Penwhapple Reservoir

first ever precast spillway for Scottish Water

by Scott Falconer BSc(Hons)

Penwhapple Reservoir is located approximately 8km east of Girvan, South Ayrshire in a remote location in the Barr Hills. The site is wholly contained within Scottish Water owned lands. Under the Scottish Water (SW) SR10 programme, Penwhapple Reservoir spillway was identified as an asset that required capital maintenance, making sure it complied 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 2008, 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.

The new precast spillway at Penwhapple Reservoir - Courtesy of LOR

Penwhapple Reservoir - Courtesy of LOR

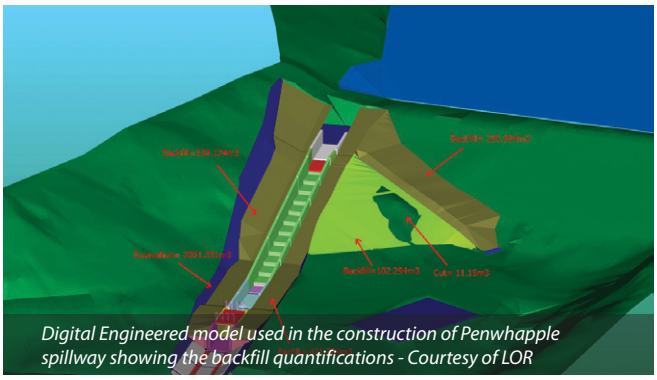
New spillway at Penwhapple Reservoir - Courtesy of LOR

Completed spillway - Courtesy LOR

Brief description of the works

Scottish Water awarded Laing O'Rourke the contract for the construction of a new spillway at an offset from the original spillway location. The upgrade works included:

- Construction of a new 100m long, 3m wide, 2.5m high reinforced concrete spillway channel predominantly in precast slab and twinwall units with two areas constructed in situ that connect the existing overflow to the downstream channel. At the downstream end, armour stone was placed to dissipate flow energy and protect the adjacent B734 road embankment from erosion.
- The new spillway being fully rock anchored into the existing bedrock.
- Realignment of the existing access track over the spillway to the existing parking area, and the construction of a new 5m wide precast concrete access bridge to cross the new spillway. The bridge is designed for construction traffic (max 100t vehicle with 16.5t axle load). The bridge carries diverted services (telemetry, electricity supply). 2 (No.) raw water supply pipes are diverted up and over the new channel.
- Removal of an existing small footbridge, re-routing of services including the main water supply for Girvan and a smaller feed to Grant's distillery and relocating some electrical/telemetry cable.
- Infilling the old spillway with fill from the new spillway excavation.



Digital Engineered model used in the construction of Penwhapple spillway showing the backfill quantifications - Courtesy of LOR


Stepped base slab being manufactured at Bison's factory Courtesy of Laing O'Rourke


Precast steps at Bison's factory - Courtesy of Laing O'Rourke


Spillway step being landed - Courtesy of Laing O'Rourke


Trapezoidal spillway mouth temporary supports - Courtesy of LOR

- Minor drainage, concrete and fencing repairs to the existing spillway channel at the overflow.
- Installation of new riverbed protection at the mouth of the new downstream channel.
- Regulation and rising of the dam crest between the valve tower and spillway to raise the low crest level in this area by ~150mm.

Logistics

The site at Penwhapple is located in the South Ayrshire Barr Hills with narrow country roads and load and height restrictions imposed by the local councils; all of which meant that access to site was restricted.

The entry route was adjusted to the new access bridge, but with a tight turn over the bridge into site, it was important that Laing O'Rourke managed traffic effectively. They liaised with delivery and transport companies stipulating that smaller vehicles were needed and due to limited lay down and storage space, implemented a *just-in-time* delivery programme.

The *just-in-time* delivery programme managed space as effectively as possible and was coordinated in conjunction with the precast manufacturers, Bison Manufacturing and Explore Manufacturing, ensuring the precast products were delivered and then installed on the same day.

The limited lay down and storage areas were crucial factors in Laing O'Rourke's decision to design the new spillway works using Design for Manufacture and Assembly (DfMA).

Delivery approach

Initially the project was to be undertaken using traditional build methods using in situ reinforced concrete for the base slabs and wall pours. Laing O'Rourke, Jacobs and Scottish Water worked together to develop the unique, robust DfMA design solution and construction approach enabling the design phase to be agreed much earlier reducing the programme, reducing on-site working hours, which made the construction inherently safer, and reducing the site carbon footprint through the early involvement in design allowing raw material wastage to be driven out from the outset.

The DfMA construction components for the spillway base slabs and twinwall sections greatly reduced the need for on-site shuttering and steel fixing activities and reduced requirement for working space excavations, which was key given the logistics and the lack of storage areas on the site.

The use of Digital Engineering (DE) on the project enabled the staff and workforce to visualise the more complex elements of the Penwhapple Spillway works and analyse pre-construction identifying interface issues.

Laing O'Rourke's Digital Engineering team was able to undertake quick and effective digital design models which allowed for cut and fill quantities to be determined. Site compound locations were coordinated.

Due to the site's remote location it allowed the team to quantify costs for materials removal from site and backfill quantities. This allowed designs of final ground profiles to be changed to accommodate the surplus excavated material on site and reduce the off-site transportation and disposal to landfill costs, therefore allowing the site to initiate changes and interventions in the virtual world rather than costly and time consuming reworking and procurement route delays.

Through the use of the DE, cross sections and rotational virtual tours were incorporated into visual task sheets to promote safe, right first time construction.

Engineering

Constructing the new spillway using DfMA precast sections has resulted in almost 90% of the project being produced off site in factory conditions and brought to site as and when required.

This has been essential due to the complexity of the site logistics for storage of materials. It has also ensured that the finished products are to the highest standards which are required in this water industry specification structure.

This DfMA solution was utilised for the precast base units (Bison), twinwall (Explore Manufacturing) and ductile iron pipework (CHt), all of which being manufactured in factory conditions meant less time was required on site for in situ works, less cost for temporary works materials and less manpower on site to install the DfMA items.

Construction phase

The project suffered two major external party setbacks which pushed the programme from a summer activity to a winter activity. This placed additional pressure on the site team to manage concreting and grouting in sub zero temperatures. The initial section of the works focused on the in situ RC concrete bridge, which paved the way for all pipe and road diversions and subsequent excavations.

It was at this time that the concrete mix design had to be challenged. It was noted that the structure had to be backfilled only when the concrete had achieved full strength. This was only identified after the team were on site. As such the initial mix which was a blended C40/50 IIIA 40% GGBS for all in situ works meant a backfill duration of 28 days.

This could have had a detrimental effect on the programme duration at the latter stages of the contract. As such it was altered to a C40/50 CEM 1 mix allowing higher strength gains to be achieved early and thus the follow on backfilling operations could be reduced in time on the overall programme.

The next phase of works was to head north and south of the in situ RC bridge section.

South of the bridge was the trapezoidal spillway section which opened up to the new entry point to the Penwhapple Burn and also included the temporary damming and over-pumping of the burn, allowing the riverbed to be broken out and re-profiled using 1-2T rock armour stones. The natural width of the burn, together with the tail swing of the excavators that were brought in to break out the burn's bed rock prior to rock armour installation proved challenging.

The trapezoidal spillway section was also challenging, requiring blinding on a slope to a strict tolerance to allow for easier landing and levelling of the precast base units.

The section to the north of the bridge was the main stepped culvert section of the new spillway which consisted of a lower and upper sloped slab section and 12 (No.) intermediate steps all of which were constructed off site and delivered in time for placing. This section was restricted on two fronts since progress was not possible until approval was given to isolate and divert the raw water supplies through the new ductile iron pipework and also due to overhead cables at the spillway tie in, which spanned the full crest of the existing dam.

Throughout this whole 70m section it was necessary to follow the original rock profile, and once either broken out or cleared off, would be blinded prior to the base slab units being installed. This sequence repeated up the full length of the new spillway until the upper in situ tie in section to the original spillway.

Trapezoidal spillway base slab being installed - Courtesy of Laing O'Rourke


Rock anchor bar and pocket in slab - Courtesy of Laing O'Rourke


Step spillway bases, prior to pouring infill stitches and anchoring Courtesy of Laing O'Rourke


Twinwall delivery prior to lift - Courtesy of LOR


Twinwall being Installed - Courtesy of LOR


Completed spillway - Courtesy of Laing O'Rourke

Prior to the installation of the twinwall wall units the precast base slabs required anchoring to bedrock. These works along with grouting the underside of the precast slabs and anchor pockets were undertaken by specialist BAM Ritichies. In all there were 69 (No.) 32mm x 4m long stainless steel anchor rods drilled and anchored throughout.

There was also a requirement when constructing the tie-in to the existing spillway that the existing dam wall was retained. A simple but effective kingpost and prop solution was developed by contractor LB Foundations which required approval from Laing O'Rourke's temporary works department and the ARPE prior to allowing the spillway break-in to commence.

The unique twinwall PC wall units allowed progress throughout a harsh winter in the Scottish hills. Once the twinwall units were in place, the follow-on joinery works to shutter up between the twinwall base and vertical joints and copes could be undertaken in any weather condition.

Due to the site location, a significant programme risk was always going to be wind related. During the construction of the full spillway it was essential that cranage was maintained on site to capitalise on any lull in weather and as such and after analysing the cost differences between crawler and mobile cranage an 80T Hitachi Sumitomo 33.5m Jib crawler crane was located on site. This gave diversity during off loading and installation due to its ability to travel to different areas of the site. This was provided with a competent operator through Select Plant Ltd.

Conclusion

This project was innovative from the pre planning stage. Under the guidance and experience of the Laing O'Rourke design manager the design was developed using DfMA and has become the first spillway of its kind for Scottish Water.

Throughout the project Laing O'Rourke maintained a good working relationship with Jacobs, Scottish Water and the Reservoir Engineer and by ensuring the structure was constructed to the highest possible standard, structural acceptance was accepted six weeks prior to contract completion.

The Project gained CAPEX 3 approval in June 2014 and construction started thereafter later In June 2014 by the Scottish Water Solutions (SWS) in-house delivery partners, Expanded and Jacobs. The Project was signed off by The All Reservoir Panel Engineer in April 2015 and finally completed and accepted in May 2015.

Graeme McInally, Head of Engineering with Scottish Water said:

> *"This has been an excellent effort by the team and I would like to thank you for the effort and manner by which this has been achieved, particularly given the challenges that have been overcome during construction. The works have been effectively and safely executed, programme recovery was achieved and the standard of workmanship is high. The communications have been good and all parties have worked well together. This has been a good example of how a project can be delivered."*

The total investment of the project was in the region of £5.7m

The editor and publishers would like to thank Scott Falconer, Senior Engineer with Expanded, for providing the above article for publication.

The author would like to thank Scottish Water, Scottish Water solutions, Jacobs, Laing O'Rourke's Explore Manufacturing and Bison Manufacturing Ltd for their assistance in this paper.