Use of precast lining within the mined spurs on Western tunnelling package, Sydney metro west

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ABSTRACT: The Gamuda Laing O'Rourke consortium on the Western Tunnelling Package of Sydney Metro West opted for a precast lining for the two, altogether 1.5km spur tunnels connecting the dive structure to the underground junction caverns at Clyde. This selection was influenced by the length of the spur tunnels, tight alignment curves, and the desire to provide a ring similar to the mainline tunnels. The mined horseshoe-shaped spur tunnels, reinforced with rock bolts and a shotcrete primary lining, presented unique challenges for the design of the permanent lining. The precast lining consisted of three trapezoidal steel-fibre reinforced segments for the sidewalls and crown, along with a steel-reinforced concrete flat invert segment. The Lining Erection Machine (LEM) was designed and built in collaboration with Herrenknecht to efficiently erect these precast concrete segments. This paper discusses the selection and design of the precast lining, the development of the complete system and process, the machine itself, and the on-site experiences throughout the project delivery.

1 INTRODUCTION

Traditionally, mined tunnels are tanked using waterproof membranes and large arch formwork. For the 1.5 km Roadheader-driven spur tunnels, GLC challenged this approach by proposing a segmental precast lining system—leveraging existing TBM lining expertise and in-house precast production at Eastern Creek.

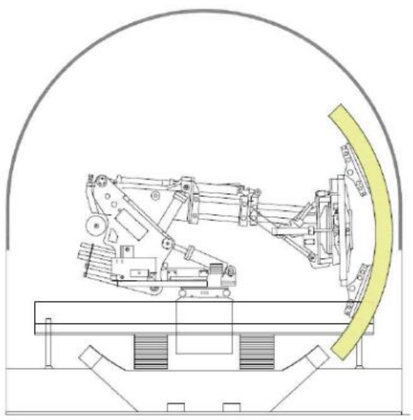

Figure 1. Original concept

The initial methodology involved segment placement using a spider grab, delivery via MSV, and staged backfilling with pea gravel and grout. This streamlined approach eliminated membrane installation and formwork, significantly improving safety and productivity. See Figure 1.

Key safety benefits included reduced work at height, lower manual handling risks, fewer tunnel interactions, and a shift to controlled off-site fabrication—leading to a 4–5x productivity increase. Additional advantages included improved finish quality and alignment with TBM tunnel standards.

This innovation introduced new challenges, particularly the use of gasketed segment joints to achieve water tightness—a rare application in mined tunnels with limited precedent or design guidance.

2 DESIGN INNOVATION

2.1 *Design integration and delivery*

To align with the construction sequence, the design was split into two coordinated packages:

- Primary Lining – excavation profile, bolting, and shotcrete support.
- Permanent Lining – precast segments, LEM interface, and backfill design.

Success relied on early integration between both packages—critical in a D&C environment where late changes would impact constructability, cost, and program. For example, the tunnel size was reduced to control backfill volume, which constrained excavation efficiency and plant access.

Figure *2* below provides the general arrangement of the two mined tunnels.

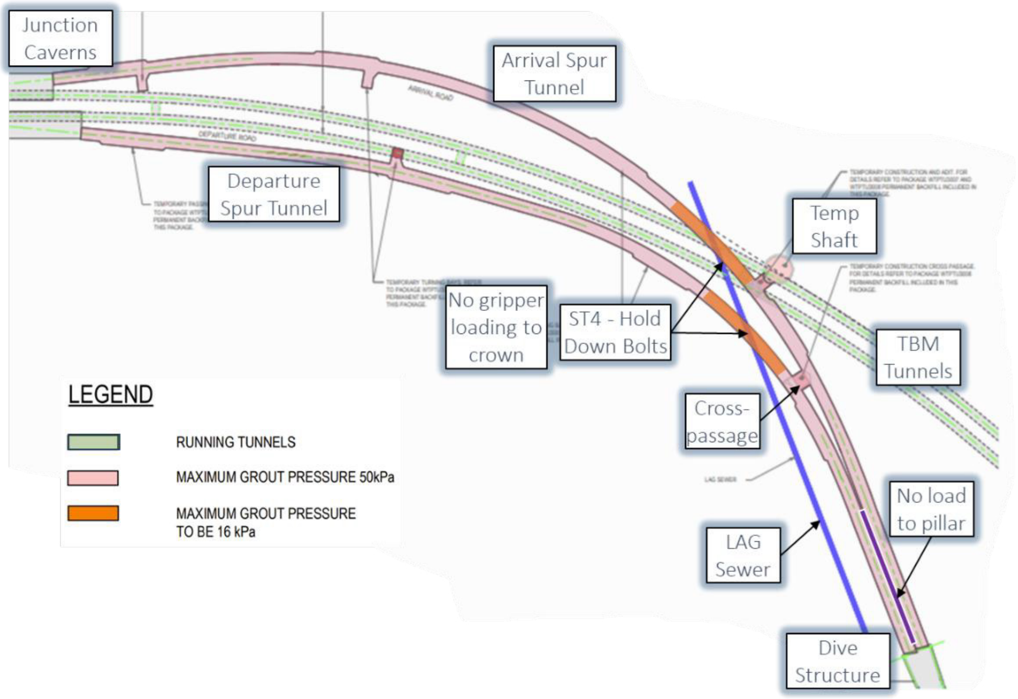

Figure 2. General arrangement

The primary lining also had to accommodate the LEM's core functions: segment placement, gasket compression, and advancement. The backfill process was later integrated into the LEM, further reinforcing the need for close design coordination.

Many key decisions during the design process needed to be made "at risk" to meet procurement and offsite manufacturing timelines, these included:

- The excavation profile and construction tolerances
- Segment size, shape and geometry, gasket and fittings

If we were to do it all again, we would be far better equipped to establish the timeline for key decisions, bring in the necessary partners at the right time and implement the key learnings from WTP into the design process.

2.2 *Permanent lining*

The permanent lining comprised three trapezoidal SFRC segments for the crown and sidewalls, and a flat invert segment with conventional reinforcement. The LEM, developed with Herrenknecht, was purpose-built to install these segments efficiently in a mined environment.

Unlike TBM tunnels, where grouting is simultaneous with ring building, this approach required several rings to be built first, followed by gravity-based backfill grouting from invert to crown—without pressure. This sequence introduced key design considerations:

- Ring Stability: Rings had to support their own weight prior to grouting.
- Buoyancy: Grout rising around unfilled voids could lift segments. This was mitigated by fully grouting the invert before installing side segments.
- Staging: Grouting was done in two stages—up to the axis, then to the crown—with a minimum compressive strength required before the second stage.
- Tolerances: The segment geometry required tight control of ring build tolerances to ensure structural integrity and alignment.

The LEM ring consists of four segments: an 8-ton flat invert (S1), two 6-ton trapezoidal SFRC side segments (S2 & S3), and a 6-ton rhomboid crown (S4). A 60 mm taper, in line with ITA guidelines, was adopted to accommodate horizontal curves. Vertical alignment was managed through packing.

Figure *3* below provides a 3-dimensional view and the left and right ring geometry.

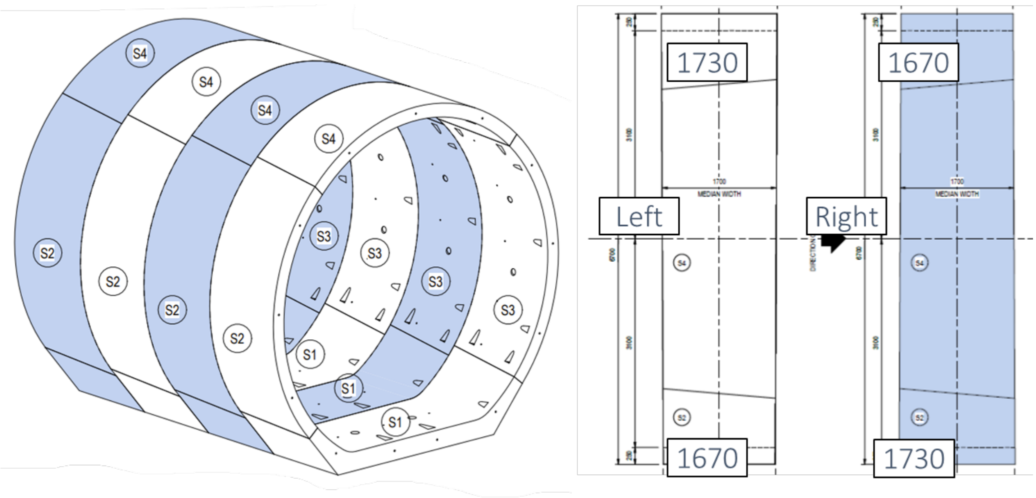

Figure 3. Ring design

2.3 *The solution taken into delivery*

The final design solution was the result of the efforts of the integrated design, manufacturing and construction. There were 3 main components:

- Temporary works / pre-work ahead of the LEM
- Ring building / gasket compression
- Backfill

Figure 4 and Figure 5 below show the complete solution developed for the LEM process

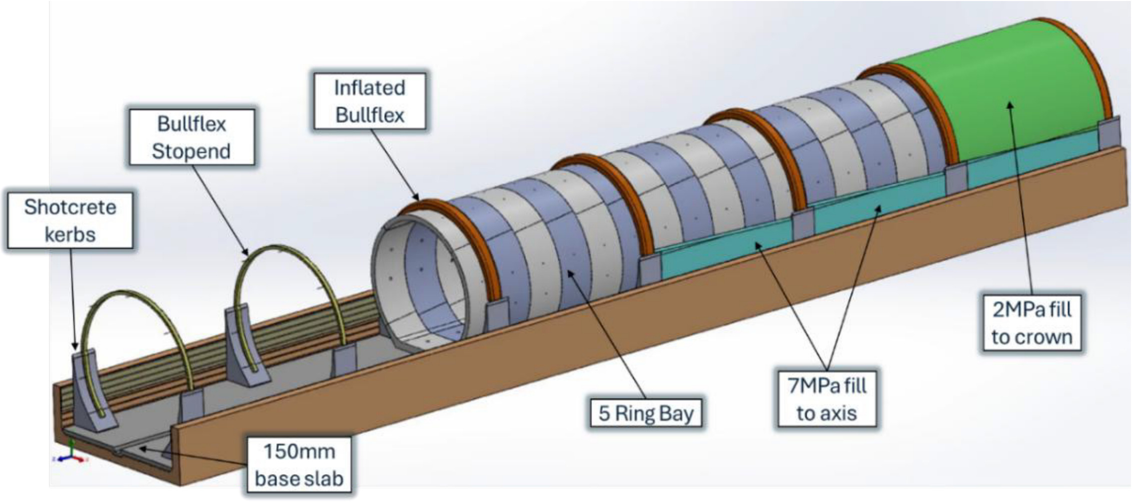

Figure 4. Segmental lining process overview

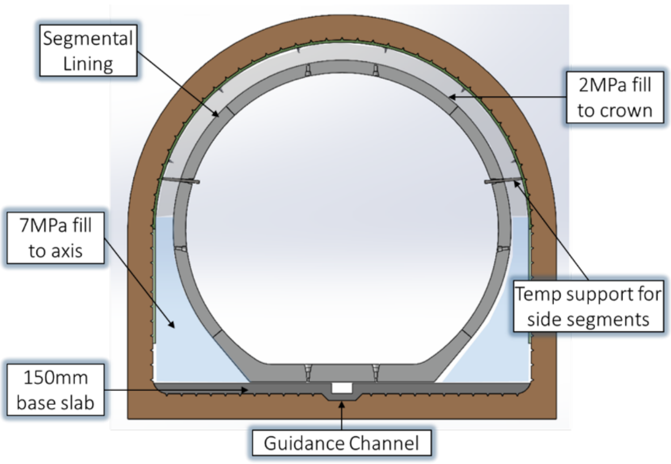

Figure 5. Segmental lining cross-section

2.3.1 *Temporary works / pre-work ahead of the LEM*

Three key elements were required to prepare the tunnel for LEM operation: the base slab, Bullflex stop-ends, and kerbs construction.

The base slab, developed in early design workshops with Herrenknecht, served multiple purposes: providing a level running surface for the 200-ton LEM, supporting the segment rings with 20 mm HDPE packers, resisting gripper forces, and guiding the machine via a cast-in channel. Alternatives such as steel rails were explored but proved costly and less effective under combined load and alignment constraints. The final concrete solution was cost-effective, quick to install, and allowed precise LEM steering via dual chassis.

Bullflex bags provided ring support during gasket compression and served as stop-ends for staged backfilling. Chosen for their proven performance in TBM launch applications, the bags were custom designed to span the tunnel arch. A full-scale tunnel trial validated their suitability.

Shotcrete kerbs were installed to form a consistent profile for Bullflex seating. After considering slipform, precast, and in-situ options, a ply-formed, mesh-reinforced shotcrete solution was adopted for its simplicity, adaptability, and integration with other ongoing works—despite some challenges with ventilation and work sequencing.

Figure 4. Temporary works ahead of LEM

2.3.2 *Ring building / gasket compression*

The LEM was developed with Herrenknecht to perform three core functions – to build the segmental ring, compress the gaskets and advance to the next position.

The LEM was purpose-built to install gasketed precast segments within the confined geometry of a mined tunnel. Its design integrated several systems to manage segment handling, alignment, gasket compression, and machine propulsion with precision and reliability.

The segment handling system comprised three main components. Segments were first transferred from the Multi-Service Vehicles (MSVs) by a segment crane, which rotated and positioned them onto the segment feeder. The feeder then advanced each segment into position for the segment erector, which lifted, placed, and manipulated the segments to construct a precise and watertight ring.

Crown-mounted hydraulic grippers provided the necessary reaction force to stabilise the machine during ring assembly. These grippers anchored the LEM to the primary lining, allowing controlled application of internal forces during segment placement and gasket compression.

Gasket compression was achieved using four pairs of hydraulic cylinders strategically positioned around the ring. These applied the necessary force to compress the circumferential and radial gaskets, ensuring watertightness at the joints. The two invert-mounted cylinders served a dual function, also acting as propulsion units to advance the LEM to the next build location once a ring was complete.

Together, these systems enabled the LEM to operate efficiently within the constraints of a mined tunnel environment while achieving the precision required for gasketed segmental lining.

Figure *5* and Figure *6* below provide an overview of the key components of the LEM.

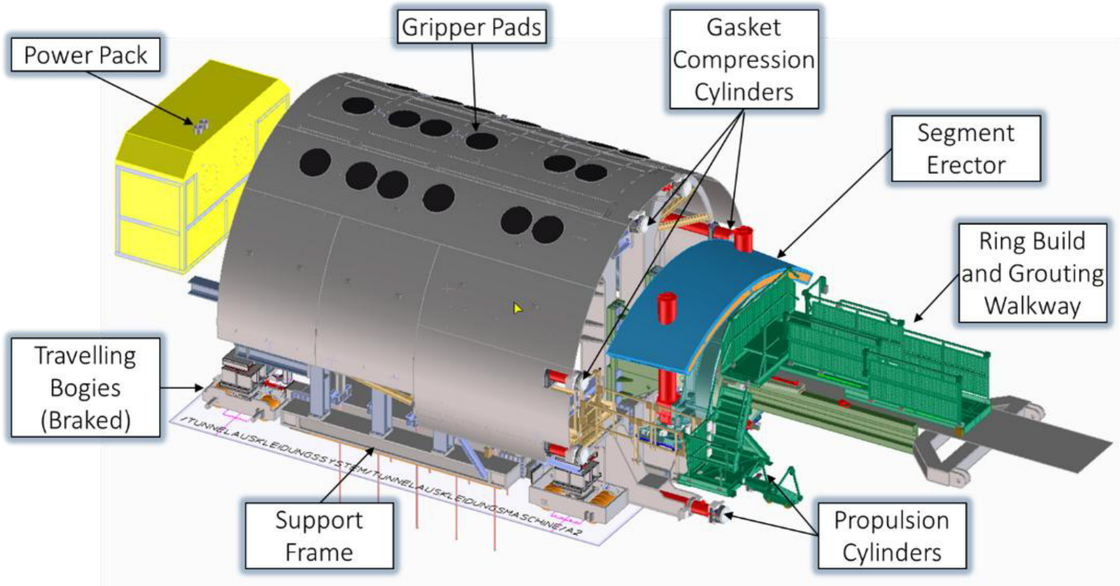

Figure 5. LEM sheild

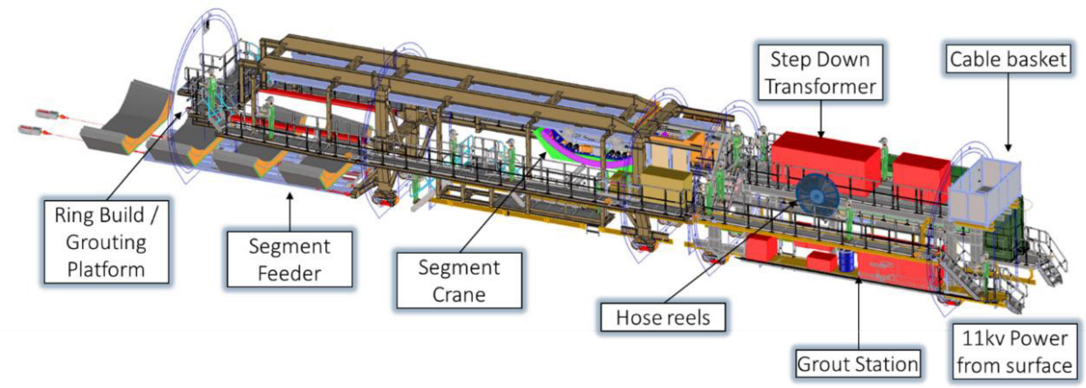

Figure 6. LEM gantries

2.3.3 *Backfill / grouting operations*

The ideal scenario was to identify a single grout product that could meet all the performance requirements for the LEM's operations. However, due to the differing functional demands, this was refined to two grout types covering three key applications:

- Invert Grout required high early strength (20 MPa), shrink compensation, and high flowability to provide a stable base for ring building and accommodating early loading. The selected solution was Masteroc MG01, which offered the necessary strength and placement characteristics soon after mixing.
- Bullflex Grout needed to be pressure-stable, high strength, and shrink-resistant to ensure reliable sealing at the stop ends. A blended grout supplied by a commercial partner was used, based on a standard base mix without retarder, enhanced with additives to stabilise flow, control shrinkage, and improve pressure response.
- Backfill Grout targeted 7 MPa compressive strength, with low shrinkage and bleed characteristics. The same blended grout base was used, this time with a retarder added to delay hydration, ensuring controlled placement behind the segment rings. Sodium silicate was introduced as a secondary component to accelerate setting and gel the grout in situ.

To support these operations, Gantry 2 of the LEM was developed specifically for grouting. It housed grout tanks, pumps, pig catchers, control panels, and a fully integrated system for storing, dosing, and delivering chemical additives. This configuration enabled continuous and controlled grouting in parallel with ring building, improving productivity and overall construction efficiency.

3 CONSTRUCTION PERFORMANCE

Construction of the segmentally lined spur tunnels presented several unique challenges that required adaptation and continuous improvement throughout the works. Although the LEM ring build shared some similarities with traditional TBM methods, the absence of a tail can, the flat invert, and the tapered geometry introduced new complexities. Building accurate, tight rings required precision in placement and sequencing, particularly in managing gasket compression and ring alignment within the mined tunnel profile. Achieving consistency in ring construction was a steep learning curve, especially in the early phases.

Flowable grout, used for backfilling, initially caused segment movement and leaks through minor imperfections. These performance issues led to the adoption of sodium silicate dosing, which enabled the grout to gel rapidly after placement, reducing the potential for leakage and helping to stabilise the rings.

Another challenge was the variability in the pre-mixed grout supplied from the batching plant. Inconsistent mix properties were observed, which affected both productivity and quality control. In response, a remixing system was established on site to improve uniformity and reliability. This gave the project team greater control over grout consistency, particularly when managing additives and maintaining performance tolerances.

Despite these challenges, the project successfully delivered 1.5 km of segmentally lined tunnel. The use of precast segments offered several advantages over conventional in-situ concrete: improved safety by shifting labour off-site, enhanced finish quality, and faster installation with reduced curing delays.

The LEM was designed to construct six rings per 24-hour period, a target achieved in the latter stages of the first drive. At the time of writing, early results from the second drive indicate that production rates are on track to exceed this benchmark.

4 CONCLUSION AND LESSONS LEARNT

The completion of the segmentally lined mined tunnels on the Western Tunnelling Package represents a significant achievement. Delivering this outcome required sustained effort, continuous innovation, and close attention to detail. The project team navigated numerous technical and logistical challenges to implement a first-of-its-kind precast lining system in a mined horseshoe tunnel. The result is a high-quality, durable, and watertight tunnel structure that demonstrates the viability of this approach in complex underground environments.

Three common questions arise when reflecting on the LEM and the segmental lining system: Was it worth it? Would we do it again? And what would we do differently? Despite operating under the constraints of a fixed-price D&C contract where innovation is often limited the project team succeeded in delivering a cost-effective system. The development and deployment of a gasketed precast lining within an excavated tunnel set a new benchmark for mined tunnel construction. Its successful implementation opens the door for similar solutions on future projects with comparable conditions.

The experience gained on this project positions the team well for future rollouts. Having refined the methodology and improved productivity over the course of the works, the system now presents a compelling alternative to conventional cast-in-place solutions. With early integration of lessons learned particularly in planning and design the approach has the potential to deliver both time and cost savings on other projects.

Looking ahead, two key areas have been identified for improvement: ring geometry and grout supply. The 60 mm left/right taper and flat invert created alignment challenges, particularly on tight curves, and strict adherence to ITA guidance proved unsuitable in this context. A more flexible approach to ring geometry linked to tunnel alignment should be explored earlier in future projects. Additionally, self-performing grout mixing on site proved invaluable for ensuring quality and maintaining production. Controlling this process from within the team allowed greater responsiveness to changing conditions and should be considered a core component of future deployments

The completed tunnel is shown Figure *7* below.

Figure 7. Completed segmentally lined tunnel