Risk assessment of dams – Recent developments in the United Kingdom

Risk Assessment für Talsperren – Neuere Entwicklungen im United Kingdom

Alan Brown, John Gosden

Abstract

This paper describes developments in use of the Interim Guide to Quantitative Risk Assessment, which was launched at the European Conference on Dams in Canterbury, UK, in 2004.

Zusammenfassung

Dieser Beitrag beschreibt die Entwicklungen in der Nutzung des Vorläufigen Handbuchs für Quantitatives Risk Assessment, welches im Jahre 2004 bei der European Conference on Dams in Canterbury, England vorgestellt worden ist.

1 Introduction

Risk assessment (RA) is the process whereby decisions are made as to whether the level of existing risk posed by a dam is tolerable or whether the risk needs to be reduced by some form of intervention. This paper describes recent developments in RA in the United Kingdom.

2 Historical context

In 1982 recommendation number four of a House of Lords Select committee reviewing dam safety in the UK was that "research should be carried out into the risks associated with reservoirs and the methodology for quantitative risk assessment (QRA) and that in the light of this research a wider spectrum of safety criteria should be introduced to take account of different degrees of risk in individual reservoirs".

A study into the feasibility of applying risk assessment methodology to reservoir safety in the UK was carried out between 1983 and 1985 (1). This was followed by a feasibility study on a 20m high 100 year old embankment dam retaining a 1 Mm^3 reservoir and reported in Cullen (2), who concluded that "in the light of present knowledge, PRA is not yet a suitable tool for inspection work".

In 2000 CIRIA Report C542 on risk management for UK reservoirs was published (3), but this was a qualitative RA, with output limited to a score on a "Location-Cause-indicator" (LCI) diagram and a qualitative "impact score".

Also in 2000 the Flood Estimation Handbook (4) was issued. This gave an updated methodology to estimate extreme rainfall, which were commonly greater than previous floods and implied wholesale upgrading of spillways might be required. Defra therefore awarded a research contract to determine if it was possible to compare the risk from floods with other threats to dams. The conclusions from this research contract concluded that it was possible to compare floods with other threats (5). The prototype system trialled in this research contract was then developed into the Interim Guide to Quantitative Risk Assessment (QRA) which was launched in 2004 (6). This includes an Excel spreadsheet, intended to encourage use of a screening level QRA.

The ANCOLD Guidelines on risk assessment (7) were published prior to the UK Guide and provided commentary on methods of QRA. The ICOLD Bulletin on RA (8) and “Risk and uncertainty in dam safety” (9) were both published in parallel with the UK Guide. In contrast to the Interim Guide, all of these are limited to principles only; rather than providing a proforma sheets for calculations, together with a worked example.

3 Interim Guide to Quantitative Risk Assessment, 2004

This guide was launched at the last European conference, some three years ago. Since then application of the Guide has identified a number of areas for improvement. Supplement No 1 was issued in June 2006 on the Defra website along with the draft Guide to Emergency Planning, providing extended guidance on the estimation of the consequences of failure. An article in Dams and Reservoirs in April 2007 identified the need for extended guidance on the Condition Score used to estimate the annual probability of failure due to internal threats, examples of such guidance being included in the article (10).

4 Application to date of QRA

4.1 Application to individual reservoirs

A number of major dam owners are using QRA, as summarised in **Table 1**. Application to a 4m high dam as part of a ten yearly safety review led to reduced spillway upgrading works, limited to removing obstructions on the crest and thus a greater length which could be overtopped rather than a major new spillway under the public highway which runs along the dam crest. The authors now use the consequence element of the QRA routinely during reservoir safety inspections to provide a rapid estimate of likely loss of life and thus the Consequence Class of the dam. This is then used to inform evaluation of the design flood, and the general adequacy of the dam.

A survey in late 2005, after a year of use, showed that half of Inspecting Engineers, those accredited to carry out periodic safety reviews under UK legislation, had used the Interim Guide for Inspections and a further 26% in some other context. Only three respondents had used the ALARP approach to determine upgrading works. In terms of promoting use of the Interim Guide as part of a Section 10 Inspection 56% had a strong or slight preference for this, 11% were neutral and the remaining 33% would not promote its use as part of a Section 10 Inspection. Comments generally supported the principle of QRA, but included a “note on client resistance”, and the wish for “a simple non computer based system”.

Table 1: Examples of application of QRA by major reservoir owners in the United Kingdom

Owner	Use of QRA
1	Portfolio risk assessment of all embankment dams (100+), with annual probability of failure (APF) due to internal erosion and slope instability (internal threats) based on Foster and Fell (14). Sensitivity studies included comparison of the three alternative methods of estimation of APF by three different methods (15)
2	Interim Guide used as part of ten yearly Inspections to test and thus provide a robust case for mandatory safety improvement works
3	Interim Guide used to probe understanding of modes of failure, and thus improve targeting of surveillance monitoring
4	Portfolio risk assessment of all embankment dams (100+), using the Interim Guide
5	Used the QRA output as a basis for "as low as reasonably practicable" calculations, showing that major strengthening works were disproportionate in cost to the reduction in risk achieved, which led to the adoption of more limited risk reduction works

4.2 Use for Portfolio Risk Assessment

Two major water companies have used Quantitative risk assessment to build up a portfolio risk assessment on all of the embankment dams owned by the company, numbering over 100 in each case, one using the Interim Guide and the other, prior to issue of the Guide using different methodology.. The scoring of current condition of the dam is carried out by interviews of the project team with the Supervising Engineer for the individual dam. Benefits to date include

a) The interview process has proved invaluable to both the Supervising Engineers and those carrying out the QRA in probing knowledge of the dam, and understanding and recording potential mechanism of failure

b) The QRA output from this project has identified that the consequence class of some dams needs upgrading.

c) the identification of "quick-fix" items which lead to an appreciable reduction in risk for modest cost

d) quantification of risk, and identification of which dams have the greatest risk of failure.

As well as the benefits listed above it is anticipated that the QRA will in due course assist in formulating capital investment programmes, and in securing Ofwat approval of such programmes

4.3 Summary of feedback to date

As might be expected publication of the Interim Guide has encountered a wide range of opinion within the UK dam industry. In terms of ease of the Excel spreadsheet included with the Guide, some have found this straightforward to use, taking typically two days to compete a QRA, whilst others, less familiar with Excel, have been unable to use it. In terms of its strategic value, some see the major benefits that QRA has in a proportionate approach to risk management and that the Interim Guide is a useful tool to assist in these judgments. Conversely others consider that RA is still too uncertain and prefer a more traditional prescriptive engineering standards approach.

5 Other applications for QRA on dams

5.1 Comparison of risk from dams with other flood risk

The quantification of risk provided by QRA allows comparison of the flood risk from dams with other forms of flooding. The loss of life in some historic dam failures, and fluvial and coastal flood events, in the UK are shown in **Table 2**. The data from the historic fluvial and coastal events are plotted on a FN chart in Figure 1, together with the estimated fatalities in the event of dam failure from the pilot study of risk from dams carried out for a major dam owner. It can be seen that the risk from fluvial floods is similar to that from dam failure, in that although a dam failure is likely to kill 100 more people than fluvial floods, the annual probability is 100 times less, such that the risk is similar.

Table 2: Loss of life in some major floods In the United Kingdom

Year	Source of flooding	Location	Annual chance	Number of properties flooded	Loss of life
2005	Fluvial	Carlisle	1 in 185	1800	3
2000	Fluvial	Widespread	Commonly 1 in 15	9000	0
1998	Fluvial	Widespread at Easter	1 in 150 to 1 in 50	Not avail.	5
1953	Coastal	East coast	1 in 500	24,000	307
1952	Fluvial	Lynmouth	1 in 750	165	34
1925	Dam failure	Skelmorlie	Not avail.	Not avail.	5
1925	Dam failure	Eigau/ Coedty	Not avail.	Not avail.	16
1912	Fluvial	Norwich	1 in 800	1200	4
1864	Dam failure	Dale Dyke	Not avail.	Not avail.	250
1852	Dam failure	Bilberry	Not avail.	Not avail.	81

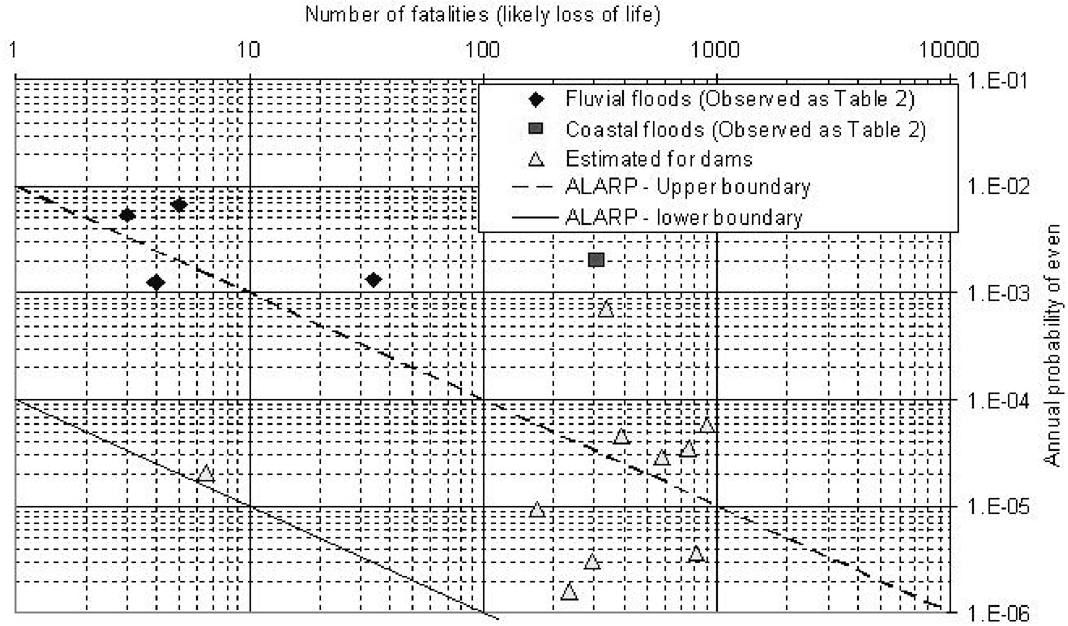

Figure 1 : Comparison of risk from various forms of flooding (UK data)

It is also noted that the risk from coastal flooding is in general significantly greater than the risk from either fluvial floods or dam failure. For example dam embankments are designed to pass the Probable Maximum Flood (say 1 in a million annual probability) safely. However, coastal defences in UK are generally designed only to retain a 1 in 200 chance per year (0.5 % annual probability) costal flood event and are not specifically designed for overtopping and are therefore likely to fail in say a 1 in 1000 chance (0.1 % annual probability) flood. When other threats are considered the annual probability of failure of dams increases, as shown on **Figure 1**, such that the annual probability of failure dams is typically 100 times lower than that of coastal defences. The loss of life in the event of failure is similar in both cases, so the risk from the coastal defences is 1000 times higher than the dam embankment.

A similar approach can be adopted to compare the risk from dam failure with other high hazard industries. This is invaluable in applying a proportionate approach to risk management.

5.2 Use of Consequence estimate to determine level of risk management measures

The consequences of failure of a dam have been used to determine both the design standard for floods in UK (11), and the frequency of surveillance in Australia (12). These were estimated by judgment. The Interim Guide provides an improved and auditable quantitative estimate of consequences, typically taking a day to complete.

In UK the Water Act 2003 provides a discretionary power for the Secretary of State to require dam owners to prepare flood (emergency) plans. The exact requirements for flood plans, and which dams will be required to have such plans is still under development, with an informal public consultation having been carried out in July 2006 (13). One of the options is to use Consequence Class, as determined from a QRA, as the basis for which dams require a flood plan, and the level of detail of such a plan. The range of likely loss of life of four orders of magnitude would logically be reflected in a similar range of level of detail (and thus cost) for flood plans.

6 Discussion : Benefits and limitations of QRA

Adoption of QRA has a number of significant advantages, including

a) explicit consideration of modes of failure

b) change in thinking from elastic design (e.g. spillway should pass the Probable Maximum Flood plus have a freeboard for wave run-up) to plastic design where the margins of safety against failure are explicitly considered (e.g. the dam should be capable of passing some factor on the probable maximum flood without failing)

c) estimates of annual probability of failure, and consequences of failure (and thus risk), which can be used to assess when the cost of additional risk management measures is proportionate to the reduction in risk achieved

In terms of limitations of QRA there are still significant uncertainties in assigning both annual probabilities and estimating consequences of failure, but these should reduce with time provided research funding is directed at reducing the greatest uncertainties.

It should also be emphasised that QRA is a tool to aid judgment, and that decisions on dam safety also need to take into account other factors. Nevertheless the advantages are considered to significantly outweigh the limitations.

7 Conclusions

Publication of the Interim Guide to Quantitative Risk Assessment in 2005 has engendered a varied response from the UK dam industry, ranging from strong support and application to the view that RA is too uncertain to be of value. This has also focussed attention on the level of risk management, and how a proportionate cost should be evaluated. On balance the benefits of QRA outweigh the limitations, such that the Interim Guide should be improved in the light of experience of its application and taken forward into a definitive Guide to QRA.

Literature

[1] SRD (1985) A feasibility study into probabilistic risk assessment for reservoirs. Water Research Centre External Report no ER 188E, Swindon.

[2] Cullen (1990) Risk assessment of earth dam reservoirs (SAC 9790). Report No DoE 0002-SW/3, DOE reference no :PECD 7/7/191. Water Research Centre, Swindon. 69pp

[3] Hughes et al (2000) Risk management for UK reservoirs CIRIA Report NoC542. 213pp.

[4] Centre for Ecology and Hydrology (2000) Flood Estimation Handbook

[5] KBR (2002) Research Report on Contract : Reservoir safety – Floods and Reservoir safety Integration. In 3 volumes. Available on Defra website www.defra.gov.uk/environment/water/rs/index.htm

[6] BROWN A J and GOSDEN J D (2004) Interim Guide to Quantitative Risk assessment for UK Reservoirs. Thomas Telford. 161pp. Supplement No 1 produced in June 2006, and available on Defra website.

[7] ANCOLD (2003) Guidelines on Risk assessment. October. 157pp excl appendices

[8] ICOLD (2005) Risk assessment in dam safety management. Bulletin

[9] HARTFORD DND and BAECHER GB (2004) Risk and uncertainty in dam safety. Thomas Telford. 391pp

[10] Brown and Peters A (2007) Update on the use of the Interim guide to Quantitative Risk Assessment. Dams and Reservoirs. 17(1). Pp19-24

[11] Floods and Reservoir safety (1978) Institution of Civil Engineers. (subsequently updated with 3rd edition published in 1996)

[12] ANCOLD (2003) Guidelines on dam safety management. August. 52pp excl appendices

[13] Jacobs (2006) Draft Engineering Guide to Emergency Planning for UK reservoirs. Available on Defra website www.defra.gov.uk/environment/water/rs/index.htm

[14] Foster M, Fell R and Spannagle (1998) Risk assessment - estimating the probability of failure of embankment dams by piping. ANCOLD 98 Conference on dams. 11pp plus 4page supplement giving example of application of the UNSW method. Repeated in A method for assessing the relative likelihood of failure of embankment dams by piping. Canadian Geotechnical Journal. 2000, Vol. 37 No 5. PP1025-1061

[15] Eddleston M and Carter IC, 2006, Comparison of methods used to determine the probability of failure due to internal erosion in embankment dams. BDS conf. pp154-164

Authors' Names and Affiliation

Alan J Brown
Jacobs
Thorncroft Manor
Dorking Road
Leatherhead
Surrey KT22 8JB
Alan.J.Brown@Jacobs.com

John Gosden
Jacobs
Simpson House
6 Cherry Orchard Road
Croydon
Surrey CR9 6BE
John.Gosden@Jacobs.com

Acknowledgments and Disclaimer

It is acknowledged that some of the work described in this article has been funded by Defra, the government department responsible for the overall management of reservoir safety in England (www.defra.gov.uk/environment). It is noted the Quantitative Risk Assessment Guidelines, recently prepared under a Defra contract for reservoirs in the UK, is currently only a consultation document and should not be taken a representing official UK policy on such matters.