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Scoping study on the need for additional research and/or guidance on reservoir conduits

Report: SC080049/R1

Flood and Coastal Erosion Risk Management Research and Development Programme

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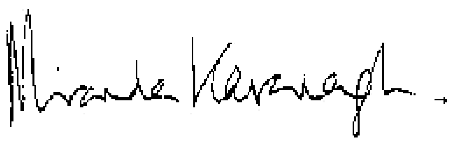

Miranda Kavanagh

Director of Evidence

Executive summary

The draft Defra Reservoir Safety Research Strategy (2008) identified priority areas for research projects aimed at drawing together best practice, operational experience and recent developments in the management of existing UK dams. One important research area that was identified was to develop guidance for the inspection, monitoring, maintenance and repair of tunnels in dams and reservoirs. The Environment Agency commissioned Black & Veatch Ltd (BV) to carry out a scoping study to identify whether there was a need for additional research on the inspection, monitoring, maintenance and repair of tunnels in UK dams and reservoirs. After consultation, the study's scope was extended to include all conduits.

Defects in, and associated with, conduits through dams have resulted in dam failure. The most dangerous mechanism of failure is internal erosion of an embankment dam's fill by water passing along the contact between the conduit and the fill. This has long been recognised as a potential failure mode. Early detection of defects can be difficult. Structural defects in conduits put at risk the operational efficiency of the reservoir, in particular the availability of emergency drawdown facilities, and can lead to an increased risk of internal erosion by a number of mechanisms.

There is specific guidance available on the safety assessment of embankment dams, concrete and masonry dams, and of valves and pipework. These documents contain some reference to safety assessment of conduits, but there is no single document that provides comprehensive guidance on the safety assessment of conduits through dams.

The current CIRIA research project on tunnels for the transport industry (McKibbins et al., 2009) will provide guidance on the inspection, monitoring and maintenance of tunnels and culverts. However, the guidance is not specifically related to reservoir safety; some of the information contained in these documents will not be relevant and there will be some matters specifically associated with dams that are not covered.

In the US, the Federal Emergency Management Agency has a document that provides comprehensive guidance on the inspection, monitoring and maintenance of conduits through embankment dams. This is potentially a useful document, but it lacks guidance on older types of culverts and tunnels, which are common in the UK. This document would have to be adapted for use under UK conditions.

We consulted with the reservoir safety community in the United Kingdom by sending a questionnaire to panel engineers and selected reservoir owners. This was backed up by a presentation at the Supervising Engineers Forum. This process established that the profession sees a clear need for a guidance document on the inspection, monitoring, investigation and maintenance of conduits at reservoirs, including tunnels, culverts and pipes.

A gap analysis has identified a clear need for consolidated guidance on the inspection, monitoring, investigation, maintenance and repair of conduits (including tunnels, culverts and pipes) at reservoirs. The currently available guidance on safety assessment of tunnels and culverts is not in a form that would be widely accepted by the UK reservoir safety industry.

No further research is necessary into the mechanisms of failure that are associated with defects in conduits or their presence in dams. We recommend that a contract is awarded for the preparation of a guidance document on the safety assessment of conduits at reservoirs.

Acknowledgements

The authors are grateful to Chris Chiverrell of CIRIA who disseminated the information contained in the CIRIA guidance document *Tunnels: inspection, assessment and maintenance* (McKibbins et al., 2009) and provided useful background information and ideas to the project team.

The authors would also like to thank Paul Tedd, formerly of the Building Research Establishment (BRE), for taking time to review the BRE incident database and providing the authors with information relevant to this study.

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1 Introduction

1.1 Background to study

The draft Defra Reservoir Safety Research Strategy (2008) identified priority areas for research projects aimed at drawing together best practice, operational experience and recent developments in the management of existing UK dams.

These research areas were presented to the Sustainable Asset Management (SAM) Theme Advisory Group (TAG) of the Joint Defra / EA Flood and Coastal Erosion Risk Management (FCERM) R&D programme. They were also presented to the Reservoir Safety Advisory Group, who gave their full support.

One important research area that was identified was to develop guidance for the inspection, monitoring, maintenance and repair of tunnels in dams and reservoirs. The Environment Agency commissioned Black & Veatch Ltd (BV) to carry out a scoping study to identify whether there was a need for additional research on the inspection, monitoring, maintenance and repair of tunnels in UK dams and reservoirs.

After discussions with the industry, it was agreed that the scope of the study should be extended to include all conduits (tunnels, culverts and pipes) at reservoirs.

1.2 Methodology

The two main aims of the study were to establish: what guidance is available, in the UK and internationally, on the safety assessment of conduits and; the need for guidance and its required scope.

CIRIA was known to be producing a comprehensive guide to the inspection of tunnels in the transport industry and so early discussions were held with them to discuss the scope of their guidance and the relevance it might have for reservoir safety. BV reservoir engineers based in the United States and Australia were contacted to find out what guidance, if any, is used in the Americas and Asia. Finally, a review was carried out of reservoir safety guidance available in the UK.

We consulted with the reservoir safety industry by sending out questionnaires and by making a short presentation at the Supervising Engineers Forum.

1.3 Types of conduit

Conduits through dams can take many forms and are put to different uses. Their principal uses are:

- outlets from overflows; these usually flow part full, but under some conditions may flow full and under pressure;
- scour or bottom outlets; these may flow under pressure in pipes to discharge downstream of the dam, but they may also discharge into larger tunnels or culverts passing through the dam or its foundation;

- drawoff pipes; these normally flow under pressure. They may be laid directly within a dam or its foundation, or may be located within a dry culvert or tunnel;
- access; it is rare that a culvert or tunnel is constructed solely for this purpose.

The principal types of conduit are:

- tunnels;
- cut-and-cover culverts in the foundation of the dam;
- culverts located on the dam foundation and covered with dam fill;
- pipelines in trenches in the dam foundation;
- pipelines in the dam fill;
- pipelines in a culvert or tunnel.

The conduits that are the subject of this scoping study are those that are in contact with the natural ground or the dam fill. The inspection of pipes and ancillary equipment is satisfactorily covered in Reader et al (1997).

1.4 Definitions

There are various definitions of a 'tunnel' and a 'culvert' that are in use in the reservoir industry. The most commonly used definitions – and those that are used in this study - are given in Charles et al (1999):

'Culvert: A structure built beneath a dam embankment in open excavation and covered by embankment fill material';

'Tunnel: A structure beneath the dam or adjacent valley driven through original ground and therefore surrounded by original ground';

Charles et al (1999) also state; *"Culverts and tunnels were frequently constructed to carry the outlet pipework, and at some dams they also allow access to the draw-off tower. These culverts and tunnels protect the dam from erosion due to defective pipework, and they permit access to pipes for maintenance and repair work to be undertaken."*

Blockley (2005) defines a pipeline as *"A long pipe carrying e.g. water, gas, oil".*

2 Modes of failure

2.1 Introduction

The potential for problems with conduits to lead to failure of a dam is well known to reservoir safety engineers. The most dangerous mechanism of failure is erosion of an embankment dam's fill by water passing along the contact between the conduit and the fill. This has long been recognised as a potential failure mode but early detection can be difficult. Contact erosion can occur without there being any physical damage to the conduit.

Physical damage to the conduit can cause problems in several ways. Fracture of a conduit could release water under pressure and cause internal erosion along the conduit/fill interface. Structural failure of a conduit, particularly a culvert, could result in displacement of part of the structure and form a passage for internal erosion along the conduit/fill interface. Conduit failure could damage scour outlet facilities and prevent them operating in an emergency.

2.2 Incidents

We searched the Building Research Establishment and Environment Agency databases for incidents relating to conduits. The total number of recorded incidents was 29. This is too few to make a reliable statistical analysis of the types of incident. A table of incidents relating to conduits is attached as Appendix A.

A well known dam failure is that at Warmwithens Dam, in 1970, when the dam breached due to overtopping. There is a strong probability that a fault related to a conduit was to blame. It is thought that internal erosion took place along the side of the drawoff tunnel and this led to the formation of a cavity. The cavity caused subsidence that eventually resulted in overtopping of the dam crest.

At Lower Rivington, minor leakage through the walls of the culvert had been monitored for many years. In January 2002 this flow increased and became cloudy, so reservoir levels were reduced by emergency drawdown. It is likely that, but for this action, internal erosion would have led to the eventual failure of the dam.

Analysis of reported incidents shows that:

- nearly 20% of incidents at dams can be either directly or indirectly attributed to conduits;
- structural failure is the most common cause (>50%) of incidents that were directly attributed to conduits. There were also several incidents involving internal erosion either along, or into, conduits;
- in less than 10% of incidents where the primary issue was not with a conduit, an issue has subsequently arisen with a conduit.

In incidents where the conduit was a secondary factor, the most common problem with the conduit was structural. There were also a few issues with internal erosion either along, or into, the conduit.

2.3 Modes of dam failure and monitoring and measuring techniques

The Environment Agency has commissioned a research project into modes of dam failure and monitoring and measuring techniques. This is in progress and the report is due to be issued this year. We have seen a preliminary copy of the report, which was issued for a workshop held on 21st May 2009. The report identifies a number of modes of dam failure and the following relate to conduits:

- blockage of spillway (which could include blockage of a spillway tunnel or culvert);
- contact erosion along ancillary structure (such as a conduit);
- damage to ancillary structure (such as culvert or tunnel);
- deterioration of ancillary structure (which could include culverts) and;
- hydraulic fracture (for instance due to the intrusion of a culvert into embankment fill).

In the report's section on monitoring and measuring techniques, there was no specific mention of monitoring of conduits, although the section had yet to be completed. Several of the monitoring and measuring techniques described would provide indication of problems due to conduits.

3 Review of available guidance

3.1 Published guidance

Among responses to the questionnaire, the most frequently quoted reference document was Charles et al (1999). The guidance on tunnels is necessarily brief, due to the document's wide scope.

The document contains a brief description of possible issues relating to tunnels. These are primarily settlement or migration of fill through cracks leading to loss of material in the dam. It contains a table of surveillance indicators for possible defects, which for tunnels includes deformation and flow of water. The probable causes and consequences for each of these are described. The guide suggests referring to a number of BRE Digests for further information on investigating the deterioration of structures, and the selection of methods of repair. It also briefly states what repairs may be carried out.

In the questionnaire responses, a couple of references were made to Reader et al (1997). This document is primarily concerned with valves and pipework. It contains detailed information on location techniques and non-destructive testing methods. In many cases these techniques could be applied to concrete or masonry conduits. This document is now over ten years old and some methods of investigation may have improved, but the basic principles of inspection, monitoring and investigation remain relevant.

Discussions with overseas colleagues, within BV, brought to our attention the guidance document from the Federal Emergency Management Agency (2005), which contains comprehensive information on all conduits through dams. This includes potential failure modes and defects, visual inspection techniques, maintenance and monitoring, emergency action and repairs and replacement. There is an excellent section on non-destructive testing techniques, which should be relatively up to date as the guidance was published in 2005. This document is specifically aimed at the US industry, so the availability of these techniques in the UK would have to be considered.

3.2 Forthcoming published guidance

CIRIA has two separate projects underway that will provide comprehensive guidance on conduits, which will be applicable to reservoirs. We are grateful for the cooperation of CIRIA in making these documents available to the project team and for their assistance during this scoping study.

McKibbins et al (2009) primarily deals with larger tunnels, those with a diameter of 1750 mm and above, which they judge to be sufficient to allow a person to enter. Much of the information in their study is applicable to smaller tunnels, but reservoir engineers will need to give some consideration to particular concerns regarding smaller tunnels.

The report contains comprehensive guidance on construction, repair and inspection of tunnels, including non-destructive testing. However, it states that further research to develop this area would be desirable. There is no specific reference to dams or reservoirs.

The proposed 'Culvert design and operation guide' (Balkham et al., 2009) is still at the drafting stage. This is not specifically aimed at the reservoir industry, but initial indications are that this document will be of use to reservoir engineers who are inspecting and maintaining conduits.

3.3 Other available references

A number of internal company guidance documents have been obtained through, or referred to in, responses to the industry questionnaire and from internal BV sources. These contain information such as inspection procedures and, from the samples made available, in many cases would be of use to the wider industry.

3.4 Conclusions

The most comprehensive guidance documents available, or shortly to be made available, are McKibbins et al (2009) and Federal Emergency Management Agency (2005). Both these documents contain relevant and up to date information on inspection, monitoring, maintenance and repair of tunnels. While much of this information is applicable to dams in the UK, neither document is directly aimed at the UK reservoir industry.

Our review of references suggests that adequate generic information on conduits already exists. However, there is no single document that could be used as guidance for the inspection, monitoring and maintenance of conduits at UK reservoirs.

4 Liaison with industry

4.1 Introduction

To better understand the industry's needs, a simple questionnaire was circulated to all Panel Engineers and the major undertakers in England and Wales. The questionnaire and the tables summarising all of the responses are included in Appendix B. A total of 225 Questionnaires were sent out and 64 individuals responded. They defined their roles in the reservoir industry as follows (note that some responders have more than one role):

- Reservoir Owner/Owner's Representative: 19;
- Reservoir Manager: 7;
- All Reservoirs Panel Engineer: 12;
- Non-impounding Reservoirs Panel Engineer: 1;
- Service Reservoirs Panel Engineer: 1;
- Supervising Engineer: 46;
- Ex Supervising Engineer: 1;
- Manager, Reservoir Safety: 1;
- Reservoir Act Coordinator: 1;
- Geotechnical Engineer: 1.

4.2 Reference documents in use by industry

The responses to the questionnaire have allowed us to understand how current reservoir practitioners define tunnels and to identify the reference documents on this topic that are available to, and used by, them. The key information obtained from the responses is presented below.

For the purposes of reservoir works and this scoping study the term tunnel will be deemed also to include cut and cover culverts. How would you define a tunnel?

Any conduit with a diameter/width greater than X mm. Please state X

Any conduit constructed in-situ rather than from prefabricated units (eg pipes but not tunnel segments)

Other (please specify)

The most common response, given by over 50% of responders, was that a tunnel should be defined as a conduit with a particular diameter. Suggested diameters ranged from 500mm up to 2000mm. This definition was often justified on the grounds that a tunnel should be sufficient for a person to enter. Overall, 30% of responders stated that person entry should be the requirement for a tunnel. However, where given, opinion on the diameter that is sufficient for a person to enter varied from 600mm up to 1800mm.

Other popular definitions included:

- any *in situ* conduit (35%);
- a conduit excavated through natural ground (15%).

Guidance for maintenance and repair of tunnels

The most common responses to this question were:

- not aware of any guidance specifically relating to tunnels – 75%;
- experience/judgment (own or others) – 10%;
- internal company guidance/documents – 5%;
- USBR Design of Small Dams – 5%;
- forthcoming CIRIA guidance document – 5%.

Areas in which additional research or guidance is required

The areas where responders identified a need for additional research or guidance, and their importance to responders, are presented in table 1.

Table 1. Areas for additional research or guidance identified by, and their relative importance to, responders.

Area	Required	Ranked 1st*
Intrusive investigation	65%	5%
Maintenance	80%	5%
Monitoring by measurement or instrument	75%	15%
Non-intrusive investigation	75%	15%
Repairs	75%	15%
Visual observation	75%	40%

** Not all responders ranked the areas*

Need for a comprehensive guide to the inspection, monitoring, maintenance and repair of tunnels and culverts at reservoirs

Eighty percent of responders believe that a comprehensive guide to the inspection, monitoring, maintenance and repair of tunnels and culverts at reservoirs is needed.

5 Gap analysis

5.1 Introduction

Following receipt of the questionnaire responses we conducted a gap analysis. This was done in two parts: the first part considers the needs of the industry and the second indicates the relevance of available guidance.

5.2 Industry needs

The need for additional guidance, from in the gap analysis, is summarised in table 2.

Table 2. The need for additional guidance as identified by the industry; from a gap analysis of questionnaire responses.

Question	Response	Comment
What guidance do you use or are you aware of: - for inspection/ monitoring of tunnels; - for maintenance/repair of tunnels.	Not aware of any guidance specifically relating to tunnels.	This demonstrates a need for guidance – either a specific guidance document or guidance on where information can be found.
	Experience/judgment (own or others).	This is acceptable for specific problems, but cannot be used for general inspection and monitoring. There is a danger of gaps in knowledge.
	Internal company guidance/documents.	These may not be readily available and could relate to specific types of structure and situation.
	USBR Design of Small Dams.	This is a design manual and not intended as guidance for inspection and monitoring.
	Forthcoming CIRIA guidance document.	This is targeted at larger diameter transport tunnels and does not cover all the issues for conduits at reservoirs.
Please state the areas in which you think that research and/or guidance is needed: - visual observation; - monitoring by measurement or instrument; - non-intrusive investigation; - intrusive investigation; - maintenance; - repairs.	 65% 80% 75% 75% 75% 75%	The figures are a clear indication of the need for some form of guidance.
Do you think that there is a need for a comprehensive guide to the inspection, monitoring, maintenance and repair of tunnels and culverts at reservoirs?	Yes 78%	

5.3 Available guidance

The gaps in available guidance and reference material, identified in the gap analysis, are summarised in table 3.

Table 3. A list of available guidance and reference documents, identified from the gap analysis, with a commentary on their content and suitability as guidance materials.

Guidance document	Comment
An engineering guide to the safety of embankment dams in the United Kingdom (BRE).	There are short sections on surveillance indicators and investigation. The information given is not sufficiently comprehensive to be used as a complete guide.
An engineering guide to the safety of concrete and masonry dams in the UK (CIRIA Report 148).	Conduits through concrete dams have much less impact on reservoir safety than at embankment dams. There is some useful information on deterioration of concrete.
Valves, pipework and associated equipment in dams (CIRIA Report 170).	This is targeted at the condition of pipes and valves, rather than conduits through dams. It does contain useful information on investigation techniques for the condition of pipes and on detection of leakage from them.
Tunnels: inspection, assessment and maintenance (CIRIA).	A very comprehensive document intended for use in the transport industry. Much of the information would be useful as a basis for a similar guide for reservoir safety. There are specific issues related to reservoir safety that are not included
Technical Manual: Conduits through embankment dams (FEMA, USA).	A thorough document containing guidance on inspection, monitoring, maintenance and repair of culverts and tunnels at reservoirs. With some editing, this could be a useful model on which to base guidance for the UK. It does not cover some of the older types of construction encountered in the UK.
Culvert design and operation guide (CIRIA) – not yet published.	Includes a section on operation, inspection and assessment of existing culverts. Although not specific to reservoir and dam culverts, this document provides useful information to practitioners, particularly with respect to the health and safety considerations of culvert inspections.
Trash Screens – Design and Operation Manual (Defra/Environment Agency).	Provides guidance on the design, operation and maintenance of trash screens at culvert inlets. This document does not consider the case of trash screens on reservoir culverts. This document is currently being revised. It is understood that it will not consider trash screens on reservoir culverts, but some of the guidance would be applicable.

6 Conclusions

6.1 Background

Conduits through dams take a variety of forms and have many uses. They are often an integral part of the safety measures for the dam, for instance forming part of the overflow provision or containing scour pipework for emergency drawdown. The most significant risk to reservoir safety, posed by conduits, is the potential for internal erosion of dam fill along the interface with the conduit. Dam failures and many incidents have occurred as a result of this process.

6.2 Available guidance

There is specific guidance available on safety assessment of embankment dams (Charles et al., 1990), of concrete and masonry dams (Kennard et al., 1996) and of valves, pipework and associated equipment (Reader et al., 1997). There is also guidance available on appropriate design standards. There is no specific guidance on the safety assessment of conduits through dams.

Two current CIRIA research projects (McKibbins et al., 2009 and Balkham et al., 2009) will provide guidance on the inspection, monitoring and maintenance of tunnels and culverts, respectively. However, the guidance is not specifically related to reservoir safety; some of the information contained in these documents will not be relevant and there will be some matters, specifically associated with dams, which are not covered.

In the US, Federal Emergency Management Agency (2005) provides comprehensive guidance on the inspection, monitoring and maintenance of conduits through embankment dams. This is a potentially useful document, but lacks guidance on older types of culverts and tunnels that are common in the United Kingdom. This guidance document would have to be adapted for use in the UK.

As well as the published guidance documents discussed above, there are internal guidance documents being used within a number of organisations that, if organisations were willing to make them available, could provide information for inclusion in a new guidance document.

6.3 Industry needs

Among the 64 responses to the questionnaire, a high proportion expressed the opinion that a comprehensive guide to the inspection, monitoring, maintenance and repair of tunnels and culverts at reservoirs is needed.

About three quarters of the respondents thought that guidance was needed on visual observation, monitoring, intrusive and non-intrusive investigation, maintenance and repairs. Guidance on visual observation was ranked as most important.

7 Recommendations

7.1 Results of gap analysis

The gap analysis identified a clear need for consolidated guidance on the inspection, monitoring, investigation, maintenance and repair of conduits (including tunnels, culverts and pipes) at reservoirs.

There is much guidance available on the assessment of the condition of tunnels and culverts, but this is not in a form that could be readily used by the UK reservoir safety industry.

7.2 Recommendations for further research

The mechanisms by which defects in conduits could lead to dam failure have been widely documented and are generally believed to be well understood. Specific problems associated with conduits are the subject of a number of papers. A targeted bibliography would be a useful resource and would be most beneficial if incorporated into a guidance document.

No further research into the mechanisms of failure due to defects in conduits is necessary.

The gap analysis identified a need for improved guidance on the design and maintenance of trash screens at reservoir culverts. We recommend that this be included in the revised Defra/Environment Agency Trash Screen Design and Operation Manual. Alternatively, consideration could be given to conducting further research on this topic with the intention of incorporating its findings into the reservoir conduit guidance document.

7.3 Recommendations for guidance document

There is overwhelming demand for a guidance document on the inspection, monitoring and maintenance of conduits (including tunnels, culverts and pipes) at reservoirs. While guidance documents prepared for other industries in the UK and the United States contain substantial relevant and useful information, the documents are not in a form that would gain wide acceptance in the UK reservoir safety industry.

It is recommended that a contract is awarded for the preparation of guidance for the safety assessment of conduits at reservoirs in the United Kingdom.

It is envisaged that the contents of the document would include:

- introduction and scope;
- description of types of conduit;
- description of failure modes;
- visual inspection techniques;
- monitoring techniques (measurements);
- non-intrusive investigations;
- intrusive investigations;
- maintenance;
- bibliography.

Further description of the scope and contents of the proposed guidance document is given in Appendix C.

The guidance document is aimed at those undertaking routine inspections and assessing the safety of conduits. Means of repairing major defects have been excluded as each case would need specific consideration by experts. However, routine repairs would be included in the section on maintenance.

The document should include a warning about health and safety issues, specifically entry into confined spaces, but detailed discussion will not be necessary as there is sufficient guidance already available.

The document should be of similar length to the guides on embankment dams (Charles et al., 1999), on concrete and masonry dams (Kennard et al., 1996) and on valves and pipework (Reader et al., 1997). To avoid excessive background technical information, cross references should be used to direct users to other documents such as McKibbins et al. (2009) and FEMA (2005).

Appendix A

Incident Data Base Information

A1 Information obtained from incident database

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Appendix A1 - Information obtained from Incident Database

Summary of number of incidents directly and indirectly attributable to issues with a conduit

Incident level	Total number	Directly attributable to conduit		Indirectly attributable to conduit	
		Number	%	Number	%
Failure	23	3	13	0	0
Serious incident	87	6	7	9	10
Incident	112	16	14	5	4
Non reportable incident	3	2	67	0	0
not known	5	2	40	0	0
Total	230	29	13	14	6

Breakdown of causes of incidents that are directly attributable to issues with a conduit

Incident level	Total attributable to conduit	Internal erosion along conduit		Internal erosion into conduit		Settlement of conduit		Structural issues with conduit	
		Number	%	Number	%	Number	%	Number	%
Failure	3	2	67	0	0		0	1	33
Serious incident	6	1	17	2	33		0	3	50
Incident	16	1	6	5	31		0	10	63
Non reportable incident	2	1	50	0	0		0	1	50
not known	2	0	0	0	0	1	50	1	50
Total	29	5	17	7	24	1	3	16	55

Breakdown of primary causes of incidents where subsequent issues occured with conduit

Primary cause	Total	Internal erosion along conduit	Internal erosion into conduit	Structural issues with conduit
Mechanical issue	1			1
seepage through dam	6	2	3	1
settlement	5			5
structural issue (not with conduit)	2		1	1
Total	14	2	4	8

A2 Incident database - incidents indirectly associated with conduits

Scoping Study on the Need for Additional Research and/or Guidance on Reservoir Conduits

Appendix A2 - Incident Database - Incidents indirectly associated with conduits

Number	Dam	Incident level	Date	primary cause	Conduit contribution	Details	Action	Assessment	Lessons, surveillance and instrumentation	Remedial actions	Papers
3	Holden Wood	2 - serious incident	Jan-45	structural issue (not with conduit)	internal erosion into conduit	In 1945, a large hole 2m square by 1m deep appeared in crest vertically above outlet culvert. It was found that a masonry wall across the culvert at the downstream side of the core was leaking and one or two masonry blocks were missing.		Inspection of the culvert revealed the leaking masonry stop wall across the tunnel. It was assumed that leakage had eroded the core into the culvert through the defective wall.	Suggested that the in the absence of frequent inspections by an observant reservoir keeper that a total failure might have occurred.	Attempts were made to plug the leakages by quick setting grout, but proved unsuccessful. A final repair was done by building a new concrete stop wall and grouting the interspace and surrounding rock. Repair in 1945 - it would be interesting to find out if further repairs have been carried out.	
10	Holmestyes	2 - serious incident	Jan 1853	seepage through dam	internal erosion into conduit	c1853 - Captain Moody (Government's Engineer at Bilberry inquest) inspected Holmestyes and found the valve shaft and culvert to be leaking and running "considerably muddy". Depressions were also identified presumably on the crest.	Not known but would have been drawn down for the remedial works to upstream face.	The valve tower is just upstream of the central puddle core. Subsequent investigations have shown the permeability of the upstream fill to be very high such that the full reservoir head is on the valve tower.		Bateman added a puddle clay blanket to the upstream slope and adjacent sides and protected by sandy fill and pitching. There is no information about repairs to the tower.	Refs. 6

13	Knypersley	2 - serious incident	Jun 1828	settlement	structural issue with conduit	June 1828. Masonry wall at core end of upstream culvert fractured and joints in cast-iron pipes through core pulled apart due to settlement of core.				The discharge pipes were replaced with thicker pipes where they had been pulled apart at joints. The masonry walls of the culvert were made thicker close to the core. Ref. 90 pp130	Ref 90
22	Torside	2 - serious incident	Nov-54	settlement	structural issue with conduit	During first filling when the reservoir was within 3m of being full on the 17 Nov 1854, considerable quantities of water emerged on the downstream slope resulting from the fracture of both discharge pipes. Ref. 6 pp181		It appeared from investigations that the base of the embankment had stretched such that the elongation was 3.5 to 5 ft in the south range of pipes. About 15 ft of the pipes are crushed into an elliptical form. Some of the joints are pulled apart. Ref. 6 pp181.Ref 5 pp130. The probable cause of the movement is the existence of a bed of hard clay 5 to 8 ft thick which underlies the gravel that forms the bed of the valley.	Avoid unprotected pipes in embankments.	Repairs were made to the pipes for temporary use. To avoid future problems a tunnel through the abutment with two pipes was constructed. A new puddle trench was sunk into the clay near the foot of the inner slope and the upper part was lined with a clay blanket. 1889 - new siphon valves installed involving repairs to pitching.	Refs. 5,6, 403

26	Lluest-Wen	2 - serious incident	Nov-69	seepage through dam	internal erosion along conduit	A horse fell into a 2m deep swallow hole on the crest close to the valve tower. Puddle clay had eroded through a 50mm gap between valve shaft and draw-off tunnel. It was feared that the dam would collapse.	People living downstream were evacuated. The 0.38m dia draw off pipe was inadequate for rapidly lowering the reservoir and a large number of pumps were used. An emergency cut was made in the spillway lowering the overflow level by 9m.	Investigations indicated that puddle clay was emerging from a 0.15m dia drainage pipe where it terminated in the draw off tunnel. Investigations after grouting showed the core had cracks and many of them open and iron stained by seeping water. The core was very soft in the vicinity of the valve shaft. Further details in Ref 77.		Subsidence had occurred in 1912 and 50 tons of cement grout had been injected in the area of the valve shaft. 50 tons of grout were injected into the puddle clay core. After grouting further investigation showed the core to contain pockets of silt and sand, many cracks and open water-worn cavities. During 1971-73 a plastic concrete core, 0.6m wide, was installed using the slurry trench method to a maximum depth of 35m. The underlying bedrock and abutments were grouted.	Refs.73, 154, 232

32	Bottoms (Macclesfield)	2 - serious incident	May-29	seepage through dam	structural issue with conduit	in May 1929 a slip was developing in the downstream slope when the reservoir was half full. Details in Ref 135. The slipped portion was found to be saturated with water. Slip caused by fractured outlet pipe which could have led to internal erosion, slope instability and breach.	The reservoir was emptied and the TWL was reduced by removing a sill from the overflow weir.	Investigation involved making a cut into the downstream of the embankment on the line of the pipes. The outlet consisted of two 300mm dia cast iron pipes 0.5m apart laid directly under the embankment at approximately ground level. Both cast iron pipes were broken close to the flanges near to the upstream side of the puddle core and the broken ends had separated by 50mm. Other breaks had taken place. Details in Ref. 135. The embankment had settled such that the top of the core was 1ft 9ins below TWL. It was concluded that the first slip was due to seepage of water over the top of the puddle when the reservoir was full.	Unsatisfactory "out of date" design of outlet arrangements. Embankment settlement led to overflow over the top of the core and to saturation of downstream fill resulting in the slip. The absence of drainage in the outer slopes contributed to the slip.	The remedial works consisted of construction new culvert for outlet works, new outlet valves, drainage of the outer slopes, cement grouting of the foundation rock, details in Ref. 135.	Ref. 135

34	Bilberry (1845)	2 - serious incident	Jan 1843	seepage through dam	internal erosion into conduit	There was a very considerable spring in the rock under the puddle trench and that it had never been stopped or carried past. Muddy water came through the culvert in 1841 and in 1843 water burst through the culvert. It is reported that the crest settled 3m between 1846 and 1851. Muddy water came through the culvert in 1841 and in 1843 water burst through the culvert. Remedial works were unsuccessful and large settlements occurred. This settlement eliminated the freeboard and soon after midnight on 5 February 1852 the embankment was over-topped and breached. It would appear that erosion of and through the puddle clay was the cause of the settlement that led to the catastrophe.		Failure to prevent the internal erosion into the culvert and no action to maintained the freeboard led to major incident.			Refs. 6, 43
38	Woodhead 1	2 - serious incident	Jan 1851	seepage through dam	internal erosion along conduit	The first embankment was within 7m of its final 29m height when the impounded water reached a depth of 9m. Seepage at this point had reached a balance with the inflow and no further water was being stored. Leakage had been observed at the downstream toe and there were also indications of internal erosion. Leakage at	No emergency actions are known	Leakage was thought to be associated with the outlet pipes through the embankment.	Much of the leakage was probably due to inadequate cut-off.	From 1853 attempts were made to stop the leakage by sinking boreholes and pouring fine ashes down them. The effect was only temporary. A second embankment was constructed immediately downstream of the original	Refs 5,6

						times exceeded 100l/s.				embankment and the area between infilled.	
40	Ogston	2 - serious incident	Oct-01	mechanical issue	structural issue with conduit	Catastrophic failure of pipework in the draw off shaft. A Larner Johnson streamline valve incorporated into the scour pipework was replaced with a butterfly valve. Failure was caused by fitting of an inappropriate valve and undersize gearbox for the required duty and configuration.	Guard valve was shut to isolate discharge by men going back through the discharging water.	The incident occurred because an inappropriate valve was fitted. The external threat was human error but the mechanism of deterioration was excessive hydraulic loading on the system	The failure of the pipework was caused by fitting an inappropriate valve and gearbox for the required duty and configuration.	Replacement of the refurbished Larner Johnson valves and pipework.	Ref 891

11	Holmestyes	3 - incident	Jan-92	seepage through dam	internal erosion into conduit	History of leaks into the valve tower and culvert. 1938, 1939, 1944, and 1992. In 1944 the total leakage amounted to 0.63 l/s. A rapid increase occurred in 1992 and at higher levels in the shaft. Leaks developed in the shaft due to increase in water in the upstream fill.		Geotechincal investigations were carried out as there were concerns about the build up of pore water pressures in the upstream that could lift the upstream clay blanket, Ref. 454. Measurements showed that pore pressures in the upstream fill were significantly less than reservoir head and therefore the possibility of the upstream clay blanket being damage due to excess water pressure on reservoir drawdown was unlikely at that time. The rapid increase in leakage into the valve tower was associated with a long period of heavy rain and build up of water levels in the upstream fill.		Remedial works to stop leakage into the shaft and tunnel include: 1939 - radial grouting from within the shaft, strengthening the culvert with steel arches, grouting and 50mm reinforced mortar skin. 1944 - caulking of joints in the shaft 1998 - tube-a-manchette grouting from the surface 1.2m outside the valve shafted to seal leaks. Remedial works to the scour valve and pipework, Ref. 694	Refs. 454, 694
18	Queen Mother	3 - incident	Apr-06	settlement	structural issue with conduit	Significant water leakage outside the toe of the dam in adjacent roadway. Unlikely that the dam would have failed.	Precautionary drawdown undertaken until situation could be assessed. Drawdown stopped once condition assessed as stable.	A technical review of all wedge block tunnel assets was undertaken. Incident caused by loss of ring compression due to softening of supporting ground surrounding the tunnel.	Ensure ALL tunnels under dams are inspected on a regular basis. All design information on tunnels should be kept with Reservoir Record and form part of Section 10 inspection.	Inlet tunnel structurally relined under dam embankment.	

19	Rudyard	3 - incident	Jan-92	settlement	structural issue with conduit	During 1992 remedial works found that cast-iron draw-off pipes had settled and distorted where they passed through the core to such an extent that they had pulled apart at the joints.		Due to settlement of the dam the draw-off pipes had pulled apart.	Unsatisfactory design with pipes going through core	A tunnel was driven through the core and the pipes were laid in it.	Ref. 90
25	Coedty	3 - incident	Jan-86	structural issue (not with conduit)	structural issue with conduit	History of leakage. Repairs in 1972 cured by grouting with high grout takes. Wet areas on DS face in 1986. Ref 281. 1988 safety assessment showed the draw-off to be in a poor condition. The steel lining was corroded and a short unlined concrete section at the downstream end showed signs of leakage.	Reservoir kept 1.5m below storage level. Full safety assessment initiated.	The concrete core wall was in poor condition. High phreatic surface in DS fill where embankment had not been rebuilt. Slope stability was marginal. V notches installed showed that substantial flow occurred as reservoir level approached full storage level. Flow increases were consistent with defective core concrete.		Stabilising fill added to downstream slope with drainage layer. Stabilising fill placed to half on the upstream slope. The culvert was lined with 1.5m diameter glass reinforced resin liner.	Ref. 281
42	Rishton	3 - incident	Jan-89	settlement	structural issue with conduit	1989 report. Masonry of upper draw-off culvert considerably distorted due to mining subsidence. Circumferential cracking evident in several places.				No recorded remedial works on draw-off culvert.	

A3 Incident database - incidents directly associated with conduits

Scoping Study on the Need for Additional Research and/or Guidance on Reservoir Conduits

<u>Appendix A3 - Incident Database - Incidents directly associated with conduits</u>

Number	Dam	Incident level	Date	Cause	Details	Action	Assessment	Lessons, surveillance and instrumentation	Remedial actions	Papers
5	Horndoyne Farm	1 - failure	Nov-90	internal erosion along conduit	It had been reported that a trickle of water was seen along side the side of the outlet pipe and this developed into a stream taking so earth with it and eventually a breach was formed partially by collapse. Breach due to internal erosion along outlet pipe. On failure the flood released a wall of water described as several feet deep. Four houses were flooded causing damage to the buildings and contents. A large residential caravan was swept over 100m from the site. There were no injuries. On the 17/11 November 1990 the dam breached in the vicinity of the overflow pipe was reported.		Internal erosion associated with draw off pipe. Volume of reservoir calculated to be 23,000m3.	Unprotected pipe through embankment.		
35	Warmwithens	1 - failure	Nov-70	internal erosion along conduit	The first sign of leakage was at about 7.30am, the breach gradually increased with a maximum at about 9.30. It gradually decreased until the reservoir was empty about 1.30 - 2.30. The water level recorder indicated a fall of level at 17.00 the day before the breach.	No action was taken. The flood overtopped the in reservoir downstream Cocker Cobbs and passed over the spillway of Jackhouse reservoir without doing serious damage.	It is thought that internal erosion took place along side of the draw off tunnel which led to a cavity being formed leading to subsidence and eventual overtopping of the crest.	Construction of a tunnel through an existing embankment provides increased potential for reduced stress, a leakage path and internal erosion. It is speculation whether the failure could have bee avoided if action had been taken on the results of the water level measurements.	Dam has not been replaced	Refs 92, 470

4	Dale Dyke	1- failure	Mar 1864	structural issue with conduit	A horizontal crack along downstream slope near the crest appeared late afternoon and at 23.30 the same day the dam failed. 8 hours prior to the failure there was no sign of distress to the embankment. The dam failed on first filling. The dam was breached at 23.30, the flood resulted in 244 deaths and extensive property damage in Sheffield.	Details in Refs 6 and 918. Both outlet pipes were opened after the appearance of the crack Poor communications at time prevented warnings being given.	Possible causes: a). Fractured unprotected outlet pipe. b). Landslide on left bank. c). Possible differential settlement where a spring was encountered and the cut-off trench was excavated with a vertical cliff over 10m deep.	Avoid very narrow cores and permeable fill adjacent to the core. Avoid unprotected pipes in fill.	A new dam was built upstream of the failed one in 1867.	
7	Carno Lower	2 - serious incident	Jan-05	internal erosion along conduit	On the 20 January 2005 the SE was notified of increased and turbid water flows in the toe drains. Flow was estimated to be 200l/s with significant silt 1% silt content. On drawdown there was large settlement over a 70m length associated with the draw-off culvert. Emergency drawdown was undertaken and large settlement occurred at the crest. This was assumed to be caused by internal erosion probably confined to the core close to the draw-off culvert. Potential for failure if emergency drawdown had not been undertaken.	low from Carno Upper was diverted. During investigation larger flows emerged to west of stilling basin and the reservoir was lowered more rapidly.	The dam has had a history of leakage which are summarised in Ref. The cause of the leakage was being investigated in 2006.		The dam is still under investigation and no remedial works have been reported yet.	Ref. 932
14	Lliedi Lower	2 - serious incident	Jan-84	structural issue with conduit	Emergency drawdown revealed faults with scour valves and inadequate protection of draw-off tunnel to scour flows. Details not known.		No details known		1984 - refurbishment of draw off works, new scour valve and scour pipe arrangements.	

15	Longwood Compensation	2 - serious incident	Jan-88	structural issue with conduit	Leakage on downstream face. Potential for erosion of fill and slope instability if no action had been taken		Excavation to investigate source of water. Complete circumferential crack in draw off pipe on downstream side near to spillway, about 2.5m below the surface.		Section of pipe repaired.	
33	Rivington Upper (Yarrow)	2 - serious incident	Jan-02	internal erosion into conduit	Minor leakage through the walls of the culvert had been monitored for many years. At 13.30 on 9 Jan 2002 Headworks staff noticed that the compensation water had increased and was cloudy. Had no emergency action been undertaken it is likely that internal erosion would have led to failure of the dam eventually. Inspection of the culvert found a jet of water issuing at full bore from a half brick opening, used for drainage, and hitting the opposite wall 1.8m away. Material was being eroded and deposited in the invert.	Inflow reduced by raising Anglezarke, the upstream reservoir level by 300mm using sandbags across the overflow weir. Outlet valves at Lower Rivington opened. Pumps, 150mm initially followed by 300mm.	Dynamic probing showed that the culvert was founded on natural ground close to a steep rock face 5m high 3m away. It was estimated that a 1m cube void had formed behind the culvert wall.	1) Culverts constructed through dam are potential hazards. 2)The incident demonstrated the importance of frequent surveillance as leakage can develop very rapidly. 3) The value of a functioning outlet to lower water level. 40 Requirement for effective on-site effective plan.	A grouting programme was undertaken to seal the shoulders foundation and core during the summer of 2002.	Refs. 882, 923
36	Redmires Lower	2 - serious incident	Nov 1850	structural issue with conduit	In Nov 1850 water escaped through the culvert from the inside which was used as an overflow and washed away part of the embankment.		It is suggested that the mortar in the stone work joints was of inferior quality and that there was differential settlement causing cracking of the culvert.		1852 - The bellmouth and vertical shaft spillway was abandoned and an overflow to a side channel was constructed. The top of the shaft was raised and converted to a valve shaft with	Ref 6

									20 in stand pipe and two 12 in inlets an different levels. Completed April 1851, Ref. 6.	
1	Ogden	2- serious incident	Aug-92	internal erosion into conduit	In August 1992 a number of substantial leaks were identified at the foot of the valve shaft. The leakage water was very cloudy and contained suspended solids of approximately 1000mg/litre. In addition, new leaks were present in the crown of the tunnel downstream of the shaft.	A controlled drawdown was undertaken and emergency works were implemented.	Investigations only carried out to prove effectiveness of remedial grouting.	Surveillance was sufficiently often to identify leaks. Rapid increase in leakage or erosion can occur without previous warning or evidence. Structures through dams are always vulnerable.	Grouting was carried out from a ring of holes drilled around the shaft from the surface using cement bentonite grout with some sand where excessive grout take occurred. Grouting was also undertaken from inside the shaft to seal leaks. The work was completed by mid October 1992. The work was successful.	Ref 605

2	Ogden	3 - incident	Aug-90	structural issue with conduit	A localised depression on the upstream slope was discovered over the low level draw off tunnel when the reservoir was drawn down. Settlement due to repeated drawdown of reservoir. Emptying the reservoir between 1990 and 1991 caused 150mm of crest settlement.	The drawdown was undertaken to carry out remedial works to the draw off tunnel, not to prevent failure of the dam. The localised settlement had been caused by the collapse of the tunnel.	Extensive monitoring of movements of the embankment was carried out partly because very large drawdown settlements had been measured and as part of the BRE study of drawdown settlements.	Reservoirs should be drawn down periodically to examine the upstream slope for deterioration. The reservoir had not been used for supply for some years and had not been drawn down significantly. The collapse and localised settlement could have been present for some years.	The collapse draw off tunnel was repaired by sinking a shaft over the tunnel and rebuilding a section with precast concrete segments. A glass fibre pipe was installed in the tunnel and the annulus was grouted with foam concrete.	Refs. 605,672
9	Coulter	3 - incident	Jan-30	internal erosion into conduit	Leak into culvert. Grouting from within the culvert reported in 1930 in Ref 32.				Grouting from within culvert reported in 1930.	Ref. 32
12	Knypersley	3 - incident	Jan-88	structural issue with conduit	1988 - Upstream end of downstream draw-off culvert seen to be noticeably distorted and major squatting and longitudinal and circumferential cracking is reported, the latter as much as 75mm open and showing rubble masonry behind the ashlar lining.		Further information is needed.			
16	March Haigh	3 - incident	Sep-97	internal erosion into conduit	In September 2007 water was discovered to be leaking under pressure into the draw off culvert from the side wall about 7m downstream of the bulkhead before the central clay core. The water was carrying a small quantity of sand. Similar leakage had occurred 25 years ago but the rate had reduced with time. Failure was unlikely to occur in the short term.	On operating the valve to lower the reservoir flow came to an abrupt halt. A blockage had occurred upstream of the draw off pipe that passed through the core. Siphons were deployed to lower the reservoir to 7.5m of TWL. Details in Ref 766.			Following a ground investigation, tube-a-manchette grout was used on either side of the draw-off pipe from the crest. There were large grout takes and grout was found to enter the draw off	Refs. 766, 837

									tunnel.	
17	Poaka Beck	3 - incident	Jan-94	structural issue with conduit	Removal of the MDPE liner that had been installed in the 15 in cast iron outlet pipe during the 1980 resulted in the fractured cast iron being removed in the drilling waste. Settlement occurred at the toe of the dam above the position of the pipe during removal of the MDPE pipe. Without remedial work internal erosion along the line of the outlet pipe could have occurred.	The reservoir was empty at the time of the incident.	Investigations indicated the MDPE liner had not been installed and the annulus grouted satisfactorily. Remedial work to removed the liner precipitated the incident but identified old fracture surfaces in the cast iron and some metal only 5mm thick. Complete collapse of the pipe between 8m and 18m from the upstream toe had occurred.	Remedial work to safe guard the unprotected cast iron pipe with an MDPE liner had not worked probably due to unsatisfactory grouting of the annulus. Removal of the liner instigated the incident.	The outlet pipe was grouted solid including the annulus between the MDPE liner and the cast iron pipe. Further grouting was carried out in the area of the settlement	Ref. 707
20	Slaithwaite	3 - incident	Jan-88	structural issue with conduit	1988 report. Spillway tunnel requires repair to loose key blocks and areas damaged by erosion.					

21	Spade Mill No.1	3 - incident	Jan-67	structural issue with conduit	In 1967, leakage developed in embankment about 30m from toe of bank above outlet pipe.		Leak appears to come from pipe.		Leak in pipe repaired by inserting short iron sleeve and forming rust joint between pipe and sleeve. The pipe was scraped and lined in 1981/82.	
23	Winscar	3 - incident	Jan-77	structural issue with conduit	Rapid increase in under drainage flows rose to 2.24 Ml/day in 1977. Flows were disproportionately high above a certain level. The rapid increase in water level measured in the under drainage flow coincided with a surface slip on the left bank downstream of the dam. Leakage also occurred through the left abutment. Details of leakage are given in Ref.64.		Two causes of the leakage were established. Leakage through the left abutment resulted in two stages of grouting in Jan 1978 and 1979 with the specific aim of tightening the contact between two rock strata (white rock/shale interface). A third phase of grouting involved emptying the reservoir which led to the discovery of cracks in the asphaltic concrete in vicinity of the toe wall. Differential settlement		Three stages of grouting of the highly shattered sandstone undertaken to reduce leakage from 1978 to 1980. The underlying rock fill, asphaltic membrane were repaired with the including of flexible copper sheath to accommodate any residual movement, details are given in Ref. 64.	Ref. 64

							between culvert and dam on first filling caused a longitudinal crack in asphaltic membrane.			
24	Wistlandpound	3 - incident	Jan-85	internal erosion into conduit	Water was entering the overflow culvert. Eventual internal erosion if not remedial measures were undertaken. Few details available.		Sampling of downstream fill and installation of eight standpipe piezometers but no results available. Water samples were taken for analysis but no details of results available.		No information available on remedial works.	

28	Bilberry	3 - incident	Aug-95	internal erosion into conduit	These observations were only possible when the downstream reservoir, Digley had been drawn down. First indications noted in Aug 1994 when a vortex was passing through collapsed pitching to rear of overflow shaft. On 16 Aug 1995 pitching stones had collapsed into a cavity 2.15 by 1.8 by 1.5m deep. When the reservoir was drawn down for the outlet remedial works a separate swallow hole was discovered near the auxiliary overflow weir. Flood from failure of the Bilberry would be contained in Digley reservoir.	Water level only drawn down for remedial works.	The two leakages were separate on the dam but have been treated as one incident. CCTV was used in the barrel culvert at the base of the dam which was built by Bateman to divert any springs arising from the base of the embankment, has been used to monitor leakage. Details are in Ref. 675. As early as 1933 The first inspection of Bilberry raised concern over the discolouration of water from the barrel culvert, Ref 6 pp169.		The outlet shaft remedial works involved grouting and pointing of shaft, grouting of the swallow hole, about 4 cubic metres, replacement of puddle clay where leakage had taken place and repairs to pitching. The other swallow hole was repaired using a mixture of sacks of fleece wool waste and bentonite followed by balls of the mixture. This stopped the flow through the swallow hole. The flow from the culvert was also substantially reduced. Full details in Ref. 675	Ref. 675, 6
30	Napton Lower	3 - incident	Jan-77	structural issue with conduit	Leakage into culvert takes place when near TWL. 1967 inspection. Walls of the outlet culvert are cracked and bulging. 1977 inspection.				Culvert refurbished with prayed reinforced concrete lining in 1985.	BWB records

31	Napton Lower	3 - incident	Jan-67	structural issue with conduit	Leakage into culvert takes place when near TWL. 1967 inspection. Walls of the outlet culvert are cracked and bulging. 1977 inspection.					
37	Redmires Lower	3 - incident	Jan-85	internal erosion into conduit	In 1973/74 and 1985 there were incidents involving inflows of water into the outlet tunnel. In both cases small quantities of clay were washed into the tunnel.		Small quantities of clay were being washed into the tunnel indicating that some internal erosion was taking place		Cement and bentonite grout were used to seal the leaks from within the tunnel.	Ref 6
41	Ditchley Park	3 - incident	Jul-06	internal erosion along conduit	New issues of seepage quickly became leakage flows. Long term seepage into drop shaft had also increased. Embankment fill would have been washed into drop shaft and out of downstream face of the embankment. Internal erosion would have caused upstream wall to be unsupported and collapse. Dam break flood wave would probably be retained by another earth embankment 100m DS.	Initially surveillance increased. Water level not lowered immediately but was later after IE visit. Level initially lowered using siphons. Switched to pumps to increase drawdown rate.	Internal erosion due to voids in the fill caused by rotting tree roots, a collapsed old water supply pipe or an inadequate seal between replacement outlet pipe and the surrounding material.	Internal erosion leading to leakage and grouting repair.	Grout injected into holes drilled into spillway shaft. Leakage flows then stopped.	
43	Cofton	3 - incident	Aug-08	structural issue with conduit	Leakage was from the lower outlet pipe near the upstream toe. Complete failure would have been unlikely as the problem with the pipe was near the upstream toe. No problems noted two months previous during S12 visit when valve was fully exercised.		Open joints in the lower draw-off pipe were identified 30.6 m and 53.3 m from the downstream end. There was débris lodged in each joint and leakage at the furthest. The suspicion was	Open joints occurred in the pipework. regular surveillance allowed early identification of problem so that action could be taken in a timely manner.	No remedial work carried out yet. Valve remains closed and agreed with AR Panel Engineer that the pipe should be lined if possible or grouted up if not. On-site plan emergency drawdown plan	

							that this débris was causing turbulence when the valve was open, leading to erosion behind the pipe.		has been re-written to take into account the loss of the outlet and the need for pumping instead.	
44	Gleadthorpe	3 - incident	Feb-06	structural issue with conduit	Coal mining close to one corner of the reservoir caused settlement and reduced freeboard. Freeboard now below the recommended minimum.	Scour pipe failed during drawdown. Repaired and drawdown continued.	CCTV investigation of pipework.			
6	Bewl Bridge	4 - non reportable incident	Jan-96	structural issue with conduit	Severe cracking of pre-cast concrete blocks forming the bellmouth spillway.	The deterioration was not an immediate problem.	Extensive investigations established that the cracking was due to Alkali Silica Reaction , Ref 691	Avoid use of ASR susceptible aggregates on dam structures.	New precast units were installed in 1999.	Ref. 691, 877
39	Toddbrook	4 - non reportable incident	Jan-81	internal erosion along conduit	The dam has a history of leakage. 1880 - complaints about leakage into mine workings, 1930 leakage observed at toe of downstream slope - 1981 -4' dia. masonry culvert found beneath dam, possibly for stream diversion during construction. Tracer tests showed this to have formed a leakage path through the dam.				Grout curtain inserted along the center line of the dam to seal up suspected porous area at the base of the core. Check on references	Refs. 588, 589
27	Pen-y-Rheol	5 - not known		settlement	Collapse of disused iron ore workings beneath reservoir following minor earthquake in 1985 caused depressions in reservoir floor. Sinkholes were approximately 2m diameter but no leakage was seen in the mine workings.		Collapse of mine workings beneath reservoir basin associated with minor earthquake in 1985 although depressions		No records of any remedial actions.	

							had been noted in the reservoir basin in 1983.			
29	Searle's Lake	5 - not known	Jan-87	structural issue with conduit	In 1984 significant leakage was emerging from either side of the culvert and at one point in the toe. A sudden increase in leakage rates occurred in early 1987 due to frost damage of the brickwork.		Could be argued that frost was the external threat.		Repair of brickwork.	

Appendix B

Questionnaire Responses

B1 Questionnaire

1. Please tick as many of the following as appropriate to describe your role in the reservoir industry:

□ Reservoir owner □ Reservoir manager

□ Supervising Engineer □ AR Panel Engineer

□ Other (please specify) …………………………………….

2. For the purposes of reservoir works and this scoping study the term tunnel will be deemed also to include cut and cover culverts. How would you define a tunnel?

□ Any conduit with a diameter/width greater than X mm.

Where X = …………. (please complete)

□ Any conduit constructed in-situ rather than from prefabricated units (eg pipes but not tunnel segments)

□ Other (please specify) ……………………………………………….

……………………………………………………………....................

3. What guidance are you aware of for inspection/monitoring of tunnels. Please identify which of these you use:

……………………………………………………………....................

……………………………………………………………....................

4. What guidance are you aware of for maintenance/repair of tunnels. Please identify which of these you use:

……………………………………………………………....................

……………………………………………………………....................

5. Please state the areas in which you think that research and/or guidance is needed, ranking your choices in order of importance (ie 1 = most urgently required):

□ Visual observation □ Monitoring by measurement or instrument

□ Intrusive investigation □ Non intrusive investigation

□ Maintenance □ Repairs

□ Other (please specify)……………………………………………….

6. Do you think that there is a need for a comprehensive guide to the inspection, monitoring, maintenance and repair of tunnels and culverts at reservoirs?

□ Yes □ No

Thank you for taking the time to complete this questionnaire. If you wish to provide any additional comments please feel free to do so overleaf.

B2 Summary of questionnaire responses

Scoping Study on the Need for Additional Research and/or Guidance on Reservoir Conduits

Appendix B - Summary of Questionnaire Responses

Question 2:
For the purposes of reservoir works and this scoping study, the term tunnel will be deemed to also include cut and cover culverts. How would you define a tunnel?

Response	% of responders
Define by diameter	52%
Man entry	30%
Excavation through natural ground	13%
An in situ conduit	34%

Question 3:
What guidance are you aware of for the inspection/monitoring of tunnels?
Please identify which of these you use.

Response	% of responders
None	53%
Engineering guide to embankment dams	14%
Confined spaces guidance	11%
Internal company documents/guidance	6%
Forthcoming CIRIA guide	8%
Experience (own or others)	8%

Question 4:
What guidance are you aware of for the maintenance/repair of tunnels?
Please identify which of these you use.

Response	% of responders
None	73%
USBR Design of Small Dams	5%
Engineering guide to embankment dams	2%
Internal company documents/guidance	3%
Experience (own or others)	9%
Forthcoming CIRIA guide	5%

Question 5:
Please state the areas in which you think research and/or guidance is needed, ranking your choices in order of importance (1 = most urgently required).

Area	Required (% of responders)	Ranked First* (% of responders)
Visual observation	75%	40%
Intrusive investigation	65%	5%
Maintenance	80%	5%
Monitoring by measurement or instrument	75%	15%
Non-intrusive investigation	75%	15%
Repairs	75%	15%

** Not all responders ranked the areas*

<u>Question 6:</u>
Do you think there is a need for a comprehensive guidance to the inspection, monitoring, maintenance and repair of tunnels and culverts at reservoirs?

Response	% of responders
Yes	78%
No	22%

Appendix C

Scope and Contents of Guidance Document

C1 Purpose and scope

The purpose of the guidance document for 'Reservoir conduit – inspection, monitoring and maintenance' is to provide a concise document which can be used equally by technicians and panel engineers engaged in the assessment of the condition of conduits through reservoir dams and their foundation. The report should thus avoid unnecessary technical discussion but there should be sufficient technical background to inform the reasons for the actions and processes described.

Means of repair of major defects should be excluded as each case would need specific consideration by experts, who would have access to a wide range of supporting information. However, routine repairs should be included in the section on maintenance.

Inspection and maintenance of valves and pipework should not form part of the guide where they are located within a larger conduit or outside the limits of the dam as there is already guidance on this subject (Reader et al, 1997).

There should be a warning about health and safety issues, specifically on the entry into confined spaces, but further discussion and advice is not necessary as there is sufficient guidance already available.

The length of the document should be similar to the guides on embankment dams (Charles et al, 1999), on concrete and masonry dams (Kennard et al, 1996) and on valves and pipework (Reader et al, 1997). The target length of the document is about 200 pages printed at A5 size.

C2 Types of conduit

The guide should encompass all types and sizes of conduit through embankment dams, their foundation and their abutments to the extent that failure of them could jeopardise the safety of the dam. Conduits through concrete dams, where they are integral to the dam's construction, need not be included and it is assumed at this stage that conduits through the foundation and abutments will have similar issues to those at embankments dams.

The types of conduit that should be covered will include, but not necessarily be limited to:

- tunnels through the abutment or the foundation;
- cut and cover culverts (in-situ construction or precast) in the foundation of the dam;
- culverts (in-situ construction or precast) located on or in the foundation and projecting into the dam;
- pipes through the dam.

The guide should cover the following types of use:

- conduits usually flowing full or part full;
- conduits that flow full or part full occasionally;
- dry conduits.

The types of conduit should be clearly described and illustrated by means of simple diagrams.

C3 Description of failure modes

The principal ways in which each type of conduit can cause a risk to the safety of the dam should be described. It is possible that this would most clearly be presented in a matrix. For each type of failure mode, the common indicators of the problem should be set out. There should be guidance on the potential for observed defects to develop rapidly and unpredictably to a point where an emergency situation arises so that the urgency for action can be assessed.

The types of problem to be described should include, but not be necessarily be limited to:

- structural collapse, total or partial failure;
- movement or displacement;
- deterioration in condition, increasing the risk of problems;
- leakage into the conduit;
- leakage out of the conduit;
- seepage along the conduit / embankment or foundation interface.

Cut and cover culverts that project into the fill of an embankment dam can cause stress fractures in a clay fill, with a subsequent risk of seepage and internal erosion. This type of secondary effect is considered to be outside the scope of this guide.

C4 Visual inspection techniques

The most convenient and direct means of assessing condition is by visual inspection, but such inspection may be restricted by access constraints. This chapter should therefore include inspection by eye and by using CCTV or similar techniques, which are deemed for the purposes of the guide to be indirect visual inspection. For direct visual inspection, the report should presume that safe means of access and egress has been provided and that there is adequate illumination.

All visual indicators of problems in each type of conduit should be set out, possibly using a matrix system to avoid repetition. Typical and common indicators should be illustrated by means of colour photographs or sketches.

Guidance on the frequency of inspection should be provided, which will depend on the type of conduit, the vulnerability of the dam and the potential downstream impact. The use of fixed CCTV at vulnerable points in a conduit should be considered to reduce the need for entry into the conduit.

C5 Monitoring techniques

The monitoring techniques to be covered comprise those that involve some form of measurement, with the aim of assessing the behaviour of the conduit abd especially how that might change over a period of time. The techniques to be described should include, but not necessarily be limited to:

- measurement of alignment (vertical and horizontal) and length of conduit;
- measurement of crack widths and steps in the sides, soffit or base of the conduit;

- measurement of shape of conduit;
- measurement of thickness of metallic conduits and elements;
- means of collecting and gauging seepage flows into a conduit.
- means of collecting and gauging seepage flows emanating from along the conduit / fill interface.

The guide should indicate to which types of conduit each technique may be applicable and should suggest the typical frequency of taking measurements. Methods of remote monitoring should be promoted to avoid unnecessary entry into the conduit.

C6 Investigations

It may not be possible to include every type of investigation technique that is available but a range of techniques should be included to illustrate what can be achieved. The intention is not to provide a handbook for investigation but to guide the user in the selection of the mode of investigation and in the extent and reliability of information that can be obtained. It is anticipated that investigations could be needed, inter alia, for assessing:

- the material parameters of the conduit wall;
- any loss of thickness of the conduit wall;
- the presence, size and spacing of reinforcement;
- the origins of seepage into or out of a conduit;
- the flow of water along the outside of a conduit;
- the presence of voids on the outside of a conduit.

Methods of investigation will involve both non-intrusive and intrusive techniques. Rather than dividing the chapter or section into these two parts, it is preferred that the methods are grouped according to the information which they are designed to discover.

A detailed description of the techniques is not necessary but reference to publications and papers that will provide information and guidance should be provided.

C7 Maintenance

This chapter is intended to cover only routine maintenance operations rather then repairs. For instance lining of a badly corroded metallic conduit would be deemed to be a repair whereas repainting it would be maintenance. The guide should indicate the maintenance which should be carried out on a routine basis, with a suggestion on the frequency, and that which is only necessary at infrequent intervals. For non-routine maintenance, there should be guidance as to when, in terms of deterioration of the conduit or the component, the work should be done.

The maintenance work is likely to include:

- cleaning;
- lighting and ventilation;
- painting of metallic conduits, linings and components;

- replacement of metallic items, eg bolts in cast iron lining;
- repairs to concrete, eg cracks and spalling;
- replacement of joint filler and sealant;
- control, collection and conveyance of seepage.

C8 Bibliography

Whilst there will be a need to acknowledge sources of information, the bibliography should concentrate on those references which will provide additional technical information such as FEMA, 2005, and McKibbins et al, 2009. It may be necessary to split the bibliography into a section on references and a section on useful further reading.

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