A New Standard: Developments Near Rail Tunnels

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Abstract: *The increasing need for urban development adjacent to existing rail tunnels induces risks to rail tunnels and may affect the rail operation and safety of the public. The developer has a legal duty to eliminate risks to safe rail operations so far as is reasonably practicable (SFAIRP). The developer is required to perform a detailed risk assessment, risk management and mitigation measures and submit as part of the development applications. Transport for NSW (TfNSW) reviews the development applications of projects near rail tunnels on a case-by-case basis to ensure that the existing rail tunnels are not adversely affected by the proposed development and the rail operations are not affected during and after the proposed construction. This assessment requires a Standard that provide assessment criteria, load assumptions, monitoring requirements and minimum requirements for documentation at various stages of the development. Asset Standard Authority (ASA) has recently published a new Standard to provide the requirements and technical guidance to the developers to assess the construction-induced effects and associated risks. In the process of developing this unified Standard, existing guidelines developed in various time frames were reviewed and incorporated in this Standard. This paper presents the outline of the new Standard for developments near rail tunnels (T HR CI 12051 ST).*

Keywords: *Rail tunnel, developments, ASA Standard, Safety, Risk*

1. INTRODUCTION

In recent years, development applications lodged along the existing rail lines are on the increase due to the demand for land for urban developments. These developments can cause damage to existing rail tunnels unless the development activities are regulated and comply with guidelines published by TfNSW. In the past, developers followed different guidelines for development adjacent to existing City Circle Line (CCL) tunnels, Eastern Suburbs Rail (ESR) tunnels, Epping to Chatswood Rail Line (ECRL) tunnel and Airport Line (APL) tunnel. To minimize confusion over using various guidelines and to simplify the requirements for development applications and approvals, a single standard that integrates the existing guidelines has been developed.

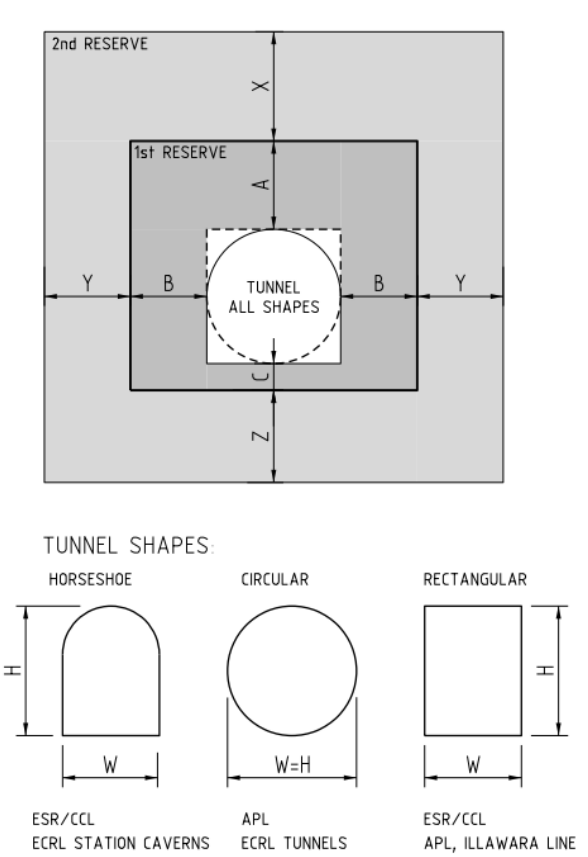
During the development of this standard, several external standards and guidance materials were referred to and considered as appropriate. The following documents provide general legislative requirements and guidance in relation to developments adjacent to rail infrastructure:

- *State Environment Planning Policy* (Infrastructure) 2007 under the Environmental Planning and Assessment Act 1979 (SEPP)
- Development Near Rail Corridor and Busy Roads – Interim Guidelines – NSW Government, Department of Planning, 2008
- Safe work NSW codes of practice for safe design of structures- WorkCover.

2. PROTECTION RESERVES

The principle concepts of protection reserves are to define proximity and mutual interaction of existing and proposed structures, planning and construction feasibility, operational safety and justification for public interest. Rail protection reserves, also known as protection zones, are defined for the protection of existing rail tunnels. For assessing the effects of adjacent developments, the rail tunnels include the main tunnel and the associated structures such as station caverns, cross passages, egress passages, cut and cover tunnels and short and long underpasses.

In this Standard, new protection reserves are defined for rail tunnels to unify reserve zones defined in all previous guidelines. The protection reserves are categorised as 'first reserve' and 'second reserve'. Figure 1 represents the area that forms the first reserve and the second reserve around the rail tunnel and the guideline to determine the extent of these reserves.



1st RESERVE

A: GREATER OF
(1) 3m FROM THE CROWN OF THE TUNNEL
(2) ONE-THIRD OF TUNNEL WIDTH PLUS ONE METRE [(1/3)*W+1]
(3) EXISTING PRE-DEFINED EASEMENT HEIGHT

B: GREATER OF
(1) HALF OF TUNNEL WIDTH [(1/2)*W]
(2) EXISTING PRE-DEFINED EASEMENT WIDTH

C: GREATER OF
(1) 1m FROM THE LOWEST TUNNEL INVERT INCLUDING CABLE AND DRAINAGE TRENCHES
(2) EXISTING PRE-DEFINED EASEMENT DEPTH

W = EXISTING TUNNEL WIDTH
H = EXISTING TUNNEL HEIGHT

2nd RESERVE

A+X: GREATER OF
(1) 1.5 * (W + H)
(2) A+25m

B+Y: GREATER OF
(1) W
(2) B+25m

C+Z: C + 1.5 * (Wn + Hn)
Wn = WIDTH OF NEW TUNNEL BELOW EXISTING TUNNEL
Hn = HEIGHT OF NEW TUNNEL BELOW EXISTING TUNNEL

NOTE: ALL DIMENSIONS IN METRES

Figure 1 - Rail protection reserves

The first reserve zone comprises the immediate surrounds of the tunnel. This zone represents the area that shall not be encroached upon by any future construction or development. The following factors have been considered in determining the first reserve in this standard:

1. existing protection zone 1 for ECRL tunnel and APL tunnel and existing easements for CCL tunnels and ESR tunnels
2. load arching height above tunnel which diverts development induced loads around the existing tunnel without affecting the tunnel lining
3. disturbed zone during the construction of the existing tunnel such as extent of rock bedding movements and stress changes around the tunnel
4. drainage pits and potential over break and backfill at the invert
5. spotbolts on the sidewalls to stabilise rock wedges

The second reserve zone is determined around the first reserve zone and comprises the zone of stress changes, and rock joint and bedding displacements that have occurred during the construction of the existing tunnel.

The second reserve zone covers the areas where future development works have the potential to impact on the performance of the tunnel support elements and the operation of the tunnel. Any developments that take place within the second reserve require an engineering assessment of the works that have potential for impact on the underground infrastructure. The following factors have been considered in determining the second reserve in this standard:

1. zone of negligible ground stress changes due to the construction of the existing tunnel
2. extent of shear displacement of horizontal rock defect or bedding and joints during construction both laterally and vertically above the tunnel
3. drainage and cable pits at the invert
4. potential stress and displacement influence zones associated with external developments based on case histories
5. potential groundwater drawdown influence zone
6. vibration influence zone

3. ADJACENT DEVELOPMENTS

Developments near rail tunnels shall be planned, designed, constructed and maintained to ensure the protection of existing tunnels and the rail infrastructure. These developments shall have no effect to rail operations including either the operational capacity or the efficiency of the rail network during any stage of the life cycle of that development including plan, acquire, maintain and dispose.

The following is a list of various activities of adjacent developments near rail tunnels that can exist:
1. excavations for basements, shafts – above / side or below
2. shallow footing or pile foundation - above / side or below
3. tunnels and underground excavations – above / side or below
4. ground anchors – above / side or below
5. demolitions or existing structure – above or side
6. geotechnical investigations / instrumentation – above / side or below

The load, displacements and stress changes that occur due to the construction of adjacent developments can affect the existing rail tunnels. The induced changes in load and displacements depend on the types of developments.

The purpose of deriving the reserve zones is to protect the existing rail tunnels from future adjacent development activities. Table 1 provides the construction restrictions that are applied to each reserve zone.

Table 1 - Construction restrictions

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

Types of construction	First reserve	Second reserve
Penetrative subsurface investigations	Allowed away from structural elements Assessment required.	Allowed subject to assessment.

[1]*Tunnel support zone includes rock bolts, canopy tubes and other means of supports to stabilise the tunnel opening.*

Future developments such as the metro rail, egress passages, utility tunnels, and ventilation and access shafts can require construction through first reserve for connections with existing rail tunnels. Such activities are not covered in this standard and require agreement of specific interface requirements between TfNSW and the future developer.

4. IMPACT ASSESSMENT

4.1. Purpose

The engineering assessment shall be carried out to ensure that no adverse effects arise from the proposed development within the reserve zones for the existing rail tunnel and the associated rail infrastructure such as cross passages, egress passages, electrical and mechanical rooms and walkways. The adverse effects can be measured against the code compliance and performance requirements provided in the new Standard.

The development shall not affect the stability and integrity of rail tunnel and associated rail infrastructure, and the safe rail operations. The engineering assessment shall demonstrate that the following causes that can affect the tunnels shall not cause any adverse effect to the rail infrastructure:

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

The engineering assessment shall include geotechnical investigations, detailed engineering analysis and impact assessments.

4.2. Geotechnical Investigation

The developer shall carry out detailed geotechnical investigations of the soil or rock strata above, alongside and below the rail tunnels, as appropriate, to establish the existing ground conditions within the area affected by the proposed development. The geotechnical investigation shall provide the following:

- accurate geological profile of the sections where the new development is proposed and the sections beyond the footprint where the development can potentially impact the tunnels
- existing in-situ stress states in soils and rock mass
- critical geological features such as bedding planes, joints, dykes, and so on
- rock and soil properties by in-situ and laboratory tests
- information on existing ground water regime
- any other man-made features

Drilling boreholes (for subsurface investigation) within the first reserve shall avoid the tunnel support zone and requires detailed study and approval from TfNSW prior to drilling works.

Before drilling, the location of proposed bore holes within the rail protection zone shall be subject to verification of borehole coordinates by project surveyor and shall only proceed after obtaining approval from TfNSW.

4.3. Engineering Analysis

The developer shall carry out an engineering analysis and impact assessment to demonstrate that the effects of the proposed development on the existing tunnels and underground facilities are not causing any adverse effect. TfNSW can request the developer to independently verify the engineering analysis and impact assessment report based on the project complexity and potential effect to tunnel.

Depending on the complexity of the development, a two dimensional or three-dimensional numerical modelling (finite element (FE) or finite difference (FD)) shall be carried out to assess the effects on the tunnels and infrastructure elements at different stages of construction and its operation after commissioning. This shall include effects of associated temporary works such as crane and construction material loading.

The numerical modelling shall be based on the realistic geological model derived from the subsurface information gathered through the geotechnical investigation. It shall include critical geological features such as bedding planes, weak layers, joints and other discontinuities. The numerical modelling shall account for existing conditions of the tunnel lining including defects such as cracks, drainage conditions and support conditions determined by dilapidation survey and in-situ strength tests as appropriate. The numerical modelling results shall be validated. The predictions can be validated during construction by carefully designed field monitoring instrumentation.

The engineering assessment shall be carried out by suitably qualified persons with experience in tunnel design and analysis. The engineering assessment report shall be prepared and endorsed by a suitably qualified person and shall be submitted to TfNSW.

5. PERFORMANCE REQUIREMENTS

The developer shall ensure that the contractor activities have no adverse effects on the performance of rail tunnel and infrastructure, including any impact on the amenity, aesthetics, structural integrity, durability, function, user benefits, safety during construction and operation and environmental performance. Throughout the developer's activities, the developer shall monitor the actual effects of the construction activities in accordance with the project-specific construction phase monitoring requirements.

The effects on the tunnel lining or any of the structural elements and rail infrastructure at any stage of the whole life cycle of the development shall be assessed to ensure that the works remain structurally code compliant. The structural elements include rock pillar supports, load bearing columns, walls and roof beams, slabs, rock anchors or bolts, track slabs, drainage structures, tunnels refuges, ventilation shafts and underground stations.

Table 2 shows the performance requirements

Criteria	Performance Requirement
Structural stability and integrity	
Design loads	- ASA Standard T HR CI 12051 ST: Development Near Rail Tunnels for load limits on various existing rail tunnel structures - Train loadings in accordance with AS5100 *Bridge Design* for live load surcharge. - ASA Standard T HR CI 12075 ST for *Airspace Developments* - ASA Standard T HR CI 12080 ST for *External Developments*.
Crack criteria	- Cracks shall not be more than 0.3 mm in width, or maximum 300 mm length during any stage of the proposed development. Cracks with “lengths” exceeding 300mm and “width” exceeding 0.2mm shall be repaired by the developer. - Configuration of cracks shall not result in concrete spalling.
Displacements	- Rock bedding movements shall not exceed 10 mm where rock bolts are present. - Track displacements shall comply with the requirements of SPC 207 Track monitoring requirements for under track excavation. - For segmentally lined bored tunnel, the allowable total movement in any direction is 15 mm and differential movement in any plane is 15 mm or 1:1000 whichever is less. These criteria are applicable if waterproofing of the segmental lining is not affected by gasket decompression.
Design stage requirements	
Shoring system design	- By an approved design organisation and verified by an independent qualified person
Unplanned excavation	- In accordance with CIRIA C580.
Design life	- Any temporary components of shoring systems that are located such that their stability has the potential to affect the railway tunnel shall have a minimum service life of 10 years.
Stray current and electrolysis	- in accordance with ASA Standard T HR CI 12080 ST, T HR EL 12002 GU.
Construction stage requirements	
Construction method	- No explosives shall be used for the splitting or removal of rock.
Noise and vibration	- Any development that occurs within a screening distance of 25 m horizontally from first reserve shall consider the impacts of vibration on the rail tunnels with an assessment criteria of maximum peak particle velocity (PPV) of 15 mm/s at the tunnel lining for brick or mass concrete in good condition or maximum PPV of 20 mm/s at the tunnel lining for cast iron, steel or concrete segment lining. - Consideration shall be given to operational vibration and ground or structure-borne noise emissions in accordance with *Developments Near Rail Corridor and Busy Roads - Interim Guideline, Department of Planning, NSW Government 2008*.

6. INSTRUMENTATION AND MONITORING

For the safety of the tunnels and rail infrastructure it is required to monitor the tunnel and tunnel structure performance during construction and to verify the predicted displacements, stress levels in structural elements and vibration levels. The developer shall implement a comprehensive monitoring system that comprises early warning criteria developed in agreement with TfNSW.

Table 3 and Table 4 show the required minimum monitoring plan to assess the risk.

Table 3 - Minimum monitoring requirement for development activities near rail tunnels – In-ground

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

Table 4 - Minimum monitoring requirement for development activities near rail tunnels – Within existing rail tunnels

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

The baseline data for each monitoring parameter shall be established before the construction work begins. The developer shall provide as a minimum, three sets of monitoring data as the baseline before excavation. The equipment that is used for remote monitoring, particularly for alarm or warning systems, shall have proven reliability for similar applications. Any alarm or warning system should have a visual and audible alarm system to activate and to stop all works as necessary and notify relevant personnel such as site manager, geotechnical consultant and nominated TfNSW representative.

Depending on the project complexity, physical inspections of the existing tunnel may be required by the developer accompanying TfNSW representative on regular basis during critical stages of construction. For monitoring, a response regime and contingency plan shall be agreed between the developer and TfNSW before work begins.

Figure 2 shows the typical extent of the monitoring.

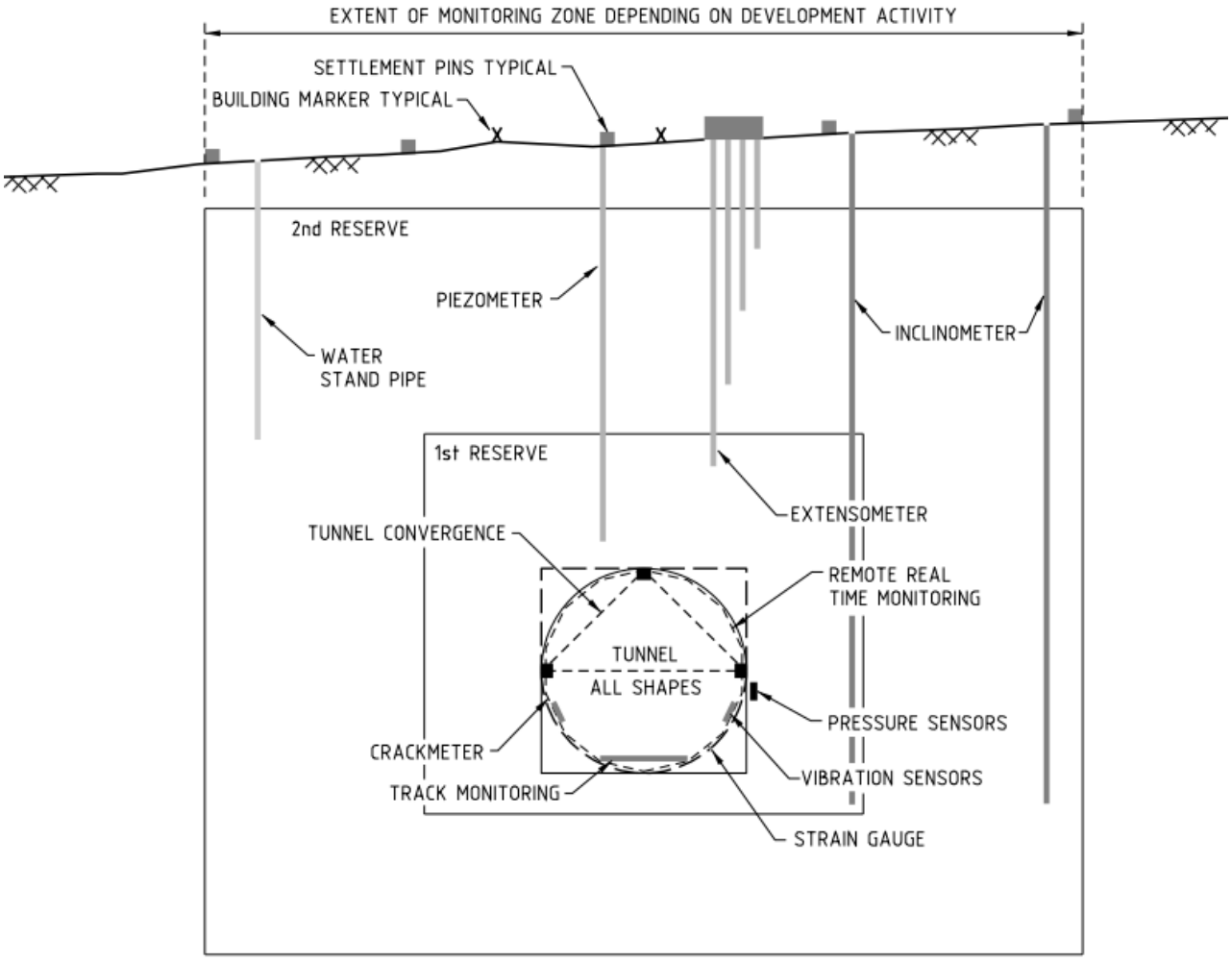


Figure 2 - Typical instrumentation layout

7. DOCUMENTATION REQUIREMENTS

The development applications (DA) are sent to Consent Authority (Council) for review and approvals. Consent Authority reviews the DA and sends it to TfNSW if the application falls within the purview of ISEPP criteria. The developer shall submit the minimum required documents to TfNSW during planning, design, construction and operation stages of the development. The minimum documentation requirements for review and approval by TfNSW are provided in the Standard.

8. CONCLUSIONS

This paper presents a unified Standard for developments near existing rail tunnel and it supersedes all existing guidelines for various rail tunnels in the metropolitan rail area, New South Wales (NSW). The standard provides technical requirements and technical guidance to assess the development induced effects and associated risks to existing tunnels and related infrastructure.

9. ACKNOWLEDGMENTS

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