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Breaking ground with umbilical and flying launch systems: innovations to manage space constraints in Australia's Suburban Rail Loop Project Tunnels South

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ABSTRACT: The flying launch method, widely used internationally, will be implemented for the first time in Australia on the Suburban Rail Loop project. This launch technique is ideal for constrained sites where full TBM assembly and conventional thrust frames are not feasible. In such cases, an umbilical launch is used, involving the partial assembly of the TBM within a shaft and the use of hoses and cables—called umbilicals—to supply services from the surface. When a thrust frame cannot be installed due to spatial limitations, a flying launch is adopted. It positions a reaction frame near the headwall, with the TBM advanced via hollow jacks and stress bars connected through a star compression ring. At the Clarinda site, four TBMs will be launched using this combined umbilical and flying launch method, each with a tailored approach. This paper explores the design, implementation, and challenges of this innovative launch strategy.

1 INTRODUCTION

Suburban Rail Loop (SRL) is a significant transport infrastructure project in Australia's fastest growing city, Melbourne. SRL is an orbital rail line that will connect the existent major railway lines from Cheltenham in the Southeastern suburbs to Werribee in the west, passing through Tullamarine Airport. The project is divided into four major sections: East, North, Airport and West. SRL East is the first phase of multi-decade project. Now into delivery, SRL East will span 26 kilometres of twin tunnels connecting six new underground stations between Cheltenham and Box Hill across Melbourne's middle suburbs.

Four TBMs will construct the tunnels between Cheltenham and Glen Waverley for the Suburban Rail Loop East's, Tunnels South. The project involves twin tunnels, each approximately 16 kilometres in length. All four TBMs will be launched from the Clarinda site, employing umbilical systems combined with the flying launch technique.

This paper explores and evaluates the various launch methods available and explains the rationale for selecting the flying launch for this project. The advantages and drawbacks of each approach are assessed and, the technical aspects of the flying launch are discussed, including design and assembly. An evaluation of the alternative solutions considered prior to finalizing the implementation strategy on site is also presented.

The Clarinda launch site, located in the south-east of Melbourne, is being prepared to accommodate all necessary equipment for tunnel construction. In addition, a shaft will be excavated and set up exclusively for the TBM launches. The shaft is divided into two sections: East and West. Each section will launch two TBMs—those in the East will tunnel towards Glen Waverley, passing through Clayton and Monash stations, whilst the West TBMs will head towards Cheltenham, passing the South Stabling Yard. Due to space limitations on site, the launch shafts cannot accommodate the full assembly of the TBMs. Traditional launch methods involving a thrust frame are also not feasible. After extensive analysis and consideration of various options to ensure an effective launch, the flying launch method, combined with umbilicals, has been selected.

The flying launch method has been developed by Hochtief Infrastructure Gmbh and was first implemented in 2006 on the North-South Urban Light Railway Project in Cologne, Germany (Assenmacher, 2007, p. 23). Since then, it has been utilised on several projects throughout Europe and Asia including Deep Tunnel Sewerage System Project Phase 2 (DTSS 2) in Singapore and Central Interceptor Project in New Zealand. The methodology has never been used in Australia.

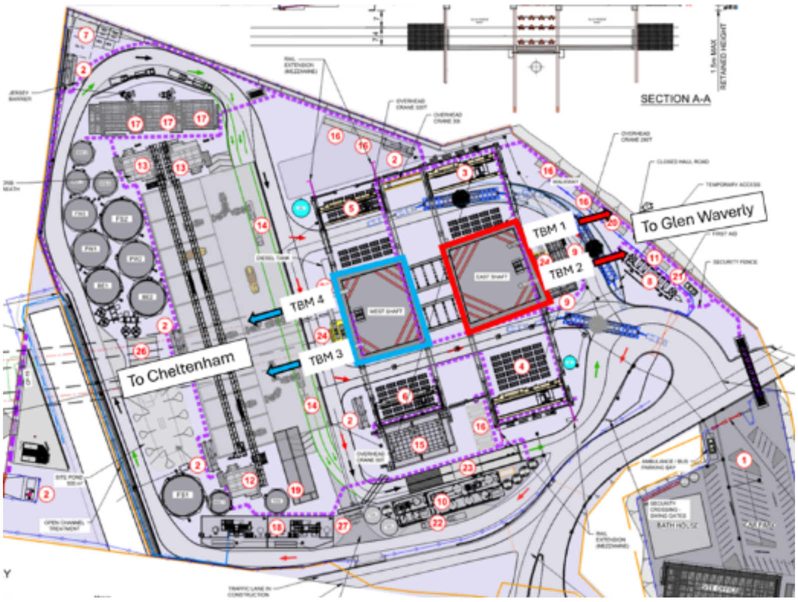

Figure 1. Alex Fraser launch site layout

2 TBM LAUNCH METHODOLOGIES

There are various methods and techniques available for launching TBMs. Typically, the TBM is fully assembled, including the shield and gantries, and launched using a thrust frame in combination with blind rings. However, in areas with limited space, the flying launch technique can be employed.

2.1 *Conventional launch*

Conventionally, a TBM launch employs a thrust frame which enables the TBM to build rings and push into the ground. The machine is positioned at the headwall, and the thrust frame is assembled behind the shield, specifically behind the tail skin. Thrust frames can vary in design and assembly methods, but they are generally portal-shaped and connected to the machine via a steel ring that is installed in the tail skin and pushed against the frame.

The steel ring is then secured to the thrust frame using welding or bolting. The TBM is pushed into the ground by thrust cylinders acting against the steel ring. After each push, which depends on the extension of the cylinders, a new precast ring is added. The thrust frame is designed to absorb the force from the cylinders and continues to hold its position in the launch area until the grouted rings in the ground can support the push. To ensure stability during the pushing phase, the frame is typically anchored to the ground or base slab with ground anchors.

Figure 2. Conventional thrust frame.

2.2 *Flying Launch*

Unlike the conventional launch, the flying launch is primarily used to pull the TBM into the ground. This method involves several key components: a reaction frame, a star compression ring, hollow jacks, and stress bars to facilitate the pulling of the TBM.

In some cases, instead of using a reaction frame, the system can be jacked from the headwall, provided the design of the headwall can support the pulling forces of the machine. The TBM shield is first assembled at the launch site, and the reaction frame is then constructed around the shield, positioned near the headwall. Similar to the thrust frame, the reaction frame is anchored to the ground to absorb all pulling forces.

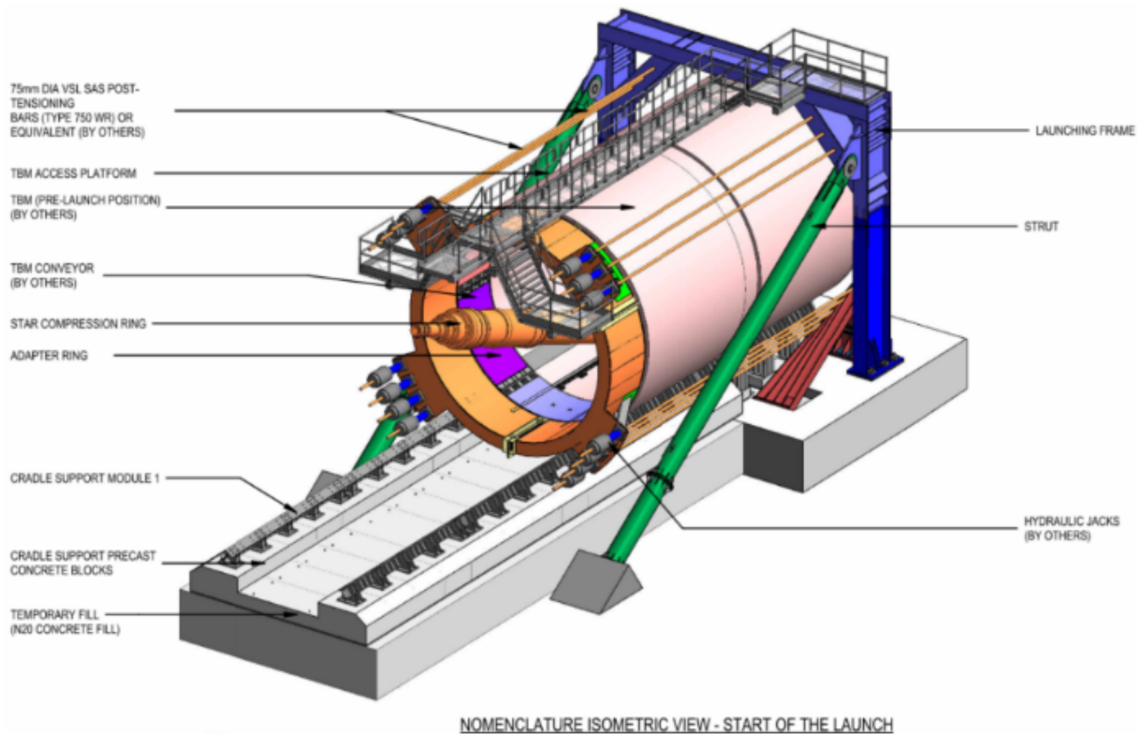

Figure 3. Flying launch assembly.

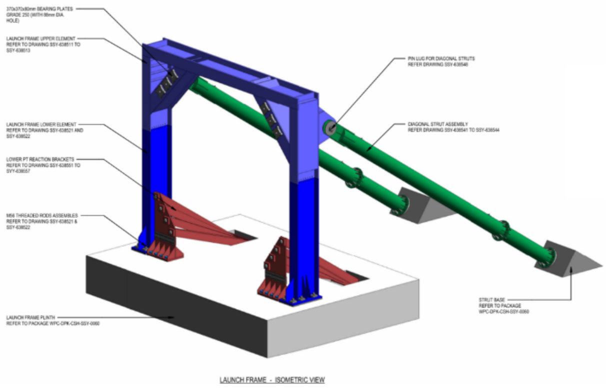

Figure 4. Flying launch reaction frame.

A steel ring is installed in the tail skin of the TBM, which is connected to the star compression ring positioned behind the tail skin. The steel ring is pressed against the star compression ring and fixed in place by welding or bolting. At this stage, hollow cylinders are positioned against the star compression ring, through which stress bars are inserted. The stress bars are secured with nuts and washer plates, connecting the hollow cylinders to the reaction frame. Additionally, a fixation point on the star compression ring helps maintain its position as the hollow cylinders are readjusted after each stroke.

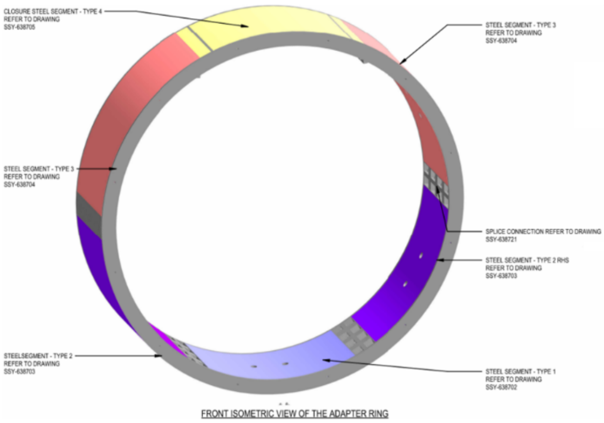

Figure 5. Adapter ring.

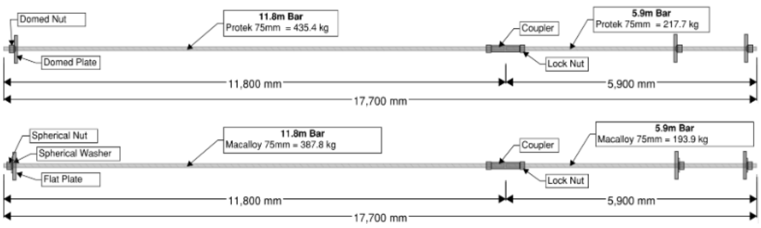

Figure 6. Stress bar assembly

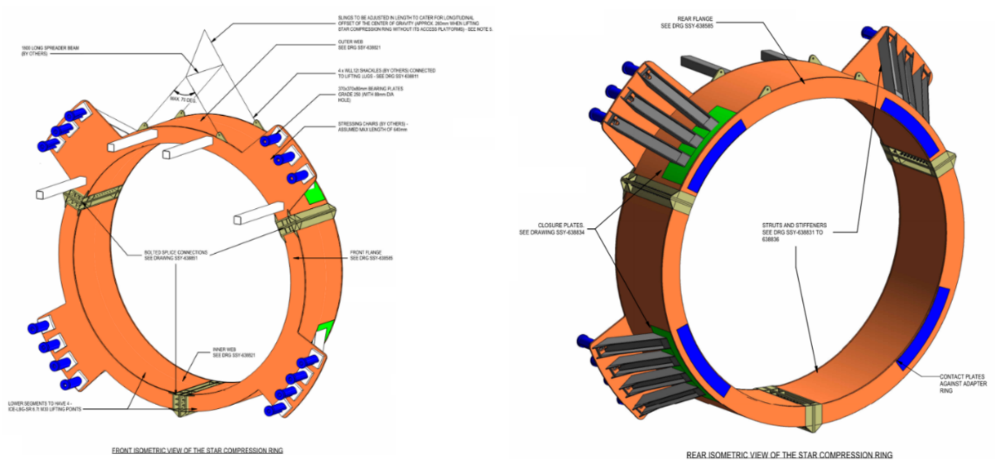

Figure 7. Star compression ring front and back view

Once the entire system is assembled, with all bars in place, the hollow cylinders are hydraulically and electrically connected to a power pack. When activated, the hollow cylinders start pulling on the stress bars, causing the TBM shield to move towards the headwall. The hollow cylinders generally have a shorter extension compared to the TBM's thrust cylinders, requiring re-adjustment after each stroke. The thrust cylinders are powered by an erector emergency pump, remaining at a fixed extension and pressure to keep the steel ring in place. As the hollow cylinders retract, the star compression ring is held in position by the fixed nuts and washer plates. The TBM, along with the star compression ring and steel ring, is then pulled until the steel ring reaches the headwall. At this point, concrete rings are installed and grouted to the ground. The star compression ring, stress bars, and hollow cylinders remain in place until the grouted rings can support the excavation.

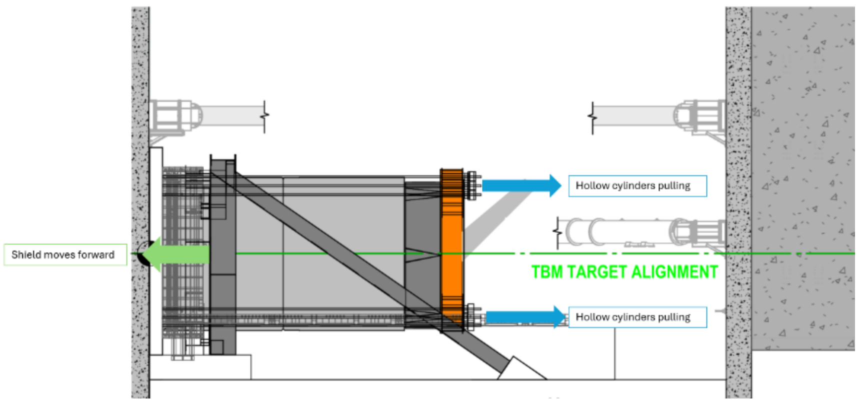

Figure 8. Initial flying launch configuration

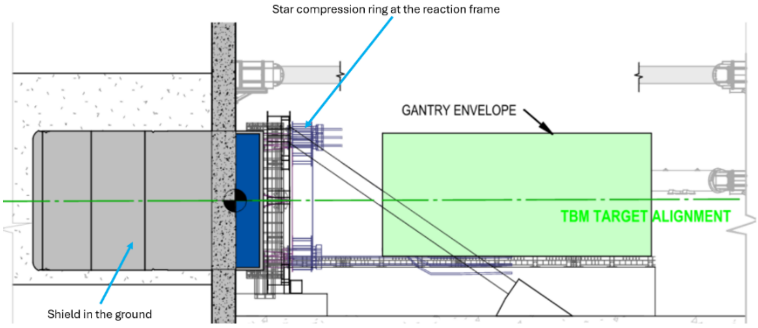

Figure 9. Final flying launch configuration

The primary difference between these two launch methods is the way the TBM is moved. The traditional thrust frame operates by pushing the TBM toward the headwall, whereas the flying launch pulls the TBM forward. The thrust frame remains stationary, and new rings are progressively installed to push the TBM. In contrast, the flying launch system moves with the TBM until it reaches the headwall. With the thrust frame, the TBM's thrust cylinders perform the pushing action, while in the flying launch, the TBM's thrust cylinders are locked in terms of pressure and extension, and the hollow cylinders handle the pulling.

The key distinction lies in the use of space: the thrust frame must be positioned a certain distance from the headwall to allow the installation of multiple blind rings to push the TBM forward and into the ground. In contrast, the reaction frame for the flying launch is placed very close to the headwall, with the star compression ring positioned at the back of the shield, making the space confined to the size of the TBM shield. This is the primary reason that the flying launch is a valuable solution in situations where space constraints prevent the construction of a thrust frame.

However, there are also some disadvantages to the flying launch. It requires additional components, such as the star compression ring, stress bars, and hollow cylinders, which increase the overall cost and extend the installation process. Furthermore, since the hollow cylinders need to be re-adjusted after each stroke, launch time is typically longer and requires additional personnel to manage the operation.

3 FLYING LAUNCH DESIGN FOR SUBURBAN RAIL LOOP

3.1 *Overview*

The design of the flying launch accounts for a maximum thrust force of 17,500 kN, as well as the design of the TBM and concrete segment rings. All associated equipment has been selected and designed to accommodate this force.

The design selected for the Suburban Rail Loop project includes the following components:

- 14 stress bars;
- 14 hollow cylinders;
- 1 reaction frame;
- 1 star compression ring;
- 1 steel ring.

Specifically for the stress bars, the system includes six bars positioned at the top and eight bars positioned at the bottom, evenly distributed between the left and right. Each stress bar is approximately 18 meters in length with a diameter of 75 mm and is designed to withstand the pulling force. 40% of the load is exerted on the top bar and 60% on the bottom.

The hollow cylinders required for this application are specifically chosen to handle the pulling force and the dimensions of the stress bars. The cylinders have a stroke of approximately 240mm and have an opening for the stress bars of 110mm.

The reaction frame consists of three main components: the portal, the reaction struts, and the reaction brackets at the bottom as shown in Figure 4. All three components are anchored to the ground to effectively transfer the forces. The portal is divided in three main sections: two columns and one cross structure that connects the columns, all of which are bolted together. The central structure holds the top stress bars. The struts are diagonal members that are connected through a bolt to the portal. The reaction brackets are not linked to the main portal. It instead consists of a diagonal member welded to a vertical column. Through the vertical column, the bottom stress bars are installed.

The star compression ring, shown in Figure 7, is designed to accommodate the pulling forces, the dimensions of the stress bars, and the size of the TBM shield, which in turn determines the size of the steel ring. It is made of three sections that are pre-assembled and fixed on surface before being lowered into the shaft.

The steel ring shown in Figure 5 is engineered to withstand both the thrust and pulling forces, as well as the concrete rings installed during the TBM's excavation. Six segments constitute the steel ring over a length of two metres, which allows the ring to reach the star compression ring without fully extending the TBM thrust cylinder.

3.2 *System installation*

The process begins with positioning the columns of the reaction frame in the shaft. Once that is in place, the TBM shield is lowered in the shaft. After the shield is set, the top part of the reaction frame and the struts are installed and secured. Next, the star compression ring is lowered into position, initially on support legs. The support legs provide stability for the star compression ring before the installation of the stress bars and hollow cylinders. Once the star compression ring is supported, the stress bars are installed and secured with a washer plate and nut system at the dead end (reaction frame) and life end (hollow cylinder). At the star compression ring side, the locking system is provided by using a counter washer plate and a nut. The hollow cylinders are installed after the stress bars are positioned and secured. The star compression ring is then fixed to the steel ring, which the TBM's thrust cylinders push against. Finally, the system is connected to the power pack through hoses and cables, making it ready for operation.

Upon activation, the hollow cylinders pull the stress bars, allowing the star compression ring to move and push the TBM forward toward the headwall. After each stroke (approximately 240 mm), the star compression ring is locked into position using the counter washer and nut, and the hollow cylinders are retracted and secured again with the washer plate and nut. The pulling process then resumes, continuing until the first concrete ring is installed. At this stage, the position of the flying launch remains fixed, and the system only serves to support the excavation. Once the grouted concrete rings can support the excavation, the flying launch system is disassembled and can be reused for the next launch.

3.3 *Umbilicals*

Given the limited space within the shaft, the back-up gantries will be installed on the surface. This unique challenge requires all services supporting the shield to be managed. The services will be managed in four different ways:

- Short support gantry: a small temporary gantry will be launched with the machine. This will follow the machine until a point it can be reconfigured to a full machine. The gantry will house the below services:
    - 2MVA transformer
    - drive motor MCC's
    - grease drums and pumps
    - grout A and B tanks and pumps
- Festoon system: an electric hoist-controlled festoon system with sufficient capacity to support machine until reconfiguration. It will contain all hydraulics to support shield.
- Cable reeler: borrowed from the back up gantries, the reelers that are usually utilised for pipe extension within the tunnel will be installed within the shaft. These will feed:
    - compressed air
    - water
    - grout A
- Cable basket: Given that the HV transformer is installed on the short support gantry, only comms and HV cables will need to be run from the shaft to the machine. These two cables will be strapped together and installed in a "figure 8" configuration into a basket which will be fed out as the machine advances.

The preferred approach for all services is to minimize / eliminate the need to break services for extensions from within the tunnel. This means all planned extensions occur within the shaft, making management of spillage easier resulting in a safer working environment within the tunnel.

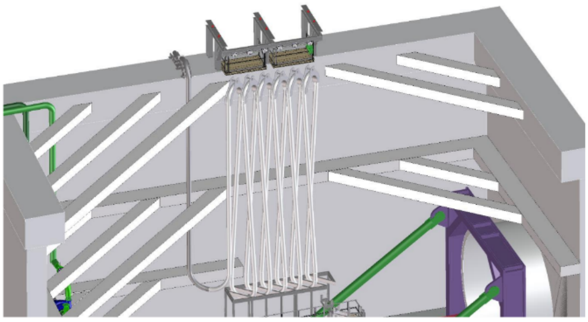

Figure 10. Umbilical festoon system

3.4 *Expected challenges and limitations*

Various challenges and lessons will need to be managed during the launch process, given that this project will employ the flying launch system for the first time in Australia. A common challenge will be to ensure consistent distribution of forces according to the design, maintaining the 40/60 thrust load ratio between the top and bottom stress bars as accurately as possible. The primary ongoing challenge that is expected, however, is maintaining TBM alignment ensuring that the cylinders extend uniformly with each stroke. This will be managed using a power pack located at the bottom of the shaft, connected to all hollow cylinders. The power pack will be equipped with a PLC system that monitors and provides data on cylinder extension and the applied pressure. This requires precise coordination among all system components.

Due to the use of umbilicals instead of the full set of gantries behind the shield, the TBM's productivity will be affected, resulting in a reduced advance rate but offset by the overall increased efficiency.

3.5 *Benefits*

The benefits of the flying launch and the reason this method was selected are:

- Reaction frame positioned at headwall rather than several metres back.
  - Increased launch efficiency due to increased shaft space.
  - Safer access to tunnel for personnel
- Reduced shaft requirements.
  - Time and cost saving in reduced shaft excavation.
- Eliminates need for high-risk false ring disassembly.

4 CONCLUSIONS

The flying launch concept offers several benefits to a conventional launch where sites have space limitations, or shafts are being constructed exclusively for launch, such as on Suburban Rail Loop's, Tunnel South. The additional time and cost associated with the more complicated launch process are easily and comprehensively offset by savings in reduced shaft excavation and by eliminating the need to install and remove false rings.

5 REFERENCES

Assenmacher, S, 2007. "Flying Shield Start-Up": Innovative Start-Up Method for Shield-driven Tunnels, in Tunnel 03/2007, p. 23

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