Taking in the views

Bachy Soletanche's anchor, grout and mini-piling division was enlisted to carry out a two-phase stabilisation project on the conduit section of the Thirlmere aqueduct near Grassmere, writes project manager Andy Tucker

HIDDEN beneath the rolling hills of the Lake District and ending in Manchester is the Thirlmere Aqueduct. Its construction began in 1885 to quench the thirst of the city's burgeoning cotton industry. Hand-built and, at 134km, it is the longest gravity-fed aqueduct in the country, making it a true engineering feat of the Victorian era.

To ensure it stays that way, and in working condition, United Utilities, which owns Thirlmere aqueduct, has been conducting a detailed maintenance programme, which has seen the aqueduct close down for short lengths of time over a five-year period.

The purpose of the project was to stabilise the conduit section of the Thirlmere Aqueduct at Nab Scar and undertake internal concrete repairs on behalf of United Utilities. At this section, spoil originally arising from sections of the tunnel was used to cover the aqueduct. As time has gone by, the spoil has weakened, posing the danger of the slope moving and causing damage to the aqueduct.

A permanent solution was required to support the conduit, and remove any potential ground movement immediately above and below it; all of which required moving the necessary machinery up the 440m-high Nab Scar fell and creating a platform off the down slope.

Originally, our works were to be conducted during a four-week outage period in October 2009, and another outage in October 2010. However, we demonstrated to the client that works could be completed confidently in one extended visit. This was thanks to a successful conclusion of the repair works and monitoring installations completed inside the aqueduct during the planned outage, alongside some very delicate piling operations.

The project was conducted in three key steps.

1. Permeation grouting

The first stage was to stabilise the ground immediately adjacent to the conduit on the down-slope side to provide temporary support to the structure and minimise the loss of fine materials during subsequent construction activities. This ground could not, in our view, be strengthened in any other way than permeation grouting.

Our team installed three rows of Tube a Manchettes (Tams) grout holes into the ground, from which to grout. These were spaced at even centres, but the holes staggered. The holes were drilled using a foam flushing medium with a 150mm-diameter rotary-cased technique down to the rock head. The Tams were installed in the casing after withdrawing the drill rods and the casing filled with sleeve grout. The casing was then slowly withdrawn while keeping the hole topped up with sleeve grout.

Grouting was carried out by injecting a specific quantity of grout in each Tam sleeve, commencing at the bottom of the hole and grouting each sleeve in turn to the uppermost sleeve. Grout pressure was controlled by automated grout-pump processes,

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A platform off a 40° cliff face had to be installed to enable remedial works to proceed

Bachy Soletanche working on a 440m fell in Nab Scar, Lake District, to conduct remedial works on the United Utilities-owned Thirlmere Aqueduct

"A permanent solution was required to support the conduit, and remove any potential ground movement above and below it... moving the machinery up the 440m-high Nab Scar"

using Bachy Soletanche's own unique grout-pressure control software. Grouting was automatically terminated when the specified volume was injected or the specified pressure reached.

Operational control of the design and reporting of grouting was implemented by the application of Bachy Soletanche's systems. These processes are robust and well proven, developed over the past 15 years, and are used on many projects worldwide. Several developments and refinements of these control systems have resulted from Bachy Soletanche's continuous experience with compensation grouting over the period 1992-2002.

The core elements of these systems are:

- A series of technical developments in the design and construction of grouting pumps and equipment, enabling the automation of pump performance throughout the injection process to both control and record the injection process in real-time;
- A series of software packages for the design and control of grout injections, for the recording and interpretation of data, and for the presentation of interpretive reports and production reports;
- Monitoring equipment, data capture, analysis, and reporting equipment and software for recording structural and soil displacements, calculating settlement volumes and assessing grouting volumes.

The amalgamation of these three areas has resulted in a series of technical modules, which are used in various combinations, depending on the requirements of individual work sites. For consolidation grouting, a number of these modules provide essential tools for controlling the process, as used in the monitoring section of the project.

2. Internal ground reinforcement

At the second stage, we were to provide permanent support to the down-slope wall of the conduit. Our solution was to install a row of paired passive piles, with one vertical pile and one inclined pile in each pair to form an 'A' frame. An individual, low-profile pile cap at the surface of the slope joins the two piles in any pair.

The arrangement of the two piles in each pair is such that the vertical pile is in compression and the inclined pile is in tension, with the pile cap acting as a pin joint, connecting the two piles together and enabling the pair to act as a unit. Each pile is

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founded well into solid rock below the fill and has a grouted zone around it in the fill to provide further stiffening against any bending load applied by ground movement.

3. External ground reinforcement

The final step was to stabilise the material between the permanent down slope with external support forces in the event of further ground movement. These were placed as close as possible to the outside wall of the conduit, subject to the imposed limitations of minimum separation. This reduces the amount of initial fill stabilisation and in the creation of the 'thrust block' after installation of the support members.

MONITORING

During the course of the works, great care had to be taken to ensure nothing would cause further movement of the ground surrounding the aqueduct and/or damage it. This is where our in-house monitoring specialists, Sol Data (part of Bachy Soletanche Group), were employed to provide systems that could monitor and survey the conduit structure and the slope hillside in real-time.

Monitoring was split into two sections: monitoring the hill slope and the aqueduct structure.

MONITORING THE HILL SLOPE

Firstly, we monitored potential, deep-seated movement within the hill slope via vertical in-place inclinometer (VIPI) instruments. These were installed within a number of boreholes that were specifically installed at locations above and below the aqueduct.

The boreholes were installed through the fill material and into solid rock to a maximum depth of 8m; this gave the project an added advantage in that the VIPI instruments were installed in 2m lengths in the borehole, providing data at several key points. The VIPIs were connected back to a data-logger system. The sensors automatically record lateral displacement of the slope or changes in the vertical profile of the inclinometer casing.

The second part of the slope monitoring was to provide slope-surface monitoring. The project specification called for very accurate tolerances for

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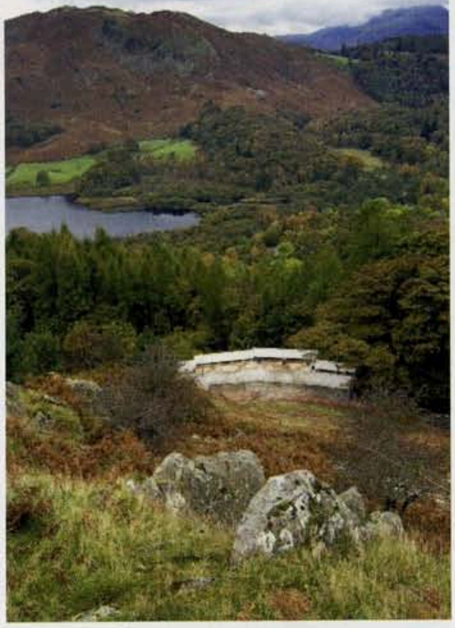

Thirlmere aqueduct is hidden beneath the rolling hills of the Lake District

this element of the work. Sol Data provided the Cyclops system – a fully automated, optical monitoring system comprising a motorised total station, controlled by computer – that observed prismatic targets that were fixed to the surface of the hill slope under observation.

The Cyclops is used for real-time monitoring of vertical and lateral displacements to accuracies better than 1mm. The Cyclops system brought the added benefits of reduced resource costs, increased monitoring observation frequency and reduced risk on site.

MONITORING THE AQUEDUCT STRUCTURE

Monitoring the aqueduct structure was a critical activity during the outage period as there was limited time available to install the instruments before Thirlmere Aqueduct returned to service. The equipment installed included, precise levelling points, rod extensometers, electro-levels, in-place inclinometers, tilt meters and crack width gauges.

The responsibility for gathering, analysis and presenting the monitoring was with Sol Data. However, as it is part of Bachy Soletanche Group, there is complete compatibility in the handling, analysis, reporting and presentation of data by both companies. This greatly facilitates the rapid analysis and interpretation of data, leading to clearer understanding of the grouting process and its effects, and closer control of site operations.

CONCLUSION

This project required great accuracy in its execution, yet the techniques carried out also had to consider the logistical challenges, and health and safety aspects of transporting the required equipment up the Nab Scar fell. We envisaged several ways of getting the equipment up, even briefly considering using helicopters.

However, our whole concept was based around the cost-effective use of mini-piling rigs and grouting equipment, so, with some very ingenious design solutions, we successfully got the equipment up there. Due to extending the original outage, our team stayed on site until March to complete the £1 million project.

Geotechnics

Following flooding and landslip, Geotechnics had to protect the famous Daniels Mill in Bridgnorth during stabilisation works on nearby slopes

THE historic Daniels Mill to the south of Bridgnorth in Shropshire was hit by the twin disasters of flooding and landslip during extreme rainfall in the summer of 2007.

These problems were associated with those of the adjacent Severn Valley Railway, which passes to the west of the site on a viaduct over the valley of the stream serving the mill. This sensitive earthworks project was conceived and directed by Geotechnics to protect this famous Mill, and maintain support to the viaduct abutment.

The landslip effected one of the outbuildings, and stabilisation works were required to address both the slope behind the building and the slopes and buttress associated with the viaduct. The mill is sited in a heritage and conservation area, and therefore required innovative and sensitive remediation to recognise the historic environment, access constraints, sustainability issues and the maintenance of stability to the viaduct during construction. Reinforced soil was seen as the optimum solution.

Geotechnics became involved when chairman and chief engineer Len Threadgold was asked, on behalf of the Mill owner's insurers, to inspect the slope failure, and examine the causes and potential solutions. Following a ground investigation, failure of the superficial deposits and weathered Keele Beds (associated with high groundwater levels) was identified. A potential solution involving the construction of a reinforced soil slope was analysed by Geotechnics' Trevor Hardie.

The solution was further developed by Paul Thurlwell of P&S Consulting Engineers (PaSCoE), which undertook the detailed design of the reinforced soil wall and slope, and close monitoring and supervision of the work on site. This allowed changes to the design and construction to be implemented as the work proceeded, following exposure of soil and rock in the slope, and minimised the volume of soil to be excavated and exported from the site. It also minimised the volume of imported material required, further adding to the sustainability of the solution. Exposure of the viaduct abutment foundations resulted in changes to the slope profile near the abutment to maintain stability.

Specialist environmental contractor WM Longreach was appointed to carry out the complex stabilisation works. Due to the access constraints, its solution was to use a long-reach excavator for the slope reconstruction, provided its own long-reach plant business, WM Plant Hire. The machine to be used was selected by Damian McGettrick following his site meeting with Len Threadgold. This was fitted with a tilting bucket attachment and could sit in one location to remove the failed material and subsequently place the new fill material in layers.