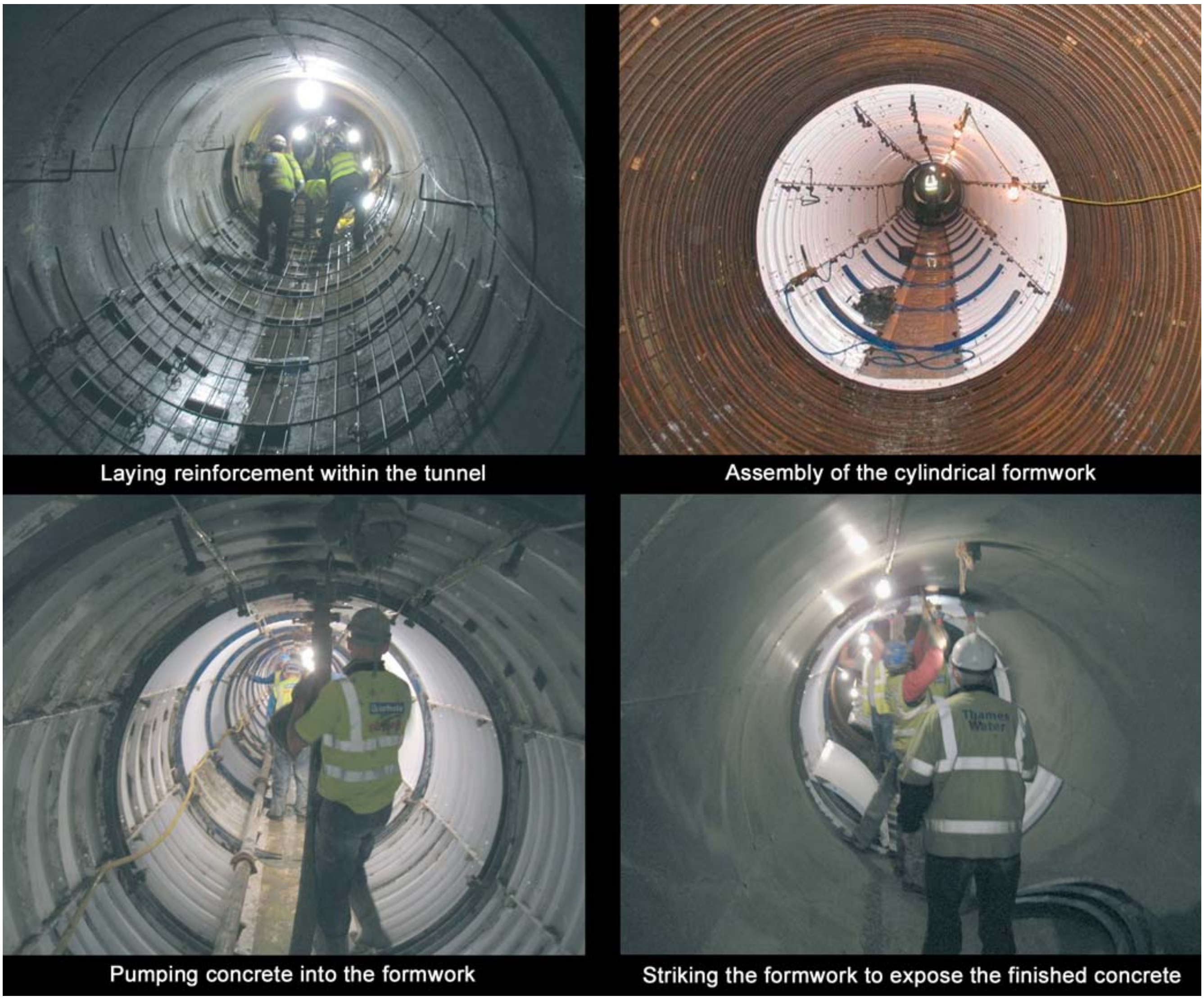
# Wraysbury Reservoir Inlet Tunnel

## in-situ structural secondary lining of existing tunnel

By
Richard Wood MEng (Hons), CEng, MICE

**Wraysbury Reservoir, near Heathrow, provides 15 per cent of London's raw water storage capacity. Water is pumped to the reservoir from the River Thames at Datchet at a nominal flow rate of 900Ml/d via a 2.7km inlet tunnel. The 2.54 metre internal diameter tunnel was built in the late 1960's using unbolted concrete wedgeblock segments and is situated 30m below ground in London clay. In April 2006, a major failure at the nearby Queen Mother Reservoir inlet tunnel occurred resulting in surface flooding. Investigations indicated that seepage through the wedgeblock lining resulted in the localised softening of the surrounding London clay and a gradual decrease in the confining overburden pressure, This caused the unbolted wedgeblock tunnel to fail under the internal pressure head of the reservoir.**




*Wraysbury Reservoir Inlet Tunnel - Four stages of Barhale Construction's "Tunneline System" as utilised by Thames Water* *photo courtesy Thames Water*

Emergency remedial works were completed before it could be returned to service, which involved structurally lining 340m of the tunnel with 2.24m internal diameter steel pipe.

This failure led to immediate concerns about the structure of the Wraysbury Reservoir inlet tunnel, which was constructed at the same time, and to the same design. As a result, a contract was awarded in December 2006 to *Barhale Construction* to install a structural secondary lining in the Wraysbury Reservoir inlet tunnel.

**Tunnel lining technique**

During the solution development stage a range of tunnel lining techniques were considered, including pre-cast concrete segments, steel and polyethylene liners and cast in-situ reinforced concrete. Although the Queen Mother Reservoir inlet tunnel was successfully lined with steel, estimates showed that for the longer Wraysbury Reservoir inlet tunnel, cast in-situ concrete lining would be quicker and significantly cheaper. This was partly because the required materials and equipment could fit into the tunnel using the existing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shafts, instead of having to sink several new shafts to facilitate the installation of liner pipes. The cast-in-situ concrete lining method would also avoid handling heavy liner pipes and welding within a confined space.

**Design development**

The new cast-in-situ lining was designed to have a 150- year design life and withstand a 5.8 bar internal water pressure without relying on resistance from the existing wedgeblock lining. This meant that the design needed to comply with the British Standard Design code for concrete water retaining structures (BS 8007). A special concrete mix was required that could be pumped, be self-compacting and meet the stringent crack with tolerances. This was achieved by using a maximum aggregate size of 10mm to assist pumping and compaction and by using Ground Granulated Blastfurnace Slag (GGBS) to control thermal cracking.

The method of concrete delivery was crucial to the duration and cost of the works. It is normal practice to install track and use locomotives to take concrete up the tunnel to where it is pumped into the lining formwork. However, the logistics of using track and locomotives are considerable, as are the services required within the tunnel, which include electrical supplies for the concrete pump. Therefore, the project team considered alternative methods of delivery to make cost and programme savings. Subsequently, it was identified that as the tunnel route was mainly underneath farmland surface boreholes could be drilled into the tunnel to allow concrete to be pumped from the surface directly into the lining formwork.

**Enabling works**

Before commencing work, the tunnel had to be adequately isolated from the existing network. Unfortunately, the reservoir did not have a full inlet tower and the inlet shaft terminated at the bed of the reservoir as a domed manifold. This meant the inlet pipework, comprising two low-velocity inlets and six high velocity inlets on the reservoir floor, could only be accessed by draining the reservoir or by using divers. As the reservoir was to remain full during the works, this arrangement could only provide a single isolation of the tunnel from the reservoir using the valves on each inlet. A number of options were investigated to provide the necessary secondary isolation and it was decided to install temporary sealing plates on the inlet openings. As these had to be installed underwater by divers, they were designed to be as light as possible and minimise underwater working, The high velocity inlet seals, were designed to fit straight into the 42" diameter concrete inlet pipes and be held in place by hand-tighten mounting bolts to avoid drilling.

The larger 2.9m square low-velocity inlet openings were sealed with panels inserted into pre-fabricated channel frames fixed onto the inlet side walls using mounting bolts. The panels were made from lightweight aluminium hollow box sections that could be safely handled. Both sealing plates systems proved easy to install underwater and remained watertight. They have been retained for future isolation of the tunnel for periodic inspection and maintenance. To facilitate tunnel access, a temporary intermediate access shaft was installed in addition to the existing shafts at either end of the tunnel. This proved cost-effective because of the increase in productivity by being able to transport materials along the tunnel from this additional shaft. With an additional three 250mm diameter boreholes concrete pumping lengths were kept to less than 400m and it was possible to pump concrete directly into the tunnel from the surface throughout the works.

*View Skyward from the temporary tunnel access shaft* *photo courtesy of Thames Water*

**Method of working**

The tunnel lining technique, known as the 'Tunneline' system, utilised a lightweight modular steel formwork that could be rapidly erected. The structural reinforcement was designed as a circular cage of 20mm diameter bars and 10mm diameter longitudinal bars on a 100mm spacing grid. A gang of steel fixers installed this reinforcement during the dayshift and the lining formwork was installed on the following nightshift. Concrete was then placed via the surface located pump the following morning. The formwork was then left for eight hours prior to striking to leave the finished product. After striking, the formwork panels were cleaned and prepared for installation again on the following nightshift. Production rates of up to 40m of completed lining per twenty-four hours were achieved using this innovative continuous working method.

**Summary**

This was the first time that a secondary cast in-situ reinforced concrete lining had been retrofitted within an existing Thames Water tunnel. The work was completed in October 2007 within the challenging four month tunnel outage period permitted. Significant out-performance of the target cost was achieved due to the innovative techniques devised by the project team, The method of working presented a steep learning curve and some significant challenges were overcome. It is likely that the techniques devised during this project will be used again in the near future to secondary line further ageing segmental tunnels.

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