

Lord of the rings

25 February 2021

A new ring-build system is said to offer health and safety gains, but also cuts ring completion times by around a third - bringing significant cost savings. George Demetri reports

Recent years have seen the technology associated with tunnel boring machines (TBMs) make huge advances. This is particularly true with the use of reinforced concrete segmental tunnel linings which create a rigid, self-supporting structure to accommodate ground loadings.

Typically, they comprise a sequence of circular rings made up of concrete segments. These can either be interconnected with bolts or dowels – or have no physical connectors at all: boltless universal rings are not new and there have been many instances of their use. Rings made up of trapezoidal segments are also not new and have been used on numerous tunnels of various diameters globally. But these have been achieved using bolts. A ring design comprising unbolted trapezoidal segments had not been achieved – that is, not until quite recently.

The use of a boltless trapezoidal lining on the £416m (US\$567m) west section of London's Thames Tideway Tunnel is the world's first-ever application of the technology. Its innovative nature was recognised at the Ground Engineering Awards 2020 where it won the award for Technical Excellence.

The Boltless Trapezoidal Ring design – essentially the brainchild of Colin Eddie of CECL Global and Ivor Thomas of the BAM Nuttall, Morgan Sindall and Balfour Beatty (BMB) joint venture which is delivering the west section of the new tunnel – has been in development since 2015. Rather like Leibniz and Newton with the discovery of calculus, both men had the same idea and came together in the joint venture.

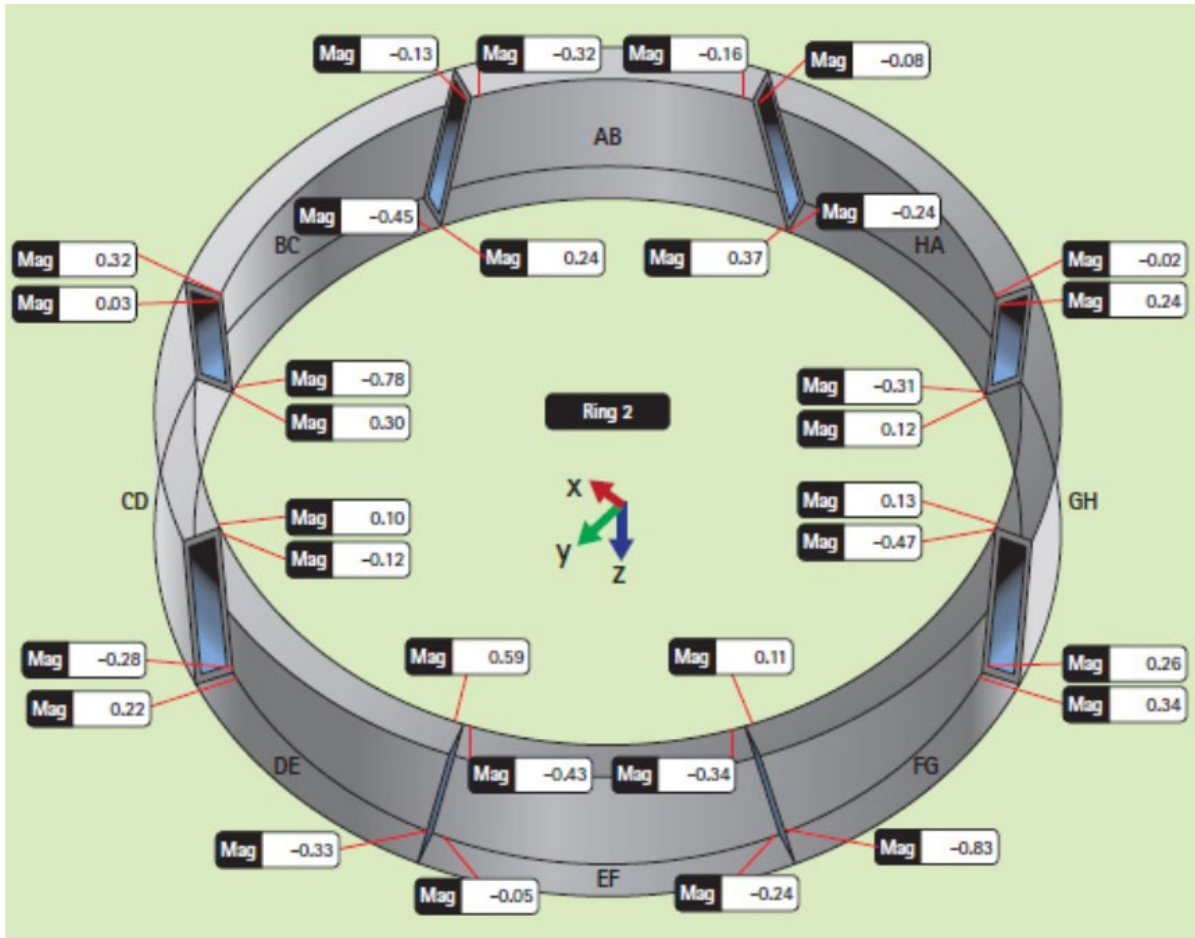


The existing surface will be covered by an in-situ poured concrete lining PHOTO: ABSOLUTE PHOTOGRAPHY LTD

The requirement grew out of a Tideway review of the construction processes for the west section of tunnel during which several alternative design options for the ring design were discussed with the client with a view to delivering value and performance improvements.

The west section contract covers the main tunnel alignment and associated structures between the Acton Storm Tanks and Carnwath Road Riverside work sites. At 7km long and with a finished internal diameter of 6.5m, the main tunnel follows the path of the River Thames from Carnwath Road in South West London to Acton Storm Tanks in the west of the capital.

Tideway's TBM-built segmental tunnel primary lining is critical to the success of the project, with tail-skin grouting employed to provide full contact between the ground and the lining. A successful tunnel lining enables the operational objective of the project to transport raw sewerage to the treatment plant. It resists imposed loads and ensures ground stabilisation and deformation control, durability and constructability.



The Boltless Trapezoidal Ring was installed within the predicted sub-millimetre tolerances

Development Process

Thomas tells Tunnels and Tunnelling: “Working with the team at Tideway, we explored how different segmental ring designs could improve the project. We decided on the Boltless Trapezoidal Ring design due to its noticeable improvement in terms of construction, health and safety, overall performance and the potential for improving quality, all resulting in programme and cost savings.”

Nearly 7km of tunnel on Tideway was built using boltless trapezoidal segments in what must be seen as a resounding vindication of the technology. The average time to build a ring on Crossrail (which used conventional left and right, bolted universal segments) was around 32 minutes; using the boltless trapezoidal system on Tideway resulted in ring-build times of around 20 minutes, with the fastest achieved being 12 minutes. Faster ring build is clearly one of the system's main benefits, but there are many others.

As an alternative system to the universal bolted ring, the tapered boltless trapezoidal rings have splayed longitudinal (radial) joints that are designed to make the rings more rigid than those using conventional segments

where joints are parallel to the tunnel axis. The programme used trapezoidal segments having a long side of 3,092mm and a shorter opposite side of 2,784mm.

Each segment had a 50mm diameter HDPE rod half-embedded on one of the radial sides parallel to the tunnel axis, and a contoured recess on the opposite side so when the ring is assembled, the rod on one segment engages with the corresponding recess in the adjacent segment. This is designed to achieve a high precision of assembly and ring quality which, says Thomas, is not typically seen with the bolted universal ring. Steel-cored HDPE dowels located on the long (circumferential) sides further facilitate the placement process. Watertightness is achieved by the inclusion of a high-performance HDPE gasket and the absence of bolt holes.

Benefits

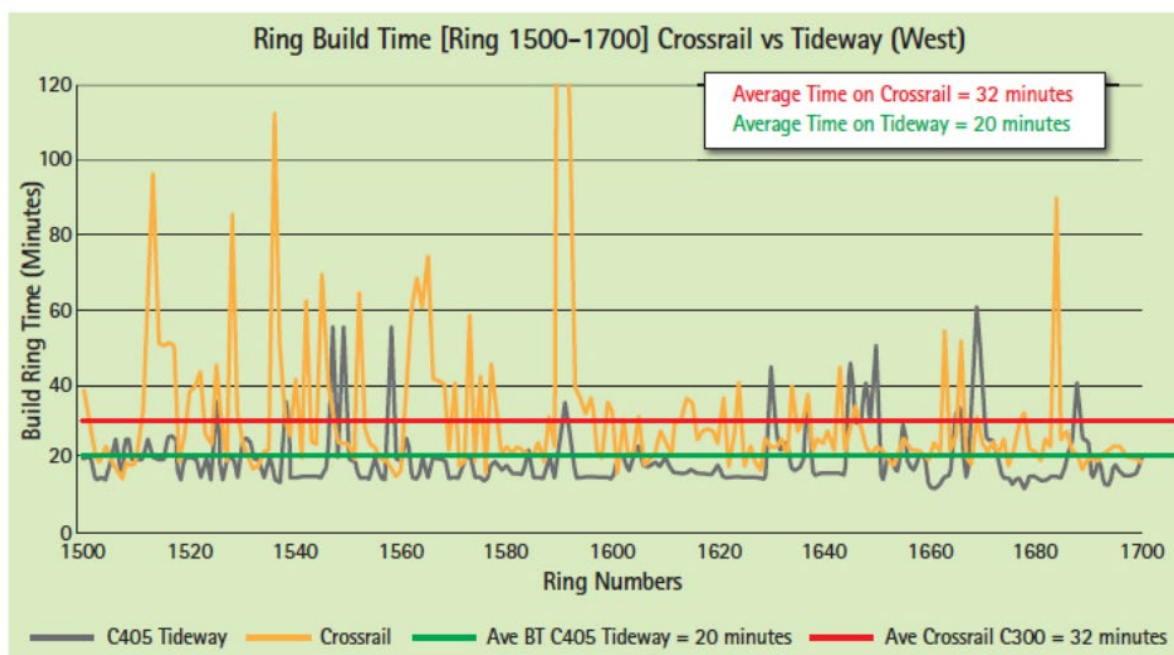
Health & Safety

Mechanical fixing of segment bolts and their removal can be hazardous – tunnellers need to stretch from TBM work platforms during installation and run the risk of hand-arm vibration (HAV) injuries resulting from the bolting process. Other health risks associated with manual handling can include repetitive strain injury (RSI) and trapped digits. These dangers are claimed to be eliminated when using a boltless system as personnel are removed from the build area – up to 3m away – thereby exposing fewer to potential danger.

Performance

The Boltless Trapezoidal Ring system is designed for improved watertightness due to the absence of bolt pockets where holes can provide a potential path for water ingress, as witnessed on past projects, such as the Dartford Cable Tunnel, London. Eliminating bolt holes can not only reduce the risk of drying shrinkage cracking, but also removes the labour-intensive operation of having to fill them once the ring is erected. According to the Joint Venture, the boltless trapezoidal system proves that bolts in tunnel linings have no real structural function; their capacity to improve lining performance by restricting in service rotation/moments is also limited, while the absence of bolt pockets gives better stress distribution and control of cracks. The system used on Tideway obviated the use of 64,880 bolts, assuming two bolts per segment; this also removes a potential future corrosion problem and so helps contribute to the attributed 120-year design life of the ring/segment. Boltless trapezoidal rings are also designed to reduce secondary loading during installation by optimising the segment geometry; this is aided by the guide rods and the centring dowels. Being more or less the same size and weight, the handling and stacking of trapezoidal segments is claimed to be more straightforward than universal ring segments.

Says Thomas: “The system does not make use of dedicated left- and right-handed rings and this results in fewer moulds than would be required for a universal ring system. The sum of this more straightforward process for ring erection can be translated into benefits in the overall production rate.”



Crossrail v Tideway west section ring-build comparison

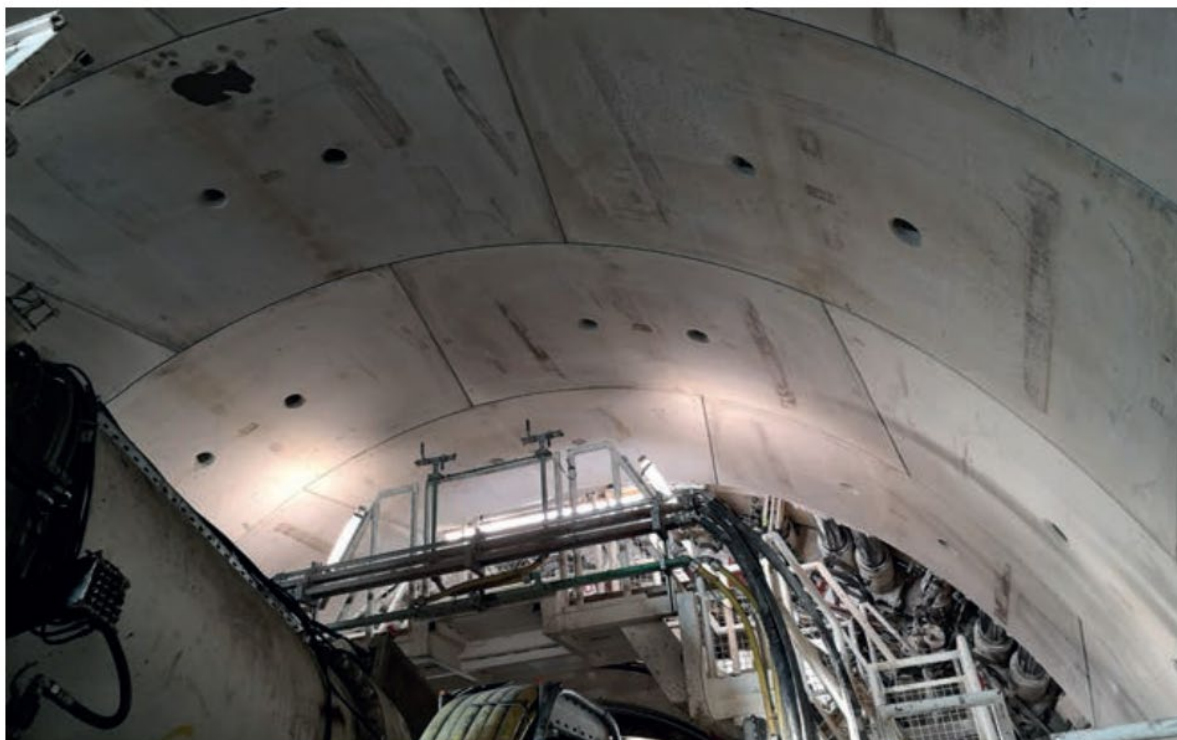
He adds: "There is no need to install a key piece at height to be fully safe as is the case with the universal segmental ring. The boltless trapezoidal lining allows a safer configuration, where the last segment erected is always in the top half of the bore."

The system is claimed to improve structural performance, watertightness, installation speed, construction safety, manufacturing efficiency and durability while reducing net implementation costs.



The tunnel structure was created without the need for left- and right-hand segments PHOTO: ABSOLUTE PHOTOGRAPHY LTD

Summing up the success, joint venture Design Manager Eoin Cheevers states: "The Boltless Trapezoidal Ring design improved efficiency on ring-build quality, temporary works and ensured safe working areas could be kept tidy during assembly. The elimination of bolt pockets in the segmental lining eliminated weak spots for potential leakages and operatives were always in a safe area when constructing the tunnel ring. The speed of ring building improved greatly compared to other projects. From the performance records, the quickest ring build on the project was 12minutes."



TBM rams pushing off the installed segments

The end result of all this is that everything is in place well within sub-millimetre tolerances and with a smooth finish with no protruding lips, gaps or steps. Unfortunately, the pristine appearance will not last as the tunnel will be lined with in-situ concrete on Kern formwork to ensure a seamless surface with minimal friction to facilitate sewage flows. But perhaps that is a price which, in the long run, is worth paying.