Preston 7 UIDs

collaboration, innovation and success in the face of adversity

by Adrian Owens BEng (Hons) & Carl Sanders RPP MAPM

The £114m Preston Tunnel and Rising Main improvement scheme has been completed as part of United Utilities' capital programme in the North West to improve the quality of the region's bathing waters off the Fylde Coast in line with European legislation. The scheme involved the complex construction of a 3.5km interceptor and storage tunnel, with an internal diameter of 2.75m, providing 40,500m^3 of storm storage. Thirteen large diameter shafts have also been constructed along with the installation of 9km of rising main. Additional components of the scheme included the construction of screens chamber, a terminal pumping station, an outfall and all associated manholes and pipework designed to upgrade the area's ageing sewer system. Construction of the project commenced in February 2010; turn of flows was achieved in December 2013 with contract completion in April 2014.

Terminal pumping station shaft & MCC building - Courtesy of KMI Water

Completed twin vortex drop shaft - City works - Courtesy of KMI Water

Background

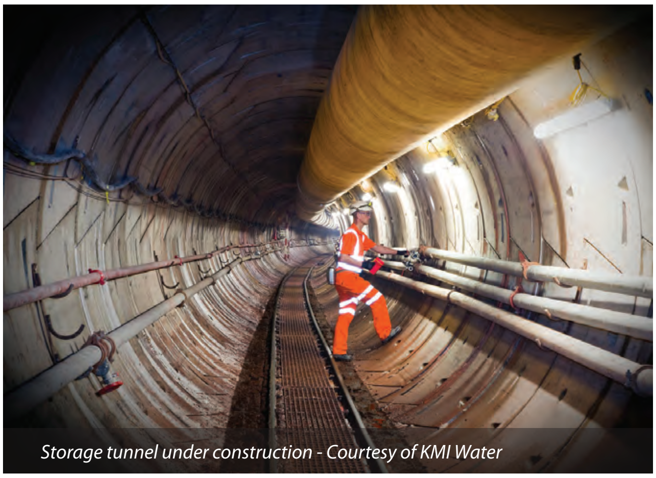
Preston is served by a combined sewer system, which dates back to the 1870s as the city grew from textile businesses and mills. In those days the pipe sizes were kept relatively small, with numerous reliefs (overflows) to drain off the excess flows during storms to the local rivers of the River Ribble in the city centre and Savick Brook for north Preston area. The area drains to Clifton Marsh WwTW to the west of the city. The area's sewer system has become more of a focus with the need to not only improve local watercourses, but also the quality of the bathing waters along the Fylde Coast and Southport areas.

Project overview

The interceptor and storage tunnels transfer flows to the terminal pumping station shaft (30m diameter and 32m deep) to lift flows from the tunnel and transport them to the Clifton Marsh WwTW, via twin rising mains. A stormwater screening structure constructed adjacent to the terminal pumping station will screen any excess storm flows before discharge into the river. From the pumping station 5km long twin rising mains along the south side of the river link to the Western River Crossing (WRX).

The construction of the WRX and the terminal pumping station (TPS) presented major challenges in the early stages of the contract. These difficult and complex issues have been overcome by teamwork and collaboration and produced some fantastic innovation and engineering both in design and delivery. At the WRX the 866m long twin pipe tunnel was installed using an direct pipe (DP) technique, a UK first and at the TPS, shafts were completed using state of the art ground engineering to stabilise weak rock beneath a partial depth diaphragm wall.

The success in meeting the challenges presented was achieved by collaboration, research, cutting edge design and value engineering by the parties involved; United Utilities, KMI Water, GHA Livigunn, Donaldson Associates and Herrenknecht.


Storage tunnel under construction - Courtesy of KMI Water


Terminal pumping station partially excavated & adjoining screens chamber - Courtesy of KMI Water

Terminal pumping station: Dry well - Courtesy of KMI Water

Construction methodology overview

The shafts and tunnels to the east of the terminal pumping station were constructed in Sherwood sandstone with the upper parts of the shafts passing through varying depths of alluvial and glacial sands and gravels. To the west of the TPS the Sherwood sandstone dipped out of the construction envelope with the Western River Crossing being constructed in glacial till.

Initial ground support for the TPS and city shafts was provided by the construction of partial depth diaphragm walls and secant piles keyed into the Sherwood sandstone below to cut off the waterbearing sands and gravels above the Sherwood sandstone. Once excavation to the Sherwood sandstone was complete, shafts were completed to formation using either sprayed concrete lining and rock bolting or installation of precast concrete rings by underpinning.

Tunnelling works for the interceptor and storage tunnels were constructed using a full face Lovat TBM with extensive ground conditioning systems. Shafts at the WRX were constructed by caissoning methods within the till and the tunnel crossing was to be completed by 2.85m (ID) EPB Lovat tunnelling machine.

Typically, within the city centre the array of shaft and tunnel construction operations were constrained by working room and third party issues; however excellent traffic management and intensive stakeholder management ensured successful relations with numerous stakeholders including EHO, LCC, Preston Guild and Alstom.

Terminal Pumping Station (TPS) & Shaft S1A

The terminal pumping station is 27m (ID) x 35m deep, constructed with a part depth diaphragm wall 23m deep with approximately 10m sprayed concrete lining to formation.

The screenings chamber adjoining the TPS to the north is 50m long by 20m wide and 16m deep. The diaphragm walls at the connection between the TPS and screens chamber are fully integrated producing a complex structure and constraining excavations

Shaft S1A (15m diameter x 30m deep), located approximately 40m to east of the TPS shaft, was required to facilitate programme and enable tunnelling works to be carried out concurrently with the construction of the TPS. Shaft S1A was also constructed with a partial depth diaphragm wall to similar depths and underpinned to formation with PCC rings.

The construction of both shafts was based on a three layer ground model comprising Upper S&G/Weathered sandstone/Sandstone. The upper sands and gravels were considered highly permeable and unlikely to dewater and as such the diaphragm walls were keyed into the Sherwood sandstone to enable the sprayed concrete lining and underpinning operations to be carried out.

On progressing the excavation to approximately 2m above the toe of the diaphragm walls, it became evident that water ingress was carrying volumes of sand and fines originating from the upper alluvial deposits. This was a major concern; whilst the situation was not deteriorating, it was clearly not sustainable for construction to proceed and the shafts were subsequently flooded.

Initially the situation was thought to be locally associated with Shaft S1A as this was the first shaft to be inundated; the immediate vicinity of the ingress was subsequently treated by permeation grouting.

However, approximately two months later and despite additional risk controls being implemented, the situation reoccurred in the terminal pumping station shaft with water and sand being emitted from the sand layer at a depth which deteriorated rapidly and resulted in the shaft having to be flooded. The flooding of the TPS indicated that the problem more fundamental and widespread than had previously been thought. By mid October 2010 both shafts at the terminal pumping station site had been flooded.

Following the inundation of the terminal pumping station, the first priority was to investigate the ground and understand why the failures had occurred. The ongoing site investigation was widened in scope and specification as initially it was not informative on the reasons for the failure mechanism. Unique high specification ground investigation methods were employed through the problem zones to inform on features that may have otherwise been interpreted as drilling disturbance.

As the site investigations continued, the project team immediately commenced looking for alternative solutions in conjunction with UU. Numerous options were raised and investigated for technical and commercial viability ranging from ground freezing and compressed air to downsizing the internal diameter and constructing a shaft-within-the-shaft. Following approximately 10 weeks of optioneering the range of options were reduced to two:

- ***Jet grouting & dewatering***: A combination of observational techniques targeted expressly at dealing with the problems associated with the ground.
- ***External secant piling***: The installation of an external ring of secant piles to below formation level to act as a full groundwater cut off.

Following further detailed design and risk analysis of both options the observational approach of jet grouting and dewatering was cited as providing the greatest flexibility in dealing with unknown ground conditions and would inform on risk as construction of the solution progressed.

Revised technical solution (RTS) – jet grouting & dewatering

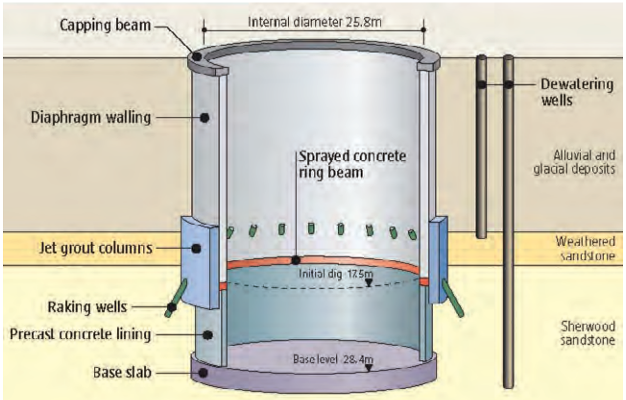
The revised technical solution comprised the extension of the groundwater cut off provided by the diaphragm walls by jet grouting bonded to the outside of the diaphragm wall at depth. Additionally, the groundwater was reduced by dewatering both the upper alluvial and glacial deposits and the Sherwood sandstone.

Jet grouting is generally a soft ground technique whereby grout pressurised to c. 400bar is jetted radially outwards from a vertical drill string through a rotating nozzle at depth. The drill string is incrementally lifted to treat the zones of interest. The pressure of the grout injection mixes the in situ material and produces a cemented column; adjacent columns can be situated such that the column diameter overlaps and produces an 'interlock' of the grouted material.

The use of jetgrouting techniques to treat weak sandstone had not been attempted previously in the UK. Information from the site investigation indicated that the problem zones comprised thin layers of un-cemented sand at depth and this information provided sufficient confidence that the use of jetgrouting would be successful in securing the ground against further inundations. In addition, the jetgrouting could be targeted specifically at the problem depths stabilising the immediate vicinity of the failed zone and secure the foundation of the diaphragm wall.

The columns produced by jet grouting in sandstone were expected to have a 'Christmas tree' effect where soft ground was jetted out and interspaced with zones of stronger material. The attached photo was taken from the tunnelling works some depth below the toe level of the diaphragm walls and shows the effect of the jetgrouting in stronger material. For this reason and others including the effects of 'shadowing', jet grouting could not be fully relied upon to exclude up to 3 bar of water pressure; an intensive dewatering system was therefore needed.

TPS Recovery: Underpinning continues - Courtesy of KMI Water



Terminal pumping station: Revised technical solution - Jet grouting and 3-stage dewatering -Courtesy of KMI Water


TPS Recovery: Base slab concrete pour - Courtesy of KMI Water

The purpose of the dewatering system was to reduce the water pressure through the full depth profile of the shaft reducing the risk that layers of un-cemented material may exist at depth with extremely high water pressures. For this a three stage intensive dewatering system was developed.

- ***Stage 1***: Deep wells were socketed into the top of the weathered sandstone layer with a response zone in the highly permeable sands and gravels; this zone was previously thought to be excluded by the diaphragm walls.
- ***Stage 2***: Deep wells targeted the sandstone at depth with a response zone from the bottom of the weathered zone to c. 20m below formation level. Installation of the jet grouting and reduction of water pressure by stage 1 and 2 dewatering enabled access to the shaft.
- ***Stage 3***: Dewatering comprised inclined well points established through the diaphragm walls to specifically target the zone about the diaphragm wall toe and pick up any areas of overbleed or water uncontrolled by stage 1 and 2; this enabled excavations to progress past the toe levels.

Throughout the whole process geotechnical supervision was employed full time to assess information and interpret observations as they were being recovered from the ground. This information was fed back to the design teams and weekly design review meetings were convened with all stakeholders to ensure accuracy and robustness of decision making.

In addition to the jetgrouting and dewatering, the lining of the shaft to formation level needed to be changed as the sprayed concrete lining relied on rock bolting to provide structural support to the rock mass, this was not compatible with the jet grouting and dewatering regime implemented. As a result a bespoke 27m ID precast concrete ring was procured through Macrete and installed underneath the diaphragm wall, supported by hangers. A ring beam was cast as a makeup between the irregular diaphragm wall toe and the segments and the shaft subsequently completed to formation level by underpinning.

Western River crossing

The Western River crossing work included several notable achievements; the first use in the UK of the Herrenknecht direct pipe technique, a twin crossing, the world's second longest direct pipe drive and setting a UK pipe jacking record with 72m in a single 12 hour shift.

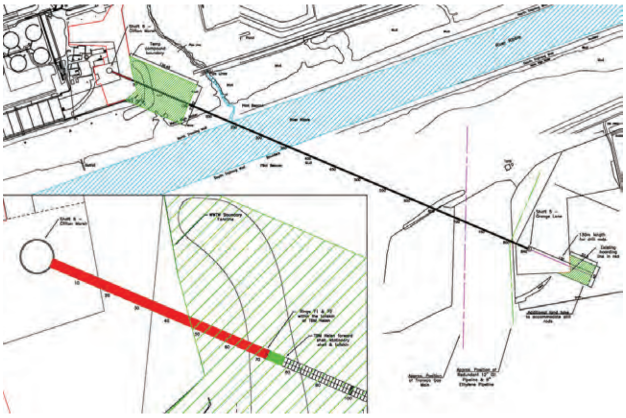
The facility included an 866m long twin pipe tunnel river crossing providing the only link to take sewer flows across the river to the treatment works. The success of this element was crucial to the overall project, the key to which was the close collaboration with designers GHA Livigunn and Herrenknecht.

In November 2010 the 2.85m ID tunnel drive constructed by a LOVAT TBM encountered ground conditions resulting in water and silt inundating the 70m of completed sewer tunnel. The TBM and completed section of tunnel had to be abandoned and a new solution sought.

The purpose of the tunnel was to carry the two 800mm diameter rising mains running from the TPS to the treatment works on the other side of the river. In order to overcome the ground conditions and install the rising mains a wide range of alternative options were considered including directional drilling and dredging.

Further investigation of these solutions resulted in many being discounted due to construction risk, third party issues or environmental impact leaving two viable solutions; the Herrenknecht direct pipe and the recovery of the TBM and completion of the tunnel as tendered.

Western River Crossing: Herrenknecht direct pipe - machine assembly - Courtesy of KMI Water



Western River Crossing (WRX): Layout - Courtesy of KMI Water

WRX: Pipe preparation - Courtesy of KMI Water

Pipe jointing - Courtesy of KMI Water

Recovery of the TBM involved the installation of a 25m (ID) shaft by diaphragm walling in front of the machine and a conical ground freeze from the shaft back over the TBM to a point past the point of the inundation. There were a considerable number of environmental risks associated with this solution not least that the TBM was located in the tidal flood plain of the River Ribble which was protected salt marsh; the working compound would have needed to be raised by some 5m to elevate it out of the flood risk.

However, the critical construction risk with this solution was that the condition of the constructed tunnel post inundation was indeterminable. Estimates of some 300m^3 of silt had entered the tunnel and the ground conditions were such that it was impossible to assess whether this loss of ground had resulted in further damage along the length of the tunnel.

With the concern over the integrity of the constructed tunnel and environmental impact the recovery of the TBM proved commercially unviable and was subsequently dismissed.

Focus on the capabilities of the Herrenknecht direct pipe increased and the team set out to understand the advantages and limitations for the Herrenknecht direct pipe option. The new technique focused on a powerful pipe-thrusting machine anchored in a shallow thrust pit at the start on the south side of the river.

The pipethruster gripped the pipeline and jacked it through the ground by the machine's pistons in 5m strokes. Strings of welded pipe 80m long are then thrust forward through the glacial sands, silts, gravels and boulders. Heading up the pipe string is a 15m long micro tunnel boring machine (TBM) which is fully computerised and operated remotely from a control room.

The main risks associated with the direct pipe methodology were that of thrust force and boulder risk; further risks were associated with tunnelling under strategic petrochemical lines which crossed the line of the drive.

- ***Skin friction***: Jacking force assessments carried out identified the possibility that in the particular ground conditions comprising glacial till clay squeeze may increase skin friction to exceed the capacity of the pipe thruster. Whilst this was considered unlikely, in the event that the risk was realised, the time required to implement remedial works could lead to an overall seizure of the pipeline. In mitigation KMI extended the thrust pit to receive a second thruster if this was needed and in conjunction with Herrenknecht, developed and implemented an automated lubrication system throughout the length of the pipeline.
- ***Boulder risk***: Substantial work was carried out by geotechnical consultants to inform on the likelihood of boulder strikes within various ground conditions. With this information a mixed ground head was selected and modified to deal with anticipated abrasivity and impact damage from cobbles and boulders. In addition as the direct pipe machine is fully welded or restrained along its length the project team developed a methodology to retract the entire pipeline in the event of encountering an obstruction.
- ***Petrochemical pipelines***: The strategic pipelines were exposed and bridged to remove any risk of settlement either through normal mining or in the event of a retraction having to be carried out.

The project team consulted closely with the HSE throughout the process who were invited to review the new technique. Overall, the direct pipe solution was considered to be substantial reduction in safety risk compared with large diameter tunnelling as the remotely controlled pipe jacking methodology eradicated the requirement for operative entry.

Herrenknecht direct pipe: Control cabin - Courtesy of KMI Water

WRX: Breakthrough at Shaft S6 - Courtesy of KMI Water

Multidiscipline risk meetings held weekly to review progress, problems and developments and provided forum to effectively manage key engineering and health and safety risks.

The tunnel drives comprised twin 1.422m steel pipes constructed with a 1.505m OD. slurry shield TBM to depths of 16m below existing ground level and passing 7m below the bed of the River Ribble (upper constraint).

The direct pipe progressed at an average of 20m a day and also resulted in considerable savings in time and cost than the use of a larger 3m TBM.

This new installation demonstrates the challenges and innovative engineering solutions that were developed to successfully overcome this major project challenge. In particular the use of the direct pipe technology at the Preston Sewerage Scheme provides an alternative solution for the UK pipeline industry as well as developing the portfolio of soils and technical capability of the direct pipe system.

The 866m twin pipe western river crossing element was successfully completed earlier than anticipated which reflected the integrated approach to providing an innovative, safe, efficient, robust and technologically advanced ground engineering alternative solution.

Key to the success was the close collaboration of KMI Water, client United Utilities, designers GHA Livigunn and pipe installation specialists Herrenknecht. The project won two prestigious UKSTT awards for Innovation and New Installation 2013.

The Editor & Publishers thank Adrian Owens, Contracts Manager with KMI Water, and Carl Sanders, Senior Project Manager with United Utilities, for providing the above article for publication.

Breakthrough at Shaft S6 - Courtesy of KMI Water

Herrenknecht direct pipe - machine assembly - Courtesy of KMI Water