



Project Title: Guidance for the Design and Maintenance of Stepped Masonry Spillways (SC080015)

Following the failures of stepped masonry spillways at Boltby Reservoir in 2005 and at Ulley Reservoir in 2007, the Environment Agency commissioned a research project to clarify the safety of such structures. The work was awarded to MWH UK Ltd and took place between October 2008 and April 2010. This report summarises the results of that research.

The conclusions from this work with regard to hydraulic action can be considered applicable to stepped spillways formed of any material. Where such spillways are constructed of discrete elements or blocks set in mortar, the results can be considered applicable to brickwork as well as masonry.

Previous work has been carried out studying the steep, stepped spillways that are typically used on the downstream faces of roller compacted concrete dams. In contrast, this research focuses on the much shallower stepped spillway slopes, typically in the order of 1v to 3h, associated with UK embankment dams.

Examples were collected of industry experience of operating such spillways and, in particular, of distress and/or remedial measures. This was supplemented by a programme of hydraulic model testing both to better clarify how flow depths can be calculated in such spillways and also to improve understanding of the localised hydrodynamic pressure fluctuations to which spillway walls and inverters may be subjected.

In terms of hydraulics, moderate flows in stepped spillways will tend to cascade from step to step losing energy progressively and with each step acting as a form of stilling basin. This is termed 'nappe flow'. Higher flows will begin to skip from step to step, with local vortices trapped within the steps. This is termed 'skimming flow'. In addition to these flow regimes, this research has identified

that very high flows may ride on the top of enlarged vortices, hardly touching the steps. In terms of design criteria the highest flow velocities, depths and hydrodynamic pressure fluctuations will clearly be associated with skimming flow and so that is the regime on which the report focuses.

In the case of flow depths, recourse was made to a significant database of model testing on such chutes held by CRM. It was identified that equations generally proposed by Chanson give the most consistent results in the case of shallow, stepped chutes. However, it was also noted that the high levels of turbulence mean that absolute flow depths are difficult to quantify; instead there is simply a transition in the air/water mix to a progressively reduced percentage of water. The design flow depth in such cases is typically defined as one where the air concentration has reached 90%. It is common practice to allow some freeboard over and above this.

The pressure distributions that can occur on the inverters and walls of stepped spillways under high flow conditions are discussed. Model testing revealed high pressure zones over the downstream surfaces of step inverters and on adjacent sections of side wall and low pressures on the vertical faces of steps, over the upstream zones of steps and, again, on adjacent sections of side wall.

If high pressures are injected into open textured masonry in high pressure zones such that they create back-pressures behind the masonry blocks in low pressure zones, then the blocks in these low pressure zones can be subject to removal. Moreover, model testing has shown that there can be considerable turbulence and pressure fluctuations during such flows, with the pressure differentials between transitory maximum and minimum pressures often being considerably higher than between associated mean pressures. It was concluded that such potential pressure

differentials on typical UK spillways could reach 5 to 10 metres of water head. The high levels of turbulence within high pressure zones can also be sufficient to dislodge blocks within those zones.

The exact zones of pressure distribution will vary depending on the geometry of the spillways in question and the flows being examined. Therefore, it is not possible to give generalised guidance but rather to draw attention to the potential and to the broad likely zoning.

Testing also indicated that significant pressure differentials could be produced by both locally protruding and locally recessed masonry blocks. Design charts to calculate such pressure differentials are given.

Advice is given in the report on the inspection of masonry spillways, how to identify unacceptable forms of distress and also on appropriate means of repair and remediation.

The integrity of mortar pointing is especially important in high pressure zones of masonry spillways and in particular, in the vertical joints, normal to the flow direction. Conversely, there may be some benefit in selectively omitting some of the vertical pointing on the vertical faces of steps to permit drainage relief. Mortar pointing in general should be finished either flush with the masonry blocks or finished with a "bucket handle" profile

The regular inspection of masonry spillways is important, as is the removal of any weeds and associated root growth in and around the spillways. Remedial measures can include simply reinstating pieces of displaced masonry, local patching with concrete, pressure pointing to restore the integrity of the surrounding mortar matrix and/or, in extreme cases, demolition and rebuilding of the spillway or the replacement of masonry with specially profiled and textured concrete.

Most stepped masonry spillways in the UK have stood the test of time, with over 100 years of successful operation since such materials formed the standard method of construction. Their use will continue to be acceptable provided that maintenance works and inspections are undertaken on a regular basis by informed practitioners and are combined with careful remediation measures when required. These actions are of particular importance when the spillways are located along the mitre of the embankment where a collapse of the sidewalls could endanger the dam.

This summary relates to information from project: reported in detail in the following output(s):

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Project manager: Gary Tustin, Evidence Directorate

Theme manager: Geoff Baxter, Evidence directorate

Research Contractor: MWH Global, Contact Peter Mason peter.mason@uk.mwhglobal.com

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Email: ferm.evidence@environment-agency.gov.uk.

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E: enquiries@environment-agency.gov.uk.

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