British Tunnelling Society
The official magazine of the British Tunnelling Society

INTERNATIONAL EDITION
February 2021

Tunnels and Tunnelling

TIGHT MANOEUVRES

High-pressure grouting research for tunnelling

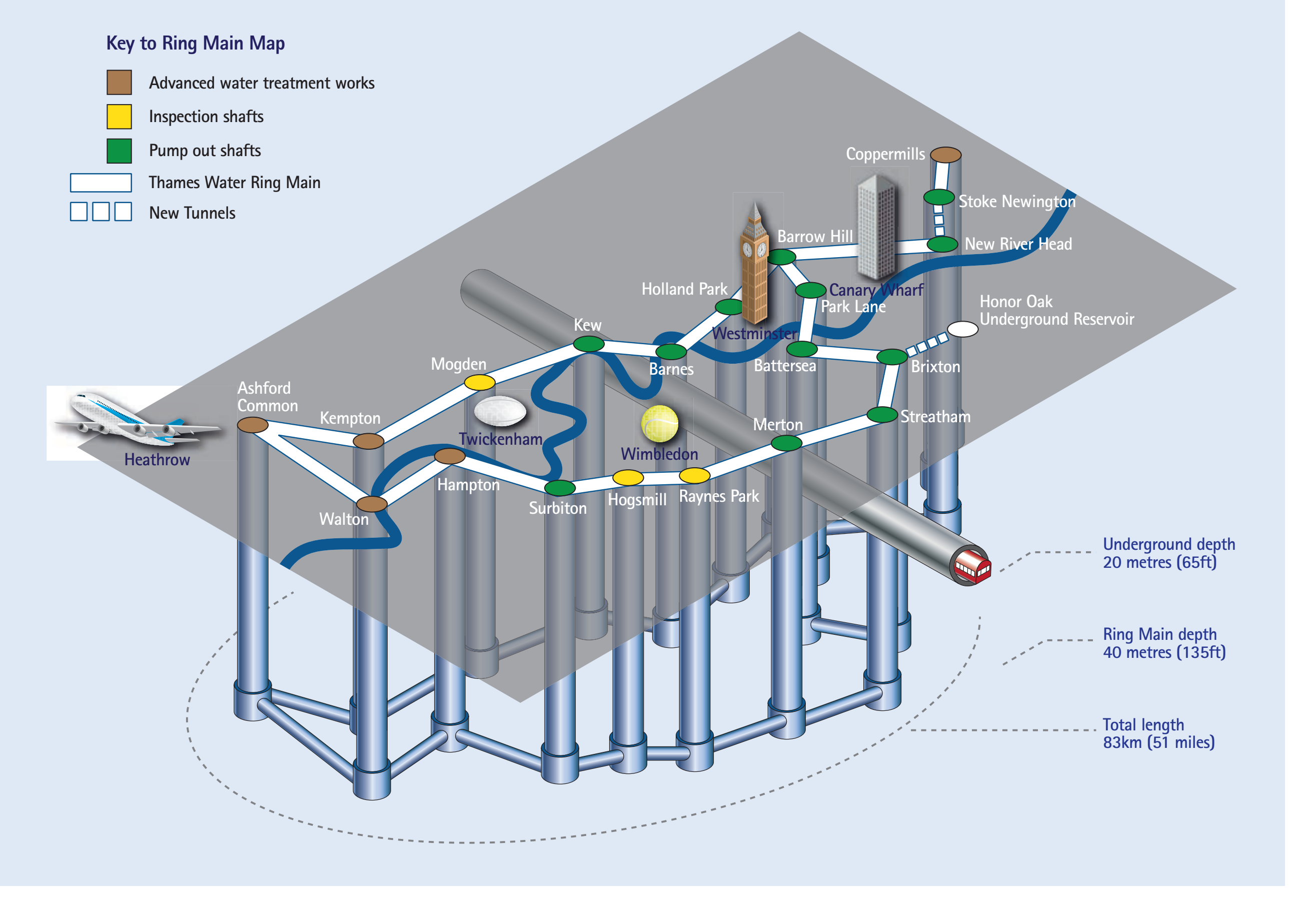
LASER SCANNING COVERS THE POINTS

Laser scanning and 3D virtual modelling were critical tools in the refurbishment of a deep shaft on London's Thames Water Ring Main, resulting in a better foundation for future repair and maintenance. **Julian Champkin** reports

THE THAMES WATER RING MAIN (TWRM) was one of the engineering achievements of the 1980s. Some 80km of concrete pipeline, mostly 2.54m in diameter, surrounds the capital and acts simultaneously as a reservoir and as a distribution system, supplying around 3.5 million Londoners. At the time of its construction, the TWRM was the longest tunnel in the UK – longer by 30km than the Channel Tunnel, which had opened less than six months earlier.

It was excavated by TBM, mainly through the easily-tunnelled and forgiving London clay – though at one point under Tooting Bec Common it unexpectedly passed through a bed of the Thanet Formation, which led to flooding and the temporary abandonment of a TBM.

The initial ring main was constructed by Thames Water between 1988 and 1993. Extensions and branches have been constructed, and further extensions are planned. The main lies



***Below:** How the ring main connects to the various shafts and water treatment works*
PHOTO: BARHALE

at depths generally between 10m and 65m below ground level. A total of 21 shafts connect it to the surface. Five of these supply it with water from the treatment works; others are pumping stations transferring water from it into local mains supply networks.

Water is fed into the main from five treatment works, on the Thames upstream of the city centre or on the River Lea to the north-east; flow is by gravity and is around 0.3 x 10^9 gigalitres daily. It is designed to be full at all times and under a pressure of around four bar; the ring design allows for reversible flow should one section have to be temporarily closed.

A MAJOR INFRASTRUCTURE PROJECT

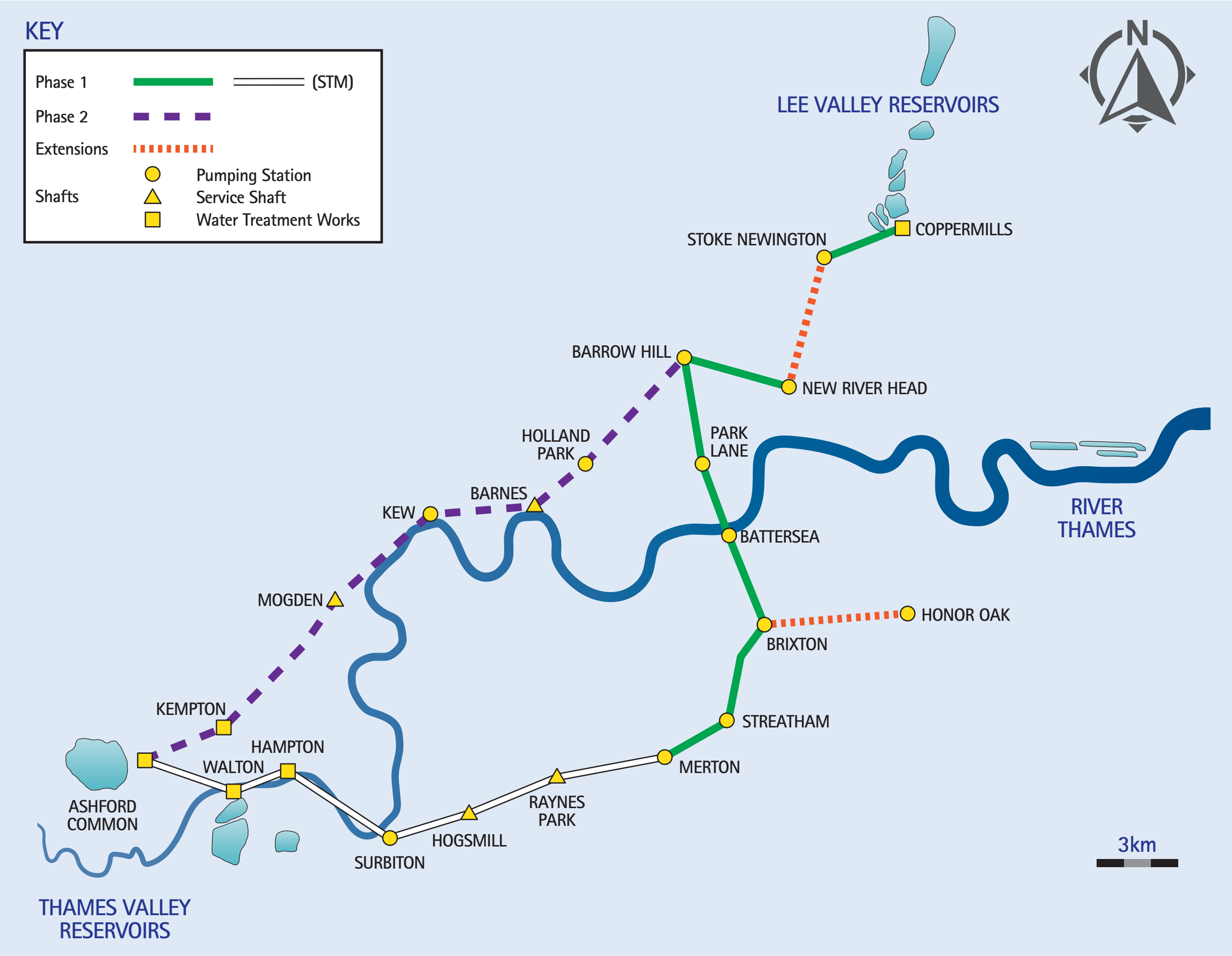
"It is rather like the M25 – running around London but carrying potable water rather than cars." So says Steve Collet, project manager for Barhale, the contractor for Thames Water responsible for the ring main. The comparison may be unfair, for it is a major infrastructure project that has served London well – and certainly with less aggravation. But the ring main is now around 30 years old. Inspections and maintenance are needed, on the shafts as on the ring itself, and are carried out on a continuous rolling programme. "Overall, the tunnels are in very good shape but much of the M&E equipment now requires replacing as would be expected within the cycle of capital maintenance," says Collet.

The deepest shaft on the system is at Barrow Hill, on the edge of Primrose Hill in North London. At 15m wide, it is also the biggest, with a four-way tunnel connection at its base. Here rising groundwater levels have brought significant water ingress to the shaft. The water has taken its toll, in corrosion and rust, and thousands of metal components in the shaft required checking and replacing. Old corroded pipework needed removing and blanking off or replacing. All the mild steel elements, such as platforms, deckings, handrails and brackets, are now being replaced with stainless steel. Electrical and communications cabling needed overhauling as well.

Collet was lead engineer on the project. "The ring was built in the 1980s to 1980s standards. We need to bring it up to today's standards" he says. A quarter of a century has brought technical advances that need to be incorporated. "As technology moves forward ,the lifespan of equipment increases, reducing maintenance and replacements needs. Pumps and valves can be modernised. Even paint has improved. It used to have a five-year lifespan; now it is ten years. So re-painting becomes less onerous and less of a Forth Bridge operation."

Legislation has also advanced: "Handrails on stairs within the access shafts now need to be higher. Bolts that were steel are now required to be stainless steel. Actuators and spindles all need bringing up to modern standards." To achieve all this, and for the regular rolling inspections and maintenance cycles,

Below: ***First landing area inside the shaft***
PHOTO: BARHALE



Above: ***The ring main's route in and around London***
COURTESY OF BARHALE

operators for Thames Water have to enter the shafts. "We need to make things easy and safe for them," says Collet.

VIRTUAL MODELLING

The major project provided a major opportunity. Here for the first time, laser scanning technology was used to create a 3D virtual model of the shaft. It is a foretaste of a digital model of the complete system that should transform the logistics of maintenance, upkeep and repair of the ring.

Conventionally, a survey team would enter each shaft ahead of the maintenance schedule to make a survey to establish the position and condition of shaft walls, piping, and equipment. Bolts and fixings, pumps, spindles and actuators all need to be checked, as well as the watertightness of the shaft walls. Replacing components, if that has to be done, is no small task. Neither is inspecting them. Laser scanning has eased the task.

3D laser scanning is a non-contact, non-destructive technology that digitally captures the shape of physical objects using laser light. The scanner is housed in a portable casing around 500mm square. It directs a beam of laser light at a surface. The light reflects from the surface it is pointed at, capturing the position of that point in space. Sensor cameras continuously record the changing distance and shape of the laser line in three dimensions as it sweeps along the object.

The scanner shoots millions of such points a second, to create a digital 'point cloud' in which each point represents part of the surface that is being mapped. Software re-creates the surface as a digital model.

Laser scanning can capture a physical object's exact size and shape, and represent it as a digital three-dimensional representation that can be sent electronically and stored, displayed and read on a tablet or computer. The technology is ideally suited to the mapping, and the measurement and inspection, of contoured surfaces and complex geometries – such as, in this case, pipework, pumps, and tunnel and shaft walls. It is quick and easy to carry out. It can generate massive amounts of data, which can be both a benefit and a drawback. The benefit is from precision: "It gives accuracy down to three millimetres," says Collet. The drawback is the large size of data-files that can be generated.

For Barrow Hill, Barhale used a Leica 3D laser scanner together with a NCTech iStar 360 camera, with BIM 360 Field software to create the model.

"Physically, the Barrow Hill shaft has a column running up

Above: **Shaft staircase**
PHOTO: BARHALE

the centre," says John Prendergast, the regional manager for Barhale. "The operator scans 360 degrees round that; it takes one or two days' scanning as a maximum to build up the data for the BIM model."

All the existing components within the shaft were picked up in the survey. The scan can spot such things as damp patches from water ingress, rust on a bolt, and blistering paintwork, all of which are visible on the digital model. "The system can give colour scans. We use monochrome, in order to reduce the files to more manageable size. It can also use thermal imaging, if required, to give still more data."

As Barhale replaced a component with something new, data relating to the new part was entered on the engineer's tablet and later transferred to the digital model.

"So, if we replaced a bolt on a pipe flange, on completion of the task the engineer carries out all the safety and quality checks, such as the type and material of the bolt and the torque on it and enters it on his tablet. That data, with his signature and any photos of the work, are automatically attached to that component on the digital map, and are available on the master model online. Anyone with access, then or later, can log in and look at it," says Prendergast.

SUCCESSFUL PARTNERING

This first use is the start of Barhale and Thames Water's rollout of BIM modelling across the whole of the ring main system. "Every time a shaft or tunnel is inspected, we shall use it; eventually we will have a comprehensive digital model of the whole of Thames Water's assets as well as the repair history and maintenance needs of each element within it."

"The scale of the shaft refurbishment is impressive," says Prendergast. "A primary task was to scaffold it to the top, to allow the inspection; but that is a challenge in itself. There are pumps in the way, and air-release pipes all the way up; it can take six or seven weeks just for that. And if a large valve to the main needs replacing, that has a body the size of the tunnel and weighs three tonnes. Craning it out of the shaft is a major operation. If you need to do that, you can see the potential clashes on the BIM model ahead of time. You can plan the lift before you get to the site and that way eliminates delays to the programme.

"That is important. An outage to the ring main is a very major thing. A huge amount of planning goes into it; you have to find a different way to move two thousand million cubic metres of water all the time that the ring main is shut. Any delay has a very big impact indeed on Thames Water, so the lifts up and down the shaft have to be done as efficiently as possible. Even the saving of an hour is well worth it. Which means that planning in advance, of the kind that BIM will allow, is a huge benefit."

KEEPING TRACK

Peter Kendall is operations manager for the Thames Water ring main. "The ring main is always full," he says, "and always under pressure; and assets that are under pressure, such as pipes and pumps and valves, imply huge safety risks if they degrade. So, all the pressurised assets need to be looked at regularly and replaced when needed." Just keeping track and record of what has been inspected when, and what repairs or replacements have been done to each asset – when and if a particular bolt on a valve was replaced, and what type of bolt was inserted in its place – is a logistical task in itself.

"That is why the BIM model will be hugely useful. It will reduce risk to employees going in to do surveys.

"On the Barrow Hill shaft the water table is quite high and in recent years it has risen. The walls are concrete segmental rings, and they are leaking. As part of the shaft maintenance we injected new resin into the joints that seals in contact with water. The model can keep track of where and when injections have been done. There are pumps that have been running to remove the ingressing water from the bottom of the shaft. Since

we have stopped the leak, those pumps no longer run; so there are energy savings for Thames Water straight away."

The eventual intention is to create a BIM model of the entire system, which can be updated anytime in real time to show changes, repairs and any maintenance data for every single component within it.

"This was a test run really," said Collet. "We want to make the entire recording and maintenance system paperless. That implies a 3D digital model that we can give to Thames Water. It will show all its assets, and the current state of them. It will also include PDF portraits of parts and components and record the maintenance history of each component. It takes away the need for manual surveys before maintenance work begins. Now, for any shaft, we scan it and model it before we put tunnel inspectors in.

"For the Barrow Hill shaft we did the scan while we were doing the works; but that was just a trial of the system. In future, engineers will download the model onto their tablets; they can take it into the shaft with them, inspect the bolts, the torque settings and so on and record those also onto the model. Then that data too can be uploaded to desktops at Barhale and Thames Water to give a permanent record. It is a two-way system: the scan and model tells the engineer what is there, then he amends the model to include the changes that he makes. If the agent or Thames Water inspector sees an issue, he can log it on his tablet, which adds it to the model, and advises it as a task for the appropriate engineer.

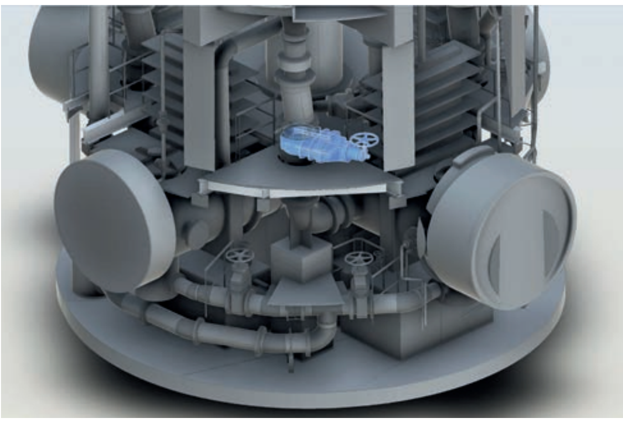
***Above:* Inspecting the Thames Water Ring Main** *PHOTO: THAMES WATER*

"We used it to replace a large-diameter valve on the main, which had to be craned to the surface with very little clearance."

The benefits to Thames Water of having a complete 3D BIM model are many and include not having to go into the shaft to survey or check information before work begins. The model will be kept live and can be viewed and updated whenever required. It can be used for design of alterations, scaffolding and temporary works and planning isolations.

"I think it is the first time it has been used on this size of tunnel within London" explains Collet. "The system is useful also on new builds, to show up deviations between the work as completed and the design drawings. It is only a start, though. It is going to become standard practice very rapidly. The advantages to Thames Water are huge, and you can see how they will translate to a huge number of other applications."

"The Ring Main is a fantastic civil engineering asset which for thirty years has brought huge benefits to millions of people who, despite it literally being right under their feet, may not even be aware of its very existence. Thames Water deserves enormous credit for its stewardship, proactively investing in its maintenance and ensuring it continues to fulfil a vital role in London's water supply."



***Above:* An early 3D model of the shaft base** *PHOTO: BARHALE*