Upgrading the spillway at Craig-y-Pistyll reservoir using a labyrinth weir

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SYNOPSIS. Llyn Craig-y-Pistyll is an impounding reservoir, retained by an embankment dam, believed to have been constructed in 1877 and originally used in connection with lead mining. It is now owned by Dŵr Cymru and supplies raw water to Bont-goch water treatment works, which serves the Aberystwyth area. It was the subject of some improvement works in the 1930s and 1960s, the latter being described in a technical paper for the 1976 ICOLD Congress (Parkman, 1976). As a result of a Section 10 inspection in 2006, the spillway is being upgraded in 2010. The primary works comprise:

- construction of a labyrinth weir (Figure 1) to accommodate the design flood with a lesser flood surcharge;
- enlargement of the rock cut spillway downstream of the new weir; and
- a vehicle bridge to replace the present ford across the spillway.

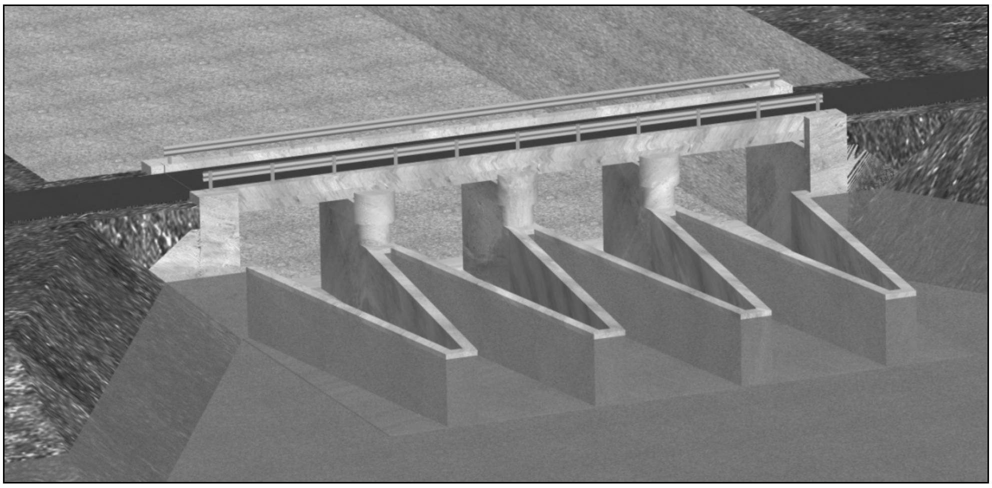

Figure 1. Proposed labyrinth weir and new access bridge

Figure 2. Craig-y-Pistyll dam in 2006, showing spillway via rock cutting at the left abutment

LLYN CRAIG-Y-PISTYLL RESERVOIR

The reservoir is relatively small, with a storage capacity of 366Ml and a surface area of about 11 hectares. The direct catchment area is about 550 hectares and there is also an indirect catchment of about 115ha which is fed into the reservoir from Llyn Llygad Rheidol, about 7km to the east. The dam is about 12m high, with a crest length of only 65m. The ‘dry well’ valve tower and drawoff tunnel are located towards the right (north) abutment of the dam and the overflow weir and spillway channel – which takes the form of a cutting through rock – are located at the left abutment (Figures 2 and 3).

Figure 3. Dam and entrance to spillway viewed from above left abutment, 2006

The construction date of 1877 is carved on a stone above the outlet from the tunnel beneath the dam. Following an inspection that ran over two days in November 1950, John Ainsworth reported that, although the reservoir was constructed for use in connection with lead mining, there were no workings under the dam itself and that mining ceased in 1906. He was of the view that 'The embankment was constructed most probably of local materials with some form of puddle core.'

At some time between 1906 and 1939 the reservoir was acquired by the water undertaking, because Ainsworth gave an account of works under the Aberystwyth Rural District Council Act 1939. These were 'carried out under the direction and supervision of Mr H B Ward, MICE, a qualified civil engineer within the meaning of the Reservoirs (Safety Provisions) Act, 1930'. These works included:

- 'improvements and additions to the reservoir including the strengthening of the embankment and an extension of the tunnel through the embankment, the provision of a valve tower, footbridge, valves and other works and conveniences.
- 'The existing tunnel with entrance to down-stream of the dam and going two-thirds of the way through the earth dam, was continued right through to the upstream side of the dam and connected to the base of the concrete valve tower.
- 'A concrete valve-tower was constructed with draw-off pipes at various levels through which the discharge of water is controlled by valves, and the tower is connected by a footbridge to the crest of the dam, on the reservoir side of which a new breast wall of concrete was built and tied into the structure of the dam.
- 'Boreholes were driven along the line of the dam into which cement grout was injected under pressure to prevent water escaping from the reservoir under the dam.'

In his 1976 ICOLD paper, Brigadier Parkman reported that: 'the embankment…is formed of a matrix of weathered slatey-shale pieces founded upon hard slatey-shale of Ordovician age. Shallow trial pits on the crest failed to reveal any clay core.' His account of the history of the dam from 1939 to the 1960s is worth quoting virtually in full.

- 'In preparing to repair the supply tunnel in 1939, part of the upstream face caved in whilst the reservoir was being drawn down. Upon refilling the reservoir after replacement of the slipped part of the embankment significant leakage appeared on the downstream face and was stopped by the insertion of 315t of cement and 3040 gallons of bitumen emulsion.

- ‘By 1966 a relatively small amount of water was again leaking through the embankment just below the steep upper 1 on 1.5 slope of the downstream face which had suffered a series of surface slips. It was decided in the same year, to return the top water level to that pertaining in 1939, by replacing the eroded rock spillway crest by a new concrete structure and, at the same time, strengthening the embankment to enable it to retain the additional depth of water safely.’

Drawings dating from 1966–68 appear to present a comprehensive picture of the works as they existed up to 1966, together with the remedial works implemented at that time. The remedial works comprised:

- placing stone pitching underlain by puddle clay on the upper part of the upstream face of the dam;
- raising the top of the concrete wavewall to a nominal elevation of 326.90m OD;
- raising the dam crest to 326.75m OD, with a width of about 5m;
- installing pressure relief wells under the downstream shoulder of the dam, together with a drainage blanket on the pre-1966 downstream face;
- placing further material over the downstream face to re-form the shoulder with a gradient of 1:2½, a 7.6m wide berm about 3.7m below the top of the dam and a rubble toe at the downstream end of the drainage blanket;
- formation of a new overflow sill at 324.56m OD, length about 18m, containing vertical steel supports channels (for stoplogs) projecting 0.7m higher;
- the installation of stoplogs to create a new overflow level of 325.09m OD (0.53m above the concrete sill);
- the construction of new retaining walls and ramps to form a vehicle access route across the spillway;
- provision of a new footbridge access to the valve tower; and
- raising the section of access road that runs along the southern shoreline just upstream of the dam to 325.53m OD (0.44m above overflow level).

According to a note in Part 10 of the current record book, the installation of the stoplogs raised the overflow level by about 0.60m and restored the 'original figure'. Another note reports that the 1966 works included pressure grouting of the tunnel.

Part 10 of the record book reports that, in 1977, the overflow channel downstream of the weir was deepened and reprofiled. According to the 1987 inspection report, this followed recommendations by Mr Bass in his 1977 inspection report. In the 1980s various further improvement and remedial works were undertaken, including pipework repairs and valve refurbishment.

In 2002, the height of the stoplogs was raised by 0.16m, following the Reservoirs Act 1975 procedures for enlargement of a reservoir, resulting in an overflow level of 325.25m OD.

Figure 4. Downstream face of Craig-y-Pistyll dam, 2006

2006 INSPECTION

In parallel with the 2006 inspection, a dambreak study was undertaken which indicated that the reservoir should be placed into Category A. This was confirmed by the inspecting engineer and a flood study was undertaken, which derived a peak reservoir inflow of 84 m^3/s for the winter PMF. An assessment of the rating relationship for the overflow weir, including the effects of 'drowning' by conditions in the rock cutting downstream, was also undertaken as part of the study.

Reservoir routing effects are modest, due to the small surface area in relation to the catchment, and the corresponding winter PMF peak outflow is about 76 m^3/s, resulting in a peak flood surcharge of 1.9m. With the stoplogs in place, this flood would rise to about 0.35m above the general crest level of the wavewall and result in a significant proportion of the total flow passing over the crest of the dam, with obvious major risks of causing a breach.

Measures were therefore recommended 'in the interests of safety' to upgrade the spillway, so that the peak outflow of the PMF could be safely passed downstream without the stillwater level in the reservoir rising above the crest level of the dam, providing an additional freeboard margin for wave action.

OPTIONS STUDY

Four options were investigated for enhancement of the overflow capacity:

- a labyrinth weir (Figure 1);
- a Crump-type weir with 1:2 upstream and downstream slopes;
- a conventional Crump weir, with 1:2 and 1:5 slopes upstream and downstream respectively; and
- a cylindrical crested weir.

The variant of the conventional Crump weir with a 1 in 2 slope both upstream and downstream of the crest was included, since this provides a higher discharge coefficient than the usual design with the gentler downstream slope.

For each option, the peak stillwater level in the reservoir was calculated for the PMF and the required wave surcharge allowance was determined using the procedure given in *Floods and reservoir safety* (ICE, 1996). The allowance required for the existing wavewall and 1:2 upstream dam slope is 0.75m, but this reduces to the recommended minimum of 0.60m if the wavewall is raised and the wave impact zone is vertical. Table 1 summarises the key parameters and analysis results for each option.

The spillway channel modifications were then determined to ensure that the PMF outflow could be passed without 'backing up' the spillway and raising the reservoir water level. These results are also included in Table 1.

Lowering the weir crest level below the existing top of stoplog level of 325.25m OD was not considered in detail, as this would both reduce the reservoir capacity and increase the spillway enlargement works required.

The labyrinth and 1:2/1:2 Crump-type weir options were drawn up for consideration by the client. The labyrinth weir would require substantial deepening of the spillway channel, making retention of the existing ford impractical, so a new bridge is included in this option. Preliminary costings showed the labyrinth weir option as approximately 20% more expensive than the Crump-type weir option. However, this option was chosen, because it minimises the risks to the dam by not raising the peak stillwater level in the reservoir, and also provided an all-weather means of access to the dam crest and outlet works.

Table 1. Options summary

Weir option	Weir details	Discharge coefficient C_d[1]	Peak outflow (m^3/s)	Wavewall level (m OD)	Peak stillwater level (m OD)	Energy level d/s of weir (m OD)	Spillway deepening required[5] (m)
Labyrinth	See details below		80	326.77[4]	326.00	325.49	1.4
1:2/1:2 Crump-type	16m wide	0.702[2]	76	327.59	326.99	326.52	0.3
Crump		0.674	76	327.64	327.04	326.63	0.2
Cylindrical crested		0.786[3]	77	327.48	326.88	326.23	0.6

1 Based on the weir equation: $Q = \frac{2}{3}\sqrt{2g}\,C_d bH^{1.5}$

2 Slightly reduced due to downstream bed level

3 Slight drowning allowed for

4 Lowest existing wavewall level (0.13m below nominal level following 1966-68 works)

5 Assuming 10m wide rectangular channel at existing footbridge location

SPILLWAY WORKS

Labyrinth weir design

A labyrinth weir would enable the existing reservoir capacity to be maintained and the required PMF outflow to be discharged whilst maintaining a suitable wave allowance, avoiding the need to raise the dam crest or wavewall. Routing the winter PMF through the reservoir storage confirmed a maximum outflow of 80 m^3/s.

The form of the weir equation used in this case is that presented by Tullis *et al* (1995):

$$Q = \frac{2}{3} C_d L_e \sqrt{2g}\, H^{1.5}$$

where Q is the weir discharge, C_d is the discharge coefficient based on experimental results and defined by graphical relationships in the paper, L_e is the effective weir length and H is the total head upstream of the weir.

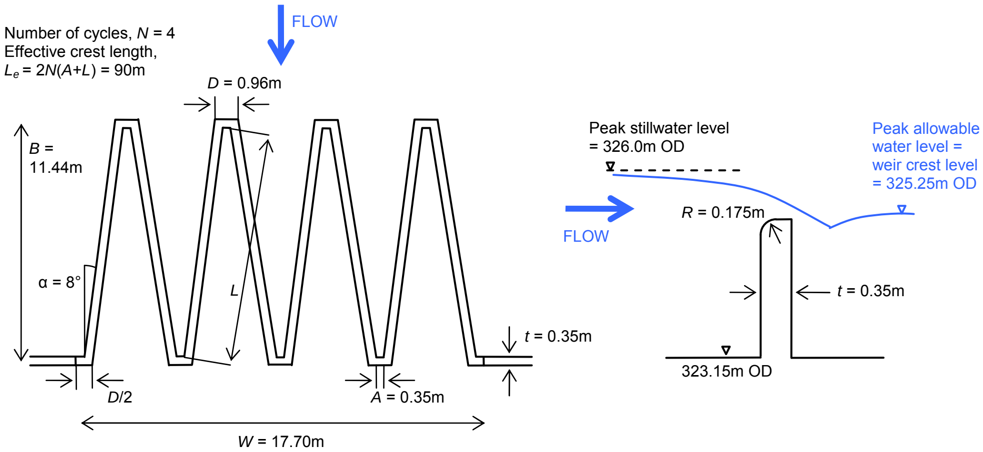

Figure 5. Labyrinth weir dimensions

The weir dimensions shown in Figure 5 were chosen to enable a discharge of about 80 m^3/s to be passed for $H = 0.75$m. Using the existing weir level of 325.25m OD, this results in a peak reservoir level of 326.00m OD. Adding the calculated wave surcharge allowance of 0.75m to this gives a peak wave level just below the minimum existing wavewall level of 326.77m OD.

The four-cycle weir provides the most efficient design for the available total width, and the side angle of 8° maximises the discharge coefficient. A rounded edge is provided to the weir crest both to improve the flow characteristics and to reduce the temptation for walking along the crest. The estimated stage/discharge rating for the overflow is shown in Figure 6.

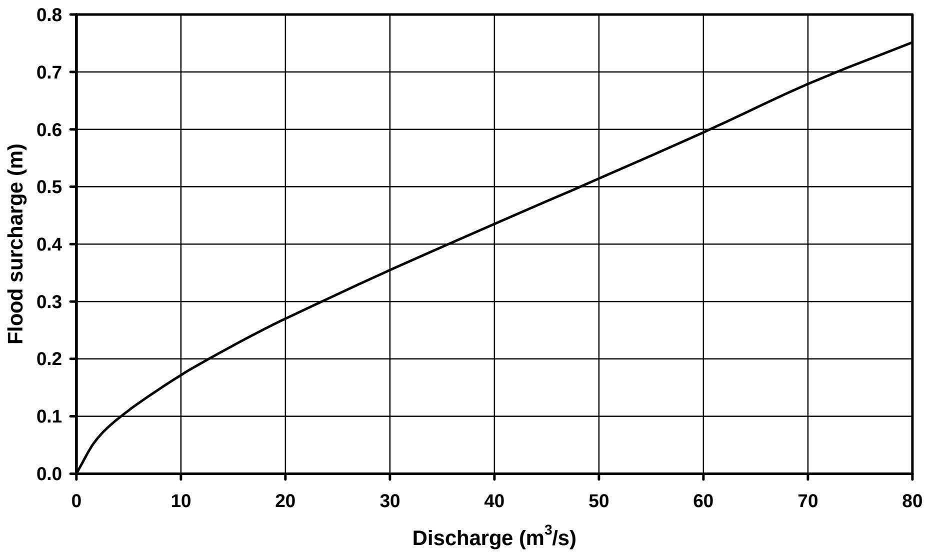

Figure 6. Rating curve for Craig-y-Pistyll labyrinth overflow weir

Very limited published information is available regarding the effect of 'drowning' on labyrinth weirs. The highest allowable water level downstream of the weir was taken as the weir crest level and the enlargement of the downstream channel was designed to achieve this.

Spillway enlargement

The spillway is a channel cut through the natural bedrock at the left (south) abutment of the dam. In order to avoid drowning out the labyrinth weir crest at up to the PMF, the depth is being increased by an average of about 1m over the 33m length, and the channel bed width is being increased by 3 to 4m.

The spillway runs along a fault, with the northern bank comprising Silurian age rocks, whereas the southern bank comprises steeply dipping Ordovician age rocks. The Silurian age rocks to the northern bank are highly weathered in places, but enabled the spillway slope to be regraded at an angle of 45°. However, due to the steep dip and high elevation of the southern bank, a retaining wall was required to support this bank. The retaining wall uses anchor rods resin grouted into the bedrock to resist overturning forces.

OTHER IMPROVEMENT WORKS

Access bridge

Vehicular access to the dam crest was previously via a ford across the original spillway, with ramps on both sides. Pedestrian access was via a footbridge. The enlargement of the spillway means that the ford and footbridge needed to be replaced. Also during high flows, the ford became unusable and the dam crest and outlet works inaccessible.

A new roadbridge was therefore proposed, but a major constraint on the design was the poor access to the site, with the final 2km on rough track that is only suitable for off-road vehicles. Hence materials for the access bridge have to be small in size to be easily transported and positioned.

The final design for the new roadbridge comprises:

- reinforced concrete (RC) bridge abutments;
- RC piers placed at the downstream vertices of the labyrinth weir at 4.5m centres;
- discrete precast concrete beams spanning between the piers and abutments; and
- a cast-insitu RC bridge deck.

Access track

A length of approximately 200m of original access track to the dam runs close to the reservoir shoreline, at an elevation below the design flood level. This is being raised to 327.00m OD, so that it is well above that flood level.

PLANNING AND ENVIRONMENT

With the improvement works to the spillway generally forming part of works required ‘in the interests of safety’ under the Reservoirs Act 1975, the requirement for a flood defence consent was waived by the Environment Agency. The scheme nevertheless required planning permission and this was granted in July 2009.

As part of the design work, the environmental impact of the scheme was considered. A thorough ecology survey, including a consultation process was completed and included in an environmental statement. A full EIA (environmental impact assessment) was not conducted, as it was not deemed necessary following the environmental statement. In addition, a landscape assessment was undertaken, to determine any visual impact on the wider landscape.

IMPLEMENTATION

Tenders are due to be submitted at the end of January 2010, with a view to mobilisation in March and construction starting in April or May 2010. The main constraint to the start of construction is the weather. In order for work to begin on construction of the new weir and access bridge, the reservoir needs to be drawn down by approximately 2.5m.

Construction is expected to last 33 weeks, but the reservoir does not need to be kept drawn down for the entire time. As soon as the weir and foundation work for the bridge has been completed, refilling of the reservoir can start.

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