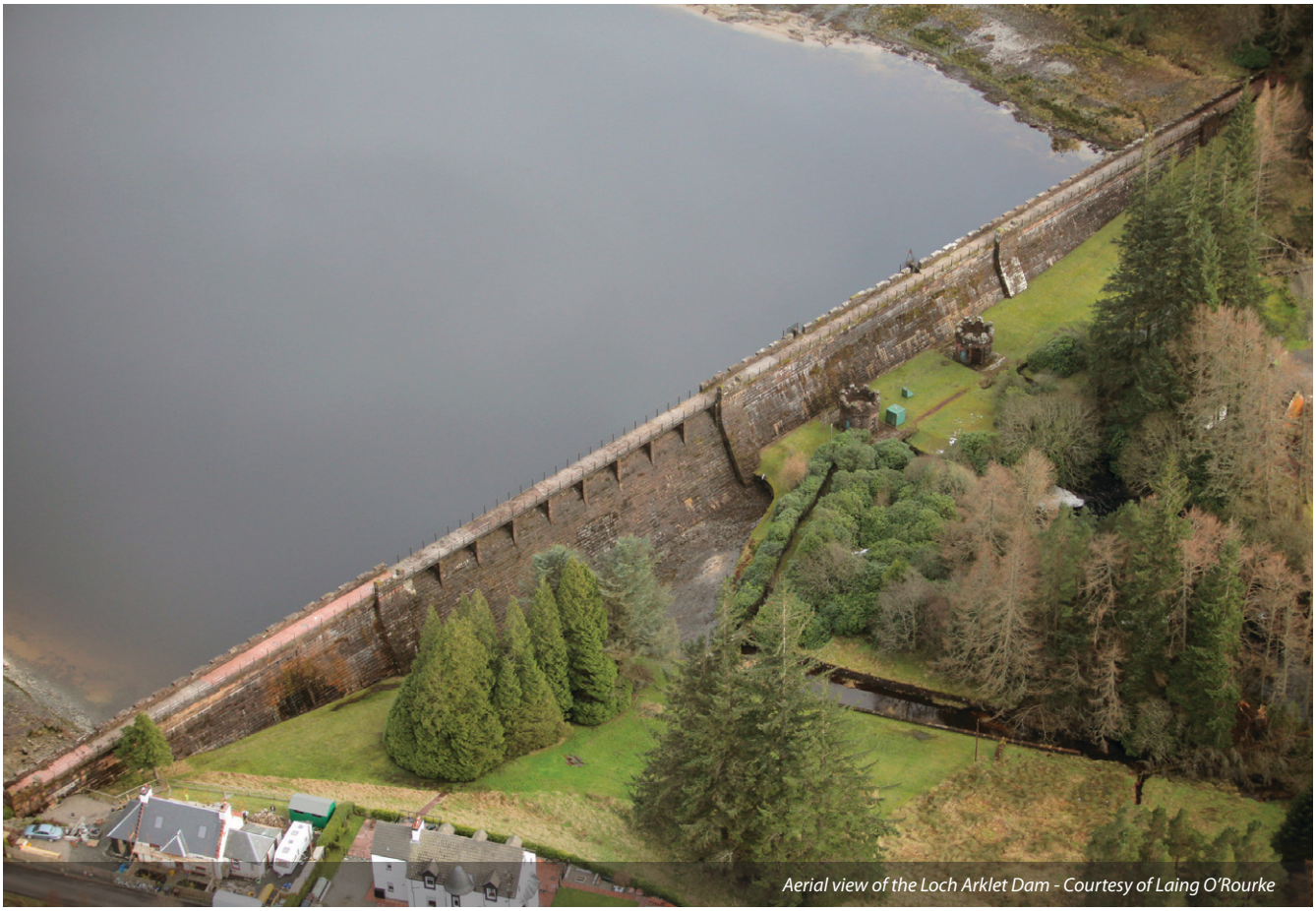
Loch Arklet Reservoir

largest anchoring scheme for Scottish Water

by Jeff Forrester

Loch Arklet is a small loch lying between Loch Katrine to the east and Loch Lomond to the west. Loch Arklet Dam was commissioned for the Corporation of Glasgow and built in 1909-1914 by JR Sutherland, engineer and Charles Brand & Son, contractors. It is a well-detailed dam which has a picturesque and prominent position in the landscape and is a relatively early example of concrete construction in Scotland. The masonry faced concrete gravity dam is 320.04m in length and is faced with Annan freestone. The dam is 10.67m in height and 3.35m in depth at the top. There are two valve houses that regulate compensation flow; the dam sits 146m above sea level. The level of Loch Arklet was raised by the building of the dam in 1914, erected to supply Glasgow with water in the early part of the 20th century. Water is fed by gravity to Katrine which in turn feeds Milngavie WTW.



Aerial view of the Loch Arklet Dam - Courtesy of Laing O'Rourke

Project drivers

After 100 years of service, owner Scottish Water reviewed the dam's future, assisted by Jacobs Engineering as part of its role in Scottish Water Solutions. Inspections in 2003 and 2009 highlighted increased concerns about leakage and movement of pilasters and masonry facing.

Loch Arklet Dam was then identified as an asset requiring capital maintenance and investment under the Scottish Water (SW) SR10 programme to ensure the Reservoir complies with the Reservoirs Act 1975. Investment was needed in order to address the set drivers: 3B-CM-RES Reservoirs Act compliance and asset risk reduction.

The main works were recommended by the All Reservoirs Panel Engineer (ARPE) after his inspection of the reservoir in 2009, as a measure in the interests of safety. This recommendation has the force of law and it required Scottish Water to complete the work within a specified timescale and under the supervision & certification of an ARPE.

Solution and brief description of the works

The works comprise the following items:

- Design and installation of 64 (N0.) rock anchors from the dam crest through the body of the structure and into underlying rock foundation depths varying from 25m to 52m, including:
  - All temporary works necessary to permit the anchors to be installed and tested. (includes scaffolding and access roads).
- Replacement of span 1 of the overflow bridge and repairs to the abutment.

- Repairs to the downstream masonry facing blocks between the valve houses.
- Capital maintenance items, including:
  - Removal of vegetation between masonry blocks on downstream overflow section.
  - Replacing the missing section of handrail at the bridge over the overflow outlet channel.
  - Repair to pitching to the right-hand upstream abutment area.
- Installation of monitoring equipment.
- Replacement of existing piezometer covers on dam crest.

This process of drilling into the dam structure is one of the largest that has been attempted in the UK, with the anchor stressing one of the largest in Europe. The work is being completed by Expanded's sub-contractor BAM Ritchies.

Logistics and challenges

The site is very remote and is reached from the town of Aberfoyle via an unclassified road much of which is uneven single track with passing places, tight corners, blind dips and locally steep gradients. With respect to traffic management, Laing O'Rourke had to liaise with the delivery and transport companies in order to reduce delivery vehicle sizes due to the access route road conditions.

Critical site logistics were challenging since loch water levels prevented floating plant and one damaged spillway viaduct section had already been removed.

The works have been completed on the top of the dam which is 2.7m, making access very restrictive and challenging, adding risks of working at height, working beside water, rotating drill rigs and plant movement.

Environmental

Due to the proximity of the existing reservoir sediment management and environmental protection procedures were of paramount importance and needed to be put in place for all activities. These included the use of a temporary matting system, silt fencing, use of Siltbuster ph correction unit and straw bales, in various locations. All activities had to be planned and organised to reduce the risk of an environmental incident.

The ecology aspects were key to delivering a successful project. Early surveys identified both otters and water voles in the site footprint. All site staff were given awareness toolbox talks on the protected species. To avoid entrapment or harm to otters, all excavations were covered at the end of each day and where deep excavations occurred, a mammal ladder was installed to allow means of escape from the trench.

All open pipes were capped to ensure that otters could not enter and all works were conducted within daylight hours to avoid times when otters were active.

Mitigation included leaving straw bales in situ until a post construction survey could be carried out. Site staff were praised by Scottish Water's ecologist for the careful approach.

Engineering

Ground anchor installation is a specialist activity. Loch Arklet has improved current best practice by bespoke drilling and installation techniques within site constraints. The ground anchors were installed by BAM Ritchies, a company with extensive dam ground anchor experience.

After 100 years, the dam has been repaired, strengthened and life extended by post-tensioning using 64 high capacity ground anchors, some of the strongest in the UK. This cost effective solution allowed uninterrupted use and ongoing social value.

Drilling on the crest of the Dam with the restricted access
Courtesy of BAM Ritchies

BAM Ritchies undertook the drilling, installation and testing of the 64 (No.) vertical high capacity ground anchors through the concrete core of the dam and into the underlying bedrock. With between 22 to 27 (No.) strands and capacities rising from 3,000 to 4,000kN, these are some of the highest capacity ground anchors ever installed in the UK.

As a result, the logistical arrangements for the three primary operations of drilling, anchor installation and stressing was critical. The anchors are double corrosion protected, in accordance with BS8081, provided by 235mm external diameter corrugated plastic sheathing, with re-stressable heads enabling future re-stressing.

These were supplied by Dywidag Systems. Specialist handling was needed because the anchors were up to 54.5m long and weighed up to 2.2tonne.

A protective nose cone was fitted to the base of the anchors and each was delivered to site on special ring frames, which fit onto BAM Ritchies anchor spooling wheel. Due to the narrow and undulating single track road from nearby Aberfoyle, articulated lorries could not be used, so only four anchors in their frames were delivered at a time.

Manhole chambers were constructed in the dam using large diameter coring and saw cutting in advance of the anchor hole drilling. Bam Ritchies' Hutte KBR 203 drilling rig with a Numa RC100 Challenger down-the-hole hammer was then used to drill the 311mm diameter anchor holes into the schist bedrock, which includes quartz veins.

To ensure high levels of environmental control, reverse circulation flush was used, with disposal of the cuttings and water arisings handled by Expanded through a complex system of dewatering, skips and tankers.

Using BAM Ritchies' specialist hydraulically-powered anchor spooling device, the anchors were installed by flooding the sheathing internally to overcome buoyancy.

Since the anchors need to be spooled, they were supplied as grout in situ anchors, where the fixed length is not factory grouted (as would be the case in many unrestricted installations). Instead, bond length grout was placed on site, displacing the internal water by pumping via a tremie line. The bond lengths vary between 8m and 9.5m.

The external grout was placed by tremie. All grout has design strength of 40N/mm^2 but to achieve high early strengths and enable quick stressing, a higher strength grout – 50N/mm^2 – was used on site.

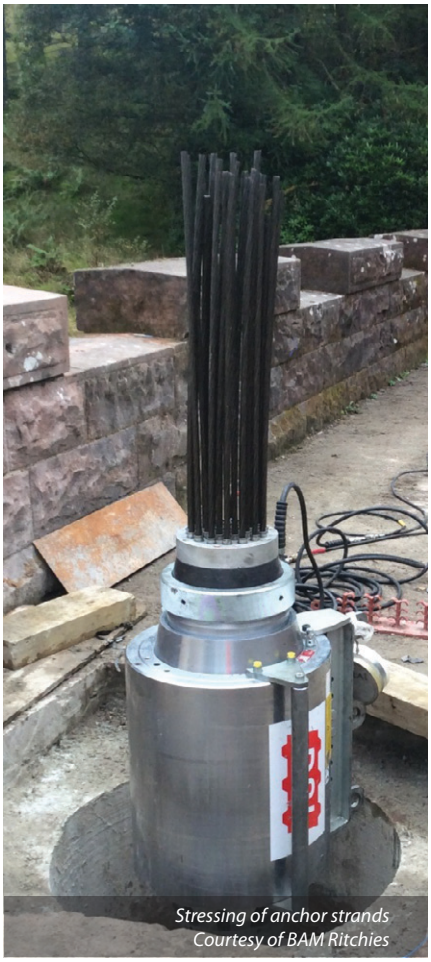
Since each anchor has a large head block with up to 27 wedges, the strands are required to splay out at the proximal end: therefore control of the wash back of primary grout and secondary grout was very important before making up the head termination. A specialist suction pump was used, so that the primary and secondary grout levels could be controlled precisely.

In advance of the main works, the team installed and tested a trial anchor to prove BAM Ritchies' in-house design. Three of the working anchors were also *'suitability'* tested and all anchors have *'acceptance'* tests at 1.5 times design working load to BS EN 1537.

A 6,800kN long stroke jack with internal gripping wedges was brought in from Dywidag in Germany to test and stress the anchors, which were locked off at 110% of working load. This is thought to be the highest capacity anchor stressing jack in the UK at the moment and, since it operates differently from conventional strand anchor jacks, the site team had to develop modified stressing and testing procedures.

Anchors being installed using the spooling wheel - Courtesy of LOR

Drill head being positioned to commence drilling - Courtesy of BAM Ritchies)



Stressing of anchor strands Courtesy of BAM Ritchies

All anchor heads are fitted with sealed corrosion-protected 'top hats' within the manholes. A major benefit to Scottish Water is that the anchors have re-stressable head details; in other words, long caps to accommodate 450mm protruding strands. This enables re-stressing of the entire anchor or individual strands in the future, if any drop off of load is detected.

The site team report that a collaborative approach, with Scottish Water Solutions, Expanded and BAM Ritchies working closely together, is helping work progress towards successful completion in June 2015.

Conclusion

This successful project has ensured that a key asset continues providing a fundamental for life, namely water to Glasgow, Scotland's largest community. By careful planning and collaborative working, project and financial management has been excellent. All parties worked together using optimum complementary skills, enabling effective management and construction efficiencies on this remote Scottish project.

By giving a key Scottish asset a longer life instead of rebuilding, the engineering involved has gone beyond the technical to make an excellent contribution to the sustainable creation. It has improved and nurtured the physical and social environment by delivering whole life value for money in a sustainable manner.

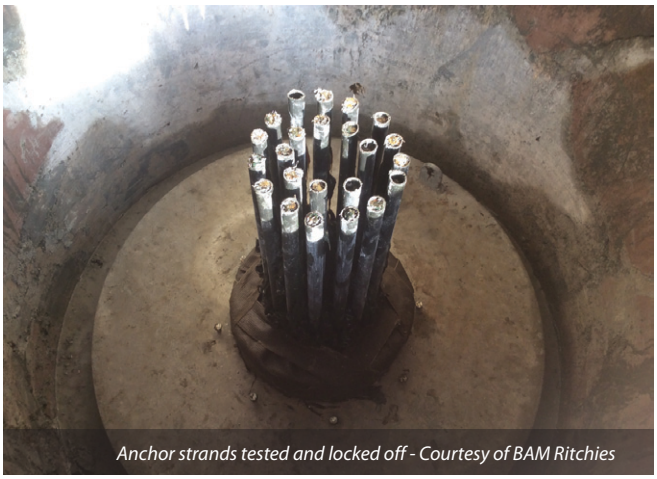
The Project gained CAPEX 3 approval in May 2014; construction started in July 2014 by the Scottish Water Solutions (SWS) in-house delivery partners, Expanded and Jacobs. The Project is expected to be accepted and signed off by The ARPE in June 2015.

Steven McConnachie, Scottish Water Solutions Delivery Manager. said:

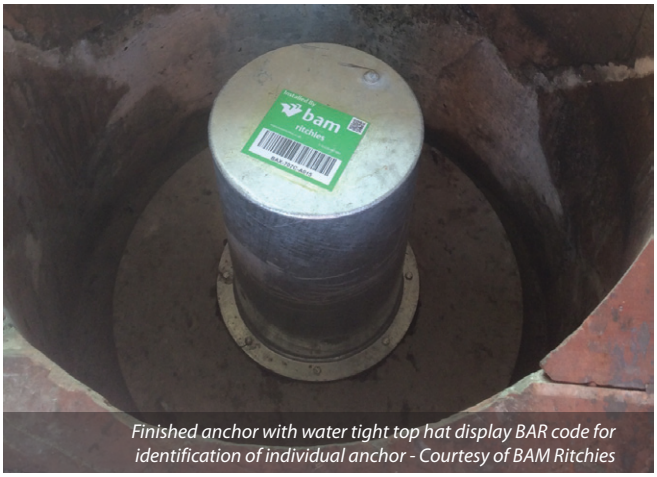
> *"I am delighted with the efforts of all involved in this project. The project team not only successfully and safely delivered the project output but displayed real partnering, care and pride in ensuring that the client received a high quality installation. In addition to the excellent work on site the project team went the extra mile to offer up solutions to some of the challenges faced and to ensure local residents were kept up to date with progress on site. A job well done."*

The total investment of the project was in the region of £3m.

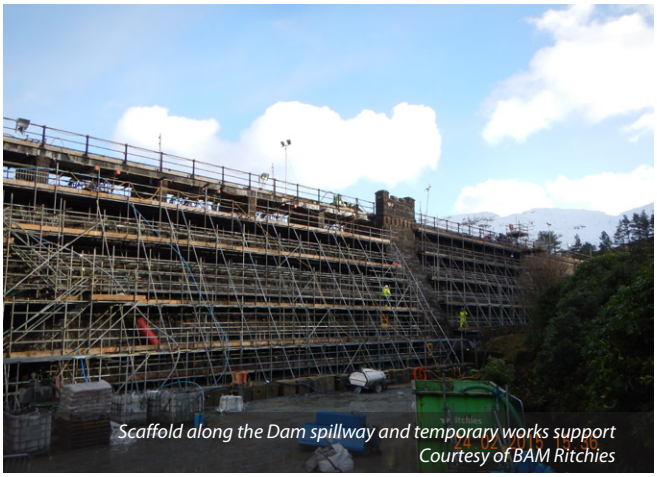
The editor and publishers wthank Jeff Forrester, Project Manager with Expanded, for providing the above article for publication. The author would like to thank Scottish Water, Scottish Water Solutions, Expanded, Jacobs Solutions and BAM Ritchies, Dywidag-Systems and Siltbuster for their assistance in this paper.



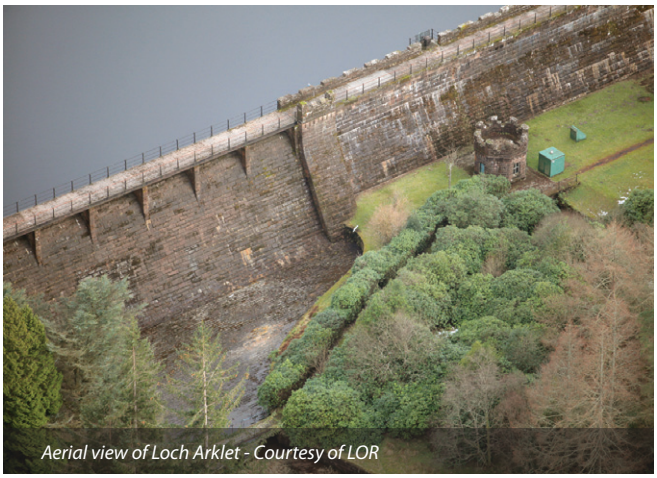
Anchor strands tested and locked off - Courtesy of BAM Ritchies



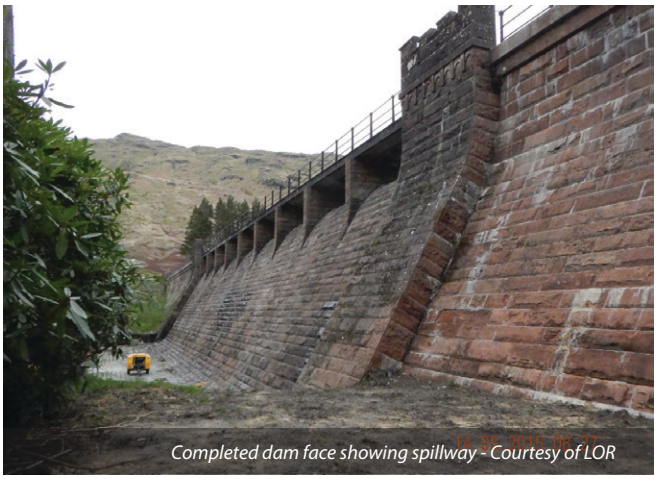
Finished anchor with water tight top hat display BAR code for identification of individual anchor - Courtesy of BAM Ritchies



Scaffold along the Dam spillway and temporary works support Courtesy of BAM Ritchies



Aerial view of Loch Arklet - Courtesy of LOR



Completed dam face showing spillway - Courtesy of LOR