

Recent incidents at canal reservoirs

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SYNOPSIS Two incidents at Cofton reservoir are described; the first relating to leakage of an old dam predominantly made of sand and the second being a problem with the draw-off pipes, which led to internal erosion in the body of the dam.

An incident at Lilly Loch Reservoir is also discussed. This was an unusual problem for a UK reservoir; the threat of material falling into the reservoir from an unstable hillside, potentially leading to an overtopping of the dam as a result of the displaced water and the impulse wave caused by the rock fall.

At the time of the incidents, the author was the Supervising Engineer for both reservoirs.

The actions taken at the time and subsequently are described.

INTRODUCTION

The Canal & River Trust, a charitable body, was set up in 2012 to look after the navigations in England and Wales which were formerly the responsibility of the British Waterways Board. British Waterways had been established in the Transport Act of 1963 to manage the canal system, nationalised in 1947. North of the border, the waterways remain in the public sector, managed by Scottish Canals.

The Canal & River Trust is responsible for 72 statutory reservoirs. There are 21 canal reservoirs in Scotland.

COFTON RESERVOIR: LEAKAGE 2006-2007

Cofton Reservoir is situated at the base of the Lickey Hills, to the south of Birmingham, England. It is the highest of four Worcester & Birmingham Canal reservoirs in the upper catchments of the River Arrow. It was originally built in 1815 as a compensation reservoir for watermills, which otherwise would have been affected by the construction of the canal. It was later used as a water supply for the canal, a function which it still serves. The embankment dam is 11.2m high and 160m long. The stored volume is 115,410m³ and the catchment area 1.4km². It is a category A reservoir.

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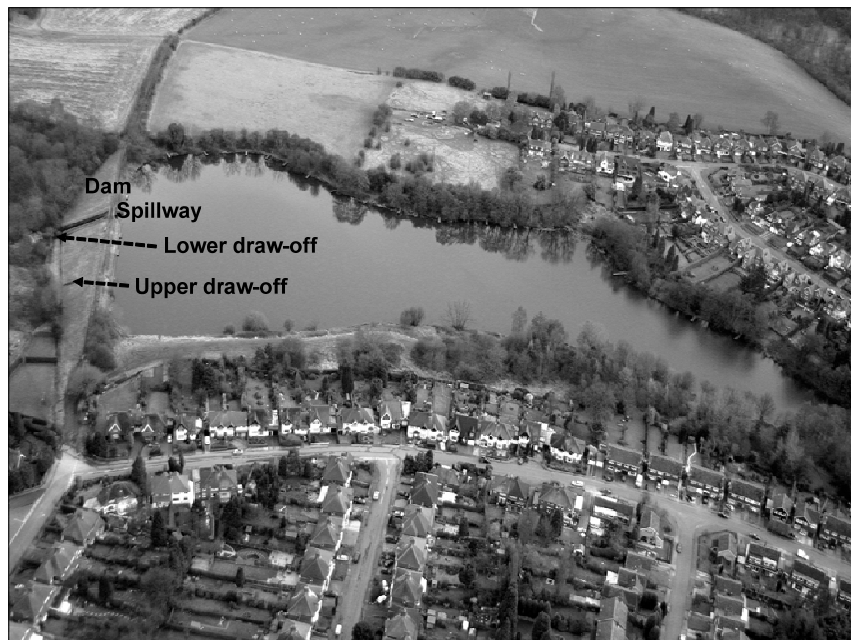


Figure 1. Cofton Reservoir from the air, showing the locations of the outlets and spillway.

Contemporary accounts, quoted by White (White A (2005)), indicate that the dam was made of sand without a core and that early leakage problems were addressed by 'stouring' or re-working the upstream face. Leakage has manifested itself from time to time during nearly two centuries of service. The first Inspecting Engineer, F. J. Dixon, in 1933 identified a spring and instructed it be drained. It is now monitored using a v-notch. An area of persistent leakage was addressed in 2000 by installing filtered fin drainage.

In December 2006, significant leakage was identified towards the toe of the dam adjacent to the concrete spillway, which had been built over the centre of the dam in 1965. The Supervising Engineer, adopting the approach recommended in *A Guide to the Reservoirs Act 1975* (Institution of Civil Engineers (2000)), invited Rodney Bridle, an All Reservoir Panel Engineer and the previous Inspecting Engineer, to give an opinion as to the significance of the leakage and a view on whether a statutory inspection should be called. Mr Bridle had carried out his inspection only a few months before and considered that there was no need to have a new inspection but that the work should be carried out as though it were 'in the interests of safety'. He advised that the reservoir level be lowered as a precaution and that filter drains and a v-notch be installed for control of internal erosion and monitoring. The leakage stopped when the reservoir level was marginally reduced.

Trial pits were excavated in the crest adjacent to the weir and voids were found. They were filled with puddle clay. When the water level was

restored, the leakage problem was found not to have been resolved. It was identified that the leakage only occurred when the reservoir started to spill and it was deduced that the ingress was through cracks and joints in the concrete cascade. The leakage path was then underneath the structure, emerging towards the toe. The original spillway drawings were not detailed but showed no drainage layer beneath the structure. There was the possibility however of settlement of the dam beneath the concrete. The joints were sealed by 'pointing' and the leakage ceased for the time being.

COFTON RESERVOIR; DRAW-OFF PIPE DEFECT 2008

Cofton reservoir has two draw-off pipes. Both are cast iron pipes buried beneath the dam and controlled by upstream 'teapot lid' type valves operated by inclined spindles. The upper draw-off pipe is 300mm in diameter and is the one normally used. The lower pipe is only 150mm in diameter and until repaired in 2005 had been inoperable for many years.

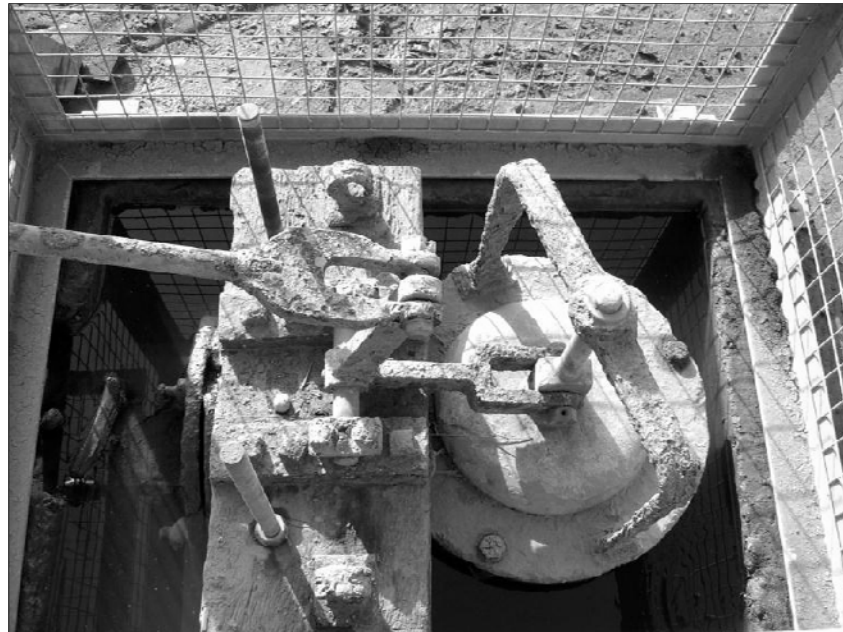


Figure 2. The upper 'tea pot lid' type valve at Cofton Reservoir before replacement.

During a routine valve test in June 2008, a defect was identified in the upper valve operating mechanism. It was decided that the water level would be reduced using the lower valve to allow the upper valve rodding to be repaired without the need for divers. There was no great urgency in carrying out the repair. The on-site emergency drawdown plan was revised to bring in additional pumping in the unlikely event of an emergency. Only when it was operationally appropriate, was the lower valve opened on Friday 1 August 2008. On the following Monday, routine surveillance identified that discoloured water and sand was being discharged from the

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lower pipe. The Supervising Engineer was contacted and he instructed that the valve be closed straight away to prevent any further erosion. A CCTV survey was carried out later in the week. Two defective joints close to the upstream valve were identified. The joints appeared to have opened up and to have debris lodged in them. The debris was thought to be deflecting the flow of water from the pipe into the embankment fill behind.

Rodney Bridle was again consulted. He recommended that the pipe be lined if possible and grouted up if not. The reservoir was completely emptied by means of siphons and pumps. Whilst the reservoir was empty, the fishing club moved the fish into a temporary home in an alternative pool. A piled cofferdam had been driven around the lower valve in 2005 and left *in situ*. It served to hold back the mud in the reservoir basin. Both the lower and upper draw-off pipes were lined with cured-in-place sleeves. These were pulled into the pipes with a winch, inflated with air pressure and cured using ultraviolet light. This system needed no craneage, unlike the hot water cured system and left no contaminated water to dispose of. The opportunity was taken to replace the upper valve, together with its operating mechanism and grille.

When the reservoir was first drawn down, a depression some 3m in diameter and 1m deep was found at the bottom of the upstream face at the toe of the dam in a zone never exposed in normal operation. Trial pits were dug identifying clean sand to a depth of one metre with a little silt in the surface zone.

It was around this time that it had become clear from Rev Alan White's research (White A (2005)) that the dam was constructed wholly in 'sand'. This provided the basis to explain the several leakage episodes that have occurred at different parts of the dam. The sand is derived from Triassic Bromsgrove Sandstone, and was much used as foundry sand. Based on particle size, it is slightly clayey sandy silt, about 50% silt sized and 40% sand sized, with a small percentage of clay sized particles. It is non-plastic (non-cohesive).

Using the terminology from the forthcoming ICOLD bulletin on internal erosion (Bridle R, Brown A (2011)), it appears that 'global backward erosion' had occurred, drawing sand into the draw-off pipe resulting in the depression. As it was at the upstream toe, it had not threatened the integrity of the dam. The erosion had initiated when sand grains tumbled through the open joint into the draw-off pipe. Erosion had probably then ceased as sand accumulating in the pipe and the formation of 'arches' in the sand above the opening had prevented further movement of sand grains. When the valve was opened, the accumulated sand was swept downstream and the global backward erosion upwards into the fill above was re-initiated. The erosion process could 'continue' as there was no 'filter' to stop it, and it could

‘progress’ into the erosion ‘pipe’ that was already present in the form of the draw-off pipe. Erosion would likely have ceased when no further material became available as the depression in the fill above the broken pipe joint formed stable slopes. Closing the valve and lowering the reservoir water level probably pre-empted the ‘natural’ cessation of the erosion.

The incident illustrates how readily erosion can occur through openings in conduits in dams. There is little, other than the size of the opening and ‘arching’ of the fill above the opening, to prevent ‘continuation’ of the erosion process, and the pipe, unless blocked by large quantities of eroded material, provides the ‘erosion pipe’ through which eroded material can be carried away.

The Lluet Wen incident (Charles *et al* (2011) seems to have been another example of ‘global backward erosion’. At Lluet Wen, it seems that clay core was ‘oozing’ into the culvert and the loss of material resulted in the formation of a large cavity in the clay core above which, being plastic (cohesive), could ‘hold a roof’ above the cavity.

The depression was filled with locally won sand. Had a less permeable material been used, accelerated erosion around the edge of the patch would have been expected.

The earlier surface sealing of cracks and joints in the spillway was not performing particularly satisfactorily. Voids beneath the concrete structure were filled by drilling and grouting at low pressure using cementitious materials. The cracks were sealed by polyester resin injection.

Following the completion of these works the reservoir was refilled and has performed satisfactorily. Minor seeps through the weir structure have been observed, where none had been seen before. It is thought that this may be an indication of the efficacy of the grouting in driving hitherto unsuspected subterranean leakage paths to the surface.

LILLY LOCH RESERVOIR; UNSTABLE HILLSIDE 2009

Lilly Loch is a raised natural loch near Airdrie, Scotland. It was converted to a reservoir in 1836 to supply the Monkland Canal and the Forth and Clyde Navigation. The main dam is an embankment dam 9.2m high. There are three additional saddle dams to prevent water being lost across the watershed. The stored volume is 763,000m³. The main dam is a Category A and the saddle dams C or D. Lilly Loch has been described in more detail in *Dams & Reservoirs* (Brown D H (2009)).

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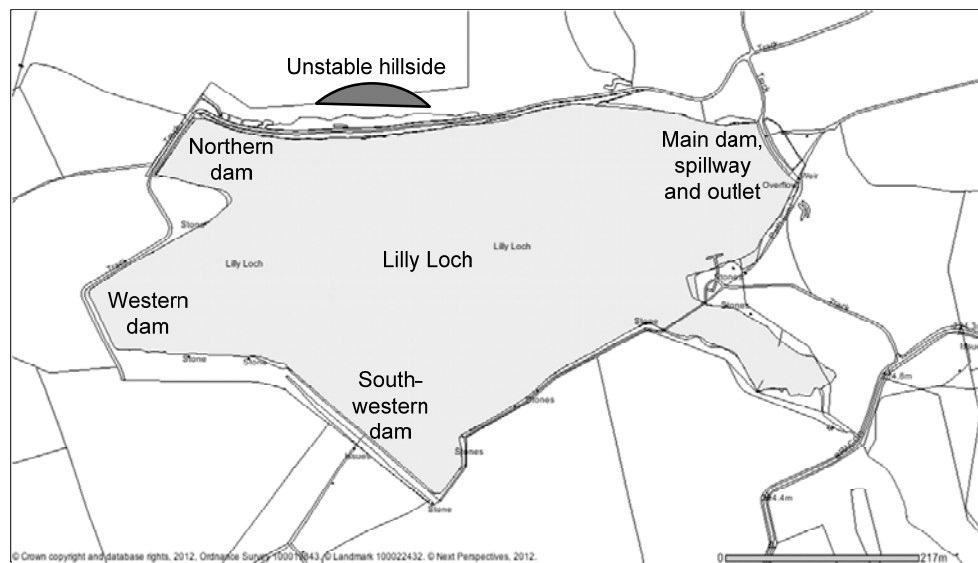


Figure 3. Plan of Lilly Loch.

Along the northern shore of the loch is a steep hillside, some 35m high, rising almost vertically out of the water. A narrow track runs alongside the reservoir and forms a berm to the toe of the slope.

On 7 December 2009 North Lanarkshire Council's footpaths officer advised the Glasgow office of land movement above the track. The concern was for the safety of walkers. It was recognised that there was also a reservoir safety concern and the Supervising Engineer was contacted. Arrangements were made for a local asset engineer to visit site that day and the track was closed to the public as a result. The Supervising Engineer, apprised of the situation by telephone and supplied with photographs by email, advised on a precautionary lowering of the water level and arranged to visit site later in the week.

Prior to this visit, the Supervising Engineer, in researching the geology, identified that the hillside had been examined by in-house experts some years before when there had been proposals to extend a nearby quarry and tension cracks had been noted at the top of the slope. The geology was therefore well understood.

The geotechnical engineer who had carried out the earlier investigation was, by the time of the incident, head of Geotechnics. He attended the Supervising Engineer's site visit, which took place on 9 December. Horizontal and vertical displacement of the rock at the top of the steep slope was observed over a distance of some 50m about 25m above the reservoir. The earlier geotechnical study was invaluable in gaining an early understanding of the mechanism of the movement.

The hillside is a quartz dolerite sill, an igneous intrusion into the coal measures. Quartz dolerite is characterised by a weathering process in which

joints in the rock, originating during its cooling from a molten state, are exploited by chemical weathering. This leads to a breakdown and loss of strength of the rock, ultimately reducing it to sand. The spacing of the joints and the rate of weathering dictate the size of the un-weathered core-stones, which remain. Rounded stones on the surface of the rock face are liable to roll down the hillside. The weathering of the rocks had, over geological time, lead to the formation of voids within the rock mass and the consolidation of the core stones, giving rise to the vertical movements at the top of the slope.



Figure 4. Movement of the northern hillside above Lilly Loch looking towards the main dam.

It was thought that the horizontal movement might be a remnant feature of a past glacial episode in which a mass of rock was moved by ice flowing over the area.

A GPS based survey of the hillside was carried out at the time to estimate the amount of loose material.

It was concluded on the day of the visit that the geology precluded any immediate concerns of a massive circular slip with the slip circle below water level, displacing the reservoir water as at Vaiont, Italy in 1963, as described in *Lessons from historical dam incidents* (Charles J A *et al* (2011)). Furthermore, a good proportion of any major fall of material would come to rest on the track and not enter the reservoir.

The hillside was privately owned and the owners were notified.

The immediate concerns had been allayed by reducing water levels but this would be difficult to sustain in the long term because inflows in wet weather can exceed the maximum rate of outflow. Storage would also be compromised.

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The options to be considered were:

- to permanently reduce water levels by modifying the spillway
- to stabilise the hillside
- to raise the dam/s
- to study the risks further to quantify the consequences of a slip

Permanent reduction in storage was undesirable from a water resource perspective.

Stabilising the hillside was impractical due to the nature of the geology and amount of material to be removed. Even site investigation was impractical due to access difficulties and the stability of the hillside

Dam raising was a possibility but if it could be shown that the wave resulting from a realistic worst case rock fall would not threaten reservoir safety, then the water level could be restored.

The Supervising Engineer considered the effect of the unlikely event of a large quantity of material suddenly falling into the water. Using Huber's approach (Huber A (1982)), quoted in *Dam Hydraulics* (Vischer and Hager (1997)), he calculated the wave height at the two most critical of the four dams of this reservoir using a pessimistic view of how much material might enter the reservoir. It was assumed that third of the rock mass (2,100m³ calculated using the GPS data) might fall.

The wave height from such an event was estimated to be 0.52m at the south-western dam and 0.5m at the main dam. There would be little increase in height due to run up because the upstream faces were protected with rip-rap. The design wave heights used in the November 2009 Inspection Report were 0.5m for the south-western embankment and 0.78m for the main dam. At the category C south-western dam, the minimum freeboard to the crest is 0.285m but there is a porous wavewall of rip-rap of a height of some 600mm. The main dam, which is category A, has a freeboard of 1.56m to the top of a concrete wavewall.

The estimated wave height from a remotely possible rock-fall was therefore of a similar order of magnitude to the design wave height.

The Supervising Engineer decided to consult an All Reservoir Panel Engineer for a second opinion before taking the decision that the water level could be restored. Accordingly, therefore on 10 May 2010, he arranged to meet Martin Hewitt, who was accompanied by a geotechnical specialist colleague, on site. The site inspection revealed shallow and outcropping dolerite, with a series of tension cracks opening up at the surface. The tension cracks appeared to be controlled by the near vertical jointing, the joints dipping into the hillside creating a 'toppling' type mechanism. Although the tension cracks were up to 2m to 3m in depth, there was no

evidence of deep seated overall slope failure potential. The failure mechanism appeared to be one of progressive erosion, creep and opening up of the tension cracks within the weathered zone of the hillside. It is possible that in the future, probably over a number of years; the upper 2m to 3m of the hillside could topple and fall indirectly into the reservoir, via the track.

The Panel Engineer's initial view was that the likelihood for a significant impulse wave to be generated by either a large moving wedge of material or falling mass was therefore very low and any rise in water level due to volumetric displacement negligible. Even if the estimated wave height were to occur it might in a worst-case result in overtopping of the south-western embankment but because of the transient nature of the overtopping and wide crest, the structure would not be breached. The valley downstream of the dam is wide, flat and uninhabited, and it was his opinion that flooding from the wave passing over the crest of the dam would be dissipated and would not pose a hazard. Following a review of available literature and methods of calculating landslide and falling mass generated impulse waves in reservoirs, most notably Heller et al (2009), he later confirmed these views and the water level was restored.

Subsequent visual monitoring of the hillside has not revealed any significant further movement. A number of boulders have rolled onto the track and this is to be expected as the process of 'exfoliation', weathering of the dolerite, continues.

VOLUNTARY POST INCIDENT REPORTING

All the incidents described above were reported to the Environment Agency, under the voluntary reporting scheme (Environment Agency (2007)), for the benefit of others working in reservoir safety.

ACKNOWLEDGEMENTS

The author is indebted to Rodney Bridle and Martin Hewitt for their assistance in preparing this paper.

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