The Lee Tunnel

London's deepest sewer - the main TBM drive and tunnel lining

by Alastair Walker

Sir Joseph Bazalgette's 150 year old sewerage system was designed for a population of 4 million (1.5 million more people than at the time); however London's population is now approaching 8 million. The Lee Tunnel provides a solution to the under-capacity network and alone will tackle 40% of all stormwater flows currently entering the River Thames. The current plan for the Thames Tideway Tunnel (TTT) is for the proposed 'super sewer' to connect into the Lee Tunnel at Abbey Mills to form one continuous stormwater tunnel from West to East London. TTT will add a further 25km to the 7km Lee Tunnel. It is 4 years since the £635m contract to construct London's deepest ever tunnel was awarded to Morgan Sindall, VINCI Construction Grands Projets and Bachy Soletanche (MVB joint venture). The project has constructed the main 7km tunnel boring machine (TBM) drive and 5 shafts to depths up to 86.5m, and the connection and surface works at Abbey Mills sewage pumping station and Beckton sewage treatment works are well underway.

View along the Lee Tunnel - Courtesy of Thames Water

Purpose

The Lee Tunnel project, when commissioned, will intercept 16 million tonnes of untreated sewage which is currently discharged annually at the Abbey Mills combined sewer overflow (CSO), and will transfer the storm flows to Beckton sewage treatment works, rather than being discharged into the River Lee. The project is part of Thames Water's overall London Tideway Improvement Scheme, which is aimed at returning stormwater discharges into the River Lee and Thames back to acceptable limits in accordance with the Urban Wastewater Treatment Regulations 1994.

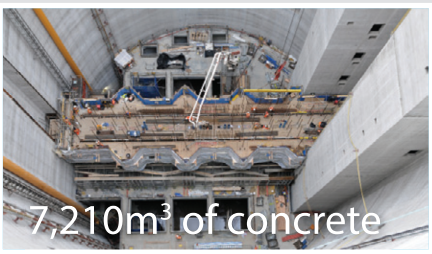
The main TBM drive

The main tunnel drive was constructed using a Slurry Pressure Balance System (SPBS) TBM and was completed in January 2014. Due to the significant depths (c.80m) and extremely high water pressures (c.8 bar) that would need to be managed whilst mining through the chalk, a SPBS was selected. The SPBS utilises a sealed cutterhead chamber, pressurised with chalk slurry that is capable of supporting the ground and groundwater pressures encountered during tunnelling.

The TBM tunnels forward using hydraulic rams to 'shove' off the previous tunnel ring that was constructed. The TBM cutterhead rotates using disc cutters and scrapers to excavate the ground. A rock crusher is used to break up the flints that exist in the chalk before the slurry and excavated material is pumped back to the surface for treatment and the recycled slurry is pumped back into the face to maintain pressure. After the TBM has completed advancing, the rams are individually retracted to allow precast, fibre reinforced, trapezoidal segments to be positioned using a 360 degree vacuum erector. The segments contain a waterproof rubber gasket that forms a watertight seal after all 8 segments are placed to form the ring. The advance cycle will then resume, with the TBM rams 'shoving' off the newly constructed ring.

Lee Tunnel partnership brings success

The slipformed, 40m wide and 70m high, dividing wall of the pumping shaft used:



and was completed by the MVB team in just 27 days.

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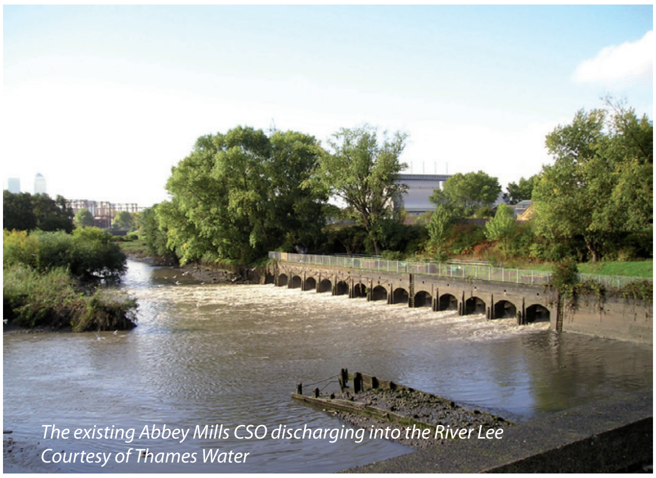
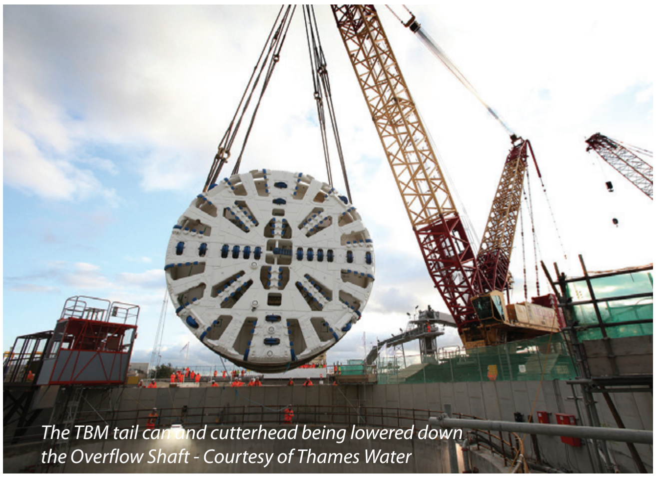
Morgan Sindall, VINCI Construction Grands Projets and Bachy Soletanche are working together as MVB, combining world-class expertise, together with CH2M Hill, to deliver the Lee Tunnel for Thames Water. An essential step in providing the capital with a 21st century sewerage system. www.mvbjv.co.uk

Watch timelapse footage of the concrete pour here:



The existing Abbey Mills CSO discharging into the River Lee Courtesy of Thames Water



The TBM tail can and cutterhead being lowered down the Overflow Shaft - Courtesy of Thames Water

Operatives position tunnel segments during the ring build Courtesy of Thames Water

Aerial view of the Lee Tunnel STP at Beckton STW Courtesy of Thames Water

The ring build construction takes place inside the TBM shield (tail can). The TBM excavates an 8.9m diameter passage through the ground and the outer diameter of the tunnel rings measures 8.5m. As the TBM advances the tunnel rings emerge from the rear of the shield through a set of brushes, which are filled with grease to maintain a watertight seal. The 200mm void between the excavated surface and extrados of the tunnel lining is then injected with rapid setting grout to reduce any surface settlement. In general, surface settlement is below 2mm.

At peak production the TBM constructed 144 rings/245m of tunnel in a 7 day period. This is a major achievement when you consider that this required 1,296 tunnel segments to be handled and placed, 32,400T spoil to be excavated, treated and removed from site and over 25 tunnel utility service extensions. The final line and level survey when the TBM arrived at Abbey Mills confirmed that the tunnel had been driven to an accuracy of 20mm in the horizontal and 60mm in the vertical.

Slurry treatment and muck away

The mixture of slurry and excavated material in the TBM cutterhead chamber is pumped back to the surface, where it is separated in the slurry treatment plant (STP). The spoil is removed from the slurry to be transported off site and the slurry is recycled and returned to the TBM. The STP is a further testament to the scale of the Lee Tunnel operation, with a plant footprint of 5000m^2, capable of managing peak flows of 2,000m^3/hour.

The separation process:

1. The slurry is first pumped into a rotating screen (Trommel) to remove all material greater than 8mm, which is sent to the muck stockpile.
2. Material less than 8mm undergoes centrifugal separation in a number of cyclones to remove all material greater than 2.5mm.
3. (a) The separated material is dewatered through vibrating screens before being sent to the muck stockpile.
   (b) The de-sanded slurry is pumped to storage tanks, where the viscosity and density of the material is closely monitored. If it becomes too high then the inlet to the tank is shut and fresh water and bentonite can be added to achieve the correct dilution before being returned to the TBM. The excess slurry is diverted to the filter presses.
4. 12 (No.) filter presses were used to dewater the excess slurry to produce cake that is sent to the muck stockpile and the removed water is recycled.

Lee Tunnel Planning Conditions dictated that all spoil material from the tunnel and shafts should be removed by river. This removed the need for 80,000 lorry movements. The STP is capable of producing a final cake with moisture content of less than 30% from the chalk slurry that is pumped out of the tunnel, which complies with the requirements of the Maritime Regulations. The spoil has been reused for capping landfill sites in Kent and Essex.

Geology

The tunnel has been constructed at depths up to 80m to provide a gravity head from West London after TTT is connected, to avoid existing underground infrastructure and also to limit tunnelling through the Thanet Sands.

Underlying the Thanet Sands are the chalk deposits. Due to chalk being water bearing and the presence of fissures within the rock, ground water pressures of up to 80 bar were expected, which is why a pressurised tunnelling system was selected. The chalk layer also contained a high number of flints, which caused significant wear to the TBM cutterhead and slurry system pipework. MVB undertook proactive monitoring so that plant and tools affected by wear could be changed and repaired without impacting production.

During the drive the TBM was required to tunnel through a geological fault that was discovered during the site investigation stage; the Plaistow Graben. This would bring the Thanet Sands into the tunnelling horizon. MVB managed this operation well, with less than 2mm surface settlement recorded.

An unknown geological feature was also encountered during the drive. The tunnelling team reported the presence of Thanet Sands and Upper River Terrace Deposits in the slurry treatment plant and subsequent borehole investigation identified this as a Pingo; a geological depression resulting from the last Ice Age. There have only ever been a few recorded cases of TBMs encountering Pingos.

Connection shaft

Shortly after the launch the TBM was required to mine into and through the Connection Shaft. One of the main risks associated with this operation was extremely high water ingress into the tunnel caused by a pressure differential as the TBM breached the shaft walls. The groundwater in the area of the connection shaft is contaminated. To exclude any potential contamination the shaft was backfilled and flooded with final effluent before the TBM entered under full face pressure.

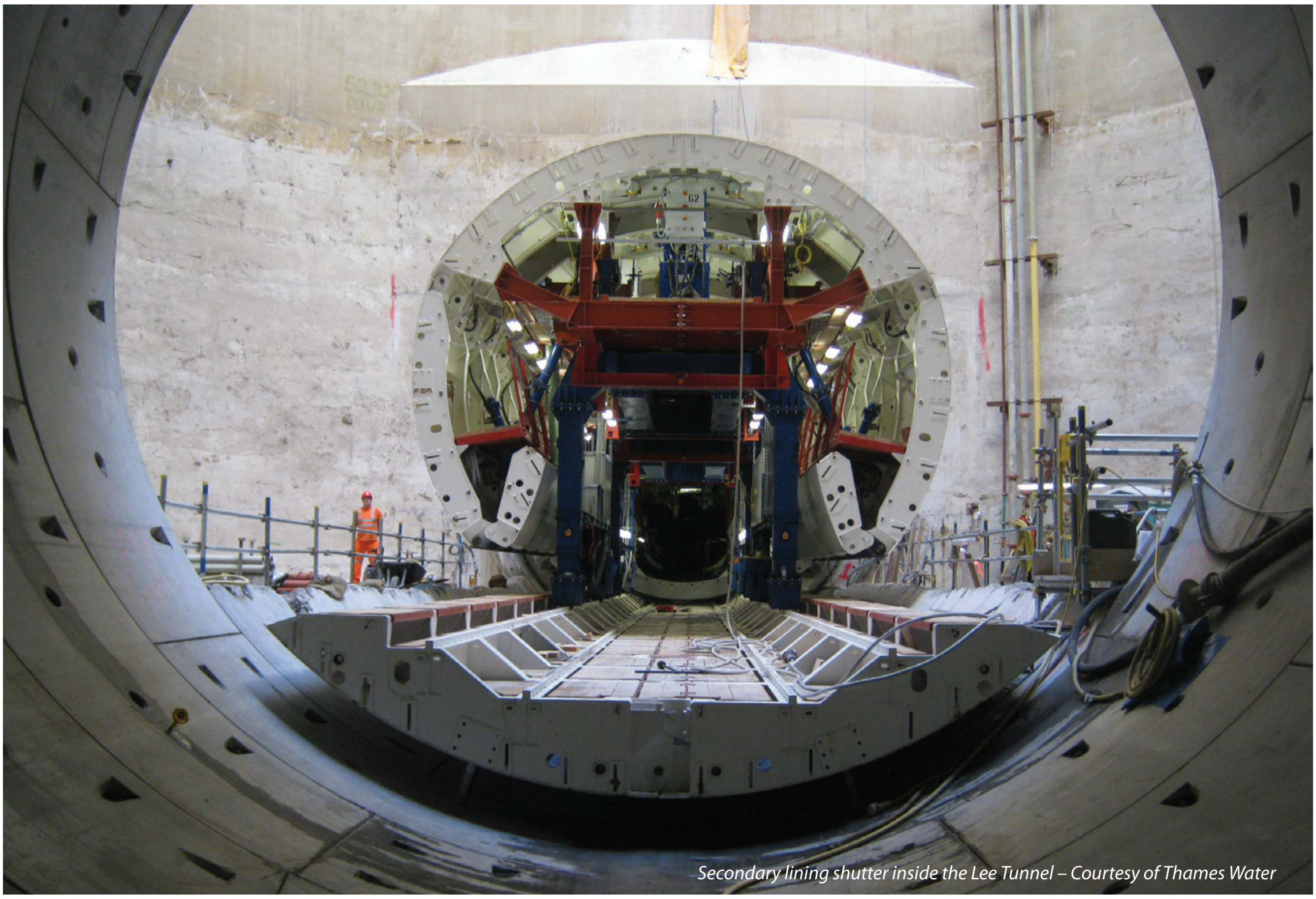
The crossing of the connection shaft was a success, with zero contamination ingress and marked important learning with regard to tunnelling through shafts in contaminated ground. The success of this operation led to MVB repeating the process for tunnelling into the two shafts at Abbey Mills.

The next challenge – secondary tunnel lining

The TBM has arrived at Abbey Mills and the complex operation of dismantling and removing the TBM and gantries from the tunnel has been completed. MVB is now embarking on the 56,000m^3 concrete pour required for the tunnel secondary lining.

The Lee Tunnel is designed with two linings; the primary lining constructed by the TBM using precast, fibre reinforced concrete

Aerial view of conveyor system used to load excavated material onto barges - Courtesy of Thames Water



Secondary lining shutter inside the Lee Tunnel – Courtesy of Thames Water

Breaking out tunnel in shaft at Abbey Mills after main tunnel drive completed - Courtesy of Thames Water

segments and the secondary lining, which will be a fibre reinforced, in situ concrete pour placed using a hydraulic shutter. Together the linings are able to resist ground loading, groundwater hydrostatic pressures and internal hydrostatic pressures exerted when the tunnel is operational, preventing any leakage into the chalk aquifer. The Lee Tunnel has been designed to withstand large cyclic loading created by the filling and draining of the tunnel.

Extensive surface trials have been completed to refine the placing and production of the secondary lining. The team is aiming to pour 2 (No.) 30m lengths of secondary lining every 24 hours. The concrete will be supplied from the dedicated Lee Tunnel concrete batching plant at Beckton STW. The concrete will be pumped down the 74.5m deep overflow shaft into rail cars that will transport the concrete along the 7km tunnel. In May 2014 the pour commenced and is progressing well.

Conclusions

To date the Lee Tunnel project has been largely focussed on constructing the deepest tunnel and shafts in London, in some very challenging ground conditions. As the project moves into the final 18 months of the contract the project team's focus will shift onto the immense MEICA packages required to ensure the system will operate correctly and the works required to integrate the tunnel into the existing assets and infrastructure. .

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The TBM team celebrate completion of the main tunnel drive - Courtesy of Thames Water

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Barchip structural synthetic fibres replacing steel mesh in the Deephams STW project.

The winning project tender bid was supplied by J Murphy & Sons Ltd, with civil designer AECOM Ltd, and M&E supply chain partner, Nomenca Ltd.

A major component of the works was the creation of 2 new 5.6 Million litre storage tanks and modifications to the existing storage tanks to allow sequential filling and draining.

The original slab design for the new tanks (pictured above) as proposed by AECOM had called for traditional steel mesh reinforcement. However, concerns over costs, construction time and durability, as well as health and safety concerns raised by contractors J MURPHY & Sons Ltd caused the design team to look for alternative solutions.

EPC design engineers worked closely with Murphy and AECOM on the flooring design in order to provide solutions to these existing concerns; coming up with a series of finite element analysis (FEA) calculations and modelling to justify their proposals. Using FEA EPC was able to accurately demonstrate the exact location of stresses in the design and provide solutions to ensure the ultimate performance and durability of the structure; especially surrounding concerns relating to the control of crack width openings in the slab so as to ensure leakages would be kept to a minimum.

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Finite Element Analysis modelling from EPC used on the Deephams Project. Modelling shows stresses in the design under specified loads.