Case studies from challenging pipes and valves works

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SYNOPSIS With current UK dam stock ageing and infrastructure meeting or surpassing its intended asset life, critical maintenance and replacement of key pipework and valves becomes necessary. The design and construction of historic assets may not have considered aspects such as ease of operation, maintenance and replacement. This paper provides case studies of recent works completed with particularly challenging environments, from projects in Wales.

Based upon multiple examples of physical projects undertaken, this paper will look into the constraints, planning, decision making involved leading up to and executing improvement works, along with the temporary works, permanent works and commissioning. The intention of this paper is to share the learnings taken from these works, which may be of use to others in the industry.

The client for the schemes presented was Dŵr Cymru Welsh Water (DCWW), and the Principal Designer and Principal Contractor was Mott MacDonald Bentley (MMB) and Edwards Diving Services (EDS) as the diving contractor.

LLYN CELYN RESERVOIR

Llyn Celyn reservoir is situated approximately 7km north of Bala in North Wales. The reservoir is formed by a gravel-fill embankment, 680m wide and 45m high, the reservoir construction was completed in 1966. The dam is a category A dam as defined by Floods and Reservoir Safety, 4th Edition (ICE, 2015) and has a capacity of approximately 81,000,000m^3. The reservoir is owned and operated DCWW, but the water level management and releases are the responsibility of Natural Resources Wales (NRW) as part of the Dee Regulation Scheme.

MMB undertook investigations to assess the conditions of the valves on the site, and reviewed the drawdown capacity against the latest guidance (EA, 2017), resulting in the following works:

- Replace existing inoperable 60-year-old 36-inch butterfly valve (V5), with a 900mm gate valve, located approximately 300m into the dam tunnel. The discharge capacity of the 36-inch scour pipeline is circa 6.4m^3/s.
- Replace the existing 2Nr 60-year-old 52-inch fixed cone valves (M1 and M2). The discharge capacity of the 66-inch supply pipeline is circa 22.4m^3/s.
- Installation of two new drawdown facilities built into the primary spillway.

Managing Risks for Dams and Reservoirs

Releases from Llyn Celyn reservoir play a vital role in the regulation of the River Dee, so these works required extensive collaborative planning with various stakeholders including specialist diving contractors and Natural Resources Wales (NRW) to ensure the works could be safely completed, whilst minimising the risk to water resource.

Two main pipeline systems are in place at Llyn Celyn, the 36” line associated with the scour and the 66” supply line associated with river regulation and the hydro turbines.

36” Valve Replacement (V5)

The function of V5 is to act as a burst control valve; shutting down the system should the downstream valves or pipework fail. The asset life of the original mechanically operated butterfly valve had lapsed, and the decision was made to replace this with an electrically actuated gate valve. In order to safely replace the valve, temporary isolations upstream of the 2Nr existing gate valves (S1 and S2) were installed to avoid working under single isolation, following HSE guidance (HSE, 2006) regarding the safe isolation of plant. The works were planned alongside EDS who developed a temporary isolation arrangement using inflatable bungs connected to steel plates. These were installed via a floating pontoon (Figure 1) lowered through a 1.5m diameter diving shaft in sections and re-assembled at depths of approximately 30m. The existing gate valves formed the primary isolation; negligible leakage passed the valves. The temporary bungs formed the secondary isolation, whilst the steel plates (Figure 2) formed a tertiary isolation should failure occur of the bung and gate valve downstream. Schematics of this are shown in Figures 3 and 4.

Figure 1. Pontoon

Figure 2. Temporary isolations

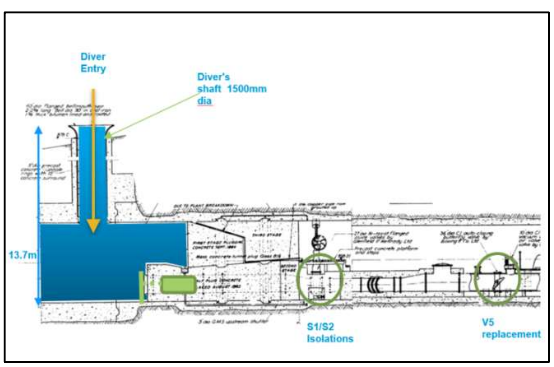

Figure 3. Section view of isolations

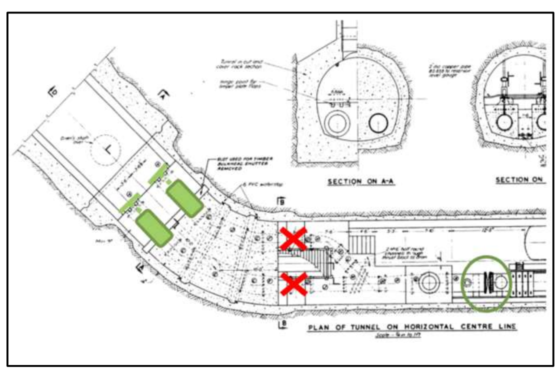

Figure 4. Plan view of isolations

Due to the location of the valve, additional temporary works and lifting arrangements were needed within the tunnel to facilitate the removal of the existing, and installation of the new valve/pipework arrangement. To facilitate this, a bespoke trolley and lifting gantry (Figure 5) system was installed by Mona Engineering, with the new gate valve weighing approximately 2.3 tonnes. The valve and pipework were lowered into the tunnel via an opening in the roof (Figure 6), transferred to the end of the tunnel on the trolley and lifted by the overhead gantry for the final 20m before being lowered into position and pipework connected (Figures 7 & 8). Given the constraints around isolation and diving, the works were carried out under Welsh Water's 'Gold Command' to monitor progress and resolve any identified issues. Upon completion of the works and the successful pressurisation of the system, divers removed the temporary isolations upstream.

Figure 5. Pipework removal

Figure 6. New valve being lowered being into tunnel

Figure 7. New valve installation

Figure 8. New pipework installation

52” discharge regulator valve replacement (M1 & M2)

Located at the downstream end of the 66” discharge system, the function of M1 and M2 is to act as terminal discharge valves, allowing flow regulation to the river. Similar to V5, the asset life these valves had expired and required replacing. The new 52-inch fixed cone valves were longer than the original valves and weighed over four tonnes. Given the size of the new valves and existing dimensional constraints, each valve could not be installed in its horizontal position. Installation via the stilling basin would have required emptying the stilling basin along with substantial over pumping, ranging between 1.5 to 16m^3/s to maintain statutory releases to the river. The project team worked with Mona Engineering to develop a bespoke lifting frame and methodology to lift and lower each valve into position with limited working room (Figure 9). The lift started with the valve in a horizontal position until it was within the building, transitioned to a 45-degree nosedive (Figure 10), before returning to horizontal as it was fixed to the upstream flange.

Figure 9. New valve installation

Figure 10. New valve installation

Drawdown enhancement valves

In order to enhance the drawdown capacity, two sets of two hydraulically actuated gate valves were installed, connected to new pipework through the primary spillway (drop shaft) wall, with trash screens at the intakes. The valves are fully submerged when the reservoir is at top water level and will be remotely operated by a hydraulic power unit (HPU) using a hand pump or petrol engine. The total discharge capacity of this system is circa 13m^3/s.

To enable the works a 9m high, 10m long scaffold was erected up and over the drop shaft spillway to provide access (Figure 11). With the works being within the reservoir basin, and within the existing spillway, the project team carefully considered the safety of the teams, the reservoir water level with NRW, and managed the risk associated with water resource.

All works were able to be undertaken during the period when the reservoir level was managed under NRW's Temporary Control Rules that were put in place to facilitate other works to construct an auxiliary spillway, and other valve replacement works described above.

Two 7m long 1.25m diameter cores were taken through the spillway to facilitate the pipework installation. A 70-tonne (Figure 12) crawler crane was used to lift the valves and lower them between the boat fender and spillway (Figures 13 & 14).

Figure 11. Scaffold installation

Figure 12. New valves and crane

Figure 13. New drawdown facility

Figure 14. New drawdown facility

LLANDEGFEDD RESERVOIR

Llandegfedd Reservoir is situated approximately 4km southeast of Pontypool. The reservoir is formed by an earth embankment dam across the valley of the Sor Brook which is a tributary of the River Usk and is quoted as having a capacity of 24,470,000m^3.

In order to enhance the drawdown capacity, a similar arrangement to Llyn Celyn was adopted, by the installation of three sets of 700mm rising spindle gate valves, installed at 6m below top water level, which discharge into a combined draw off / overflow tower (Figure 16).

The project was programmed around the annual drawdown of the reservoir. To facilitate the installation, taking account of a variable water level, a suspended scaffold (Figure 15) with lifting beams was constructed from the top of the valve tower to gain access to the working area. Barges were utilised to transfer the new valves and fittings to the tower.

The alternative solution to achieve the same output was to install large diameter siphons and run pipework to the downstream watercourse. Significant carbon and cost savings have been achieved through delivering this solution.

Figure 15. Scaffold arrangement

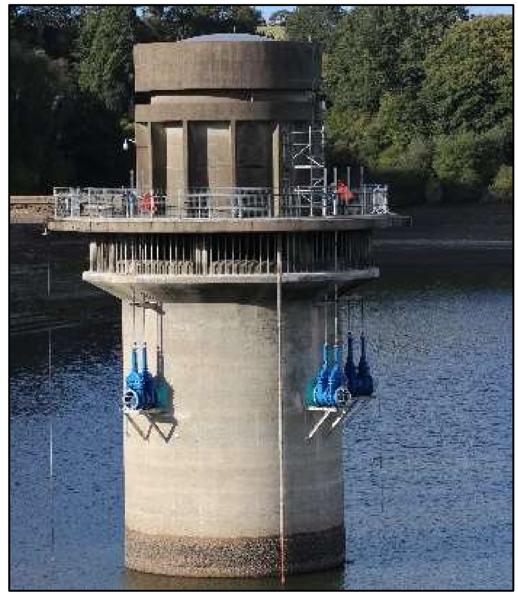

Figure 16. Installed drawdown facilities

USK RESERVOIR

Usk Reservoir is formed by an earth embankment dam, which completed constructed in 1955 with an approximate capacity of 12,268,000m^3. The dam is 480m in length, with a maximum height of 31m, and supplies raw water to Bryngwyn Water Treatment Works. The reservoir also provides compensation water to the River Usk which is classified as a Special Area of Conservation (SAC) and a Site of Special Scientific Interest (SSSI). The project focuses on the replacement of the reservoir draw-off pipework within the dam's outlet tunnel.

The project was to design and construct the replacement of both 18-inch scour mains in the 2.4m diameter horseshoe-shaped tunnel to improve emergency drawdown capacity and to provide a facility for enhanced releases to the River Usk. The works also included for 'enhanced releases' allow a range of discharges from the reservoir, with the aim of providing benefits to the River Usk and its habitats.

Optioneering

The historic pipework and tunnel characteristics caused a variety of constraints on the new system that needed to be considered when finalising the desired pipework arrangement. The project aimed to safely maximise the potential drawdown capacity whilst working within these constraints.

At the upstream end of the tunnel, the historic 18-inch pipes pass through a concrete plug, which could not be replaced without a full drawdown of the reservoir. Emptying the reservoir was not feasible due to Usk Reservoir supplying large volumes of raw water for supply and compensation purposes. As a result, the historic 18-inch pipe section formed a constraint on the design and construction of the permanent works.

A long list of options was developed, with the chosen solution to replace the twin 18-inch pipework with a single larger diameter pipe, offset to one side of the tunnel (Figure 16). This option maximised the outflow from the reservoir and maximised space for access, inspection and maintenance. To merge the two 18-inch pipe sections from the tunnel plug, an asymmetric manifold (Figure 15) was designed to combine the flow, with guard and duty valves upstream of this (Figure 17). Enhanced releases are provided by two flow control valves installed offline to the new drawdown pipework (Figure 18), that could be remotely operated using a telemetry system located in a new control kiosk. The tunnel is circa 190m long and has two 45-degree bends. To facilitate the construction and future maintenance, a screed was applied to the floor of the tunnel. A remote-controlled pipe bogie was utilised to move the pipe sections and valves to their final position.

Design considerations

Another consideration in the pipework design was to limit the flow velocity through the twin 18-inch sections of pipework and valves. If the system was operated for a prolonged duration with excessive velocities, there would be a risk of causing damage to the system through cavitation and excessive wear.

Figure 17. Manifold at bulkhead

Figure 18. Scour pipework and thrust block

Figure 19. Existing valves concreted in place

Figure 20. Discharge valves

Managing Risks for Dams and Reservoirs

Following the feasibility stage, the pipework system was further optimised to improve hydraulic efficiency whilst maintaining velocities to a suitable level. The manifold was optimised to achieve balanced flows between both legs, to prevent significantly higher velocities within a single leg. The results of the optimisations enabled the diameter of the larger pipework to be reduced from 900mm to 800mm diameter, leading to a reduction in material costs and embodied carbon by approximate 10%.

For details around the siphon temporary works installed as part of this scheme, see parallel paper by Carruthers and McAree (2024).

PANT-YR-EOS RESERVOIR

Pant-yr-Eos Reservoir is situated approximately 2km east of Risca in the City of Newport, Monmouthshire. It is impounded by a 27m high, 280m long embankment dam with clay core, and has a storage capacity of approximately 0.6Mm^3. The reservoir was completed in 1878 for provision of water supplies to Newport.

Improvement works were required to allow safe passage of the safety check flood, remedial works to the masonry spillway, improvements to the emergency scour system and a new filtered drainage blanket on the downstream embankment toe with associated instrumentation.

Drawdown Study and Remedial Works

The existing draw-off system consisted of a wet masonry valve shaft located a short distance upstream of the dam, which is accessed by a steel footbridge. The valve tower includes an open approach channel with parallel masonry walls through the upstream shoulder. The masonry walls are propped by an array of iron props. A masonry culvert passes through the core and under the downstream shoulder.

Within the valve shaft, gate valves at four levels convey water from the approach channel into the wet tower. From the base of the wet shaft, a gate valve conveys water into a 450mm pipeline through the masonry culvert to an outlet headwall at the downstream toe of the embankment, where it continues to the decommissioned water treatment works. This pipeline is capped off downstream of the treatment works. The water level in the reservoir was controlled via a 150mm washout, branching off the pipeline prior to the treatment works. Only the gate valve on the washout was operable, with the bottom draw-off valve and the valve at the base of the wet shaft seized in the open position.

The scour system consisted of a short length of 300mm pipe from the base of the approach channel, through the wet tower, discharging into the masonry culvert passing through the dam, at the base of the concrete plug. The scour valves were inoperable and buried under circa 4m of silt.

A drawdown assessment was completed and proposed various options to improve the drawdown capacity to meet the published UK guidance (EA, 2017). The options considered to increase drawdown capacity were compared by considering the technical, system resilience, construction, cost, programme, environmental, carbon, operational, and maintenance risks and impacts. The chosen solution to increase drawdown capacity converted the historic supply main into the emergency drawdown system with provisions to re-configure for supply if required in the future. This included replacing the four gate valves at the interface between the approach channel and wet shaft (Figures 21 and 22), and the valve at the bottom of the wet shaft. The existing pipework through the culvert was maintained, and a 450mm washout provided at the toe of the embankment with a stilling basin prior to discharging to the watercourse.

The original emergency scour system was then discontinued, enabling major environmental benefits in the prevention of large volume of silt removal. The works were undertaken with a partial drawdown of the reservoir utilising a suspended scaffold to replace the top three valves and underwater works using divers to replace the fourth valve.

The drawdown study was undertaken in conjunction with an assessment of the slope stability of the upstream face under rapid drawdown conditions. The study aimed to provide rates that the reservoir can be drawn down safely during a routine operational drawdown and an emergency drawdown, to help inform operational procedures and emergency planning.

In order to complete the works, various isolations were required at different stages of the scheme in order to safely deliver the works. With the reservoir partially drawn down, the 150mm washout valve isolated, with an additional blank plate installed, the adjacent feed to the treatment works was tapped to prove the downstream isolation was effective. This enabled divers to safely produce a template of the lowest valve's bespoke flange, which was used to fabricate and install a blank plate. This subsequently enabled works within the wet shaft and the embankment toe to progress. Isolations to replace the fourth valve were provided by the new valve at the base of the wet shaft and the new washout valves, with the pipeline being isolated from the decommissioned treatment works.

For details around the control of the water levels during the construction period, see parallel paper by Carruthers and McAree (2024).

Figure 21. Scour valves and spindles

Figure 22. Access within valve tower

UPPER CARNO

The dam at Upper Carno reservoir is a single earth embankment dam approximately 15m high and 280m long, and it impounds the Ebbw River. The reservoir is believed to date from around 1875 and currently impounds 3,400,000m^3 of water. Works were undertaken to many aspects of Upper Carno; for further details please see parallel paper by Swetman et al. (2024).

The drawdown facilities at Upper Carno consisted of a wet tunnel that conveyed water approximately 70m to a valve tower located immediately upstream of the dam crest. The valve tower was a congested space (2m x 4m plan area), which was split in half with a cast iron wall embedded into the valve tower. This wall allowed for a 'wet' upstream side and 'dry' downstream side which housed a pipework stack and all the draw-off valves.

From the valve tower, water was conveyed through a short section of scour pipeline, where it would discharge directly into the downstream tunnel (Figure 23) when operated. The supply system would convey water through pipework located in the tunnel, until it was beyond the footprint of the embankment, where it would be directly buried to the downstream water treatment works. The tunnel would continue to convey the water from the scour pipeline to the spillway located downstream.

The works to refurbish the system included retaining the wet tunnel upstream of the valve tower and install a trash screen at the intake. To enable the drawdown of the reservoir for the works, temporary twin siphons were installed to draw-off the top levels of the reservoir, in conjunction with a pump arrangement to fully drawdown the reservoir. For further details on the temporary siphon system see parallel paper by Carruthers and McAree (2024).

The valve tower was converted into a dry tower by removal of the central wall, and the installation of a plug at the interface between the wet tunnel and shaft. The pipework stack and associated valves were all replaced within the shaft.

The existing tunnel immediately downstream of the valve tower, under the embankment, was 1.5m diameter and had significant water ingress and had begun to deform in shape (Figure 23). Therefore, it was lined with a 1m diameter pipe, with the annulus infilled with structural grout, which formed part of the new draw-off system. In order to enable the works to the tunnel, and to re-route the new draw-off pipework outside of the dam profile, a 7m diameter tunnel was sunk 11m through the embankment to intercept the tunnel to drive the pipework sections and tunnel the new pipework away from the dam (Figures 24 and 25).

Downstream of this shaft, a 2.4m diameter tunnel was driven to install the dam draw-off pipework to outside of the dam profile. From this point, the draw-off pipework was micro-tunnelled at 9m depth for 80m (Figure 26) and conventionally open cut for 60m to a submerged discharge valve and chamber adjacent to the receiving watercourse.

The draw-off works were completed, commissioned and received the MITIOS sign off for the associated recommendations prior to the statutory date.

Figure 23. Original tunnel

Figure 24. Shaft installation

Figure 25. Tunnel installation pre-infilling

Figure 26. Micro-tunnelling scour main

CWMWERNDERI RESERVOIR

Cwmwernderi Reservoir appears to have been constructed by 1901 and is situated 5km northeast of Port Talbot. The embankment impounds the headwaters of Nant Cwmwernderi, and is approximately 75m long, 23m high, and has a stated capacity of 159,000m^3.

The existing drawdown system at Cwmwernderi did not have reliable upstream control, or safe access to the valve tower, due to the condition of the valve tower, and associated access bridge. The original scour system consisted of a penstock that was in the closed position and inoperable. The supply system had a washout circa 1km downstream of the site and was limited to reducing the reservoir level to approximately 7m below top water level due to the lower draw-off valve being in the closed position and inoperable. The spigot socket pipework in the tunnel was installed circa 1911 and had no formal thrust restraint at the bends. The drawdown capacity with the supply pipework did not meet drawdown guidance (EA, 2017).

The scheme to remediate the lack of upstream control, the valve tower and access bridge, and drawdown capacity was planned to be delivered in two phases. The first phase of works consisted of providing a new outlet near the toe (Figure 27) of the embankment to convert the historic supply pipe into a scour pipe, and to provide thrust restraints (Figure 28) to the existing pipework within the unlined rock tunnel. The existing unlined rock tunnel varies in shape and diameter, reducing to around 1.2m high in places.

Figure 27. New scour outlet

Figure 28. Thrust restraints

LLYN BRENIG

Llyn Brenig is located in the county of Conwy around 15km south of Denbigh, north Wales. The reservoir feeds compensation flows to the River Dee and is a critical asset to the Dee Valley Consultative Committee in unison with Llyn Celyn and Llyn Tegid. The reservoir has a stated volume of 61,550,000m^3 and is impounded by a 50m high rockfill dam with a 1200m long crest length, constructed in the 1970s.

The scheme included the scope below. For further details, see paper by Carruthers et al. (2024).

- Replacement of the "goliath crane" mounted to the top of the combined draw-off and overflow tower.
- Installation of a new secondary isolation gate
- Replacement of the scour bulkhead gate
- Replacement of the primary scour gate
- Replacement of all gate control systems including new control panel and caballing

CONCLUSIONS

Careful consideration, consultation and planning is essential for complex pipework and valve systems refurbishments to existing dam infrastructure. Defining a suitable methodology to undertake the works safely and quickly, while working within the constraints of a given scenario is essential. Involvement between asset owners, permanent works and temporary works designers, contractors and specialist subcontractors is seen as essential as early as possible to the planning, programming, pricing and stakeholder management required to successfully execute such complex projects.

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REFERENCES

Carruthers G A and McAree M J (2024). Control of reservoir water levels during construction when existing scour facilities are not available. In *Managing Risks for Dams and Reservoirs - Proceedings of the 22nd British Dam Society Conference* (Thompson A and Pepper A (Eds)). British Dam Society, London, UK.

Carruthers G A, McAree M J and Shakespeare S (2024). Improving the emergency drawdown reliability at Llyn Brenig reservoir – Part II. In *Managing Risks for Dams and Reservoirs - Proceedings of the 22nd British Dam Society Conference* (Thompson A and Pepper A (Eds)). British Dam Society, London, UK.

EA (2017). *Guide to drawdown capacity for reservoir safety and emergency planning.* Environment Agency, Bristol, UK

HSE (2006). *HSG253 - The safe isolation of plant and equipment.* Health & Safety Executive, London, UK.

ICE (2015) *Floods and Reservoir Safety – 4th Edn*. Institution of Civil Engineers, London, UK

Swetman J and McAree M J (2024). Upper Carno: A case study of multidisciplinary remedial works to an embankment dam. In *Managing Risks for Dams and Reservoirs - Proceedings of the 22nd British Dam Society Conference* (Thompson A and Pepper A (Eds)). British Dam Society, London, UK.