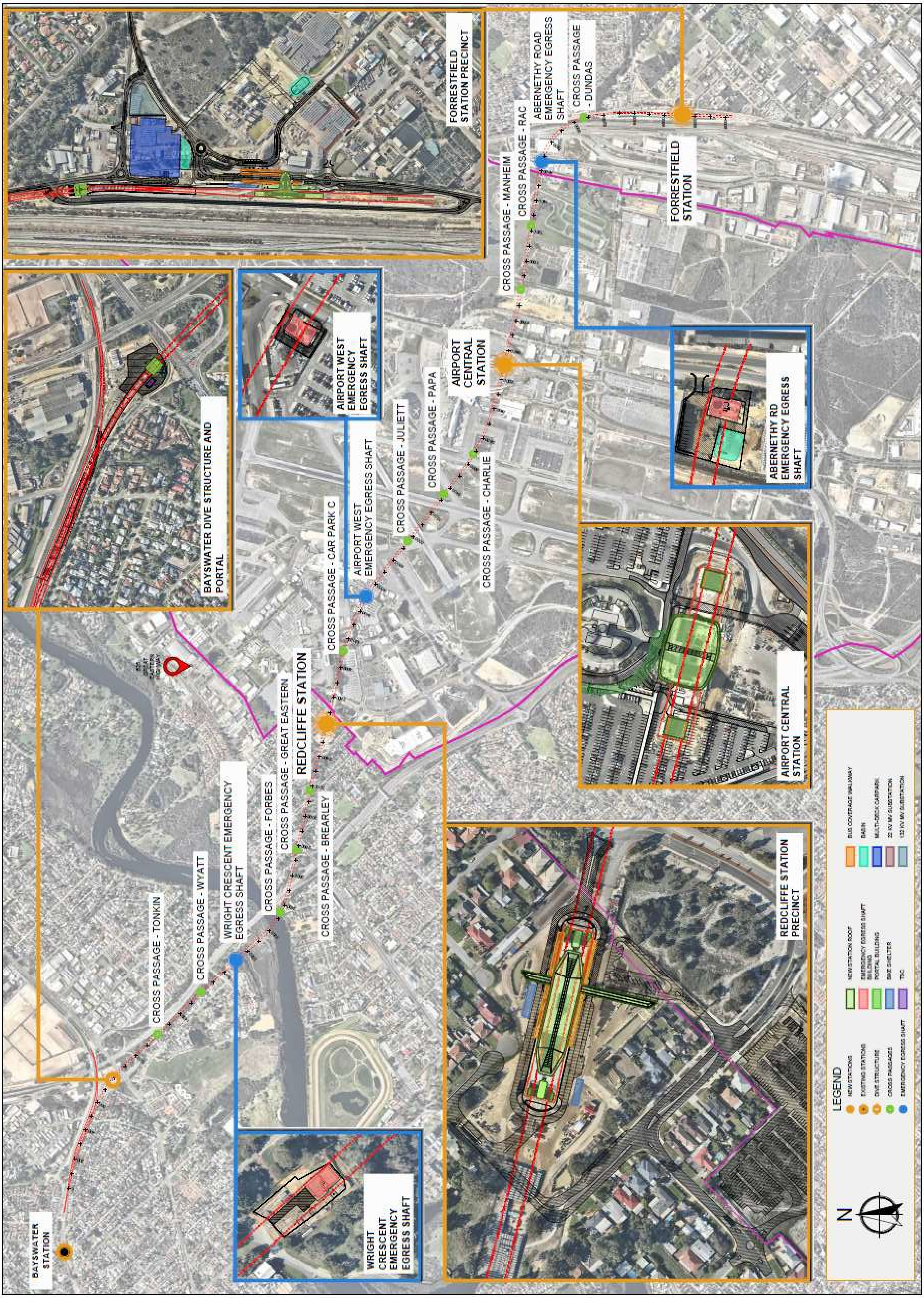
Ministerial Report:
Cross Passage Dundas rectification works

Final Report

Date: October 2019


FORRESTFIELD STATION PRECINCT
CROSS PASSAGE - MANHEIM
CROSS PASSAGE - RAC
ABERNETHY ROAD EMERGENCY EGRESS SHAFT
CROSS PASSAGE - DUNDAS
FORRESTFIELD STATION
BAYSWATER DIVE STRUCTURE AND PORTAL
AIRPORT WEST EMERGENCY EGRESS SHAFT
AIRPORT CENTRAL STATION
CROSS PASSAGE - PAPA
CROSS PASSAGE - JULIETT
CROSS PASSAGE - CHARLIE
AIRPORT WEST EMERGENCY EGRESS SHAFT
CROSS PASSAGE - CAR PARK C
ABERNETHY RD EMERGENCY EGRESS SHAFT
REDCLIFFE STATION
CROSS PASSAGE - GREAT EASTERN
CROSS PASSAGE - FORBES
CROSS PASSAGE - BREARLEY
WRIGHT CRESCENT EMERGENCY EGRESS SHAFT
CROSS PASSAGE - WYATT
CROSS PASSAGE - TONKIN
AIRPORT CENTRAL STATION
REDCLIFFE STATION PRECINCT
BAYSWATER STATION
WRIGHT CRESCENT EMERGENCY EGRESS SHAFT
LEGEND
NEW STATIONS
EXISTING STATIONS
DIVE STRUCTURE
CROSS PASSAGES
EMERGENCY EGRESS SHAFT
NEW STATION ROOF
EMERGENCY EGRESS SHAFT BUILDING
PORTAL BUILDING
BIKE SHELTER
TSO
BUS COVERAGE WALKWAY
BASIN
MULTI-DECK CARPARK
22 KV MV SUBSTATION
132 KV MV SUBSTATION
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1. Executive summary

On 22 September 2018 a leak developed during construction of the first tunnel cross passage, Cross Passage Dundas, in Tunnel One approximately 200m north of the Forrestfield Station site. As a result, water and silt entered Tunnel One (TBM Grace's tunnel) leading to the formation of a sinkhole at the surface alongside Dundas Road.

The pressure of the groundwater, and the associated loading, caused permanent localised distortion to the tunnel shape and movement of the segments which make up the tunnel lining, ultimately damaging a 26m-long section of Tunnel One (16 rings). Rectification works were successful in repairing both the tunnel leak and sinkhole and temporary steel frames were installed to support the tunnel. These rectification works allowed tunneling and cross passage construction works to continue whilst the Contractor investigated the incident and developed a proposal for the permanent repair of the damaged tunnel section.

Incident investigations have determined several contributing factors that are likely to have given rise to this incident. Given ongoing contractual discussions, and potential legal implications, it would be inappropriate to make statements concerning these as it could prejudice an outcome or weaken the Public Transport Authority's position. These investigations have influenced work procedures project wide to ensure that a similar incident does not reoccur.

The Contractor, Salini Impregilo – NRW Joint Venture (SI-NRW), engaged the support of specialist engineering consultants to provide a comprehensive analysis of the incident and a proposal for rectification. The reinstatement works proposed include the installation of a secondary spheroidal graphite iron (SGI) lining within the existing pre-cast concrete segmental lining. PTA accepts SI-NRW's proposed solution and accepts the proposed specification departures which do not significantly compromise the design and retain the 120 year asset design life.

2. Project background

The Forrestfield-Airport Link is jointly funded by the Australian and Western Australian governments and will deliver a new rail service to the eastern suburbs of Perth. The rail link includes construction of three new stations, including one at Perth Airport, and 8km of twin-bored tunnels to ensure minimal disruption to the existing land and road network. Tunnelling is performed by two Tunnel Boring Machines (TBMs). These are large machines that excavate below the ground surface, while simultaneously installing concrete lining units (segments) to build a tunnel. Two TBMs were specifically designed for the Forrestfield-Airport Link by German company Herrenknecht, the world's leading supplier of TBMs.

There are various types of TBMs to cater for different ground conditions and project requirements. For this project, the TBMs are Mixshield which use the latest dual-mode technology capable of adapting to variable ground conditions (such as sand, rock and clay) as the machine progresses.

In addition, the design calls for 12 tunnel-to-tunnel cross passages to be constructed to allow passengers to evacuate from one tunnel into the adjacent tunnel in the event of an emergency. There are also cross passage connections between the tunnels and three emergency egress shafts (which provide for evacuation to the surface), thus providing a total of 15 cross passages along the alignment.

In April 2016 the PTA awarded the design, construct and maintenance contract to SI-NRW. Salini Impregilo, part of the joint venture with NRW to build the Forrestfield-Airport Link, is a world leader in complex construction with more than 110 years' experience building tunnels and infrastructure around the world. Their work to date includes the delivery of 1587km of tunnels and 7534km of metros and railways.

3. Tunnel damage

As a result of the incident, some displacement of the concrete tunnel lining has occurred. Prior to the excavation of Cross Passage Dundas, five prisms were installed to measure potential convergence during the various stages of cross passage construction. These prisms measured values ranging from 1mm inward during the excavation of the cross passage to 7mm once the event had begun, to a peak displacement of 133mm on September 29.

From the tunnel dive structure at Forrestfield up to Ring 110 on the near side of the cross passage, and from Ring 125 onwards on the far side of the cross passage, segments are well placed and do not present any indication of overstressing or unfavourable deformation following the incident.

Between Rings 114 and 122, the originally circular cross section of the tunnel experienced an ovalisation, with an increase in the diameter between the top left and bottom right (looking in the direction of excavation) of the tunnel and a shortening of the opposite inclined diameter. The diagram below is exaggerated however it gives an indication of the change in tunnel shape through the damaged section.

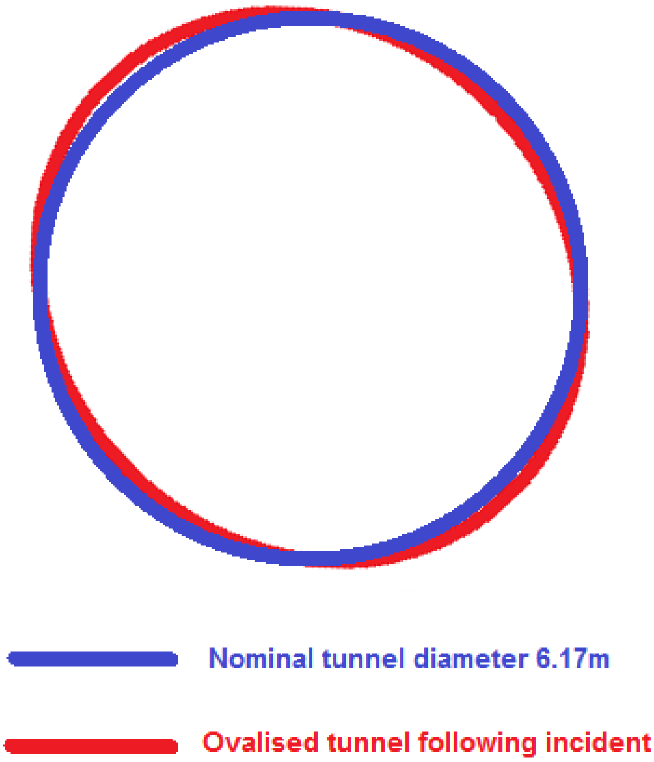

Figure 1 – Diagram of tunnel cross section showing ovalisation

The measurement for both diameters was carried out with a laser distometer. The inspection for Ring 115, for example, gave a reading of 6.31m from top left to bottom right and 6.11m from top right to bottom left as opposed to the required length of 6.17m

The change in dimensions to Tunnel One is at its greatest between Ring 113 to 123. On the approach to the cross passage (between Ring 111 and 113) and after the cross passage (Rings 123 and 124) there are transition zones between the impacted stretch and the return to design specification. This ovalisation has had various impacts on the tunnel surface, including tension cracks and steps or lips between tunnel segments.

Figure 2 - View of Ring 117 (left) and Ring 120 (right) both with tension cracks and lips

Close monitoring continues to record any further movement of the axis of Tunnel One, or changes to tunnel lining rings, including cracks, steps and lips. Neither Tunnel Two nor Cross Passage Dundas exhibit any sign of overstressing or unexpected deformations in tunnel segments.

The tunnel deformation is the most significant factor influencing consideration of rectification options. As mentioned in Section 2 Project background, the TBMs used for this project were specifically designed by Herrenknecht to suit Public Transport Authority (PTA) requirements and specifications. This included consideration of the internal tunnel space (or diameter) required to accommodate the necessary infrastructure including track, overhead electrical equipment, maintenance and emergency egress pathways etc. Any proposed rectification works would be required to maintain acceptable internal tunnel space to accommodate the necessary infrastructure.

4. Other constraints

In addition to the space proofing requirement mentioned in the previous section, there were other constraints that were necessary to consider in the development and analysis of rectification options.

Compliance with safety, quality and durability requirements

Tunnelling has become commonplace for both rail and road projects around the world. The decision to build a tunnel, or indeed any underground infrastructure, usually comes from a need to minimise ground level disturbance. This is often because there is already development at ground level and it can be both difficult and expensive to acquire surface level properties to form a road or rail corridor. Likewise, the operation of either a rail network or a road highway introduces a level of unavoidable audible and visual disturbance to adjacent properties. This can be a constraint to the adjacent development, be a ‘barrier’ between adjacent communities and can restrict land use potential in proximity to the road or rail infrastructure.

Whilst tunnelling has become commonplace, it invariably involves a complex construction process that must be planned and executed in a way that ensures the safety of workers and the environment impacted by the tunnelling operation (including at the surface level above or adjacent to the tunnels).

Public transport infrastructure is considered to be permanent infrastructure. The oldest underground railway system in the world is in London and this first opened in 1863. Whilst it is not realistic to define a level of specification that ensures it will last eternally, the PTA has defined a tunnel design life of 120 years in line with international practice.

To achieve this 120 year design life SI-NRW has had to demonstrate that the procedures and materials used for the construction of the tunnel meet stringent quality and durability standards that were defined within the contract. These standards also account for potential unforeseen events, such as a catastrophic fire within the tunnels, which could cause the structure to prematurely fail.

Any rectification proposal is required to meet the same stringent safety, quality and durability requirements as the initial tunnelling proposal that was approved by the PTA. Where factors prevent absolute compliance, detailed exploration of proposed departures is required to demonstrate a reasonable and acceptable level of compliance to PTA's satisfaction.

Potential disturbance to adjacent critical infrastructure

Three significant utility lines run parallel to Dundas Road and cross over the tunnel alignment in relatively close proximity to the damaged tunnel section, as shown in the figure below:

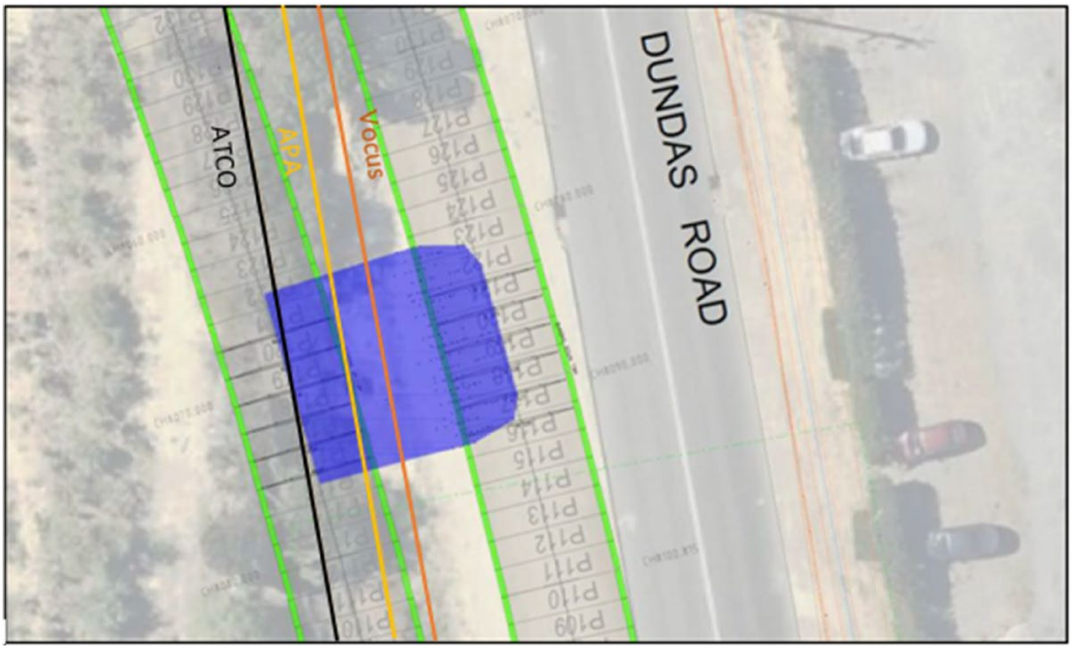

Figure 3 – Critical infrastructure in close proximity to tunnels

- The Vocus fibre optic cable conduit lies 10m west of Dundas Road curb line. The conduit is 100mm PVC.
- The APA Parmelia high pressure gas pipeline lies 13m west of Dundas Road curb line, above the east extrados of the up-running tunnel. The pipeline is 450mm diameter steel.
- The ATCO gas pipeline lies 16m west of Dundas Road curb line, above the centreline of the up running tunnel. The pipeline is 200mm steel.

In addition to these services below the ground surface (but above the tunnels) the proximity of Dundas Road to the tunnels is also evident.

Minimising potential disturbance to adjacent and surface level infrastructure, ensuring appropriate worker and environment safety during rectification works and the requirement to comply with quality and durability specifications were all inputs into the identification, assessment and selection of a preferred rectification solution and the development of relevant procedures for carrying out the rectification.

5. Scope of analysis and proposal development

Mott McDonald, a global design and engineering consultancy, was engaged to provide a comprehensive analysis and proposal development service incorporating:

1. Review of documents related to the design and construction of the tunnel.
2. Review of incident and remedial measures implemented.
3. Development of a geological model and 3D survey to inform understanding of site and tunnel features and to develop and model potential solutions.
4. Develop a final design for ground stabilisation treatment around the damaged tunnel section to allow for rectification works.
5. Review of tunnel alignment and space proofing requirements to determine potential constraints.
6. Structural, durability and fire engineering assessments of the proposed solution to determine physical properties and characteristics.
7. Concept design of the proposed solution.
8. Analysis of proposed solution alignment to original project scope and an explanation of departures.
9. Develop construction staging and monitoring.
10. Safety in Design to identify potential risks and mitigation measures.
11. Review operation and maintenance requirements.

6. Rectification proposal

As briefly covered in Section 2 Project background, the tunneling construction method used for this project involves the mechanical extraction of soil via TBMs which install precast concrete tunnel lining segments as they move through the soil. This is a common tunneling construction technique used around the world. In the case of this project, it also presented an opportunity to showcase local capability and create local jobs with the concrete tunnel lining segments being produced in Western Australia by local workers.

The concrete tunnel segment lining process was adopted locally for this project. Elsewhere around the world there are alternating lining systems used. i.e one project may include alternate lining types for different sections of a tunnel. The type of lining used is determined by a number of factors including whether it is an entirely new tunnel or a modification or extension to an existing tunnel. One of these alternate tunnel lining construction techniques involves the use of steel rings or, more specifically, spheroidal graphite iron (SGI) tunnel lining rings in lieu of concrete tunnel lining rings.

Figure 4: London Underground Kennington Loop SGI step plate junction

The production and installation technique is similar to our own concrete tunnel lining process in that SGI tunnel lining segments are produced offsite and then, once soil is extracted to form the tunnel, they are bolted together in place to form tunnel lining rings. They ultimately form a self-supporting SGI tunnel structure with comparable specifications to a concrete tunnel structure.

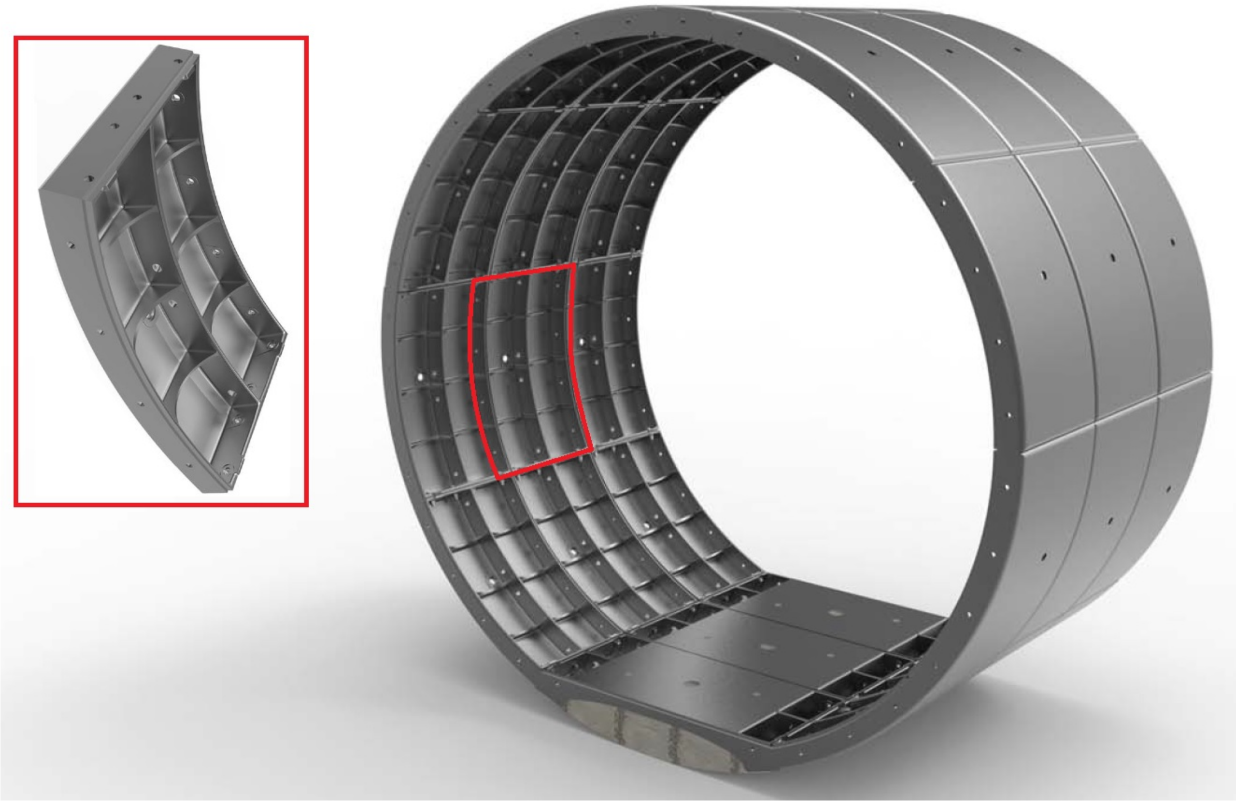

Figure 5: Spheroidal Graphite Iron tunnel section and segment

The recommended rectification proposal for the damaged section of tunnel is the installation of an SGI tunnel lining inside the damaged concrete lining. In this application the SGI lining will be self-supporting and act as a brace within the existing concrete tunnel lining.

This is an oversimplification however, essentially, the ground around the damaged tunnel section will be stabilised, the existing concrete tunnel segments will remain in situ but, noting their current deformed state, will be honed to create the necessary space and an appropriate surface for the installation of the SGI tunnel lining structure.

7. Acceptable departures

Despite honing of the existing concrete tunnel lining to accommodate the SGI tunnel lining this proposal does impose some minor spatial constraints through the damaged tunnel section. The internal space reduction will not impose a significant operational constraint other than a 14mm reduction in the width (nominally 850mm, locally 836mm) of the emergency egress / maintenance walkway that runs parallel to the tracks at an elevated level (train floor/door height).

Likewise, the change in material (iron alloy in lieu of concrete) and the need to install the SGI lining by hand from within the existing tunnel imposes other constraints to waterproofing and fire resistance requirements that represent departures from the original tunnel specification.

SGI segment fastening or joining requires an alternate joint system and gasket type which differs from the concrete segment tunnel specification however this will not impact durability and is unlikely to impact waterproofing.

SGI lining is more likely to be damaged or to structurally fail during a catastrophic fire event than concrete lining. As a result, a Fire Safety Qualitative Risk Assessment (QRA) was conducted for the proposed SGI solution to determine if the risk was within tolerable allowances. The QRA also considered the impact of applying a spray on protective lining to the SGI lining to determine if it adequately changed conditions.

The QRA demonstrated that the change in either likelihood or consequence of a catastrophic fire event in the tunnel triggered by the SGI lining was insignificant (which was predictable given the relatively short 26m section of tunnel with alternate properties to the remainder of the tunnel).

In addition to this, the application of a spray on protective lining to the SGI section did not demonstrate adequate improvement with the costs likely to be grossly disproportionate to the benefits. The spray on protective coating also imposes a further spatial constraint within the tunnel (35mm thick around the entire tunnel intrados or internal circumference), would complicate installation of the SGI lining, obscure fasteners preventing periodic visual inspections and there would be other associated complications with maintenance and attachment of equipment to the tunnel intrados.

As a result, PTA has asked SI-NRW to further investigate fire protection options which can be applied after the SGI tunnel lining has been installed. SI-NRW is making enquiries concerning potential treatments that could moderately increase the structural integrity of the SGI lining without imposing other constraints. It is relevant to consider, for example, the full life-cycle costs and risks of application and reapplication of any coating within a tunnel environment. These risks must form part of the consideration whether treatments are acceptable given that they are beneficial but not essential given the relatively small section of tunnel impacted.