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TBM launch temporary works: Melbourne North East Link

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ABSTRACT: North East Link freeway is a 10km long portion of Melbourne's northeast transport network. The Spark consortium has been contracted by North East Link to complete the missing link in Melbourne's orbital freeway between an upgraded Eastern Freeway and the M80 Ring Road. Spark is responsible for delivering the Primary Package under a public-private partnership (PPP) framework encompassing the design, financing, construction and commissioning of the Works, including 6.5km twin three-lane tunnels, with interchanges at Manningham and Lower Plenty Roads and upgrades to Greensborough and Bulleen Roads. To complete the 6.5km twin 14.1m internal diameter tunnels, two tunnel boring machines (TBM) were assembled and launched from the Watsonia trench site. The TBMs will arrive, traverse and relaunch at the Lower Plenty Road cut and cover structure and will finish at the Manningham cut and cover structure. Delve Underground, in close collaboration with Spark, designed the TBM assembly gantry crane foundations, launch frame, cradles, false ring support and launch seals. This paper discusses the design of the above elements, providing insight into key design decisions and the structural behaviour of the temporary works versus the modelled predictions.

1 INTRODUCTION

North East Link (NEL) freeway is a 10km long portion of Melbourne's northeast transport network. The project includes Victoria's longest and largest twin road tunnels from Watsonia to Bulleen. The segmentally lined tunnels are 14.1m internal diameter (ID) designed and constructed along most of the alignment using the latest industry practice.

Two tunnel boring machines (TBM1 and TBM2) were assembled and initially launched from the Watsonia trench site. This paper aims to share lessons learnt from the NEL project TBM assembly and launch. A number of integrated elements of temporary works are required to safely assemble, launch and service the TBMs. A general overview of the Watsonia trench site is shown in Figure 1 below, which includes the following Temporary Works design scope:

- Temporary runway beams and columns located on top of the Watsonia permanent piled walls for the support of the TBM assembly gantry crane.
- Temporary foundation beams and retaining wall behind the Watsonia piled headwall for the support of the TBM assembly gantry crane.
- TBM launch frame, ground anchor hold-downs and foundations to support the TBM thrust loadings during launch and initial excavation.
- Temporary eye seal for TBM launch fixed with ground anchors into rock to provide confinement of annulus grouting during initial permanent segment installation.
- TBM launch cradle and TBM backup gantry trench to enable the assembly and support of the TBM equipment during assembly and launch.
- Temporary frames to support the temporary false concrete tunnel segments. This supports the false rings which transfer the TBM thrust loads to the launch frame.

This paper concentrates on the TBM launch frame and gantry crane temporary runway beams and columns.

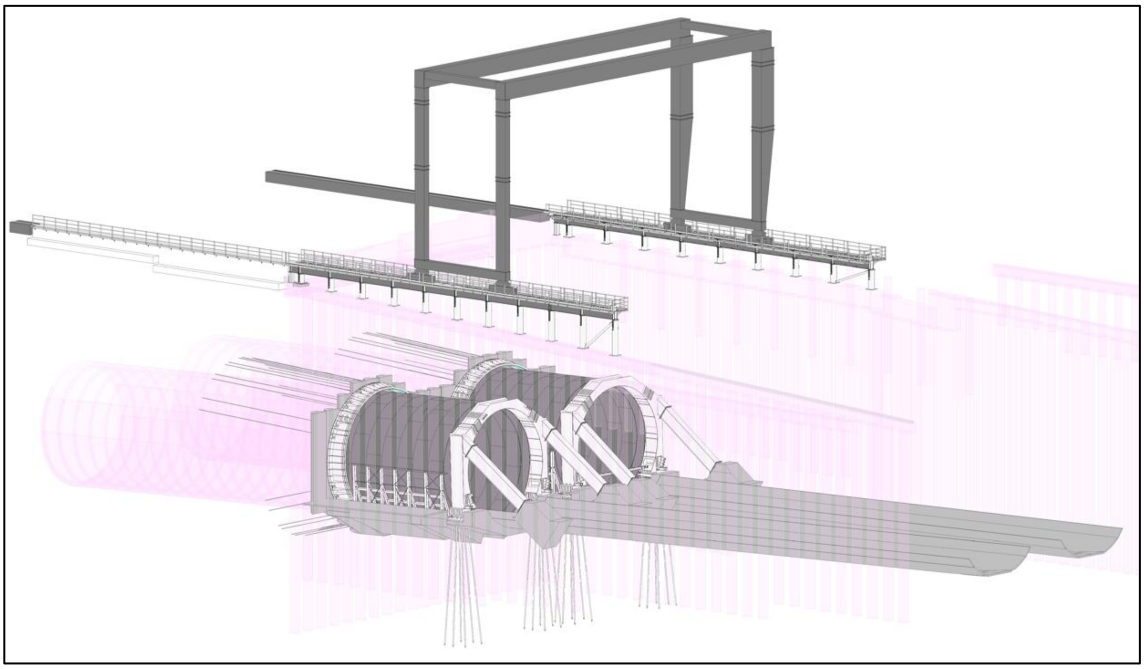

Figure 1. TBM temporary works at the Watsonia trench site

2 DESIGN DEVELOPMENT

The Watsonia TBM Temporary Works package was risk assessed and identified as a critical design package, and as such, was delivered using the same design management plan as the Permanent Works. The design was delivered in a staged manner: Preliminary Design, Draft Certified Design and Certified Design. 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 key changes implemented over the design stages for key elements of the Temporary Works design package.

2.1 TBM launch frame

To construct the 14.1m ID segmentally lined tunnel, a 15.55m TBM with a bore diameter of 15.61m was procured. The TBM consists of a 2500tonne, 13.5m long shield and three trailing backup gantries. The total length and weight of the TBM with backup gantries is 90m long and 4000tonne respectively. At the Watsonia trench launch site, the ground conditions were predominantly in moderately weathered siltstone which provided a relatively strong sub-grade for the temporary foundations to bear onto.

The design TBM launch thrust load at Watsonia trench site was 38,000kN, applied via 20 thrust jack pairs evenly arranged around a 14.6m 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. Both the temporary and permanent tunnel rings are 500mm thick. The thrust jack positions are shown on the left-hand side of Figure 2, below.

The custom fabricated box beams that are typically used for added stability on large TBM launch frames have an inherently high torsional capacity which allows for flexibility in the location of the web and stiffener plates in relation to the TBM thrust jack positions. To simplify the installation of the frame and reduce the amount of site splices, the inherent torsional stability of the box beams made possible for the adoption of a horseshoe arrangement for the main launch frame. The horseshoe arrangement resulted in the upper splice connection between the top and side members requiring less manipulation during installation due to the splice plates being on an angle. The top member could be directly lowered into the space between the two side members more efficiently compared to a more traditional launch frame which would be composed of a horizontal top member and angled corner members resulting in two vertically oriented splice plates on each side of the traditionally framed top member. The front frame was designed to be lifted in separate pieces or one large module. This improved the installation and removal for the initial use at Watsonia trench site and for re-use at Lower Plenty Road cut and cover structure.

Adopting the horseshoe arrangement, however, resulted in a more complex loading arrangement than a traditional frame's top member. The combined structural actions of bending, shear, and torsion in the top member of the horseshoe had to be carefully considered. To accurately model the structure, a full 3D finite element (FE) model was utilized as shown in Figure 2, below. The higher stressed regions in the upper web of the top shoulders of the horseshoe-shaped frame required a thicker web plate to resist the additional shearing stress due to torsion in the member.

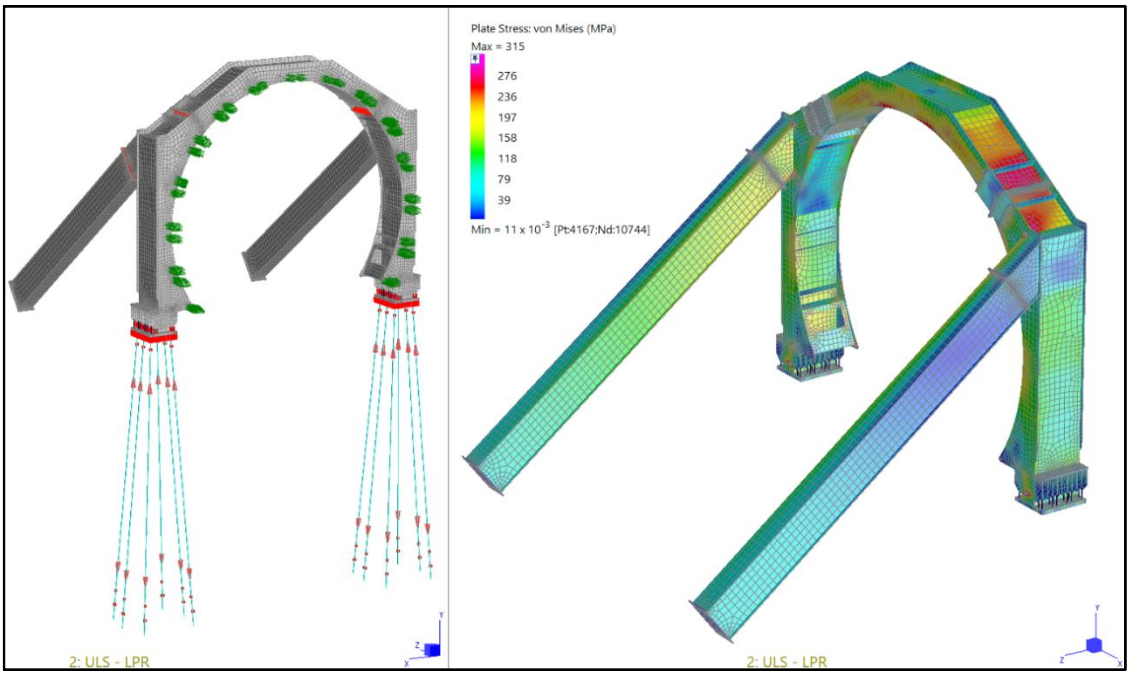

Figure 2. TBM launch frame FE model

Tensioned ground anchors were used to resist the upwards force created by the rear strut angle, shown on the left-hand side of Figure 2, above. 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 ensured 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 3, below.

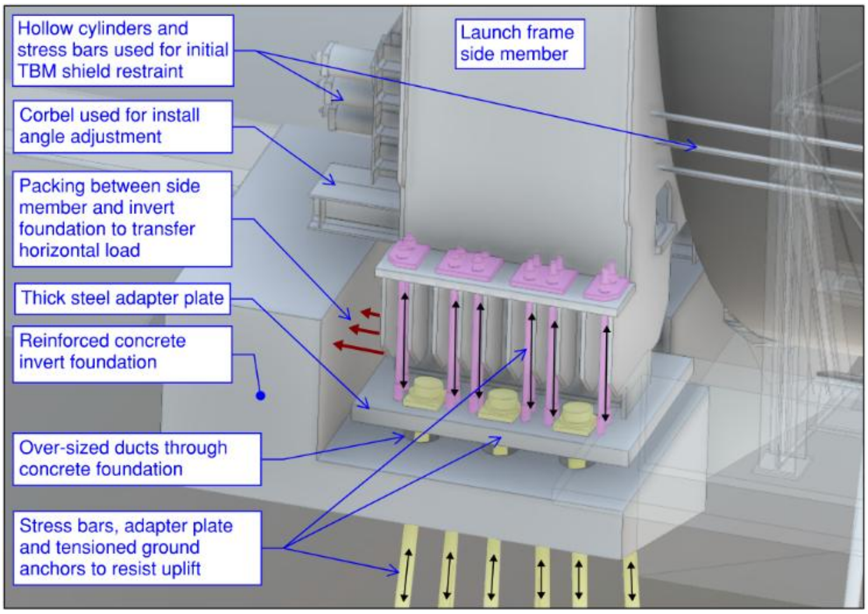

Figure 3. Launch frame side member load paths

Another simplification made to the launch frame was the omission of a steel bottom member and instead, using a reinforced concrete invert foundation. The concrete invert foundation transferred the loading directly from the lower TBM thrust jacks and each launch frame side member into the vertical face of the excavated siltstone cut face. To accurately model the complex shape and loadings, a 3D soil structure interaction (SSI) brick model was used to assess the design actions for the design of the concrete and reinforcement, as shown in Figure 4, below.

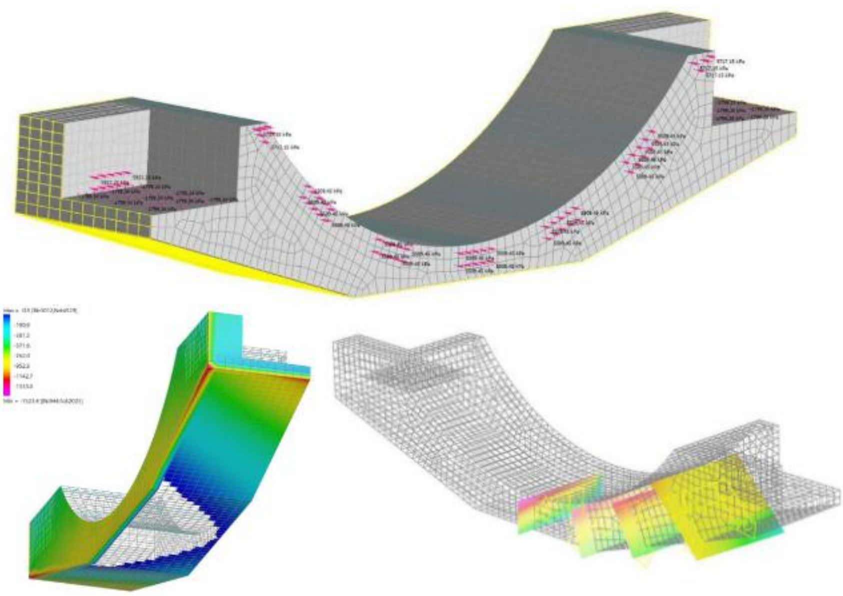
Figure 4. TBM launch frame reinforced concrete invert FE brick model

Certain steel elements in the launch frame required relatively thick steel plates. The risks and effects of lamellar tearing were assessed, from both the fabrication sequence and the loaded state, and the joints were detailed accordingly to mitigate the through plate tension stresses. Examples of this detailing are the launch frame hold-down connections and the upper frame to side member connection are also shown in Figure 5 below. For critical connections in tension, under head bolt loads were transferred in bearing and compression into stiffeners with long fillet welds along the stiffener edges working in shear rather than a direct end plate to flange butt weld. For plates greater than 32mm thickness, plate with improved through thickness properties (Z-grade) and/or weld pre-heating were specified.

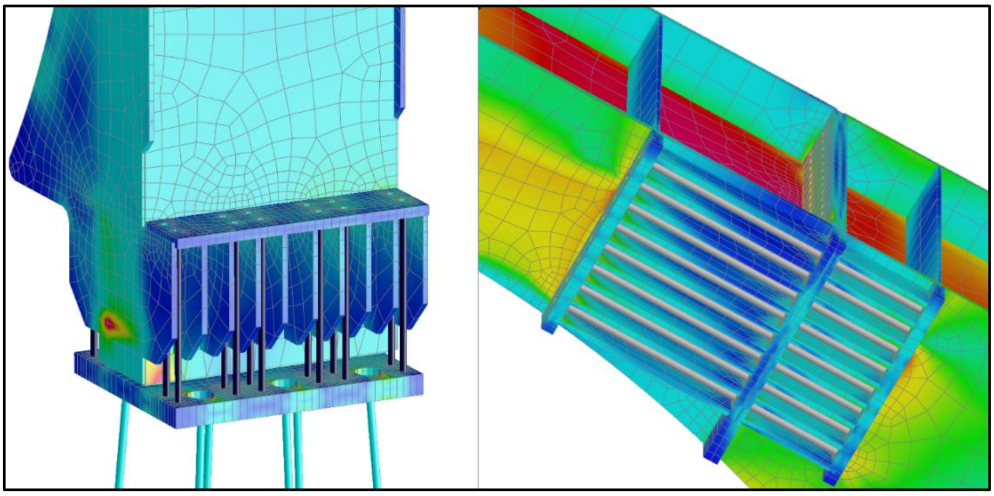

Figure 5. TBM launch frame hold-down and upper shoulder connection detailing

2.2 Gantry crane support structure

To assemble both TBMs in the Watsonia trench, a 550t capacity gantry crane was proposed. At the initial concept design stage, two 21m span gantry cranes were planned, which would have required a central temporary steel runway beam supported on temporary columns between the two TBMs. As shown in Figure 6 below, the clearance between the two TBMs was quite limited. Having a central crane beam on columns would have greatly reduced the already tight access and reduced the overall structural redundancy in the system, should the columns ever be subjected to collision loads by plant or lifted loads. Other design considerations regarding the relative stiffness between the central temporary columns and the reinforced concrete piled permanent trench walls, and how to effectively brace the central crane beam without creating additional lifting hazards would also have needed to be addressed.

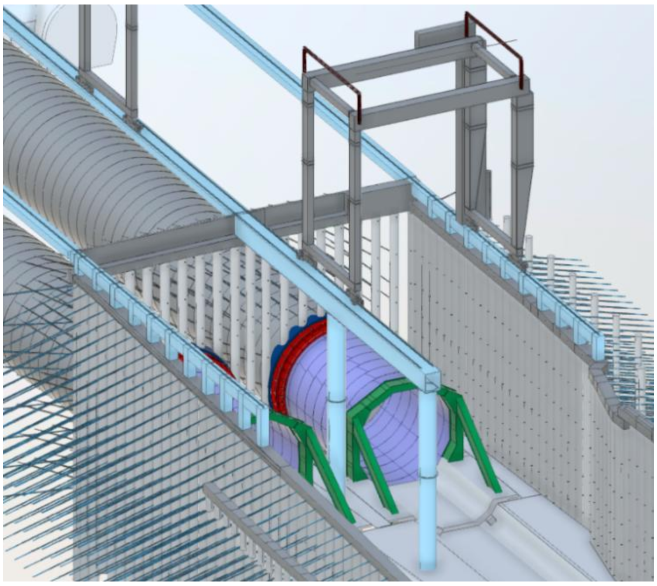

Figure 6. TBM assembly gantry crane original concept with central beam supported on columns

Considering the issues previously discussed, the decision was made to procure a larger 47m span gantry crane and omit the central beam on columns. This resulted in a safer and more structurally sound solution. In the assembly yard, the gantry crane rails ran on top of concrete cast inplace ground beams. Over the trench, the crane rails ran on top of steel box beams, which were supported by temporary steel columns on top of the permanent structures retaining walls, as shown in Figure 7.

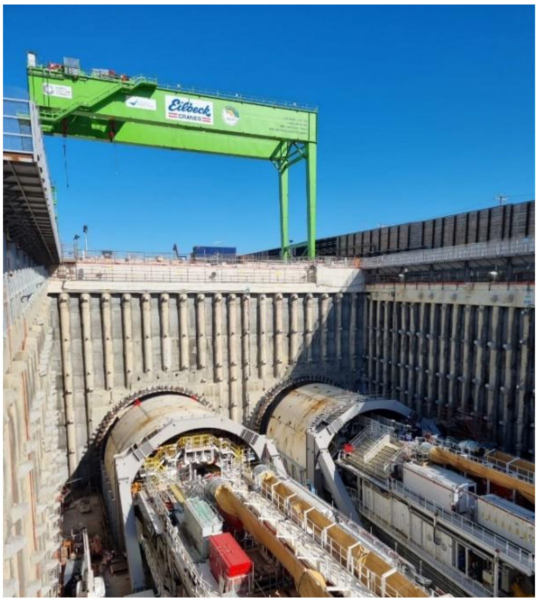

Figure 7. 550t capacity, 47m span gantry crane

Careful design and detailing of the temporary structure were required to keep the loadings centralized, prevent unwanted eccentricities and provide a solution that was simple to install and deconstruct at the top of the trench wall. Structural detailing of the beam-to-column connection is shown in Figure 8, below.

Figure 8. Gantry crane support beam connection detailing

3 CONSTRUCTION MONITORING

3.1 *TBM launch frame*

Launch frame displacement was monitored daily (at 8-hour intervals) during the initial TBM launch. Survey prisms were mounted on the top member to record the parallel displacement, as shown in Figure 9, below.

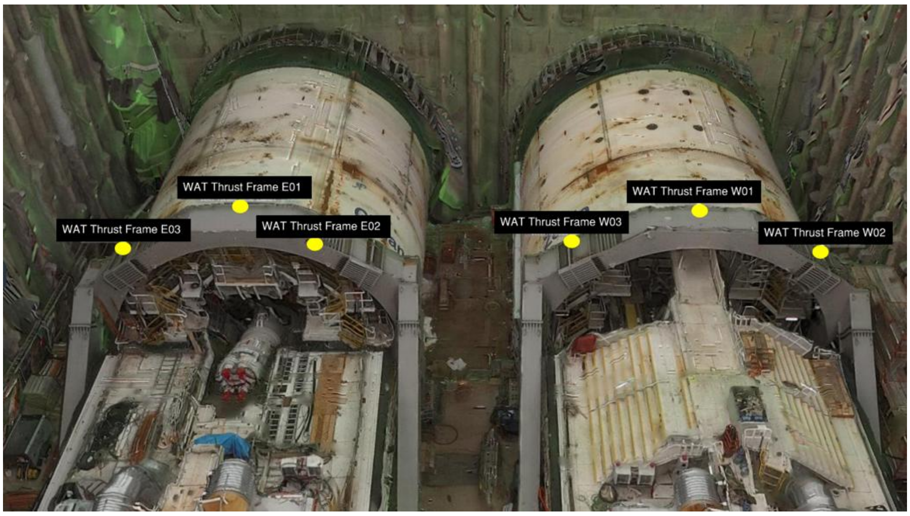

Figure 9. TBM launch frame monitoring prism locations (in yellow)

In Figure 10 below, a plot of the recorded parallel displacements of the launch frame top member is shown. For TBM1, the peak displacements were measured between 14/08/2024 and 16/08/2024, when the TBM cutterhead was excavating through the GRP-reinforced piles and the first 15m of rock. The thrust load at this stage of the initial TBM launch ranged from 24,000kN to 34,800kN. Displacements typically reduced after commencement of tail skin grouting, with the exception of minor increases in displacement when thrust forces were increased. Displacements stabilised until TBM1 launch frame was removed on 15/09/2024. Negative thrust frame movement recoded on 21/08/2024 was due to survey control, which required a review of the survey data and re-baselining. Similar trends were observed for the TBM2 launch.

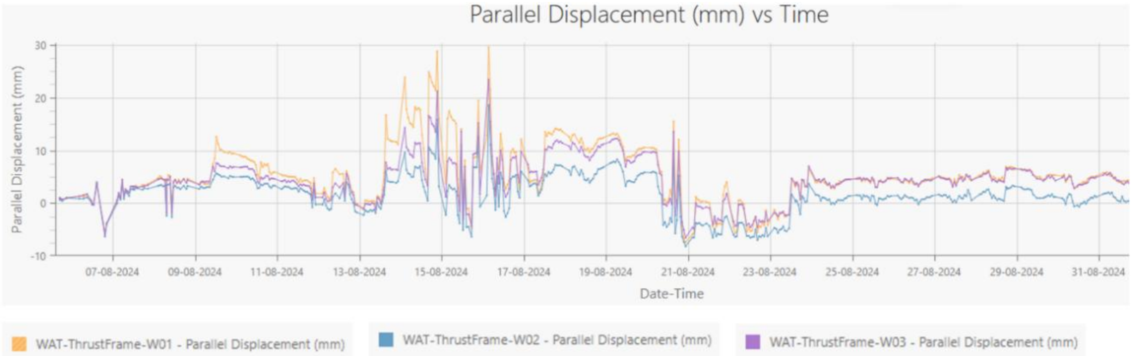

Figure 10. TBM1 launch frame monitoring results

The measured maximum displacement of 30mm at 30,000kN during initial TBM launch was backchecked by inputting this thrust load into the FE model. The FE model was in close agreement with a predicted 32mm of displacement in the top member.

3.2 *Gantry crane support structure*

Gantry crane beams and columns were monitored continuously during operation with increased frequency for lifts greater than 250t. Monitoring points were installed at the top of all columns and at mid-span points for the runway beams. The estimated mid-span vertical deflection was

9mm for a 550t lift (crane leg load of 4650kN), and 4mm for a 250t lift. The estimated maximum lateral displacement when operating at the maximum allowable loading conditions was approximately 5mm.

In Figure 11 below, a typical example of the monitoring plots reported daily for the gantry crane runway beams and columns is shown. Lifts between 250t to 520t showed noticeable displacements on both the gantry crane beams and columns, while lifts below 200t showed negligible movement. It is worth noting that certain lifts, such as the tail skin, required the load to be suspended until welding was completed, which could take several shifts over a period of days. Lifts that occurred over a longer period required further collaboration with the gantry crane supplier to develop additional load cases and reaction loads for specific lifts, considering various wind speeds over the lift period. Outliers in the data below represent days over which lighter loads, such as the tail skin, were suspended over a period of days, and higher winds than expected (that were still within safety margins) were experienced. This led to the Amber monitoring trigger level being exceeded. In turn, the frequency of monitoring and inspection of the monitoring data were increased over the period.

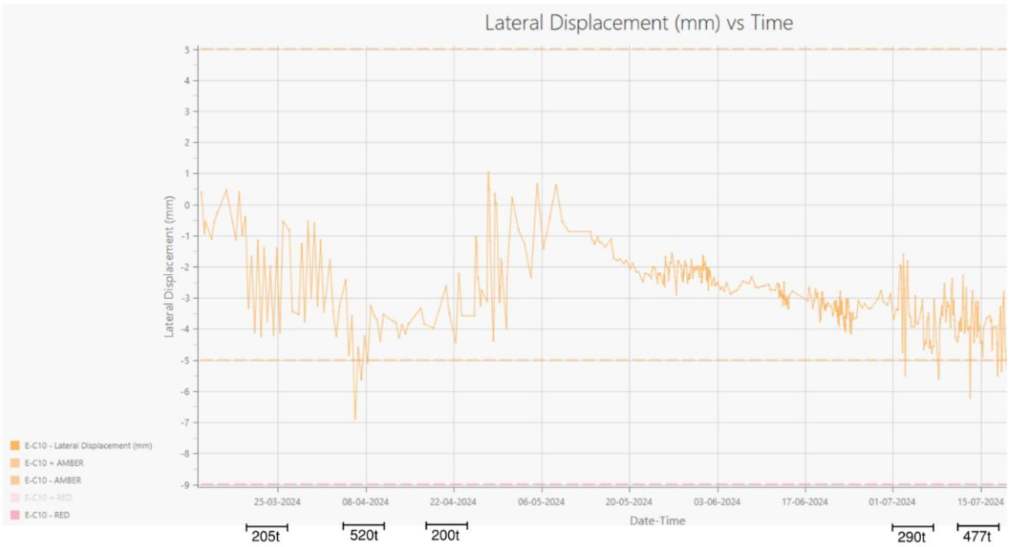

Figure 11. Gantry crane lateral displacement with corresponding key lifts for TBM2

4 CONCLUSION

This paper presents valuable insight into the design development and construction monitoring of large-scale Temporary Works designs on the North East Link Project. Optimized designs were effectively implemented through close collaboration between the contractor, design engineer and crane supplier.

Generally, the structural models closely matched real-world deflections and displacements. However, the installation of the TBM tail skin highlighted a loading condition that at first did not appear to be critical, due to the tail skin's relatively light weight, but did cause an exceedance of trigger levels due to the extended period the load was suspended. This highlights the requirement for detailed consideration of gantry crane skewing loads and closer consideration of the consequences of wind loading being higher than anticipated when loads need to be suspended over a period of days.

5 ACKNOWLEDGEMENTS

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