may be subject to additional settlement arising from ‘consolidation’ of the soils due to construction de-watering and groundwater drawdown. However, the geotechnical investigations indicate that the alluvial soils are relatively thin beneath the club, so settlement as a result of consolidation beneath the Veneto Club is estimated to be less than one millimetre. As such, the critical assessment case would be due to the ‘net’ effect of differential displacements due to ground movements caused by excavation alone. The main building lies outside of the influence zone of ground movement caused by excavation and would therefore experience negligible differential settlement.

Significant differential ground movement movements would only affect the arched entrance portico and polished concrete column.

The portico arch is located approximately 40 metres from the retaining wall of the cut-and-cover tunnels opposite Bulleen Oval. The portico comprises three arched girders on concrete plinths with sheet steel ‘spandrels’ (panels) between the arches. It measures approximately 23 metres (to ‘springing’) by 6 metres. Figure 8-5 is a photograph of the northern half of the portico structure. Figure 8-6 shows the foundation plinths for the arched box girders.

Figure 8-5 Veneto Club portico arch (north side)

The estimated displacements (excluding consolidation effects) range from two to six millimetres on the east-west axis. However, because the excavation is at a ‘skew’ to the structure, a small torsional component may also be experienced.

Modelling of the response of the portico to the estimated ground movements was conducted in the structural FEA program *Strand7* based on the as-built dimensions of the structure.
The results of the modelling indicate that minimal additional bending and axial loading occurs due to the settlement. These loads were considered negligible when compared with the capacity of the structure. A minor increase in the stresses at the connection between the roof arches and concrete footings indicates that localised cracking at the interface may occur, but this effect is reduced if reinforcement is assumed in each face is as specified on the design drawings provided.

The monumental column located in front of the portico structure comprises a tapered polished pigmented concrete column approximately eight metres above ground level, shown in Figure 8-7. The actual foundation details are unknown. Calculations indicate that conservatively, the column could tolerate a tilt of at least 1 degree (or a gradient of approximately 1:44). The estimated ground slopes arising from the area of the order of 1:3200 so it is considered unlikely that adverse effects would be felt by the column.

It was observed that the concrete slabs surrounding the column and beneath the portico have been affected by historic cracking (radially around the column water feature) and local exposure of reinforcing bar. Sections of the slab at the entrance to the lobby of the building appear to have been replaced. This suggests that historical differential movement due to consolidation of the ground beneath may have occurred.

Figure 8-6 Veneto Club portico arch plinths (south side)

Appendix C10 summarises the results of the second stage assessment for this structure. From the analysis work conducted, it can be summarised that the damage risk to the portico and column as a result of ground movement is considered ‘Negligible’ and a detailed assessment is not warranted. Nonetheless, because of community value of the structures, it is recommended the following EPRs are applied:

- EPR GM1 – **Geotechnical model and assessment**
- EPR GM2 – **Ground Movement Plan**
- EPR GM3 – **Condition surveys (property and infrastructure).**

Replacement of the concrete slabs may also be required once North East Link was constructed as the existing cracking may be exacerbated by construction ground movements.

Figure 8-7 Veneto Club monumental column

8.3.10 Bulleen Road west sewer

This assessment considered the potential for planned road embankments near Bulleen Road and the shaft excavation required for the relocation of the East Yarra Main Sewer to cause ground movement that damages the Bulleen Road west sewer (risk GM23).

This reinforced concrete pipeline runs from Bulleen Road to the Carey Grammar Sporting Complex and comprises a 2.25-metre internal diameter reinforced concrete pipeline.
The planned road embankments that would connect the Eastern Freeway to the cut-and-cover section south of the mined tunnels would pass over this pipeline. Planned flood mitigation measures at this location along the alignment include the provision of a concrete slab on piles within the road embankment. These proposed works are expected to induce ground movements in the soil surrounding the pipeline. While no construction drawings for the sewer have been obtained, information sufficient for a second stage assessment has been obtained from the Yarra Valley Water Asset database.

It is understood the sewer was installed using trenched excavation methods in 1966, but the composition of the backfill material is unknown. The available geotechnical data indicates that the ground comprises alluvial clay at this location. Given the age of the sewer and the construction method, it has been assumed the sewer is rubber ring jointed.

The second stage assessment was conducted by comparing the vertical ground displacement profile as determined using *RS2* with the maximum allowable joint rotation and joint pullout. In lieu of any detailed pipe information, the assessment was carried out conservatively by considering the worst possible combination of pipe segment lengths and joint locations. Realistically, a pipe segment length of 2.4 metres is common for reinforced concrete pipes with a diameter of 2.25 metres. The effects of the trench backfill and beneficial ground structure interactions have been ignored. This assessment is summarised in Appendix C11.

Bracegirdle et al. (1996) quotes a range of allowable joint rotations and pull-out displacement for bell-and-spigot pipe joint geometries. For this assessment, an allowable rotation of 2.5 degrees (equivalent to a minimum radius of curvature of 0.05 kilometres for the assumed pipe length) and pull-out displacement of 7.5 millimetres will be assumed. The maximum joint rotation determined from the calculated ground movements was 0.07°, with an associated radius of curvature of approximately 4.5 kilometres. The maximum joint pullout was calculated to be 0.01 millimetres. These results indicate that the rotation, curvature and pullout experienced at the pipe joints would not be expected to exceed the assumed capacity for a typical rubber ring jointed concrete pipe in good condition.

The results of the second stage assessment indicate that a detailed evaluation is not warranted for this utility, but due to limited information on its condition, the following EPRs are recommended to monitor condition and control impacts based on the final design:

- EPR GM1 – **Geotechnical model and assessment**
- EPR GM2 – **Ground Movement Plan**
- EPR GM3 – **Condition surveys (property and infrastructure).**

8.3.11 Koonung Creek culvert

The Koonung Creek conduit runs parallel and partly to the south of the Eastern Freeway between Bulleen Road and Doncaster Road. The conduit comprises ‘three-pin’ reinforced concrete arch structure measuring 6.6 metres wide and 4 metres high, founded on a reinforced concrete slab. In the area of interest, the conduit lies at shallow depth beneath the public open space created by the creek diversion for the Eastern Freeway.

Studies undertaken for the reference project indicate the culvert would not tolerate the additional loading from the expanded freeway. A solution has been proposed whereby the Koonung Creek is ‘bridged over’ by a concrete slab beneath the motorway embankment. This would minimise the ground movement at the depth of the conduit and the risk of ground movement induced damage would be negligible. No second stage ground movement assessment has therefore been undertaken on this conduit. Nonetheless, as this receptor is a critical piece of Melbourne Water infrastructure, it is recommended the following EPRs are applied to monitor and control impacts based on the final design:

- EPR GM1 – **Geotechnical model and assessment**
- EPR GM2 – **Ground Movement Plan**
- EPR GM3 – **Condition surveys (property and infrastructure).**

8.4 Detailed assessment

8.4.1 Helmet

This assessment has considered the potential for the excavation of the Manningham Road interchange and tunnelling beneath Banksia Park to cause ground movement leading to damage to the sculptural installation 'Helmet' (risk GM20).

This detailed assessment focused on the critical component of the sculpture, that being the vertical steel structure that lies on the eastern edge of the installation. Drawings of Helmet were obtained from Manningham City Council to provide the structural details. Detailed modelling of the stresses induced in the structure, when subject to the anticipated ground movements, was undertaken using the structural FEA program *Strand7*. Where specific details were absent in the drawing set, conservative assumptions were made regarding the structure. For example, the steel plates were modelled to be welded to the vertical and horizontal steel members to imply a rigid joint assessment.

The location of the sculpture and the skewed orientation of the structure with respect to the tunnel axis suggested the ground movement risk would be sensitive to the sequence of tunnel excavation. To identify the critical ground movement case, the following scenarios were analysed: the northbound tunnel constructed first; the southbound tunnel first; and, both tunnels completed.

The modelling conservatively assumed the Greenfield displacements would be applied directly to the foundation with no relative ground stiffness effects. Wind and gravity loads were also considered. The scenario that included both tunnels was found to have the highest ground movement damage risk as the horizontal and vertical displacements combined to impart two-way bending within the steel plate cladding.

For the critical ground movement case, two models were considered: one with the ground movement applied at depth on the concrete piers[5] and the other with the ground movement applied directly to the base of the steel columns at ground surface. The design output assessed the response of the outer steel plates and the diagonally-braced interior frame structure. For the assessment of the plates, the design output compared the yield strength of the existing steel plates against Von Mises yielding criteria which defines the limits of elastic behaviour under any possible combination of stresses. For the assessment of the frame, maximum tensile and compressive fibre stresses were assessed. Table 8-4 summarises the results from the *Strand7* assessment.

Figure 8-8 and Figure 8-9 show the stress development in the plates and the frame for the most critical case (ground movements applied to the base of the steel columns at ground surface), viewed from south-west (refer Figure 8-4). Failure zones are indicated in white.

The detailed assessment thus indicates that unacceptable strains and damage to the sculpture may be expected. The following EPRs are recommended:

- EPR GM1 – **Geotechnical model and assessment**
- EPR GM2 – **Ground Movement Plan**
- EPR GM3 – **Condition surveys (property and infrastructure)**
- EPR GM4 – **Properties and assets impacted by ground movement and settlement.**

[5] Applied at 2/3 of the footing height after Devriendt & Williamson (2011)

Table 8-4 Helmet detailed assessment results summary

Assessment	Plate response	Bracing response
Ground movements at base of column	Yield	Yield
Ground movements at footing	No yield	Yield

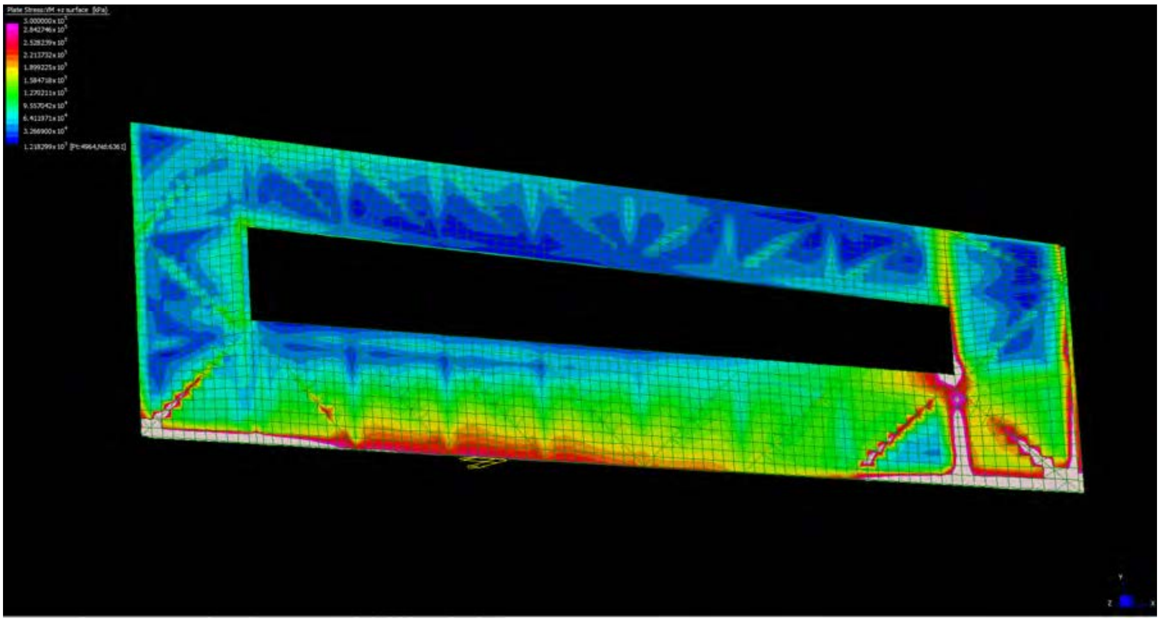


Figure 8-8 Stress development in steel plates

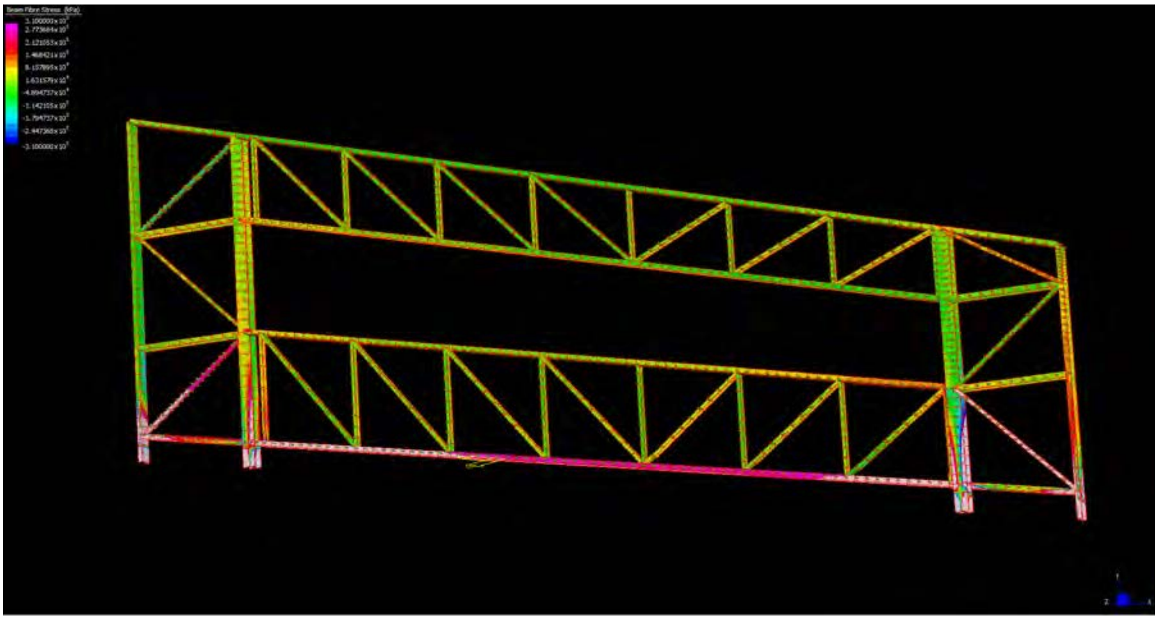


Figure 8-9 Stress development in bracing

8.5 Alternative design options

While the reference project for North East Link is largely finalised, there are currently two alternative design options being considered for the arrangement of the Manningham Road interchange, and two locations for the launch of the TBM being considered. For information on the design options, refer to EES Chapter 8 – Project Description.

This section explains how the potential impacts associated with the alternative design options would differ from the impacts associated with the project design assessed in Section 8.1 to Section 8.4.

8.5.1 Manningham Road interchange

This design alternative comprises lowering the vertical alignment of the TBM tunnels and Manningham Road interchange by up to two metres across a total length of around 1,700 metres. Given the change in elevation is small, this would have a minor effect on the magnitude and zone of influence of ground movement over this area. Generally, a deeper tunnel would have a wider zone of influence and a lower magnitude of settlement when compared with an equivalent tunnel at a shallower depth. When considering the implications on the risk of damage to structures or assets, a wider zone of influence and smaller magnitude of ground movement can decrease the tensile strains induced, potentially reducing the damage classification as shown in Table 5-3.

As an indication of the anticipated change in ground movement effects, assuming a 'Gaussian' (see Section 5.7.1), the change in the trough width parameter 'i' and the maximum settlement 'S_{max}' can be directly computed for a two-metre lowering of the tunnel For a single tunnel, the parameter 'i' would increase by approximately one metre (equivalent to a three-metre increase in trough width extents) and the maximum settlement would decrease by approximately three millimetres. Therefore, for the two parallel tunnels, this equates to a negligible change in maximum tensile strain and would not modify the structure or asset damage classification and risk rating.

Figure 8-10 shows the anticipated change in vertical settlement profile for a section within the Heide sculpture park, where the alternative design option proposes the two TBM tunnels are two metres deeper. This shows the current alternative design would have a slightly wider settlement trough compared with the current proposed design. Closer to the tunnel centreline, the change in settlement is insignificant.

8.5.1 Northern tunnel boring machine (TBM) launch

The potential ground movement impacts of the alternative TBM launch site have been reviewed. Considering that the alternate launch site does not involve substantial changes to the excavated geometry and does not change the estimated extents of ground movement, the same EPRs currently recommended would be effective at minimising ground movement impacts.

8.5.2 Banksia Park tunnel boring machine (TBM) retrieval shafts

This design alternative involves the excavation of two separate TBM retrieval shafts on the north side of Bridge Street within the Banksia Park area. The proposed rectangular shafts are each 25 metres wide by 50 metres long and reach a depth of between 30 to 34 metres. On the basis of the preliminary construction program estimates, the shafts would be completed before the Manningham Road interchange excavation works commence.

The effect of construction dewatering on ground movement has been ignored on the basis of the lack of soft or compressible soils in the area of the nearby sensitive receptors.
Initial construction programme estimates suggest that dewatering of the retrieval shaft excavations would occur nine months before the dewatering of the adjacent Manningham Road interchange excavation.

Net ground movement occurring as a direct result of the open shaft excavations increases the extents of the zone of influence within the Banksia Park area when compared with the reference project. The increase would result in an additional receptor falling within the zone of influence, being a single residential property on Bridge Street that lies immediately to the east of the excavation (risk GM27). Figure 8-11 presents the estimated ground settlement contours associated with the excavation of the TBM retrieval shafts before excavation associated with the Manningham Road interchange.

Preliminary assessment indicates that the identified residential property is located on the limit of the 10-millimetre settlement contour, placing it on the edge of the Rankin (1988) risk category 2 (Slight), warranting a second stage assessment.

Second Stage assessment of the Bridge Street residential property was progressed by estimating the construction details by inspection of available public records. In lieu of more detailed information the property is assumed to comprise a timber framed and weatherboard structure founded on a perimeter masonry wall and strip foundation. The timber portion of the structure would be much less susceptible to damage as a result of much lower relative stiffness, therefore the focus of the assessment is on the masonry base course.

The results of the second stage assessment of the base masonry courses for the Bridge Street residential property (Appendix C12) suggests a 'Negligible' damage risk category for this structure.

While the damage risk category does not warrant a Detailed Assessment, it is recommended that the following EPRs are applied to monitor condition and assess impacts based on the final design:

- EPR GM1 – **Geotechnical model and assessment**
- EPR GM2 – **Ground Movement Plan**
- EPR GM3 – **Condition surveys (property and infrastructure).**

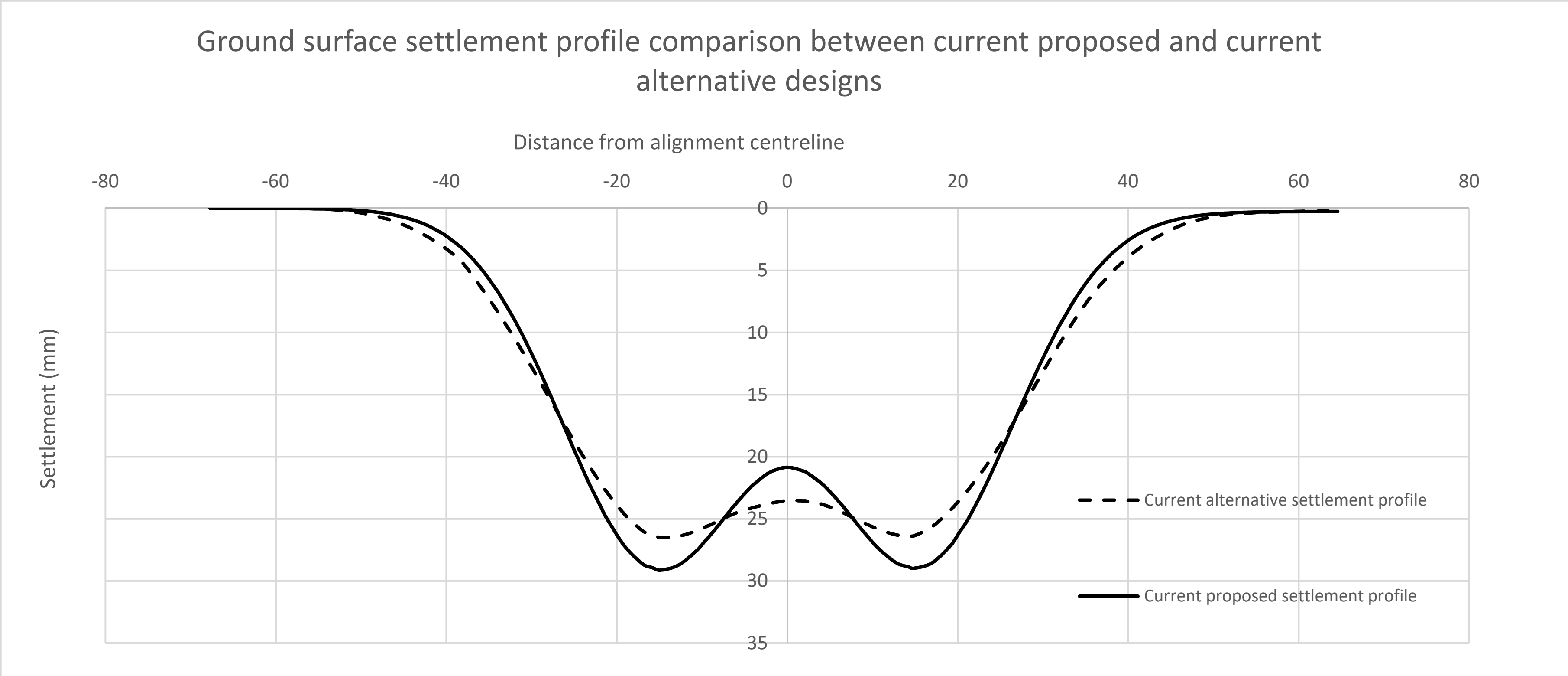
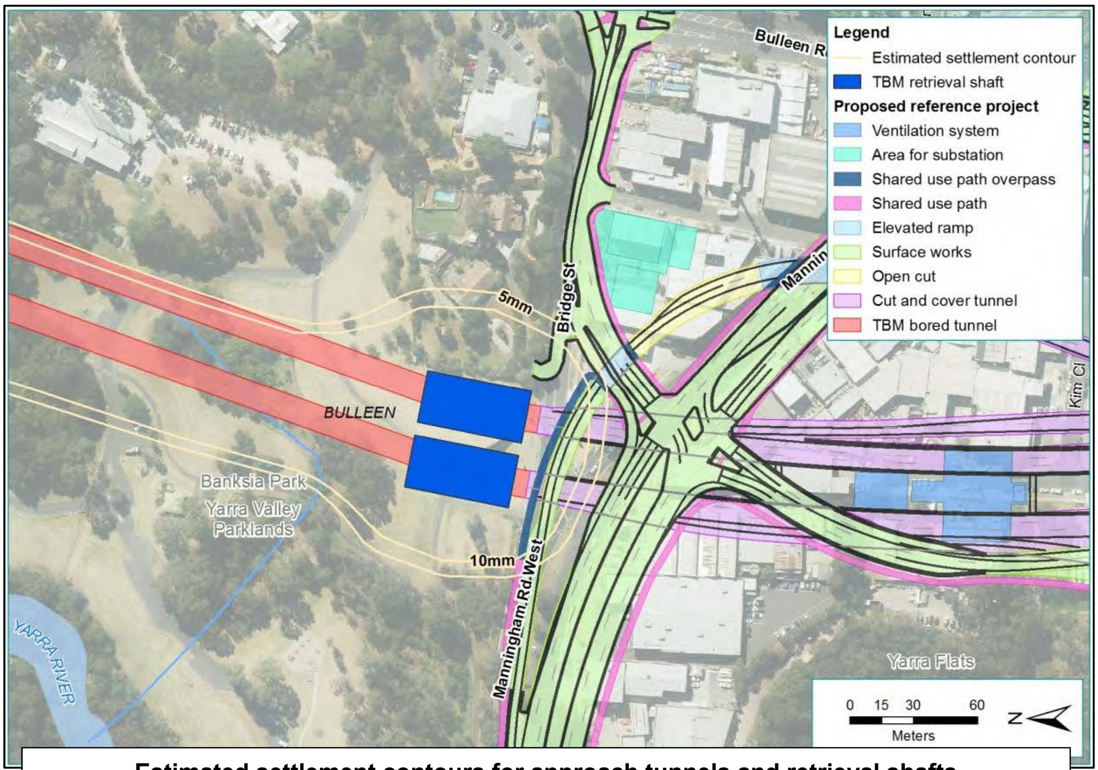


Figure 8-10 Current proposed and current alternative design option settlement profile comparison



Estimated settlement contours for approach tunnels and retrieval shafts

Figure 8-11 Banksia Park Tunnel Boring Machine retrieval shafts estimated ground movement contours

9. Environmental Performance Requirements

Table 9-1 lists the recommended Environmental Performance Requirements (EPRs) relevant to the ground movement assessment. Table 9-2 summarises all the EPRs recommended for specific structures and utilities based on this assessment report.

Table 9-1 Ground movement EPRs

No	Description
EPR GM1	**Design and construction to be informed by a geotechnical model and assessment** Develop and maintain geological and groundwater model(s) (as per EPR GW1) to inform tunnel and trench design and the construction techniques to be applied for the various geological and groundwater conditions. The model(s) are to: • Identify sensitive receptors that may be impacted by ground movement • Inform monitoring of ground movement and ground water levels prior to construction to identify pre-existing movement • Inform tunnel design and the construction techniques to be applied for the various geological and groundwater conditions • Assess potential drawdown and identify trigger levels for implementing additional mitigation measures to minimise potential primary consolidation settlement • Assess potential ground movement from excavation and identify trigger levels for implementing additional mitigation measures to minimise potential ground movement.
EPR GM2	**Implement a Ground Movement Plan to manage ground movement impacts** Develop and implement a Ground Movement Plan(s). The Ground Movement Plan must be informed by EPR GM1 and EPR GW1 (predictive model) and: • Address the location of structures/assets which may be susceptible to damage by ground movement • Identify baseline ground movement monitoring prior to construction • Identify appropriate ground movement impact acceptability criteria • Identify appropriate mitigation measures should the geotechnical model (EPR GM1), predictive groundwater model (EPR GW1), or subsequent monitoring program indicate acceptability criteria may not be met • Establish ground movement monitoring requirements for the area surrounding proposed project works to measure ground movement consistency with the anticipated ground movement in the predictive model.
EPR GM3	**Carry out Condition surveys for potentially affected property and infrastructure** Conduct condition survey(s) of property and infrastructure predicted to be affected by ground movement based on the results of the geological and groundwater model (EPR GM1) or, where a property owner reasonably expects to be potentially affected and has requested a pre-construction condition survey. Develop and maintain a database of pre-construction and as-built condition information for each potentially affected structure identified as being in an area susceptible to damage (see EPR GM1) or where a property owner has requested a pre-construction condition survey, specifically including: • A list of identified structures/assets which may be susceptible to damage resulting from ground movement resulting from project works • Results of pre-construction condition surveys of structures, pavements, significant utilities and parklands to establish baseline conditions and potential vulnerabilities • Records of consultation with land owners in relation to the condition surveys • Post-construction stage condition surveys conducted, where required, to ascertain if any damage has been caused as a result of project works. Pre- and post-condition assessments must be proactively shared with the property owner. All stakeholder engagement activities must be undertaken in accordance with the Communications and Community Engagement Plan (see EPR SC2).
EPR GM4	**Rectify damage to properties and assets impacted by ground movement or settlement** For properties and assets affected by ground movement caused by the project, undertake required repair works or other actions as agreed with the property or asset owner. For places listed on the Victorian Heritage Register, consultation with Heritage Victoria must be undertaken. Establish an independent mediation process for the assessment of claims for property and asset damage that cannot be agreed between the Project and the property or asset owner.

Table 9-2 EPR summary table

Receptor	EPR GM1	EPR GM2	EPR GM3	EPR GM4	Comment
Maroondah aqueduct	Yes	Yes	-	-	-
Residential properties (general)	-	-	Yes	-	Applied to all properties located within the zone of influence but not exceeding the 'Slight' risk damage category.
Residential properties (LP2, BC1 and 2, and BR)	Yes	Yes	Yes	-	Those residential properties that required a Second Stage assessment.
Elder Street gas main	Yes	Yes	-	-	-
Simpson Barracks Buildings	Yes	Yes	Yes	-	Refers to both the main building and the outbuilding
Lower Plenty road water main	Yes	Yes	-	Yes	Pipe re-alignment is at conceptual phase
Banyule Creek sewer	Yes	Yes	-	-	-
Banyule swamp	Yes	Yes	Yes	Yes	Environmental sensitivity
Heide: 'Theoretical Matter' and 'Crescent House'	Yes	Yes	Yes	-	Structures at 'Negligible' risk but of community value.
'Helmet'	Yes	Yes	Yes	Yes	-
Study area east of Manningham Interchange	Yes	-	-	-	-
Veneto Club portico and column	Yes	Yes	Yes	-	Structures at 'Negligible' risk but of community value.
Bulleen Road west sewer	Yes	Yes	Yes	-	-
Koonung Creek conduit	Yes	Yes	Yes	-	Design intent is to bridge over this structure, therefore ground movement strains were not assessed on the existing structure.
Bridge St residence (alternative)	Yes	Yes	Yes	-	Applicable to the alternative TBM retrieval shaft option (Section 8.5.2)

10. Conclusions

The purpose of this report is to present the potential ground movement impacts associated with North East Link to inform the preparation of the EES. It is based on the reference project alignment and realistic assumptions regarding construction methods and program. In addition, a high-level understanding of the geology, hydrogeology and geotechnical conditions has been presented, based on a review of the factual investigations undertaken by GHD for the project.

The risk assessment has proceeded in a three-stage approach following international best practice. The classification of risk to surface buildings followed the recommendations of Rankin (1988) and Burland et al. (2001). For buried structures and utilities, typical serviceability criteria were adopted to assess the potential for adverse ground movement effects.

In general, the assessment shows that ground movement effects due to groundwater drawdown, cut-and-cover tunnel, open retained trench and bored tunnelling (TBM and mined-SEM tunnels) results in a ‘slight risk’ of damage or less for the majority of structures considered. The only exceptions are ‘Helmet’ – a sculptural artwork located close to the temporary TBM tunnel portal at Banksia Street – and an outbuilding located within the Simpson Barracks.

Based on the second stage and detailed evaluations, environmental performance criteria (EPRs) have been proposed to ensure the contractor undertakes the work in a manner that fully assesses the ground movement risks at detailed design. The EPRs seek to ensure that appropriate monitoring and remedial measures are put in place to manage the risks and that ground movement effects are kept to acceptable levels.

Should a change in project alignment or design be adopted in detailed design, a review of this risk assessment may be required. In particular, further detailed assessments may be required for the Lower Plenty Road water main when the exhumation and reinstatement design has been confirmed.

11. References

PB Attewell, P. B. & Woodman, J. P., 1982. Predicting the dynamics of ground settlement and its derivatives caused by tunnelling in soil. *Ground Engineering,* Volume 8, pp. 13-36.

Banyule City Council, 2018. *A brief history.* [Online]
Available at: https://www.banyule.vic.gov.au/Council/About-Banyule/History/A-brief-histoy

Boscardin, M. D. & Cording, E. J., 1989. Building response to excavation induced settlement. *Journal of Geotechnical Engineering,* 115(1).

Bracegirdle, A., Mair, R., Nyren, R. & Taylor, R., 1996. *A methodology for evaluating potential damage to cast iron pipes induced by tunnelling.* Rotterdam, Balkema.

Burland, J. B., 1995. Assessment of risk of damage due to tunnelling and excavations. *First International Conference on Earthquake Geotechnical Engineering,* pp. 1189-1201.

Burland, J. B., Standing, J. R. & Jardine, F. M., 2001. *Building response to tunnelling. Case studies from the Jubilee Line Extension.* s.l.:CIRIA Special Publication 200.

Clough, G. & O'Rourke, T., 1990. *Construction induced movements of insitu walls.* s.l., ASCE.

Department of Environment, Land, Water and Planning, n.d. *Planning Schemes Online.* [Online]
Available at: http://planning-schemes.delwp.vic.gov.au/

Devriendt, M. & Williamson, M., 2011. *Validation of methods for assessing tunnelling-induced settlements on piles.* Cambridge: Unversity of Cambrige and Arup.

Dimmock, P. & Mair, R., 2007. Estimating volume loss for open face tunnels in London Clay.. *Proc. Institution of Civil Engineers. Geotechnical Engineering 160 (GE1).*

EPA Victoria, 2009. *Waste.* [Online]
Available at: https://www.epa.vic.gov.au/your-environment/waste/landfills

Franzius, J. N., Potts, D. & Burland, J., 2006. The response of surface structures to tunnel construction. *Geotechnical Engineering ,* pp. 3-17.

Gaba, A. et al., 2017. *Guidance on embedded retaining wall design,* London: CIRIA.

Gaba, A., Simpson, B., Powrie, W. & Beadman, D., 2003. *Embedded retaining walls - guidance for economic design,* London: CIRIA.

Heritage Council Victoria, 2018. *Victoria's significant heritage places and objects.* [Online]
Available at: http://vhd.heritagecouncil.vic.gov.au/

Hoek, E., 2008. *The 2008 Kersten Lecture. Integration of geotechnical and structural design in tunnelling..* Minneapolis, s.n.

Hoek, E., Carranza-Torres, C., Diederichs, M. & Corkum, B., 2008. *The 2008 Kersten Lecture - Integration of geotechnical and structural design in tunneling.* Minneapolis, University of Minnesota.

Hoek, E., Kaiser, P. & Bawden, W., 1995. *Support of Underground Excavations in Hard Rock.* London and New York: Taylor & Francis.

Mair, R. J., Taylor, R. N. & Burland, J. B., 1996. *Prediction of ground movements and assessment of risk of building damage due to bored tunnelling.* Rotterdam, Balkema, pp. 713-717.

O'Rourke, T. & Trautmann, C., 1982. *Buried pipeline response to tunnelling ground movements.* Switzerland, Cornell University, pp. 9-15.

Peck, B., 1969. *Deep Excavations and Tunnelling in Soft Ground,* Urbana, Ill. USA: University of Illinois.

Rankin, W. J., 1988. Ground movements resulting from urban tunnelling: predictions and effects. In: *Engineering Geology of Underground Movements.* s.l.:Geological Society Engineering Geology Special Publication No. 5, pp. 79-92.

Victorian Places, 2015. *Bundoora.* [Online]
Available at: http://www.victorianplaces.com.au/bundoora

Vorster, E., Klar, A. & Soga, K., 2005. Estimating the effects of Tunneling on Existing Pipelines. *Journal of Geotechnical and Geoenvironmental Engineering,* 131(11).

Appendices

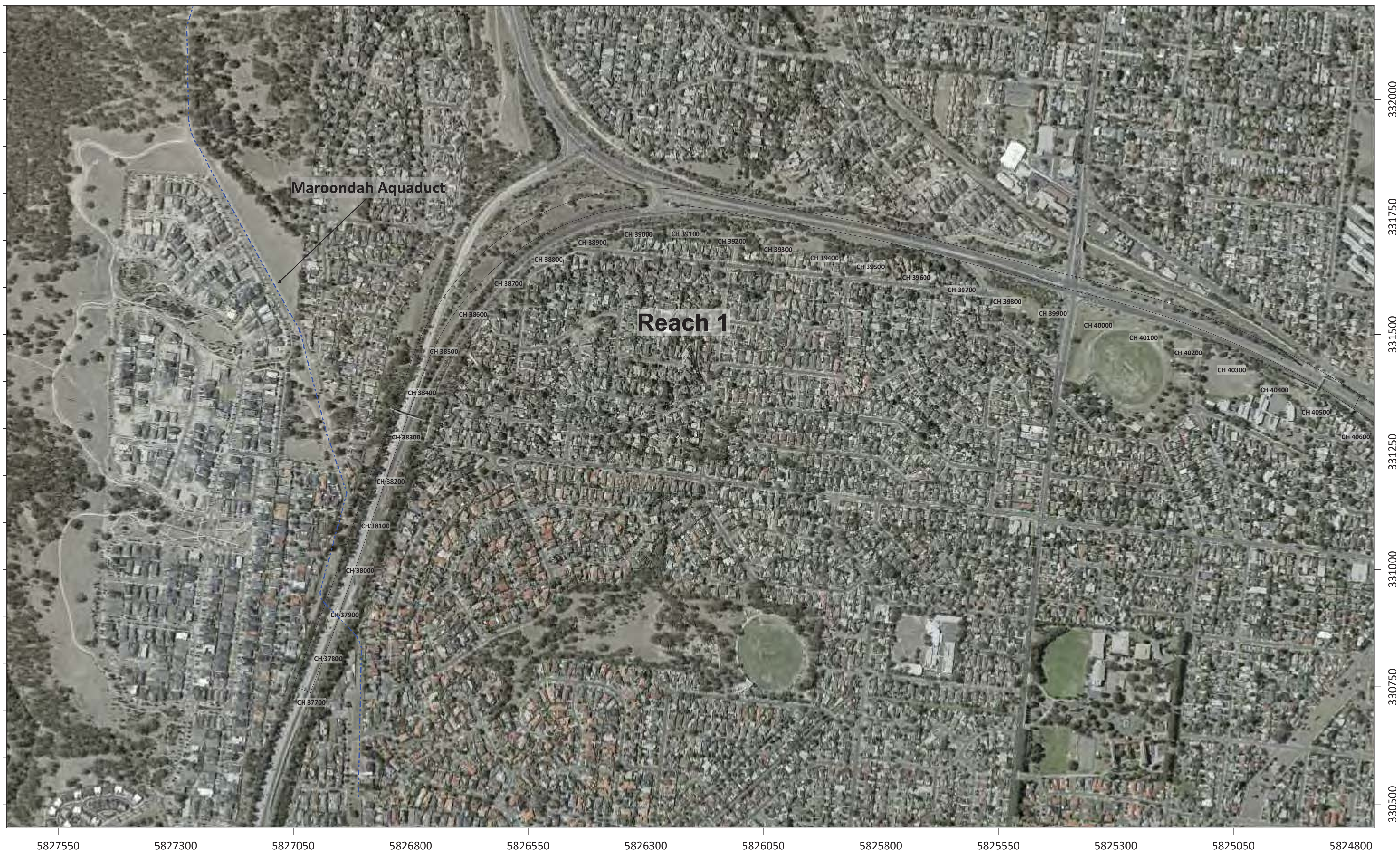
Appendix A – Risk Assessment

Risk ID	Potential threat and effect on the environment	INITIAL RISK								RESIDUAL RISK						
		Initial EPR	Magnitude of consequence			Overall consequence	Likelihood	Risk level	Reasoning	Final EPR	Magnitude of consequence			Overall consequence	Likelihood	Risk level
			Extent	Severity	Duration						Extent	Severity	Duration			
CONSTRUCTION																
GM01	Upgrade works to M80 pavement/subgrade cause ground movements that lead to damage to the Maroondah aqueduct.	GM2, GM3	Local	High	3 months to 2 years	Moderate	Possible	Medium	The aqueduct is still an operational utility and any new motorway works above it represents a potential hazard to the structural integrity of this structure	GM1, GM2	Local	High	3 months to 2 years	Moderate	Rare	Low
GM02	Open cut and cut-and-cover excavations between Watsonia Station and Lower Plenty Road causing ground movement leading to damage to nearby residential properties, infrastructure and utilities adjacent to Greensborough Road.	GM2, GM3	Local	Low	3 months to 2 years	Minor	Unlikely	Low	Excavation offset to Greensborough Rd is about 20m typically so depending on the "stiffness" of the support systems the effects should be kept to a minimum - risk increases with closer proximity in places	GM1, GM2, GM3	Local	Medium	3 months to 2 years	Minor	Rare	Very low
GM03	Construction of the northern portal (TBM) temporary retention structures causing ground movement leading to damage to adjacent residential properties (and minor utilities).	GM2, GM3	Local	Medium	3 months to 2 years	Minor	Possible	Low	the portal structure is very close to the road and nearby houses, and also located within the faulted ground controlling Banyule Creek drainage course	GM1, GM2, GM3	Local	Low	3 months to 2 years	Minor	Rare	Very low
GM04	Construction of the trench south of Yallambie Road causing ground movement leading to damage to buildings in Simpson Barracks.	GM2, GM3	Local	High	3 months to 2 years	Moderate	Possible	Medium	Close proximity of open (no permanent roof) retained cutting excavation	GM1, GM2, GM3	Local	Low	3 months to 2 years	Minor	Possible	Low
GM05	TBM tunnelling between Lower Plenty Road and Banyule Flats may cause ground movement leading to damage to residential, sensitive or heritage buildings (for example Banyule Homestead, Viewbank house, Goodstart Early Learning).	GM2, GM3	Municipality	Low	3 months to 2 years	Minor	Possible	Low	Dense residential development over alignment plus known potential for wide fault zones and deeper weathering in this area.	GM1, GM2, GM3	Local	Low	3 months to 2 years	Minor	Rare	Very low
GM06	TBM tunnelling between Banyule Flats and Banksia Street causing ground movement leading to damage to residential, sensitive or heritage buildings (for example Banyule flats, Heide Sculpture Park).	GM2, GM3	Local	Low	3 months to 2 years	Minor	Possible	Low	known potential for wide fault zones, variable/unpredictable top of rock and poorly consolidated alluvial sediments in this area.	GM1, GM2, GM3	Local	Low	3 months to 2 years	Minor	Rare	Very low
GM07	TBM tunnelling between northern edge of Banyule Flats and Banksia Street causing localised heave or settlement leading to permanent visible changes to landforms.	GM1, GM2	Local	Medium	0-3 months	Minor	Possible	Low	known potential for wide fault zones, variable/unpredictable top of rock and poorly consolidated alluvial sediments in this area.	none	Corridor	Very low	3 months to 2 years	Minor	Rare	Very low
GM09	Groundwater drawdown associated with temporary dewatering of Manningham Road Interchange excavations may cause drawdown settlement related ground movements, adversely affecting parklands and landscape areas including Bolin Swamp and Manningham Interchange Slope.	GM1, GM2, GM3	Local	Low	2-7 years	Minor	Possible	Low	Preliminary hydro-modelling indicates that it is possible that widespread drawdown can occur. However given the local geological conditions, the susceptivity of the local compressible soils to groundwater drawdown is not expected to cause any major consequence.	GM1, GM2	Local	Low	2-7 years	Minor	Possible	Low
GM10	Groundwater "mounding" associated with Manningham Road Interchange retention structures may cause swelling or compaction related ground movements, adversely affecting adjacent utilities, Bulleen Road, commercial and residential buildings.	GM1, GM2, GM3	Local	Low	2-7 years	Minor	Unlikely	Low	Lack of sufficient geotech BH information means there remains significant uncertainty here.	GM1	Local	Very low	2-7 years	Negligible	Possible	Low
GM11	Sequential Excavation Method (SEM) mined tunnelling beneath the area between Bulleen Road and Rocklea Road, causing ground movement leading to damage to adjacent utilities, Bulleen Rd, and residential buildings.	GM2, GM3	Local	Medium	3 months to 2 years	Minor	Possible	Low	The risk is greater close to the portals where ground cover is reduced. Elsewhere, should be OK depending on actual geology found.	GM1, GM2, GM3	Local	Low	3 months to 2 years	Minor	Unlikely	Low

Risk ID	Potential threat and effect on the environment	INITIAL RISK								RESIDUAL RISK						
		Initial EPR	Magnitude of consequence			Overall consequence	Likelihood	Risk level	Reasoning	Final EPR	Magnitude of consequence			Overall consequence	Likelihood	Risk level
			Extent	Severity	Duration						Extent	Severity	Duration			
GM12	Sequential Excavation Method (SEM) mined tunnels may cause unacceptable strains on Historic Clarendon Eyre House (6 Robb Close) if variable ground conditions (deep weathering, paleo-channel deposits) are encountered.	GM2, GM3	Local	Medium	3 months to 2 years	Minor	Unlikely	Low	Highly dependent on possible alternative alignments - previous project alignments resulted in potentially high risk to this structure. Current alignment is far enough away to be OK	none	Local	Very low	3 months to 2 years	Negligible	Rare	Very low
GM13	Construction of the cut-and-cover/retained excavations south of Rocklea Road causing ground movement leading to damage to adjacent residential properties and minor utilities.	GM2, GM3	Local	Medium	3 months to 2 years	Minor	Possible	Low	Awaiting planned additional geotechnical BHs - this distinctive geomorphological feature may reflect alluvial/colluvial modification of a historic fault scarp - unknown	GM1, GM2, GM3	Local	Low	3 months to 2 years	Minor	Unlikely	Low
GM14	Construction of the cut-and-cover/retained excavations south of Rocklea Road causing ground movement leading to damage to the Veneto Club and the Bolin Swamp Integrated Water Facility.	GM1, GM2, GM3	Local	Medium	3 months to 2 years	Minor	Possible	Low	'Close proximity of retained cutting excavation plus potential temporary construction de-watering may result in short term and drawdown related settlement for the Club	GM1, GM2, GM3	Local	Medium	3 months to 2 years	Minor	Unlikely	Low
GM16	Eastern Freeway upgrade works parallel to/and above the Koonung Creek Culvert causing ground movements leading to damage of the concrete (BEBO) arch structure in areas where it is not bridged over.	GM2, GM3	Municipality	Medium	2-7 years	Moderate	Possible	Medium	Potential changes in engineered fil around the conduit plus substantial increase in ground load from widened embankments could affect sections of the structure not proposed to be 'bridged' over.	GM1, GM2, GM3	Corridor	Medium	2-7 years	Moderate	Unlikely	Low
GM17	Trenched excavations and de-watering associated with the Bulleen Road cut-and-cover section as well as pipe jacking associated with the Bulleen Road sewer diversion works causing ground movement leading to permanent surface settlement/depressions and water ponding in playing fields.	GM2	Local	Very low	3 months to 2 years	Negligible	Possible	Low	Existing low lying area (including flood retention basin) and soft alluvial soils expected in this area. Any settlement may be visible as surface water filled depressions after heavy rainfall.	GM1, GM2	Local	Low	3 months to 2 years	Minor	Unlikely	Low
GM18	Pipe-jacking for Bulleen Road sewer diversion works in shallow cover beneath Trinity Grammar Sporting Complex causing ground movement leading to localised "sinkholes" or surface "blowout" and damage to fields.	GM2	Local	Low	3 months to 2 years	Minor	Possible	Low	In shallow cover and loose alluvial soils, there is a risk that pipe-jacking may cause damage to the fields.	GM2, GM3	Local	Low	3 months to 2 years	Minor	Unlikely	Low
GM19	Tunnelling between Lower Plenty Road and edge of Banyule Flats may cause ground movement leading to damage to Banyule Creek sewer.	GM2	Local	Low	3 months to 2 years	Minor	Possible	Low	sewer directly over alignment so may suffer adverse effects.	GM1, GM2	Local	Very low	3 months to 2 years	Negligible	Possible	Low
GM20	Tunnelling beneath Banksia Park at Banksia St portal in addition to the Manningham Interchange cut-and-cover excavation may cause ground movement leading to damage to "Helmet", a sculptural installation owned by Manningham Council.	GM1, GM2, GM3	Local	High	3 months to 2 years	Moderate	Likely	Medium	Potential high settlement at TBM launch will affect sculpture	GM1, GM2, GM3, GM4	Local	Medium	3 months to 2 years	Minor	Likely	Medium
GM21	Tunnelling beneath Banksia Park at Banksia St portal in addition to the cut-and-cover excavation may cause ground movement leading to damage to "Journey's End" heritage building (and adjacent property).	GM3	Local	Low	3 months to 2 years	Minor	Rare	Very low	Heritage structure; adjacent house is slightly closer to works	none	Local	Very low	0-3 months	Negligible	Rare	Very low
GM22	Upgrade works to Eastern Freeway pavement/subgrade causes ground movements that leads to damage to the 1.15 metre diameter pipeline near Kenneth Street (Kenneth Street water main).	GM2, GM3	Local	High	3 months to 2 years	Moderate	Unlikely	Low	Pipe material is expected to be resistant to the anticipated increase in surface loads induced by the road widening in the vicinity of this utility.	none	Local	Medium	3 months to 2 years	Minor	Rare	Very low

Risk ID	Potential threat and effect on the environment	INITIAL RISK								RESIDUAL RISK						
		Initial EPR	Magnitude of consequence			Overall consequence	Likelihood	Risk level	Reasoning	Final EPR	Magnitude of consequence			Overall consequence	Likelihood	Risk level
			Extent	Severity	Duration						Extent	Severity	Duration			
GM23	Construction of the road embankment between Bulleen Oval and the Eastern Freeway causes ground movement leading to damage to the 2.25 metre diameter North Yarra Main Branch sewers (Bullen Road west sewer).	GM2, GM3	Local	High	3 months to 2 years	Moderate	Possible	Medium	The construction of the road embankment at this location is expected cause ground movement. The large pipe diameter increases the sensitivity of this utility. Pipe material is expected to have reasonable resistance to ground movement.	GM1, GM2	Local	High	3 months to 2 years	Moderate	Unlikely	Low
GM24	Upgrade works to Greensborough Road causing ground movements that lead to damage to the Dandenong - Melbourne ring main (Elder Street gas main).	GM2, GM3	Local	High	3 months to 2 years	Moderate	Unlikely	Low	The ground conditions here comprise around 2.5 m of compressible soil underlain by bedrock material. Given the low thickness of the compressible soil, significant ground movements due to the increased surface loads are not expected.	GM1, GM2	Local	Medium	3 months to 2 years	Minor	Rare	Very low
GM25	Tunnelling beneath Banyule Flats may cause ground movement leading to damage to parklands and landscape areas, including the Banyule Wetlands swamp.	GM2	Local	Medium	7+ years	Moderate	Unlikely	Low	Ground movement may modify the embankment elevation at the outfall location and compromise the water level regulation of the wetlands.	GM1, GM2, GM3, GM4	Local	Medium	7+ years	Moderate	Rare	Low
GM26	Lower Plenty Rd water mains (conceptual re-alignment) adversely affected by the TBM launch/reception in potentially faulted ground (high VL %)	GM2, GM3	Local	High	3 months to 2 years	Moderate	Likely	Medium	Given the proximity of the conceptual alignment to the cut and cover excavations, ground movements and pipe strains are expected to be high.	GM1, GM2, GM3, GM4	Local	High	3 months to 2 years	Moderate	Rare	Low
GM27	Excavation of TBM retrieval shafts at the southern end of the TBM tunnels adversely impacting residential properties on Bridge Street.	GM1, GM2, GM3	Local	Low	3 months to 2 years	Minor	Possible	Low	The TBM retrieval shaft alternative option is located approximately 35m from the residential housing on Bridge Street, with an estimated depth in the region of 30-35m.	GM1, GM2, GM3	Local	Low	3 months to 2 years	Minor	Unlikely	Low

Appendix B – Settlement Contour Maps



Paper Size A3

0 250 500 750 1000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

LEGEND

- No assessment *
- Second Stage Assessment
- Preliminary Assessment
- Detailed Assessment

The 5 mm contour indicates the ground movement zone of influence

* No assessment conducted as properties are to be acquired

NORTH EAST LINK PROJECT

North East Link Project

Settlement Contour Map
EES Ground Movement Report

Job Number	31-5006
Revision	7
Date	6 Feb 2019

Appendix B0

Paper Size A3

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Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

LEGEND

- No assessment *
- Second Stage Assessment
- Preliminary Assessment
- Detailed Assessment

The 5 mm contour indicates the ground movement zone of influence

* No assessment conducted as properties are to be acquired

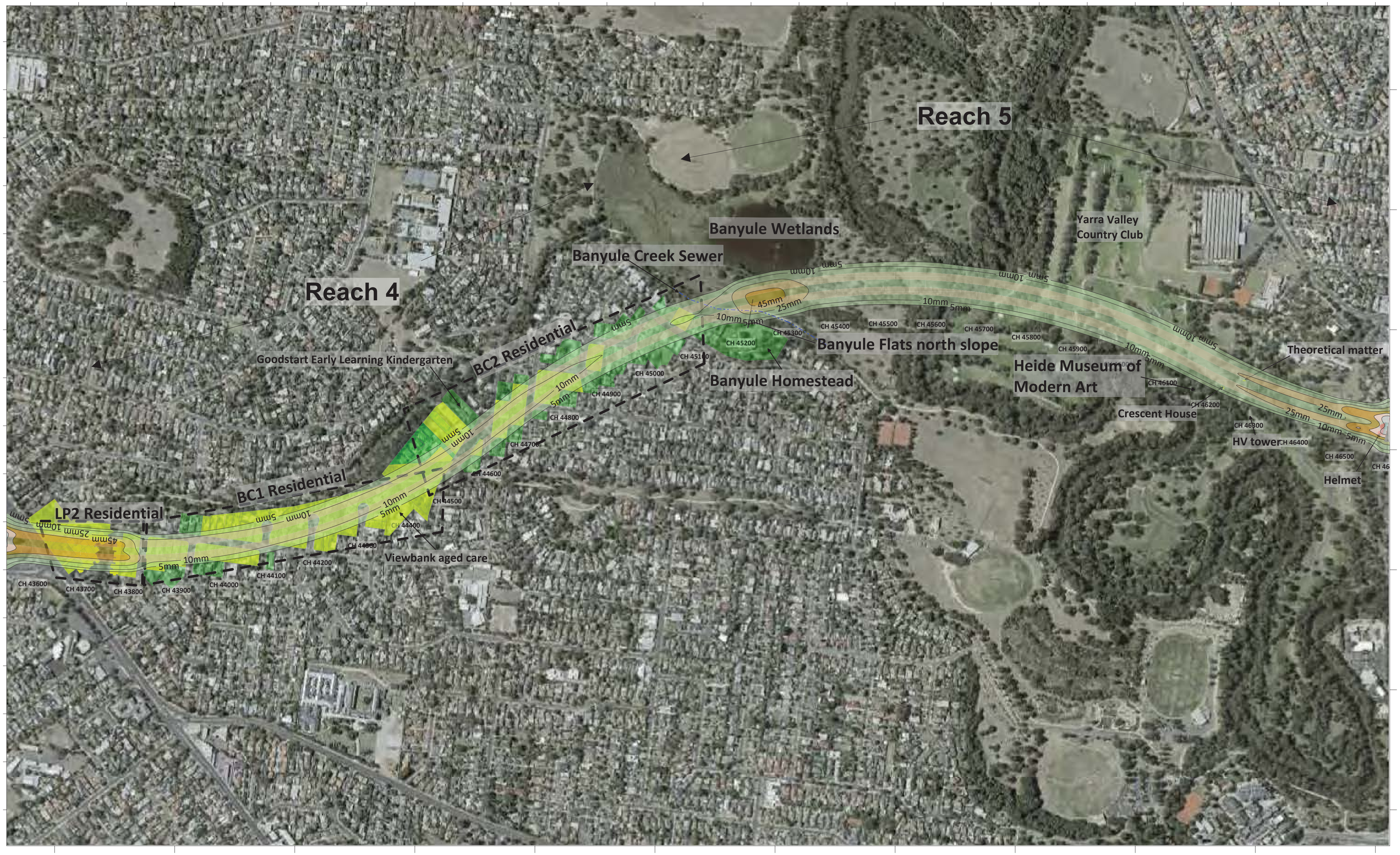
NORTH EAST LINK PROJECT

North East Link Project

Settlement Contour Map
EES Ground Movement Report

Job Number	31-5006
Revision	7
Date	6 Feb 2019

Appendix B1



Paper Size A3

0 250 500 750 1000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

LEGEND

- No assessment *
- Second Stage Assessment
- Preliminary Assessment
- Detailed Assessment

The 5 mm contour indicates the ground movement zone of influence

* No assessment conducted as properties are to be acquired

NORTH EAST LINK PROJECT

North East Link Project

Settlement Contour Map
EES Ground Movement Report

Job Number	31-5006
Revision	7
Date	6 Feb 2019

Appendix B2

Paper Size A3

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Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

LEGEND

- No assessment *
- Second Stage Assessment
- Preliminary Assessment
- Detailed Assessment

The 5 mm contour indicates the ground movement zone of influence

* No assessment conducted as properties are to be acquired

NORTH EAST LINK PROJECT

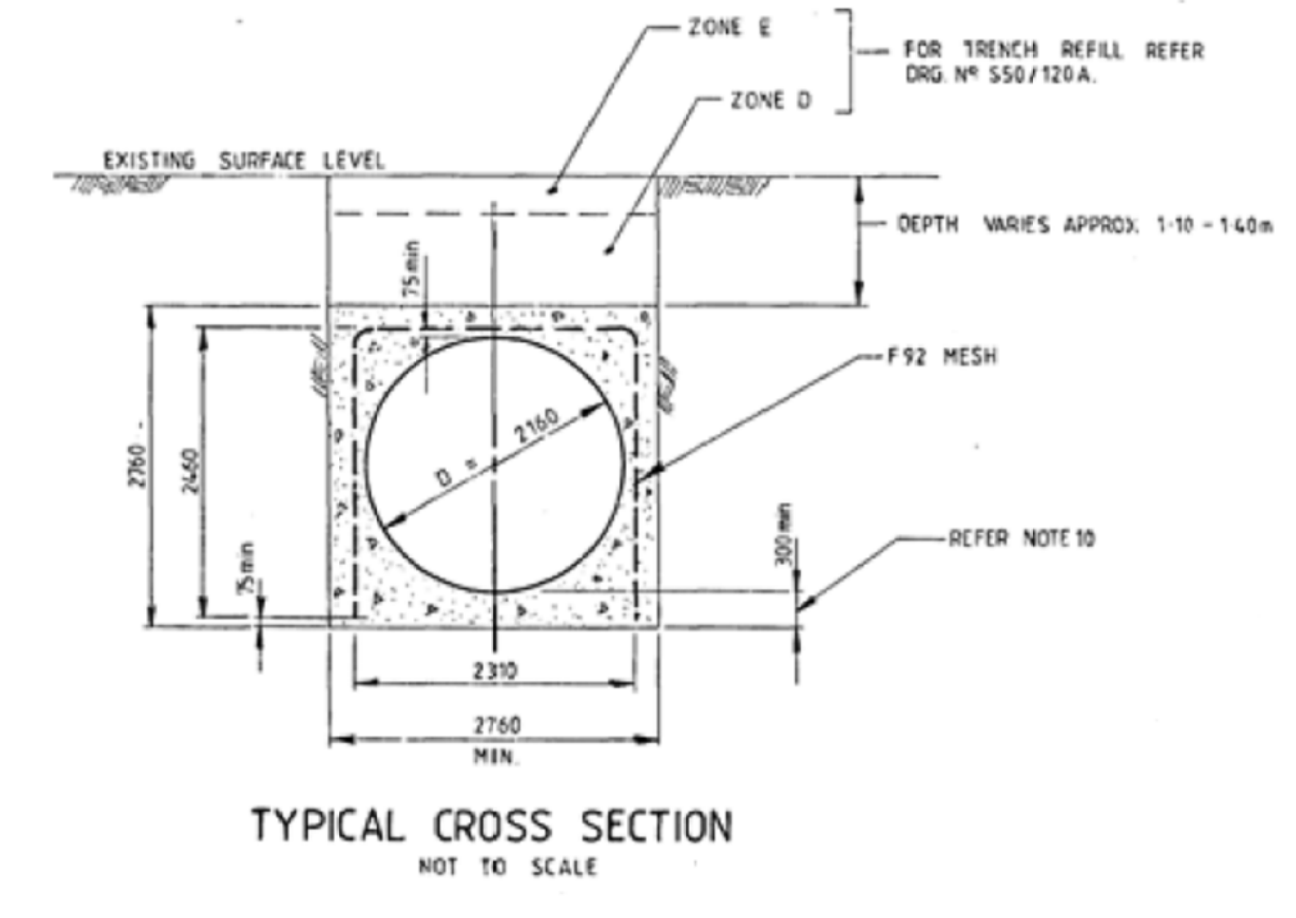
North East Link Project

Settlement Contour Map
EES Ground Movement Report

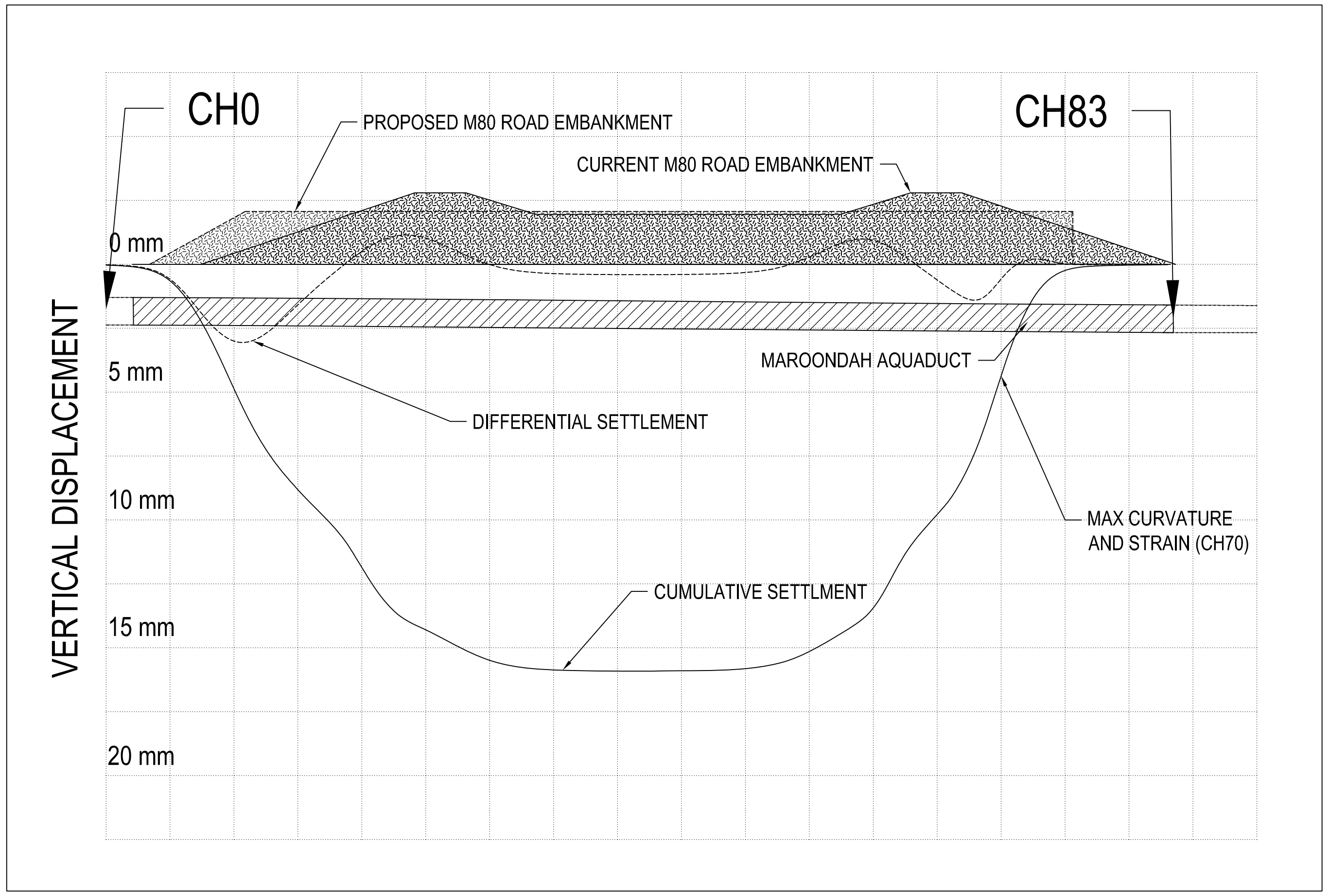
Job Number	31-5006
Revision	7
Date	6 Feb 2019

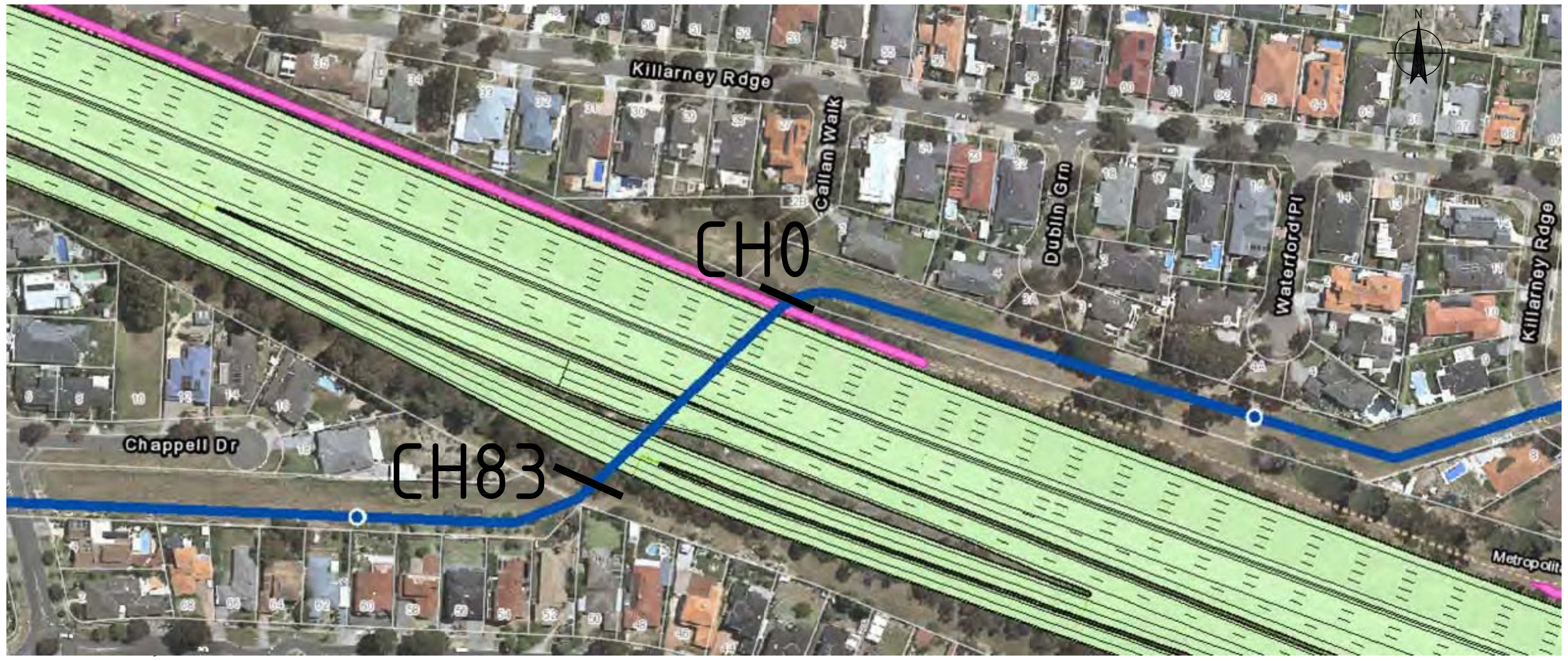
Appendix B3

Appendix C – Second Stage Assessments



MAROONDAH AQUEDUCT





PIPE PROPERTIES	
MATERIAL	CEMENT LINED STEEL (CLS)
INSIDE DIAMETER (mm)	2100
WALL THICKNESS (mm)	10
PIPE SEGMENT LENGTH (m)	CONTINUOUS
PIPE JOINTING	WELDED
SOIL-PIPE INTERACTION	RELATIVELY FLEXIBLE

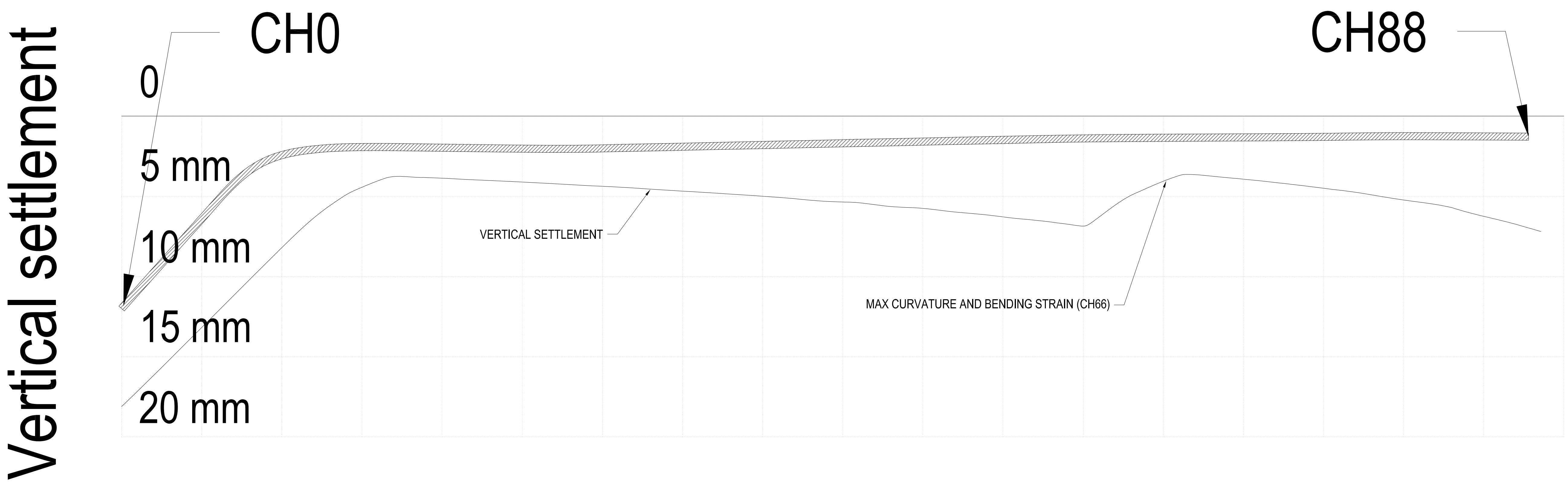
RESULTS (CUMULATIVE SETTLEMENT)				
	VALUE	LOCATION	RANKIN RISK CATEGORY	
MAX. SETTLEMENT (mm)	16	CH58	SLIGHT	
MAX. SLOPE V:H	1:824	CH70	NEGLIGIBLE	
	VALUE	LOCATION	THRESHOLD	WITHIN THRESHOLD?
MIN. RADIUS OF CURVATURE (km)	5.4	CH75	2.65	YES
MAX. BENDING STRAIN (με)	197	CH75	400	YES

EES Ground Movement Report
Second Stage Assessment - Maroondah Aqueduct

APPENDIX C1

North East Link Project

Job Number | 31-35006
Date | 21 Dec 2018

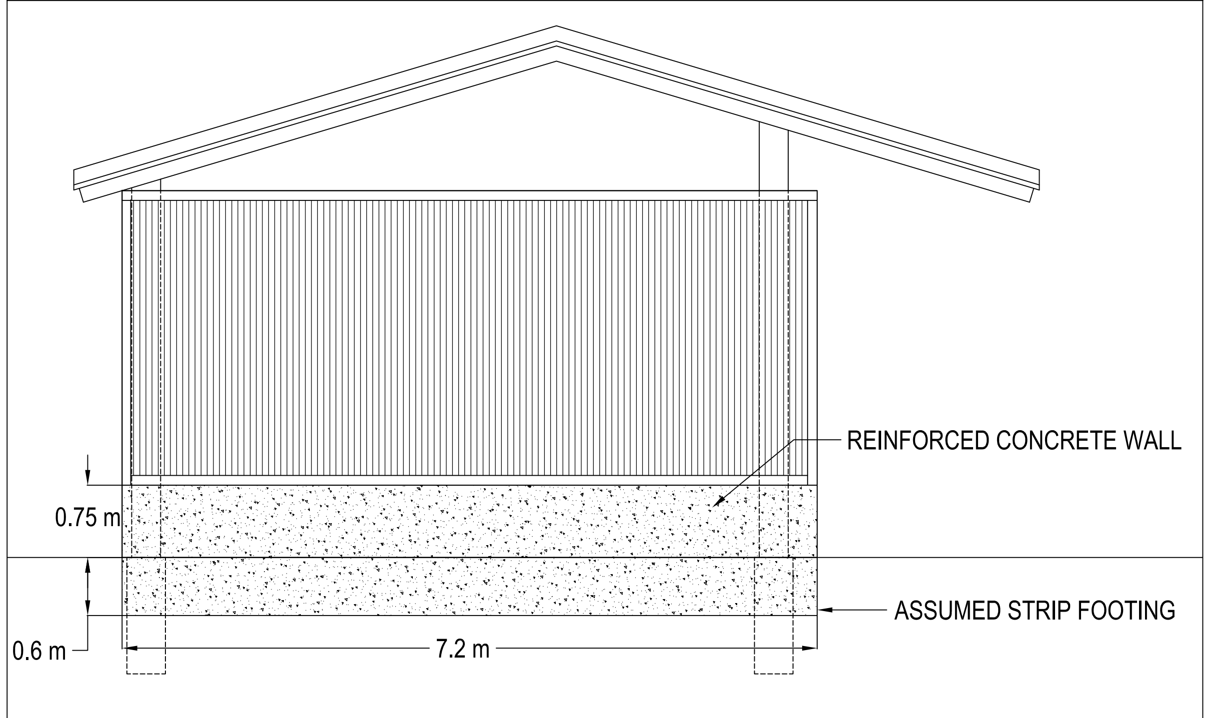


ELDER STREET GAS MAIN

PIPE PROPERTIES	
MATERIAL	STEEL
INSIDE DIAMETER (mm)	441
WALL THICKNESS (mm)	8
PIPE SEGMENT LENGTH (m)	CONTINUOUS
PIPE JOINTING	WELDED
SOIL-PIPE INTERACTION	RELATIVELY FLEXIBLE

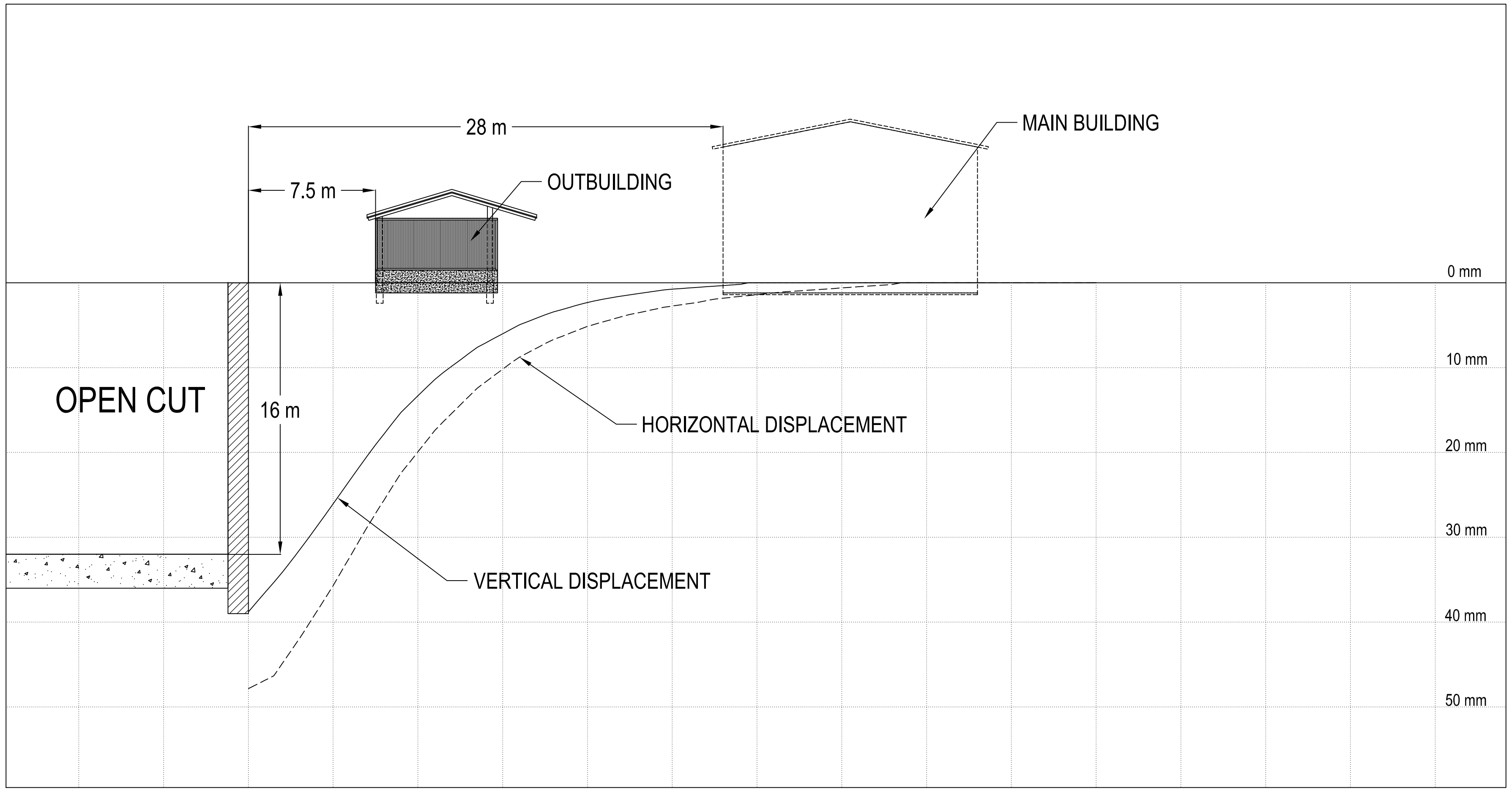
RESULTS				
	VALUE	LOCATION	RANKIN RISK CATEGORY	
MAX. SETTLEMENT (mm)	18	CH0	SLIGHT	
MAX. SLOPE (V:H)	1:998	CH8	NEGLIGIBLE	
	VALUE	LOCATION	THRESHOLD	WITHIN THRESHOLD?
MIN. RADIUS OF CURVATURE (km)	4.3	CH66	0.6	YES
MAX. BENDING STRAIN (με)	53	CH66	400	YES

SIMPSON BARRACKS OUTBUILDING



ASSUMED STRUCTURAL DETAILS

CORRUGATED GALVANISED STEEL SHEET CLADDING ON STEEL CHANNEL FRAME, BOLTED TO REINFORCED CONCRETE FOUNDATION

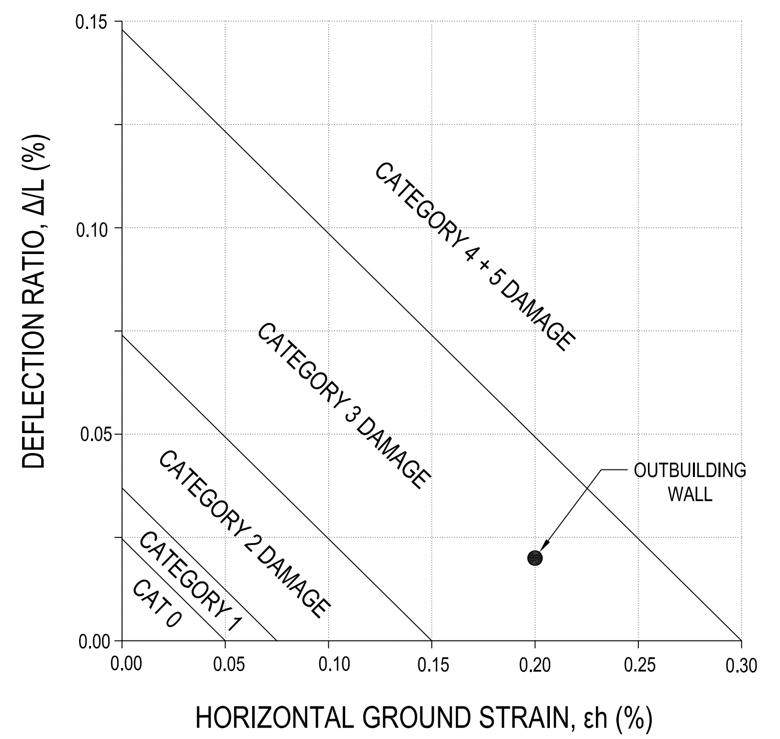


EXCAVATION		BUILDING (OUTBUILDING)	
DEPTH (m)	16	LENGTH (m)	7.2
WIDTH (m)	35	HEIGHT (m)	0.75
DEPTH TO AXIS (m)	N/A	FOUNDATION DEPTH (m)	0.6
VOLUME LOSS (%)	N/A	E/G	2.6
k	N/A	MAX. SETTLEMENT (mm)	19
S_{max} (mm)	39	MAX. SLOPE (V:H)	1:400

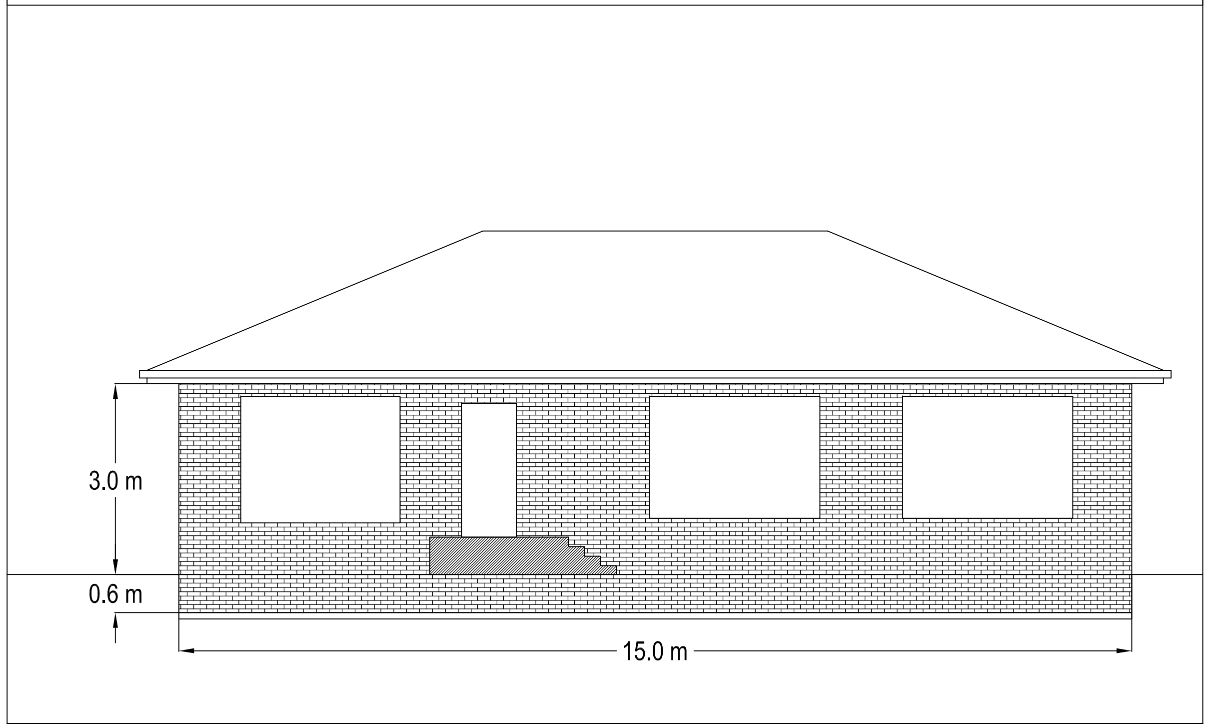
DAMAGE RISK CATEGORY (Burland, 1996)	Category 3 (Moderate)

	HOGGING ZONE	SAGGING ZONE
MAX. HORIZONTAL GROUND STRAIN (%)	0.2	-
DEFLECTION RATIO (%)	0.02	-
CRITICAL STRAIN MODE	BENDING	-
LENGTH IN CURVATURE ZONE (m)	7.2	-
L/H RATIO	5.3	-

Relationship of Damage Category to Deflection Ratio and Horizontal Tensile Strain

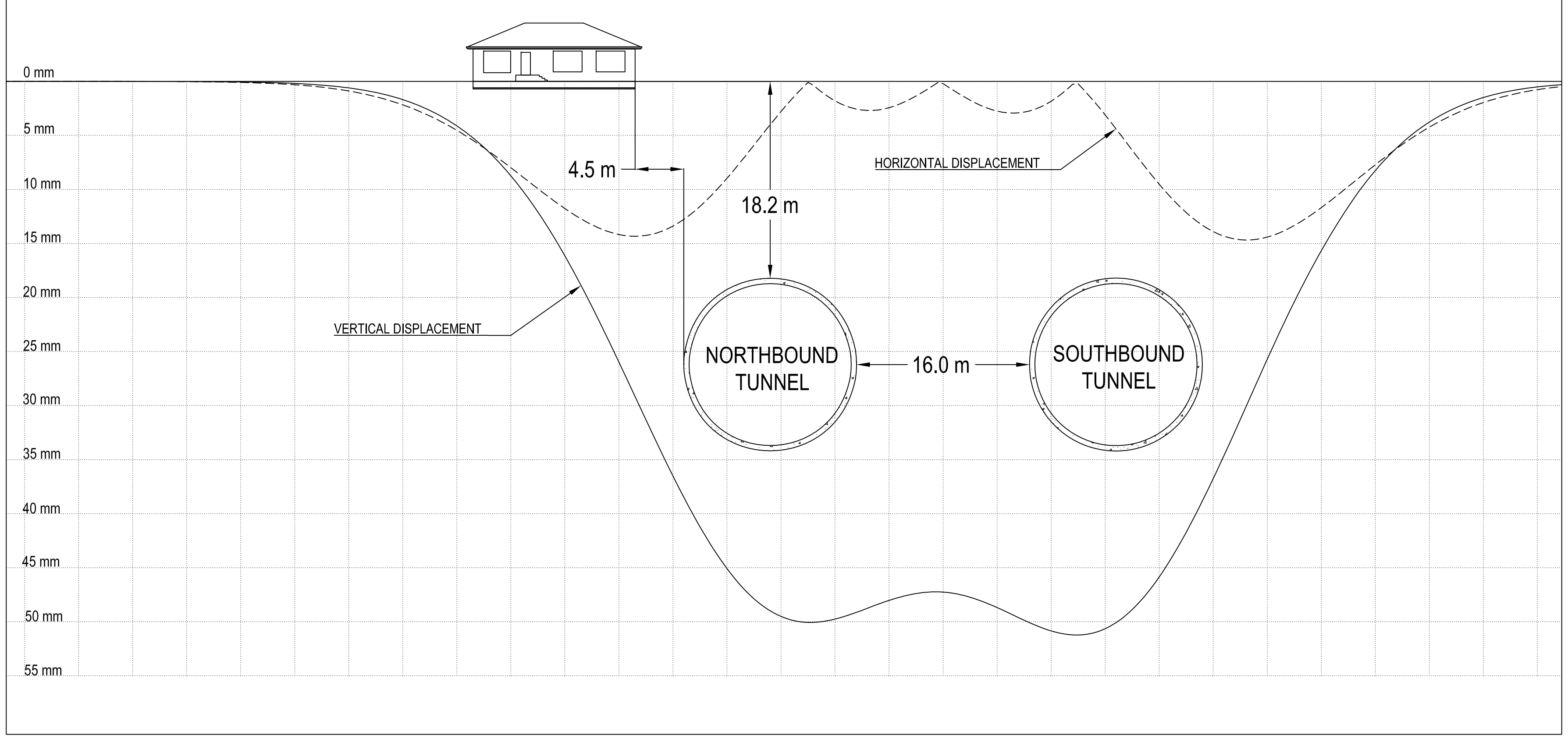


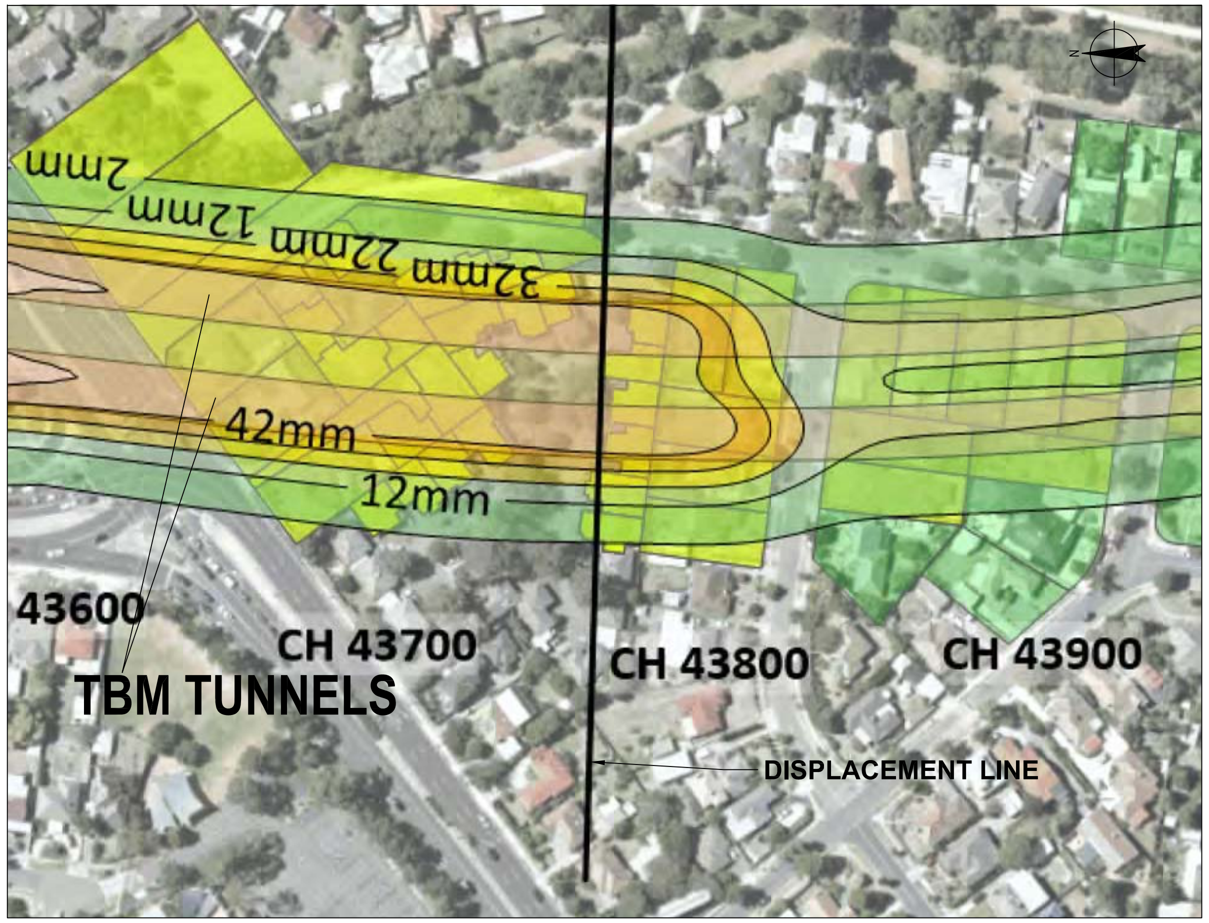
LOWER PLENTY PORTAL RESIDENTIAL



ASSUMED STRUCTURAL DETAILS

SINGLE STOREY BRICK VENEER FACADE ON PERIMETER CONCRETE STRIP FOOTING TIED TO TIMBER SUB-FRAME. BRICK PIERS INTEGRAL TO FACADE SUPPORT THE SUB-FLOOR BEARERS AT THE PERIMETER WITH STUMPED FOOTINGS PROVIDING INTERNAL BEARER SUPPORT. HIP ROOF 20° PITCH WITH EAVES.

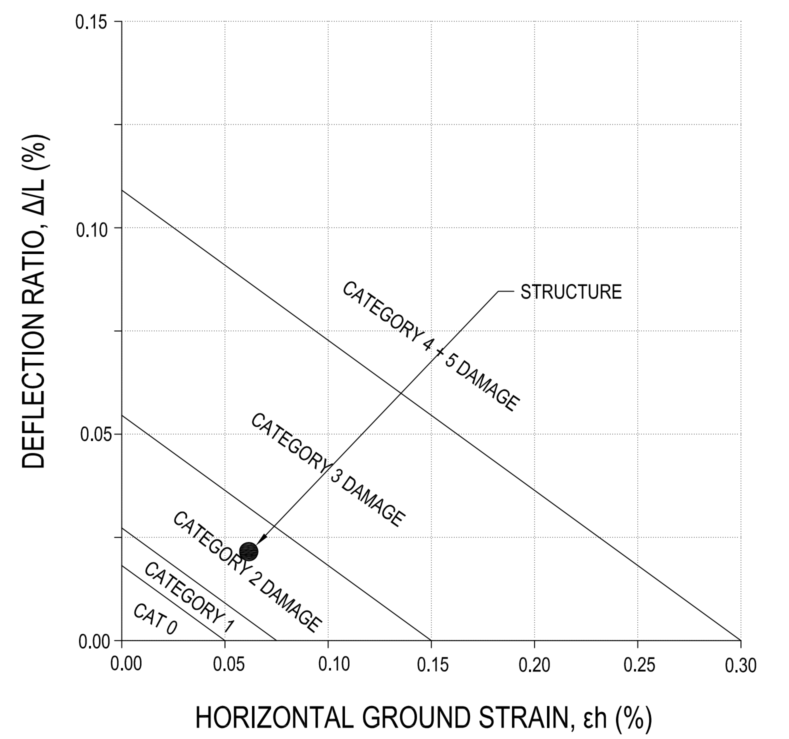




TUNNEL		BUILDING	
DEPTH TO CROWN (m)	18.2	LENGTH (m)	15
DIAMETER (m)	16	HEIGHT (m)	3.6
DEPTH TO AXIS (m)	26.2	FOUNDATION DEPTH (m)	0.6
VOLUME LOSS (%)	0.8	E/G	5
k	0.5	MAX. SETTLEMENT (mm)	29
S_{max} (mm)	51	MAX. SLOPE (V:H)	1:385

	HOGGING ZONE	SAGGING ZONE
MAX. HORIZONTAL GROUND STRAIN (%)	0.06	-
DEFLECTION RATIO (%)	0.02	-
CRITICAL STRAIN MODE	BENDING	-
LENGTH IN CURVATURE ZONE (m)	15	-
L/H RATIO	4.2	-
DAMAGE RISK CATEGORY (Burland)	2 (SLIGHT)	-

Relationship of Damage Category to Deflection Ratio and Horizontal Tensile Strain



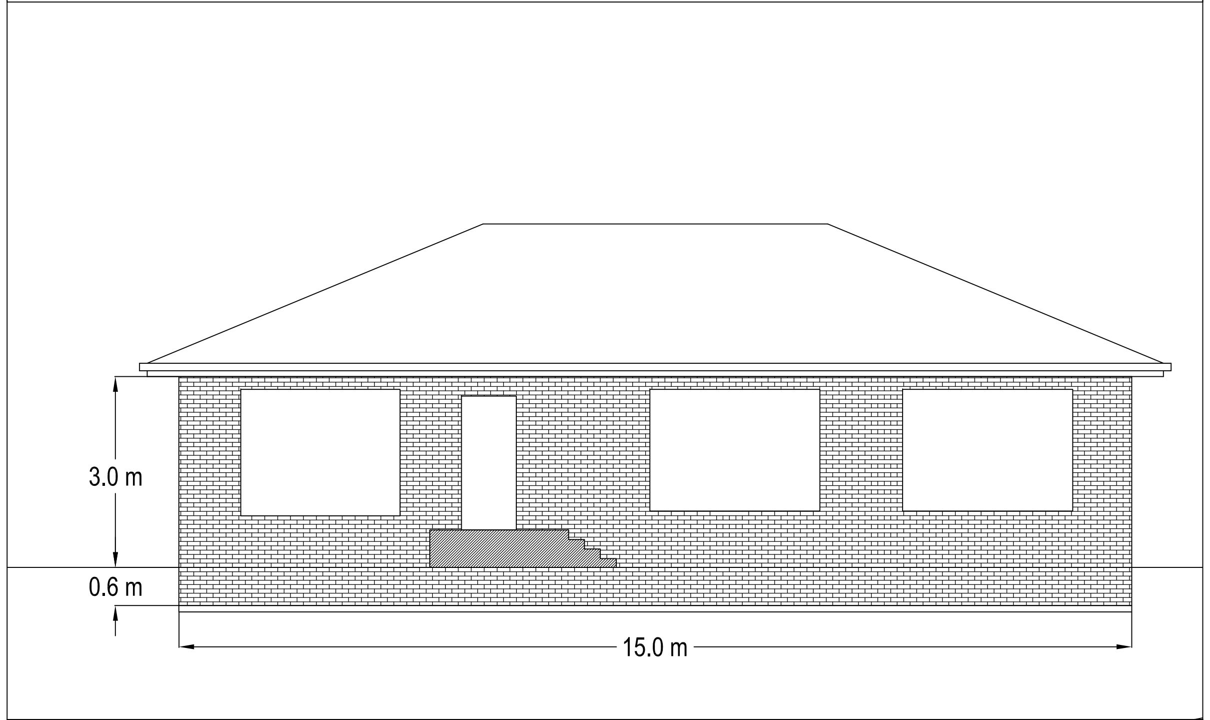
EES Ground Movement Report
Second Stage Assessment - Lower Plenty Portal Residential

APPENDIX C4

North East Link Project

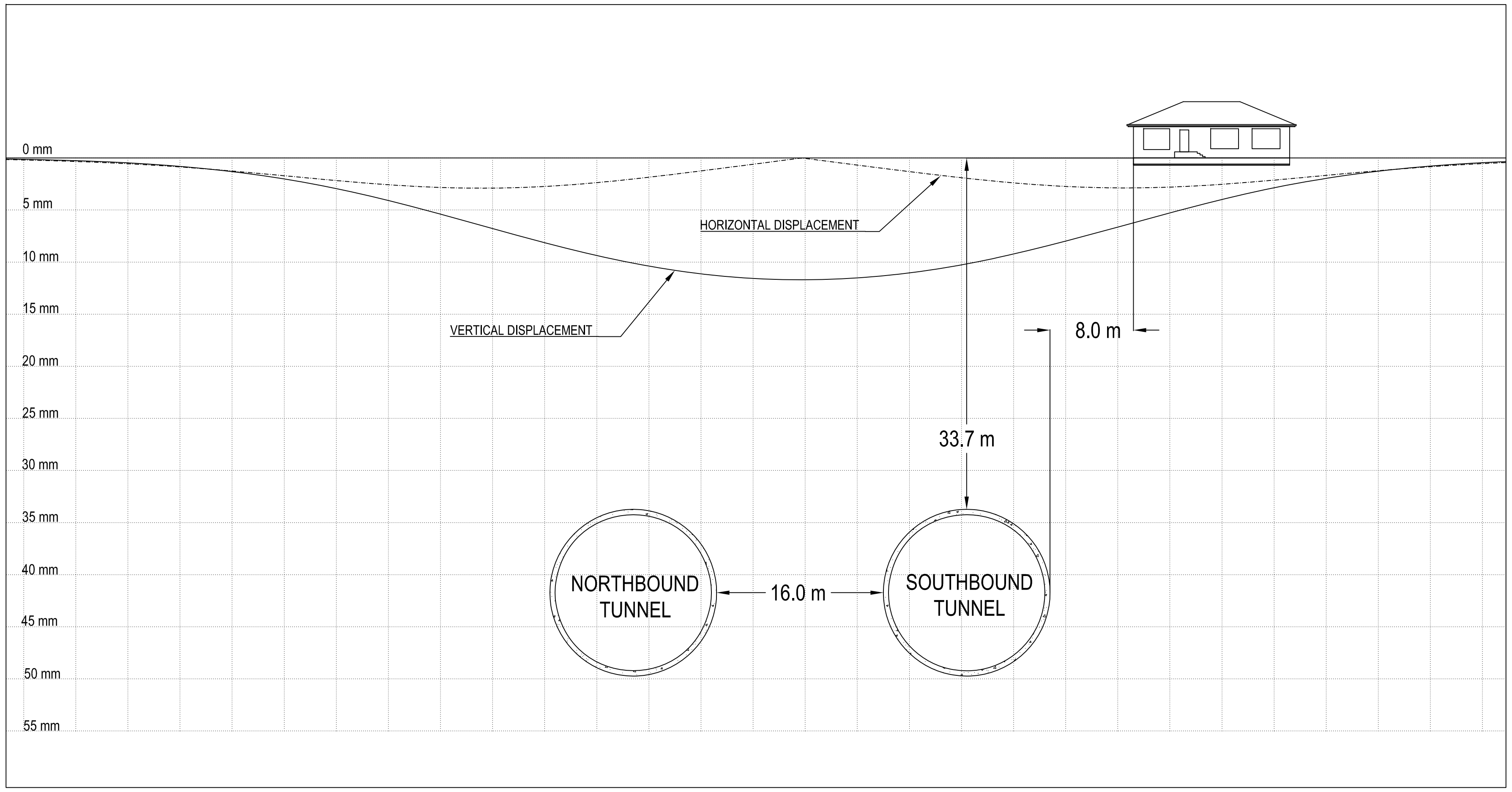
Job Number 31-35006
Date 21 Dec 2018

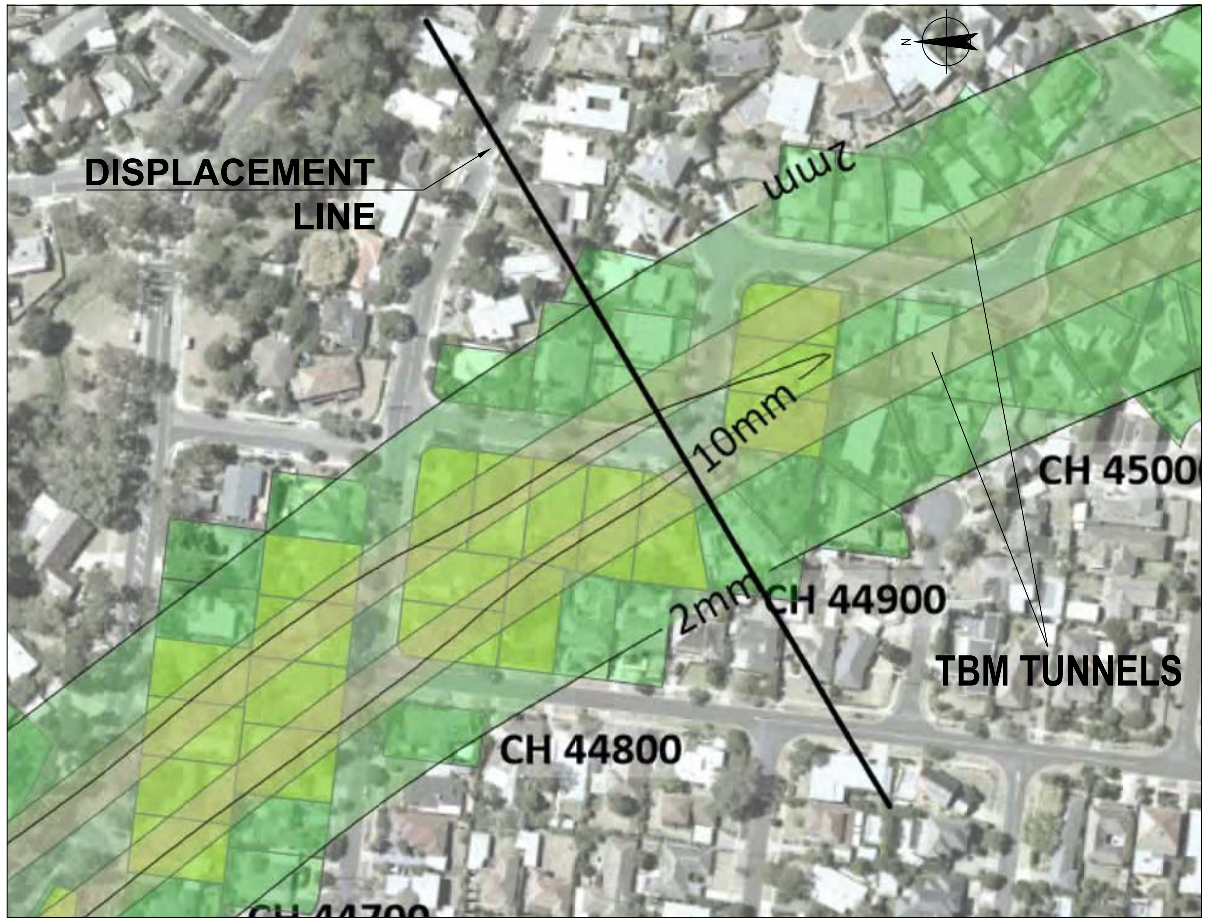
BANYULE CREEK RESIDENTIAL



ASSUMED STRUCTURAL DETAILS

SINGLE STOREY BRICK VENEER FACADE ON PERIMETER CONCRETE STRIP FOOTING TIED TO TIMBER SUB-FRAME. BRICK PIERS INTEGRAL TO FACADE SUPPORT THE SUB-FLOOR BEARERS AT THE PERIMETER WITH STUMPED FOOTINGS PROVIDING INTERNAL BEARER SUPPORT. HIP ROOF 20° PITCH WITH EAVES.

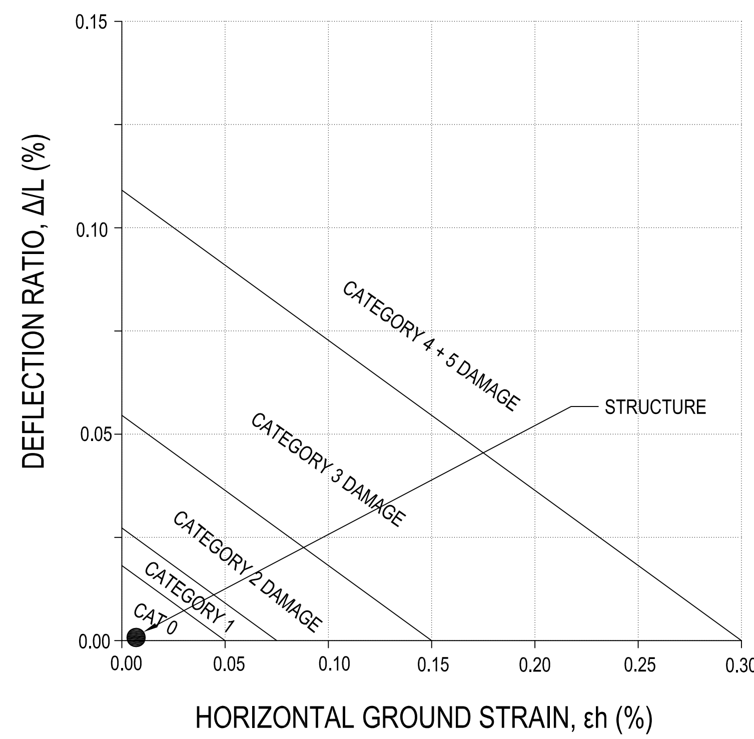




TUNNEL		BUILDING	
DEPTH TO CROWN (m)	33.7	LENGTH (m)	15
DIAMETER (m)	16	HEIGHT (m)	3.6
DEPTH TO AXIS (m)	41.7	FOUNDATION DEPTH (m)	0.6
VOLUME LOSS (%)	0.2	E/G	5
k	0.5	MAX. SETTLEMENT (mm)	6
S_{max} (mm)	12	MAX. SLOPE (V:H)	1:3800

	HOGGING ZONE	SAGGING ZONE
MAX. HORIZONTAL GROUND STRAIN (%)	0.004	-
DEFLECTION RATIO (%)	0.001	-
CRITICAL STRAIN MODE	BENDING	-
LENGTH IN CURVATURE ZONE (m)	15	-
L/H RATIO	4.2	-
DAMAGE RISK CATEGORY (Burland)	0 (NEGLIGIBLE)	-

Relationship of Damage Category to Deflection Ratio and Horizontal Tensile Strain

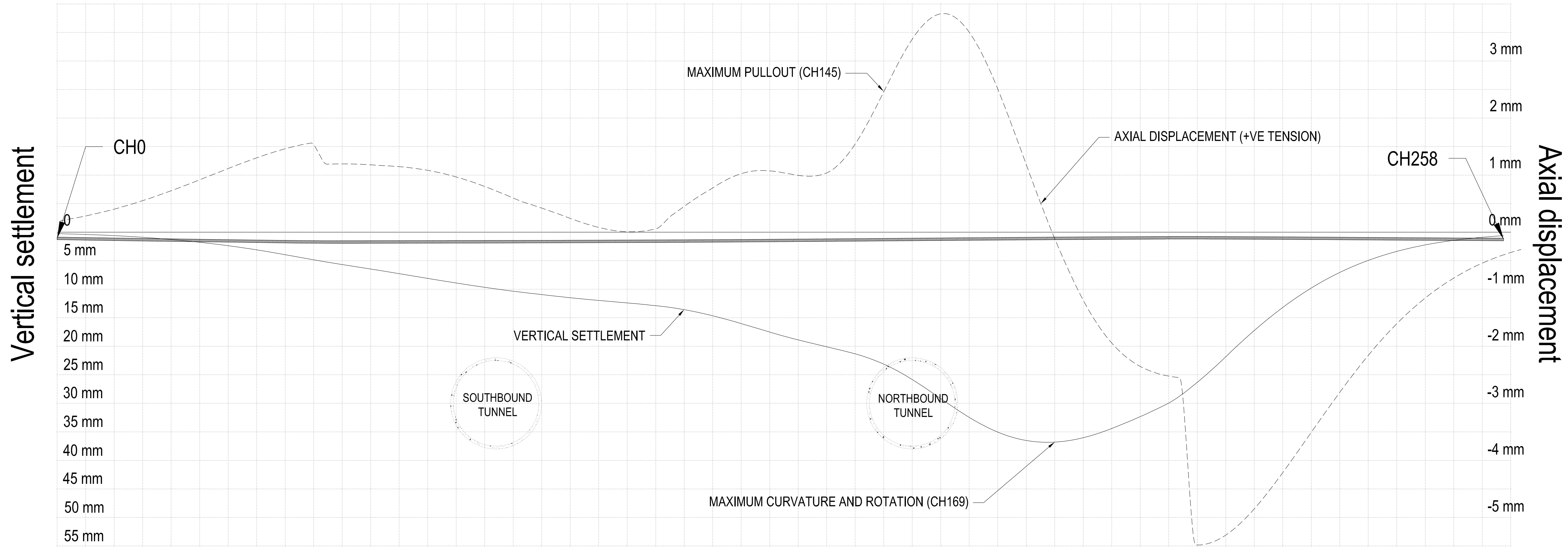


EES Ground Movement Report
Second Stage Assessment - Banyule Creek Residential

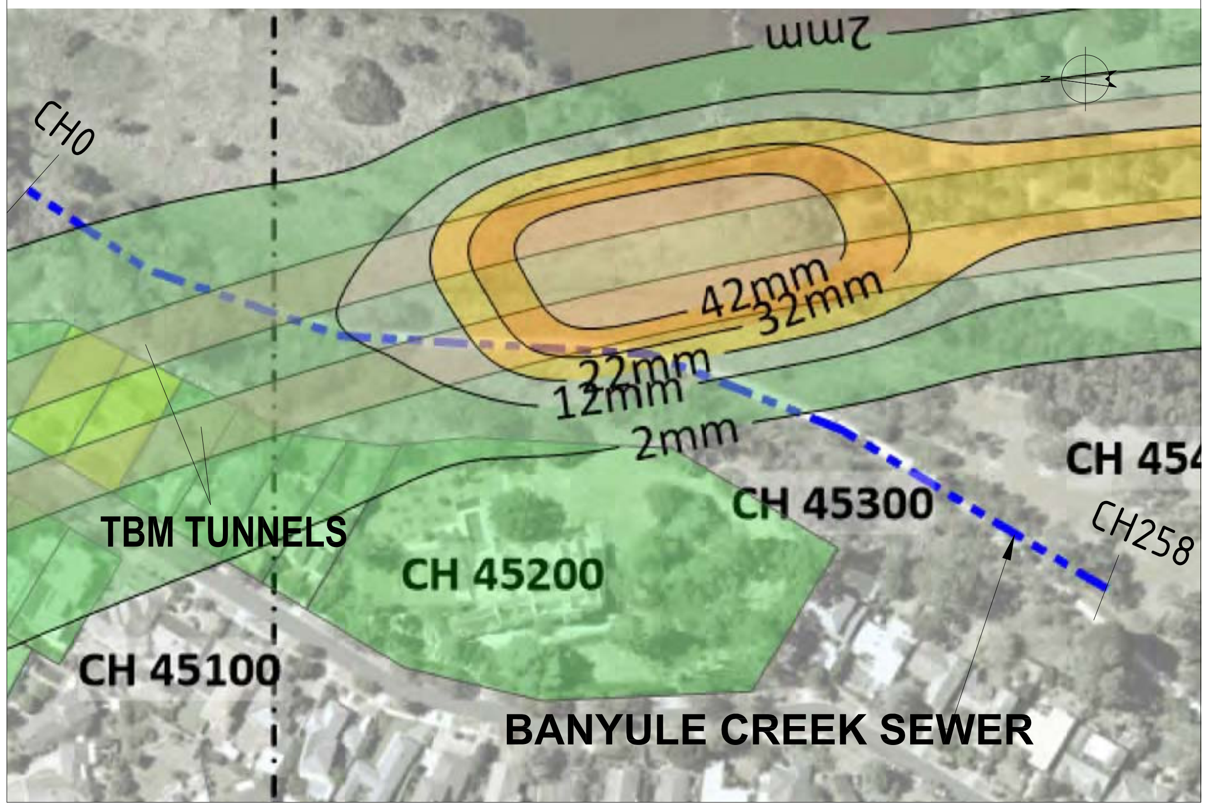
APPENDIX C5

North East Link Project

Job Number | 31-35006
Date | 21 Dec 2018



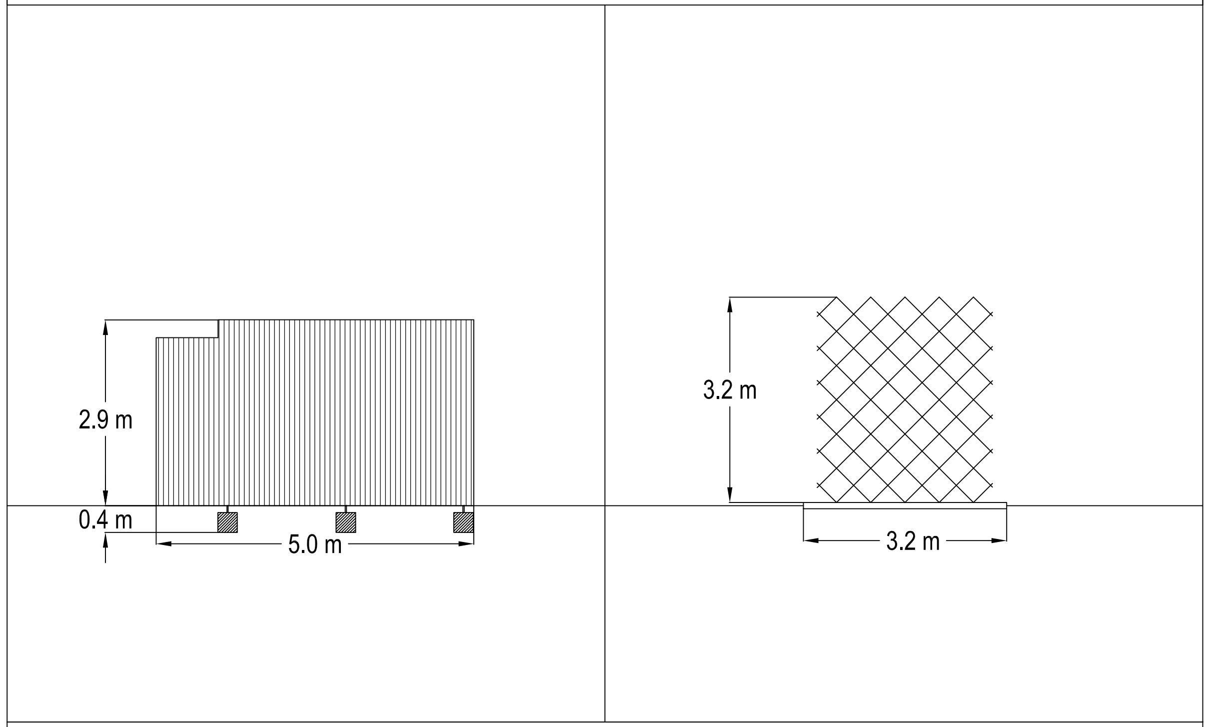
BANYULE CREEK SEWER



PIPE PROPERTIES	
MATERIAL	VITRIFIED CLAY
INSIDE DIAMETER (mm)	450
WALL THICKNESS (mm)	30
PIPE SEGMENT LENGTH (m)	0.6
PIPE JOINTING	SOCKET/SPIGOT
SOIL-PIPE INTERACTION	RELATIVELY RIGID

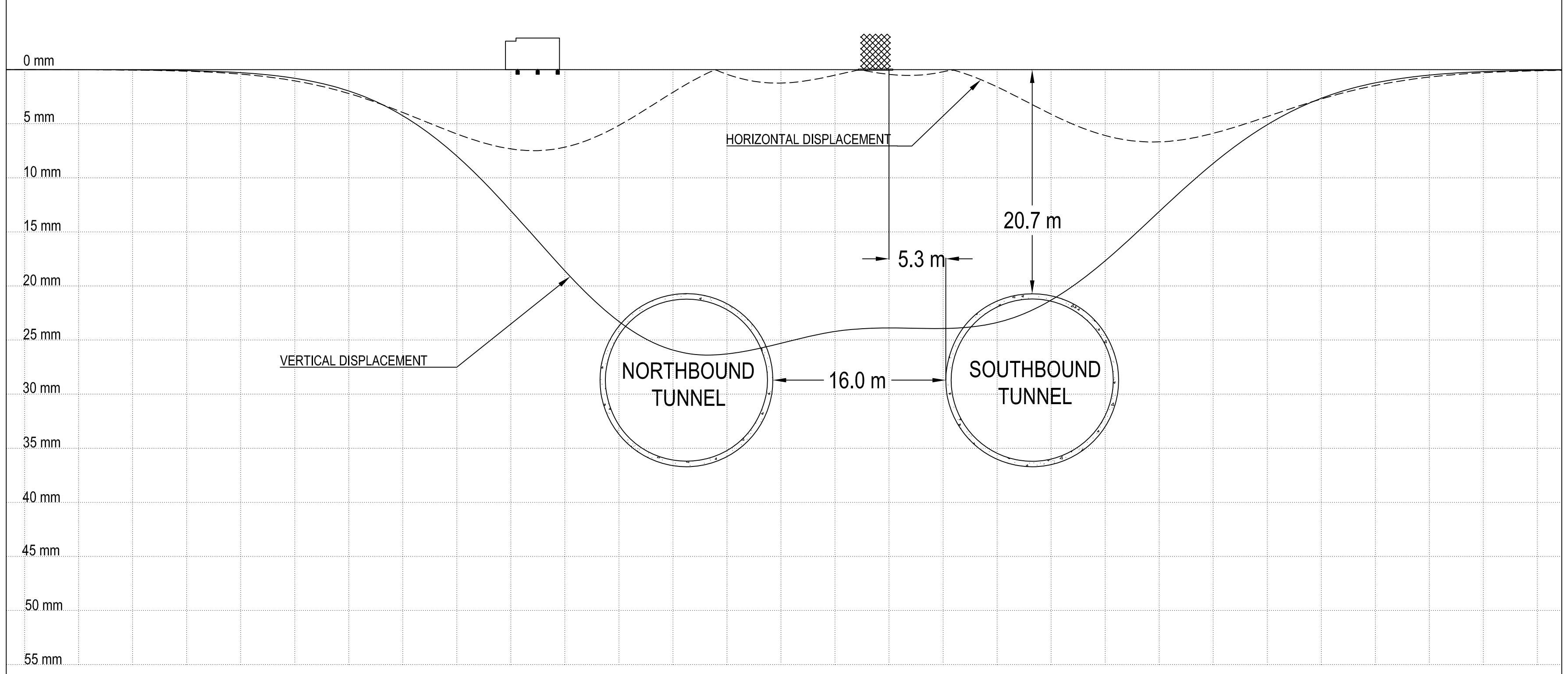
RESULTS				
	VALUE	LOCATION	RANKIN RISK CATEGORY	
MAX. SETTLEMENT (mm)	36	CH175	SLIGHT	
MAX. SLOPE (V:H)	1:1016	CH200	NEGLIGIBLE	
	VALUE	LOCATION	THRESHOLD	WITHIN THRESHOLD?
MAX. PULLOUT (mm)	0.25	CH155	7.5	YES
MAX. ROTATION (deg)	0.002	CH169	0.5	YES
MIN. RADIUS OF CURVATURE (km)	18	CH169	0.07	YES

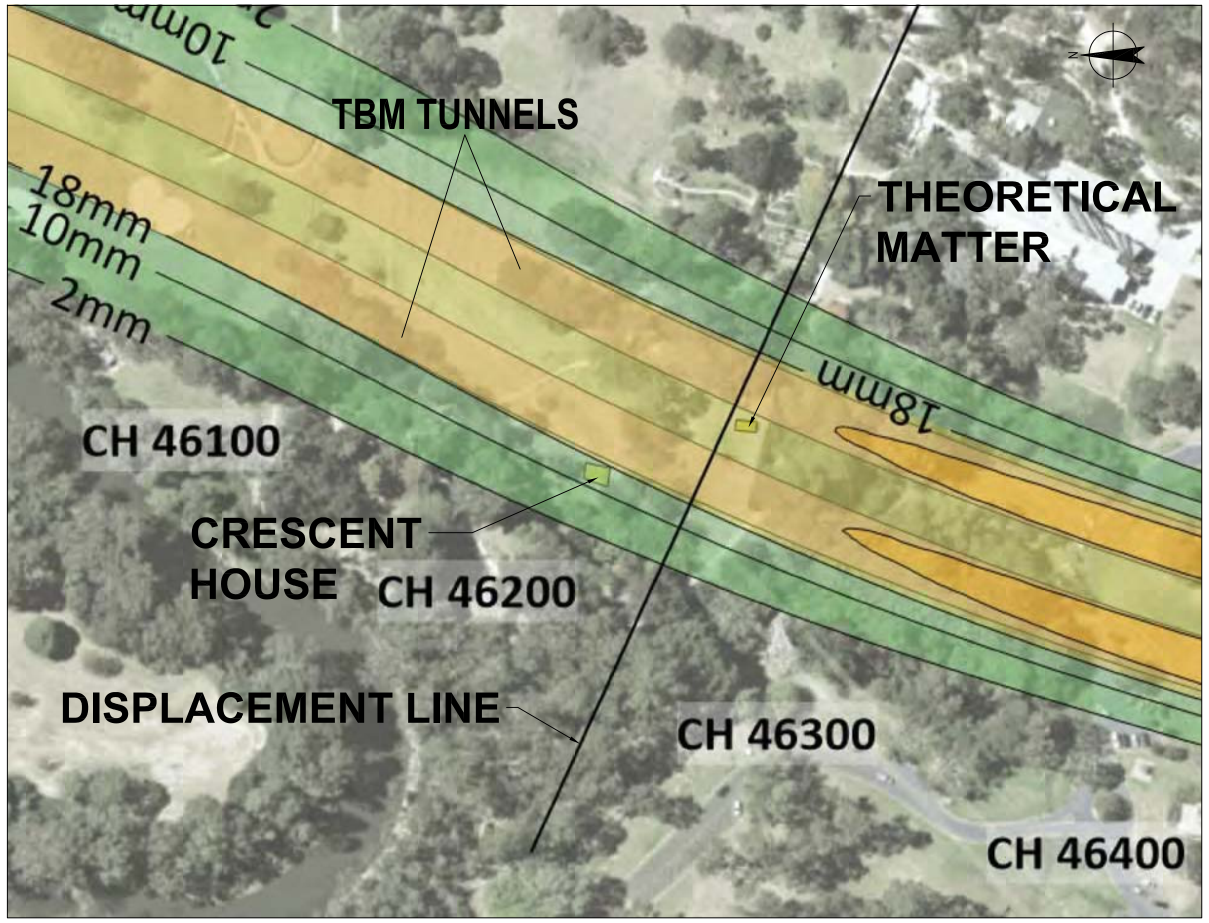
HEIDE PARK SCULPTURES



ASSUMED STRUCTURAL DETAILS

CRESCENT HOUSE: TIMBER FRAME CLAD WITH CEDAR BOARDS, TIMBER SUB-FLOOR FOUNDED ON PAD FOOTINGS.
THEORETICAL MATTER: DEFORMED STEEL BAR WELDED INTO LATTICE RESTING ON RE-INFORCED CONCRETE SLAB.





TUNNEL		BUILDING (CRESCENT HOUSE)	
DEPTH TO CROWN (m)	20.7	LENGTH (m)	5
DIAMETER (m)	16	HEIGHT (m)	2.9
DEPTH TO AXIS (m)	48.7	FOUNDATION DEPTH (m)	0.4
VOLUME LOSS (%)	0.4	E/G	N/A
k	0.5	MAX. SETTLEMENT (mm)	18
S_{max} (mm)	26	MAX. SLOPE (V:H)	1:900

BUILDING (THEORETICAL MATTER)	
LENGTH (m)	3.2
HEIGHT (m)	N/A
FOUNDATION DEPTH (m)	0.1
E/G	N/A
MAX. SETTLEMENT (mm)	24
MAX. SLOPE (V:H)	1:41500

	HOGGING ZONE	SAGGING ZONE
MAX. HORIZONTAL GROUND STRAIN (%)	0.009	-0.008
DEFLECTION RATIO (%)	0.001	0.001
CRITICAL STRAIN MODE	N/A	N/A
LENGTH IN CURVATURE ZONE (m)	2.5	2.5
L/H RATIO	N/A	N/A

HOGGING ZONE	SAGGING ZONE
0.01	-
0.000	-
N/A	-
3.2	-
N/A	-

EES Ground Movement Report
Second Stage Assessment - Heide Park Sculptures

APPENDIX C7

North East Link Project

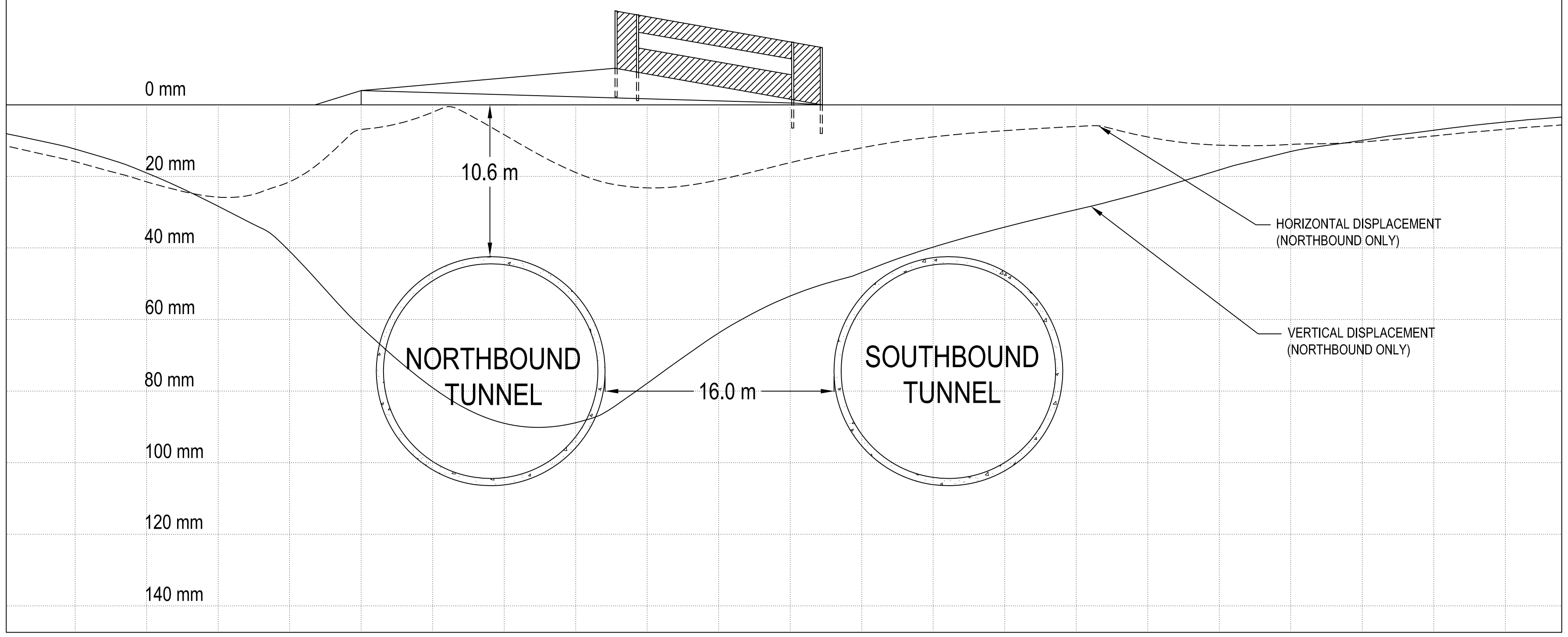
NORTH EAST LINK PROJECT

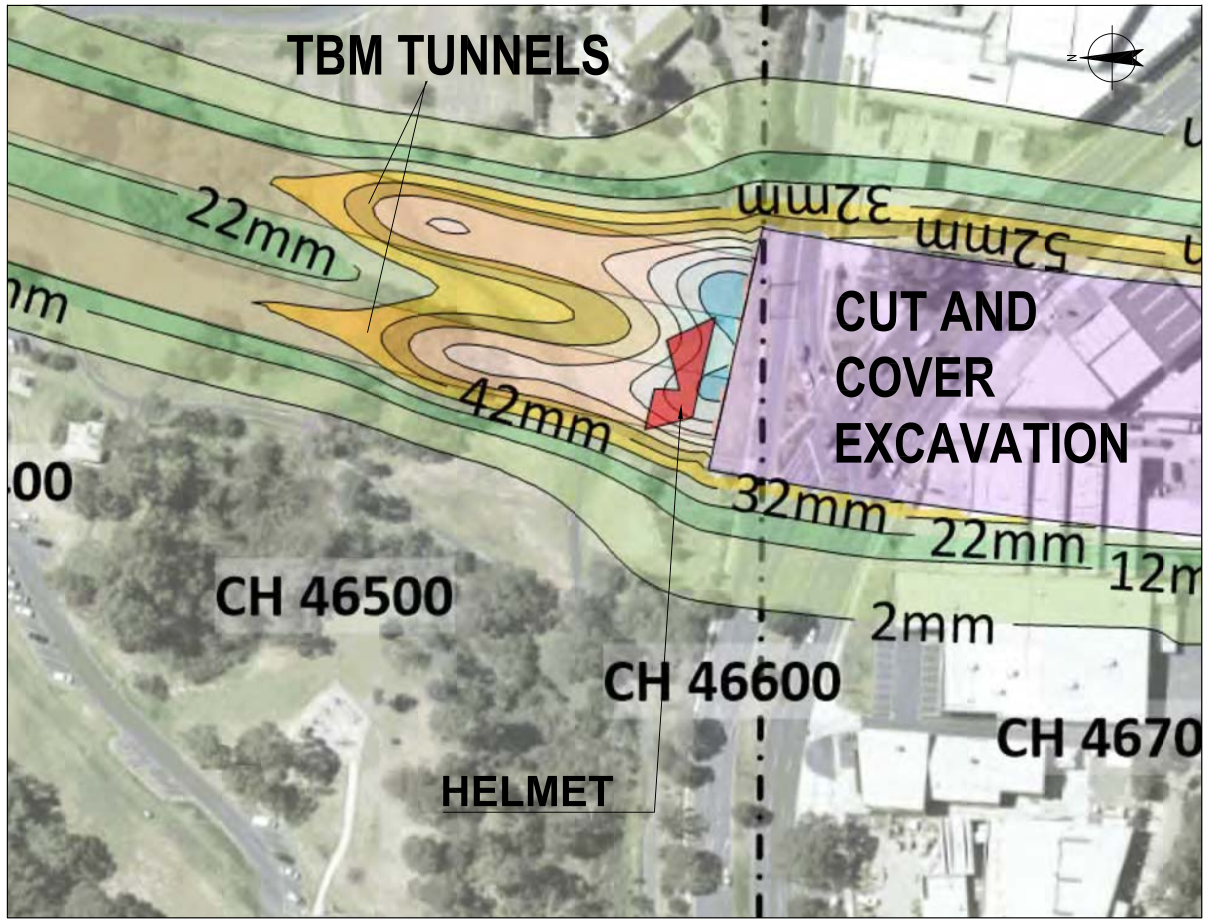
Job Number | 31-35006
Date | 21 Dec 2018

HELMET

STRUCTURAL DETAILS

STRUCTURAL STEEL I-BEAM SUB-FRAME CLAD IN CORTEN STEEL SHEET METAL SPOT WELDED TO FRAME. BOLTED TO FOUNDATIONS THAT CONSIST OF CONCRETE FILLED BORED PIERS.

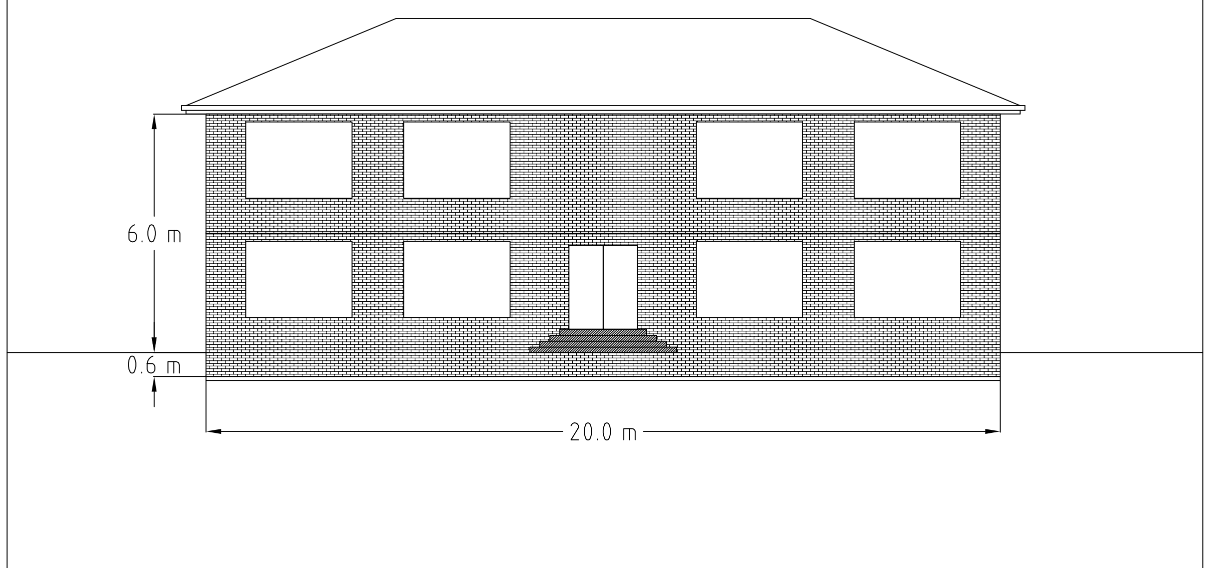




TUNNEL		STRUCTURE	
DEPTH TO CROWN (m)	10.6	LENGTH (m)	15
DIAMETER (m)	16	HEIGHT (m)	3.5 - 5
DEPTH TO AXIS (m)	19.6	FOUNDATION DEPTH (m)	2.7
VOLUME LOSS (%)	0.8	E/G	N/A
k	0.5	MAX. SETTLEMENT (mm)	92
S_{max} (mm)	93	MAX. SLOPE (V:H)	1:541

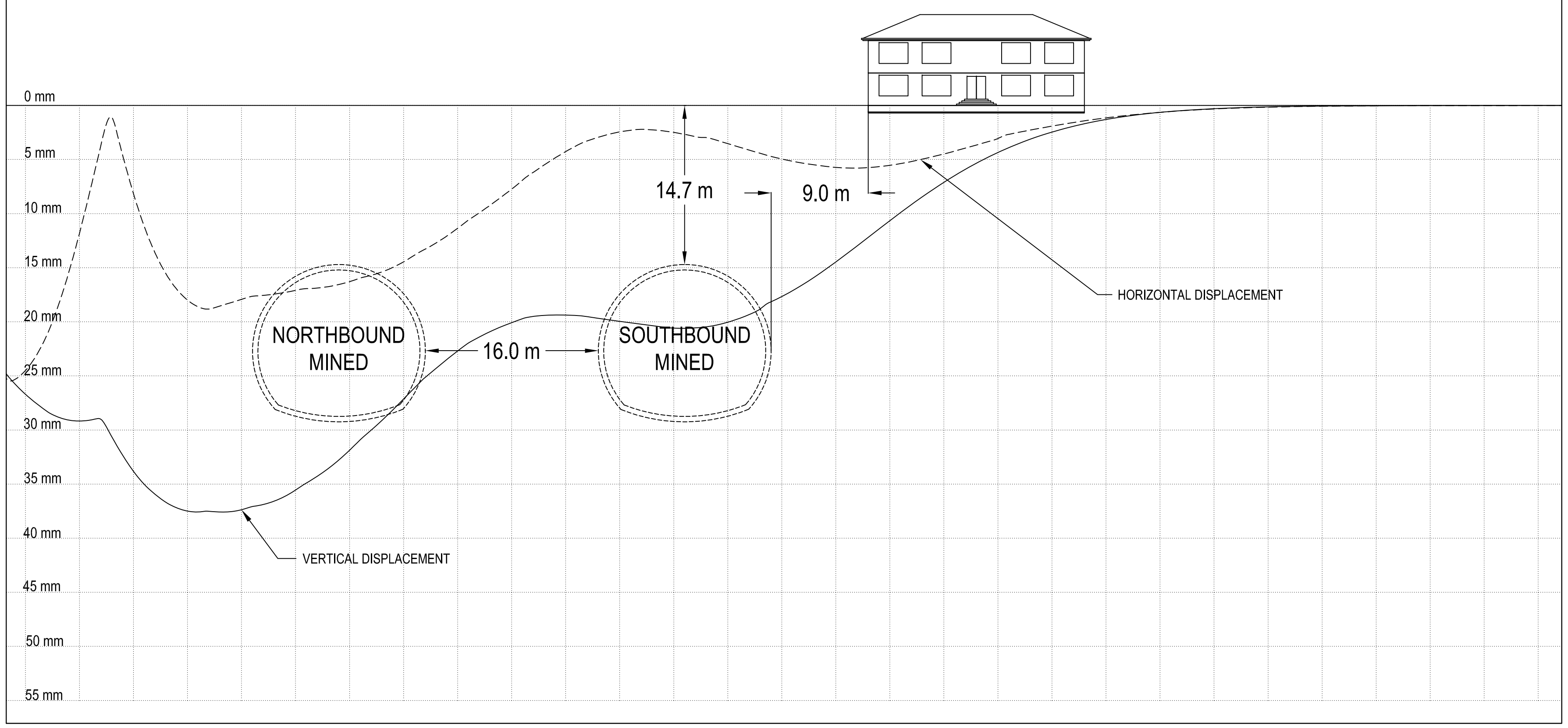
	HOGGING ZONE	SAGGING ZONE
MAX. HORIZONTAL GROUND STRAIN (%)	0.12 (both tunnels)	0.11 (NB only)
DEFLECTION RATIO (%)	0.06 (NB only)	0.08 (NB only)

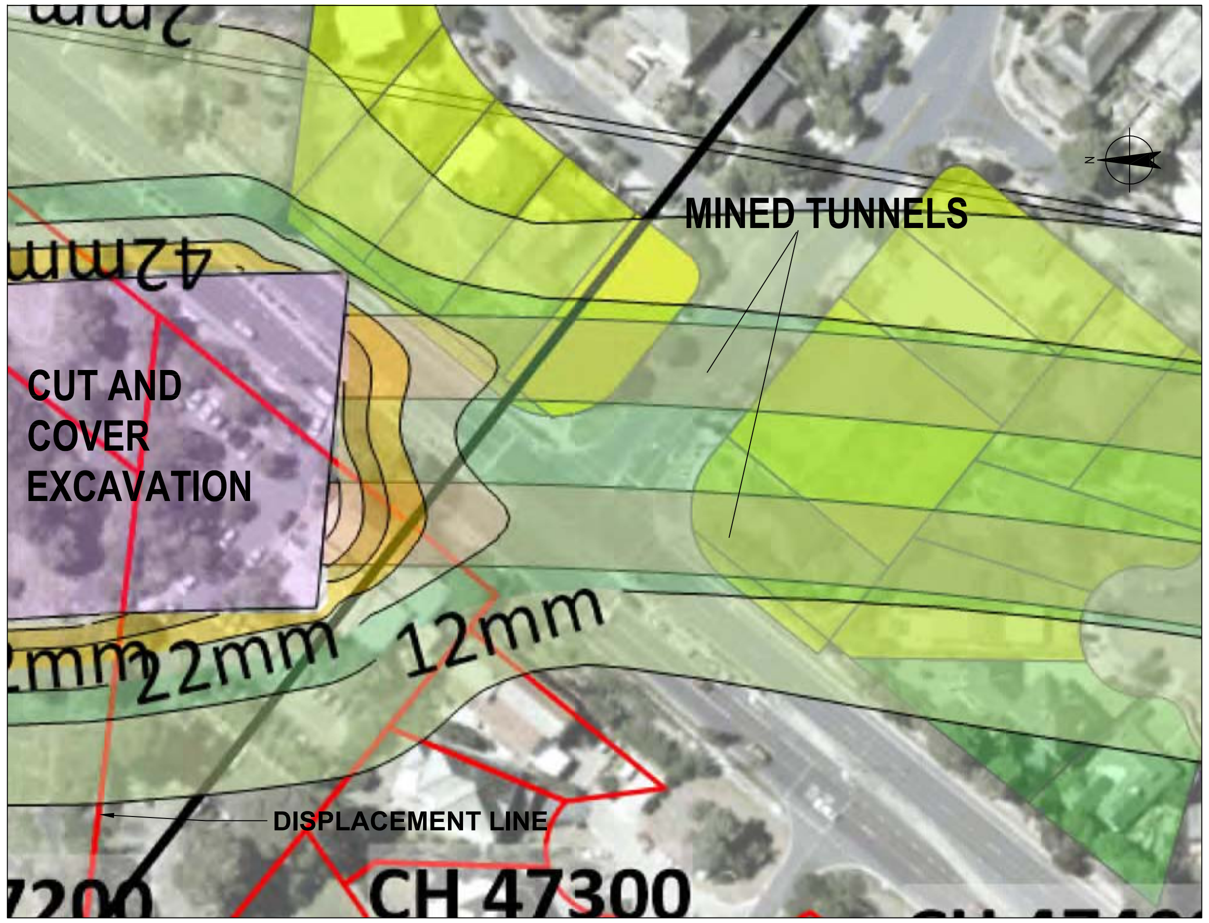
BULLEEN AREA RESIDENTIAL A



ASSUMED STRUCTURAL DETAILS

DOUBLE STOREY BRICK VENEER FACADE ON PERIMETER CONCRETE STRIP FOOTING TIED TO TIMBER SUB-FRAME. BRICK PIERS INTEGRAL TO FACADE SUPPORT THE SUB-FLOOR BEARERS AT THE PERIMETER WITH STUMPED FOOTINGS PROVIDING INTERNAL BEARER SUPPORT. HIP ROOF 20° PITCH WITH EAVES.

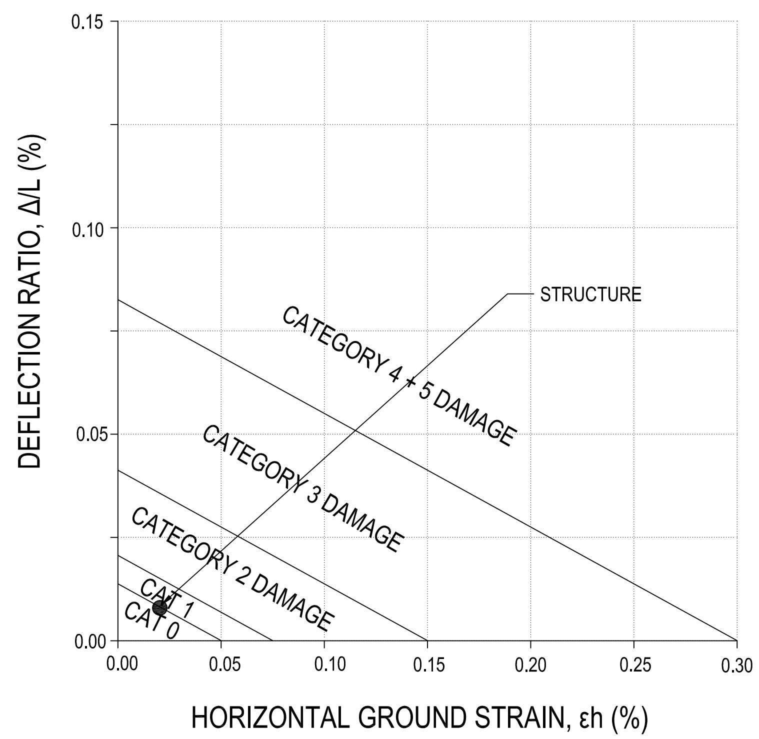




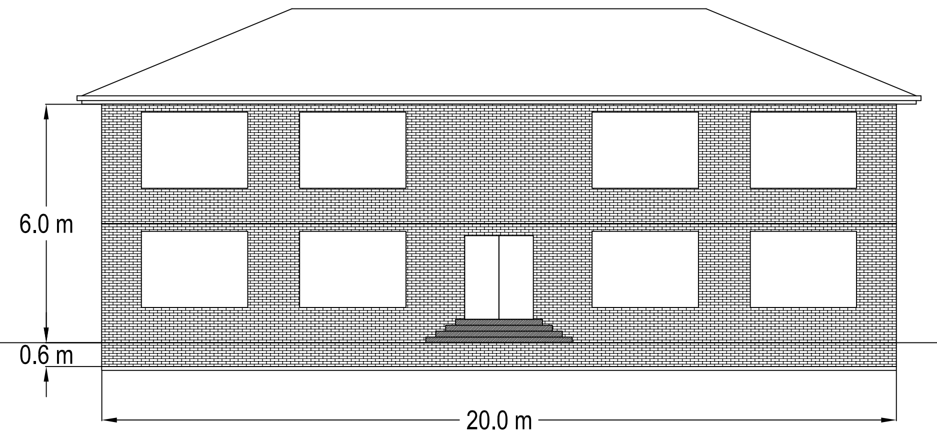
TUNNEL		BUILDING	
DEPTH TO CROWN (m)	14.7	LENGTH (m)	20
DIAMETER (m)	16	HEIGHT (m)	6.6
DEPTH TO AXIS (m)	22.7	FOUNDATION DEPTH (m)	0.6
VOLUME LOSS (%)	0.3	E/G	5
k	0.5	MAX. SETTLEMENT (mm)	10
S_{max} (mm)	38	MAX. SLOPE (V:H)	1:2100

	HOGGING ZONE	SAGGING ZONE
MAX. HORIZONTAL GROUND STRAIN (%)	0.02	-
DEFLECTION RATIO (%)	0.008	-
CRITICAL STRAIN MODE	BENDING	-
LENGTH IN CURVATURE ZONE (m)	20	-
L/H RATIO	3.6	-
DAMAGE RISK CATEGORY (Burland)	1 (VERY SLIGHT)	-

Relationship of Damage Category to Deflection Ratio and Horizontal Tensile Strain

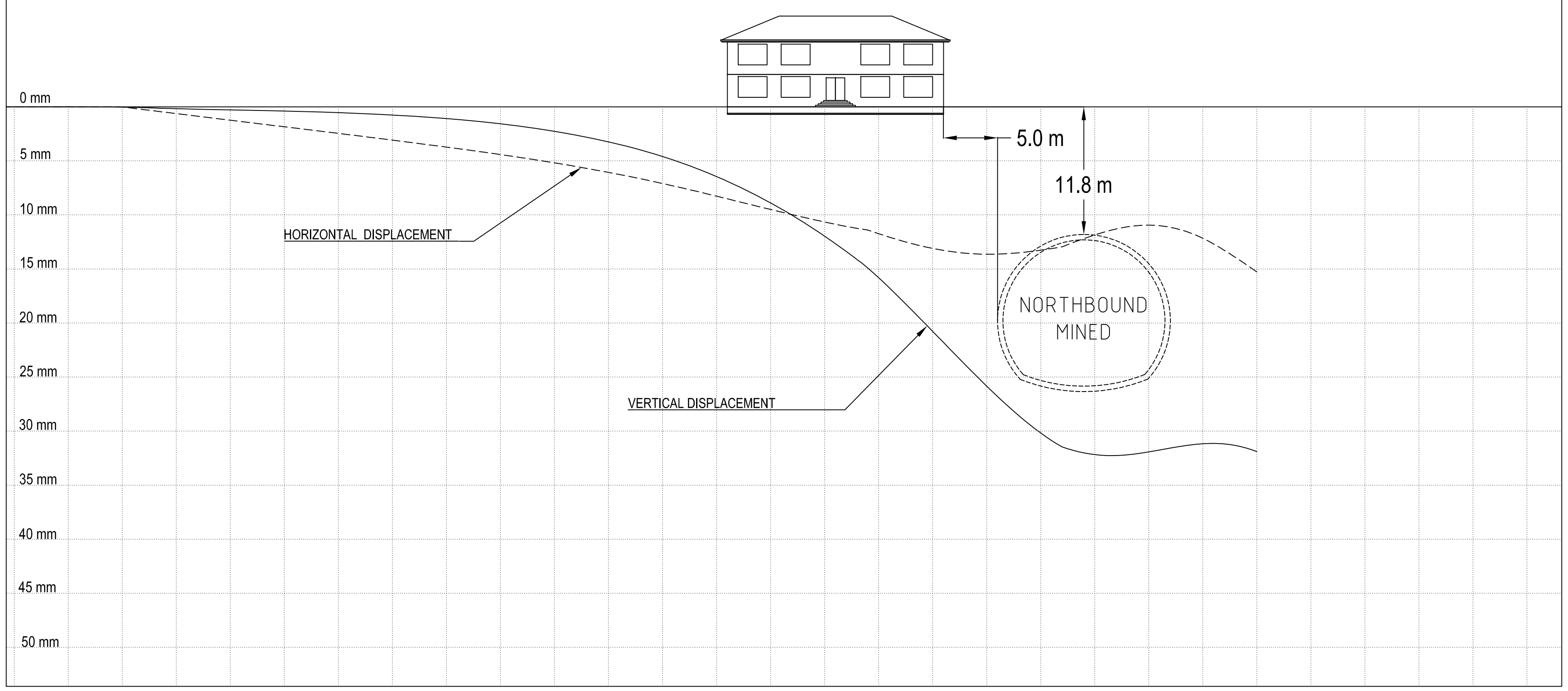


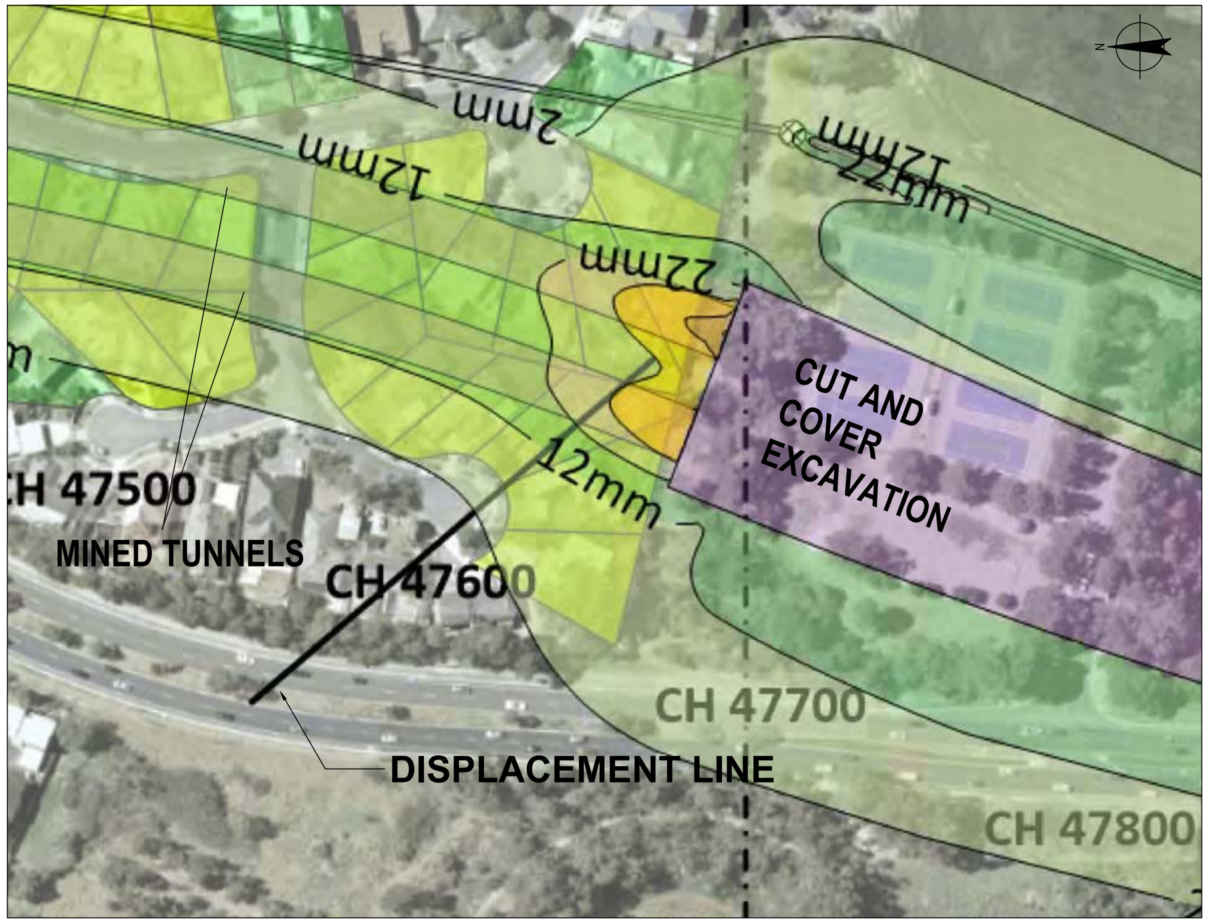
BULLEEN AREA RESIDENTIAL B



ASSUMED STRUCTURAL DETAILS

DOUBLE STOREY BRICK VENEER FACADE ON PERIMETER CONCRETE STRIP FOOTING TIED TO TIMBER SUB-FRAME. BRICK PIERS INTEGRAL TO FACADE SUPPORT THE SUB-FLOOR BEARERS AT THE PERIMETER WITH STUMPED FOOTINGS PROVIDING INTERNAL BEARER SUPPORT. HIP ROOF 20° PITCH WITH EAVES.

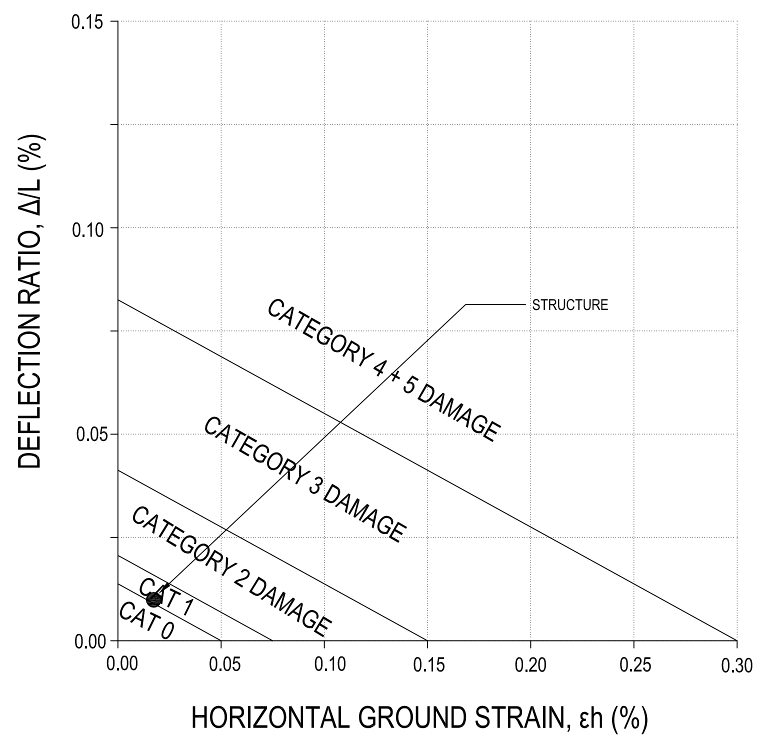




TUNNEL		BUILDING	
DEPTH TO CROWN (m)	11.8	LENGTH (m)	20
DIAMETER (m)	16	HEIGHT (m)	6.6
DEPTH TO AXIS (m)	19.8	FOUNDATION DEPTH (m)	0.6
VOLUME LOSS (%)	0.3	E/G	5
k	0.5	MAX. SETTLEMENT (mm)	22
S_{max} (mm)	33	MAX. SLOPE (V:H)	1:1307

	HOGGING ZONE	SAGGING ZONE
MAX. HORIZONTAL GROUND STRAIN (%)	0.02	-
DEFLECTION RATIO (%)	0.008	-
CRITICAL STRAIN MODE	BENDING	-
LENGTH IN CURVATURE ZONE (m)	20	-
L/H RATIO	3	-
DAMAGE RISK CATEGORY (Burland)	1 (VERY SLIGHT)	-

Relationship of Damage Category to Deflection Ratio and Horizontal Tensile Strain



EES Ground Movement Report
Second Stage Assessment - Bulleen Area Residential B

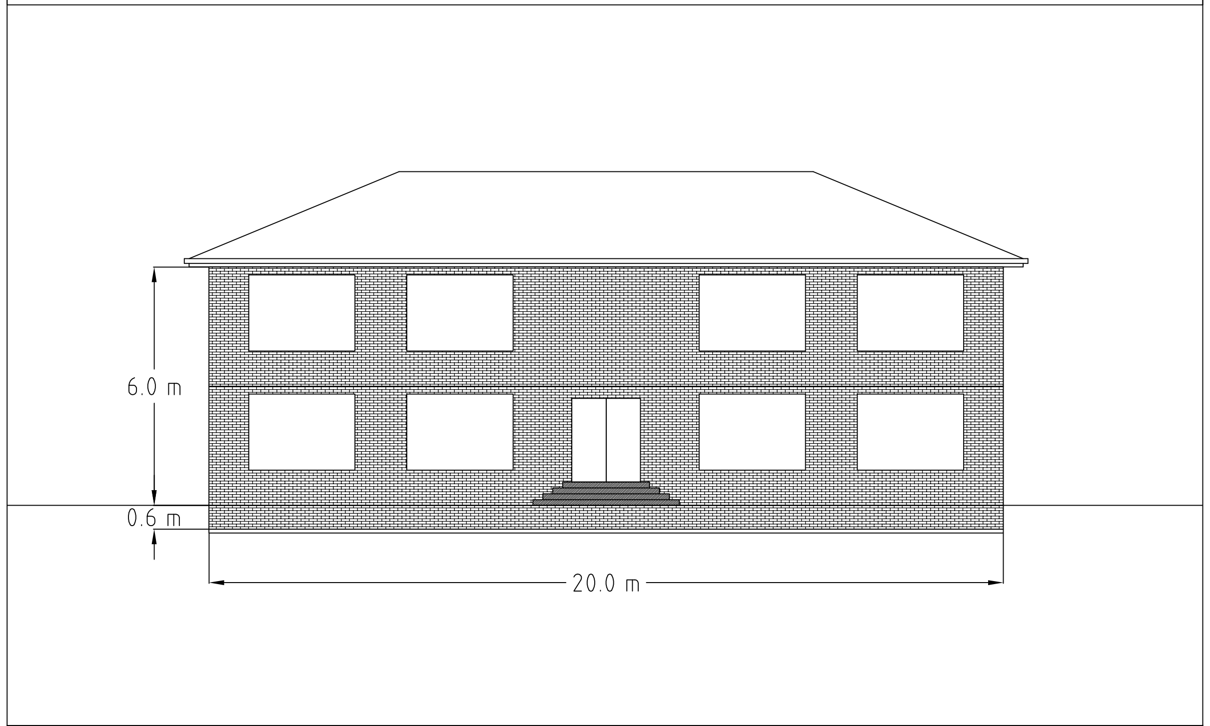
APPENDIX C9.B

North East Link Project

NORTH EAST LINK PROJECT

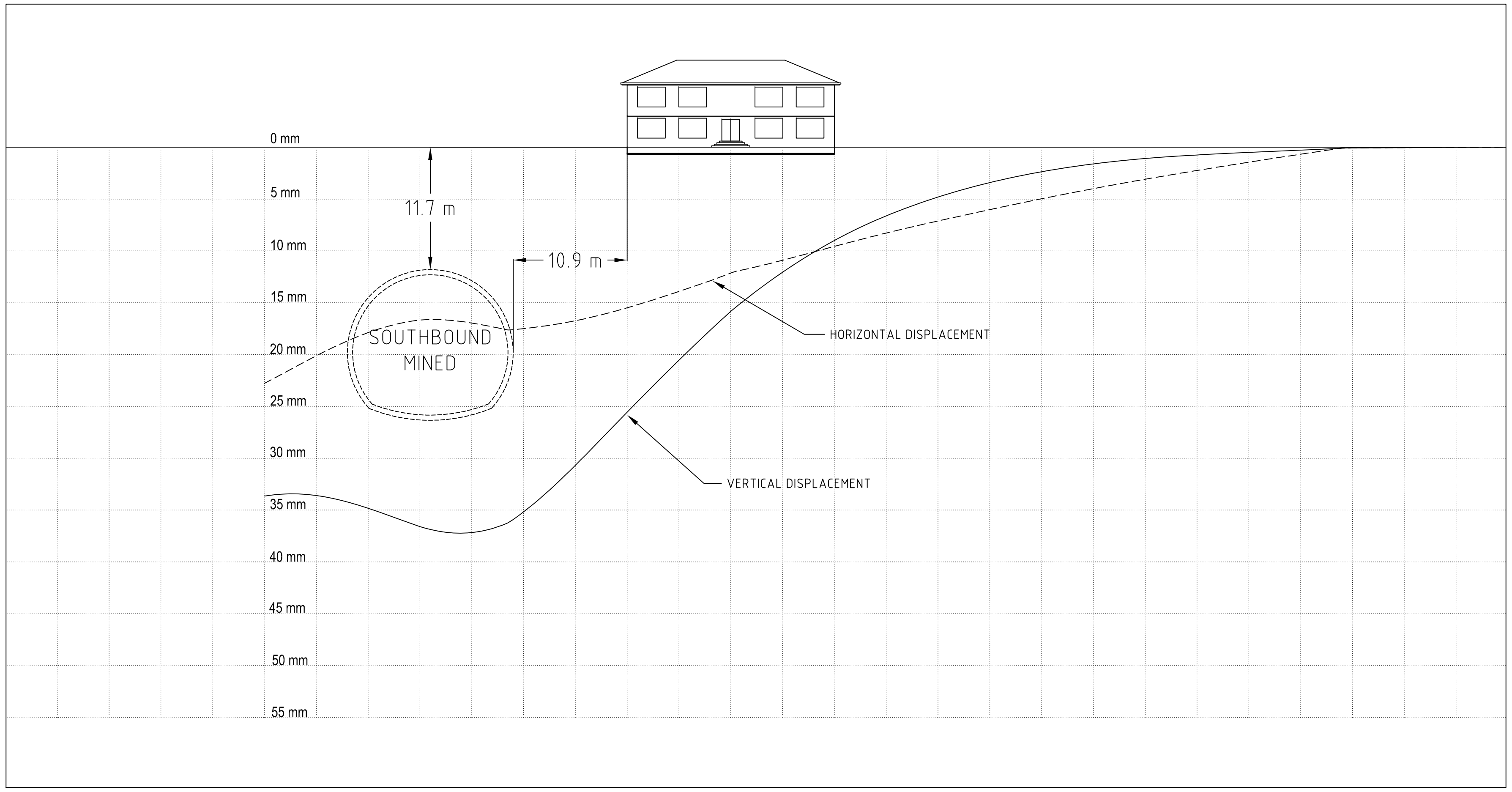
Job Number | 31-35006
Date | 21 Dec 2018

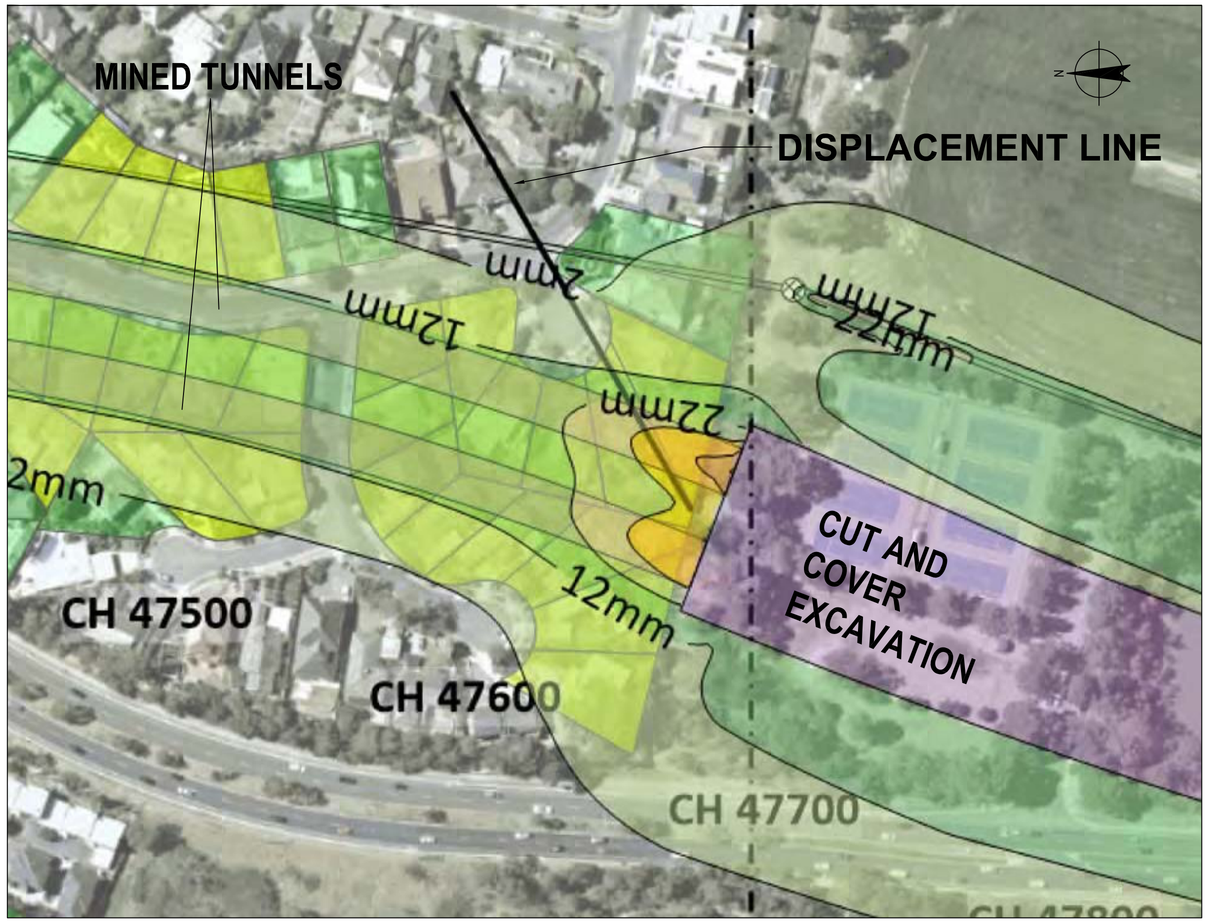
BULLEEN AREA RESIDENTIAL C



ASSUMED STRUCTURAL DETAILS

DOUBLE STOREY BRICK VENEER FACADE ON PERIMETER CONCRETE STRIP FOOTING TIED TO TIMBER SUB-FRAME. BRICK PIERS INTEGRAL TO FACADE SUPPORT THE SUB-FLOOR BEARERS AT THE PERIMETER WITH STUMPED FOOTINGS PROVIDING INTERNAL BEARER SUPPORT. HIP ROOF 20° PITCH WITH EAVES.



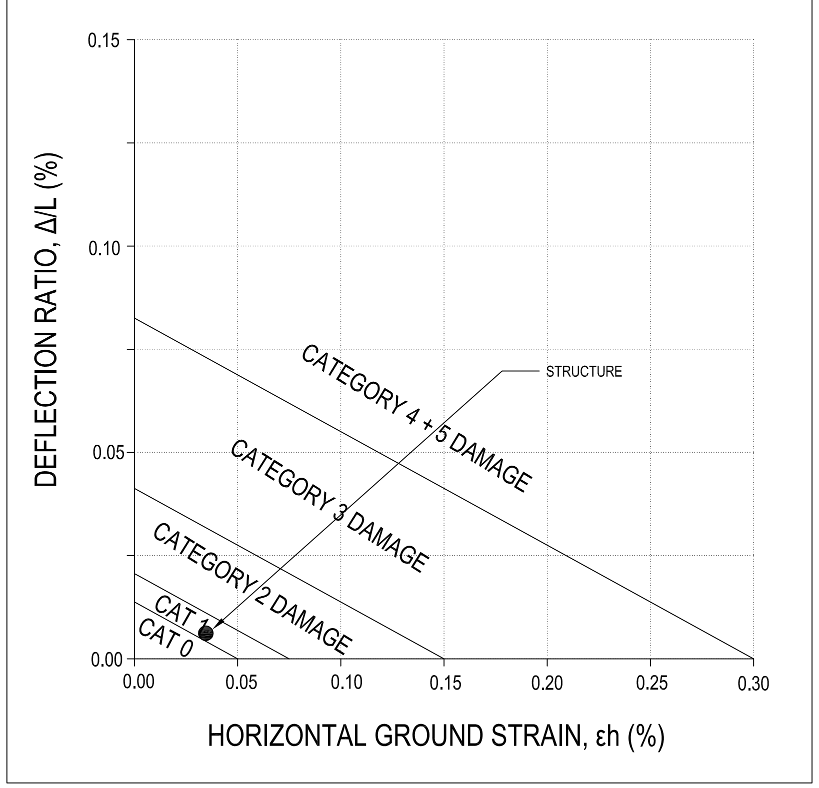


TUNNEL		BUILDING	
DEPTH TO CROWN (m)	11.8	LENGTH (m)	20
DIAMETER (m)	16	HEIGHT (m)	6.6
DEPTH TO AXIS (m)	19.8	FOUNDATION DEPTH (m)	0.6
VOLUME LOSS (%)	0.3	E/G	5
k	0.5	MAX. SETTLEMENT (mm)	26
S_{max} (mm)	37	MAX. SLOPE (V:H)	1:1207

	HOGGING ZONE	SAGGING ZONE
MAX. HORIZONTAL GROUND STRAIN (%)	0.03	-
DEFLECTION RATIO (%)	0.007	-
CRITICAL STRAIN MODE	BENDING	-
LENGTH IN CURVATURE ZONE (m)	20	-
L/H RATIO	3	-

DAMAGE RISK CATEGORY (Burland)	1 (VERY SLIGHT)	-

Relationship of Damage Category to Deflection Ratio and Horizontal Tensile Strain



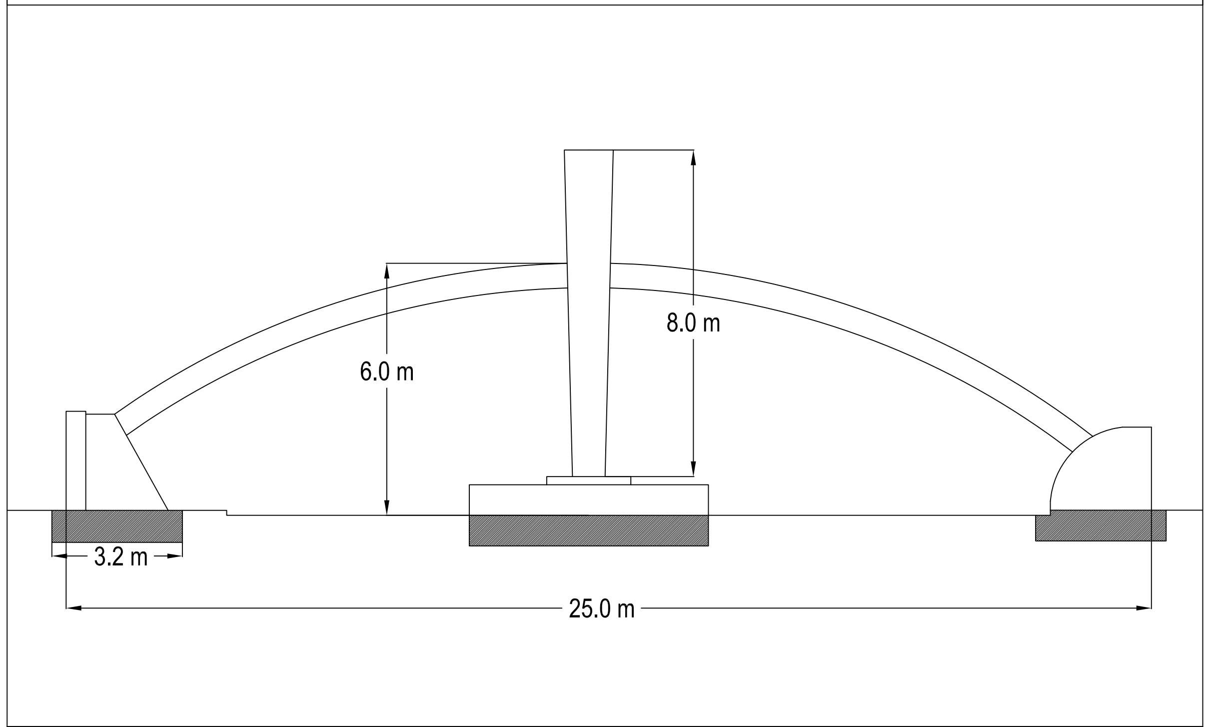
EES Ground Movement Report
Second Stage Assessment - Bulleen Area Residential C

APPENDIX C9.C

North East Link Project

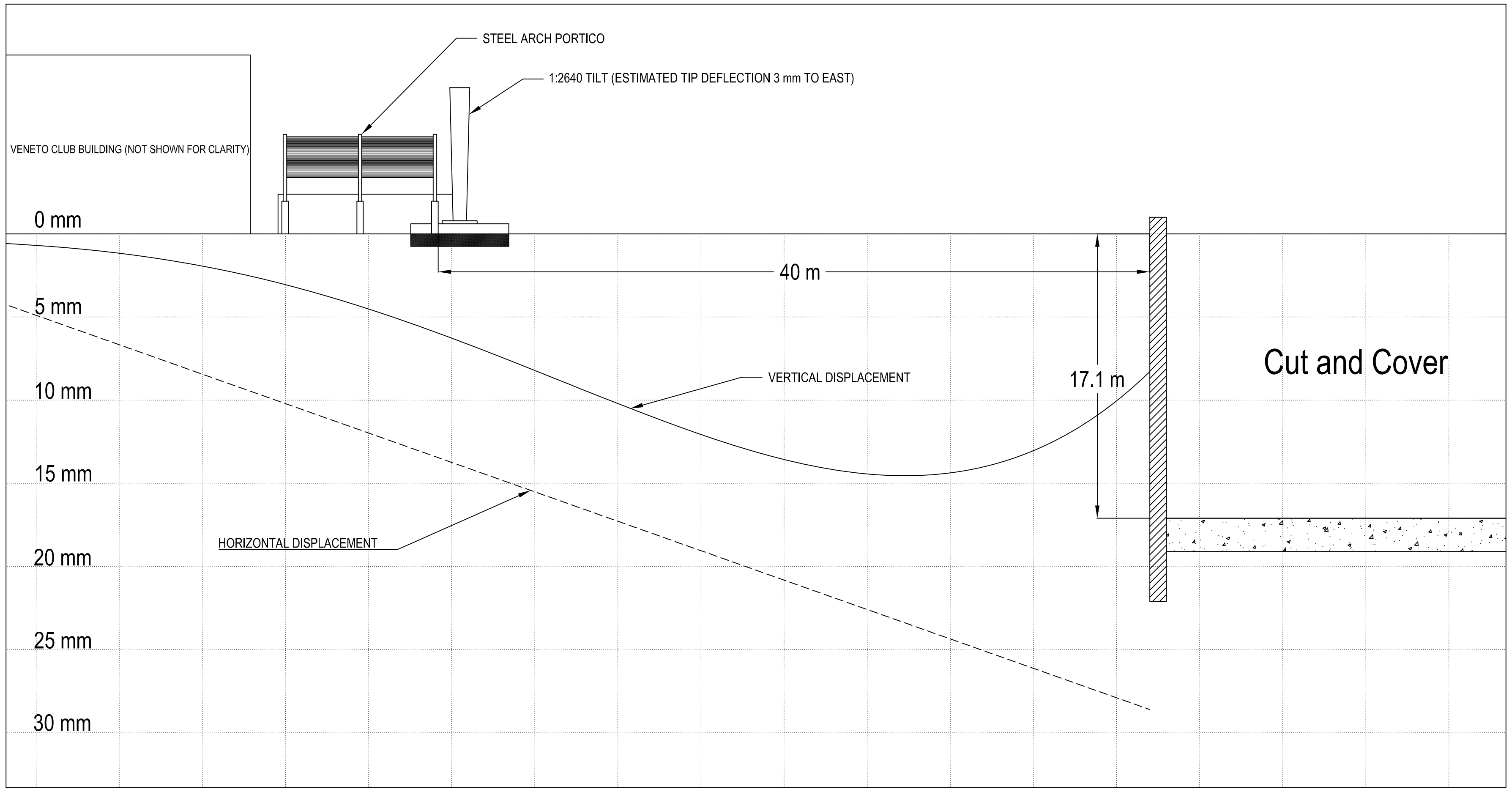
Job Number | 31-35006
Date | 21 Dec 2018

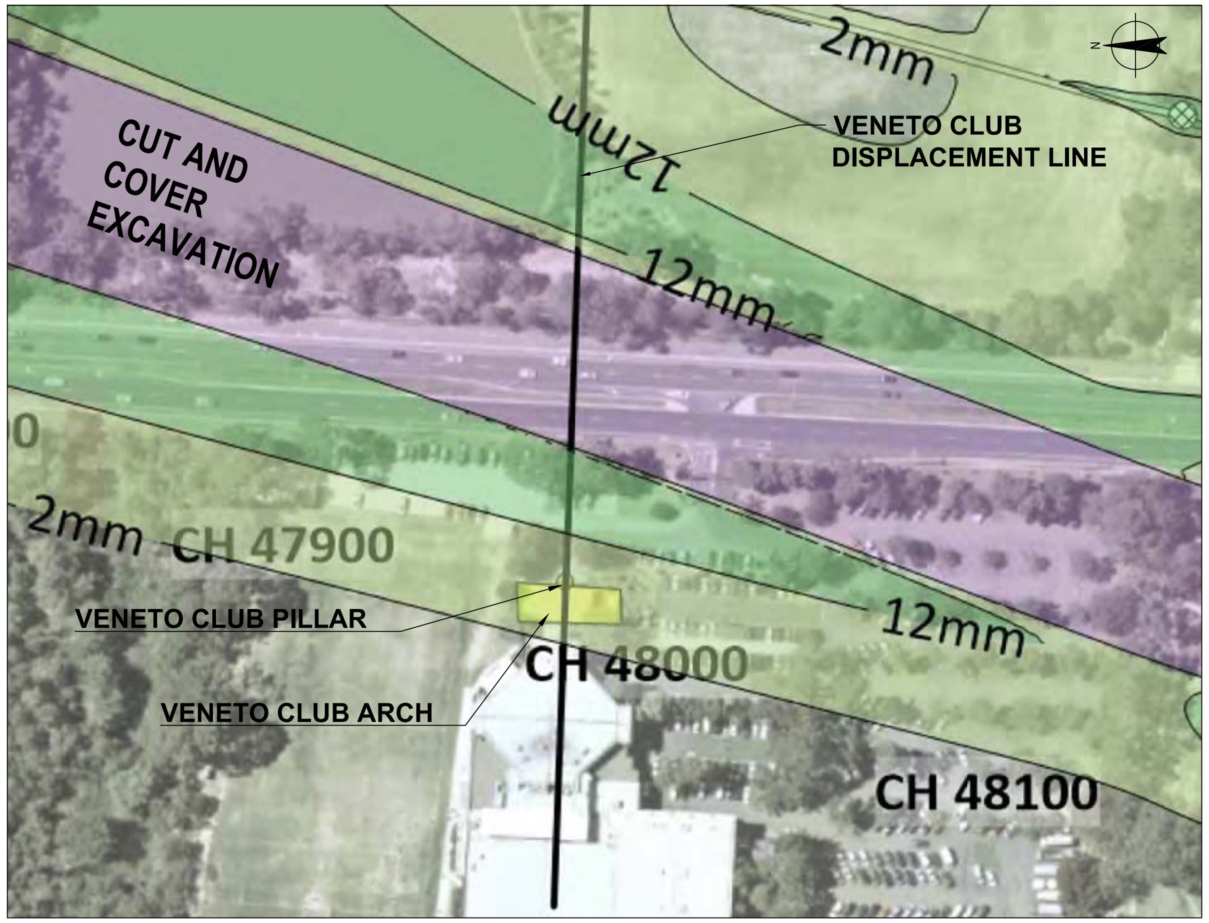
VENETO CLUB PORTICO ARCH + PILLAR MONUMENT



ASSUMED STRUCTURAL DETAILS

STEEL BOX SECTION GIRDER ARCH ON STRIP FOOTING, 3 SECTIONS. MONOLITHIC CONCRETE PILLAR ON CIRCULAR PLINTH.



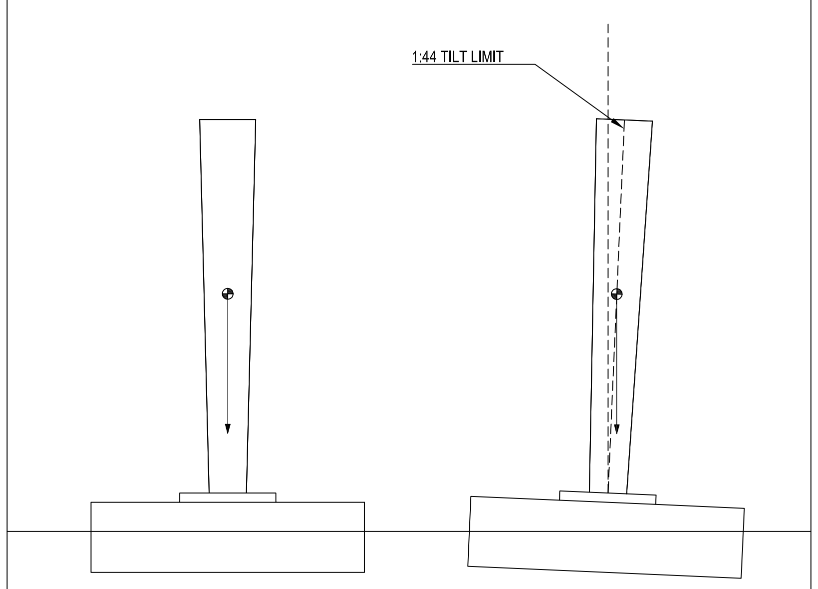


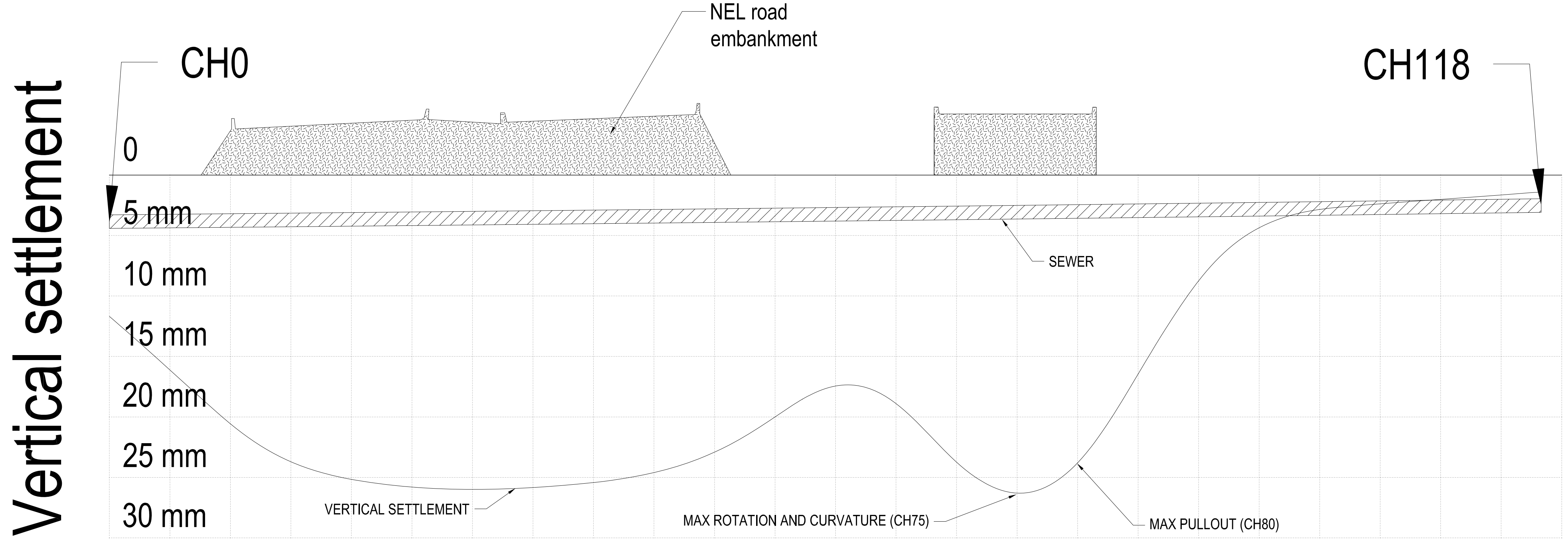
EXCAVATION		BUILDING (ARCH)	
DEPTH (m)	17.1	LENGTH (m)	10.3
WIDTH (m)	50	HEIGHT (m)	5
DEPTH TO AXIS (m)	N/A	FOUNDATION DEPTH (m)	N/A
VOLUME LOSS (%)	N/A	E/G	N/A
k	N/A	MAX. SETTLEMENT (mm)	6
S_{max} (mm)	15	MAX. SLOPE (V:H)	1:3200

	HOGGING ZONE	SAGGING ZONE
MAX. HORIZONTAL GROUND STRAIN (%)	0.03	-
DEFLECTION RATIO (%)	0.001	-
CRITICAL STRAIN MODE	-	-
LENGTH IN CURVATURE ZONE (m)	10.3	-
L/H RATIO	N/A	-

PILLAR TILT LIMIT

ASSUMING PILLAR ROTATES WITH GROUND SURFACE AND EXCEEDS THE PILLARS ULTIMATE BENDING CAPACITY THROUGH ECCENTRIC LOADING



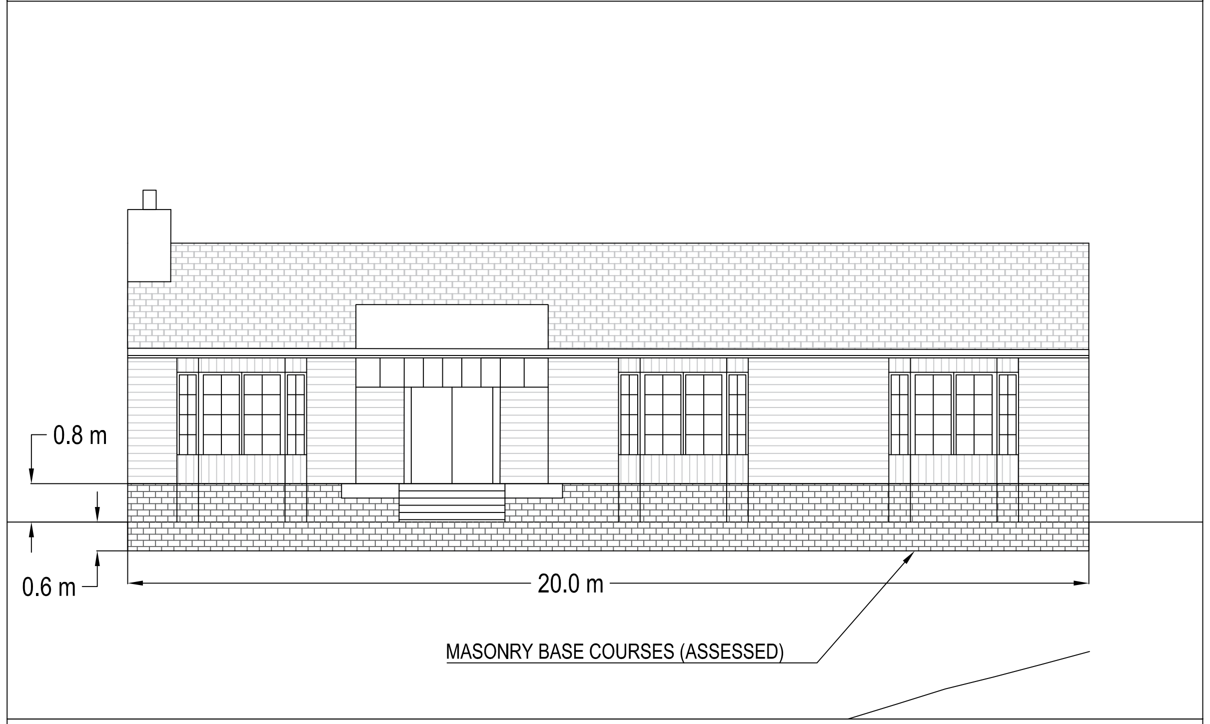


BULLEEN ROAD WEST SEWER

PIPE PROPERTIES	
MATERIAL	REINFORCED CONCRETE
INSIDE DIAMETER (mm)	2250
WALL THICKNESS (mm)	UNKNOWN
PIPE SEGMENT LENGTH (m)	2.4
PIPE JOINTING	RUBBER GASKET
SOIL-PIPE INTERACTION	RELATIVELY RIGID

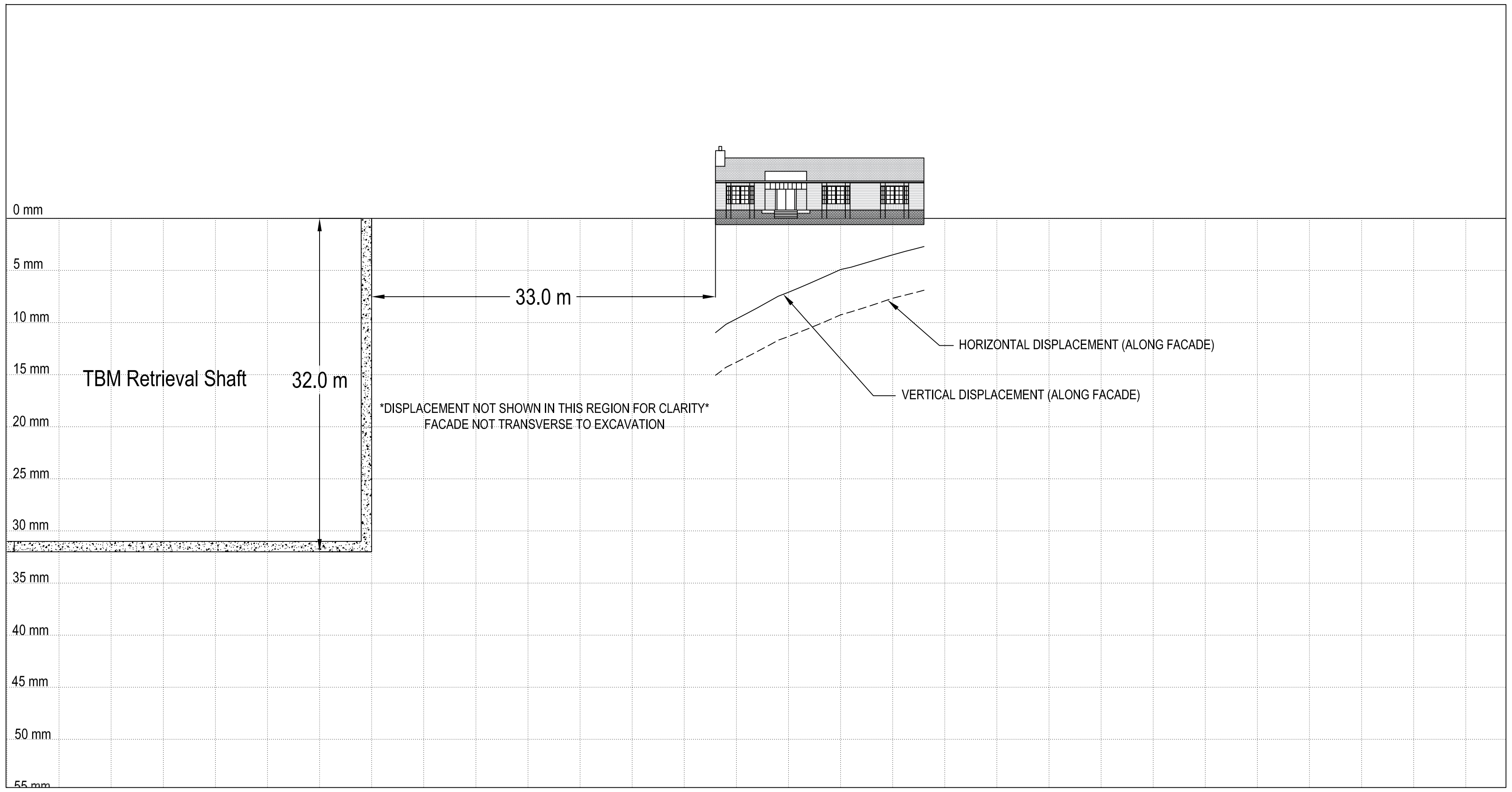
RESULTS				
	VALUE	LOCATION	RANKIN RISK CATEGORY	
MAX. SETTLEMENT (mm)	27	CH75	SLIGHT	
MAX. SLOPE (V:H)	1:560	CH80	NEGLIGIBLE	
	VALUE	LOCATION	THRESHOLD	WITHIN THRESHOLD?
MAX. ROTATION (deg)	0.07	CH75	2.5	YES
MAX. PULLOUT (mm)	0.008	CH80	7.5	YES
MIN. RADIUS OF CURVATURE (km)	4.5	CH75	0.05	YES

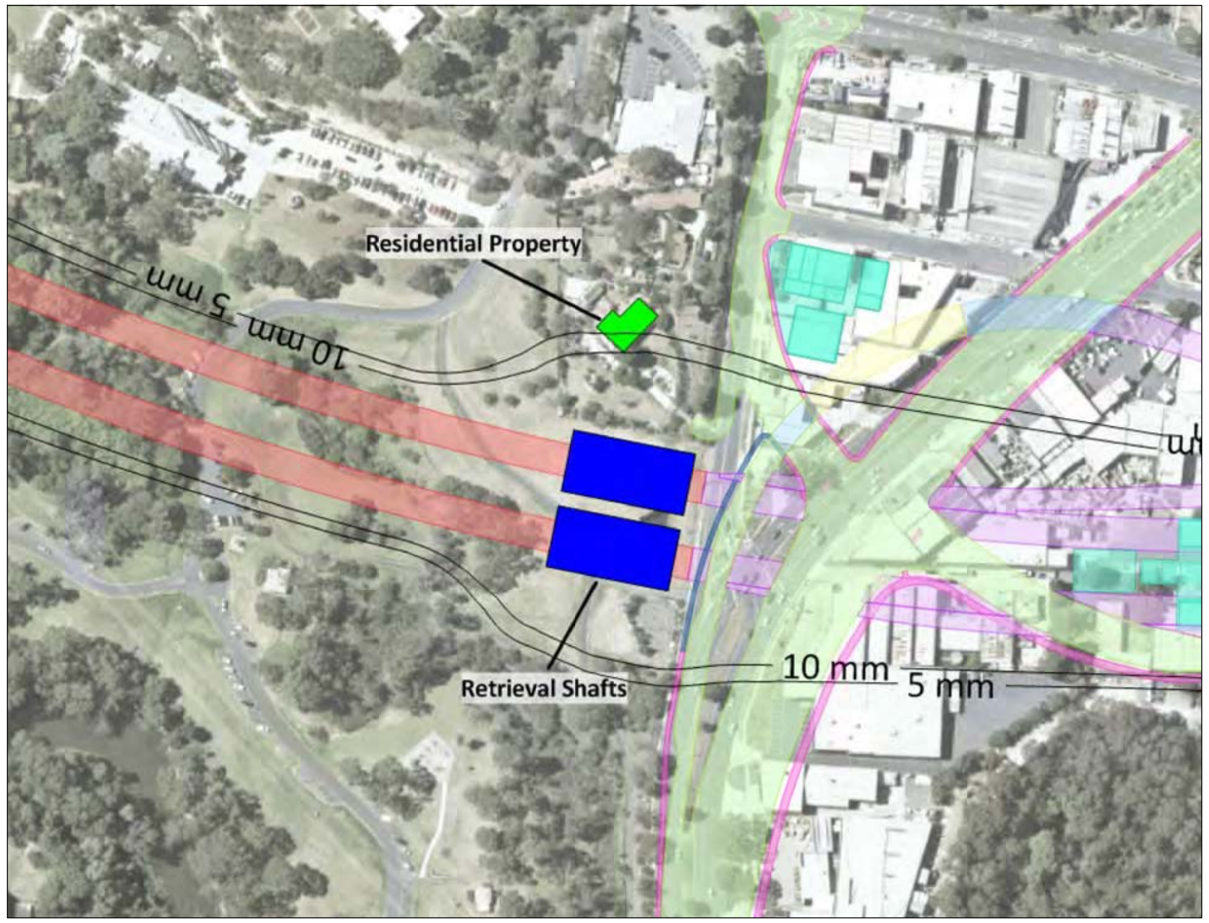
BRIDGE STREET RESIDENTIAL



ASSUMED STRUCTURAL DETAILS

SINGLE STOREY TIMBER FACADE ON MASONRY BASE COURSE WITH INTERNAL STUMPED OR PIER FOOTINGS SUPPORTING SUB-FLOOR.

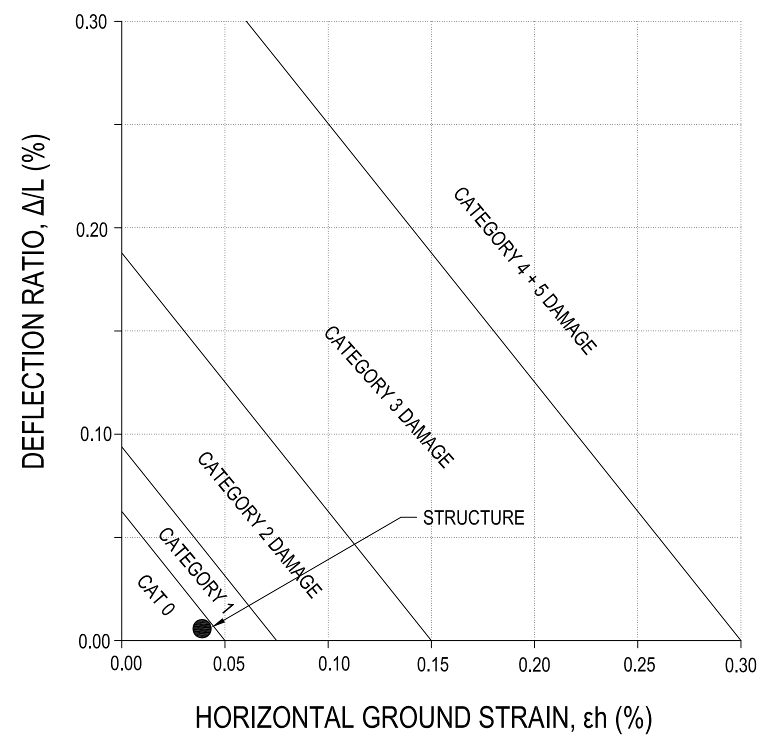




EXCAVATION		BUILDING (MASONRY)	
APPROX. DEPTH (m)	32	LENGTH (m)	20
WIDTH (m)	25	HEIGHT (m)	1.4
DEPTH TO AXIS (m)	N/A	FOUNDATION DEPTH (m)	0.6
VOLUME LOSS (%)	N/A	E/G	2.6
k	N/A	MAX. SETTLEMENT (mm)	11
S_{max} (mm)	96	MAX. SLOPE (V:H)	1:1230

	HOGGING ZONE	SAGGING ZONE
MAX. HORIZONTAL GROUND STRAIN (%)	0.04	-
DEFLECTION RATIO (%)	0.005	-
CRITICAL STRAIN MODE	BENDING	-
LENGTH IN CURVATURE ZONE (m)	20	-
L/H RATIO	14.3	-
DAMAGE RISK CATEGORY (Burland)	0 (NEGLIGIBLE)	-

Relationship of Damage Category to Deflection Ratio and Horizontal Tensile Strain



Appendix D – Numerical Validation

Appendix D1 - Numerical Validation - Tunnelling

1. Introduction

Tunnel excavation inevitably leads to some degree of ground movement. This is because relaxation and inward movement of the ground occurs well ahead of the tunnel face, such that the volume of ground removed at the tunnel face will always exceed the theoretical volume of the tunnel. In soft ground (such as clay, gravel, or highly fractured or disturbed/weathered rock), the additional excavation can be significant, whereas in stiff/dense ground or good rock the movements may be very small.

The additional excavation in excess of the theoretical excavated volume can be described in terms of “volume loss” which can be defined as a ratio of the additional excavated volume of ground over the theoretical volume of the excavation. This ratio may be expressed as a percentage of the theoretical excavated area of the tunnel face (V_L%), or as a rate of additional volume of ground excavated per metre run of tunnel (V_s, m^3/m).

In soft-ground tunnelling, it is common to apply an empirical approach to the estimation of ground movement based on the “Gaussian curve” method proposed by Peck (1969). The approach assumes that vertical displacements (or “settlement trough”) at the ground surface above a tunnel conforms to the shape of an inverted normal probability curve to a good approximation. The method also assumes that the additional volume of excavation around the tunnel is exactly matched by the volume enclosed by the surface settlement “trough”. Parameters required for the purposes of assessing the degree of risk to affected structures and utilities (such as horizontal displacement, strain, ground slope) can be mathematically derived from the equation defining the shape of the normal probability curve.

For tunnel excavations in rock, this same method can be applied where the behaviour of the rock is expected to be relatively homogeneous. This situation might arise when the tunnel is large relative to the spacing of fractures in the rock, or when the rock is “massive” but relatively weak compared to the in situ state of ground stress. Care must be taken for cases where the rock acts in a non-homogeneous way, such as when ground movements are driven by displacements on widely spaced discrete fractures within the rock. However if the potential for block displacement is well controlled by an appropriate in-tunnel support, the displacements are then more likely to give rise to displacements not dissimilar to that simulated by a Gaussian curve.

For the North East Link project (NELP) Environmental Effects Statement (EES) analysis, it has thus been assumed that all tunnel ground movement effects can be assessed by assuming the ground displacements follow a Gaussian distribution. In order to calculate the potential displacement field, an estimate of the maximum vertical displacement ($S_{v,max}$) and the “trough width parameter” (i) is required. $S_{v,max}$ can be determined directly from the volume loss. The trough width parameter is typically estimated as a simple ratio of the tunnel depth (Z_o); for granular soils a value of $i = 0.3{*}Z_o$ has been found to be generally applicable, for clays $i = 0.5{*}Z_o$ and values of up to $i = 0.7{*}Z_o$ for fractured rock have been observed. For the purposes of the EES analysis, a value of $0.5{*}Z_o$ is considered generally applicable and conservative.

The following appendix describes the numerical and analytical models undertaken in order to validate the empirical assumptions taken for the volume loss and trough width parameters.

2. Volume Loss Validation

2.1 Overview

The Confinement-Convergence Method (CCM) of analysis (Panet, 1995) was employed to estimate the displacement of the ground around the tunnel excavations, which was then converted to a “volume loss”. This method enables the movements ahead of the face to be estimated, as well as radial movements behind the tunnel face, prior to installation of the permanent tunnel lining. The magnitude of these movements is dependent on the geotechnical conditions around the tunnel, as well as any internal support pressure applied and the proximity of lining installation to the tunnel face.

Two key approaches were taken in the application of the CCM analysis to validate the volume loss assumptions; an analytical solution as described by Hoek et al (2008) and a numerical solution using 2D finite element analysis (FEA). The FEA approach also enabled a check on the trough width parameter assumptions also required for this analysis.

2.2 Analytical Assessment

The analytical approach to CCM modelling requires that a number of simplifying assumptions be taken to ensure that a solution can be obtained. The two key assumptions being that solutions are restricted to circular openings and the initial stress field within the rock mass is hydrostatic (horizontal and vertical stresses are equal). Furthermore, the tunnel support is modelled as an equivalent internal pressure and as such, the different types of tunnel support or lining are not considered explicitly.

For the case of tunnels excavated by tunnel boring machine (TBM), these assumptions are nonetheless a reasonable approximation given the circular geometry of the excavation and the surface support techniques typically employed (e.g. segmental pre-cast linings). To provide an example of an analytically derived estimate of volume loss using the CCM approach, the following analysis of a single TBM drive tunnel passing beneath the Yarra Valley is presented.

2.2.1 Assumptions

The proposed NELP alignment beneath the Yarra Valley will require the tunnel to be driven through rock that is generally classified as Silurian siltstone of the Melbourne/Anderson creek formation. The predominant weathering grade of the rock at the depth of excavation is slightly weathered to fresh; some sections of moderately weathered rock may be encountered in the tunnel crown.

In terms of rockmass characterisation and intact substance strength, a range of values of Geological Strength Index (GSI) and compression strength, σ_{ci}, were estimated from the available information that included laboratory testing, rock core photography and historical studies. The GSI ranged from approximately 20 (faulted rock with soil-like geotechnical properties) to 60 (“blocky”, well-interlocked rock). The σ_{ci} ranged from 10 MPa to 30 MPa, being generally dependent on the weathering grade of the rock. The unit weight of the Melbourne formation was estimated to be 0.024 MN m^{-3}, with the unit weight of the overlying clay alluvium estimated to be 0.02 MN m^{-3}. The analysis will be conducted as a total stress analysis on the basis of the assumption that the ground being excavated consists of a relatively impermeable zone of clast supported fault material, with a clay matrix. The initial elastic convergence of the excavation boundary will induce internal suction forces within the material, negating any short term effects of pressure balance provided by an Earth Pressure Balance (EPB) TBM. A schematic representation of the analytical model is shown in Figure 1 below.

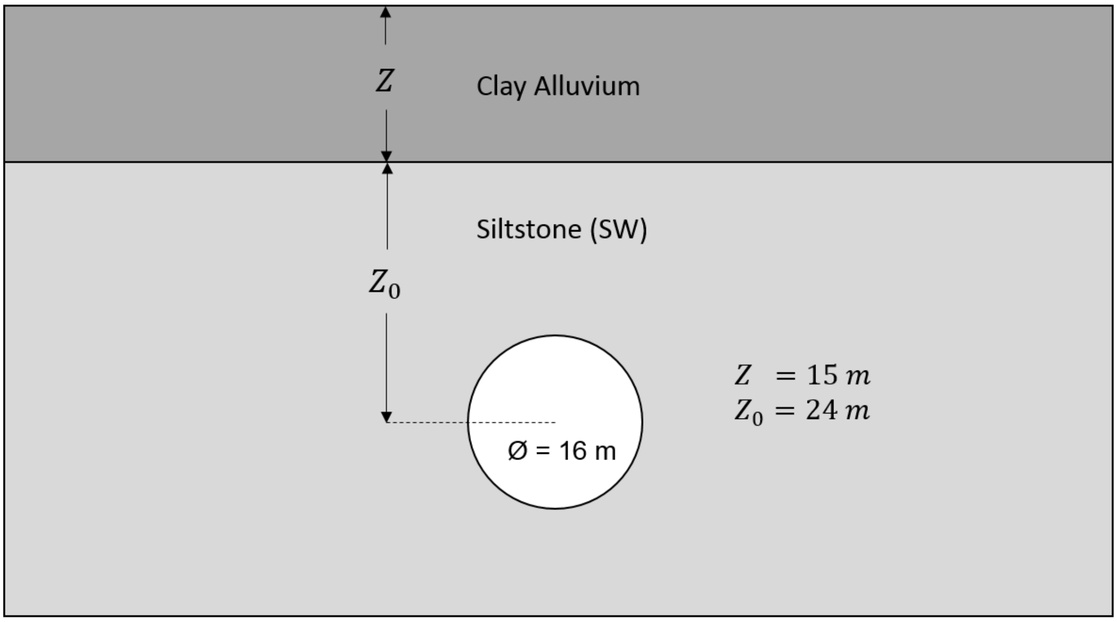


Figure D1 Conceptual model of a single TBM drive below the Yarra Valley

For the purposes of this example calculation, the following values were adopted for the key input parameters:

- The depth to the top of rock from the tunnel axis, Z_0, was taken to equal to 24 m.
- The rock mass may be characterised by a homogeneous value of GSI = 25, representative of highly fractured or disturbed/weathered rock.
- The rock substance may be characterised by a homogeneous value σ_{ci} = 20 MPa.

It is important to note that the analytical solution assumes that the rockmass behaves as an elastic-perfectly plastic material, with the onset of yield (plastic deformation) defined by the Mohr-Coulomb failure criterion. Suitable values of rock mass strength properties are readily estimated from the GSI and σ_{ci} values respectively.

2.2.2 Analysis

The equivalent internal friction angle, φ, and cohesive strength, c', of the rock mass were estimated to be approximately 43° and 0.1 MPa respectively Hoek et al (2002).

Failure of the rock mass at the excavation boundary occurs when the internal support pressure, P_i, is less than the critical support pressure, P_{cr}. In the case of an unsupported tunnel, failure may be expected when the hydrostatic stress exceeds approximately 2 times the compressive strength of the rock mass, σ_{cm}.

The hydrostatic stress field was estimated to be approximately 0.9 MPa based on an assumed 15 m depth of clay alluvium overlying the siltstone. The adopted values of GSI and σ_{ci} yielded a σ_{cm} of approximately 0.25 MPa, suggesting that plastic yield around the tunnel excavation would be expected.

Hoek et al (2008) outlines a method for approximating the radial convergence of a tunnel boundary at a given distance from the tunnel face, based on estimates of the maximum unsupported convergence, u_{max}, and the convergence at the tunnel face, u_0. Figure 1 below presents the calculated longitudinal displacement profile for the given input parameters, where X/R_t is given by the distance from the face divided by the tunnel radius.

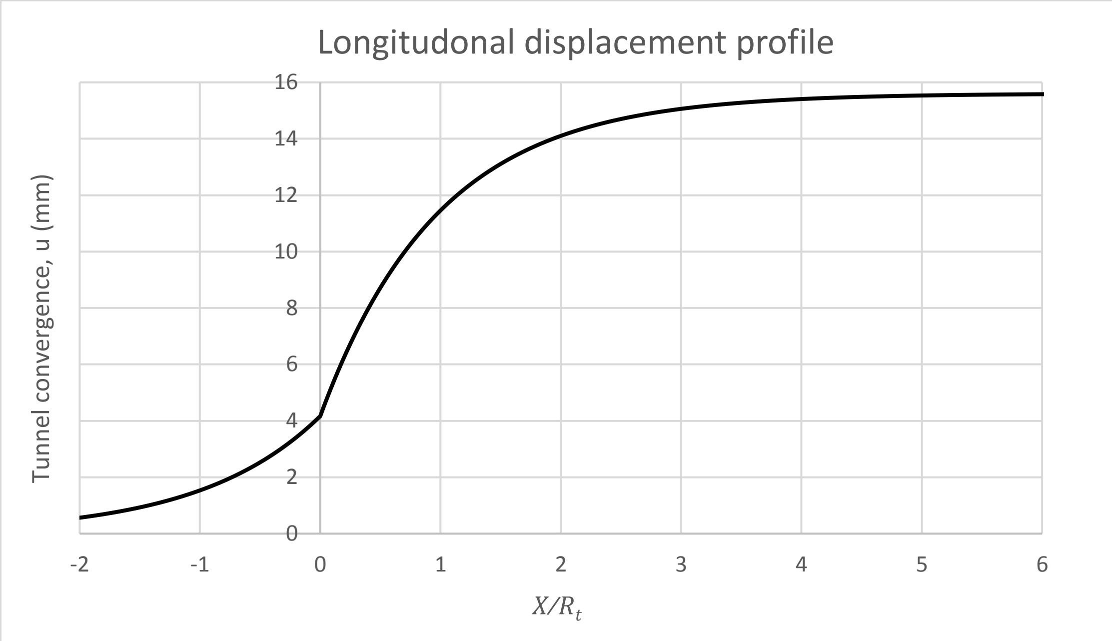


Figure D2 TBM drive, Longitudinal displacement profile

It can be observed that the radial displacement asymptotes as it approaches u_{max}, however, ground support will be installed at some distance from the face, which will reduce further convergence at the tunnel boundary. For this example, a value of 2 has been adopted for the parameter X/R_t, which is equivalent to ground support installation occurring at approximately 1 tunnel diameter behind the face.

It is assumed that a lining consisting of pre-stressed concrete segments can provide a maximum elastic displacement of approximately 9 mm prior to yield, with a corresponding peak support pressure of 1.7 MPa after Hoek et al (1995).

Considering the radial convergence occurring both prior to the ground support installation and before the support becomes effective, it was found that the boundary of the excavation would achieve a state of stable equilibrium at a radial convergence of approximately 14 mm without support. The resultant pressure applied to the lining would thus theoretically be very small.

The equivalent volume loss, assuming a circular opening, can then be defined by;

$$Volume\ loss = \frac{4\delta}{D} \times 100\%$$

Where δ is the radial displacement and D the tunnel diameter (taken to be approximately 16 m). For this example, the equivalent volume loss is therefore approximately 0.35%.

2.3 Numerical Assessment

As previously discussed, a number of limitations imposed by the analytical approach to CCM analysis make it unsuitable when considering non-circular excavations, inhomogeneous ground and non-uniform stress fields. In the case of a tunnel constructed using the sequential excavation method (SEM), it is necessary to employ an iterative numerical approach to estimate the final convergence of the excavation boundary (hence volume loss).

This example will consider a section of SEM mined tunnels to the south of the Manningham Road interchange. The analysis was undertaken using the 2D finite element program, *RS2* by *Rocscience*.

2.3.1 Modelling assumptions

The proposed NELP alignment south of Manningham interchange will require the tunnel to be driven through rock that is generally classified as Silurian siltstone of the Melbourne Formation. The estimated weathering grade of the rock at the depth of excavation is moderately weathered, with some sections of slightly weathered to fresh rock anticipated in the tunnel invert.

For the purpose of the example analysis, the following key parameters were adopted for the RS2 model: GSI = 52 (representative of a fractured, "very blocky" rock mass); σ_{ci} = 5 MPa; Modulus ratio = 250; and, Poisson's Ratio = 0.25.

It was assumed that the tunnel would be excavated in a sidewall drift (1) and enlargement (2), followed by bench (3) and invert (4) sequence as shown below in Figure 3.

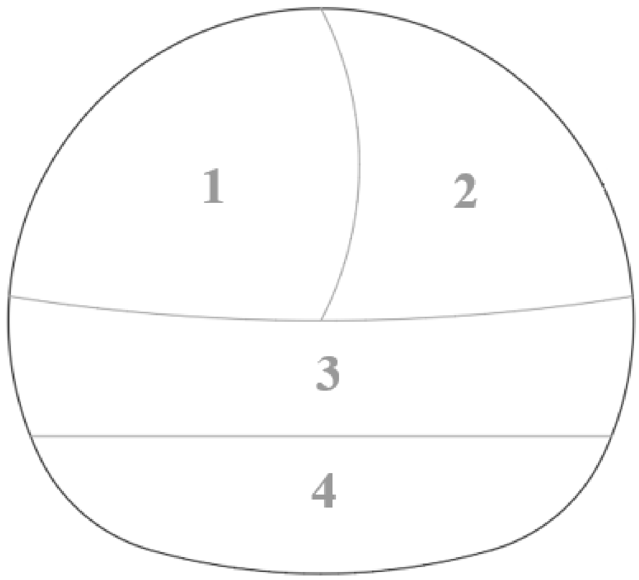


Figure D3 SEM tunnel excavation sequence

2.3.2 Analysis

A CCM analysis was conducted for each stage in the excavation sequence. As with the analytical method, the radial tunnel convergence that is anticipated to occur between excavation and support installation was accounted for following the solutions developed by Panet (1995). A plot of the cumulative tunnel convergence on completion of the invert is shown in Figure D5.

The Reference Design was based on the assumption that the shotcrete lining would be installed at an X/R_t of approximately 0.5. In the case of excavation of the first sidewall drift, this equates to an advance length of 2 m - assuming an equivalent tunnel radius, R_t, of 3.8 m.

The average tunnel convergence around the excavation boundary was found to be approximately 7 mm. Using the previously presented method to determine the equivalent volume loss suggests that a value of 0.2% would be an appropriate estimate for the SEM tunnel case presented.

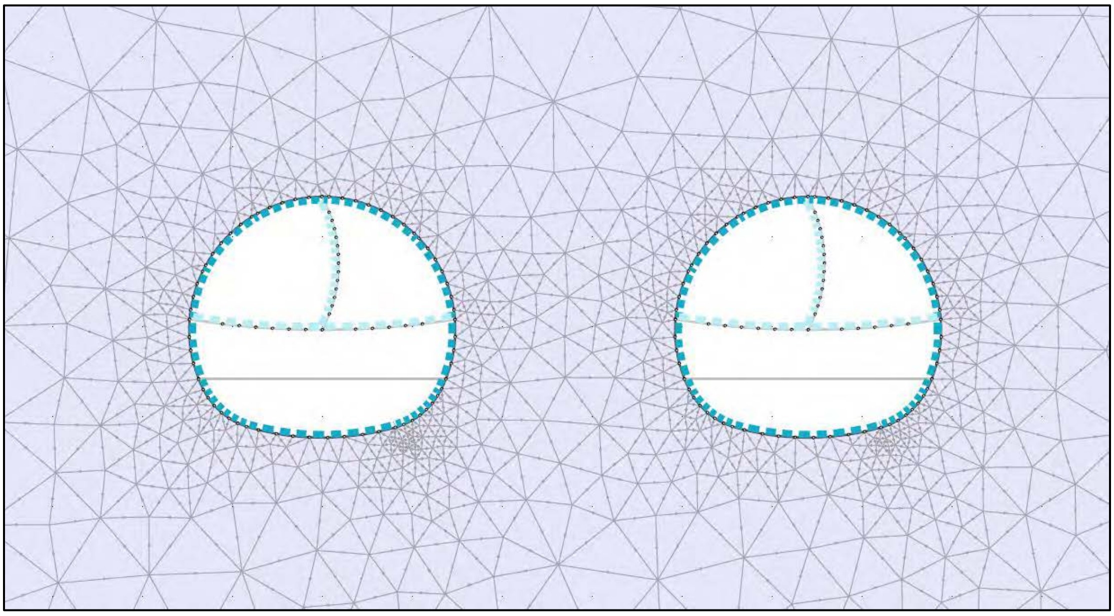


Figure D4 SEM Tunnels FEA model geometry, showing excavation stages

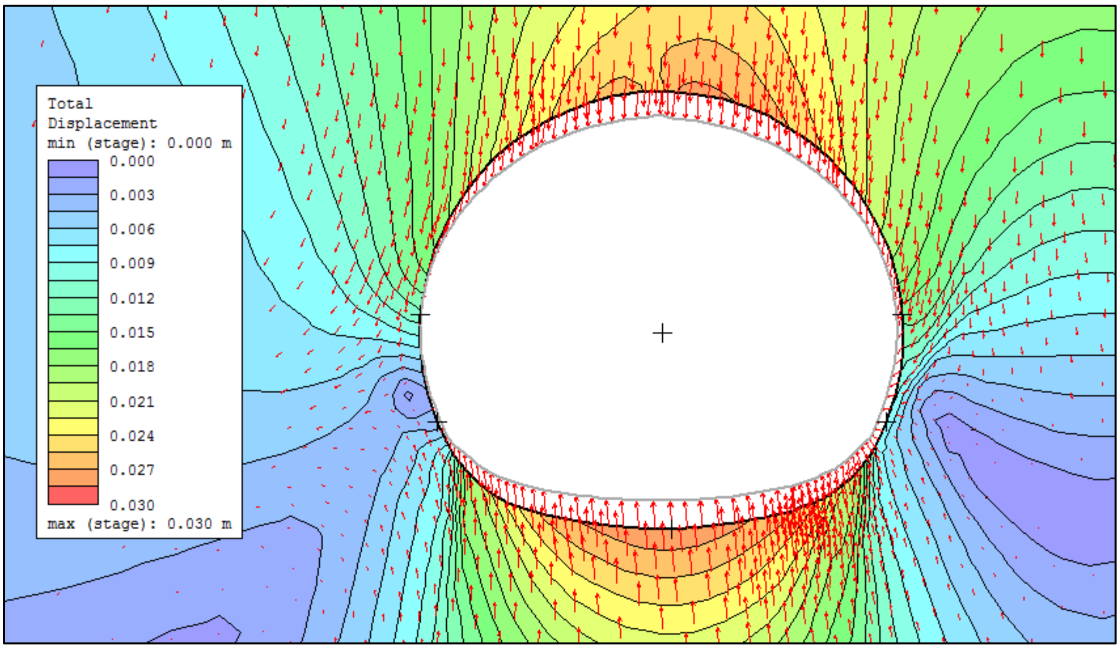


Figure D5 SEM tunnel final stage convergence in Siltstone (MW)

3. Trough width Validation

3.1 Overview

Numerical analysis can be used in the validation of the empirical assumption that the ground settlement profile above a tunnel excavation approximates a Gaussian function.

Mair et al (1993) presents a method of determining the tunnel trough width parameter, i, from observational data. The method can also readily be applied to the output of numerical analysis to determine how closely a settlement profile follows a Gaussian shape. In this application, the linearity of a plot of $\log_e S/S_{max}$ against y^2 is used as a measure of how well the assessed data adheres to a Gaussian shape; where S is the settlement, $S_{v,max}$ the maximum settlement over the tunnel axis and y the transverse horizontal distance from the tunnel axis.

For illustrative purposes, a section of TBM tunnel driven beneath the Yarra Yalley has been assessed in the following section.

3.1.1 Modelling assumptions

The modelling assumptions adopted for the settlement validation are the same as those presented in Section 2.2.1, with the difference being that they will be applied to a 2D FEA model of the excavation.

The settlement profile will be taken at the top of rock, as the overlying clay alluvium was represented as a uniformly distributed load to facilitate modelling efficiency.

3.1.2 Analysis results

Plotting the surface settlement profile from the output of the RS2 analysis produces the vertical settlement curve presented in Figure D6. It can be observed that S_{max} is approximately 14 mm, with an estimated trough width parameter, i, of approximately 12.8 m.

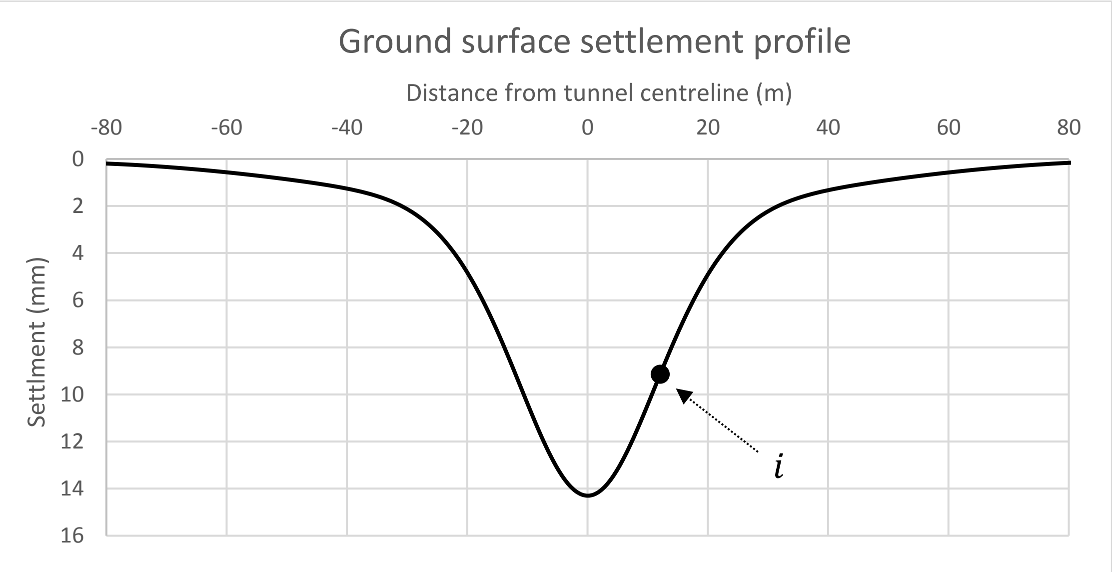


Figure D6 Ground surface settlement profile calculated by FEA

The settlement data have then been transformed as described by Mair et al (1993) as shown in Figure D6. As can be seen, a linear line of best fit follows the settlement profile reasonably well indicating that the calculated settlement profile is a reasonable approximation to a Gaussian curve.

From the Gaussian curve, the point of inflection can be found where the vertical settlement is 60.6% of the maximum vertical settlement (i.e. equivalent to one standard deviation from the mean). The natural log of this value is 0.5, so by reading across from the vertical axis to the line-of-best-fit, the value of y^2 is approx. 163 m^2, thus the value of $i = \sqrt{163}\,m^2 = 12.8\,m$.

Based on the ratio between i and Z_0, the value of k is approximately 0.5.

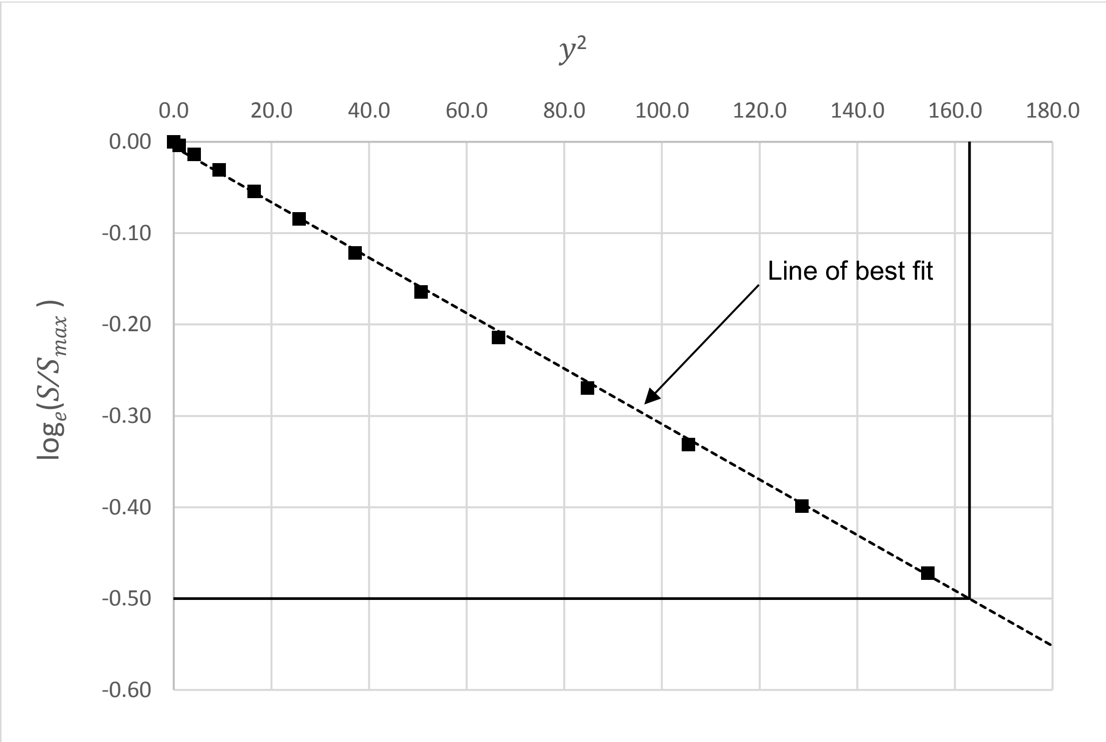


Figure D7 Plot of $\log_e(S/S_{max})$ versus y^2

4. Conclusion

It has been shown through both analytical and numerical methods that the empirical assumptions adopted for the assessment of ground movement effects applicable to the NELP alignment are appropriate for the purposes of the EES analysis.

Using the methods presented herein for each of the key tunnel segments along the proposed alignment, along with appropriate geological input parameters, yields the Volume loss estimates as summarised in Table 1 below (extract from section 5.7.1 of the main report).

It must be noted that the Volume losses presented represent the upper range of values anticipated within each section of tunnel identified.

Table 1 Volume loss estimates applied to the EES assessment

Location	Volume loss – V_L (%)	Reasoning
Lower Plenty Road to Leura Avenue	0.8	Faulted zones have been detected near the temporary portal in the vicinity of Lower Plenty Rd. Reduced ground cover above the tunnel, with some superficial soil.
Leura Avenue to Yarra Valley	0.2	Greater than one tunnel diameter of cover above the tunnel crown and material is believed to be mainly competent siltstone.
Yarra Valley northern valley interface	0.8	Reduced ground cover above the tunnel crown beneath the Yarra Valley. The ground cover consists of a thick layer of geologically “recent” alluvial soils and highly weathered/fractured rock; potential “mixed ground” conditions in TBM face.
Yarra Valley	0.4	Ground cover above tunnel crown increases as the alignment continues under the Yarra Valley. Siltstone in this location is of lower GSI as rock fracturing is more prominent and fault zones are possible.
Yarra Valley southern valley interface	0.8	Ground cover of material above tunnel crown decreases as the alignment rises to meet the Manningham Road interchange box. Surface material comprises weathered siltstone with some fault zones expected.
Mined tunnels	0.3	Moderately weathered, moderate strength fractured rock is anticipated in this section of the alignment.

5. References

1. Hoek, E., Carranza-Torres, C., Diederichs, M., Corkum, B. (2008). *The 2008 Kersten Lecture, Integration of geotechnical and structural design in tunnelling'*, Annual Geotechnical Engineering Conference, Minneapolis.
2. Hoek, E., Kaiser, P.K., Bawden, W.F. (1995). *Support of Underground Excavations in Hard Rock,* Chapters 8 and 9.
3. Hoek, E., Carranza-Torres, C., Corkum, B. (2002). *Hoek-Brown failure criterion – 2002 Edition.* NARMS-TAC Conference, Toronto.
4. Hoek, E., Diederichs, M.S., (2005). *Empirical estimation of rock mass modulus*. International Journal of Rock Mechanics & Mining Sciences, Issue 43, Page 203-215.
5. Hoek, E. (2005). *Uniaxial compressive strength versus Global strength in the Hoek-Brown criterion*. Vancouver.
6. Marinos, P & Marinos, V & Hoek, Evert. (2007). *The Geological Strength Index (GSI): A characterization tool for assessing engineering properties of rock masses.* Proceedings International Workshop on Rock Mass Classification for Underground Mining. 13-21. 10.1201/NOE0415450287.ch2.
7. Macklin, S., Schult, M., Terzic, Z., Chu, D. 2014. *Strain-dependent Stiffness of the Weathered Melbourne Formation*. 15^{th} Australasian Tunnelling Conference 2014, Sydney, NSW.

Appendix D.2 – Retaining wall ground movement validation

1.1 Introduction

The process of construction of retaining walls may induce ground movement as a result of installation effects and lateral deflection of the wall during excavation. This ground movement is a function of the ground conditions, depth of excavation, relative stiffness of the wall and the propping/excavation sequence. For the North East Link project EES assessment it has been assumed that potential ground movements can be approximated by empirical models derived from case studies as published by Clough & O'Rourke (1990) and the CIRIA C760 Report (Gaba, et al., 2017).

1.2 Overview

The sources of ground movement associated with the construction of retaining walls include:

- **Construction of the wall**: Ground movement is associated with vibration, removal of obstructions or "volume loss" of the guide trench excavations and the wall excavation itself. These are highly dependent on construction methodology.
- **Excavation in front of the wall**: Ground movement arises from stress changes induced by the excavation and is influenced by soil strength and stiffness, propping arrangements, relative wall stiffness and the depth of the excavation.
- **Changes in groundwater level**: Ground movement may be associated with changes in pore water pressure in compressible soils due to construction de-watering. Dependent on the water control requirements of the construction methodology and the local ground conditions.

Gaba et al. 2017 recommend that empirical methods should be favoured in preference to the use of complex ground movement analysis such as finite-element analysis (FEA) for estimates of ground movement. This is because the applicability of numerical models can be limited unless an understanding of the small strain nonlinearity of the soil modulus has been established from field measurements. Nonetheless, it is good practice to undertake a cross check between the results of numerical models and empirical estimates for validation purposes.

This appendix aims to compare the empirical ground movement profiles used for the EES ground movement analysis to that derived from preliminary 2D FEA numerical modelling in *PLAXIS* undertaken for the **Reference Design as of August 2018**.

1.3 Empirical approach to ground movement estimations

In general, there are two patterns of ground movement induced by retaining wall excavations (Gaba, et al., 2017). These patterns have been termed the cantilever pattern (associated with a 'cantilever movement' of the wall) and the concave pattern (associated with a 'deep inward movement' of the wall) as shown in Figure 1.

The progressive installation of wall support in the form of temporary propping or ground anchoring during excavation governs the expected ground movement pattern. The initial stages of construction will give rise to 'cantilever' wall deformations (Figure 1.a). When the excavation advances to a deeper level, wall deformations are restrained by the installation of support, giving rise to a deep inward movement of the wall associated with the concave ground surface settlement profile (Figure 1.b). The ground surface displacement profile therefore arises due to cumulative wall deflections during the staged excavation and progressive support of the retaining wall.

Clough & O'Rourke (1990) note that the concave profile is the predominant form of wall deformation for deep cuts in soft to firm clay, whereas the cantilever profile is more common in sand and stiff to very hard clay conditions.

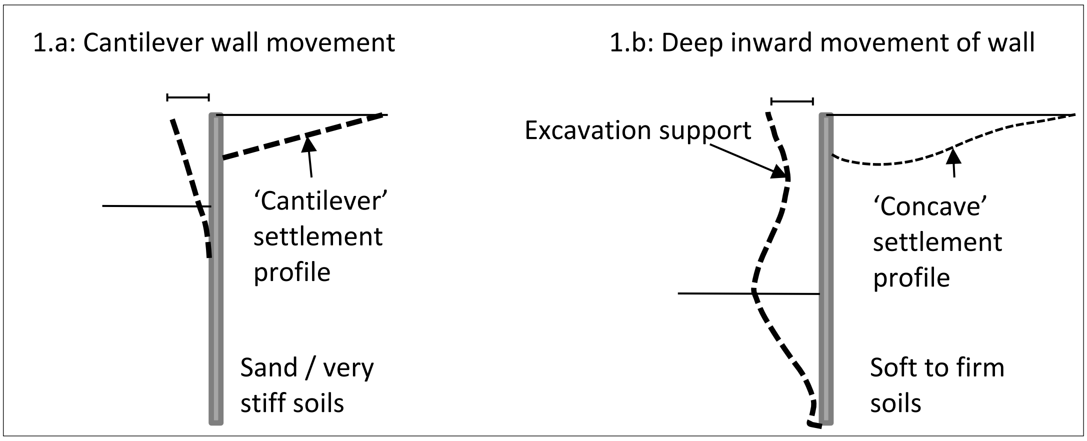


Figure 1: Patterns of wall movement and ground deformations after Gaba, et al. 2017.

The retaining wall excavations proposed for North East Link are expected to fall into the following four sections:

1. Bored pile excavations, from Watsonia Station to just north of Erskine Road, Greensborough;
2. Diaphragm wall excavation from north of Erskine Road, Greensborough to the northern TBM portal at Lower Plenty Road, Greensborough;
3. Diaphragm wall excavation at Manningham Road interchange; and
4. Diaphragm wall excavation for the southern TBM portal, South of Rocklea Road, Bulleen.

The above sections will be referred to by their respective number in the following discussion.

Retaining wall excavations of up to 35 m depth are anticipated, with varying levels of wall support in the form of ground anchors, propping or permanent "bridge" slabs.

Retaining wall sections 1 – 3 will typically be excavated through highly weathered to faulted rock and residual soils and are therefore expected to have lateral wall displacements more comparable to the cantilever profile. These ground conditions are considered to exhibit stiffness comparable to a stiff to very hard clay. Section 4 is expected to be excavated through alluvial deposits which comprise mainly firm to stiff clay and therefore expected to have lateral wall displacements more comparable to a concave profile.

Other key assumptions involved in the selection of an empirical ground movement curve include:

- Diaphragm and contiguous bored pile wall excavations are considered to have a high system stiffness (compared to say, sheetpile or kingpost walls).
- Where the excavated material in front of the retaining walls varies from residual soils and terrace alluvium close to ground surface to competent siltstone at depth, the material close to surface is conservatively assumed to govern the ground movement curve selected.
- Long-term ground movements in compressible soils due to changes in groundwater level were not considered to contribute to the cumulative ground movements in the excavations north of

Lower Plenty Road. However, these effects were considered for the trenched excavations south of Rocklea Road.

The following empirical ground movement curves were therefore deemed to be applicable for this assessment based on the variation in ground conditions:

Table 1: Empirical ground movement parameters

Movement type	Sections 1 to 3		Section 4	
	Surface movement at wall (% of max excavation depth)	Zone of influence (multiple of max excavation depth)	Surface movement at wall (% of max excavation depth)	Zone of influence (multiple of max excavation depth, H)
Horizontal	0.8%	3.5H	0.15%	4H
Vertical	0.3%	3H	0.04%	4H
Empirical model	Excavations in stiff to very hard clay, Clough & O'Rourke (1990) Fig. 9		Excavation in competent stiff clay, Gaba et al. (2017) (CIRIA C760 report) Table 6.3	

The above Clough & O'Rourke (1990) empirical model was derived from a wide range of case data, including data from retaining wall systems with lower stiffness (such as sheet pile walls constructed using a "bottom-up" sequence[1]) than what is currently proposed for the Reference Project. It is therefore reasonable to consider the empirical model to be a conservative representation of the anticipated ground movements for the bored pile and diaphragm wall excavations, some of which will be constructed using a "top-down" sequence[2]. Refinement of the Clough & O'Rourke (1990) empirical model was therefore undertaken by a comparison with results from numerical analysis (Section 1.4).

The ground movement profile from the CIRIA C780 report was used for the Section 4 retaining walls and was derived from support systems of high stiffness, therefore no further refinement using numerical analysis was considered necessary. Figures 2 and 3 below show the ground movement curves after the CIRIA C760 report (Gaba, et al., 2017).

---

[1] Trench excavation constructed by progressive installation of temporary propping as excavation proceeds downwards. Typically gives rise to a lower system stiffness and higher overall ground movements.

[2] Roof slab installed before excavations commence, restraining walls from significant ground movements during excavation. Typically gives rise to a higher system stiffness and lower overall ground movements.

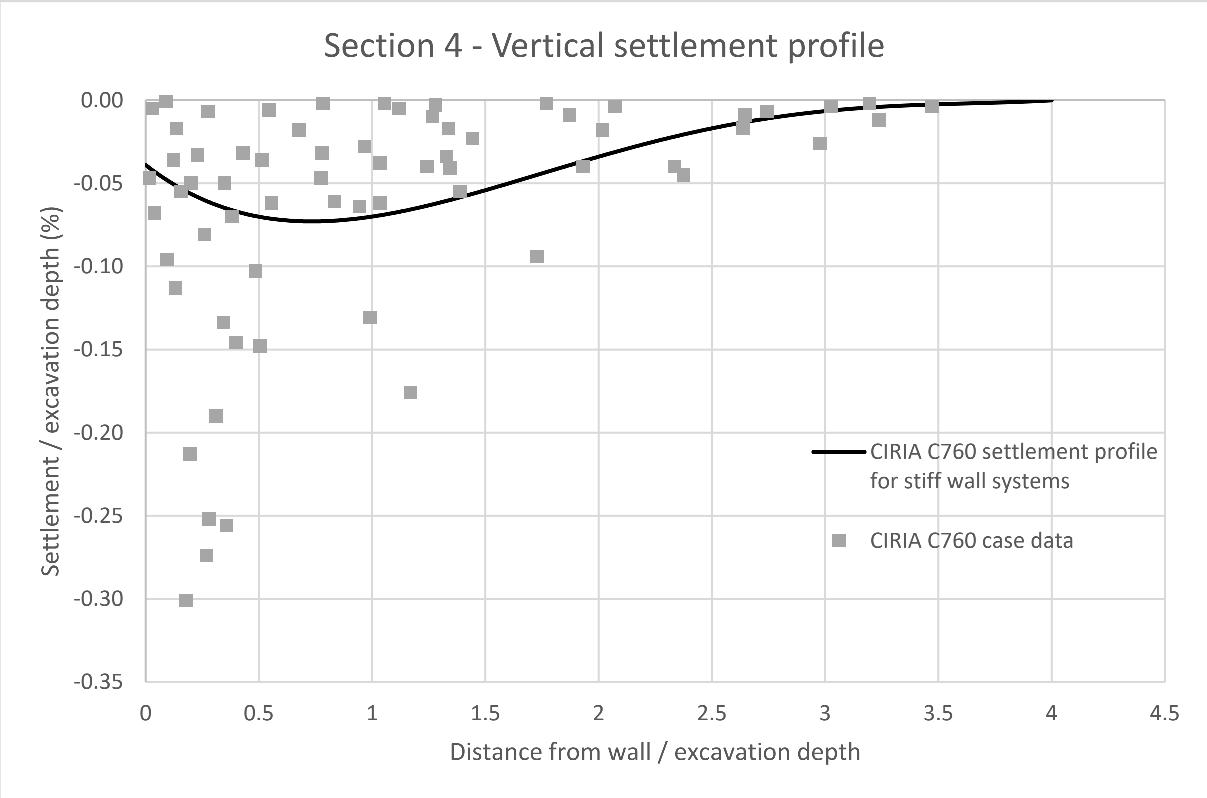


Figure 2: CIRIA C760 vertical settlement curve after Gaba et al. 2017

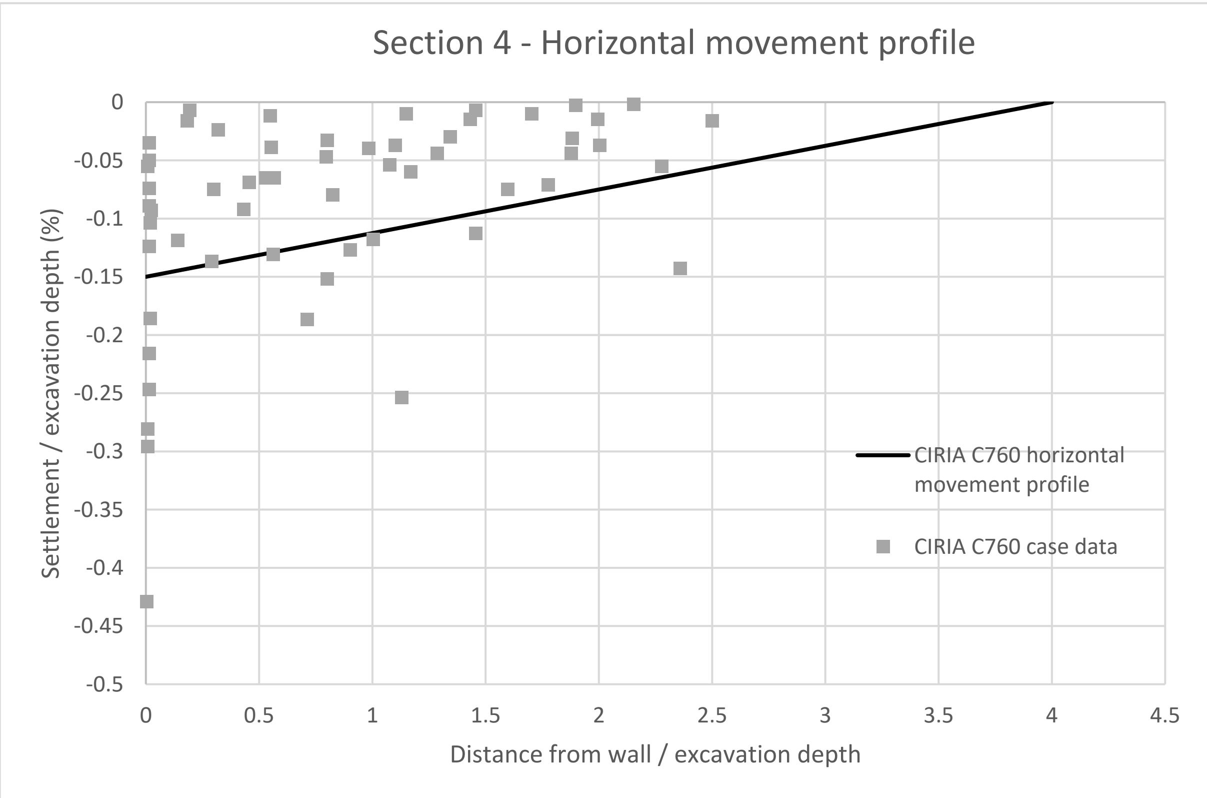


Figure 3: CIRIA C760 horizontal movement curve after Gaba et al. 2017

1.4 Numerical validation – Retaining wall sections 1 to 3

The finite element analysis program *PLAXIS* was used to model ground movements adjacent to retaining walls at critical sections along the alignment for the Reference Project. The retaining wall design varies throughout the alignment given the variation in ground conditions, excavation depths and groundwater conditions. For the purposes of this validation exercise, the *PLAXIS* results of a critical retaining wall section was selected for comparison against the empirical curves for Sections 1 - 3. The selected section comprised a 12 m deep diaphragm wall excavation with ground anchor support constructed using a bottom-up sequence.

The key inputs and assumptions for the *PLAXIS* modelling included:

- Criteria for maximum lateral deflection of the retaining wall is 0.5% of the wall height. A diaphragm wall of 1.2 m thickness was proposed to meet this criterion.
- The stiffness of the wall was reduced to account for crack development during construction.
- Varying forms of wall support were modelled, including temporary anchors and temporary propping.

Figures 4 and 5 below show the Clough & O'Rourke (1990) empirical data for vertical settlement and horizontal movement (grey data points) compared to the results from the *PLAXIS* analysis (black dashed line). A 4th order polynomial was fit to the *PLAXIS* results (solid black line) and represents the curve ultimately used for the EES ground movement assessment. This curve is considered to be an approximate representation of the anticipated ground movements, because stiff retaining wall systems are proposed for the Reference Project.

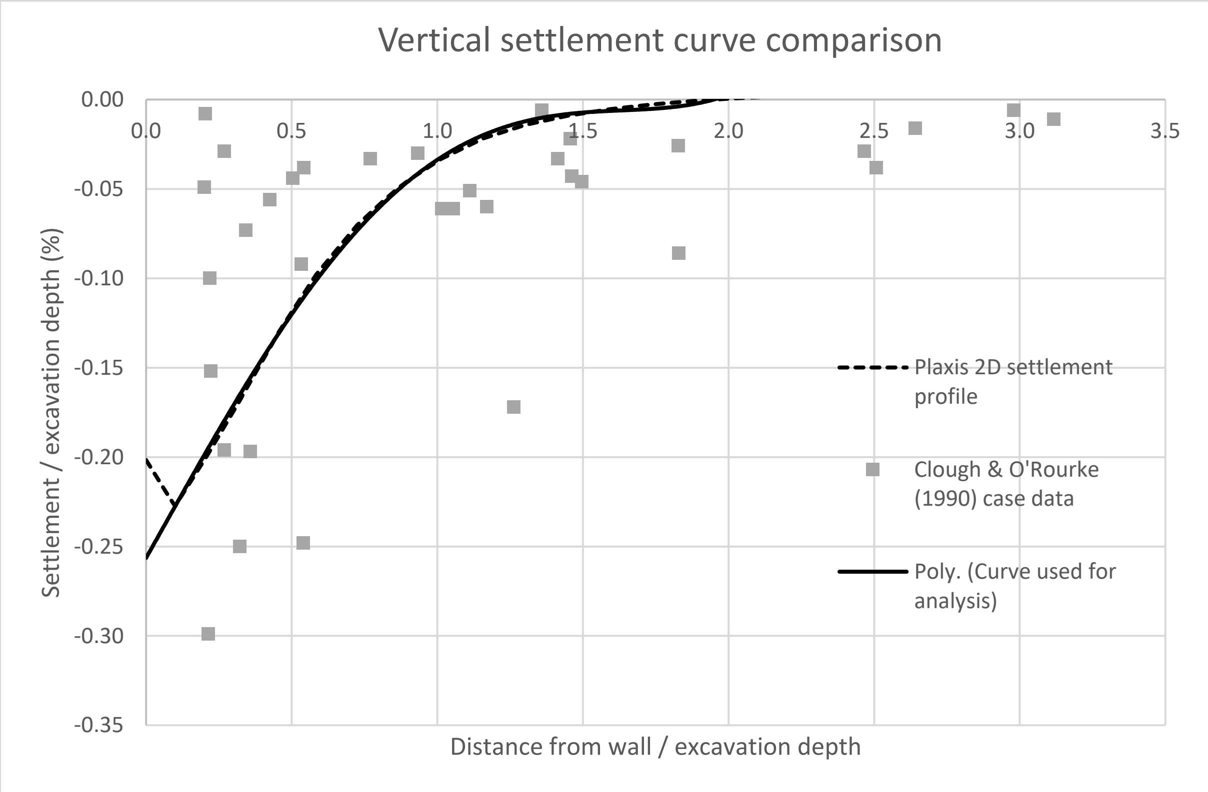


Figure 4: Comparison of the **Clough & O'Rourke (1990)** empirical data and PLAXIS 2D settlement curve

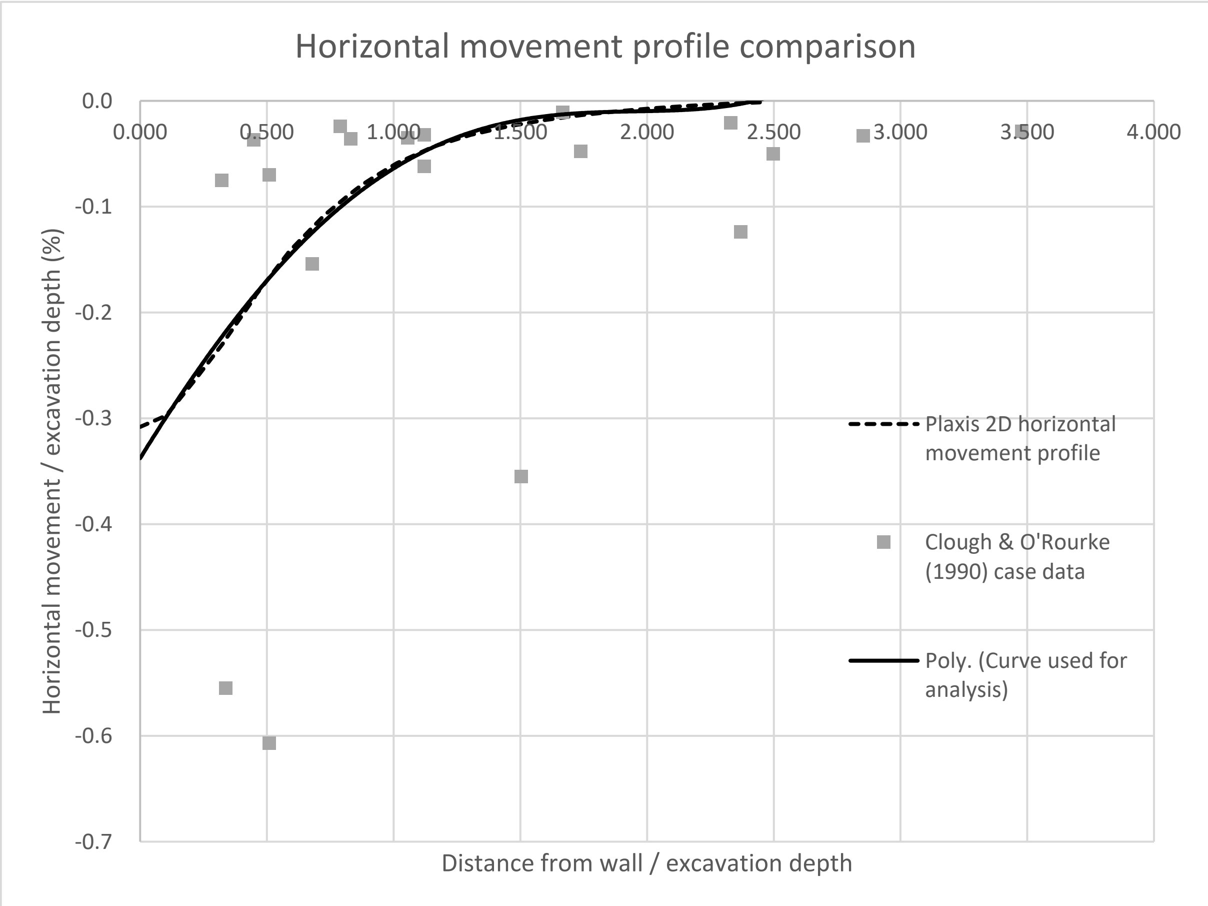


Figure 5: Comparison of the **Clough & O'Rourke (1990)** empirical data and PLAXIS 2D horizontal movement curve

Table 2: Selected ground movement profile for Sections 1 to 3

Movement type	Sections 1 to 3	
	Surface movement at wall (% of max excavation depth)	Zone of influence (multiple of max excavation depth, H)
Horizontal	0.35%	2.5H
Vertical	0.25%	2H

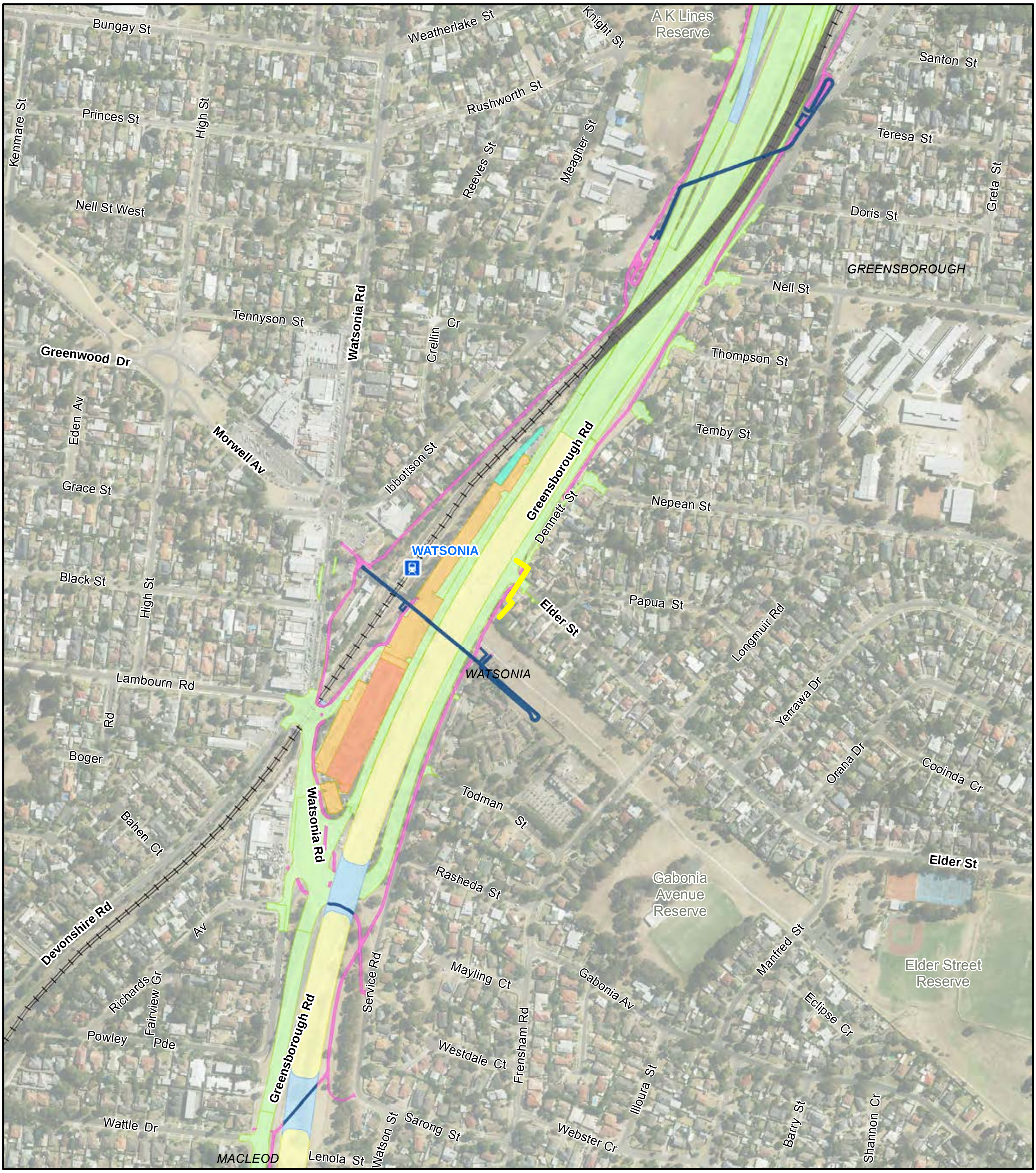
References

Clough, W. & O'Rourke, T. D., 1990. *Construction induced movements of insitu walls.* New York, ASCE.

Gaba, A. et al., 2017. *Guidance on embedded retaining wall design,* London: CIRIA.

Gaba, A., Simpson, B., Powrie, W. & Beadman, D., 2002. *Embedded retaining walls: guidance for economic design,* Southampton: CIRIA.

Appendix E – Map of Sensitive Receptors



Legend

- Elder Street gas main

Proposed reference project

- Area for substation
- Shared use path overpass
- Shared use path
- Multi-deck car park
- Public transport infrastructure upgrade
- Elevated ramp
- Surface road
- Road in trench
- Rail tunnel
- Railway
- Train station

Paper Size A4

0 40 80 160

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

NORTH EAST LINK PROJECT

North East Link Project
Environment Effects Statement (EES)

Job Number 31-35006
Revision D
Date 18/03/2019

Sensitive receptors map

Appendix F

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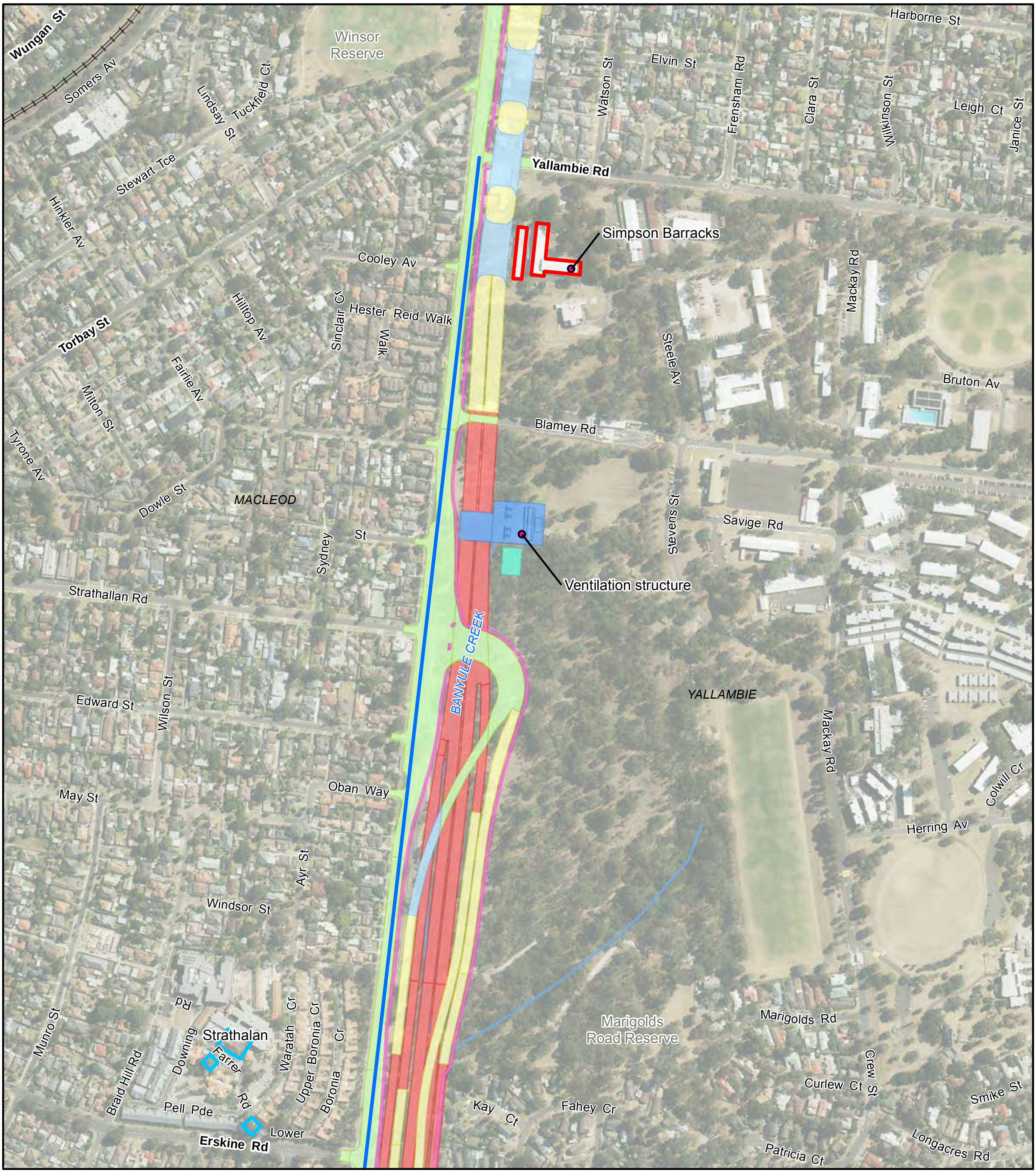
Data source: CIP Imagery - DELWP - 2018 | roads, watercourses, parks, rail, localities, planning zones - Vicmap - 2019 | precinct, project infrastructure - GHD, AECOM - 2019 Created by: trighetti



Legend

- Greensborough Road water main
- Simpson Barracks buildings
- Strathalan

Proposed reference project

- Ventilation system
- Area for substation
- Shared use path
- Elevated ramp
- Surface road
- Road in trench
- Underground tunnel
- Railway
- Stream

Paper Size A4

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Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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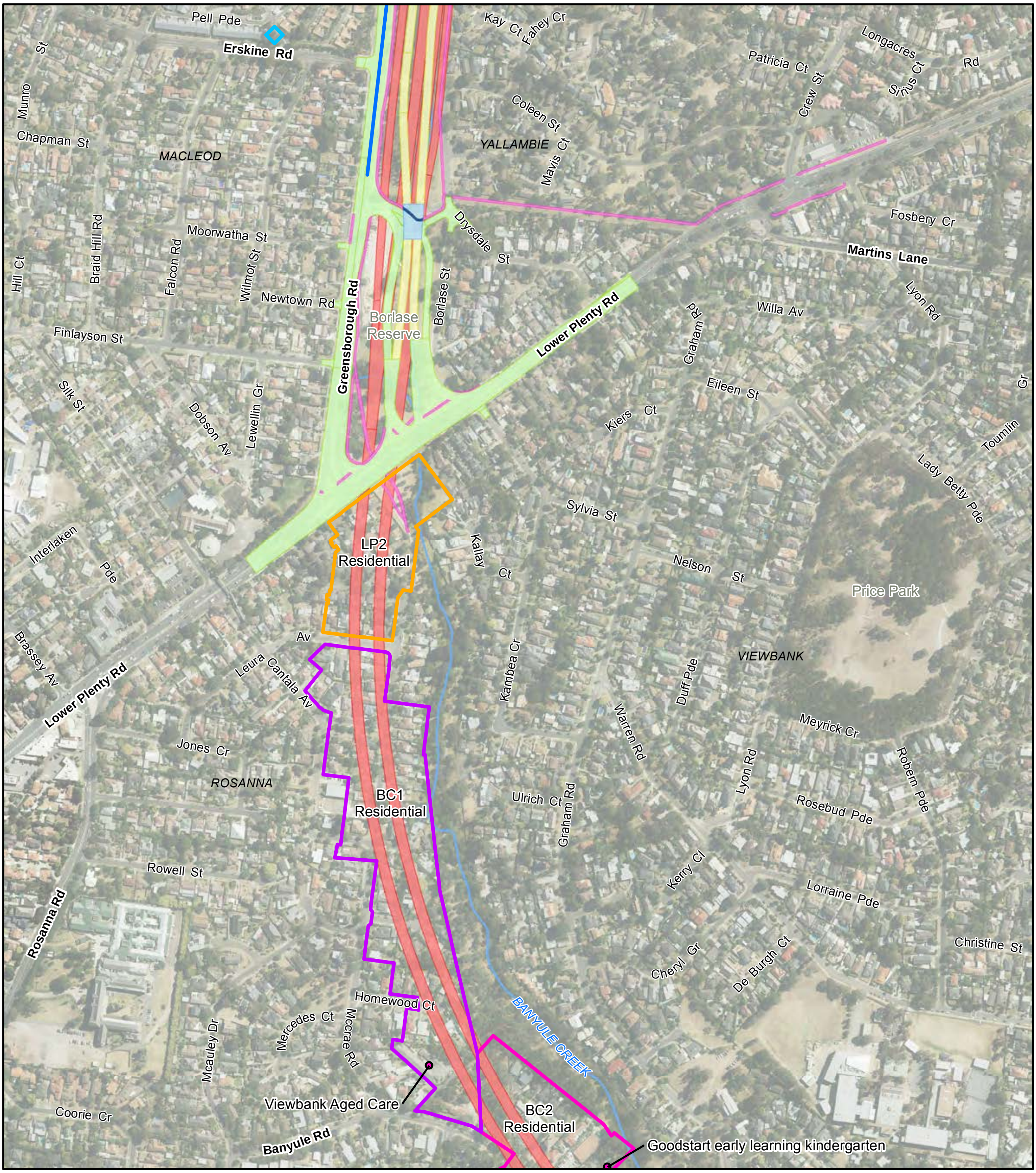

Legend

- Greensborough Road water main
- Strathalan
- BC1 Residential
- BC2 Residential
- LP2 Residential

Proposed reference project

- Shared use path overpass
- Shared use path
- Shared use path underpass
- Elevated ramp
- Surface road
- Road in trench
- Underground tunnel
- Stream
- Drain or channel

Paper Size A4

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Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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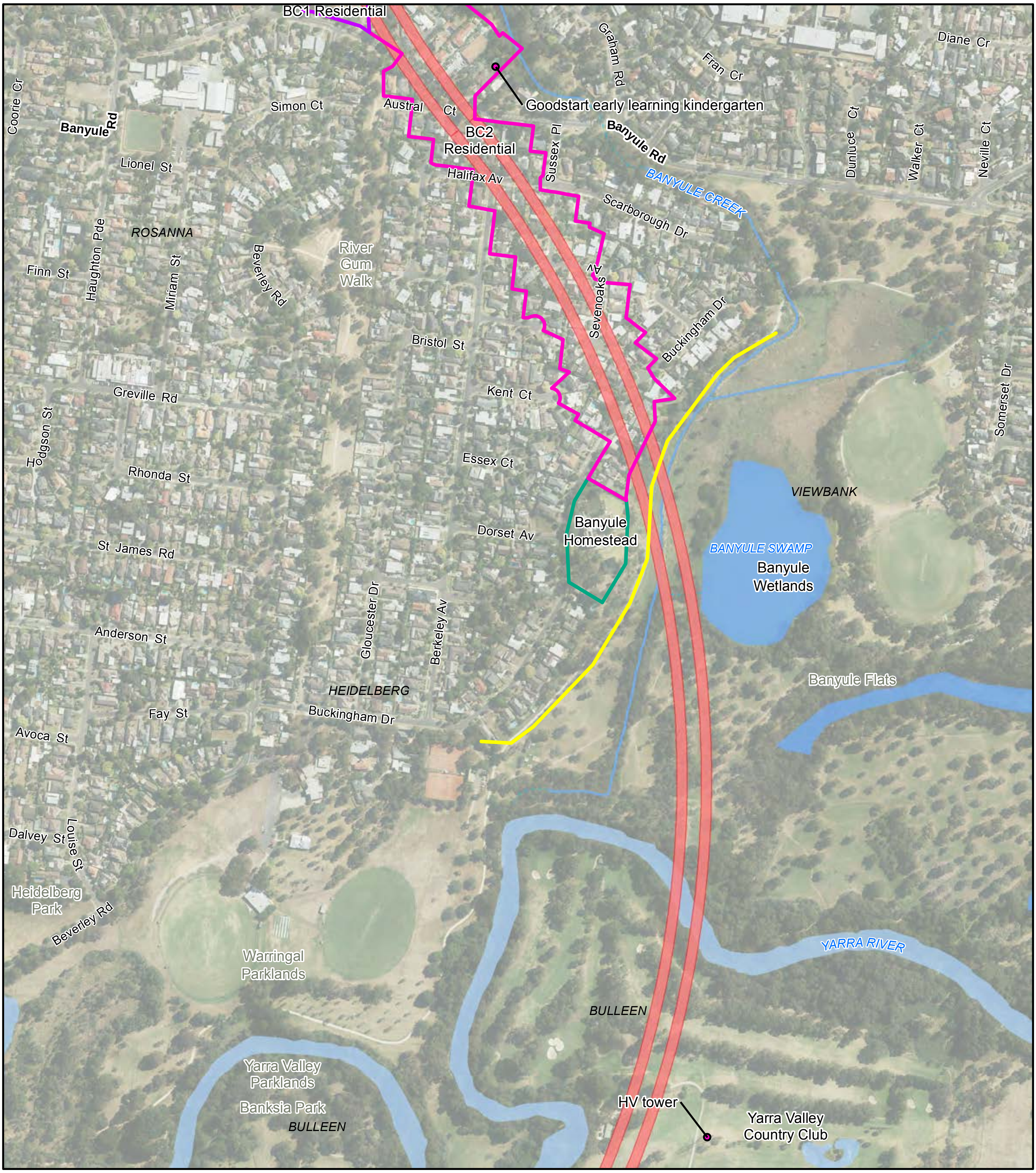

Legend

- Banyule Creek sewer
- BC1 Residential
- BC2 Residential
- Banyule Homestead

Proposed reference project

- Underground tunnel
- Stream
- Drain or channel
- Watercourse
- Lake

Paper Size A4

0 40 80 160

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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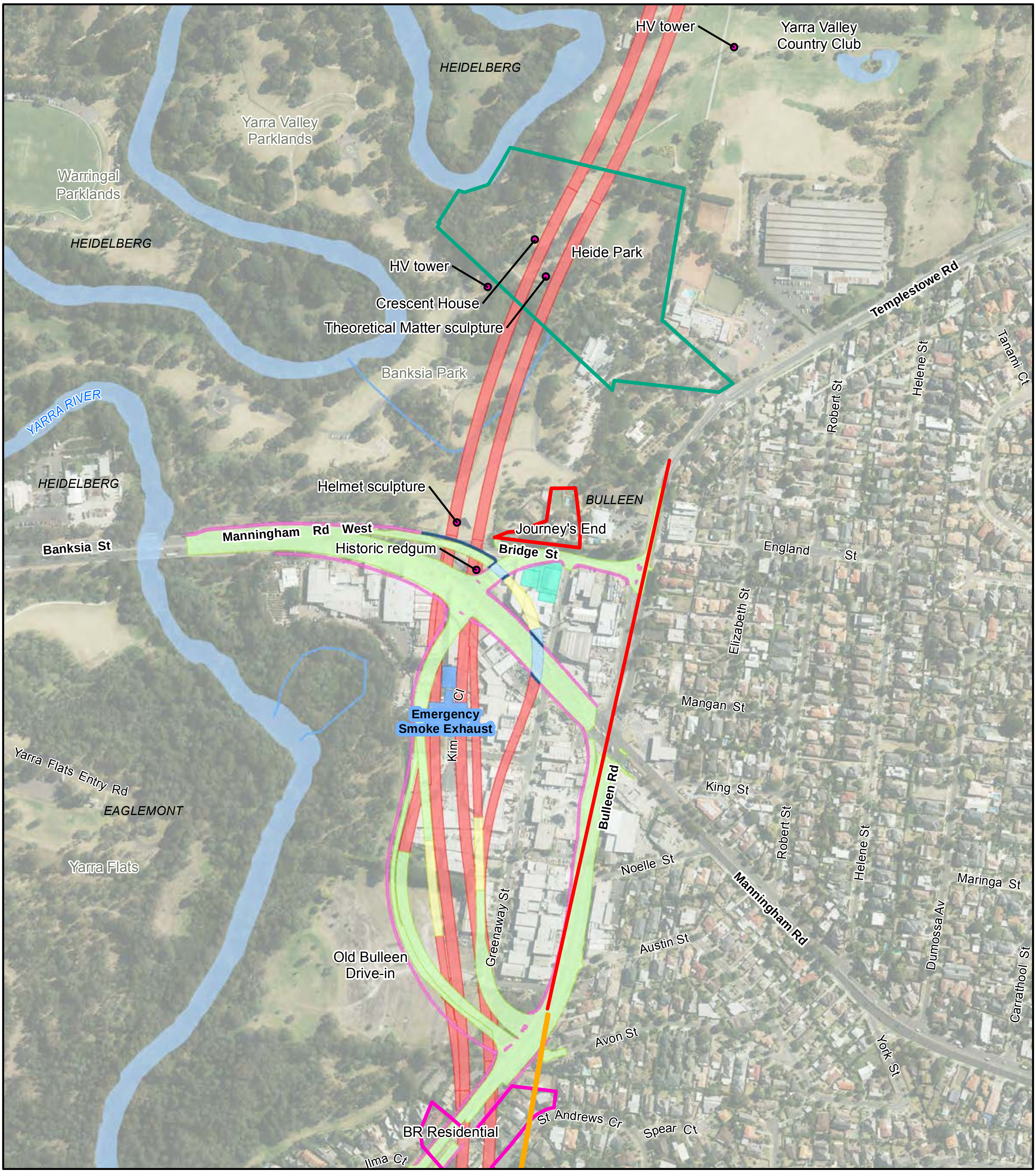

Legend

- Bulleen Road sewer
- Bulleen Road sewer realignment
- Heide Park
- Journey's End
- BR Residential

Proposed reference project

- Ventilation system
- Area for substation
- Shared use path overpass
- Shared use path
- Elevated ramp
- Surface road
- Road in trench
- Underground tunnel
- Stream
- Watercourse

Paper Size A4

0 40 80 160

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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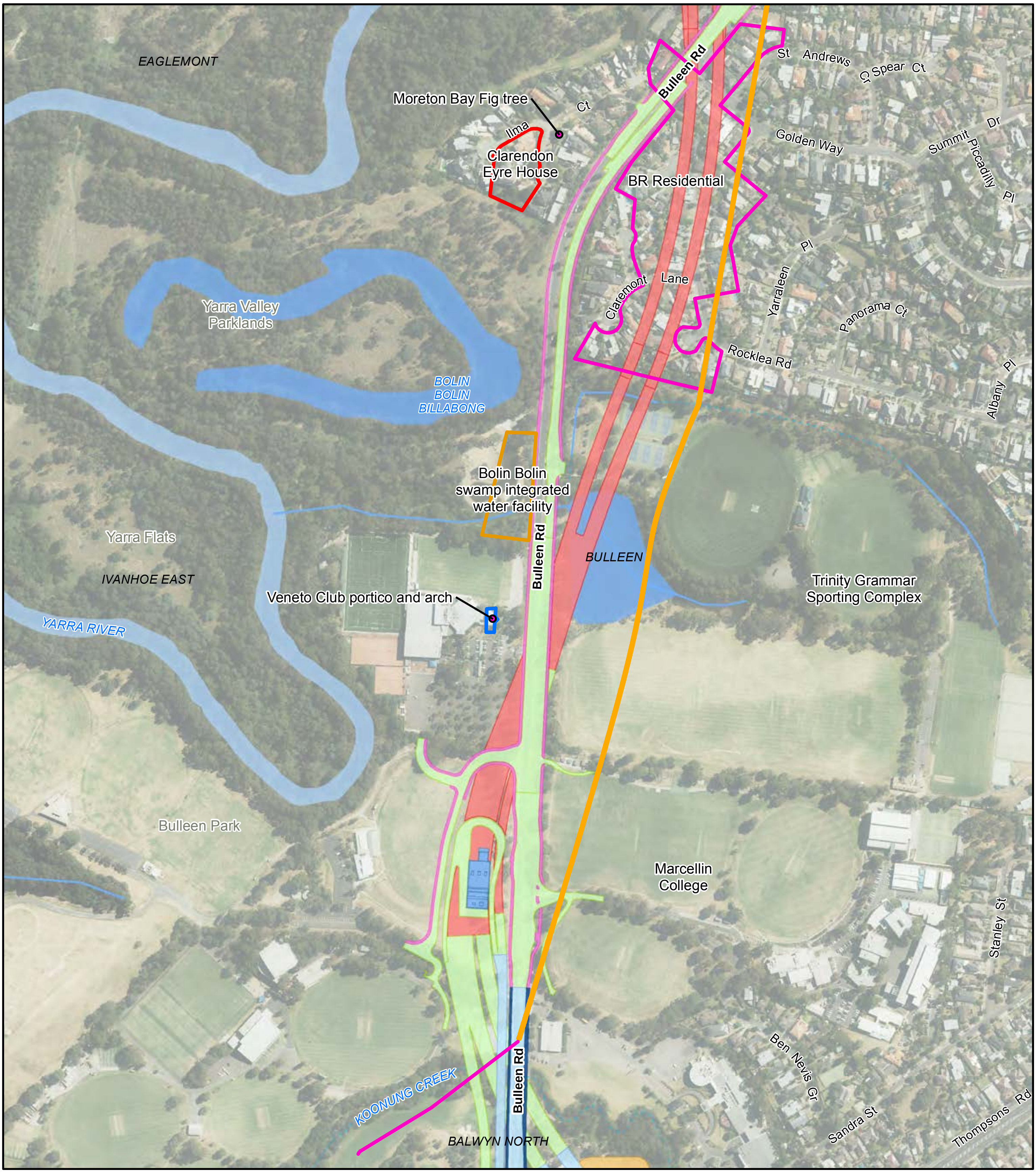

Legend

Bulleen Road West sewer	Clarendon Eyre House	Shared use path overpass	Surface road	Watercourse
Bulleen Road sewer realignment	BR Residential	Shared use path	Underground tunnel	Lake
Bolin Bolin swamp integrated water facility	**Proposed reference project**	Public transport infrastructure upgrade	Stream	
Veneto Club portico and arch	Ventilation system	Elevated ramp	Drain or channel	

Paper Size A4

0 40 80 160

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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Revision	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
Final	S Macklin	K Aldous		M Roser		April 2019

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