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Sydney metro west—eastern tunnelling project—TBM temporary works

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ABSTRACT: The Eastern Tunnelling Package section of Sydney Metro West includes twin 3.5-kilometre tunnels with tunnel boring machine (TBM) drives, starting from The Bays Station box, traversing through Pyrmont Station cavern, and finishing at Hunter Street Station. Delve Underground, working in close collaboration with the John Holland CPB Contractors Ghella Joints Venture (JV), designed the TBM launch frame, steel temporary rings, steel cradles and launch seals. Notable elements include an oversized launch frame that enabled partial assembly before the TBM shield traverses through it, and the use of steel rails with a travelling jacking dolly for the traverse of Pyrmont Station using the TBM thrust jacks. This paper discusses the design of the TBM temporary works and presents key feedback from the contractor on the design.

1 INTRODUCTION

Sydney Metro is Australia's biggest public transport project, with the vision "to transform Sydney with a world-class metro." In 2030, Sydney will have four metro lines, 46 stations and a 113-kilometre standalone metro railway system, revolutionising the way Australia's biggest city travels. Sydney Metro West (SMW) is a new 24-kilometre metro line with nine new stations confirmed at Westmead, Parramatta, Sydney Olympic Park, North Strathfield, Burwood North, Five Dock, The Bays, Pyrmont, and Hunter Street in the Sydney central business district.

For the Eastern Tunnelling Package (ETP) section of the works, two tunnel boring machines (TBM1 and TBM2) were assembled and initially launched from The Bays Station; received, traversed through and re-launched at Pyrmont Station; and then retrieved at Hunter Street Station.

The following temporary works (TW) design elements were delivered as a design package:

- TBM launch, retrieval and traverse alignments
- TBM shield cradle and jacking dolly*
- TBM backup gantry rails and supports*
- TBM launch frame and foundations*
- Temporary steel ring segments and steel fuses*
- TBM launch seal*
- Temporary backfill and concrete slabs

This paper will concentrate on key innovations for the items noted with an asterisk above, and key monitoring results and feedback from the constructor.

2 DESIGN DEVELOPMENT

The TBM TW design package was identified as a High-Risk package, thereby requiring an independent proof engineer (peer review). Throughout the design stages, workshops were held with the constructor to identify key issues and decide on the best strategy to overcome them. This section details the key design features that were implemented as a result of the close collaboration between the constructor and the designer. One of the main high-risk elements was the travers and relaunch of the TBMs inside a Sequentially Excavated (SEM) station at Pyrmont with no overhead access.

2.1 *TBM shield cradle and jacking dolly*

The TBM shield cradle supports the shield using two rails—in this case, with a 56-degree inclusive angle—and is designed to transmit the shield into the foundation. The normal load (applied radially) to the shield cradle rails is supported on steel stools with a steel tension tie between the stools which prevents them from splitting apart as shown in Figure 1, below. The use of a tension tie reduces the required number of fixing anchors into the foundation slab.

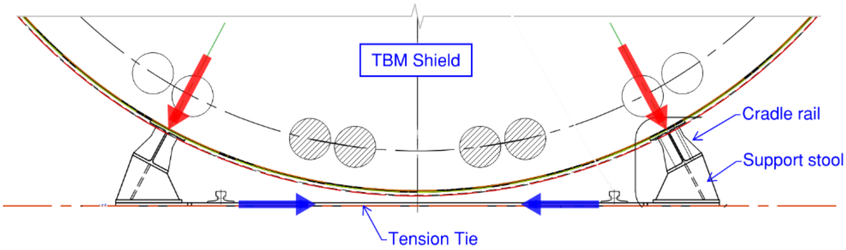

Figure 1. TBM shield cradle tension tie load path

The support stools were set at 1.7m spacings to match the length of the permanent tunnel segment rings. This spacing was adopted as it simplified the jacking dolly and jacking packer arrangement, described in detail below and shown in Figure 2, below. Cradle modules of 11.9m and 3.4m were adopted with each module consisting of a pair of rails with welded support stools and loose tension ties. Each rail has hollow bars welded in centrally at 1.7m spacings over the support stools. The hollow bars act as keepers for the steel pins used to transfer load from the jacking dolly into the cradle rails. The long modules are used for straight alignment sections and the short modules are used for curved alignment sections. For traversing each station, three different horizontal curves were designed for; 500m, 355m and 165m. To install the cradles at the required the horizontal curves, different length web splice plates between the short modules were specified.

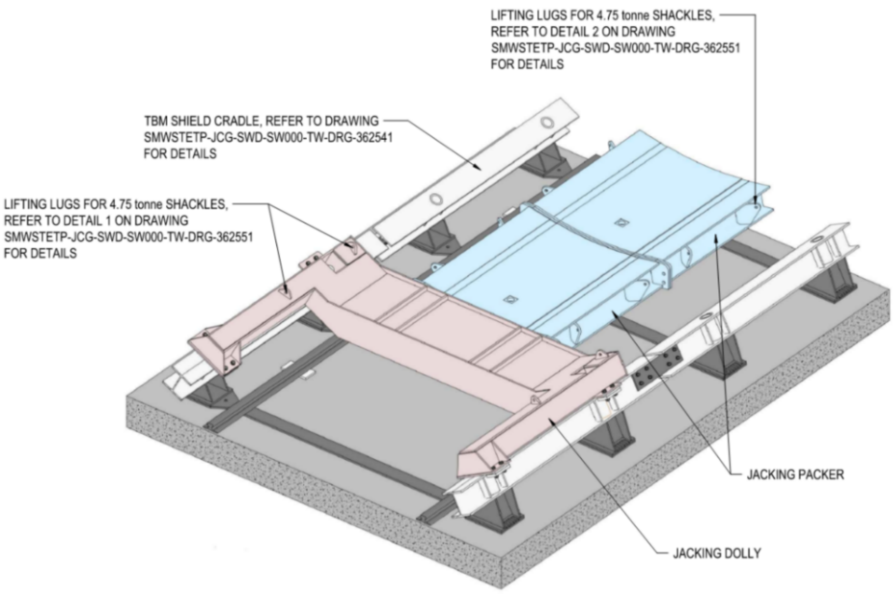

Figure 2. TBM shield cradle and jacking dolly

Figure 3. TBM shield during assembly on shield cradle, jacking dolly in foreground

The jacking dolly is used to advance the shield and backup gantries forward when outside of the ground while traversing through stations. At The Bays Station, the TBM shield was assembled approximately 50m back from the headwall. Once the TBM shield was assembled, the jacking packers were installed inside the TBM tail skin / ring build area. The jacking dolly was then fixed onto the TBM shield cradle behind the TBM shield by means of large steel pins on each side that are lowered into the holes in the TBM shield cradle rails. The bottom two thrust jack pads then pushed against the jacking packers and jacking dolly causing the TBM shield (and TBM backup gantries when connected) to advance. As the TBM shield is pushed forward, the tension force created by friction between the TBM shield and the rail surface is resolved by the shear load transferred into the cradle rails via the jacking dolly pins behind the shield as shown in Figure 4, below.

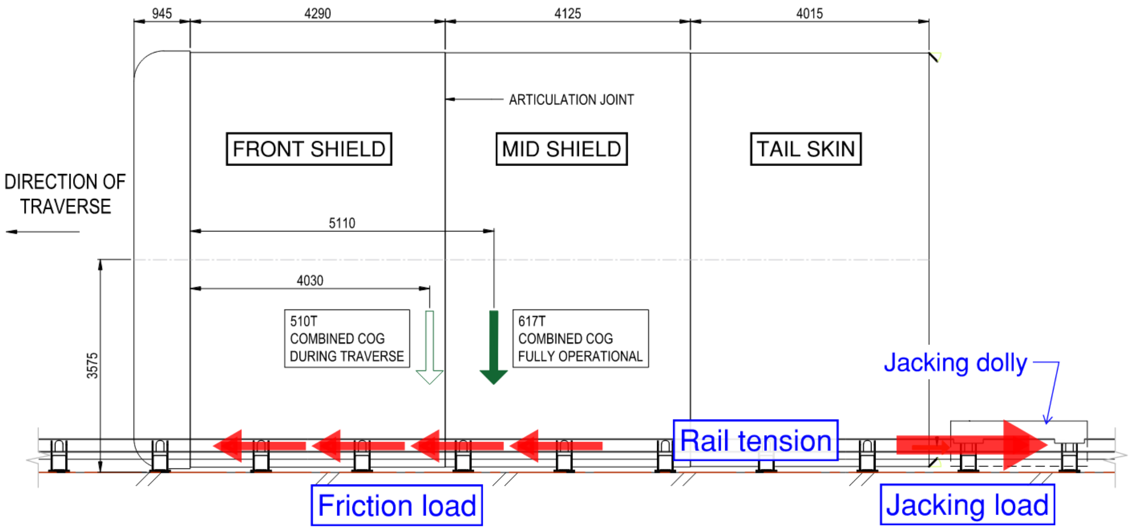

Figure 4. Balance of TBM jacking force in cradle rails

2.2 *TBM trailing backup gantry cradles*

During typical station traversing, the backup gantries travel on vertical legs with steel wheels on steel rails. This reduces the amount of steelwork required for traversing the backup gantries. However, when the backup gantries are operational and inside the tunnel rings, the gantries ride on angled bogies. This meant short gantry cradles to support the angled bogies were required for both the TBM launch and TBM retrieval. The arrangement is shown in Figure 5, below. The higher cradle rails are used for Gantry 1 bogies with an inclusive angle of 110°. The lower cradle rails are used for the typical gantry bogies with an inclusive angle of 70°. Various design options for the angled support legs were provided to cater for the varied site requirements.

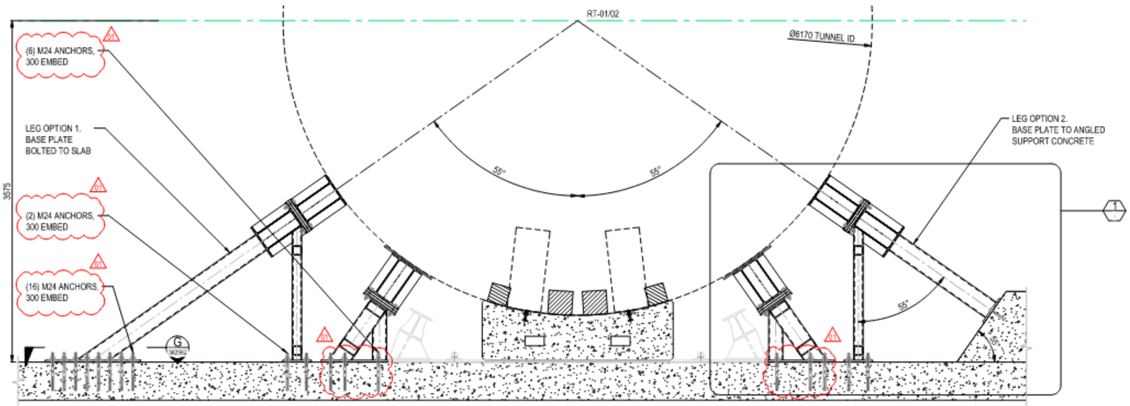

Figure 5. TBM trailing backup gantry transition cradles

2.3 *TBM launch frame*

To construct the 6.17m internal diameter (ID) segmentally lined tunnels, two 6.97m TBMs with bore diameters of 7.02m were procured. Each TBM consists of a 620-tonne, 13.38m-long TBM shield, eight trailing gantries and a bridge gantry section between trailing backup gantry one and two. The total length of each TBM with trailing backup gantries is 126.5m. At The Bays Station launch site, the ground conditions were predominantly in Unweathered Class I/II sandstone rock, which provided a relatively strong base for the temporary foundations to bear onto.

The design TBM launch load at The Bays Station box was 15,500kN, applied via 18 thrust jack pairs, evenly arranged around a 6.43m-diameter circle. The thrust jacks are used to advance the TBM shield forward as it mines through soil and rock; initially pushing on the launch frame, then temporary false rings, and then the typical case of pushing onto the permanent tunnel rings.

Early in the concept design phase, the decision was made to adopt a “drive-through” type frame arrangement. This consists of an oversized external frame with rear struts that the TBM shield can still pass through when the frame is erected first. This external frame included the foundation and load transfer elements. Once the TBM shield has traversed through the main outer frame and rear struts, smaller members, sized to be installed by chain hoist, are installed inside the main outer frame. This offers both time savings and a reduced risk. The risk of lifting large members inside a confined space that typically exists inside sequential excavation method (SEM) station box caverns is reduced because the lifted items are smaller and lighter. It is also very hard, if not impossible, to install the TBM side member that is between the TBM and the cavern side wall once the backup gantries are in the way. The use of an oversized “drive-through” frame avoids this issue. The TBM launch frame main frame is shown in Figure 6, below. The green shaded main side members and rear struts are installed first. The remaining members shown in various shades of pink/purple are installed after the TBM shield passes through the outer frame members and rear struts. An overview showing the entire temporary works in place just prior to TBM launching is shown in Figure 7, below.

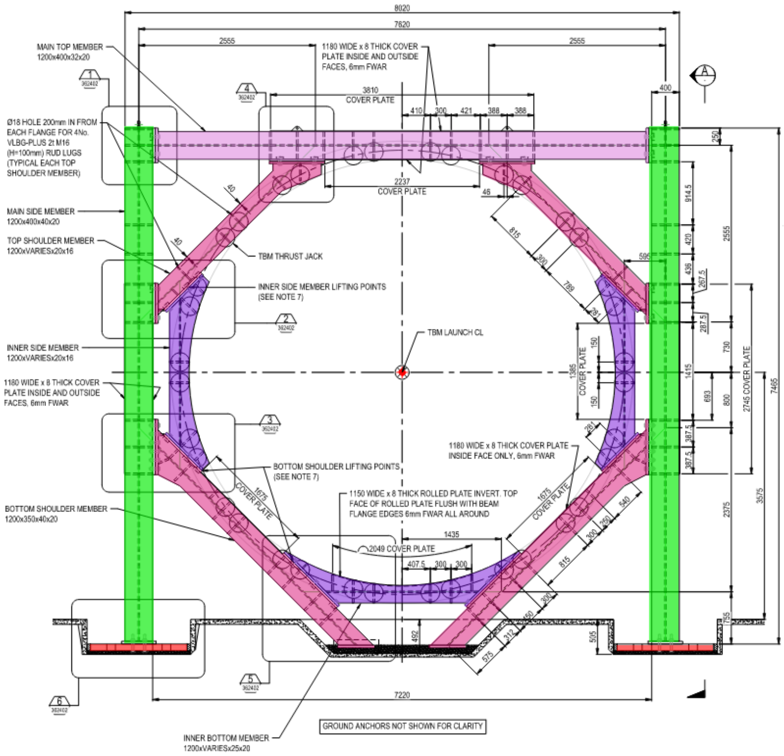

Figure 6. TBM over-sized "drive-through" launch frame

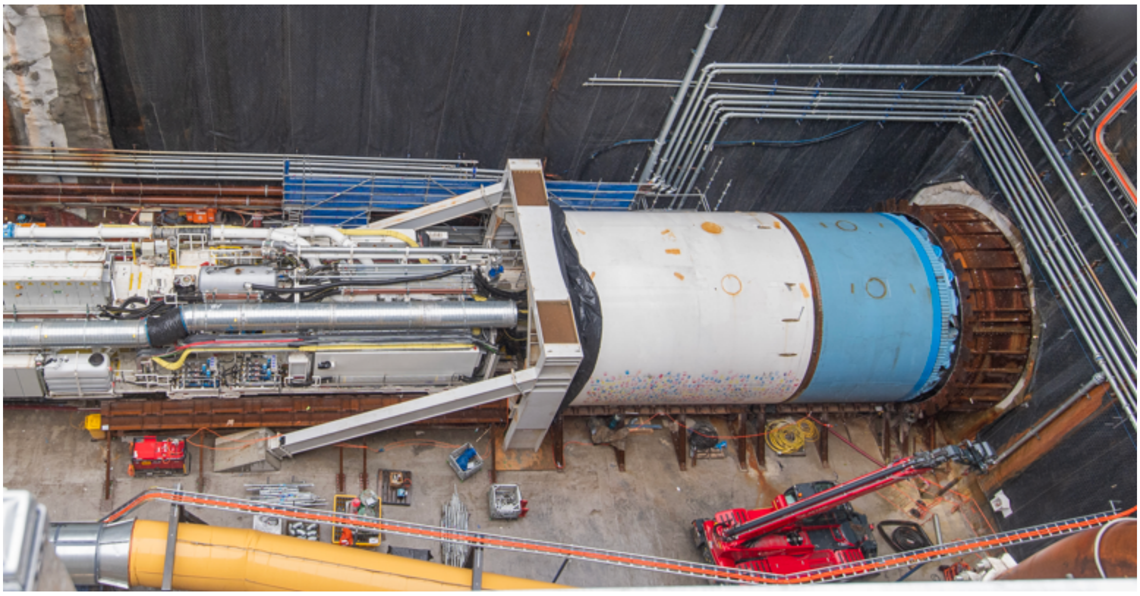
Figure 7. TBM backup gantry cradle, launch frame, temporary ring cradle and launch seal at the headwall

Tensioned ground anchors were used to resist the upwards force created by the rear strut angle. The tensioned ground anchors were connected to the side members via thick steel adapter plates. Using adapter plates with oversized holes for the ground anchors provides more installation tolerance than cast-in threaded anchors. After the ground anchors were installed through oversized holes in the concrete foundation, the thick steel adapter plates were lowered over the top of the ground anchor tendons into position, then flood-grouted underneath. The ground anchors were then proof-loaded and locked off, with the specified lock-off load based on the expected working load in the anchors, ensuring a small amount of stretch in the anchors. This provided a pinned rather than a fixed-end connection, thereby equalizing the load in the stress bars that connected the side members to the adapter plate. Steel packing behind the bottom of the launch frame side members transfers the horizontal shear load into the concrete invert foundation. This arrangement is shown in Figure 8, below.

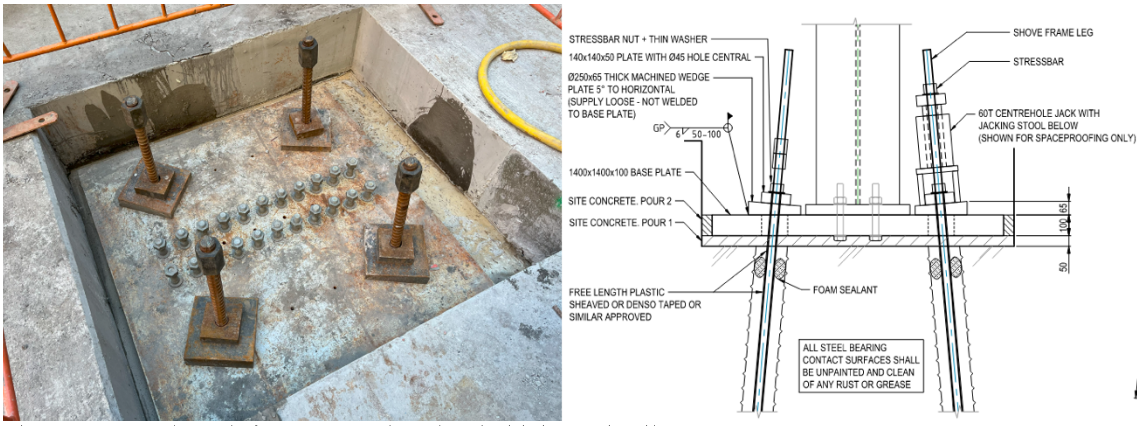

Figure 8. TBM launch frame ground anchor hold down detail

2.4 *Temporary steel rings*

To simplify installation, removal and re-use, temporary steel rings were used rather than reinforced concrete. An advantage of using steel rings is that segment side restraint frames are not required because the steel rings are lighter than concrete rings and the radial joints between the segments are designed to resist ring self-weight ovalisation. Removal of the steel rings is generally less disruptive during removal to other works at the tunnel portal when compared to concrete temporary rings (which are typically demolished). The temporary steel rings have greater flexibility in removal as well as they are designed to be lifted out as either one full ring, separate rings, or individual segments.

2.5 *TBM launch seal*

The launch seal provides containment for the TBM slurry and TBM annulus grouting. The launch seal steel can length is set to allow the TBM cutterhead to be pushed completely past the two rubber lip seals prior to the TBM being launched. Once the cutterhead advances past both lip seals, the TBM head chamber can be pressurised with slurry. As the TBM shield advances completely through the launch seal, the inflatable seal is pressurised with grout to seal the larger gap between the launch seal and the extrados of the last temporary steel ring. A launch seal design section and site photo of both launch seals are shown in Figure 9 and Figure 10 respectively.

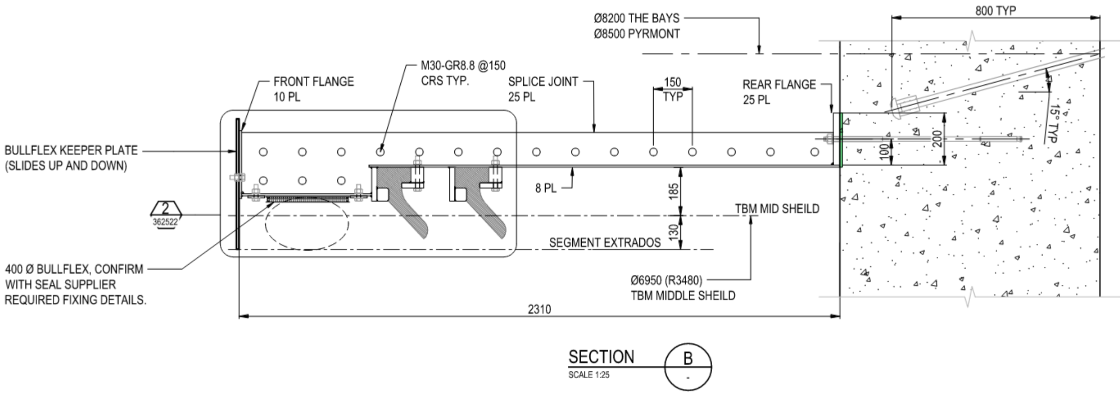

Figure 9. TBM launch seal section


Figure 10. TBM launch seals at The Bays Station

The launch seal is designed as a bolted steel tension shell loaded primarily in hoop tension from the pressurized slurry initially, inflatable seal pressure, and then finally the external anulus grouting. A load path for the TBM shield weight is provided with legs underneath the launch seal which have levelling nuts to help with installation. The outwards force from the internal fluid pressure is transferred through the shell into the headwall via bolts and then into the ground using ground anchors splayed outwards away from the TBM alignment.

After completion of the TBM launch at The Bays, the launch seals were removed for re-use at Pyrmont Station.

2.6 *Design process*

The design process for the launch of a TBMs within the Bays station box was a critical phase in the ETP project as it needed to ensure a safe, efficient, and timely commencement of tunnelling operations. Early integration between the JCG JV construction team and the Delve Underground design team played a pivotal role in optimizing this process. By collaborating from the initial planning stages, both parties were able to align design proposals with practical construction methodologies, leading to significant cost savings and improved efficiency. This early engagement allowed for the identification and mitigation of potential risks, streamlined the approval process for temporary works, which included Proof Engineering, and enabled the reuse of steelwork and other components where possible.

As a result, the TBM launch was executed smoothly, with minimized delays and enhanced safety, demonstrating the tangible benefits of early and continuous collaboration.

2.7 *Construction benefits of the design*

The final design for the TBM temporary works has the following benefits to the construction team:

- The ability of the steel rings to be re-used in subsequent launches of the TBMs, instead of casting additional concrete segments (and demolishing them).
- The jacking dolly not being permanently fixed, and instead utilizing pins, offered several key benefits during the TBM launch at The Bays Station. Mainly, its removable design allowed for greater flexibility during assembly and launch operations, enabling it to be easily repositioned once the TBM shield had advanced.
- For the launch frame, the oversized external frame allowed the TBM shield to pass through before the full frame assembly was complete, offering considerable time savings and

flexibility in the construction sequence. By enabling the installation of the smaller internal members after the TBM had traversed the main frame, the design minimized the need for lifting large structural components in the confined environment of the station box. Components of the launch frame were also to be re-used for the second TBM launch from the Pyrmont station towards the new Hunter Street station.
- Tension ties which connected the stools of the TBM shield cradles reduced the amount of fixings into the slab, providing both time and cost benefits.

In summary, it was key for the JCG JV construction team to launch the TBMs within The Bays Station box on time and therefore any programme savings resulting from efficient and simple temporary works designs provided considerable benefits for the project. Minimizing the fixing anchors, minimising the quantity of steelwork and reducing the amount of steel connections within the design ensured the programme savings were achieved.

2.8 *Lessons learnt*

Overall, the design was efficient and cost effective for the construction team. However, the following items at The Bays Station launch were identified as potential improvements:
- It would be beneficial to reduce the amount of fixings between the eye seal and the concrete headwall, as it was difficult to line the launch seal up with the protruding bolts. Having larger oversized holes through the rear flange of the launch seal would also improve installation tolerance.
- For the upcoming Pyrmont Station launch, which reuses the temporary works, the site is more confined than The Bays Station box and therefore creates greater constructability issues. A better understanding of the constraints at Pyrmont Station from the construction team at the time of detailed design may have allowed for more provisions incorporated into the launch design for Pyrmont Station.

3 CONCLUSION

This paper presents valuable insight into the design development and construction monitoring of large-scale Temporary Works designs on the Eastern Tunnelling Package section of the Sydney Metro West project. Optimized designs were effectively implemented through close collaboration between the contractor and design engineer.

4 ACKNOWLEDGEMENTS

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