The Lee Tunnel - TBM Launch

one of the most complicated TBM launches ever undertaken to prevent 16m cubic metres of storm water and sewage being discharged annually

by Morgan Anamoah & Martin Feeney

Thames Water has embarked on a programme to improve London's sewer network which will increase storage capacity and avoid the need to discharge combined sewage into both the River Thames and the River Lee. Lee Tunnel is the first section of the London Tideway Tunnels Programme which forms a major part of this improvement scheme. The Lee Tunnel Project is a 7.2m internal diameter and 6.9km long storage/transfer tunnel from Abbey Mills Pumping Station to Beckton Sewage Treatment Works (built within a predominantly chalk strata). As part of the £635m Lee Tunnel scheme, the tunnelling works requires a Tunnel Boring Machine (TBM) and this article details the launch procedure of the TBM.

TBM being lifted into the Overflow Shaft - Courtesy of Thames Water

Background

The Thames Water London Tideway Improvement Scheme, of which Lee Tunnel forms part, is designed to return storm discharges into both the River Thames & River Lee back to acceptable limits (as set out by the Urban Wastewater Treatment Directive).

The Lee Tunnel project consists of a 6.9km long 7.2m internal diameter tunnel, 3 (No.) 75m deep shafts at the Beckton Sewage Treatment Works (STW) and 1 (No.) 70m deep shaft at Abbey Mills Pumping Station.

Based on reference design undertaken by Thames Water, the choice of TBMs were limited to two types of tunnelling process, an Earth Pressure Balance TBM or a Mix Shield Slurry TBM. Following contract award and extensive detailed design by the Contractor, a Herrenknecht 8.85m diameter mixed slurry TBM was selected by the team. The TBM was designed and manufactured in Germany, and then dis-assembled and transported to site in suitable sections to comply with UK & European highway haulage requirements.

The fully assembled TBM is over 120m long and consists of the main shield section that contains the cutterhead, propulsion system and primary ring erection system (this is supported by 5 (No.) gantries that are pulled by the shield and contains the mechanical & electrical systems) and the required safety equipment for the tunnelling process.

Launch shaft

Thames Water had identified the launch of TBM as one of the most significant risks to the project. Early site investigation and design works had stipulated that the Overflow Shaft to be best suited to be the launch shaft (in part due to proximity to the River Thames).

The launch of the TBM could be undertaken in one of two methods, the first required the construction of a large launch chamber where the TBM could be fully assembled below ground. This required the construction of large forward or back shunts using sprayed concrete lining (SCL) construction techniques in high pressure groundwater zones in fissured geology connected to the river Thames. The

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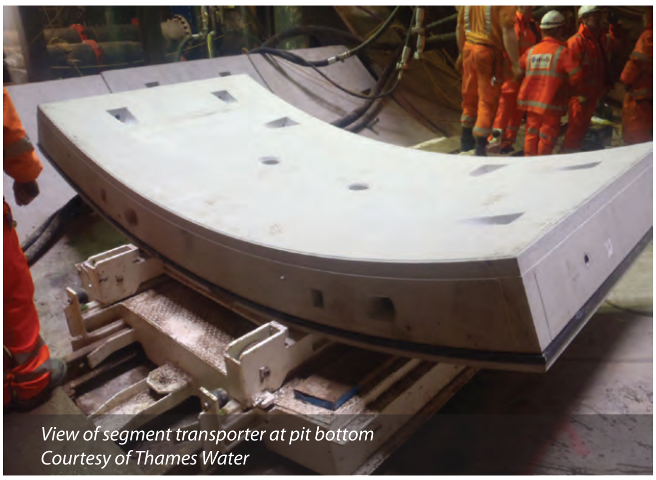
View of Overflow Shaft showing launch platform being installed over TBM - Courtesy of Thames Water


View of launch platform installation nearly complete Courtesy of Thames Water


Launch platform set-up complete with TBM control cab and units on the top level - Courtesy of Thames Water


View of segment transporter at pit bottom Courtesy of Thames Water

second required the TBM to be launched in a short format mode from within the confines of the overflow shaft, with the backup systems for the TBM being installed as the TBM advanced and constructed the tunnel.

After review, the team decided to launch the TBM from the overflow shaft in the 'short launch mode' format, as this removed the high risks associated with the alternative method of constructing a SCL chamber in the high water bearing chalk geology. The chosen method for launching the TBM required careful design and planning to enable all the equipment and systems (required to operate the TBM) to be installed within the confines of the shaft.

Value and programme engineering

Following the selection of 'short launch mode', a review of methodology and programme were undertaken to further improve on the installation efficiency, to take advantage of size of site set up to enhance delivery, reduce safety risks and gain programme benefits. The initial proposal was for the TBM to be assembled in sections at the bottom of the overflow shaft after the shaft had been constructed.

This required all the sections of the TBM weighing up to 150 tonnes to be lowered and assembled at the shaft bottom, which itself had inherent risks. The review identified that significant benefits were to be achieved if the TBM was to be assembled on the surface and lowered into the shaft. The benefits were namely:

- Assembling in open space as opposed to a confined space at depth (a major safety concern with the amount of welding necessary), reduction in handling of components.
- Reduced safety risks.
- Significant time saving.

There were only two cranes commercially available which could undertake the lift in the full assembled mode. The limited availability of the crane with the long lead time posed a significant risk to programme. The safety risks to undertake such unprecedented tunnelling challenges were stark but considered achievable with effective management.

Temporary works

To enable the TBM to operate in 'short launch mode', all essential equipment to facilitate production had to be in place but this time housed at the pit bottom. However, in this situation, there was limited space available in the pit bottom after the installation of shaft exit/launch eye, shove frame, strengthening structures and required access system. With the shaft 75m deep, the only viable option left to ensure safe operation of the numerous MEICA systems was to set up levels of temporary working platforms within the shaft. The network of MEICA pipes and cables, connecting their sources to the TBM, are usually referred to as 'umbilicals'.

Conscious not to lose any of the programme gains from the value engineering, modular prefabrication was adopted for the temporary launch platforms. The design had to be thorough due to the presence of other structures within the shaft. The two floors of steel structure straddling the TBM launch cradle were fabricated, pre-assembled to ensure fitness, dis-assembled and then transported to site. When the shaft works were complete, the components were re-assembled in a dedicated zone on the site surface and craned down in modules for fixing within the shaft. By the adoption of this strategy, the programme targets were achieved, and by eliminating the requirements to work at height for individual components, significant safety risks were avoided.

Launch sequence

The launch sequence had to be carefully co-ordinated to ensure all the required equipment and operating systems were installed in the correct order. The basic TBM launch sequence was as follows:

- Preassemble TBM on the surface.
- Install launch seal at the shaft bottom.
- Install Launch rails.
- Assemble TBM and lower to shaft bottom and push into launch eye.
- Install shove frame.
- Install launch platforms.
- Install Umbilicals.
- Install mechanical & electrical equipment on the launch platforms.
- Commission and ready to launch.
- Launch and construct 20m of tunnel.
- Install temporary launch gantry to assist with handling of slurry hoses and umbilicals.
- Advance TBM and construct 140m of tunnel.
- Install TBM backup gantries and commission TBM fully.

Tunnel consumables (segments, grout and greases) and logistics

The segments for the project are produced in Ridham, Kent and transported to site on flat bed trailers with the circumferential surfaces horizontal (upright on their side) to reduce induced stresses in the segments. The TBM segment handler and erector accept segments with those surfaces horizontal. To assure safety of personnel, structural integrity of the segments and the uninterrupted flow of segments, the Segment Tippler, which is used to turn the segments for the launch phase, was installed on the surface.

In a fully constituted mining setup, pipes would be transported on a specially designed and fabricated cradle secured onto flat bed bogies. To manage the confined space within the shaft and take advantage of the additional space generated as the TBM progresses during the launch period, the logistical effort was set up into three phases:

- ***Phase 1***: When the TBM was less than 30m away from the shaft, temporary bogies were used to transport materials (including correctly oriented segments) and pipes to the working area in the shield. These bogies have been specifically adapted by the manufacturer to suit the launch phase. The bogies were mounted on and guided by the rails and move in and out of the tunnel by winch systems fixed to the TBM and the shaft. To ensure safety, the bogies were designed to come to a stationary halt within 5 metres by friction (in the unlikely event of detachment).

- ***Phase 2***: To provide safe access and a working platform to high levels to manage the umbilicals and segments, a temporary platform was introduced. Gantry G1.1 (as it was referred to) was placed at the rear of the TBM only when the TBM had advanced sufficiently forward to provide adequate space for the pit bottom to operate effectively. The gantry had two working platforms: the lower deck had two safe working zones with lifting tackles to install and manage slurry and service pipes. The upper deck was used to align the flexible slurry lines from the head of the TBM to connect to the steel pipes at the lower level. Also at the upper deck, the MEICA umbilicals were fixed to the monorails and extended out as the TBM advanced.

- ***Phase 3***: When the TBM had advanced sufficiently, assessed to be after 30m, a bogie was introduced. The bogie was winch operated with vulcanised wheels and moved along the invert of the tunnel. To assure safety and ease of operation, the bogies were guided by the installed rails.

In full production mode the TBM is capable of advancing 9m before the extension of the slurry line is required. In the launch mode, to avoid handling difficulties, shorter lengths (6m) of pipes were used and therefore extended every third ring. Tunnel cooling water,

View of temporary TBM Gantry in operation
Courtesy of Thames Water

A pre-assembled TBM Gantry being transported to launch site
Courtesy of Thames Water

View of the surface of Overflow Shaft showing a TBM Gantry being lifted into launch shaft - Courtesy of Thames Water

View of TBM Gantries installed in tunnel
Courtesy of Thames Water

wastewater and air lines were similarly extended after every third shove (each ring is 1.7m long).

Grout was pumped from a tank located at the pit bottom via 50mm diameter steel pipes. For safe and easy access for maintenance, grout pipes were placed on the lower section of tunnel brackets (closer to the invert). Two additional lines were installed for the additive to the grout mix.

The length of all service pipes were set at 6m and were changed during a 'service extension' period within the production cycle.

Tunnel ventilation bagging was secured to a 6mm wire rope fixed to the tunnel shoulders. The 600mm diameter temporary ventilation pipe was installed from the upper deck of Gantry G1.1.

Logistics buffer yard

It had been noted during the planning stages that the TBM production rate during launch phase would be low. Advantageous to the project was the availability of surface land areas, within the Beckton STW. A logistics buffer yard was set up to provide uninterrupted supply of materials to the TBM.

Ordered parts, fittings and tunnel consumables were sorted, prepared and only forwarded on to the launch shaft when required.

Management of umbilicals

There were three cassettes of essential umbilicals to be prepared, installed and managed on the TBM temporary launch platforms. Each cassette housed hydraulic, electrical and control cables containing approximately 200m of cables placed in a figure-of-eight shape (to facilitate feeding out) and secured.

Systems of chain hoists mounted on monorails were used to control and manage the feeding out of cables as the TBM advanced.

To avoid over stressing the umbilicals, the feed process to the TBM had to be carefully and safely orchestrated at three locations:

- Firstly, at the connection to the relevant power pack, transformer or pump on the a level above the cassettes.
- Secondly, at the cassettes location where they had to be raised and released from the figure-of-eight position before being allowed to move.
- Thirdly, at the tailskin area where as the TBM advanced with each ring, monorail systems within the crown of the tunnel and supporting the umbilicals had to be extended.

Shove frame and temporary tunnel

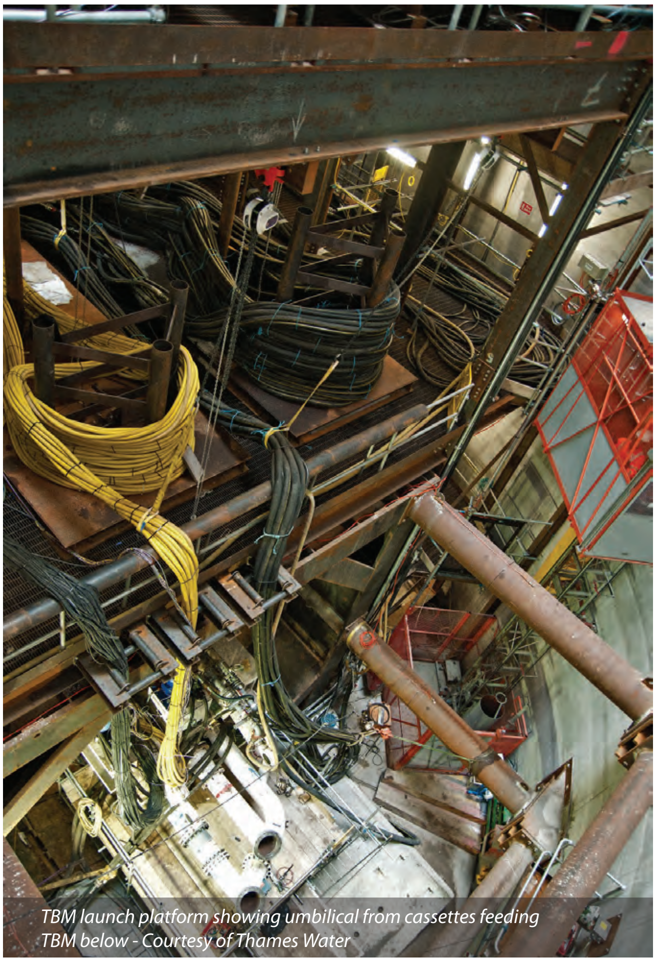
During normal production, the TBM advances by pushing the shove rams against the last ring built. In the launch phase, the reaction for the shove rams was provided by a fabricated steel frame. The designed shove frame weighed in excess of 150 tonnes and the stresses generated as the TBM excavated were in excess of 4000 tonnes of thrust as the TBM advanced through the shaft wall.

As the stresses generated were much higher than concrete segments can sustain, the first ring was therefore made of fabricated rolled steel sections.

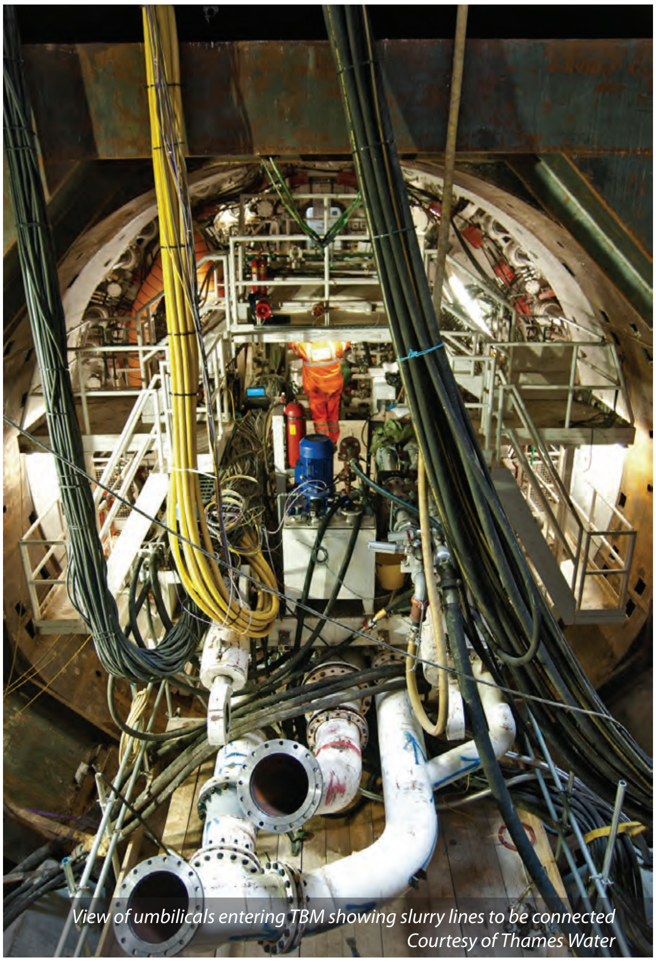
To further dissipate the stresses generated, reinforced concrete segments to build the rings were used for next 5 rings. To ensure good levels of safety, strain gauges and load cells were installed at specified locations on the shove frame and shaft to confirm that the 70MN of Ultimate shove load calculated was never exceeded.

Creating a watertight seal for TBM break-out

With a potential 8 bar of groundwater pressure and the presence of fissures within the chalk geological strata, ensuring water tightness as the TBM broke out of the Overflow Shaft was considered to be one of the highest risks to the success of tunnelling.



TBM launch platform showing umbilical from cassettes feeding TBM below - Courtesy of Thames Water



View of umbilicals entering TBM showing slurry lines to be connected Courtesy of Thames Water

Ground improvement works were undertaken prior to the TBM launch to create a grout block at the start of the tunnel route to stem fissure flows.

To further ensure this water tightness, a special launch seal was designed. This seal consisted of three rows of wire seal brushes similar to those used on the TBM. These wire seal brushes were continually injected with Condat WR89 to enhance the seal as the TBM launched and broke out through the shaft lining.

When the first permanent segmental ring was constructed a 'Proserve' inflatable seal was used to ensure the annulus between the shaft launch eye and the external face of the ring was completely sealed. The launch was completed without any water ingress into the Overflow Shaft.

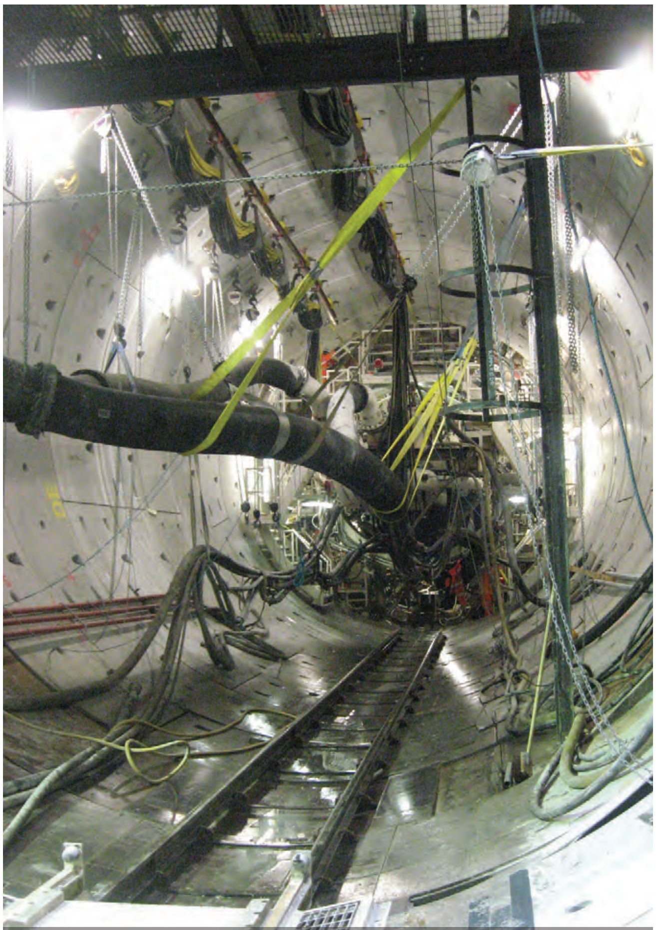
Conclusion

The Lee Tunnel TBM launch was one of the most complicated ever undertaken, in fissured ground connected to the river Thames, at groundwater pressures in excess of 7 bar. Due to the planned approach and skill of the operatives the launch was completed successfully.

The Editor & Publishers would like to thank the following for providing the above article for publication (listed alphabetically):

Morgan Anamoah, Senior Construction Engineer with CH2M HILL, Nick Butler, Tunnelling Construction Manager with Thames Water, John Corcoran, Tunnelling Manager, Martin Feeney, Chief Mechanical Engineer, Rafik Karouzene, Senior Tunnelling Engineer, all with MVB Joint Venture, and Alastair Walker, Project Engineer with Thames Water.

The authors thank Thames Water for permitting the publication and presentation of this paper.



TBM at Ring 19 showing management of umbilicals and slurry pipes
Courtesy of Thames Water