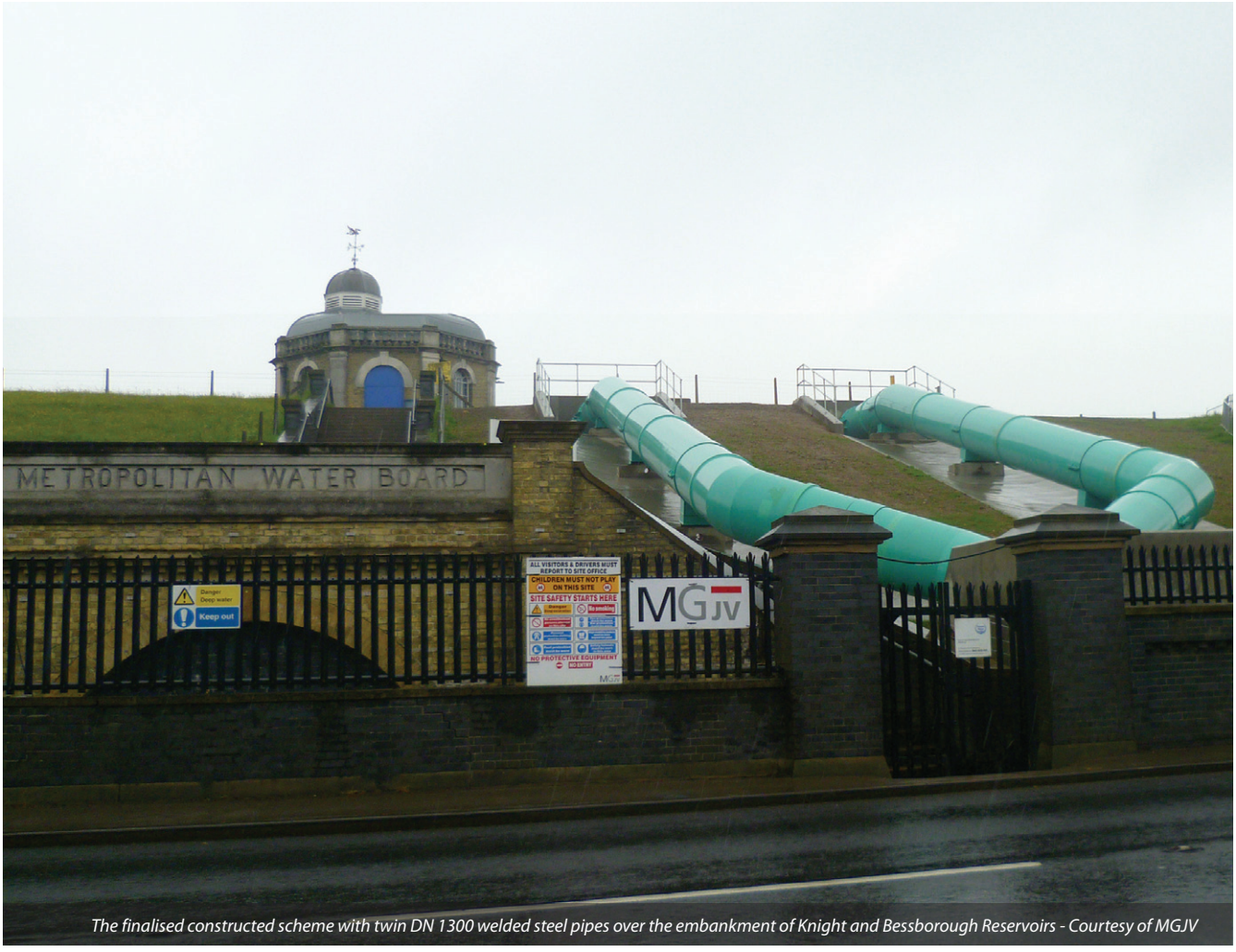
Knight & Bessborough Reservoirs Inlet Mains Replacement

construction of two new DN1100 welded steel pipes to replace two existing buried 54″ riveted steel mains to protect reservoir embankment from risk of erosion

by Khai Ng

Knight & Bessborough Reservoirs are operational statutory reservoirs in Walton-on-Thames, owned and operated by Thames Water (TW) and located within the Thames Valley abstraction system. The reservoirs were built circa 1907 and are retained by an 11m high continuous earth-fill embankment with a clay core keyed into the underlying London Clay. The existing twin 54″ riveted steel inlet mains under consideration are about 100 years old and are designed to carry raw water from pump numbers 10 and 11 at Walton WTW into the Knight & Bessborough raw water storage reservoirs. The operating pressure in the 54″ main was approximately 1.4 bar with a maximum inflow rate of 254,000m^3/day. Both mains are buried within the external embankment of the reservoir and cross the puddle clay core close to the embankment crest. The short leg discharges at the entry point into the reservoir whilst the long leg runs further into the reservoir and connects to a 48″ inlet main which discharges close to the centre of the reservoir.



The finalised constructed scheme with twin DN 1300 welded steel pipes over the embankment of Knight and Bessborough Reservoirs - Courtesy of MGJV

Issues

Leakage was observed in the embankment near the steps to the valve/outlet tower by TWU personnel in 2007. Following the leakage, the longer 54″ riveted steel main, which is connected to the 48″ main running to the centre of reservoir, was taken out of service. A drop test was conducted on the pumps at Walton WTW which indicated that the main was indeed leaking.

Continued leakage of the longer 54″ riveted steel main could undermine the slope of the reservoir. Therefore, a solution to the leakage problem had to be found in order to protect the reservoir embankment.

Undertakings

Thames Water, as part of the AMP5 Delivery Process, is working with its delivery partner MGJV (Morrison Galliford Try Joint Venture) to deliver capital improvements to the networks in South London. On this project, MGJV worked closely with Thames Water and their designers, Mott MacDonald, to develop options to address the leakage issue of the existing 54″ steel inlet mains.

The preferred solution

At the optioneering stage, four options were suggested to mitigate the risk associated with the leaking main. Through consultation with the All Reservoirs Panel Engineer, the preferred option was two new DN 1300 steel replacement pipes placed above ground on the slope of the embankment and grouting up of the existing 54" riveted steel mains through the embankment.

A concrete leakage collection channel was designed to prevent erosion of the embankment material in the event of a leak from one of the new pipes, which could remain undetected for 18 hours.

The advantages of constructing the replacement pipe above ground were to minimise the level of excavation needed when compared to the below ground pipe option and avoid the risks associated with disturbing the buried pipelines within the reservoir embankment. Any future issues with maintaining underground pipelines would also be avoided with this new arrangement.

Geotechnical analysis

Although some historical ground investigation data was available, this was not in the location of the proposed pipeline and the data indicated that the embankment fill had very low SPT 'N' values. In July 2012, three cable percussive boreholes were drilled on the existing embankment slope to depths of 10m - 15m.

The embankment fill was described as a loose to very loose clayey sand and gravel. Underlying the embankment fill, River Terrace Deposits were encountered overlying London Clay. SPT 'N' values within the embankment fill were in the range of 3 to 8, with significant variability in each 75mm drive. The results from this ground investigation indicated the presence of a loose granular material within the embankment fill, therefore confirming the historical data.

The conclusion from this was that the material in the embankment was of a highly variable nature. Settlement of the pipeline footings was analysed and the data inputted into a pipe stress analysis. The highly variable nature of the embankment fill resulted in the possibility of variable settlement across the separate footings, therefore inducing high stresses in the proposed pipes.

Pipe stress analysis

The pipelines were modelled for stress analysis using the finite element pipe stressing package, 'Caesar II', more commonly used in the oil and gas industry. The programme shows the stresses within the pipeline, and also force and direction requirements for the supports.

The output from this analysis indicated that due to the possibility of variable settlement of the pipe footings, intolerable stresses within the pipeline were possible. The solution to this was to provide ground improvement in the embankment fill material beneath these footings. Each pipeline leg was held rigidly at the base, and analysed to move freely up the slope and have a stress free sliding, laterally guided, end at the top connection. This required a top coupling with sufficient longitudinal leeway for the range of temperatures to be experienced by an exposed pipeline in a temperate climate.

The stresses were made more complicated by the required vertical and horizontal bends to avoid the existing pipeline in the embankment below. The pipeline was designed to slide over the pipe supports, normally transferring only vertical loads to the piles, horizontal loading only temporarily occurring during expansion and contraction movements.

Piled foundations

The design undertaken by Mott MacDonald recommended 2 (No.) 150mm piles per pipe support. MGJV awarded the contract for the driving of the piles to Tri-Tech Piling & Foundations who used a system of Grundomat driven piles with cast in-situ pile caps connected to the pipe support upstand for each pipeline footing.

This system was chosen to allow for a safer system of work using a reduced rig, working on the grass embankment slope of 1 in 3. A total of 16 (No.) piles were installed to a maximum depth of about 12m. This cost and time efficient system was found to provide a safe and effective means of transferring the pipeline loads through the poorly compacted embankment fill material to the underlying River Terrace Deposits and London Clay.

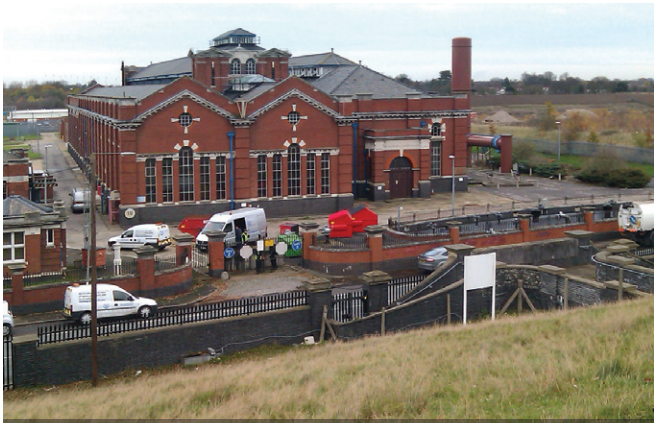
Connection between existing and new pipes

The invert of the two existing 54" mains at the toe of the embankment was at a depth of approximately 2m below existing ground level. The connection between the existing 54" mains and new 1,300mm pipes were made at this location using a flanged spool section welded to the existing mains and a flange adaptor to the first section of the new 1,300mm diameter main rising out of the embankment toe.

Fabriweld joints were used to eliminate internal weld spatter with flange adaptors for the connection. This section was encased in a reinforced concrete thrust block at the toe of the embankment to take the thrust from the pipeline and to provide a rigid support for the pipe on the embankment.

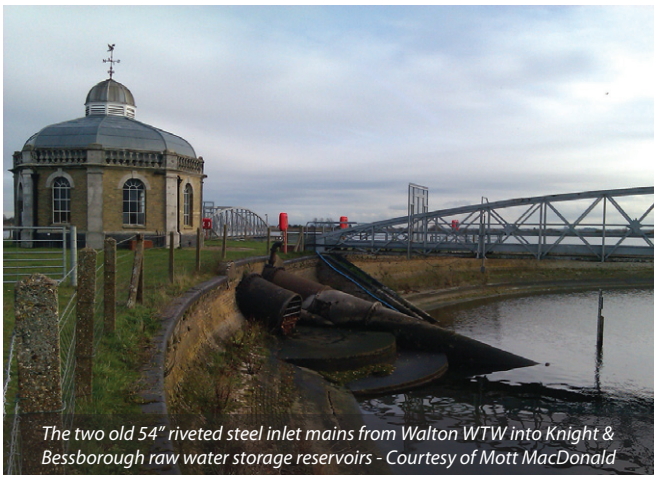
To summarise, the preferred option required the key design of the following:

- New twin DN 1300 welded steel pipes to be constructed up the reservoir embankment slope, on one of a number of possible alignments, and held on pipes supports at regular intervals.

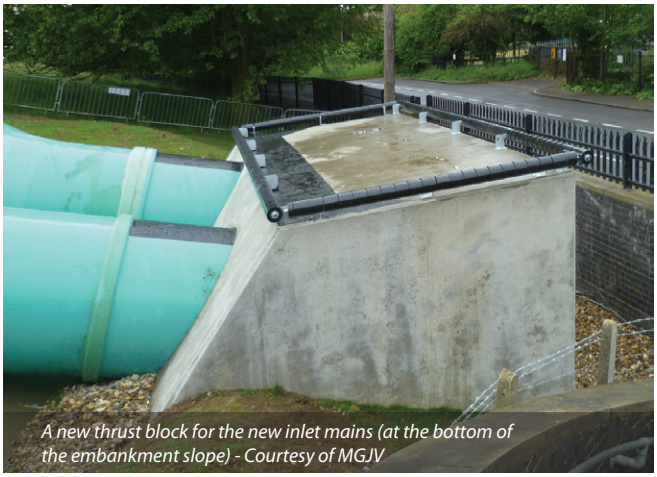


The existing water treatment works with the existing 54" mains through the embankment - Courtesy of MGJV

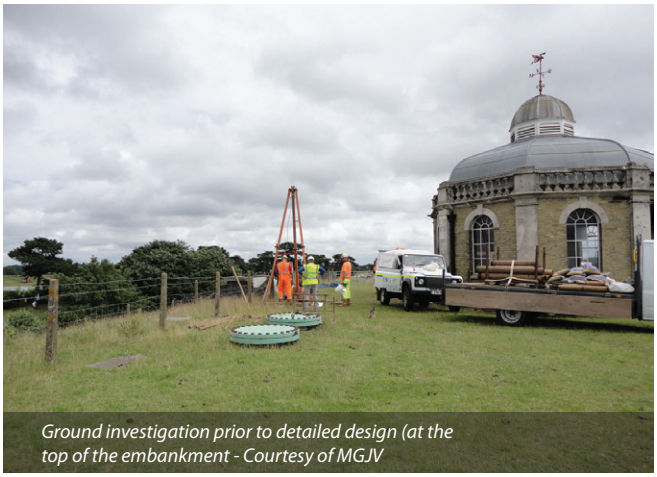
One of the new DN1300 inlet mains (viewed from the top of the embankment away from the reservoir) - Courtesy of MGJV



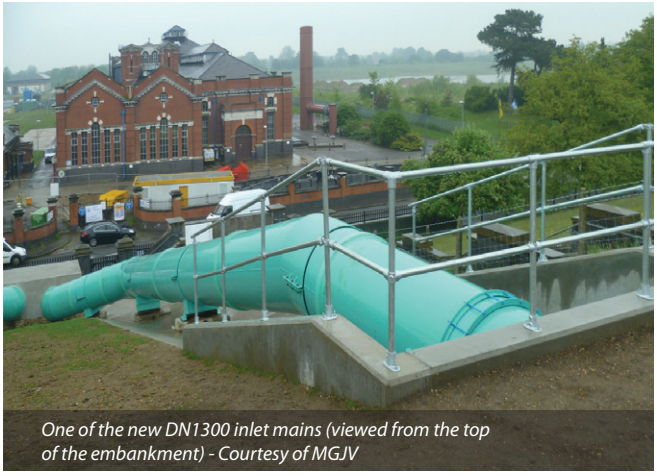
The two old 54" riveted steel inlet mains from Walton WTW into Knight & Bessborough raw water storage reservoirs - Courtesy of Mott MacDonald



A new thrust block for the new inlet mains (at the bottom of the embankment slope) - Courtesy of MGJV



Ground investigation prior to detailed design (at the top of the embankment - Courtesy of MGJV



One of the new DN1300 inlet mains (viewed from the top of the embankment) - Courtesy of MGJV

- Leakage collection channels to prevent erosion of the embankment material.
- At the reservoir end, connection of one of the new pipes into the old 'long leg' 54" pipe, with the other new pipe connecting upstream of the outlet of the 'short leg' pipe that discharges directly into the reservoir.
- Sealing details around pipes where they encroach into the embankment clay core.
- Connection of new pipes to existing mains at the base of the embankment.
- The filling of the redundant sections of the existing 54" pipes with concrete grout.

Challenges

There were many challenges that had to be overcome in order to deliver the Knight & Bessborough Reservoirs inlet mains replacement project. These were:

- The Knight & Bessborough Reservoirs are nationally designated as Sites of Special Scientific Interest (SSSI). The proposed works at the reservoirs required consent from Natural England who had to be consulted regarding the works methods and proposals to make them appropriate for the protected area.
- As there was very little working space available at the toe of the embankment and the construction was relatively close to the road, all efforts were made to minimise the impact on traffic flows, allow a reasonable working area and at the same time not compromise on the embankment stability during excavation at the embankment toe.
- The preferred solution required shutdowns of the inlet mains in order to make the new pipe connections. New fittings were designed to allow for quick connection in order to shorten the shutdown time.
- The works would have been ideally suited to a 3D design, but a 3D survey was not available until too late in the design period to be effective. This was overcome by producing drawings in 2D perspective for the pipeline drawings in particular, a technique used in the oil and gas sector.

Added value

The connection between the existing riveted pipes and the new mains has taken the operational aspect and downtime of the existing mains into consideration. The fittings required to undertake the connections were carefully designed to meet the operational requirements/arrangement and time allowed for shut down.

MGJV's construction experience, together with Mott MacDonald's expertise in pipeline design and geotechnical design, meant the chosen design robust and withstood the various technical and environmental constraints imposed on the project.

The preferred option also minimised impact on local traffic.

Conclusion

Thames Water fulfilled the requirements of the recommendation under Reservoirs Act by resolving the consequences of identified leakages on the mains. In doing so, they ensured that both mains were returned to full operational capacity and secured supply to both reservoirs.

The Editor & Publishers would like to thank Khai Ng, Civil Engineer, Keith Macpherson, Geotechnical Engineer, Robert Ashiley, Mott MacDonald-MGJV Framework Manager, and John Atkins, Senior Civil Design Engineer, all with Mott MacDonald for providing the above article for publication.

The authors would also like to thank MGJV (Morrison Galliford Joint Venture) and Thames Water for their assistance in the preparation of this article.