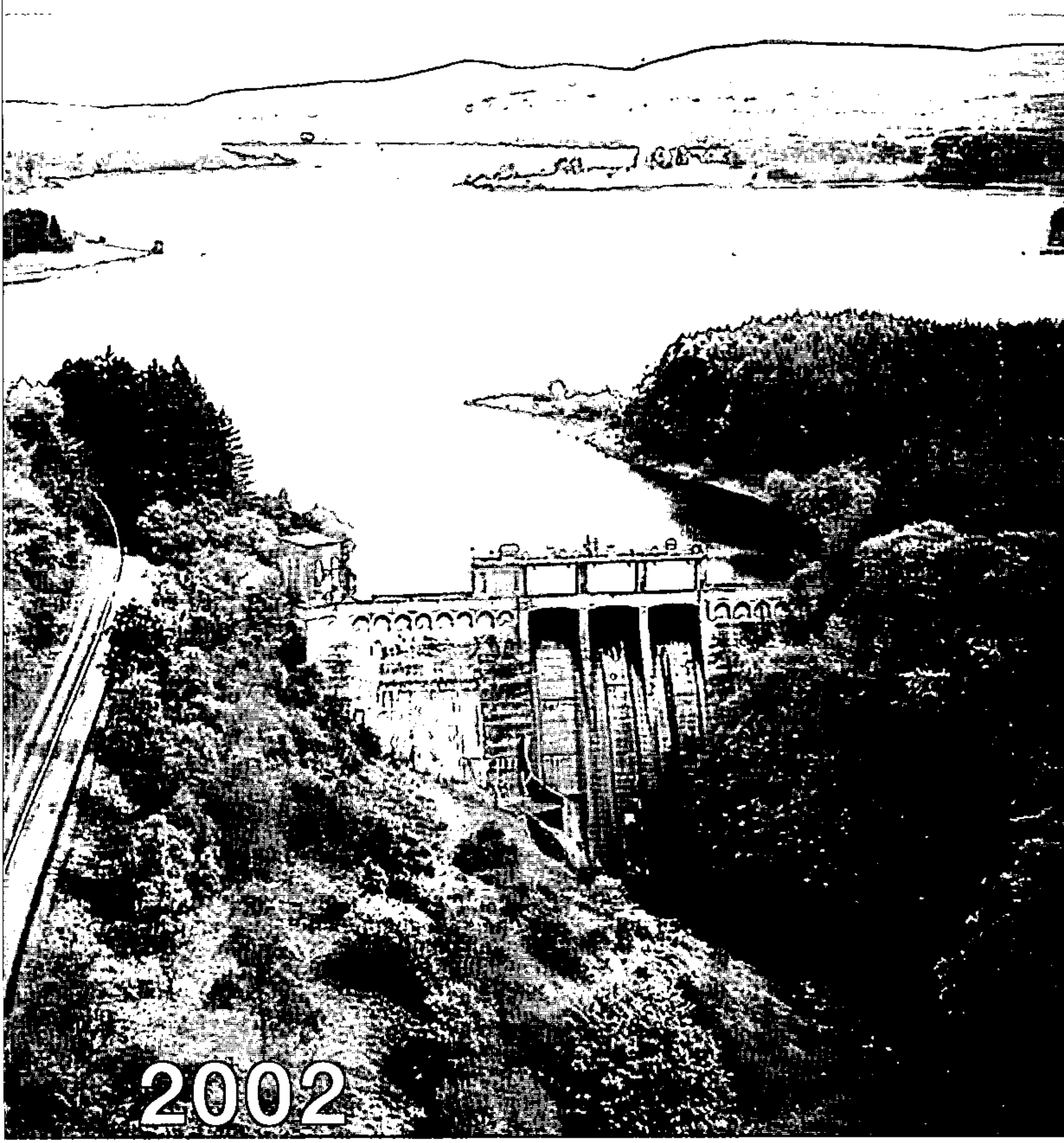
Reservoirs in a Changing World

DISCUSSION



2002

British Dam Society

BRITISH DAM SOCIETY

RESERVOIRS IN A CHANGING WORLD

DISCUSSION

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PREFACE

This volume contains the complete record of discussions from the Twelfth Conference of the British Dam Society entitled "Reservoirs in a Changing World" which was held at Trinity College, Dublin between 4-8 September 2002. It also contains a copy of the Geoffrey Binnie Lecture written by Dr Geoffrey Sims.

The Conference papers are in a separate volume published by Thomas Telford Services Ltd and are available from the bookshop at the Institution of Civil Engineers, Great George Street, London SW1P 3AA.

CONFERENCE OPENING

by Professor Jane Grimson, Vice-Provost, Trinity College

Good morning everybody: you are all welcome to Dublin, and especially to Trinity College. I'd like to thank the organisers for inviting me to open the conference: I've had a long fascination with water engineering and dams going back to when I was about five years old: I was living in Southampton when my father was at the university there and he used to build hydraulic models. On Saturday mornings, my two elder brothers used to go to the local cinema to watch films of Cowboys and Indians which had no attraction for me. Since my mother wanted us all out of the house, I used to go off with my father and spend several hours on Saturdays playing around with his hydraulic model of Southampton Water. I found the whole thing quite fascinating, especially the fact that the tide went up and down very quickly and I found it very hard to appreciate that time could be scaled as well as the physical model.

When I was a teenager I did a project on the Volta River Scheme in Africa and was fascinated by the engineering of the dam and also its impact on the environment and society, with the effect on the local people being moved, its effect on health, etc. I then spent a summer at the foot of a large dam in France where we used to estimate the time of day from the shadow of the dam. Despite this early interest in dams, I ended up doing computer engineering rather than civil engineering, for which I apologise.

For those of you who don't know about Trinity, I should tell you that it was founded in 1592 by Queen Elizabeth I as the first constituent college of the University of Dublin: the intention was that it would become like Oxford and Cambridge with a series of colleges being founded over the years, but in fact we only ever had one college, so Trinity College and the University of Dublin are essentially one and the same. The engineering school is one of the oldest ones in the UK, having been founded in 1841, and like most of them started off with civil engineering. We now offer civil engineering, environmental, mechanical and manufacturing, computer engineering and electronics and electrical engineering. As I said, I am a computer engineer and the computing area is very closely allied to the engineering school because we see it very much as an engineering discipline. The College now has 15,000 students, of which about 2,000 are in the engineering faculty, so it is thriving at present.

I have great pleasure in opening this conference and hope you have a fascinating few days. I gather you have already visited some sites and you will be going to one of my favourite spots up in the Dublin Mountains at Turlough Hill: hopefully the weather will be kind to you. I wish you all an enjoyable conference.

Jack O'Keeffe (ESB)

Good morning, ladies and gentlemen. As I was the person responsible for issuing the invitation to the BDS to come to Dublin, I have been asked to say a few words. First of all, I would like to join with the Vice-Provost in welcoming you to Dublin and Trinity. You might ask how the British Dam Society ends up in Dublin. Over the years many of the Irish delegates here have been attending BDS conferences, and several UK delegates have said, usually over a few pints late at night, that we must go to Dublin sometime. As one does at these occasions, we all agreed, and then went home and did nothing about it. When, however, the BDS submitted a bid for hosting the ICOLD meeting in 1999, I offered to arrange a tour in Ireland that would be associated with it. Although the ICOLD bid was unsuccessful there were a number of people who seemed to be disappointed that they weren't coming to Dublin. Before the BDS conference in Bath, I decided to check out what was available in Ireland to suit the style of conference that the BDS holds: in other words a university campus with accommodation attached and I considered Trinity to be the most suitable venue. I then made a formal offer to Rod Bridle prior to the Bath conference and you all voted, or rather the majority of you voted, to come here, and so we are all here today.

As I mentioned, a lot of the Irish delegates will have been at these conferences, which are usually wonderfully organised and we enjoy them and benefit from them. I now know, however, that it takes a lot of work by a lot of people to bring these things about. I would like to thank all those at the Irish end who have helped me in bringing the conference here. I know there was a lot of concern when Trinity was suggested as a venue that the numbers might be small, but I think that concern has been totally refuted. I was very pleased to see the numbers coming up in early August: I would not like to have been the person who caused the British Dam Society to go broke! The numbers have exceeded our expectations and now that you're here I hope that you will find everything to your satisfaction and enjoy a few pleasant days in Dublin. You will be seeing me again in a number of roles over the next few days, but for the moment I will say thank you very much for coming here.

Dr Andy Hughes, Chairman, British Dam Society

Thank you, Jack. I should point out that Jack's role, and that of the organising committee, is to take all the flak if anything goes wrong. I should admit that I was one of the people who said that we should think very carefully about going to Dublin, but I am now sure that it will be a success due to the hard work of the organising committee.

This is the twelfth biennial conference: the title is "Reservoirs in a Changing World". I think we all know that the world is changing rapidly: perhaps it is just that we are getting older and slowing down while the world is staying the same. Things are also changing for the British Dam Society: there has been an abrupt increase in our membership numbers for 2002 and my target before I step down as Chairman in March 2003 is to get the membership over 500. Believe it or not, there are 50 Panel Engineers (all of the Panels) who are not members of the BDS: I am after these people, so if you are sitting out there, you will be joining the BDS.

It has been a year of success, but it has also been a year of sadness with the tragic loss of Geoff Sims. As many of you know, Geoff was to have presented the Geoffrey Binnie Lecture tonight. We are very pleased that Vivienne and Jacqueline Sims are with us as our guests here for the conference. As a mark of respect, I now ask you to stand for a minute's silence for Geoff Sims.

The themes in our conference are: development and construction of dams; seismic performance of dams; remedial works to concrete and masonry dams; hydraulic structures; embankment dam performance, and safety and risk. It is always the aim of the organising committee to set a theme so that whatever paper you have can be slotted in somewhere. We have 47 papers in our very high quality proceedings. This, I think, is one of our most successful conferences in terms of numbers of people: we have 172 delegates and about 30 accompanying persons. It is always encouraging to have a large number of accompanying persons with us, as well as delegates. It is also nice, with the ICOLD meeting in Brazil coming up at the end of the month, to have a fairly large overseas contingent, and I particularly welcome those from countries including Australia, Germany, Canada and Italy.

I extend a special welcome to Phil and Jenny Cummins from Australia: Phil is the Chairman of ANCOLD. We have Peter Rissler, who is Chairman of the German National Committee; Gabriella Vaschetti from Italy; Rod and Pam Vincent from Malaysia and representatives from SWEB Power, Austria Hydro, Turkey and forgive me if I have left anybody out. A very warm welcome to you all from overseas.

SESSION 1
SAFETY AND RISK

Chairman Andy Hughes
Technical Reporter Henry Hewlett

Papers presented

1. Risk assessment and the safety case in dam safety decisions
   D N D Hartford and R A Stewart
2. Risk assessment - its development and relevant considerations for dam safety
   J McQuaid
3. Reservoir risk assessments in the north of Scotland
   F Tarrant, J Ackers and N Graham-Smith
4. A review of systems used to assess dam safety
   A J Brown and J D Gosden
4. Lake Sarez risk mitigation project
   L J S Attewill and L Spasic-Gril

Papers not presented

1. Tailings dam incidents and new methods
   A D M Penman
2. The IMPACT project - continuing European research on dambreak processes and the failure of flood embankments.
   M W Morris
3. A historical perspective on reservoir safety legislation in the United Kingdom
   J A Charles
4. Multi-attribute performance monitoring for reservoir systems
   J W Hall, J W Le Masurier, E A Baker, J P Davis and C A Taylor
5. Where to keep your dam documents?
   J Stewart
6. The characteristics of UK puddle clay cores - a review
   A I B Moffat (Note: presented under Session 6 - Part 2)

Chairman
This is a session on safety and risk. There are a number of papers published but not being presented. Authors of most of these are present and available to answer any questions in the discussion period.

The first paper by Des Hartford delivers a conceptual approach on dam safety and makes a strong case for using risk assessment to provide a defensible decision making method system. The important point he makes from my point of view is that the risk assessment should be used to inform the decision making process, and not used to make that decision.

Jim McQuaid's paper may be somewhat controversial. He looks at risk assessment and discusses the issues relevant to dam safety and also looks at the HSE's involvement in a dam safety case. Perhaps this is something that the BDS needs to debate.

Fiona Tarrant and John Ackers talk about the use of the CIRIA risk assessment report in the north of Scotland. The important issue recognised when the report was written was that the topic was in a development stage and would need to be modified once it had been subjected to more widespread use.

Alan Brown is going to talk about the work being done on the DEFRA project on integrated risk which is now coming to an end and is about to be published.

Lawrence Attewill is talking about this huge lake that was formed. I was surprised to see that it was formed in 1911 and they've been struggling with this for nearly 100 years. This is a practical case of risk assessment and the problems associated with something that was not expected.

Derek Knight (Consultant)
There are four matters to which I would draw attention. These relate to major changes in recent years to the way things are done, and which, I believe, affect our ability to assess dam safety and risk in the UK.

Firstly, organisations have changed, often as a result of mergers, take-overs and sell-offs. When owners of organisations change, with immediately visible external differences in names and logos, so also do the insides change, with new management ideas and practices.

Secondly, greater movement of staff within organisations means that fewer people constitute a "knowledge core" of an organisation's past experience, leading inevitably to a loss of that knowledge and experience.

Thirdly, and as a direct consequence, detailed records and technically valuable archive information will be forgotten or unrecognised or disposed off. Keys may be re-cut if another exists. Old dam record/ archive material may have no such genetic recourse.

Finally, in this age of financial accounting - "creative" or otherwise - balance sheets and bottom lines, the cost of every item may be known, but not its value. Times most certainly change; facts about the structures built in previous ones do not.

Alan Brown (Halliburton KBR)
I agree that there is a problem with records becoming lost and knowledge being forgotten, to the detriment of dam safety. The question we need to address as a profession is how should this information be recorded and managed, and who will pay for it? I suggest that ultimately the person who pays will be the owner, through regulation if he does not take the initiative himself.

The benefit of an integrated system of risk assessment is that it provides a tool that improves our understanding of the risk from a particular dam. In the UK, some of our dams are very low risk, and only come under the Act because of their volume. The object of the integrated system is to differentiate real high-hazard from low-hazard, and thus prioritise where record keeping would be of value. A second point is that, if owners don't do it, and if ultimately there is a failure, then the HSE may step in and impose additional requirements, including record keeping. Is it better that we put our own house in order and manage our dam safety with current best practice, or wait until it is imposed?

Iain Moffat (University of Newcastle)
One or two general points about the contributions we have heard relating to reservoirs and risk - I speak from having been involved with CIRIA Report C542. Firstly, we should appreciate that public perception of what is an acceptable level of risk depends on what risk is being considered. For example, the general public will accept very low but nonetheless finite risk when travelling by air; they will not accept a comparable level of risk if associated with a dam or a similar structure. I don't feel this has necessarily been taken sufficiently into account in some of the presentations.

The trial application of CIRIA C542 to some Scottish reservoirs was noted with interest, but with respect some of the examples illustrated in that presentation were rather extreme cases, e.g. weirs about 1m high. That is not quite the situation the CIRIA report was designed for when it was drafted. As a corollary to the Scottish study, it would be interesting to know if there was any corresponding evaluation of what response might be mounted in the event of an incident developing at one of the less extreme sites assessed. We should not carry out assessment of risk and hazard in isolation. We must also consider the capacity of the local authorities and emergency services to respond appropriately.

The papers by Messrs McQuaid and Hartford were also of interest, but I would be concerned that we could be in danger of creating yet another lawyers' benefit. Engineers have always recognised a certain duty of care towards their clients and to the public, and going down the path of attempting to cover all the societal involvements is not necessarily going to improve real levels of safety. We heard much about the HSE approach, and of the current position that the railways are in. I would suggest that if you look at historical events, railway safety was formerly much more effectively, efficiently and expeditiously dealt with by HM Railway Inspectorate than it is now under the aegis of the HSE. To put matters into perspective it is also worth bearing in mind, amidst all the ill-informed media chatter about railway safety, that the total number of passengers killed on the railways of the UK since the first locomotive ran is almost exactly the same as the annual death toll on the roads. Strange perceptions emerge to replace cold logic when uninformed politicians, lawyers and others become overly involved.

John Ackers (Binnie Black & Veatch)
It is a fair comment that perhaps the procedure in the CIRIA Report is like using a sledgehammer to crack a nut for the small dams. Nevertheless, the client wanted all his reservoirs covered by a consistent procedure, and they were perfectly entitled to ask for this. As for having gone on to do other things, we should have been delighted to, but our project was strictly limited to the scope set out by our Client, which was basically following the CIRIA Guide.

Tony Allan (King's College, London)
I'm not an engineer, I'm an environmental scientist. We're talking about a changing world. The social theorists have looked at this and they have seen that around 1970 there was a dramatic shift in how people looked at the environment and other things, including risk. I'd like to make the point that the 1970's was an important period, but to get to the 1970's took some 20 years to put in place the idea that the world was an uncertain place rather than a certain place.

All those here in their 50's and 60's have lived through a period of dramatic shift in how society in the developed world looked at risk, so there has been constructed for us, sadly not by the engineers or environmental scientists, but by 'green' activists who set the agenda for the changed world that we are in now. Having lived through that, my message is that all of us living in this new world in which we have discovered that knowledge can be constructed, the 'green' people constructed knowledge just as brilliantly as dam engineers construct dams because we are dancing to the tune of that constructed knowledge. If we are in that game and being so much affected by it, we need to think along these lines: We can't ignore the political process and put into it our best ideas and try to ensure that the next shift in a changing world is more affected by the wisdom of those here than by people who have imposed their own ideas on this industry.

Chairman
Thank you very much for those comments. We as the BDS, and the dam fraternity as a whole, have seen with the WCD report that we cannot ignore other activists and we must embrace them and take this forward for our own benefit and use our skills to move on.

Chris Binnie (Consultant)
We have heard about what I would call 'natural' risks, such as internal erosion, overtopping, etc. What I'd like to ask is, in those risk assessments, are other types of risk such as mal-operation of the reservoir leading to failure included? What about terrorist attacks, especially after September 11? There was a dam in Yugoslavia which was blown up a few years ago from inside.

When I was involved in the design of Marchlyn Dam, I had to write a highly confidential paper for the client about how a terrorist could actually attack the dam and breach it. There is also the external effect like an aircraft landing on one of the reservoirs near Heathrow and breaching the dam causing a severe flood. Are these external impacts included in the risk analyses?

John Ackers
The CIRIA report divides the process into three stages. Stage 1 assesses the impacts in the event of dam failure, and only if the impact score is above a certain figure do you proceed to Stages 2 and 3. In Stage 3 you would look at all the other risks, including mal-operation, terrorism and aircraft impact.

Des Hartford (BC Hydro)
The short answer to Chris Binnie's question is yes.

Misoperation has occurred on several occasions. Much depends on whether the owner of the dam has the courage to face the problem of analysing the reliability of its people. There is much experience in the nuclear and aerospace industries. From the perspective of terrorists, since September 11 a large number of risk assessments for dams have been carried out: these were quick screening level assessments rather than detailed quantitative ones. Means of risk mitigation were installed in terms of surveillance, blocking off access to dams, etc.

In relation to simulation of various terrorist attacks or aircraft accidents, work has been done in France which was presented to ICOLD in Beijing. In principle, these risks can be assessed but in practice it is not done very often because we have not risen to the overall challenge of assessing the risks posed by dams to the same level as other industries.

Emma Langman (University of Bristol)
I'd like to ask Alan Brown and Des Hartford about qualitative and quantitative risk assessment. Since 1990 we've been moving away from allocating probabilities towards qualitative methods. How can we use our quantitative methodologies and our expert judgements together?

Alan Brown
I don't consider this to be a problem. When doing a quantitative analysis you rapidly realise that there is significant uncertainty in the available data, for example in our understanding of the processes of internal erosion, human reliability etc. We therefore have to resort to expert judgement to reduce this uncertainty. In my opinion by 'quantitative' we are trying to say that there will be an overall annual probability of failure due to the various potential failure modes, but in building that up, we may have to use expert judgement.

Des Hartford
I believe that good engineering does implicitly involve consideration of uncertainty. It is, therefore, already built into what we do at the moment. The area of difficulty is not in relation to qualitative versus quantitative but how to externalise good engineering practice in a mathematically correct way. I don't therefore see any difficulty between the two methods: it is more a case of demonstrating that the logic is correct and, as we found out when writing the ICOLD document on risk assessment, it is easy to produce plausible statements which, when put into a mathematical form are complete nonsense. We have to make a better job of transforming what is implied into what can be properly externalised, made tractable, and, in relation to

the quantification of risk, it is in the matter of full characterisation of the uncertainty in the correct way. It is, however, already there in the qualitative methods.

Jim Findlay (Babtie Group)
Almost all the speakers and contributors make reference to the influence of judgement in risk assessment. Even so-called quantitative approaches involve the application of judgement in the framing of the problem if not in the processing of the assessment. Judgemental approaches cannot simply be dismissed as inadequate.

Jim McQuaid set the correct tone when quoting "that the approximate answer to the right question is much more valuable than the precise answer to the wrong question". To my mind this characterises the potential failings of highly numerical or statistical risk assessments but highlights the advantages of rapid assessment techniques.

The key issues in risk assessment are: the development of a logical framework to define the area of concern, preferably dealing with more than just cost; populating this framework with readily available information; making defensible assessments based on that information; and finally presenting all of this in a transparent and auditable way, for widest possible discussion by those directly involved.

FMECA (Failure Mode Effect and Criticality) type techniques still represent a relatively quick, effective and economic approach to risk assessment, including the covering of less obvious hazards as highlighted by Chris Binnie. These can be applied to most Business Critical activities. My work for Babtie Group in this field is endorsed by an increasing portfolio of projects and clients equipped with effective decision making tools. As such, the role of qualitative risk assessments should not be overlooked in the search for precision.

Peter Kite (Environment Agency)
I think we are agreed that we should be doing risk assessment and it provides a useful, consistent methodology. The question of following on from that is 'what are we going to do with the results once we have done the risk assessment?' We have heard today that it provides a

useful tool for prioritisation of works. I would add that it is also a methodology to assist in the prioritisation of mitigation measures we take. Once we have identified the risk we can take measures to minimise the risk. Somebody today referred to this as 'response'. How can we reduce the effects that we have identified and enable a good 'response'? We need to have systems in place which should be exercised. One thing that is for certain in this field of uncertainty is that once an incident has occurred, questions will be asked by politicians and the media about who is to blame and what was done to minimise the risk in the first place.

Arthur Penman (Retired Chairman of ICOLD Committee on Tailings Dams)
I just want to put in a plea for tailings dams, which as far as the BDS is concerned, is probably not very much of a problem, but from a world wide point of view, it is. In general, dams designed to retain water do not fail. A correctly designed dam should last for ever. The only way it fails is due to lack of maintenance, change of ownership, loss of records, etc as we have been hearing this morning. Tailings dams, however, are failing around the world at a rate of 1.7 per year. Each one that fails kills somebody and costs the owners a lot of money. This is a serious problem that is to do with dams. A tailings dam is a dam. It may not be retaining much fresh water but it still is retaining a material that can be disastrous when allowed to flow all over the place.

I should remind you of Aberfan which was a pile of waste that went out of control and killed 144 people. A public inquiry was held which lasted three months and the judge made the famous statement that 'we must do something so that this never happens again'. During this three month inquiry, as Iain Moffat has said, ten times more people were killed on the roads. We are therefore very concerned about dams that do not fail while people are dying on the roads every day.

Written contribution

Alan Gordon (Scottish Water)
The decision to carry out dam break assessments on all 90 reservoirs

was to allow a prioritisation on those that presented the greatest threat both to our operations but also to their downstream populations. The review was initiated by the North of Scotland Water Authority Contingency planning manager so that in addition to alerting the management teams to potential problems, the review provided information that could be discussed with the regional Emergency Planning groups in North of Scotland. This was to allow them to prepare evacuation plans etc if required.

In the event because of the reorganisation of Scottish Water this has not been followed through. I would hope that once the new management team have been appointed this will be picked up again.

The reason I would like to raise this is because a couple of the commentators and one of the earlier speakers were keen to know how the risk assessment tool was being used and to whom the information should be communicated. The view of North of Scotland Water was that dambreak information should only be made available to recipients who could use it sensibility understanding the basis of the analyses e.g. planners, EPO's, and associated engineering disciplines.

SESSION 2
HYDRAULIC STRUCTURES - HYDROLOGY

Chairman Jim Claydon
Technical Reporter Aled Hughes

Papers presented

1. The release of large diameter draw-off and control valves
   R P Enston and D C F Latham
2. Refurbishment of outlet tunnel and associated pipework at Piethorne Reservoir
   A Briscoe, A A George, I C Carter and P Grundy
3. Sluiceway isolation for gate replacement at Kotri Barrage in Pakistan
   I E Padgett and K F Morrison
4. Langsett Reservoir: Numerical simulation of hydraulic structures
   D R S Woolf and I Scholefield

Papers not presented

1. Maintaining the Thames tidal defences in a century of climate change
   J Lewin and S Lavery
2. Flood control using the automatic tops spillway gates: A case study of the Avis Dam, Namibia
   P D Townshend and K A Lund
3. Remedial works at Brent Reservoir to address leaking sluice gates
   R A N Hughes and P Kelly
4. Langsett Reservoir: A combined analytical and CFD study of a reservoir side-spillway
   D R S Woolf and J N Hacker
5. Rehabilitation of Upper and Lower Bohernabreena Spillways
   D E MacDonald and JD Molyneux

Jim Claydon (Yorkshire Water)
Could someone answer a question about Piethorne Reservoir? In the event that the annulus is not grouted, you can get full reservoir head into that annulus and a potential cause of failure in my view is the failure of the host pipe letting that water head into the body of the embankment.

Ian Carter (MWH)
It might help the audience if I was to provide some more information about the new and old pipework at Piethorne Reservoir and to explain the thinking behind some of the decisions we took.

The design of the original outlet facilities was relatively unusual in that the closure bulkhead was built some 15 m upstream of the puddle clay core, as shown in the Figure below. The watertightness of the dam therefore relies upon the integrity of the culvert and the impermeability of the surrounding ground.

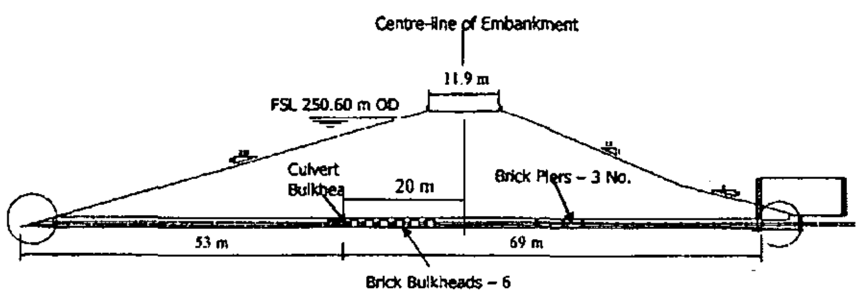


Figure 1
Section through outlet culvert showing location of bulkheads and pillars.

The 6-feet diameter culvert had suffered from problems throughout its 140-year life. Failure of the downstream shoulder during construction caused cracking of the 2 feet thick masonry. Up to 350 mm settlement also occurred and the sag (a uniform bow-shape) was subsequently eradicated by adding a false invert in mass concrete. Despite various attempts to stabilise the structure (which included the installation of massive brick bulkheads and slender brick pillars), the structure continued to distort.

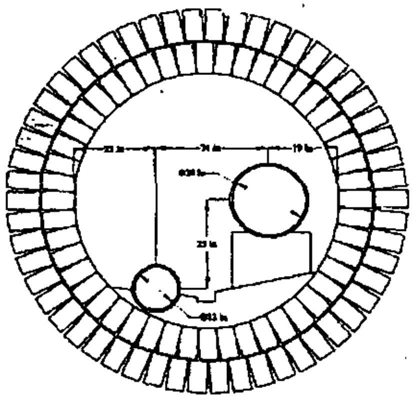


Figure 2
Typical section showing original culvert construction

By 2001 the structure had deteriorated into a very poor condition with evidence indicating continued distress. The pillars showed signs of punching into the crown of the culvert. The circular shape had become flatter and broader by about 75 mm and some of the cracks had opened by as much as 12 mm. Settlement had continued over the years and the false invert sagged by at least 60 mm. There were a number of leaks into the culvert and there was much concern over the vulnerability of the reservoir to internal erosion.

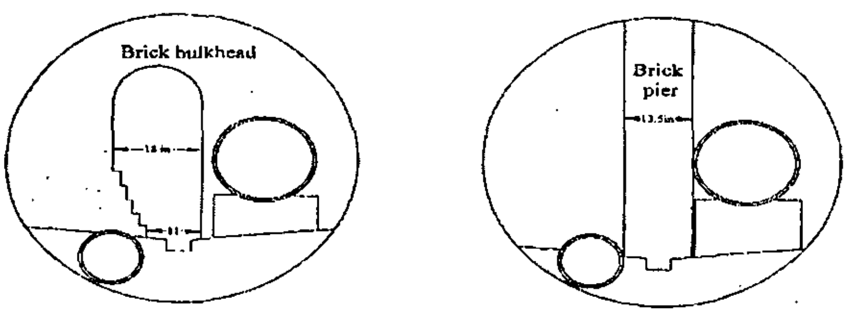


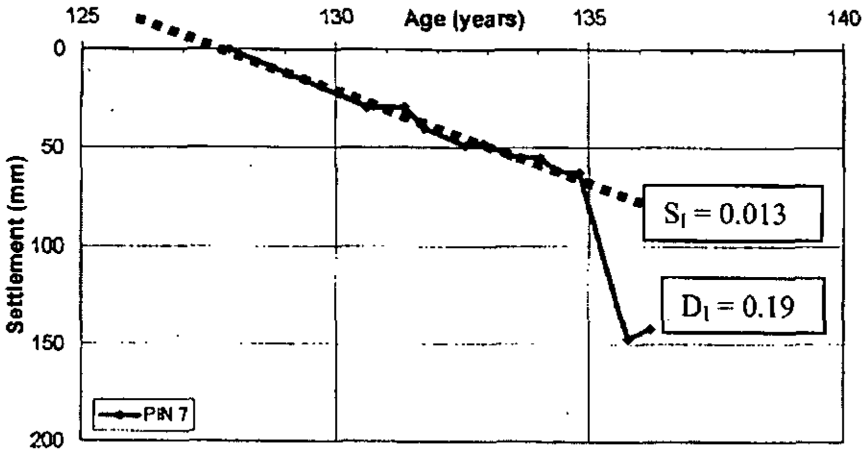
Figure 3
Details showing bulkhead and pillar arrangements inside the culvert

The condition of the two outlet mains inside the culvert was also the subject of concern. The spigot and socket, cast iron pipes were installed over 135-years ago. Both had become corroded in the dank conditions inside the culvert, particularly the 20-inch supply main. Each was internally inspected and checked ultrasonically. The supply main wall thickness varied between 22 and 30 mm, with the underside of the pipe tending to be thinner than the upper section. A failure of either main inside the culvert could have led to an uncontrolled release from the reservoir, as the upstream valves were not known to be fully operational or drop tight.

The replacement of the upstream valves and the installation of the structural polyethylene pipe inside the original main effectively reduced, if not eliminated, the latter risk. However the parlous condition of the culvert, with its propensity to distort, meant that further action was desirable in order to prevent (a) loss of fill material into the culvert via internal erosion, and (b) collapse or partial collapse of the structure, both of which could endanger the dam.

The deformation behaviour of the culvert-embankment-foundation is poorly understood. The crest of the dam itself sags with the centre being about 500 mm lower than the left abutment. Recent data indicates steady crest settlement over the seven years preceding the recent drawdown. The settlement index, S_I, was calculated to be about 0.013, as shown on the attached chart, and if this value had applied over the whole life of the dam, then it would have equated to a gross settlement of about 600 mm. The six-month drawdown in 2001 caused about 75 mm permanent settlement and the corresponding drawdown settlement index, D_I, was calculated to be 0.19 and the mean vertical strain was 0.36%. The 2001 drawdown caused the upstream section of the tunnel to close by a further 5 mm, presumably in response to the increase in effective stress within that shoulder.

In essence, the culvert was a dangerous void into which the roof and walls might collapse. Alternatively, the void might allow a substantial quantity of soil to settle out from leakage water and thereby allow internal erosion incident to pass undetected. Filling of the entire culvert downstream of the closure bulkhead with low-strength foam concrete was seen as an effective remedy to the permanent stabilization of the culvert. The foam concrete would support the structure and form an effective, non-erodible surround to the existing pipework. If, at some



time in the future, the inner polyethylene pipe were to fail beneath the embankment, and in doing so, precipitate a failure of the original cast iron main outside, then the embankment should not be at risk.

Thought was given to sealing known leakage points but it was uncertain whether that could be achieved in practice. However blocking the exit points could have raised piezometric pressures and caused leakage to develop along new and less easily detectable flowpaths (e.g. along the interface between the culvert and the dam). A piped drainage system was therefore laid on the invert prior to pumping the foam concrete into the culvert. The existing groundwater regime (which was tolerable) was maintained with leakage flows being taken to a valved discharge point at the Hatchery, which can be monitored.

While the density of foam concrete is lower than traditional concrete, it was recognised that it would nevertheless impose an additional load on the foundation, albeit small in magnitude, which might give rise to further settlement of the structure. As our detailed knowledge of the tunnel behaviour to loading was poor, movement joints were installed at regular intervals to allow the structure to articulate.

The 25mm annulus between the cast iron pipe and the PE liner was left un-grouted to provide additional flexibility, albeit small, to ongoing movement in the system. In addition it also provided the client with some degree of confidence the liner could be extracted should unforeseen problems develop or operational changes occur in the future. The disadvantage in this approach was that a fracture or leak into the outer pipe upstream of the closure bulkhead could fill and pressurise the annulus. Watertight seals were installed into each annulus were the liners emerged from the cast iron main. At the downstream end, within the Hatchery Building, a 22mm valved drain was installed into each annulus by drilling and tapping the cast iron pipe upstream of the seal. Pressures or rate of leakage could then be recorded.

The drains have been monitored since the reservoir was refilled and there is evidence of leakage into the annulus. The flow rate observed has been small and it is clear that substantial head loss occurs between the entry and discharge points. There are no plans to carry out any annulus grouting at present.

Christine McCulloch (University of Oxford)
I have two non-technical questions. The first one queries why there has been no hydrology mentioned in this session despite its title. That leads to a supplementary query about how much dam owners and engineers are contributing to hydrology today? Many of the dams and reservoirs in the UK were built on very imperfect hydrological knowledge and many reservoirs owners spent a great deal of money taking regular records of rainfall and flow. I wonder whether this enthusiasm for measurement and for contributing to hydrology in general is being maintained or whether it has evaporated?

The second question is also related to management. The first lecturer said that it was cheaper to remedy the valves rather than to pay for their regular maintenance. Is this one of the changes that is happening in reservoir management today? Is it cheaper to let things go wrong and then remedy them rather than pay for their regular maintenance?

Robert Bone (Scottish Water)
On the question of whether there is an interest in hydrology, I can say that certainly in Scottish Water there is and what we have been doing

over the last few years has been quite interesting. The three former water authorities in Scotland that was the East, North and the West along with SEPA decided that our yield assessments really had been done over many years using different methodologies and there was some criticism from the Scottish Executive that we didn't have a consistent methodology. The 3 authorities plus SEPA got together and decided that we should come up with a common methodology for Scotland. This basically uses a variation on HYSIM plus AQUATOR, a system simulation tool and these are joined together so that when the Water Framework Directive comes along and hits us we can talk about some of the real issues rather than the technology about relicencing and so on so that we are agreed on how the yield are assessed. I think that that was a step forward to develop that jointly.

On the question of gathering of hydrological data, I would think that probably our performance has deteriorated over the years in terms of gathering rainfall information just because of reduction in manning levels at reservoirs and it is something we need to address in conjunction with the Meteorological Office.

David Latham (Hydra-Ject Limited)
If I can talk with my old hat on of when I was Director of Operations years ago in Anglian Water, I think that two sorts of problems occur. One is that there is a very short institutional memory that tends to exist now in the Water Industry with the rapid changes of manpower, changes of owners that has already been talked about and the pressures that are on to reduce costs. The institutional memory tends to forget some of the issues that it has experienced in the past so that what tends to happen is that you start to look a what can I stop doing to trim costs. One of those is to perhaps not to operate the valves because you've never experienced either a nasty moment when you wished those valves did operate and/or a tendency to forget that the valves were put there for a purpose. If you're not going to regularly operate them then you have to ask why on earth were they put there in the first place for?

So I think that there are a number of issues; the big one is the changes in manpower in the last 13 - 14 years that have occurred since privatisation. The result is that the perpetual changeover at the management level means that management has forgotten or the institutional memory has forgotten the need to regularly move its critical valves. Although to some extent that has now been changed by companies identifying their critical valves.

Chris Binnie (Consultant)
I think it's not only the valve we should think about but also the scour system itself. I inspected a reservoir down in Cornwall which may indeed have been one of David's at one stage and the water company was absolutely scared of the Environment Authority accusing it of polluting the river downstream. The water company said it would open the scour valve at the bottom of the reservoir for 30 seconds. As there was about 30 or 40 metres head on this guard valve I stood well clear. The amount of water that came out was about the amount a couple of people could pee.

What had happened was that this procedure had done at each successive Inspecting Engineer's visit. There was silt in the reservoir and, each time the valve was opened, a bit more silt was drawn in but not flushed out and the next time more silt was drawn in. I do put a plea out to Inspecting Engineers, particularly when the valves and drawoff system has a small diameter, please could they be sure that the whole system is flushed out. It is no good having the valve operable if the actual pipework system isn't.

My question to Jim Claydon is, now you're working to FEH, can you tell us what Yorkshire Water's policy is regarding FSR and FEH and what standards you are using for your spillways?

Jim Claydon
Very briefly, we are following the Interim Guidance issued by DEFRA.

Option 1 is to postpone works if a delay is considered practicable. We have not taken this approach.

Option 2 is a two stage approach using FSR design rainfall, then further increasing the capacity if and when a higher standard is recommended.

Option 3 is to increase the capacity using the worst case from FSR PMF and FEH 1 in 10 000 year.

We have generally followed Option 3 and in all comparisons so far PMF has turned out to be the worse case. We are taking catchment descriptors from FEH so in fact that is changing the calculations a little bit. In the case of Langsett we were in an interim state at the time of the publication of FEH and we didn't know which way to go. As a result of this study we know what we will do if we have to increase the discharge capacity, which will be to reinforce or heighten the wave wall. However at the moment we do not plan to do any more than needed under the PMF calculation.

Chris Scott (Binnie Black & Veatch)
I have a question pertaining to the DEFRA project ongoing that we heard about this morning. My recollection as to the terms of reference to that project was that it also had references to the comparison of PMF's and the T-year approach to flood estimation and as I gather the project is drawing to a conclusion. I'd be interested to know what the conclusions of the research team were in that respect.

Alan Brown (KBR)
It is correct that the scope of works for the Integrated Risk research contract included what use should be made, if any, of PMP in future. Our conclusion was that in the medium to long term we should go for the T-year approach but because of the uncertainty in estimating the magnitude of extreme T-year events, PMP would continue to be used in the short term.

Chairman
How long do you expect this short term to continue Alan?

Alan Brown
DEFRA are initiating some other research work, probably through our contract as a supplement to look at the extreme rainfall (1000 to 10,000 years) element of FEH versus FSR. As that's in progress I don't honestly know the answer but it is being taken forward in small steps at a time.

George Hallowes (Consultant)
With reference to Christine McCulloch's second question I'd like to be reassured about what Peter Enston actually was saying in his presentation. It was not my understanding that he said that we should not operate valves, or that we should leave them until they are stuck and then free them. I understood simply that he was comparing the cost of replacing a stuck valve with freeing a stuck valve. If my understanding is correct then Christine would be reassured.

Peter Enston (Hydra-Ject)
Firstly there is a huge difference in cost between replacement and repair and secondly the point made about the maintenance falling by the wayside is based on observation, from going up and down the country and seeing what's happened. Basically some people have come to the conclusion that there is no ready solution and they've buried their heads in the sand on this one because the only option previously was to replace it and there are major costs involved as you can well imagine. This refurbishment technology is the far far cheaper option.

George Hallowes (Consultant)
And you are not advocating leaving valves until they are stuck and then fixing them?

Peter Enston
No I am not.

Andy Hughes (KBR)
I just want to make the point that many Panel Engineers insist that valves are operated over their full range at least once a year and require to see the valve operation demonstrated to them and/or see valve operating records.

Having been involved in an emergency recently, I concur with Chris Binnie that it is essential that scour facilities should be available to lower water levels in the absence of or to supplement pumping. I would like to see full operation of the scour facility long enough for the water to run clear to ensure silt is flushed from the pipe. I believe arrangements have to be made with the Environment Agency etc. and that this is often done by many owners, to allow this to happen.

On the subject of maintenance and in particular surveillance after the emergency, the owner concerned has increased the level of surveillance to ensure that each dam is visited at least once every 24 hours. This is against the current trend of reducing surveillance and I believe the owner should be applauded for this action.

Peter Kite (Environment Agency)
Just to respond to the question about data, the Environment Agency collects data by the bucket full if not by the reservoir full in terms of rainfall data and river flow data and it is freely available.

The other question, raised by Chris Binnie, on the reluctance of Undertakers to fully open scour valves on the occasion of an Inspecting Engineer's visit due to perceived difficulties with Environmental authorities in arranging discharges through draw off valves. I am sure that every company wants to have a good environmental performance itself and if it is part of their normal practices to occasionally open draw off valves then they should make arrangements with the environmental authorities to ensure that they do not cause pollution and damage the wildlife. As part of our normal practices the Environment Agency works with people and we understand the potential problems.

SESSION 3
SEISMIC PERFORMANCE OF DAMS

Chairman Wendy Daniell
Technical Reporter Mark Noble

Papers presented

1. Seismic assessment of Scottish dams
   K J Dempster, A C Morison, S C Gallocher and S Bu
2. Seismic hazards in the UK - another look
   C W Scott and J J Bommer
3. A methodology for seismic investigation and analysis of dams in the UK
   P Rigby, S Walthall and K D Gardiner

Papers not presented

1. Assessing the seismic performance of UK intake/outlet towers
   W E Daniell and C A Taylor

Derek Knight (Consultant)
On the 16th of July 1990 a 7.7 magnitude earthquake struck central Luzon in the Philippines where a series of dams were located within 22km of the epicentre. Dr Paul Black and the writer visited the dams shortly afterwards in response to a request from the National Irrigation Administration to inspect and report on the earthquake damage, and to advise on remedial works. An account was subsequently published in the Dams & Reservoirs Journal (Knight, D J - Behaviour of five dams in the Philippines during the 1990 earthquake, Vol. 1, No.2, November 1991, pp 8-14). The behaviour of some ancillary plant and structures deserves highlighting, as noted in the following three instances.

The first instance is from the Gate chambers of the 120m high Pantabangon/Aya dam complex across the Upper Pampana River. Two separate chambers serving the irrigation and power tunnels contained large, vertical vacuum relief valves downstream of the control gates. Each valve casing stood several metres high, effectively as a free-standing steel "cylinder" containing water at full reservoir pressure.

Immediately after the earthquake substantial leakage developed between the flange joints of both vacuum relief valves together with considerable bending and stretching of the bolts securing the flanges. It seemed that the earthquake caused appreciable flexing of the vertical pipework of the cylinder referred to. Grave concern was felt that the system may well have come close to complete failure, resulting in uncontrolled discharge of the reservoir until its level reached that of the upstream low-level intake tower. Steps were taken to ensure that a future earthquake would not cause rupture of the pipes and valve system.

The second instance was noted on a separate visit to the earthquake area shortly afterwards. A low concrete buttress dam served as the intake control structure from the Pampana River into a main irrigation channel. The headstocks for the bank of control valves were grouped in the open air but beneath a heavy concrete canopy supported by light columns, which were insufficiently robust to prevent complete collapse of the roof on to the headstocks. It is easy to imagine the potential for failure to operate the valves in these circumstances.

The third instance is really a forward projection and general application of the previous two, and is addressed to all who may be responsible for the assessment of existing installations, or the design of new ones, world-wide much attention is rightly given to the seismic resistance of intake towers, which are particularly of concern in strong earthquakes. The behaviour of other ancillary plant and structures subjected to strong, cyclic horizontal loadings also needs consideration. A water-retaining structure is not just the dam.

Written contribution

Jonathan Hinks (Halcrow Group)
I found the paper on seismic hazard in the UK quite refreshing and also reassuring. The BRE guide has now been around for 11 years and a lot of dams have been checked. I think I am right in saying that only two have had to be strengthened to meet guidelines. Upper Glendevon and Aral and probably both would have required work anyway for other reasons. The only thing in the paper that I feel is

misleading is the statement that 'no well built embankment dam has ever failed due to seismic action'. Of course it is all a matter of definition. What is the definition of failure and what is the definition of well built? In fact a lot of embankment dams have failed as a result of earthquakes.

For the 145 dams that failed in Japan in the Nihon-kai -Chubu earthquake in 1983 the definition of failure was:

- Sliding of slope
- Longitudinal crack more than 50mm wide
- Transverse crack
- Crest settlement more than 300mm
- Leakage of water

Some of these 'failures' may not, therefore, have involved a catastrophic release of water although they would probably have involved reconstruction of the dam. In this it is worth noting that irrigation reservoirs may only be full for a couple of weeks per year and that 'failure' will often not lead to a catastrophic release of water.

There are other dams that could be mentioned including those damaged in the recent Gujarat earthquake in India. From the photographs I have seen damage at some of the dams looks pretty bad.

Of course many of the dams I have mentioned in China and Japan were of only modest height.

The reference to well built dams not failing seems to go back to H Bolton Seed's 1979 Rankine lecture but it is worth quoting his words in full. What he said was:

'Virtually any well built dam on a firm foundation can withstand moderate earthquake shaking, say with a peak acceleration of about 0.2, with no detrimental effects'.

Many of the dams I have mentioned probably suffered accelerations well in excess of 0.2 but I feel the reference to well built dams is a bit dangerous. The time to decide whether a dam was well built is after the earthquake and not before it.

Chris Scott (Binnie, Black & Veatch) (In response to J Hinks)
I would quote Ambraseys and Jackson's paper in which to the view that the max UK earthquake was MS 5.5. Musson and Winter clearly acknowledged that UK seismicity does not support an event greater than 6.2. Ambraseys and Jackson's paper went on to draw attention to the danger of drawing inferences between events across the world which have low seismicity because you have to understand what is the seismic rate in the area.

As regards the 500 dams that have failed, in the paper I refer to Lower San Fernando dam. This is a hydraulic fill dam which failed after the earthquake due to liquefaction and is not the sort of failure I was referring to. The majority of the dams in the list presented would certainly not be classed as 'well built' dams.

Ian Gowans (Faber Maunsell)
There have been no failures in Scotland although some minor cracking has been evident on various dams following seismic events. Some 40 years ago Lower Glendevon experienced a seismic event, with cracking experienced on the dam. The dam did not leak, the draw off tower cracked and a series of metal straps were installed to brace the tower following the event. In Scotland the movement of plates takes place in swarms over a number of years, the last being 40 years ago The next is due, the largest event measured by the Geological Society being 5.4.

SESSION 4
REMEDIAL WORKS TO CONCRETE AND MASONRY DAMS

Chairman Ian Carter
Technical Reporter Ian Davison

Papers presented

1. Stability reassessment and remedial works at Leixlip dam
   B O'Mahony and B Haugh
2. Rehabilitation of old masonry dams at full reservoir level - a comparison of successful rehabilitation projects
   V Bettzieche and C Heitefuss
3. Underwater work as a means for the rehabilitation of large hydraulic structures under operation and unrestricted water supply
   C Heitefuss and H J Kny

Papers not presented

1. RCC Construction at Tannur dam
   M Airey

Iain Moffat (Newcastle University)
Firstly may I simply congratulate our German friends for a superb presentation and a fascinating piece of work. My question is addressed to Brian O'Mahony in relation to Leixlip dam. It was mentioned that the original design assumed 67% uplift. Was the same assumption made when you were doing the preliminary work for the most recent round of rehabilitation because the 67% is a somewhat obsolete assumption for that?

B O'Mahony (ESB International)
No it wasn't. I think the paper says 100% uplift was assumed but was assumed to act on 85% of the area of the foundation.

B O'Mahony
In answer to the question about Leixlip, in the early 1990's movement monitoring devices were installed including joint meters,

inclinometers, extensometers, and crest alignment measuring facilities. There were no particular concerns about movement as there was nothing unusual showing from the measurements that were taken. It was the presence of the weak layers in the rock that gave us some concerns about the overall stability of the dam.

Written Contribution

Jonathan Hinks (Halcrow Group Ltd)
I have visited Tannur dam a number of times and think that Martin Airey and his colleagues can be proud of a very nice piece of work. In fact at the end of the job the Panel of Experts told the Jordan Valley Authority that they had an excellent dam.

There is, however, one feature that is not very satisfactory. I refer to the bottom outlet, which can release up to 60 m^3/sec of water at nearly 30 m/sec into a culvert. So far so good. Unfortunately the culvert then has a 61 degree horizontal bend on a 14 m radius into the stilling basin as shown on Figure 1 in Martin's paper. On reaching the bend the supercritical flow will attempt to go straight on and will corkscrew around in the culvert until it reaches the end where it will fly out in all directions into the stilling basin. It is of course, very difficult to arrange bottom outlets in RCC dams so that they do not interfere with the RCC process. The obvious alternative of putting the bottom outlet in the middle of the valley would doubtless have disrupted RCC placing.

The arrangement has not been model tested so what will happen when it is operated nobody quite knows. Perhaps it will give highly efficient energy dissipation. Perhaps it will never be used but, if it is, it should be a sight worth seeing.

Written contribution

Martin Airey (Mott MacDonald)
During the Design Review stage, the low level outlet and draw-off works were re-located in a single culvert on the lower left abutment offset from the dam centreline by approximately 50m and

approximately 7m above the lowest foundation level. This arrangement introduced a bend at the downstream end, which it is accepted had added some complications to the hydraulic design of the works. However a significant factor in positioning the outlet works was the need to create a large area in the central section of the dam where the Contractor would be able to progress the RCC placing during the early part of the Contract, whilst the draw-off works were being constructed simultaneously.

In the event the Contractor elected to create a temporary opening through the dam wall at the location of the culvert and to defer the construction of the permanent draw-off works until later in the programme, when the RCC placing was complete. Based on this construction strategy it is quite possible that the temporary opening could have been formed in a more central location without adverse impact on the programme, and in which case the straight alignment for the culvert would have obviated the need for the downstream bend.

Tony Allan (Kings College, London)
Question to paper 2
We did have one economic number indicating the cost per metre of driving the tunnel but is this rehabilitation expensive? How costly, can you say, and what is the cost benefit in terms of not doing it?

V Bettzieche (Ruhrverband)
My colleague mentioned that the reservoir was lowered by about 2.5 m and the capacity of the reservoir was reduced from 12.5 million to 10 million cubic metres. If there had been sufficient water we would have done nothing but there was not enough water for the supply of the Nurae region so we had to do something. First concept was to build a diaphragm wall, which was double the cost of the rehabilitation cost with the tunnel boring machine. So I think that we used a very cost efficient method.

Tony Allan
The costs were recovered from whom?

C Heitefuss (Ruhrverband)
We work for a water association and the costs are covered by both the water consumer, in the price of water, and we were subsidised by the State. The consumer paid about 30 Million Marks and the State 10 million Marks. It is important to let the public know where the money ends up.

Arthur Penman
My particular interest is in embankment dams and I know nothing about these concrete dams at all. My recent work has been in the supervision of an embankment dam in Brazil. But these concrete dams amaze me. The first question that I have is in relation to the dam that is only 20 km upstream. Were movements measured and were you concerned about it because it looked as though it was going to fall apart? The other question relates to the German dams. How stupid can you get to have a dam designed in 1908 with excellent drainage and then fill up the drainage galleries with grout. What we have always said is any dam will last for ever if its properly maintained and there are dams going back to the middle ages that are still working because the society managed to stay stable and keep the dam maintained. As soon as society disintegrates and you get no more maintenance or as happens today there is change in ownership and money plays a part the whole thing goes downhill and you get people grouting up the drainage galleries. So have the Germans any comment about this?

V Bettzieche
Now we come to the stupid Germans. I simply agree with your opinion but I mention that in the 50's I wasn't alive. In the 50's they discovered that the seepage moved through the masonry wall and the drainage system was not operational because it was filled with cement that had leached out of the masonry. They tried to stop the seepage by making injections into the masonry and unintentionally filled the drainage system. We know now that this was the wrong way to do this. The authorities ordered the reservoirs to be lowered. So I think that they were not stupid but just wanted to find a quick solution.

C Heitefuss
In the case of the Ennepe dam, we took over the dam from another association in 1997. Our impression was that the former owner had not taken care of the dam and had not carried out any repair work for twenty years. Since we took over the dam we have tried to improve the situation and we probably wouldn't have grouted the drainage gallery either.

Iain Moffat (Newcastle University)
I don't think that we should be too critical of our German friends as up to the 1960's we weren't putting any drainage our large dams and what we saw earlier today was a classic example of that. I can think of one further dam where for sheer stupidity we match that of grouting the internal drainage system, in that the internal drainage system was installed with no outlet to actually relieve the drainage pressures. You'll understand, session chairman, why I don't identify the dams concerned.

Jim Millmore (Babtie Group)
Our German colleagues have referred in their presentation to their Reservoir Supervisory Authority. Who is this Authority? What procedures and processes exist in Germany for Reservoir Safety Supervision? Are there Safety Inspections every year or every 5 or every 10 years and what reporting follows these inspections?

C Heitefuss
As you might know we have a Federal structure in Germany and we live in the State of Westphalia. The state authorities are in charge of the technical supervision of the dam. We have to send all our assessments on the safety of our dams to them. We do that work ourselves but send all our findings to the supervising authority. For example in a case where we have a meeting on the construction site we always have people from the supervising technical authority with us who decide along with us what to do. But we make the suggestions but they approve it. We also prepare annual reports on the safety of the dams and every ten years we have what we call intensive safety report which covers every aspect of the dam safety.

Written contribution

Chris Owens (W S Atkins)
I like the elegant solution to the provision of drainage to a tunnel on the upstream face of the dam, even if it is not the cheapest solution. I was impressed also by the provision of a tunnel beneath and close to the upstream face, where it needs to be. But I am very uneasy about the use of drilling and blasting in that location. What measures were taken to ensure that there was no collapse of the reservoir floor leading to water under full reservoir head entering the tunnel?

C Heitefuss
First of all we took very little charges so we had sometimes only 100g of explosive and we had one little bucket of muck to carry out. You have got to be very careful. At the Ennepe dam, a very slender structure, we wanted to avoid drill and blast so we used a tunnel boring machine. What we did at the Moehne dam 25 years before with the drill and blast method were considered as too risky. We had a very intense surveying activity to maintain the safe course of the tunnel. Two independent consulting firms calculating the course of the tunnel boring machine.

SESSION 5
DEVELOPMENT AND CONSTRUCTION OF DAMS

Chairman: Jim Millmore
Technical Reporter: Martin Hewitt

Papers presented

1. Design, construction and performance of Fullerton Pollan dam and reservoir, Co Donegal, Ireland
   R C Bridle, J Holohan, D Gillespie, D A Smith, S Fawcett, S McInerney, I C Carter and R Evans
2. Some aspects of early Irish dam construction
   E Fleming
3. The contribution to society of Irish hydro-electric dams
   J D O'Keeffe
4. Challenging values of dam builders
   C S McCulloch
5. Ghazi-Barotha hydropower project: social issues and engineering design
   P E Jones, J C Ackers, and A Chaudhury

Discussion (Part 1)

Discussion on Design, construction and performance of Fullerton Pollan dam and reservoir, Co Donegal, Ireland, presented by R C Bridle.

Derek Knight (Consultant)

Just a brief correction to what Rod Bridle said in his very interesting introduction, in which he used the word invention. Arthur Penman can certainly give the history of the wet core; all I did was to use what had been invented many, many years ago.

Arthur Penman

Thank you very much Derek, that's very kind of you to put it that way round. I regarded Derek as my student in the early days and I was delighted when he took on the wet core approach, which a lot of people weren't doing at that time.

A question now to Rod Bridle, if I may. In measuring pore pressures in the core, is there a section with a number of piezometers across its width, to show steady state seepage pressures when the reservoir is full? The reason I'm asking is because we know that the permeability of all materials is to do with effective stress. In cores the effective stress can only increase on the downstream side as the downstream side drains into the filter. The upstream side is supplied by the reservoir water and when people found that the pore pressure in the first half or three quarters width of the core were equal to the reservoir level they thought that there was a fault, for example cracks. But it's not that at all. It's simply that you loose all the head, commonly, in the last quarter width of the core, and I wondered if you had enough measurement locations to show this.

Rodney Bridle (Consultant)
I think, from memory, that there are three levels in the core where piezometers were installed; the first is in the cut-off, the second about halfway up and the third higher. There are also some in the upstream and downstream shoulders but not across the core. Placing instrumentation was awkward and limited by the size of the dam, which is quite small, so no, we can't demonstrate the point of changing permeability.

T A Johnston (Babtie Group)
The choice of a composite design as at Fullerton Pollan is fairly uncommon but it is clear that the designers considered a number of alternatives before deciding that the composite design would be economic. Was consideration given to inviting tenders for alternative designs as this sometimes reveals that contractors' views on the cheapest design vary from designers?

It is normal to locate the inspection gallery in a concrete dam close to foundation level as this makes it easier to determine whether water in the drainage system has come through the dam or through the foundation rock. Depending upon the topography this can result in the need for pumping or long outfall drains to drain the gallery. It would be interesting to know the reason for adopting the chosen location.

Rodney Bridle
There was quite a lot of peat and glacial till overburden. The dam is 24m high above foundation level but only 15m or so above ground level. The gallery level was set to drain it by gravity. Relief wells extend from the gallery into the bedrock below.

Although it seems funny that having two types of dam was the most favourable solution, there were some dams shown yesterday with concrete overflows and fill flanks. If we had had a fill dam the overflow arrangements would have required a large spillway channel; this is what pushed the costs up for fill dams. If we had had a totally concrete dam we wouldn't have benefited from the relatively inexpensive fill. Overall, the composite solution was the most economic.

Chris Binnie (Consultant)
I think that one of the most emotive and sensitive issues when planning a new dam is quite often the passage of migratory fish, generally salmon. Firstly, it looked to me that the design was very similar to that built by the North of Scotland Hydro Electric Board in the 1960s. What development has there been since then? Secondly, how much has the fish movement changed since construction of the dam? My experience is that it's easier to get the fish to come into the pass going upstream, but rather more difficult to entice them into the pass going downstream direction. I wondered if any particular measures were taken regarding that, and also, what numbers of fish had been measured going through the pass and whether these were the same prior to building the dam. Such data is vital for future reference.

Rodney Bridle
It's a Borland type fish pass, similar to Scottish Hydro's, but updated following consultations with them. I have seen fish passing through it but not since construction finished. It is managed by Buncrana Angling Club. I don't have any real data and it would be nice to get an update from the County Council in due course.

George Hallows (Consultant)
Can you comment whether you got any uplift of your concrete grout cap. I know that the Grouting Intensity Number (GIN) method is

considered to be a good way to limit this, but even Lombardi in his 1993 paper did comment that it probably wasn't quite enough to prevent it near the top. Did you load the cap at all, or did you observe uplift?

Rodney Bridle
We put piezometers in but they never seemed to do anything; whether we grouted them up, or couldn't wait long enough, I don't know. So although we hoped we would get some uplift information, we don't really have any.

Written contribution

Derek Knight
The interesting paper on Fullerton Pollan dam in Co. Donegal, Ireland by Bridle, Holohan, Gillespie et al refers on page 45 to the use of the "wet core" method for the construction of the global fill core of the flanking embankment dams, for which low ground pressure tracked bulldozers were the compaction plant. In his presentation of the paper in this session, Mr Bridle kindly (but incorrectly!) attributed the wet core methods "invention" to me. The concept of placing clayey core materials at their natural moisture contents well above their optima is, in fact, a very old one; Dr Arthur Penman had advocated it for a long time and reminded us of its pedigree in puddle clay cores of an earlier century. My involvement did not begin until construction trials began in 1978 for the 85m high Monasavu dam in Fiji, completed in 1982. I was simply a part of the team which used the method, albeit in new circumstances, which, with others, I have since had the opportunity of describing in various papers, beginning with those for ICOLD in 1982 (Rio) and 1985 (Lausanne). A few additional remarks on the Monasavu core construction are given in the discussion of Mr Moffat's paper on puddle clay cores in session 6.

Discussion (Part 2)
Discussion on the remaining papers presented and submitted under this section.

Written contribution

Jonathan Hinks (Halcrow Group Ltd)
I would first like to thank Christine McCulloch for so carefully preserving the anonymity of her interviewees. Having said that I think I recognise myself as "Disappointed of Swindon".

Despite our good intentions I don't think that as dam engineers we can claim exemption from well informed criticism about our activities. Christine has pointed out that it is not enough that our efforts should do more good than harm. If possible we must also see that no individuals are worse off after our projects than before.

A few days ago I was flying over the Aral Sea and had time to reflect on the destruction of the fishing industry (on which 60,000 people used to depend), the drying out of the ecologically rich deltas of the Syr-Darya and Amu-Darya, the salinisation of large areas of land and the dramatic deterioration of the health of the people. Christine referred in her presentation to reversibility. I am afraid that what has been done to the Aral Sea is not really reversible. I suppose that as engineers we have to share in the blame for this disaster although I hope Mr McCully and his colleagues aren't going to ask us to take responsibility for all the other misdeeds of the Soviet Politburo.

What I find a bit depressing is that the anti dams lobby and even the WCD do not seem to recognize that dams produce real benefits. They rightly point out that things have gone wrong but they do not acknowledge the huge benefits which derive from hydropower, water supply, irrigation and flood control. In one of the thematic papers I pointed out that if it was not for the El Cajon dam in Honduras there would have been another 1,500 Mm3 to add to the flooding after Hurricane Mitch. This didn't find its way into the WCD report which preferred to highlight cases where dams, not built for flood control, failed to prevent flooding.

We all know that irrigation schemes are highly multidisciplinary and that a successful scheme requires everything to be right; soils, drainage, fertilizers, credit, marketing, roads, schools, clinics etc. It is not surprising that some schemes have problems. I am not an irrigation engineer but I have been involved with irrigation dams which bring prosperity to huge numbers of people. On one occasion I visited a village that was downstream of a dam that was used to supply irrigation water but which was now drawn down on safety grounds. I was very shocked by the state of the village. There were no animals and no young, or even middle-aged people. Only a few old people living in abject poverty. Certainly the dam had been providing a benefit which was probably only fully appreciated when it was withdrawn.

I think the WCD report is a very useful document to help us to design better schemes. In particular we must try to see that resettlement always receives the attention it deserves. But I think we are entitled to ask that the real benefits brought by dams should be recognised.

Tony Allan (Kings College, London)
I found the suite of papers most stimulating. Dr Jones has described a very important process happening in Pakistan. We've had in my view too little on where things are actually happening in the world of dams; there's not very much happening in north-western Europe, but an awful lot happening in China, India and south Asia, so it's good to hear from that part of the world.

You come, I sense, from a part of the United States where dramatic things happened at the end of the 1970's in the dam building community. At that point, 1976, Jimmy Carter had been got at by the Green movement and he wanted to stop building dams because he thought they were costing too much (scarce) money. By that time there was in place in the United States two massive institutions; the US Army Corps of Engineers and the United States Bureau of Reclamation (USBR); no equivalence in north-western Europe. They thought they had won the battle, along with the senators and others who wanted more dams built. But the battle in fact, although lost by Carter, was easily won by the next president, Reagan, and he virtually cut-down the USBR, turning it into a very small organization compared to what it had been. As it happened the Corps of Engineers were nimble and had spotted that things ought to change and there had been some very advanced things happening in the United States in terms of consultation and participation from the early 1980s onwards.

I presume Dr Jones was well and truly alive and observing it happen from a non-engineer's point of view, an environmentalist's possibly. So when we talk about change the most important changes were led by environmentalists in California, Arizona and the mid-West. They set the agenda which changed how things were looked at in the United States. We have someone, Dr Jones, from North America, who finds himself working in Pakistan which has not adopted many of the ideas that have been deeply adopted by the dam building community in North America.

In the North we have an approach that is driven by the green movement, too far some would say, and they are still pushing for more. There is a discourse going on. About a billion and a bit people live in the north and about 5 billion in the south, with Pakistan being very much part of the South. Who decided to have a social scientist as part of the team; was it the World Bank, or another agency from the North? The point I'm trying to make is that we're here in a world in which discourse is going on. Christine McCulloch indicated there is a discourse going on between the North and the South. The ideas from the North are easily pushed aside by China; in India it's mixed. Could I just ask who decided to employ him on that project? And, could he comment on some of the things I've said?

Phil Jones (Embry-Riddle Aeronautical University, Prescott, Arizona, USA)
I've only been in Arizona about 3 years, my life has really been more in, or working on projects, in south Asia. But in Arizona I do hear about people who would like the Glen Canyon dam to be taken down, and there is a movement for this. I think they are taking one dam down in Oregon, and so the debate goes on.

It was the World Bank who decided there ought to be a social as well as an environmental scientist. I worked along with Dr Peter Aims, of Harza Engineering Co on this project. The World Bank had just put out its Operational Directive OD4.30 and we were the first major international project to try to implement it. I think that having social and environmental scientists in at the ground floor of a project is a good idea.

Alison Bartle (Editor, Hydropower & Dams)
Christine McCulloch has given us an interesting insight into the different values she has found among dam engineers. But I would like to draw attention to the diversity of views which also exist among the NGOs who oppose dams. Much has been said about bringing anti-dam NGOs into our debate, but before we embrace all of them, it is important to remember that they are not just one homogeneous group. We must be sure we know who we are dealing with, perhaps by looking at their constitutions or mission statements.

We can find, for example, some quite radical political groups, who subscribe not only to the NIMBY (Not In My Back Yard) concept, but also to the more extreme BANANA concept (Build Absolutely Nothing Anywhere Near Anything). While it is important to keep these people informed, they are often anarchists, and there is probably no way to modify their views in a debate.

Then there are more altruistic groups, who base their campaigns on human rights issues, and in some cases perhaps they have knowledge of some projects where issues such as resettlement may not have been handled so well in the past. It is clearly worth listening to what they have to say. However, most of the cases where things have gone wrong, and from which lessons have been learned, are certainly in the past.

We know that there are also a great number of special interest groups dealing with various ecological subjects (flora and fauna, fish protection) who are knowledgeable and responsible, and it would certainly be constructive to involve them in discussions.

But while a wide range of values and missions may exist among these anti-dam NGOs, the one thing which they all seem to have in common is that, while they oppose the construction of dams, they have no realistic alternative to offer in terms of providing much needed water and energy to the world's rapidly increasing population over the next 50 years.

What we have to get across to all of them is the unique, multipurpose role that carefully planned, and well operated dams and reservoirs can play in fulfilling a number of vital needs for society; and, we have to publicise well documented case studies of best practice. That is one way in which we can demonstrate the knowledge which has existed in the dam engineering profession for some 30 to 40 years on the management of social and environmental issues.

Chris Binnie
I'd like to ask Dr Jones or John Ackers what was the extra cost of the re-alignment and what was it as a proportion of the overall scheme?

And to Christine McCulloch I'd say well perhaps if we're getting criticised for dams lets take a city, say Birmingham, and consider how it would have faired during the 1976 drought if reservoirs had been banned from the beginning and it didn't have any. May I commend a brief review of that or discussion with Severn Trent as to what the effects would have been; may be that would be a salutary element to add to your studies.

Phil Jones
Approximately $60M on $2,200 M. The Government complained.

Christine McCulloch (University of Oxford)
A quick reply to Chris Binnie. I was not taking a view point myself in the paper. I was looking at values you were expressing and the alternative view points being put forward by others. If Chris really wants to know whether I think any reservoir should be built or no reservoirs at all, I would say yes. Some reservoirs are necessary and functional, but we need to examine very carefully where we place them, and what the real cost is. Not in terms just of the cost of construction but the real cost and not to regard costs to cause less social disruption, such as the $60M referred to by Dr Jones, as added extra. That should be an integral part of the consideration as to whether you need a dam or not.

I would like to ask Dr Jones whether there are plans for long term monitoring of the social effects of the hydropower project. Much of the population of Bradford comes from two small areas in Pakistan where people were displaced by dams and this has had a very long term effect on social history and the distribution of people in the world. The immediate effect of the dam is one thing, the longer term another. They are British Citizens and they aren't going back to Pakistan, I believe.

Phil Jones

Yes they are monitoring the long term social impacts of the project.

The people who went from the village of Ghurghushti went long before the dam was even planned or designed. When we did the social impact assessment we found in Ghurghushti particularly, it's a large village of some 35,000 people, that they had gone to Bradford a long time before we came along. There is a kind of back and forthing that goes on of course. I think that very often the first generation of people who come to Britain do go back and retire and very often you find that they take their girls back when they are of marriageable age; those that they can get to go back, some of them don't want to go back and there are all sorts of issues around that I understand in Britain.

The biggest group that went to Britain went from the Mangla dam that was built before Tarbella. They began moving to Britain in the early 60s and even late 50s. They were given compensation money and there weren't any visas at that time, and they thought it would be very nice to go to Britain. So you do find a lot of the Mangla people in Britain, and they come back. I'm now working on raising of the Mangla dam and you do find these huge palace like buildings that they've come back and built, but then again I think it's going to be a generational thing. I'm speculating here of course that the early generations will come back but that as time goes on you'll see less and less of that. So I hope my paper is clear, I didn't mean to suggest we had pushed those people into Bradford, no.

SESSION 6 - PART 1
EMBANKMENT DAMS: PERFORMANCE AND REMEDIAL WORKS

Chairman	Jack O'Keeffe
Technical Reporter	Jon Green

Papers presented

1. Rehabilitation of irrigation dams in Albania
   J L Hinks and Y Dedja
2. Internal erosion in European embankment dams
   J A Charles
3. The successful grouting of Heapey embankment, Anglezarke reservoir
   C D Parks and S Walthall

Chairman

We have three papers in this session. The first is entitled the Rehabilitation of irrigation dams in Albania and will be given by Jonathan Hinks. It seems a very interesting paper on a particular problem of resources versus problems and a unique way of overcoming it. The second is a report by Andrew Charles on Internal Erosion in European Embankment Dams. It is a report on the work of the European Working Group. Finally we have a report on the successful grouting of Heapey embankment, at Anglezarke reservoir by Chris Parks In this session we have an extra presentation by Peter Rissler who will be giving us a few minutes on the Dresden floods which I am sure we will be very interested in hearing.

Derek Knight (Consultant)
Ref: Eigiau, Coedty and Cowlyd dams in North Wales

On page 500 of his valuable paper on the history of reservoir safety legislation in the United Kingdom, Dr Charles refers to the failures of the Eigiau and Coedty dams in North Wales on 2 November 1925, causing the Dolgarrog disaster. In 1926 Sir Alexander Gibb, the founder of the renowned firm which bore his name, Sir Alexander Gibb & Partners, reported as requested to the Aluminium Corporation, as owners, on the causes of the disaster, as well as on the performance of all the dams belonging to them.

These included Cowlyd dam in the adjacent valley, and which came very near to catastrophic collapse on the night of 31 December 1924/ 1 January 1925, some ten months before the Eigiau/Coedty failures. Details of that earlier grave incident were reported at the conference which began this series (Knight, D J - "Problems and remedies at Cowlyd dam, North Wales", papers 5.6-1 to 7 of Proceedings, BNCOLD/University of Newcastle Upon Tyne Symposium, "Inspection, operation and improvement of existing dams", Newcastle, September 1975). The present writer remembers retrieving in the early 1960s (probably) that 1926 report from the extension Gibb archives, at the outset of a thirty year involvement with that dam, culminating as the inspecting engineer under the 1975 Act. That first retrieval of a valuable archive was not the only occasion it was consulted, during years of subsequent investigations and remedial works.

Whilst Cowlyd dam continued to be closely monitored changes were also occurring at the rebuilt Coedty dam. Leakage was detected in 1971 and grouting of the central concrete core wall done in 1972. Despite this, leakage continued, and in 1988 a further borehole investigation was made into the core wall, revealing a high aggregate content, honeycombing, black staining of voids, leakage paths and, elsewhere, evidence of alkali-silica reaction. Extensive remedial works were carried out, involving modifications to the upstream draw off intake, additional upstream fill and a new downstream seepage control system, following a decision to abandon reliance on the deteriorating concrete core wall for seepage control. This philosophy and the remedial works were described in a paper for an earlier conference (Knight, D J, Jackson, E A, Halcro-Johnston, J, and Makinson, C, - "Safety considerations with existing embankment dams and in their raising". Proceedings, 6th BDS Conference, "The Embankment dam", Nottingham, September 1990, pp. 127-133).

Concrete quality left a lot to be desired in these three early twentieth century dams. The abundance of large aggregate and displacers, together with the complete absence of fines as pointed out by Mr

Moffat, in the Eigiau section, and the honeycombing found in both the Cowlyd and Coedty dams core walls, are evidence of this. Anticipated future deterioration in the latter cases means that the reservoirs in a changing world may be retained by changing dams as well.

Pamela Rigby (Bechtel Ltd)
Question directed at Andrew Charles. How easy was it to get information about failures of dams across Europe, I know that dam owners are quite secretive about this kind of thing happening.

Andrew Charles (BRE)
One advantage of having a European Working Group was that we trusted that each member would produce some information for their country. We did not set out to obtain comprehensive information, we were looking for interesting and illustrative case histories and in this we succeeded.

John Sammons (Consultant)
I'd like to ask Mr Parks on their problems with seepage. You did quite a lot of investigation but you didn't actually find out what the problem was. I wonder why didn't you consider digging into the area of seepage, improving drainage with a filter so you would allow the seepage to continue with a safe controlled outlet. Was that alternative considered?

Chris Parks (Bechtel Ltd)
The investigation of Heapey embankment was designed to identify areas of leakage and to prove that the construction of the dam was as recorded in the clerk of works records. Both of these aims were successfully completed. We installed French drains to intercept the leakage which were, in turn, connected to flow monitoring stations. The flow monitoring stations discharged through a pipe which provided an accurate record of the leakage. You are correct in saying we did not pinpoint the cause of the leakage, however, one of the major causes of embankment failure and leakage is typically the interface between pipes through an embankment and the embankment material. Therefore the obvious first choice for remedial works was

to grout the old discharge pipe. The remedial works were phased, partly in consideration of monetary constraints, but with the emphasis being on sound engineering judgement based on the results of the investigation and assessment of the possible causes

Andy Rowland (Binnie Black & Veatch)
Jonathan Hinks' paper reflects the conference theme of a changing world. When the communist regime in Albania was overthrown, the state and regional institutions responsible for design, construction and maintenance of dams collapsed. When I visited Albania in 1998 to carry out initial inspections of some of the irrigation dams, it was clear that there has been no management or maintenance of the reservoirs in the intervening period. Indeed there is some doubt about the standard of maintenance under the communist regime. Now that there is a different political structure in Albania, is Jonathan confident that any new institutional framework will be able to ensure that the newly rehabilitated dams are managed and maintained to an adequate standard?

Jonathan Hinks (Halcrow Group Ltd)
We are working quite hard at capacity building, i.e. training people to be dam inspectors. We've held seminars and we've taken them to dams to write reports for discussion. In addition we had a group in UK for a study tour of Welsh and English dams.

Of the Albanian dams in the programme that which was in the best condition was the largest. The dams are all between 15m and 30 m high, but the largest was designed by the Design Institute who designed the bigger dams. It appears that the communist authorities told local organizations to get on and build as many dams as possible to meet their 5-year plans, so the smaller dams tend not to be particularly well designed. Maybe they didn't have a good hydrologist to hand or they were weak on soil mechanics. There is a long way to go, but we are trying to bring the dams up to standard and to set up a regime for regular inspections in the future.

Wyatt Osmond (M.C. O'Sullivan & Co Ltd)
A question on the investigation side. Why is nothing presented on the

use of geophysics in detection?

Chris Parks
Our particular embankment was very steep and it was clear where the leak was emanating from. We therefore considered that using geophysics to pinpoint any changes in moisture content was inappropriate in our case.

David Dutton (British Waterways)
Regarding geophysics, I would refer you to my paper in the proceedings about temperature sensing for leakage detection. British Waterways acts as the agent for GTC in this country and we have used the procedure at a number of our dams. Drayton Reservoir had piling installed in 1970's because it leaked a lot. It started leaking again fairly recently and we used the temperature sensors to locate the points of leaking downstream of the piles. Saddington started leaking earlier this year and we've just undertaken a temperature sensing investigation there and can quite clearly pick out 3 locations of leakage over about a 50m length. So yes there are certain geophysical methods that can be used to locate leakage very closely.

Iain Moffat (University of Newcastle)
I think Derek Knight was being over kind to the quality of concrete illustrated in Eigau. A question for Chris Parks: In the longitudinal section of Heapey embankment I noticed an extremely steep step in the left embankment. Is there any history of any problem at that end of the embankment as opposed to the problem you were working on? Also a question to Dr Charles: Can he give us an indication of whether he feels that the puddle clay core profile dam is more or less vulnerable to this type of problem than some of the other types embankment?

Chris Parks
As far as we know there is no history of leakage associated with that step.

Andrew Charles (BRE)
Different types of soil do have different erodibilities. An example was given of a dam in France that had failed with a low reservoir

head and which was clearly very vulnerable to internal erosion. The Swedish representative on our European Working Group informed us that a large number of dams in Sweden had had internal erosion problems but there were no catastrophic failures. In Norway there were far fewer cases of internal erosion, probably because, at an earlier stage they had more conservative filter designs. The puddle clays used in British dams do generally seem to be more resistant to internal erosion than quite a number of types of soil used in dams in other countries. However, once internal erosion has started our puddle clays may be a good deal less self-healing than some soil types.

Ian Gowans (Faber Maunsell)
Regarding Geophysics, we have in Scotland a number of mini hydro schemes planned taking advantage of the government's new initiatives. We are involved with several projects involving the construction of low dams. These dams all require site investigation. The nature of the foundations, weathered rock and hidden valleys in the rock profiles caused by glaciation lends to geophysical investigations for these low dams.

Chris showed a very good slide of the grout take on the dam. In Scotland we don't have so many puddle clay dams but we do have the similar sort of leakage problems. Most of the dams that have leaks have got a very large grout take at the rock interface and it was quite clear on your slides that there wasn't really the sort of grout take at that location that I would have expected from dams built in Scotland. How closely did you examine that rock soil interface because that is an area of weakness in many of our dams?

Chris Parks
The original tender drawings that are represented in the paper have an indication of the possible or predicted extent of the cut off trench. The actual extent was considerably deeper and the core was constructed for some distance into the rock all along the embankment. The investigation boreholes penetrated below the core into the rock some 5-6 m below the core depth and the rock was found to be tight below the dam. To the right abutment, where we recorded a large grout take during the grouting works, the rock was visibly loose and

open in places, within a pit excavated to establish locations of services in that area. That is why we believe we had a larger grout take in that area. I must point out that although we used a phased approach and we commenced with the most obvious probable leakage path, phase 1 was not fully successful.

Following phase 1, NWW were able to achieve an increase in the top water level before leakage started to occur, however, this was below the required top water level. Phase 2 was completed successfully and NWW were able to raise the water level above the normal operating level without significant leakage becoming apparent. We are still not precisely sure of where the leakage path was located. We grouted around the old discharge pipe, we grouted a zone of the embankment away from that pipe, in the second phase, towards the right abutment and we had some large grout takes. It is impossible to say the leakage was through a particular location. It could well have been a rock embankment interface but it might just as easily have been some interconnectivity of fissures within the embankment material near the crest. We can be sure that the leakage path commenced at a high level and that it was successfully treated.

Alan Johnston (Babtie Group)
Andrew Charles' paper on internal erosion is a valuable analysis of work being done to understand the mechanism of internal erosion and to identify the types of dam most at risk. This year's Geoffrey Binnie Lecture by Geoff Sims includes a section on internal erosion and alerts us to the need to continue to investigate the phenomenon.

Both papers refer to the need for surveillance of existing dams and the important questions - "What should be observed?" "How?" And "When?". To date I am not aware of any case where instruments have been in an apparently satisfactory embankment with the aim of giving early warning of an internal erosion problem. Perhaps Andrew Charles has knowledge of such cases, either in the UK or in the rest of Europe.

One can imagine dam owners and their engineers reading accounts of how quickly internal erosion develops and feeling that they should be taking rather more action than watching for damp areas at the dam toe or on the face. What advice would Andrew Charles give such owners and engineers?

Andrew Charles

The frequency of ordinary surveillance by knowledgeable operatives is quite an issue because my suspicion is that it has been tending to decrease, i.e. whereas it might have been once a day now it might be once a week so I think that's a retrograde step that needs to be reversed. There is the question of should some instrumentation be installed in dams where there is no apparent problem, depending on the hazard posed by the dam and its age etc. I think some pre-emptive exploration work needs to be higher on the agenda than it is at the moment particularly on the use of geophysics and temperature measurement etc.

Additional Presentation

Peter Rissler (Ruhrverband, Chairman German Committee on Dams)

Floods in Saxony

Weather conditions

This event happened in the Ore Mountains during 12th and 16th August, in Dresden (and in Czech Republic) during 10th and 22nd August 2002. It was caused by a strong low-pressure region in the northern Mediterranean Sea that pumped muddy wet air along the eastern corner of the Alps to the north. There was extreme precipitation in Bohemia and in Saxony (also in Austria and Bavaria) up to 120 - 280mm in 24 hours and 200 - 400 mm in 48 hours. The average precipitation in Saxony, a region of 3000 km^2 was 200 mm in 24 hours.

Discharges were measured (or estimated)

- within catchment/areas of 100 km^2 2000 l/s/km^2

- within catchment/areas of 10-20 km^2 up to 4000 l/s/km^2

Reservoirs

25 reservoirs and 9 flood protection basins of the Saxonian Reservoir Administration were strongly affected. The input to 6 reservoirs was close to the 10,000 years event, in other cases it was between a 500 and 1000 years event. At the Klingenberg dam the crest elevation was impounded. No reservoir was damaged except some smaller problems at stilling basins where the flood design (1000 year) was exceeded.

It should be mentioned that the Klingenberg reservoir at the moment is the only source for drinking water for 500,000 people in Dresden, because the two waterworks at the river Elbe had been damaged.

Discharge in Dresden

Normally, the discharge of the river Elbe is around 300 m^3/s. Flood situations have been observed there for about the last 500 years, the most extreme situation, ever reported before, was the flood of 1845 with a peak water level of 8.77m. Usually the water level is between 2m and 3m. Now the level climbed up to 9.40m.

The discharge was estimated to exceed 6000 m^3/s.

As far as the figures are reliable, about 50 persons died in Germany 20,000 to 30,000 persons lost their houses and at least part of their property and 300,000 persons were forced to leave their homes

Discussion

Chris Parks

You say the flood level was close to the 10,000-year event level. Does the level reached during this event give you concern that that 10,000-year event level is incorrect and would this flood cause you to re-assess that level?

Peter Rissler

We in Germany are obliged to use the 1000-year discharge for the design of the spillway so the 10,000-year event is more or less estimated. It has been much more than a 1000-year event.

SESSION 6 - PART 2
EMBANKMENT DAMS: PERFORMANCE AND REMEDIAL WORKS

Chairman	Rod Bridle
Technical Reporter	Brian Morris

Papers presented

1. River Shannon hydro-electric scheme: Fort Henry embankment: upstream slope failure and remedial work
   B Casey, M Long and T Fitzgibbon
2. The influence of climate and climate change on the stability of embankment dam slopes
   P R Vaughan, N Kovacevic and A M Ridley
3. The characteristics of UK puddle clay cores - a review
   A I B Moffat

Papers not presented

1. Settlement of old embankment dams and reservoir drawdown
   P Tedd, J A Charles and A C Robertshaw
2. The use of temperature measurement for detection of leakage in embankment dams - British Waterways Experience
   D P M Dutton
3. River Shannon hydro-electric scheme: failure of upstream slope of Fort Henry embankment: Analysis
   M Long, I Lydon and E Conaty
4. Long term behaviour of Portumna embankments
   E Conaty and M Long
5. The influence of climate and climate change on the stability of abutment and reservoir slopes
   P R Vaughan, N Kovacevic and A M Ridley

Chairman's Introduction to Paper 1

Paper 1 is presented by Mike Long who is a lecturer in geotechnical engineering at University College Dublin.

Discussion on Paper 1

Chris Binnie (Consultant)

It's the pore water pressures that are very important on this matter. I have one question. What assumptions did you make regarding pore pressure dissipation, as I didn't quite follow that? I did a rapid draw down assessment at a dam for a water company some years ago. We actually measured the pore water pressure under draw down condition in the upstream slope and found that there was relatively little dissipation, perhaps 10% or thereabouts. We believe that as the dam had been constructed during the 1930's there had been very little compaction of the fill. Consequently, there was still a lot of air as well as water in the pores. With the water pressure outside the embankment diminishing all that happened was that the air expanded a slightly. Therefore, you retained almost the same pore pressure after drawdown. Did you try measuring this in-situ?

Mike Long (University College, Dublin)

We found exactly what you described there Chris. There were some piezometers in the embankment prior to 1979 so we had some idea of the piezometric regime. Subsequently, there have been a significant number of instruments installed and these have shown exactly what you said. The variation is very small, probably for the same reasons, because the embankment material was placed very loosely.

Tony Morrison (Halcrow Group Ltd)

Tying in with some rather different work presented yesterday, I was wondering whether you had considered any seismic analysis of the embankment as well. It does look to have a rather marginal factor of safety under draw down conditions.

Mike Long

We have done pseudo-static seismic analyses following the guidelines of the BRE Report that was mentioned yesterday. Due to the low siezmicity of the area it does not have a great effect on the factor of safety.

Arthur Penman (Consultant)
We did work like this many years ago at Glen Shira. The problem was put to us, by the consultant who designed the dam, about what limitations he should impose on draw down. We advised that he had two choices. He could either assume that the pore pressure stays the same after draw down as it was before (which is highly dangerous) or assume that it reduces with the release of total stress as the weight of the reservoir goes down. We thought that it was reasonable to assume a condition somewhere in between.

However, the answer was to actually make measurements. This particular dam was a pumped storage reservoir and consequently the water level was designed to fluctuate quite a lot. We had the opportunity of full draw down from top to bottom water level and to monitor the effect on pore pressure. We found that the pore pressures stayed the same after as before, for a few hours and then they started to reduce, as it was a silty material. It was a dangerous situation if you dropped the whole thing extremely quickly and it all depends, as has been said, on the permeability of the fill material. The reason that the pore pressures stay up is that there is air in the fill and we put this explanation forward.

It was suggested that after the embankment had been in use for a few years the volume of air in the fill may have reduced and the situation would be different. Approximately five years later, due to some work on the tunnel, we had the opportunity to empty the reservoir once more. Again, we were able to make detailed measurements of the pore pressures during draw down. In fact, they were identical to the readings recorded five years previously confirming that the air was still present. This is published, if I can draw your attention to some very old publications, in 'Pore Pressure and Suction of Soils' 1960, published by Butterworth and now out of print of course.

Chairman's Introduction to Paper 2
Professor Peter Vaughan is a very senior member of the British Dam

Society, Senior Research Fellow at Imperial College and Senior Consultant with The Geotechnical Consulting Group (having founded it). He has done such a lot in the field of geotechnical engineering. I would like to use this occasion just to say that I was fortunate enough to be appointed to help Professor Vaughan and Professor Bishop when they were appointed as consultants at Empingham and I can say that my life has been considerably improved by having had contact with Peter. So thank you.

Discussion on Paper 2

Derek Knight (Consultant)
In the construction of the 85 metre high Monasavu dam in Fiji 20 years ago we used a clay that was actually very wet. It was between 18 and 20% above optimum moisture content. For compaction of that material we used low ground pressure tracked dozers. I simply wish to take this opportunity, as Rod Bridle mentioned wet cores this morning and as Peter Vaughan is here, to record the contribution Peter made to the successful completion of this project. For four years between 1978 and 1982 Peter Vaughan was the chairman of the four man Special Board of Consultants and made a total of 8 visits to the project in Fiji. I would like it to be placed on record that it was through his helpful guidance, support and authority that we were able to establish the feasibility and successfully use low ground pressure tracked dozers for compacting the very wet clay core in a modern rock fill dam.

Peter Vaughan (Imperial College, London)
I remember our last report in which we said that it would be advisable not to fill up the reservoir too quickly. So what happened...they had a terrible hurricane and the last 20 metres went in in about 20 hours.

Chairman's Introduction to Paper 3

Iain Moffat was until recently Deputy Head of the Department of Civil Engineering at the University of Newcastle upon Tyne and has become almost part of the fabric there. He was the person who organised the first of these conferences. Iain has done a great deal of service for the British Dam Society and previously with BNCOLD and he is now going to summarise his findings over the years about puddle clay cores.

Discussion on Paper 3
There were no discussion items relating directly to this paper.

Chris Peck (Thames Water)
As there were no other questions I wish to raise a matter not directly related to the papers that we have been hearing this afternoon so far. I have been looking at my conference programme and I cannot see any other sessions in which I might raise it. I am responsible for a few service reservoirs in the London area. We have had a couple of incidents recently where we have had emergency helicopters making landings on top of our reservoir roofs. I was just interested if anyone else in the room had any similar experiences. Furthermore should we be designing our service reservoir roofs for helicopter loadings?

Neil Williams (Severn Trent Water Ltd)
We have not had any experience of helicopter landings on Severn Trent service reservoirs. However, I suppose they could have come and gone without our knowledge. I can understand that a reservoir roof would make a very attractive location to land for an emergency helicopter. Certainly consideration does need to be made as to whether we should consider that type of loading in the design.

Chris Peck
We have considered putting a large cross on the roof and sign indicating no landing.

Written Contribution

Derek Knight
Ref: Monasavu dam, Fiji - core and construction

The extensively researched and most interesting paper "The characteristics of UK puddle clays - a review" (pp 581-601) by A.I.B. Moffat contains a wealth of data about our old dams, both in respect of the materials comprising the water barrier and of the construction methods for placing them. In his presentation Mr Moffat referred to the change from the very labour-intensive method of puddling of the clay by foot to a more mechanised method with the arrival of the steam-driven pugmill, and the end of the puddle clay by foot era in 1960. I should like to amplify here some brief remarks I made in Session 5 regarding Fullerton Pollan dam's wet core construction and the subject of mechanisation, as pertaining to Monasavu dam in Fiji. The very wet clayey sandstone core material was laid in 100 mm thickness layers and "compacted" with low ground pressure tracked D6 bulldozers ("swamp" dozers), for the full length of the 85 m high clay core/rockfill dam. Its geotechnical properties were unusual, as may be seen from the following summary:

Moisture content	76%
Dry density	0.86 t/m^3
Wet density	1.52 t/m^3
Passing 0.075 mm	96%
Liquid limit, plastic limit	107%, 59%
Dry density / maximum dry density	87%
Moisture content - optimum moisture content	18%
Unconfined compressive strength	34 kPa

Regarding the clay therefore as saturated gives an average undrained shear strength, from 1008 tests, of 17 kPa. Full details are given in a paper to The Mineralogical Society (Knight, D J - 1986, "Geotechnical properties and behaviour of the Monasavu halloysite clay, Fiji", Clay Minerals (1986) 21, pp 311-332). From the above data it will be clear that the clay used was not only an unusual one but also very wet! This produced challenging construction problems and, initially, an unnerving shaking of the very soft core. The client (Fiji Electricity Authority) and its consulting engineers (Gibb) were helped greatly during this process, beginning with early construction trials by the support, experience, sound advice and the soil mechanics acumen of the chairman of the four man Special Board of Consultants appointed to watch over the project, namely Dr Peter Vaughan. The writer is glad of this opportunity of acknowledging this.

The dam was successfully completed in 1982 as a key component of the Monasavu Hydro-electric Scheme. A few years later this experience was applied to an even higher wet core dam, Wadaslintang in Java, Indonesia, at 120 m high. The same basic soil mechanics principles implicit in the old English dams, described by Mr Moffat have found further expression in newer dams in other parts of the world.

SESSION 7
PERFORMANCE AND REPAIR OF UPSTREAM MEMBRANES

Chairman Dr Paul Tedd
Technical Reporter Ian Scholefield

Papers presented

1. Improving the watertightness of Winscar Reservoir
   I C Carter, J R Claydon and M J Hill
2. Turlough Hill - Upper Reservoir: condition of the lining after 30 years
   B Haugh
3. Colliford and Roadford dams: performance of the asphaltic concrete membranes and the embankments
   J K Hopkins, P Tedd and C Bray
4. Breaclaich dam - upstream face joint bandage sealant and wavewall refurbishment works
   K J Dempster and N Lannen

Chairman
I have two written contributions that we will start with before we move on to the discussion.

Written contributions

J G Cowie (Consultant)
Ref: Analysis of leakage measurements at Breaclaich dam

Scottish & Southern Energy maintain a very large database on information relating to all their dam structures that is available to Inspecting Engineers at the time of an Inspection under Section 10 of the Reservoirs Act 1975.

In the case of Breaclaich dam, the contributor was appointed as the Inspecting Engineer and was presented with some 2400 weekly records of leakage measurements and related reservoir levels obtained during the period 1985 to 2000, in addition to construction records and copies of previous reports. The readings were analysed by plotting leakage against reservoir level for 5 year periods commencing 1985 to 1989 and adding trend lines to the plots for both north and south v-notches.

The results indicate that the bulk of the total leakage was measured at the south v-notch and that there is a direct relationship between leakage and reservoir level. Moreover, successive 5 year periods show a worsening trend confirming the data presented in Figure 3 of the paper by Dempster and Lannen and justifying the expense of repairs described in the paper. Data obtained covering the post repair period confirm that leakage at the south v-notch has returned to levels recorded in the period 1990 to 1994.

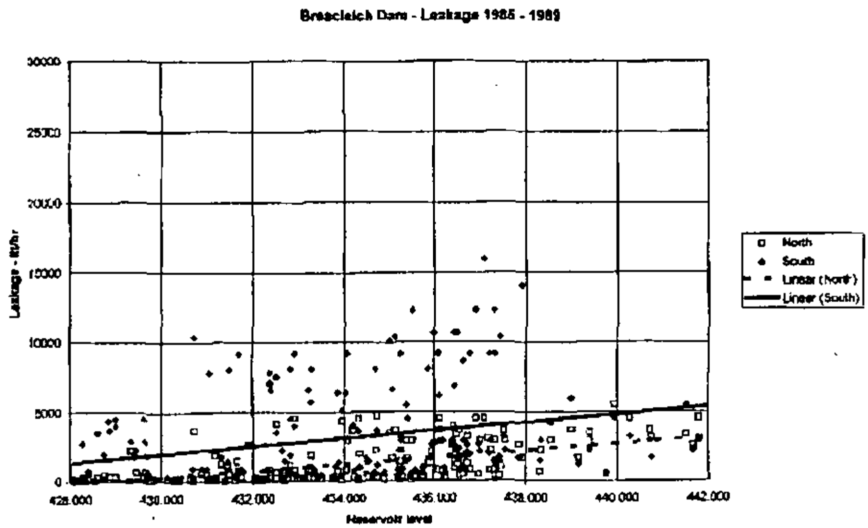


Figure 7.1 Breaclaich Dam - Leakage 1985 - 1989

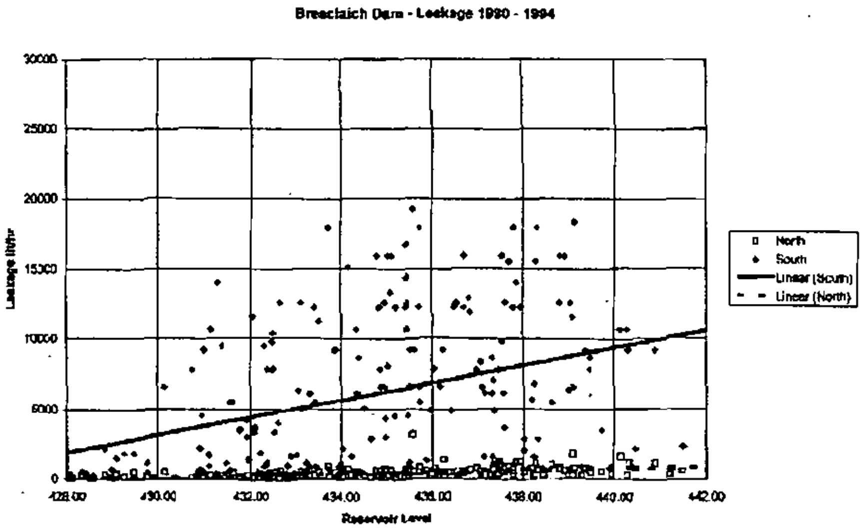


Figure 7.2 Breaclaich Dam - Leakage 1990 - 1994

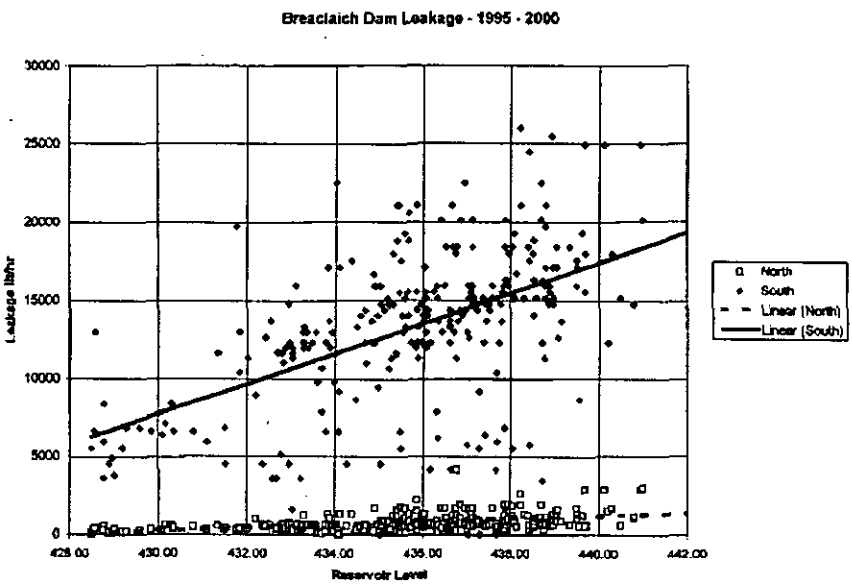


Figure 7.3 Breaclaich Dam - Leakage 1995 -2000

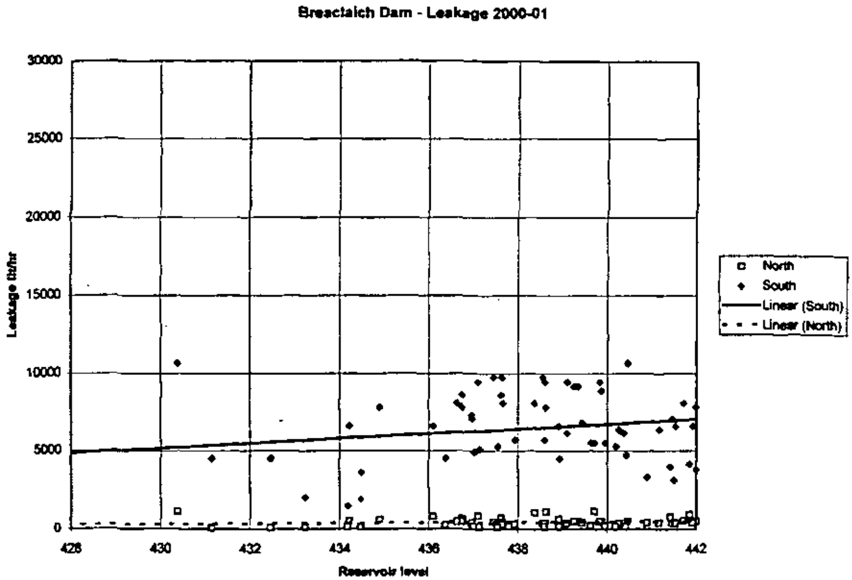


Figure 7.4 Breaclaich Dam - Leakage 2000 - 2001

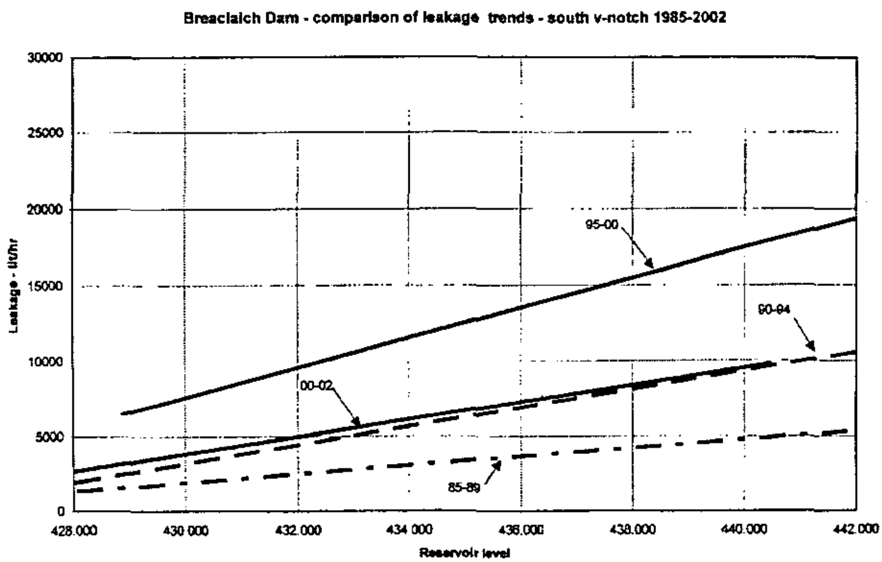


Figure 7.5
Breaclaich Dam - Comparison of leakage trends - south v-notch 1985 - 2002

Owen Williams (First Hydro Co., Edison Mission Energy)
Marchlyn Mawr Reservoir, etc.

I congratulate the authors on their excellent papers on the specialist interest subject of upstream membrane dams.

First Hydro owns and operates Dinorwig and Ffestiniog pumped-storage hydroelectric power stations in Snowdonia, (in that part of Britain designated as "other" on the BDS web-site!).

Dinorwig's top dam is Marchlyn Mawr. It is faced in asphaltic concrete and was first filled in 1981 - therefore UK's next-in-line after Winscar. News from Marchlyn is both good and bad. Good for First Hydro in that there are no apparent problems; bad for our friends at the specialist contractors in that their services are not required - yet.

For special access to Winscar and to site records at a worrying time for us and a very busy time indeed for them, I record my sincere appreciation and thanks to Jim Claydon of Yorkshire Water, his colleagues and consultants. The understanding, and reassurance, gained was most helpful. Appreciation too to Bill Carlyle and his Binnie team who worked with Winscar's designers and incorporated the early lessons into Marchlyn with success.

Surveillance at Marchlyn, however, is being stepped up:
- the unseen 75% of the face/toe-gallery joint will be mini-ROV'ed soon;
- additional monitoring of mitre and downstream seepage, inc. by temperature.

In the rapidly changing world of reservoirs and power generation, we are also:
- trialling FEH v. FSR despite the incomplete (and stalled?) debate;
- implementing CIRIA C542, inc. short-form dambreak, despite reservations on its merits compared to alternatives, as BC Hydro, still under consideration;
- adding Larinier baffles to a fish-pass weir to improve bi-directional performance;

- dealing with proposals to designate the whole Marchlyn area, inc. dam, a SSSI;
- sponsoring a PhD at Cranfield into site specific catchment modelling;
- reassessing pumping control instrumentation in accordance with IEC61508;
- continuing studies into raising dams for additional stored energy;
- operating in an extremely competitive commercial environment where fuel efficiency and environmental considerations are, for the time being, devalued.

The brochure on our five busy dams and reservoirs, prepared for BDS at Bangor in 1998, remains available free to subsequent members on request.

Discussion

Arthur Penman (Consultant)
I'd like to say something about Winscar because we were closely connected with it during its early stages. John Humphreys was the mastermind and we talked him into this idea that a rockfill dam could be better than other types of dam when use was made of modern compacted rockfill containing sufficient fines to fill potential voids between the larger pieces. The fines both reduce contact stresses and lock the larger pieces in place, producing a rigid fill. Such a dam could have a smaller volume and suffer less deflections, making it suitable for an upstream membrane. We all know about concrete membranes and that they can be cracked by small movements, but asphalt was the new thing and should certainly be suitable for this dam.

We fitted the dam with extensive instrumentation to check on movements of the face and during reservoir impoundment they were extremely small; only a few centimetres, not enough movement to cause cracking. It came as a bit of a surprise that leakage occurred. Cracks were found, as has been described by others, caused by lack of good compaction around the culvert: an example of the old problem of putting a large culvert through a dam. These were repaired by cutting out and replacing the damaged areas, but leakage was not completely cured and it has continued and steadily increased. As Jim has pointed out, upon close inspection there were found to be cracks all over the place and one is led to the question of how good are asphaltic membranes? There are other cases where cracking has developed, said to be due to ageing, brittleness and such things, so perhaps they are not very satisfactory. If we can repair Winscar by putting a geomembrane over the top of the membrane, what is wrong with using a geomembrane to start with and not have any other membrane? Who would support that idea? I think the manufacturers of the membrane claim a long life and it is immune to damage by sunlight, etc. So the argument would seem to be, build a dam for an upstream membrane to use a 2.5 mm thick liner as the permanent lining. I will welcome comments.

I might add that the use of geomembranes for dams has been accepted in France for many years. A symposium was held in 1996 and a second at Saint …tienne during June 2002. The Proceeding of this recent symposium available form the Comite Francais des Grands Barrages, gives many examples of dams built with geomembranes as their waterproof membranes, the oldest now more than 20 years old.

Chairman
Thank you Arthur. I think that we need to be around in 500 years time to see if the PCV is still working. Are there further question relating to the performance of the asphaltic membrane. Are we going to have to come back to them and repair them or do continual maintenance every 25 or 30 years?

Gabriella Vaschetti (Carpi Tech SA)
Just a comment: the 500 years life is not claimed by manufacturers but has been ascertained in laboratories by accelerated ageing tests. We would claim a fairly good amount of years, in any case more than 50 years for membranes that are always exposed, and much more than that for membranes that are not always exposed.

M Airey (Mott MacDonald)
A question for Mr Claydon regarding Winscar. At some of the more

remote reservoir locations there can be a problem with vandalism. With this in mind was the possibility of deliberate or accidental damage to the upstream membrane taken into account when assessing the long term risks associated with this solution? If the membrane were to be damaged or if a section was deliberately cut out and removed, how easy would it be to carry out repairs?

Jim Claydon (MWH)
Yes, the choice of membrane against asphaltic concrete was partially influenced by the resistance to attack. There are boats on Winscar and we are keeping them away with a series of buoys and ropes. They are the most likely cause of impact damage. You could get people lobbing lighter things on the face over the wave wall and the membrane might possibly be damaged by burning.

The advantage, a huge advantage, of the geomembrane over asphaltic concrete is that it can be repaired very easily. Patches can be welded on by hand held equipment or you can do a mechanical repair with resin anchors and just bolt a piece over the top. You can do this underwater if you have to. It does not need the mobilisation of hot asphaltic equipment to do those repairs and we have kept all the spare green material.

M Airey
A question for Mr Haugh regarding Turlough Hill. Whilst there had been an increase in leakage through the asphaltic concrete lining to the reservoir, the total loss of around 3.5 litres/sec would seem to be relatively low particularly in the context of a pumped storage scheme. Mr Airey enquired what had been the governing factor in deciding to execute repairs, and whether it was felt that the leakage had represented a potential problem with the integrity of the rockfill embankments.

Brendan Haugh (ESB International)
The 3.5 l/s was continuous leakage over a period of time. But there were isolated peaks of 7 or 8 l/s and these were deemed to be above the maximum specified 6 l/s, which was the original specification for the lining, so it was felt that the leakage was getting progressively worse and that immediate action should be taken.

Derek Knight (Consultant)
Ref: Ajdabiya Reservoir, Libya

Dr. Penman's observation, following presentation of the repair of Winscar dam, that geomembranes would appear to be a better material for an upstream face water barrier than asphaltic concrete, is a reasonable one. A geomembrane was in fact used for the upstream face and entire floor area of the huge circular Ajdabiya reservoir near Sirte (I seem to recall) for the Great Man-Made River Project in Libya involving pumping water from deep boreholes in the South of the country and piping it to the north. It will be interesting to know how that material has performed after a comparable period of time. It will certainly need to attain Turlough Hills asphaltic longevity.

Ian Carter (MWH)
In response to Arthur Penman's question, I can confirm that a number of large dams have already been constructed with a geosynthetic lining material as the principal impermeable membrane. Some of these dams have been relatively high, e.g. Bovila Dam in Albania, which is 90m high. That dam was originally designed as a CFRD but redesigned during construction with a PVC geomembrane as the watertight element.

Dam engineering is evolving continuously. Just as the days of steel and timber linings have receded into the past, I believe that the conventional membrane materials of today, i.e. traditional and asphaltic concrete, will pass into history. I expect newer, higher technology materials to take their place and I am convinced that geomembrane lined dams will become increasingly common in the future.

MWH has recently been involved in the design of two large dams in Panama. We came to the conclusion that a geomembrane lined dam would offer the best technical and economic solution for the site. We felt that a PVC lining would perform better than either a concrete deck or an asphaltic membrane. Our design incorporated a light concrete shotcrete facing above the waterline, which would protect the membrane not only from UV ageing but also from accidental and malicious damage.

We felt that we had a good design and our EPC contractor client thought so too. We were pleased that the Owner, their Engineers and Consultants gave us a positive response but saddened when the Independent Engineer appointed by the Funding Agency did not agree. Lack of sufficient precedent was cited as the prime reason for rejection and a very good design was stopped it in its tracks. I feel that an overly conservative and backward-thinking engineer won that day but I see this as only as a temporary setback for geomembrane-lined dams. Their day will come.

While our paper on Winscar Dam showed an asphaltic membrane in a poor light, I would be the first to admit that asphaltic concrete can, and does, perform excellently. The 6,000 m^3/day leaking from Winscar Dam was more than one hundred times greater than the flow passing Roadford and Marchlyn Mawr Dams. Asphaltic concrete seems to perform even better in cores than it does in membranes. At Queen's Valley Dam in Jersey the leakage through the core has fallen year on year such that it is now less than 1 m^3/day, i.e. one hundred times better than the aforementioned asphaltic membrane dams. This performance is not that different to a geomembrane. Asphalt, if used carefully, can be very effective as a watertight element. The matter just comes down to imagination, application and economics.

BRITISH DAM SOCIETY

5 September 2002

The Geoffrey Binnie Lecture

"The Challenge for British Dam Engineers"

by

Geoffrey P Sims

Geoff Sims

1940 - 2002

THE CHALLENGE FOR BRITISH DAM ENGINEERS

THE GEOFFREY BINNIE LECTURE

Geoffrey P Sims, Consultant, Brown & Root
Past Vice President, International Commission on Large Dams

3.3.5 Repair of war damage
3.3.6 Greater regulation
3.3.7 Poor operation and maintenance

4 MODERN DEVELOPMENTS IN REHABILITATION
4.1 Introduction
4.2 Rehabilitation carried out with the reservoir at operational level
4.2.1 Introduction
4.2.2 To improve the foundation drainage
4.2.3 Rehabilitation of valves and similar equipment
4.2.4 Seal the upstream face
4.2.5 Summary of lessons for working with the reservoir full
4.3 Rehabilitation of dam foundations
4.3.1 Introduction
4.3.2 Further trends from Bulletin
4.4 Include maintenance in the design
4.4.1 Introduction
4.4.2 Carhuaquero tunnel
4.4.3 Kotri barrage

5 THE BRITISH DAM SOCIETY
5.1 British Dam Society
5.2 Membership of BDS
5.3 European database of dam incidents
5.4 Archive of older construction data
5.5 Future training of dam engineers

6 CONCLUDING REMARKS

7 ACKNOLEDGEMENTS

8 REFERENCES

THE GEOFFREY BINNIE LECTURE 2002

Foreword by T A Johnston

Geoff Sims was aware that he might not deliver this year's Geoffrey Binnie Lecture and he discussed the implications with his family and some others. It was Geoff's wish, a wish shared by his family, that the lecture should be delivered.

The text was virtually complete at the time of his death. As a tribute to a fine engineer and a friend to so many dam engineers here and around the world I have undertaken the final editing of the text which is given below and the presentation of a shortened version at the BDS Conference in Dublin.

THE CHALLENGE FOR BRITISH DAM ENGINEERS

Geoffrey P Sims, Consultant, Brown & Root
Past Vice President, International Commission on Large Dams

1 INTRODUCTION

1.1 Opening remarks

I am deeply aware of the honour given to me by the British Dam Society in inviting me to give this lecture. I accepted it with some trepidation and a determination to do the job credit. I have lived in an interesting time. Too young to have worked on the Scottish hydro, I found myself with a PhD and a desire to travel, in time to contribute to the development of hydropower projects in Australia, particularly in Tasmania and New South Wales. The result is that I now have two Australian daughters and a strong affinity with that country. My own experience has been largely acquired overseas; not only in Australia, but also in Kenya and Peru and includes about equal quantities of new build, rehabilitation and management. I have been happy to be a member of the British Dam Society (BDS) since our return here from Australia, and I have certainly benefited from the shared experience and comradeship in BDS and the International Commission on Large Dams (ICOLD), particularly the European end of it. I am giving this lecture during the first meeting of BDS in Ireland. This alone gives me a great deal of pleasure. To bring together the engineers of such close geographical neighbours can only be of advantage to all of us. I have worked on the ICOLD Committees of Ageing and Rehabilitation, chairing the latter and publishing Bulletin 119 in 2001. In offering you the Binnie Lecture for 2002, I would like to take advantage of my experience over the last forty years to offer you some personal observations that seem relevant to British dam engineering as we enter the 21st century. I will draw on examples from my own project work to illustrate points I will be making.

I will be offering not only examples of project work, but also examples that reveal the importance of team working and communication. I may be one of the last Binnie Lecturers to have worked directly with the great engineer himself. In 1962 I was a junior member of the team designing elements of Mangla Dam in Pakistan. It was through his personality that I was introduced to the profession of civil engineer. Upon reflection I can see how the strands of the man's character contributed to his role as mentor to so many engineers of my generation. I can see now how important it was for him to provide confident steady leadership over a range of technical issues, many of which, particularly in the field of soil mechanics, were only just becoming accepted. I can see how his communication skills would have been tested to the full in developing his project through detailed discussion with the World Bank, the Pakistani authorities, and the other consulting firms with a range of roles. There is no doubt that he was inspirational, even to a young man like myself. But I can see too how far we have come in the last 40 years in understanding the way in which human teams work together. At the time the young Sims was toiling at his drawing board there was comparatively little thought given to what was needed to help him mature into a competent and confident civil engineer.

I have indeed been fortunate in the inspirational leaders I have worked with and learned from. Not only Geoffrey Binnie himself, but Sir William Hudson on the Snowy Mountains Scheme in Australia, Roy Coxon and Paddy Moorhead at EPD Consultants. These were formidable engineers, confident and innovative, but not necessarily renowned for their skills as team builders or indeed as technical pioneers. Professor Sir Alfred Pugsley's ability to dominate a lecture theatre while speaking at no more than a whisper is an example, teaching us about the nature of working together, of teamwork. I will refer to this aspect later, in the context of transformational and transactional leadership.

1.2 Choice of themes

1.2.1 Introduction

In introducing the three themes I propose for this lecture, let me try to describe to you my reactions to some of the challenges to dam engineers in the coming century. My train of thought starts with the recent publication of the report of the World Commission on Dams. The WCD Report has opened our senses to what others think of us, both as a profession, and as the British Dam Society. They have identified many issues, but of these I would like to select three of particular relevance to BDS. These three are

- Team working and communications
- Rehabilitation
- The future contribution of the British Dam Society.

1.2.2 Team working and communications

My first theme is the importance of communication among engineers, and with other professionals and non-technical people. This is a theme emphasised by WCD. An extension to the theme is the skill of teamwork and that of building teams. In meeting the challenges before us of dam safety, the rehabilitation of the existing stock of dams, and for the development of new projects, this becomes a skill of dominating importance. I shall illustrate my views on teamwork with reference to the Geehi River Aqueduct, giving an account of how even brilliant people can fail in certain circumstances. This is important because poor management can cost immense amounts of money.

Difficulties arise when there is poor teamwork and much of my professional life has been spent in building teams that perform better than the sum of the individual members. My experience of working in Australia has sensitised me to the issues of management and teamwork. Prime Minister Gough Whitlam responded to Australia's poor showing at the 1972 Olympics, where they won no gold medals, by setting up the sporting academies. The result has been a steady improvement in performance. Motivation was the key and it is no surprise that Australian companies are conspicuous in offering motivation skills to businessmen.

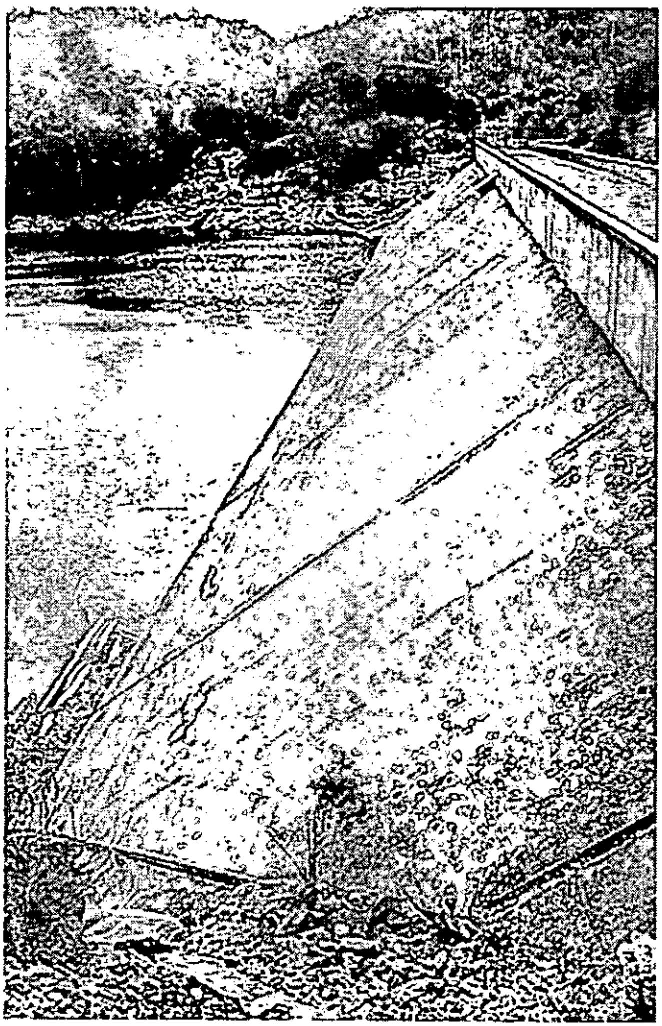


Figure 1.1 Wilmot dam 40 years later

The early 1970s were an interesting time to be working in Australia. Faced with a strong national need for hydroelectric power, water supply and irrigation there was a surge in creativity among dam engineers. The strong sense of teamwork contributed to the success of the ideas introduced. Concrete faced rockfill dams (CFRD) were among the innovations.

Wilmot Dam in Tasmania is by no means the biggest dam of this type but it was the first CFRD to be constructed by the Hydro-Electric Commission and was used as an experimental prototype (Figure 1.1). The details of the design of the plinth and the connection of the slab to it have changed little in the intervening period. Figure 1.2 shows the dam recently and shows that it has lasted pretty well.

A second major innovation was the design of the spillway for Crotty CFRD which is sufficiently flexible to be mounted on the downstream face of the fill. The savings in the cost of construction compared with a separate spillway structure can easily be imagined.

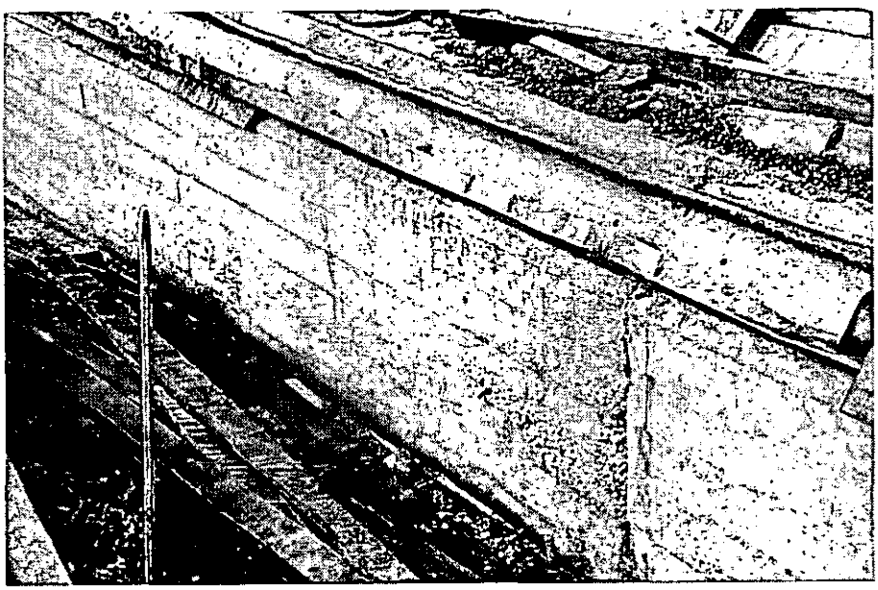


Figure 1.2 Wilmot Dam during construction - plinth at upstream toe.

1.2.3 Rehabilitation

My second theme is the need to make existing projects work better. We have a duty to make them safer and to make them earn their keep more effectively. This is at the heart of almost every technical conference on dams in the world today. Improving the efficiency of operation of existing dam projects covers not only the operation and maintenance of the projects, but also their efficient and economic rehabilitation. In a nutshell WCD says that money spent on rehabilitation and monitoring is well spent and that on the whole, worldwide, dam projects do not live up to their design predictions. Where an existing project is not looked after properly it will be difficult to persuade people living nearby that the project is worthwhile, or that a new one will be any better.

Rehabilitation of dams is likely to be the greater part of the work of British dam engineers in the foreseeable future. I take advantage of my work on the ICOLD Committee to set out my thoughts on the development of this important field. I will outline some of the more important reasons for rehabilitation including unfortunately the problems of poor maintenance and of designs that made no provision for access or maintenance. I have taken care to concentrate on the issues that most affect British dams, but I am aware that many of us still have an active interest in dam engineering overseas. I will for example refer to Kamburu dam in Kenya where the pursuit of a then unknown technical problem with concrete led almost incidentally to the realisation that there is life after alkali-silica reaction (ASR) and demonstrated the continuing importance of modern developments in rehabilitation.

1.2.4 The future work of the British Dam Society

My third and final theme follows logically from the first two. Suggestions in the fields of communication and rehabilitation lead to ideas on how BDS can facilitate the processes and I hope to explain why and to whom the proposals are important. BDS must surely comprise some of the best British civil engineering intellects to judge from our membership of the Royal Academy of Engineering. I have no doubt that it will prosper in the future.

There are undoubted opportunities for us to improve by harmonising our work as dam engineers within a European context. I will discuss the merits of a European database of incidents to dams and how it might be organised and deal also with the relevance to British dam engineering of recent developments in risk management, particularly with regard to quantification of the risk to an individual dam.

I will now look more closely at each of these three themes, hoping to demonstrate that all three are linked in a positive and constructive way.

2 TEAM WORKING AND COMMUNICATION

2.1 Introduction

The engineering of dams and their appurtenant structures requires *multidisciplinary teams of engineers and the quality of new works* and of rehabilitation projects is dependent on the broadly based skills and experience of the design teams. After setting the scene, I will describe two examples - one scheme where serious consequences followed the work of too specialised a team and another project which benefited from broadly based experienced engineering input.

2.2 Managing a design team

The two main issues in managing a team are first communicating well, both within and outside the technical field, and second using people effectively and optimally.

In commenting on the building and running of teams I draw on my experience as Chief Civil Engineer at Balfour Beatty Power Engineering Ltd. I came to appreciate the importance of each individual in the team understanding the role he can, must or should play. We have made progress in understanding how the make-up of an individual determines the limits of his contribution. Typical is the approach of Dr Meredith Belbin (Henley College) who identified nine types of individual and proposed means by which an individual and a team can know what type each member of the team is, and what role can be best allocated to him. It is important too, to understand the allowable weaknesses of each type. Gone forever are the days when all that your manager knew was your surname. Too often he appeared to have no understanding of your career aspirations, experience, weaknesses and strengths. Today's approach is intended to develop greater trust and confidence leading to transformational behaviour with measurable benefits in the performance of the team.

Modern engineering organisations tend to use what are called flat organizations in which the role of the middle manager has been substantially diminished. These circumstances require engineers who are empowered more by the force of their personality and inspirational behaviour than by a company-endorsed position. Such inspirational leaders are those who manage to leave their thumbprint on an organisation or design team. What is interesting is how they work with the design process. They have an unselfish desire for others to succeed and are able to give transactional leadership in which people receive direction where this is needed.

My central technical theme in this lecture is rehabilitation. The human aspects of effective rehabilitation and of the associated risk and portfolio management are discussed further below. Suffice to say at this stage that the importance of understanding the motivation of people as individuals, and of official departments, is not infrequently overlooked when it comes to planning or making assumptions about the quality of the operation and maintenance work that can be expected.

Managing design overseas.

So often one hears that for a project in the third world one should sub-contract the design to a designer in a third-world country. Here without doubt can be found highly intelligent engineers fully capable of mastering the technical aspects of the design process. All that has to be provided, the argument goes, is for those responsible for the design to manage the work itself. My own experience is however that there is more to it than this. There is a higher level of engineering that comprises the interpretation of data and the output of computer calculations on the one hand and the optimisation of design and the selection of the most appropriate approach to the design on the other, which requires frequent and detailed intervention. Considering the cost of expatriates living overseas, the design company may often decide to do the design work in its home office. For a multidisciplinary project such as a hydroelectric plant, the arguments for doing the work at home are stronger if anything.

However, there are projects where the balance of preference will lie with designing the project "in country", accepting that there will be a substantial contingent of expatriates. Such projects may reveal for example the difficulties faced by a foreign consultant working in a politically turbulent area where communication and teamwork may be impossible to achieve because of culture clashes.

An example of a project designed in country remote from the consultant's home was the Carhuaquero project (Figure 2.1) where the geotechnical design was complex (Rossinelli et al, 1994). El Nino was experienced and a guerrilla war caused frequent difficulties.

The organisation of the Cahuaquero design team employed positive measures to counter the difficulties of working in an unsettled area with a socially diverse team. The 125MW Hydroelectric Project is in the Andes in the north of Peru. The project was procured by ELECTROPERU through a Joint Venture of Skanska, ABB and EPD Consultants. The design for the project was carried out by a team of about 50 including some 15 expatriates. The work was characterised by the good relations between the JV partners on the one hand, and the owner and his engineer on the other. Key practical points for successful collaboration included:

- The large distance, 1000km, between the site and the design office, which reduced the temptation to make changes unless they were of real importance.
- The establishment of liaison engineers from each JV partner in the offices of the others. This led to greater understanding of design issues with a greater clarity of the status of the design and the date beyond which it was frozen.
- The careful individual management of the key local staff, building on their existing strengths.

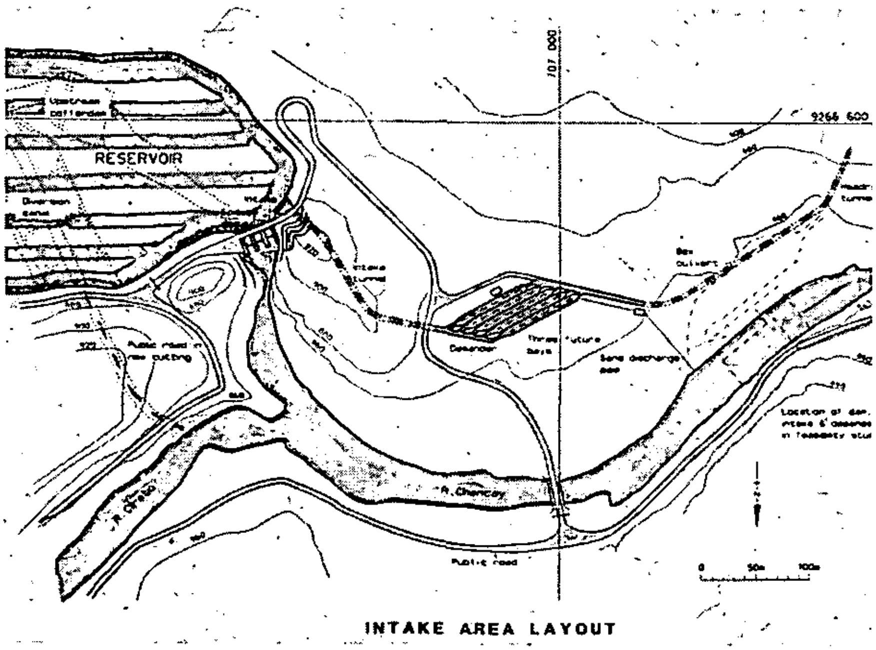


Figure 2.1 The Carthuaquero Project

- The close living of the whole design team, both expatriate and Peruvian so that the aspirations, strengths and weaknesses of each member could be fully understood.
- Routine seminars on design and construction-related issues.

This concentration on excellent communication, together with a generous approach to the training and development of the local staff proved to be successful. All who worked on the project look back on their contribution with pride.

2.3 Multidiscipline teams

2.3.1 Landslides and buried valleys

Communications are essential for the success of a multidiscipline team. Exactly what multidiscipline means can be debated, but the essence is that professionals who are able to work effectively when isolated from others are called upon to work with others outside their specialisation. An example of a multidiscipline team of particular relevance to dams and hydropower projects is one comprising engineering geologists and civil engineers. I am not alone in wishing to stress the importance of geology to civil engineering. Indeed this was the subject of Hutchinson's 4th Glossop lecture (Hutchinson, 2001).

Serious geotechnical design issues have dogged many projects arising from the failure to appreciate the existence and the extent of landslides or buried river valleys. The World Bank has drawn attention as long ago as 1985 (World Bank, 1985) to the serious consequences of not understanding the foundations of a dam with sufficient accuracy. They contrast an expenditure of less than 1% of the civil works cost on site investigation with cost overruns on the civil works of up to 84%. As may be expected the morphology of the steep, young Andean mountains reveals many and spectacular examples of landslides and of buried river valleys.

The significance of a major landslide on the Maipo River in Chile lay in it being so large that it was not appreciated that it was a landslide. From the valley it is considerably less clear than from the air as shown here. Until this was accepted, it was not possible fully to appreciate the structure of the valley in which the project was located. The debate confirmed how powerful is the simple question *'Why is the river just here?'* But it was also an issue of communication, being resolved through hard and trusting debate between experienced civil engineers and engineering geologists who were prepared to bring all their knowledge to the table while risking having their initial position shown to be wrong.

Samanalawewa dam and Lar dam are rather well known examples where lack of knowledge of the foundation has caused difficulties. Such projects in countries under conditions of heightened political tension suffer from the inability of senior managers to spend as much time on difficult technical issues as they deserve. A foreign consultant may find himself spending a disproportionate time on understanding and dealing with local political issues as he strives to establish his team and effective communication.

The intake for the Cahuaquero Project is sited in a buried valley on the Chancay River (Figure.2.2). Our detailed conventional geotechnical exploration revealed the earlier bed of the river that had been filled with lacustrine deposits. The design of the foundations of the structures was strongly affected by this knowledge.

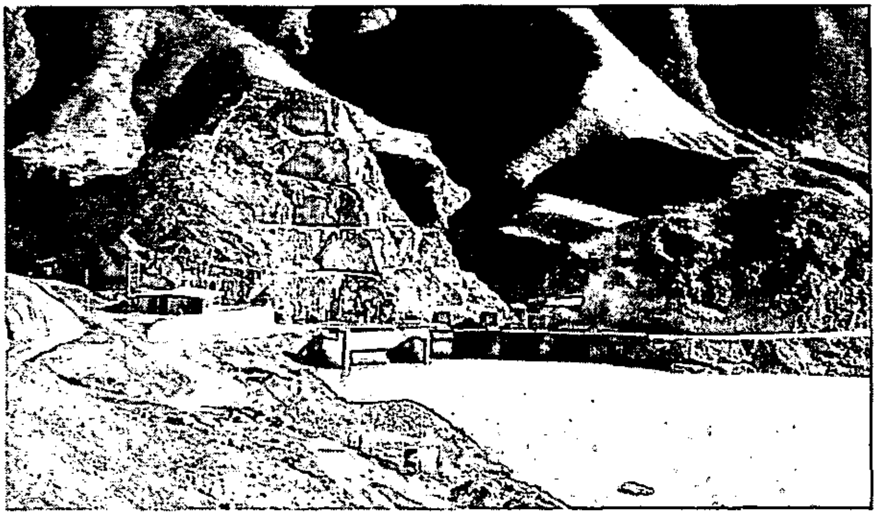


Figure 2.2 Carhuaquero buried valley.

Lake Sarez in the Pamirs in the Republic of Tajikistan is a sword of Damocles hanging over the upper reaches of the Amu Darya river (Figure.2.3). The lake was formed in 1911 by a landslide following a powerful earthquake that blocked the river at 3263m above sea level to form a lake of 17 million m^3 60km long and up to 500m deep. It is passing a substantial leakage flow and is in urgent need of detailed monitoring of its condition. The disaster of the Aral Sea downstream of Lake Sarez is a visible lesson to us all and together with that lake provides an example of the importance of good communication between civil engineers and engineering geologists. One of the world's largest inland bodies of the water, the Aral Sea has suffered a drastic reduction in volume in a few tens of years because of poor management of the flows in the Amu Darya and Syr Darya rivers (Sarsembekov, 1997). The uncertain condition of Lake Sarez together with the poverty of the region emphasises the importance of the role to be played by the engineer and his communication with others. Should this fragile dam fail, a wave 30m high would cover an area of $52km^2$ with a population of over 5 million in Tajikistan, Uzbekistan and Afghanistan. Although on the eastern borders of Europe, the resulting socio-economic impact following the failure of this natural dam would affect all of us.

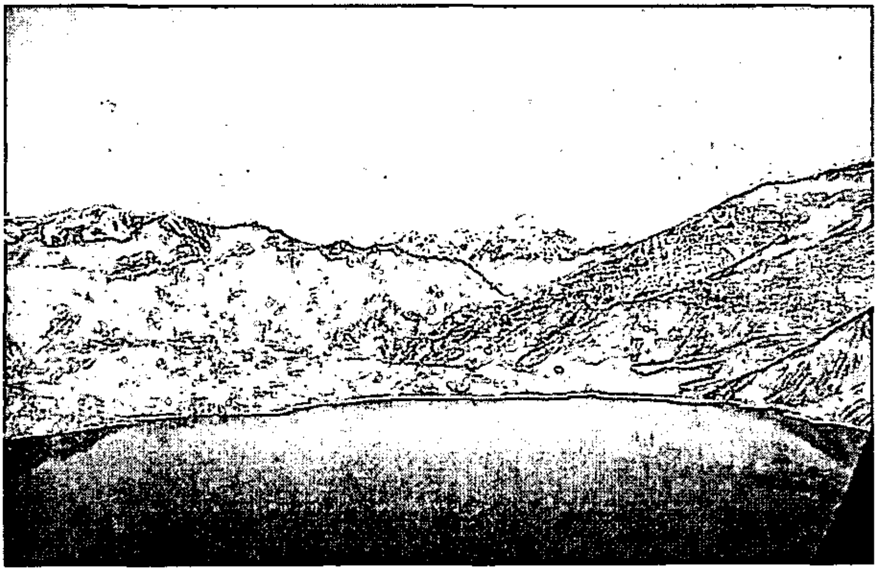


Figure 2.3 Lake Sarez

2.3.2 Failure of an aqueduct

The Geehi River Aqueduct in Australia provides an example of the failure of a rehabilitation project. The failure was one of management and was not caused by any incompetence of the highly skilled engineers involved. The specialist team was not broad enough to consider adequately all the failure possibilities. Once this shortcoming had been addressed the rehabilitation was completely successful. I am indebted to the Snowy Mountains Authority for their permission to publish this short account.

The Collapse

The buried Geehi River Aqueduct is about 15km long and up to 2m in diameter. It passes through a 2 km tunnel, and crosses five deep valleys to intercept the flow from smaller streams where the maximum static head is up to 150m. The valleys are deeply incised and of doubtful stability locally. For historical reasons the crossings are called siphons. The long-term average flow is about $3m^3/s$, making the aqueduct worth a capitalised £20 million. It is a valuable asset earning several million dollars a year in electricity generation. The original failure caused serious damage to the aqueduct route with both environmental and cost penalties for the owner.

The concrete pipes of the aqueduct failed several times often near the bottom of a siphon. The solution proposed by the specialist advising the original designer was to line the aqueduct with thin gauge stainless steel strong enough in tension comfortably to resist the internal pressure within the aqueduct at even the deepest siphon. It was believed that the concrete pipe would provide sufficient support to allow the pipes to resist net external pressure.

Within weeks, the stainless steel liner had failed over a length of 335m on the upstream limb of a siphon and the level of the lower end of the failure was 6m below the static pool level. The liner collapsed under external pressure into two or more lobes (Figure.2.4). The lower end of the damaged section was described as 'quilted', implying that it had collapsed several times and had been pushed out again by internal water pressure.

The Analysis

Following the failure the owner set up a working group under a senior director to advise on the appropriate solution. The first question was to determine the precise reasons for the collapse. If it was net external pressure, how did this come about, and why was the failure limited to one area? In assessing the cause of the failure attention was focused on:

- internal vacuum, from an as-yet unknown cause
- external pressure from water trapped in the annulus between the liner and the concrete pipe.
- aqueduct hydraulics
- fatigue failure.

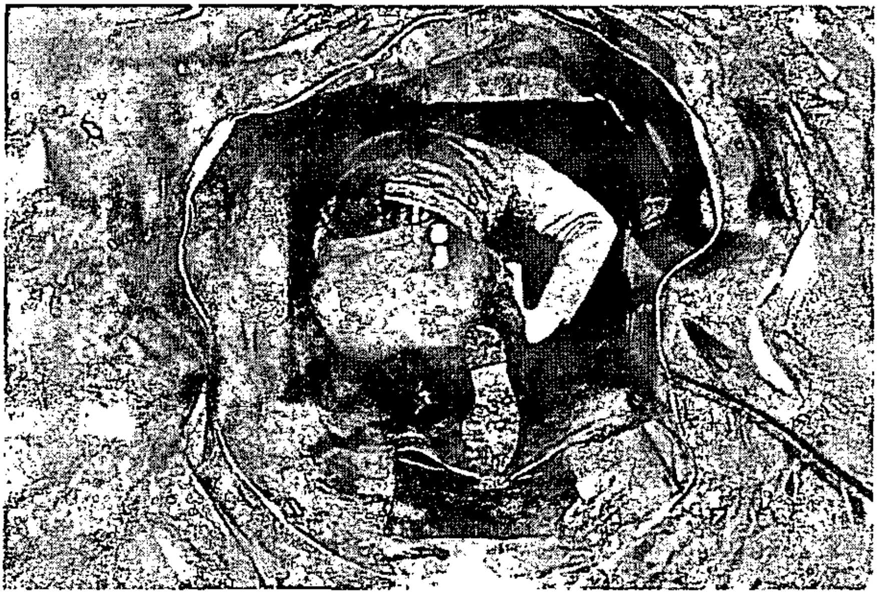


Figure 2.4 Geehi aqueduct - damaged liner.

Key to the strategy was to appoint a team of widely and disparately experienced specialists. The owner was indeed fortunate in the experience of the engineers available to him. Some of the actions taken will reveal the extent and depth of the Working Group.

A 1:8.86 scale hydraulic model was made of the damaged length of aqueduct. A mathematical model was made too. These were used to plot the surface water profile within the aqueduct and to compare this with what could be inferred from the field. The hydraulic measurements in the field and laboratory showed that the pressure within the aqueduct at the failure site on the upstream limb of the siphon fell substantially below atmospheric, by up to about 30 kPa, and that the size and location of the air vents had a profound influence on the measured pressure.

Metallurgical studies were done to confirm that the stainless steel, a chromium nickel austenitic steel, specified as grade 304, fulfilled the requirement of the Australian standard and that the welding was of appropriate quality. Importantly tests were done to determine the nature of the surfaces of cracks in the failed liner. These showed that most of the failures of the liner were caused by a relatively small number of high stress reversals, up to about ten were noted.

In considering the key variables and data for the collapse of a thin cylinder under external pressure the initial out-of-roundness, the ratio of diameter to thickness, and the distance between supports are important. The collapse pressure is not high compared with the pressures measured in the model.

The Working Group established a hypothesis for the beginning of the failure. It was made possible by the visualisation of the flow in the physical model and in the mathematical model. At certain flows a hydraulic jump occurs within the aqueduct, while the water surface is in contact with the roof of the aqueduct further upstream. This combination is the engine for the destruction of the thin liner. Air is drawn out of the unvented space above the jump reducing the pressure there. The reduced air pressure above the jump causes the liner to collapse, blocking the pipe to an extent. The air pocket shrinks, the velocity through the constricted aqueduct increases and the hydraulic jump moves downstream. The liner is damaged progressively further downstream. The damage is arrested where the flow through the constricted pipe impinges on the slower moving water downstream. Cavitation is possible in the shear layers around the separation bubbles downstream of the constriction.

The Solution

The design solution had to be robust, maintenance free and to address the defects shown to have caused its failure. The liner had to withstand a net external pressure of up to about 14kPa with a factor of safety of 4. Calculations had shown that the original 1.6mm thick liner could resist an external pressure between 2kPa and 14kPa depending on the geometry and without a factor of safety. Thus a liner thickness of about double the original at 3.25mm was used.

The Lessons

There are lessons of a strictly technical nature to be learned from the failure of the aqueduct. These have to do with the hydraulics of flow in aqueducts and are beyond the scope of what I want to say here. There is an important lesson however concerning communication and teamwork. The danger of over specialisation in the design team was vividly demonstrated. The mechanical work was done brilliantly. The stainless steel was specified well, the welding was excellent, the job well managed. But, the fundamental importance of the hydraulics within the pipe was not considered deeply enough. A balanced team, including civil engineers is best and is certainly worth the investment in the cost of the Working Group.

2.4 Communications

2.4.1 Introduction

The Report of the World Commission on Dams invites us to consider the benefit of improved communications not only with our professional colleagues, but also with non-technical people, including those affected by new projects and those who oppose dams on ideological grounds. To be effective in setting out the benefits of his schemes, the modern European engineer must communicate. I have often thought that there is a correlation between the quality of an engineer and his ability to write clearly and simply. *'But you know what I mean'*, is the cry of the second-rate. Communication includes offering our views and arguments as well as actively listening to the views of others. Jargon has its place and we must be careful to keep it there, to use it only to help us to advance the issue. Some of us use the same word to mean quite different things. For example the word control is a particular difficulty, meaning quite different things in English and Spanish.

2.4.2 Working with the opponents to dams

It appears that there have always been objections to new infrastructure projects including those concerning water. Smiles (1969) for example describes the often violent objections to both the drainage works in the Fens undertaken by Vermuyden, and also the opposition to the construction of the New River in Hertfordshire carried out by

Myddleton. It appears that where understanding is lacking opposition will follow.

We face determined and coordinated resistance to new projects and indeed pressure to decommission others from such organizations as the International Rivers Network and Friends of the Earth. Some of those who oppose our work present serious arguments (see for example McCully, 1996). Others, such as the novelist Arundhati Roy, appear to be less interested in the justification for a project such as the Narmada in India and more concerned with challenging the decision makers in an attempt to improve the decision-making process.

To be successful in supporting projects that society needs, we engineers must demonstrate and explain good practice. Where there is clearly a business and political case to be made, who else can do it better than we? This is not a task that can be comfortably dealt with by politicians or others without a sound technical base to their activities.

Lomborg (2001) raises four concerns with the activities of environmental pressure groups that all bear directly on the responsibility of technically competent people to correct them.

- Scientific research is applied to areas with many problems, giving the impression that there are more problems than is the case.
- The self-interest of the usually well-meaning people who run environmental groups. They need to be noticed. There is the temptation to exaggerate.
- The media always prefer bad news to good. The effect of El Niño on the USA between 1997 and 1998 was to cause $4bn of damage and $19bn of benefits in terms of saving lives through higher winter temperatures and other factors. The good news was reported far less than the bad.
- People tend to worry about things that are potentially spectacular and that often turn out to be of short-term importance. The reward can be a *feel-good factor* in the immediate term.

2.4.3 How to use the strengths of the opponents of dams

A subtle, perhaps political, approach might be useful to deal effectively and in the interests of society with the substantial challenge we European dam engineers face at the beginning of the millennium. As Johnston pointed out in his Binnie Lecture (Johnston, 2000), in many countries, including here in the UK, we are no longer as influential as we were when the infrastructure was being developed, nonetheless society needs us, whether it realizes it or not. It is our duty to make sure that politicians have the appropriate level of understanding of the technical information of which we are the masters. Our communication skill is especially needed in areas of high technical complexity. We are better equipped than most to provide the technically based arguments on what infrastructure society will need in the future. This is part of my third theme and I will return to it later when I suggest appropriate activities for the British Dam Society.

To be successful in arguing the case for dams we have to demonstrate environmental and social awareness, safety of operation, and excellent value for money for the projects we are dealing with. The better we do these things, and the more we can relate them to real economics and real politics, the more influential we will be.

We must be aware of and avoid the trap of the siege mentality. Sure of ourselves and of our facts, we can afford to be gracious. We must communicate to win the battle with forces opposed to the construction of new dams. The opponents are well organized, although often technically weak, but very influential. We must seek to be as well organized and ICOLD is doing its best in this regard with the appointment of a public relations expert. Many if not all of us are proud of the progress we have made in understanding and dealing with the environmental and social issues of our projects. We are determined that our projects should protect the quality of life of our fellow citizens in all respects.

Notwithstanding this, we cannot deny that some, perhaps even many projects in the past have not been well designed or constructed or operated. WCD is right to draw these projects to our attention. Acknowledging the shortcomings and demonstrating a willingness to work towards improvement gives us an opportunity to work more closely with those whose initial instincts are to oppose us.

2.4.4 Progress we have made

I am encouraged by the progress we have made in communications. The formation of the Club of European members of ICOLD, or EURCOLD is a step in the right direction. From our first meeting in Chambery in 1993 to that in Geiranger in 2001 we have steadily consolidated our understanding of each other, and of engineering in Europe.

ICOLD has a part to play in these processes of communication within the profession and it does it pretty well. After all, an Annual Meeting attended by 80 countries whose representatives all think the meeting is of sufficient quality to merit the cost cannot be that bad. European and National Symposia such as this one are positive signals that we wish to communicate. Our position papers help us to give rapid, full and helpful answers to general questions when challenged (ICOLD, 1999; ICOLD, 2000).

But we should examine seriously the possibility of working with the environmental specialists and those who oppose the development of dam projects. We should draw them into our debates; give them complimentary membership of our organizations; or invite them to lecture at meetings like this one. We share goals with them. As things stand it is too easy to find oneself isolated in a situation in which conflict is hard to avoid, precisely what the IBRD and the IUCN sought to prevent when they established the World Commission.

2.4.5 Summary

In summarising the first theme of my lecture, I offer the following key points:

Dam building is an unusual branch of engineering, requiring more extensive collaboration between specialists and experts that many other civil engineering endeavours. Team building is essential.

The full and effective use of research that helps our understanding of the way we behave as people is an essential component of team building.

Transformational leadership, in which colleagues are inspired, is just as important as the more traditional transactional leadership in which colleagues are told what to do.

Opponents of dam projects do not understand their basis sufficiently and it is our role to draw them into the debate so that all the issues are more fully understood.

3 REHABILITATION IN THE FUTURE

3.1 Introduction

The purpose of this section of the lecture is to present rehabilitation as a valid aspect of modern dam engineering with the study of ageing as one of its principal causes. A further aim is to introduce the other causes of rehabilitation to encourage discussion of their relative importance to dam engineering in the future. It may be helpful to recognise that good rehabilitation is a possible point of common interest with opponents of dams, providing a link with the earlier chapter on communication. Thus communication is relevant not only in organising the team to do the work but for keeping in touch with the local community. The WCD report emphasises the importance of rehabilitation. A link with the final part of the lecture is provided by the idea that a database will help with the prioritisation of rehabilitation, connecting the subject of rehabilitation to that of the future work of BDS. Training and professional development are needed to reduce or eliminate some of the aspects of rehabilitation, providing another link to the work of the BDS.

The challenge of rehabilitation

As Chairman of the ICOLD Committee on Rehabilitation, I have collected a reasonable amount of data and a few thoughts on the subject of rehabilitation. The challenge of rehabilitation on the worldwide stage is simply stated. There are more than 45,000 large dams in the world. In 1950 there were 20,000. This means that there are now at least 20,000 dams in the world that are more than 50 years old. Some 70% of British dams under the Reservoirs Act 1975 are more than 50 years old and of these 517 are within the ICOLD definition (Tedd et al, 2000). The importance of the subject is well represented by the percentage of asset worth spent annually on maintenance, reckoned by one British water company at 2.5%, a figure confirmed by the Water Authority of Western Australia. This is big business.

Naturally in this lecture I will make particular reference to rehabilitation in Britain, but not exclusively because British engineers are interested in dams overseas. Some 20% of the references in ICOLD's Bulletin 119 were either about British dams, or by British engineers about foreign dams.

3.2 Rehabilitation as a means of communication with opponents

The World Commission on Dams has now presented its report and we should consider the implications of its recommendations on rehabilitation, particularly on the management rehabilitation. WCD indicate that additional money spent on maintenance and performance monitoring is well spent, and that, on the whole, dam projects do not live up to their design predictions. Many members of the British Dam Society have worked with teams that have identified new dams that will be needed to improve the future supply of water either in this country or overseas. You will probably have come across people, potentially voluble, influential, and well funded who have to be convinced that a dam is the best available solution. The linkage between the management and quality of the maintenance on the one hand and the acceptance of a new dam project on the other is one that the WCD have identified as vital. As I have explained earlier in the lecture, this communication with largely non-technical people is an aspect of the dam engineer's work that, although important now, can only become more so in the future.

Where an existing project is not maintained properly it will not produce the water that was intended, some would say promised, by the designer. It will be difficult to persuade people living nearby that the project is worthwhile or that a new one will be any better. There may be an issue of safety or of the loss of supply of water or power. There probably will be one of inefficient use of funds. In some countries, particularly in the developing world, there may be an issue of regional instability in the sense that lack of water may provoke hostilities.

Both Pircher (1992) and Van Roebbroek (1996) in their Binnie Lectures have referred to this danger.

Jimmy Hoffa, American Teamsters Union leader from 1957 to 1971 is credited with saying that maintenance is the difference between a successful country and one that fails. He therefore supports my belief that a well-maintained project, doing efficiently what it was designed to do will be welcomed by all elements of society. This holds true, although perhaps to a lesser degree, to those who would initially have opposed the project. So I believe that good maintenance is a useful link between those who oppose dams, and those, the engineers, responsible for them

If this is true, it is difficult to understand why so many owners, particularly in the developing world, refuse to commit to a sensible Operation and Maintenance programme. This is a puzzling psychological blockage of some magnitude. Certainly, good O & M is costly and the recommendations of the WCD will make it more so. But money is not the only issue. There is an opportunity here to invoke some of the principles I have discussed earlier in this lecture, in connection with motivation and teamwork, to improve the overall quality of maintenance of dams.

3.3 Reasons for Rehabilitation

3.3.1 Introduction

In addition to the fundamental requirement for rehabilitation to improve the level of safety, there is a commercial requirement for the rehabilitation to be viable from the economic point of view. The engineer as a businessman must understand and be able to explain, to communicate, the value of the dam in terms of its operating costs and the benefits to be derived from its operation.

British dam engineers are likely to find that their work contains an increasing proportion of rehabilitation work. This will probably apply to work within the UK as well as that abroad. ICOLD Bulletin 119 on rehabilitation draws attention to the several reasons for a dam to need rehabilitation and these are described briefly below. Broadly these can be divided into those that are influenced in some way by inadequate human intervention, and those that are not.

3.3.2 Ageing

Ageing is a major class of deterioration in dams and appurtenant works which will be a matter of increasing concern as time goes by. ICOLD Bulletin 93 Ageing of dams and appurtenant works (ICOLD, 1994) seeks to describe the major ageing phenomena, to indicate appropriate methods for their detection, investigation and evaluation. It also suggests appropriate simple remedial measures. The Committee identified 31 scenarios to describe the ageing processes affecting embankment dams, concrete and masonry dams and appurtenant works. This is not the place to go into detail; suffice it to say that the major drivers of deterioration in an ageing context are:

- Decay through weathering and the passage of seepage water
- The effect of repeated and static deformation
- Erosion and solution hydrodynamic effects including scour, abrasion and cavitation
- Loss of serviceability after prolonged operation.

I have already mentioned the 20,000 dams that are more than 50 years old. Worldwide, dams are being constructed at the rate of more than 1 per day.

3.3.3 Poor design and construction

Poor design and construction can accelerate the ageing process and are fertile sources of problems. Two anonymous Indian masonry dams, built about 100km apart, illustrate the point. The younger, dating from the 1980's, was built about forty years after the older one.

The younger dam is obviously in poor condition (Figure. 3.1). It is seeping badly, the masonry is disintegrating, and the spillway gates are reluctant in their operation. The older is still in first class condition (Figure 3.2). The following table summarises some selected design data and shows the similarity in the approach to the design.

	Older dam (1940s)	Younger dam (1980s)
Grout curtain	3 rows, 40% of height	3 rows, 40% of height
Hearting mortar mix	1:1:3 to 1:1:5 cement: lime: sand	1:4 and 1:5 cement: sand
Impervious zone mortar	2:1:6	1:3
Seepage	zero	>25 l/min

Table 3.1 Comparison of Design of Two Dams

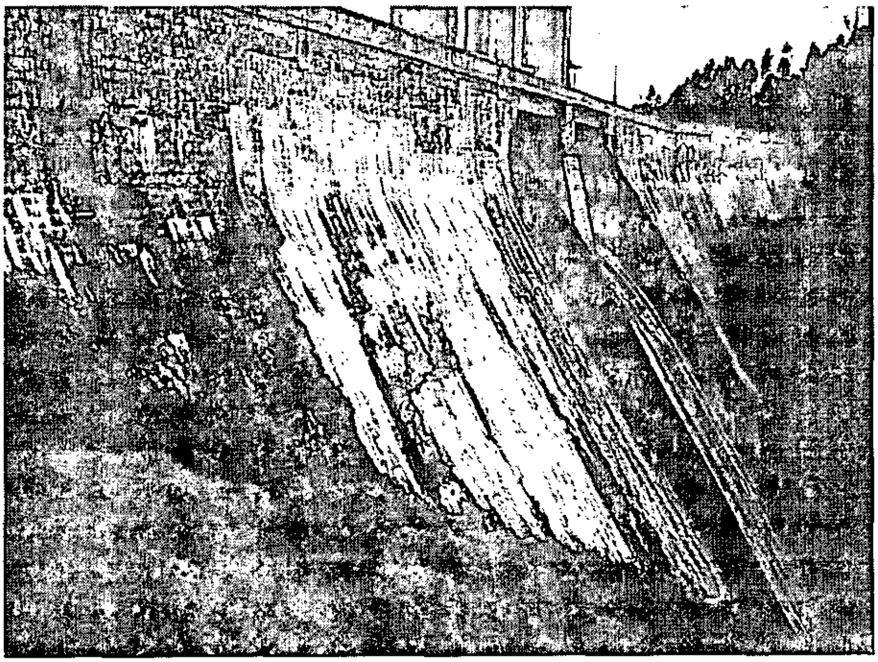


Figure 3.1 Masonry dam built in the 1980s.

The two dams give a snapshot of the development of masonry dams over the last century. A more detailed discussion is found in Sims(1994). The younger dam contains no lime in the mortar mix; the cementitious material is entirely cement. Cement was an expensive commodity early in the twentieth century when it was common practice to use lime, and for large stones to be introduced into the concrete, not only to give a better shear resistance across the lift joints, but also to reduce the volume of cement needed. It became clear before the middle of the century, even in the third world, that the price of concrete using cement was lower than the cost of masonry with its high labour input. In more advanced countries, among which I include

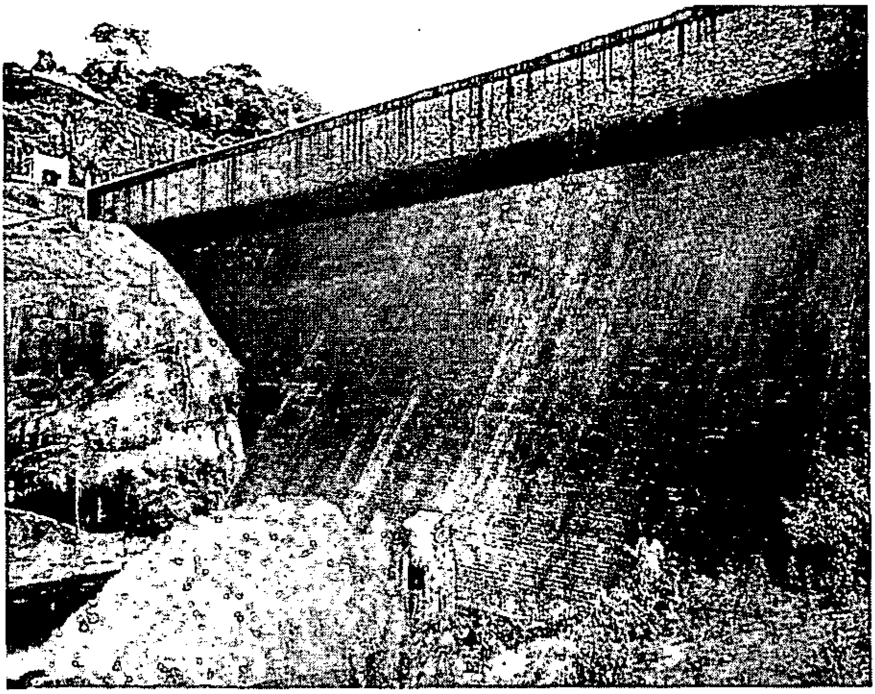


Figure 3.2 Masonry dam built in the 1940s.

the UK, concrete dams were being designed in the 1950s with an awareness of the need for durability to be achieved through a low water/cement ratio and the use of air entrainment. However, these two dams show rather surprisingly that the younger dam, with all the advantages including the availability of better design techniques and the use of cement, is outperformed by the older one, and by a large margin. Clearly there is another factor in play and it is likely to be the quality of the design and construction. It appears that the designers of the younger dam did not have the same understanding of the key parameters as the engineers of the earlier generation. This comparison demonstrates that successful dam engineering depends upon a thorough understanding of the physics and chemistry involved and this is not always available to the hard-pressed organisation tasked with providing the dam. There is a clear link here with the development of teamwork I discussed earlier in this lecture.

Such comparative analysis as I have referred to above is greatly simplified when access is available to a database of incidents. This would initially be on a national basis but could well develop internationally. Also valuable is an accessible record of photographs and written material of older dams.

The purpose is to keep fresh the details of design and construction of the structure for those tasked with rehabilitation. As I will discuss further below, it is my recommendation that the British Dam Society should support both these initiatives and should consider whether it should have a role in the collections.

3.3.4 Advancing knowledge

Improved estimation of the effect and magnitude of earthquakes and floods are examples of our advancing knowledge. Similarly we know more about uplift. Despite the insight of Deacon and Hawksley (Deacon, 1895) during the design of the Vyrnwy dam at the end of the nineteenth century, even fifty years ago as a profession we grudgingly accepted that this is one of the fundamental forces to be considered in design. It was not until the 1950s for example that the USBR clearly advocated that designers take this pressure into account over the entire foundation surface. Leliavsky in 1958 wrote that uplift was something that could not be altogether neglected. There are scores of masonry dams in Europe and elsewhere, designed without taking it fully into account. The situation in Britain however seems to have been better, providing us with a smaller problem in this regard. For example, James Mansergh, working on the Elan Valley Schemes at the beginning of the twentieth century, much the same time as Deacon and Hawksley were working on Vyrnwy, provided each of the four masonry dams, Caban Coch, Craig Goch, Pen-y-Gareg and Dol-y-Mynach with galleries from which drains were used to penetrate the foundation. Blackbrook has a formal system of relief drains. Derwent and Howden dams appear to be unusual among British dams without such provision. However, the issue seems to have been well considered because a detailed arithmetic check at a recent inspection showed appropriate factors of safety.

There are two ways of achieving the necessary stability for a gravity dam that has proved to have inadequate downforce. The first is to decrease the uplift by the installation of drains, the larger the better.

The second is to apply additional downforce directly. Many of those dams designed without an adequate allowance for uplift have been imaginatively rehabilitated either by improved drainage, or by the addition of vertical force.

An excellent example of the first approach is the rehabilitation of Ennepe dam in Germany. This masonry gravity dam is 50m tall and is not unlike some of our dams in Britain. The rehabilitation work (Rissler et al 1999) illustrates both the need to rehabilitate a dam so that it meets current national design standards and also the skill required to do the work without wasting stored water. About 100 years old and designed according to the rules of Prof Intze, the dam had insufficient allowance for the uplift pressure in respect of the modern German design code. The rehabilitation works include a 3.0m drainage gallery, which was excavated at the base of the dam, some 3.5m from the reservoir face. The gallery was unlined and located at the contact between the masonry of the dam and the foundation rock (Figure. 3.3).

At first it was intended to excavate the tunnel by blasting but this proposal was superseded by the use of a 3.0m dia. full-face tunnel boring machine (TBM) (Figure 3.4). The adopted approach was developed in collaboration with the contractor. The TBM entered the ground through a portal 30m downstream of the dam. From there the machine accessed the foundation of the dam through a 90-degree curve with a 40m radius. Such a tight radius was possible because of the specific design of the TBM.

An alternative approach has been followed in rehabilitating some of the masonry gravity dams in Western Australia. Both Canning dam and Harvey Weir have been fitted with large post-tensioned anchors. The need for continuing maintenance of the large anchors and the importance of precision of measurement will play a large part in comparing the attractiveness of each alternative. This is not to say that drains do not need maintenance, but it is generally of a simpler nature.

3.3.5 Repair of war damage

The deliberate destruction of a dam during war is not an easy subject. The dilemma is particularly acute if the failure of the dam will obviously threaten the lives of many people. The best known to a British audience are the Moehne, Eder and Sorpe dams in the Ruhr. At Moehne Dam there was an obvious need for immediate repairs following the bombing and the damage was repaired in 4 months (Figure. 3.5). There is also a requirement to repair damage that has a longer-term effect. Sorpe is an embankment dam and the dam did not fail, but recently the impermeable element within the structure has been repaired, some 60 years after the damage was done.

Peruca embankment dam in Croatia was damaged by land forces who placed bombs within the inspection galleries. The remedial work was intended to repair the damage. It is too early yet to know whether the bombs have damaged to dam in such a way that rehabilitation will be needed within a few decades.

3.3.6 Greater regulation

In the US the cost to manufacturers of legal claims has reached 3.5% of the GDP and is rising sharply in relation to GDP. Although the proportion may be lower in Europe, it can only be a matter of time before the American practices become normal in Europe (Booker et al, 2001). One of the consequences of the world becoming more litigious may be an increase in prescriptive national regulations relating to design, construction and maintenance. I shall return to the question whether there is benefit in EURCOLD working towards a model set of regulations, meeting the minimum needs of all European countries. For the last ten years the likelihood of European legislation has been consistently denied by those with knowledge of the workings of the European Community. But we should stay on guard because of the important differences in approach to dam safety we have compared with other countries of the Union. Our own approach, embodied in the Reservoirs Act 1975, depends heavily on the individual competence of Panel Engineers. Increasingly elsewhere there are regulations that involve panels of engineers to work together. This implies the dilution of the individual responsibility I have mentioned in connection with our own system. At the very least we need to maintain vigilance over

Figure 3.3 Ennepe dam, drainage gallery.

the quality of our Panel Engineers. The continuing importance of Continuing Professional Development in a world in which our engineers have fewer opportunities to practice on large-scale projects cannot be underestimated. I will refer later to the role that BDS can and does play with regard to the technical training of our engineers.

3.3.7 Poor operation and maintenance

The World Commission on Dams provides data in support of berating owners for not maintaining dam projects better. Their report shows that for irrigation schemes ten years after construction, the best-fit line represents an output less than 75% of the planned figure. Poor performance is most noticeable during the earlier life of the project as the average achievement of irrigated area projects rises from around 70% in year 5 to nearly 100% in year 30. The WCD say that hydro projects perform a little better but that water supply projects are worse. In my experience it is in the developing world where the problem of

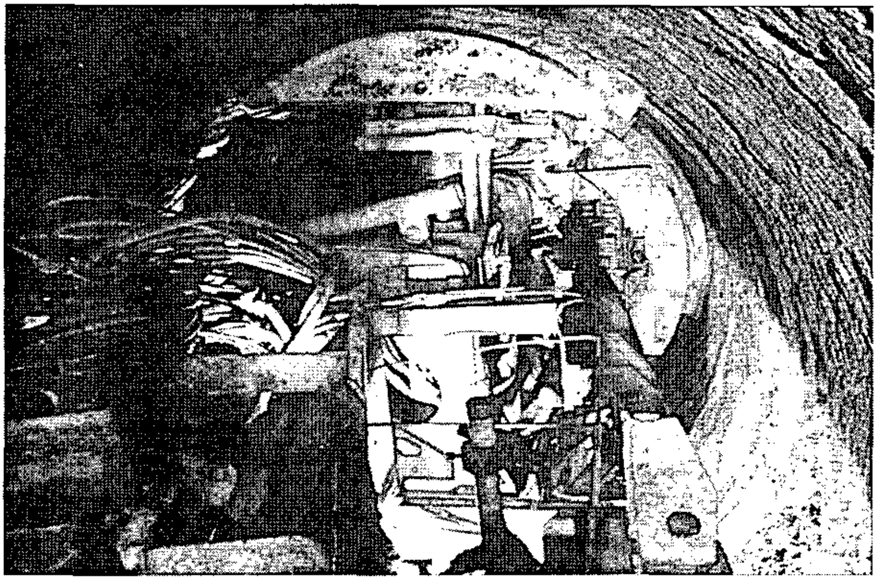


Figure 3.4 Ennepe dam tunnel boring machine.

poor operation is most serious, not only because of the loss of production that results from poor operational management, but the large proportion of the GDP this can represent for a small country. Too often the problem is made worse because the operational function is not supported by management.

Poor operation and maintenance are potent sources of rehabilitation in the third world. In addition designers have often not made provision for operation and maintenance tasks, a theme I shall return to. In relation to the poor performance of existing projects, WCD urges us to:

- improve the efficiency of output of existing projects, acknowledging that operation and maintenance will cost more,
- monitor the performance and behaviour of existing projects on a regular basis.

The linkage of this exhortation to the development of a database of incidents is clear.

It is sometimes overlooked that the level of instrumentation appropriate

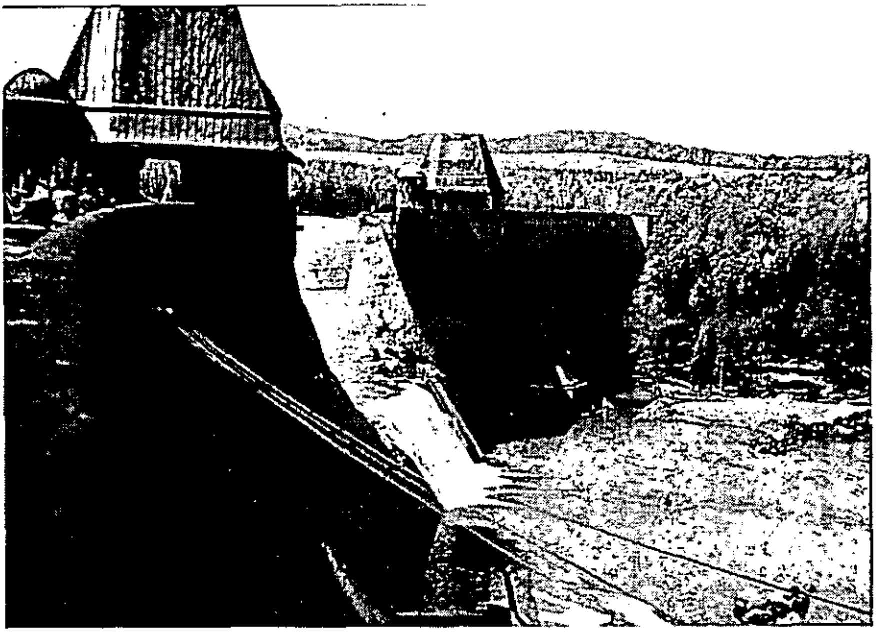


Figure 3.5 Moehne dam, 1943, after bomb damage.

for the monitoring of construction of a dam may be altogether excessive for the monitoring of the dam after the first five years of its life. Inappropriate monitoring can contribute to the demoralisation of the O&M team.

I note in passing that Owners have a particular responsibility in the modern age where consultants now have to compete, usually on price. I shall refer later to the example of experiments carried out at La Girotte dam in France where the owner EDF is unique in having access to all the experimental data. It is much less common now for a consulting firm to maintain the detailed involvement over the years necessary to consolidate knowledge of a given structure.

4 MODERN DEVELOPMENTS IN REHABILITATION

4.1 Introduction

The purpose of this section is, through reference to ICOLD Bulletin 119 on the rehabilitation of dams and appurtenant structures, to show where the state of the art lies, and where the major developments in rehabilitation are to be found.

4.2 Rehabilitation carried out with the reservoir at operational level

4.2.1 Introduction

In writing the bulletin we were struck by the imagination of rehabilitation works done with the reservoir full. There appear to be three types of major rehabilitation works for which the owner will consider the practical implications and economics of emptying the reservoir. They are to improve or replace:

- foundation drainage
- ageing valves, gates and pipes
- the watertightness of the upstream face.

The monetary value of water stored in a reservoir has long been appreciated and the loss of use of the stored water may well represent a significant sum. For example, a million m^3 of water held in a reservoir might well be considered to be worth several hundred thousand pounds, a significant percentage no doubt of the total cost of the rehabilitation. Too often as well, there are practical difficulties in actually lowering the water level and in gaining safe access to the work place. For these reasons attention is being given increasingly to the practicability of undertaking major rehabilitation works with the reservoir full.

4.2.2 To improve the foundation drainage

I have already mentioned the spectacular works at Ennepe dam to provide a drainage tunnel close to the water face of the dam. However, not every dam is built on rock of sufficient quality to allow a 3m tunnel to be excavated under 50m head within 3m of the reservoir water body itself and recent advances in directional drilling techniques can be of value in improving the speed, safety and cost of this sort of work, particularly where man-sized access is not needed. At least some of the impetus for developing directional drilling techniques comes from the offshore oil industry. Recent reports (NCE, 2002) refer to sub horizontal holes up to 1.06m in diameter, 400m long being drilled within a tolerance of 300mm over 400m. In such holes the pilot hole progressed at 2.5m/h in granite and the subsequent reaming progressed at about 1m/h.

4.2.3 Rehabilitation of valves and similar equipment

The ICOLD conference proceedings contain an increasing number of detailed reports of replacing valves underwater. Ladybower dam in the UK (Shephard, 2002) and Moehne dam in Germany illustrate the trends well. As was so often the case, the original designers did not provide a safe means of isolating the devices to be rehabilitated even though it must have been clear that the life span of gates and valves is far less than the concrete or masonry structures in which they are embedded. A common characteristic of their rehabilitation is the need for a thoroughly detailed plan of work, usually in three major stages. The initial physical mapping, often made more difficult by the turbidity of the water, is followed by a plan to hold the water back using a stopper of some kind. Finally the temporary work must be safely removed once the work has been done.

Recently Severn Trent Water has replaced sixteen 50 year old cast iron outlet valves in the valve towers at Ladybower dam (Figure 4.1). I am indebted to them and to Babtie for the information on the work. For operational reasons it was not acceptable to empty the reservoir and underwater working was therefore required. The 40m depth of water imposed a 30-minute duration on each diving activity.

Specifically designed and manufactured temporary inflatable mechanical stoppers were introduced into each of the draw off pipes. Divers had earlier entered the 120m long conduit upstream of the valve to measure the site for their installation. The measurement was made more difficult in the horseshoe-shaped conduit whose 1400mm height was often substantially reduced by sediments up to 500mm thick. Visibility was poor, hence the absence of a photograph. Speaking as one who has done a confined spaces awareness course, I can only admire the bravery of the people who made this swim and wonder at the detailed planning required to keep it safe.

The stopper was installed and removed using a remotely operated vehicle (ROV) (Figure 4.2). The ROV had two cameras, a colour and a silicon intensified target (SIT) camera for use where there was little

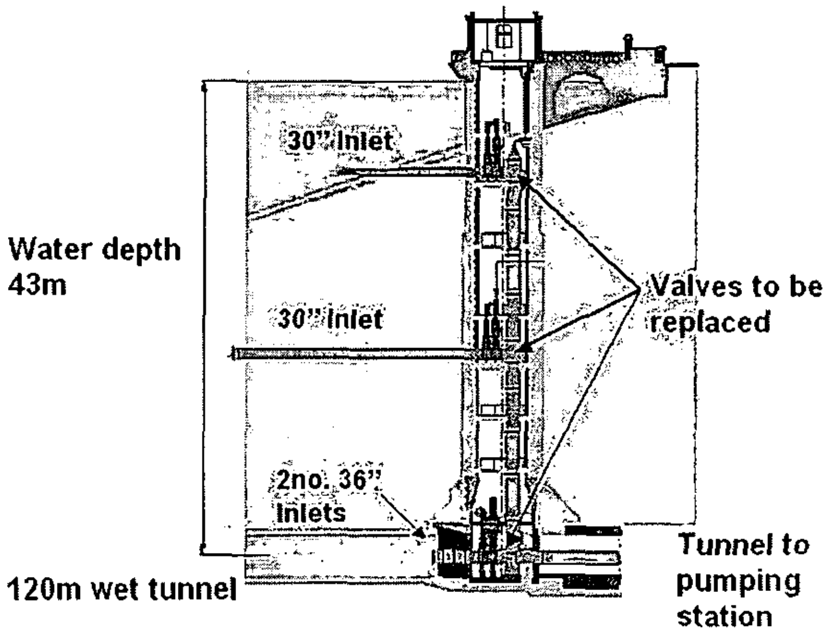


Figure 4.1 Ladybower dam, valve tower

light. Visual confirmation of the successful latching of the stopper was difficult. To overcome this the ROV was fitted with a hose through which clean water was pumped in front of the cameras. Once it was in place and holding back the water pressure, the condition of the stopper was continuously monitored to ensure that the internal pressure was adequate.

An alternative approach at Moehne dam has been described by Campen et al (1994) and Rissler (1998) (Figure 4.3). They took the opportunity to line the four bottom outlets with steel.

A temporary bulkhead gate was fitted to the upstream end of the liner, allowing the ageing valves to be removed and the new ones installed. The steel liners were installed and backfilled with concrete by divers working under a depth of 35m. The specialist divers were heavily involved with the design of their equipment and the planning of the work. They used a steel pipe 9m long below their barge to leave the water. The pipe was maintained dry with compressed air and the

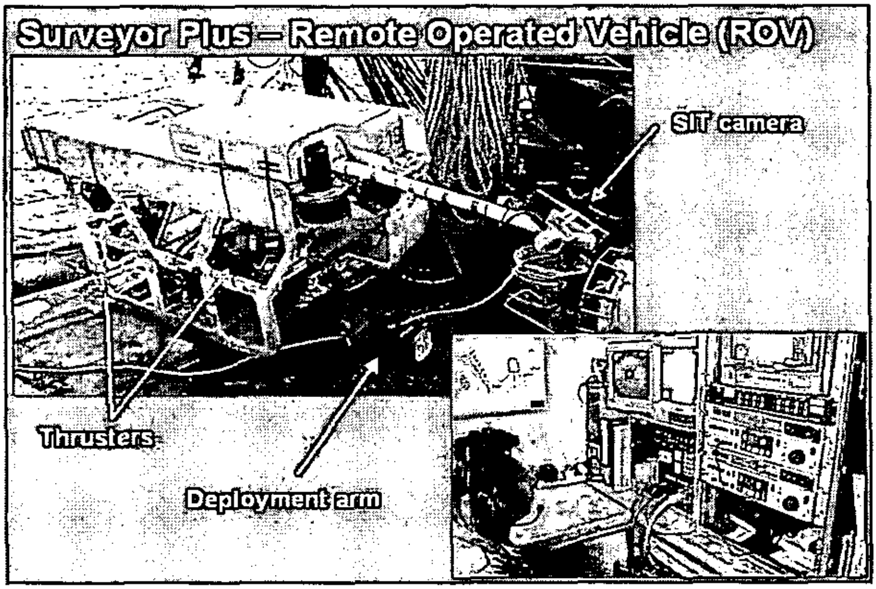


Figure 4.2 Ladybower dam, remote control vehicle.

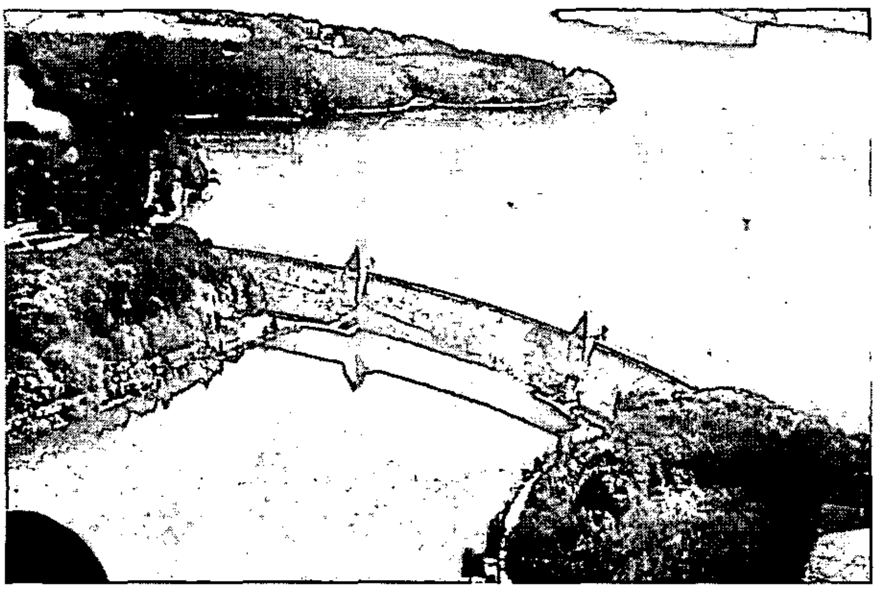


Figure 4.3 Moehne dam, aerial view.

divers used an elevator to reach the pressure lock leading to the decompression chamber. An emergency pressure chamber was provided that could transfer a patient to hospital within 30 minutes.

4.2.4 Seal the upstream face

A third justification for seeking to lower the reservoir level during rehabilitation is to seal the upstream face of the dam. It may safely be asserted that the primary cause of degradation of all types of dam is the seepage of water through the dam. ICOLD's Bulletin 93 on the ageing of dams and appurtenant works shows that of the 11 major ageing scenarios identified for concrete and masonry dams, 7 are driven by or exacerbated by the seepage through the dam. For embankment dams 7 of the 14 scenarios are driven by seepage. Thus, of the total of 31 scenarios ICOLD has identified for the ageing of all types of dams and appurtenant works, some 14, or nearly half, are driven by the effect of seepage water. The difference in appearance and in performance of the two dams shown on figures 3.1 and 3.2 is largely due to the effect of seepage.

Some of the effects of seepage are interesting. As an example of many, alkali silica reaction is a chemical process that needs a continuous supply of water for it to continue. Hence a feature of successful treatment of ASR is to apply a watertight membrane over the face of the dam. Kamburu Dam in Kenya experienced *popouts*, a typical expression of the reaction (Figure 4.5) and the spectacular cracking sometimes associated with this reaction (Figure. 4.6). Table 4.1 confirms that despite appearances, the strength of the concrete remains surprisingly high.

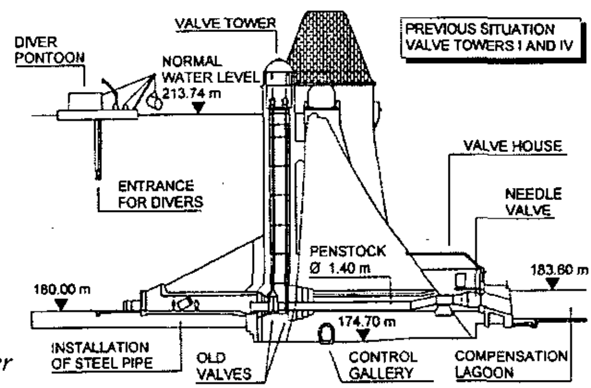


Figure 4.4 Moehne dam, cross section of valve tower

Figure 4.5 Kambura dam, concrete popout.

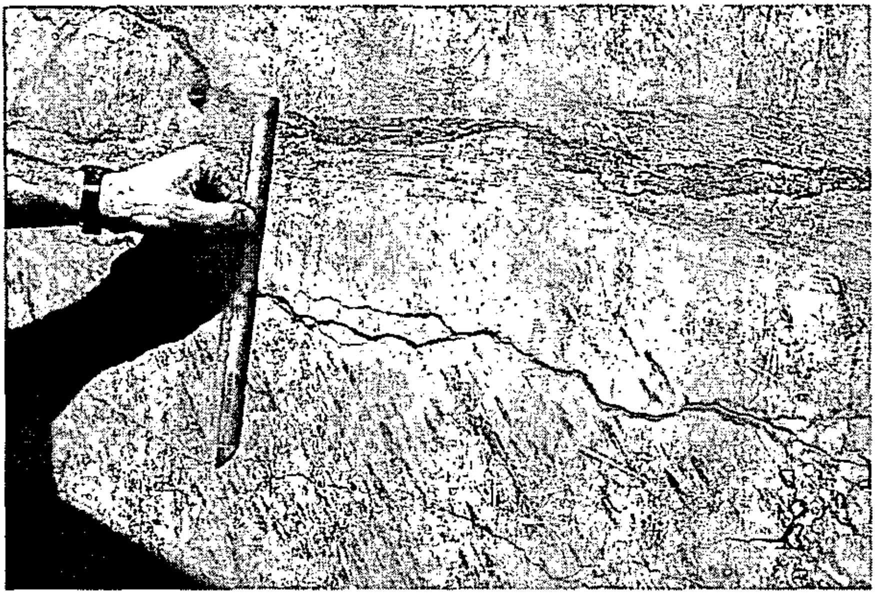


Figure 4.6 Kambura dam, concrete cracking.

	Percentage of unaffected concrete strength for expansions of:		
Property	0.5mm/m	2.5mm/m	10.0mm/m
Uniaxial compression	95	80	70
Flexural tension	75	70	-
Elastic modulus	100	50	30

Table 4.1 Residual Mechanical properties of ASR-affected concrete (ISE, 1992)

La Girotte Dam is a 18-vault multiple arch dam in the French Alps 1753m above sea level (Figure. 4.7). We are indebted to Electricite de France who, since the early 1950s have been experimenting at La Girotte on a wide range of products designed to provide an impermeable upstream face to the dam (Bister et al, 1993). The concrete was suffering badly from the effects of freezing and thawing and the abrasive action of the ice on the lake. The pH of the water in the lake is 4. They have tried a wide range of products, from covering individual cracks to linings of specially formulated paint. In more recent years EDF have experimented with a pvc membrane which has shown more encouraging results than the earlier materials they have trialled.

A geomembrane has been installed at Illsee dam in Switzerland, a 36m high concrete arch gravity dam 76 years old with a rough masonry face (Figure. 4.8). Three main materials are used in the modern installation of such a lining, an impervious pvc membrane, a relatively thick geotextile providing protection against puncture and a drainage mesh against the dam surface. Such a design is capable of resisting a pressure of up to about 200m of water.

Recent advances supported by extensive laboratory and field testing have allowed the complete application of a pvc geomembrane underwater. Harlan et al (1998) have described the apparently successful work at Lost Creek dam in the United States. This appears to be a landmark development and we await with interest the reports of its performance.

4.2.5 Summary of lessons for working with the reservoir full

This brief account of the effect and control of seepage through the upstream face of a dam, culminating in the installation under water of a waterproof membrane, can be considered together with the two European examples of replacing valves, without emptying the reservoir. These, and the case studies reported in Bulletin 119 surely represent the current state of the art and suggest the following tentative lessons have already been learned from working under water.

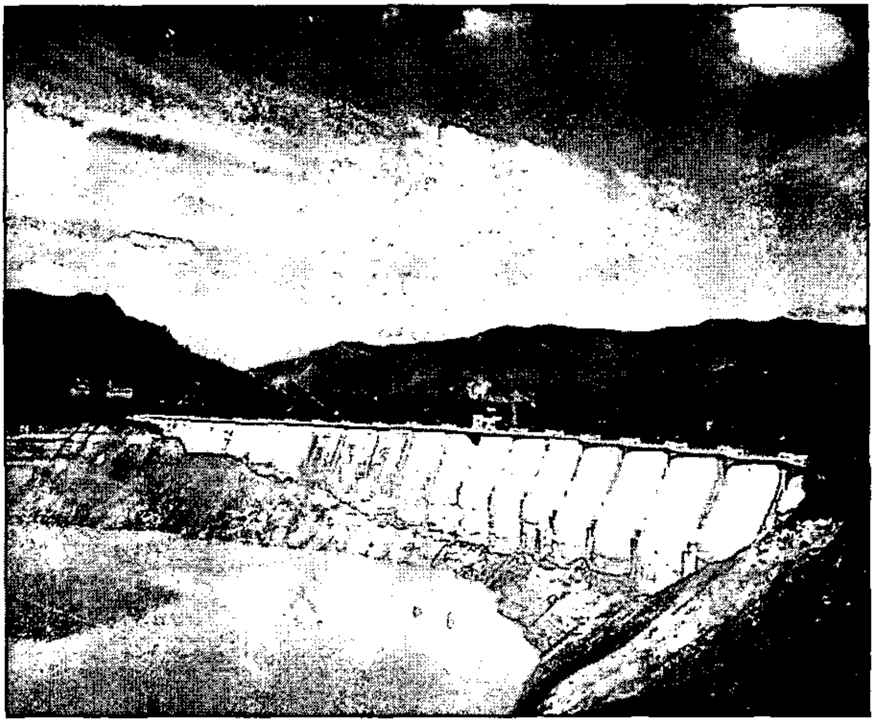


Figure 4.7 La Girotte dam

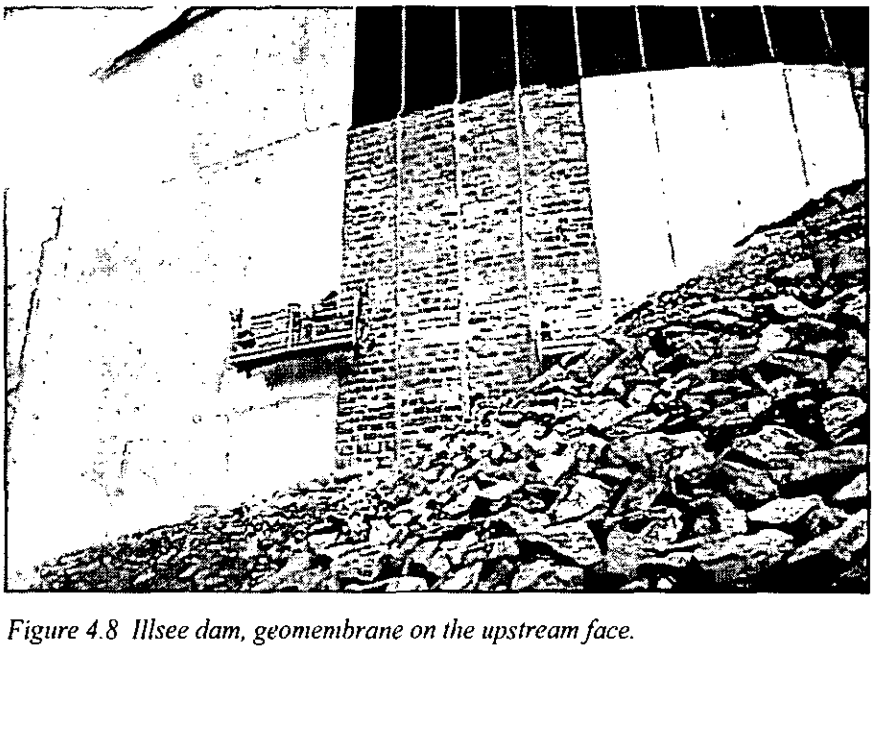


Figure 4.8 Illsee dam, geomembrane on the upstream face.

- The work must be planned in extreme detail, involving a specialist contractor early in the detailed debate between the designer and the owner.

- Diving is dangerous and the safety of the workforce is paramount. As a result the underwater working component can amount to 30% of the cost of the rehabilitation

- Diving technology derived from the oil industry will probably be cost effective

The development of successful underwater working will be helped by research into the design and use of robots including those used in directional drilling. Improved technology for repairing concrete underwater will also be valuable.

4.3 Rehabilitation of dam foundations

4.3.1 Introduction

The ICOLD Bulletin 119 has revealed in some measure the current state of the art with regard to the rehabilitation of the foundations of dams. It appears that many problems, particularly with dams designed before the middle of the last century, can be attributed to a poor understanding of the significance of the geotechnical situation below the dam. Figure 4.9 illustrates the point. Phewa dam in Nepal failed in about 1966, quite possibly as a result of a lack of understanding of the nature of the foundation (Figure. 4.9). As explained by Coxon et al (1983) both the original dam that had failed, and its successor were sited across the boundary between the original phyllite country rock and a much younger and weaker conglomerate that had filled an older valley. Once this was realised the scope of the site investigation was enlarged until a sufficient understanding of the structure beneath the dam was available.

This rather jaundiced view of the quality of foundation engineering before the 1950s is reinforced by the excellent design records traditionally produced in India. To judge by these reports, early in the century the British engineers in India regarded rock as rock with

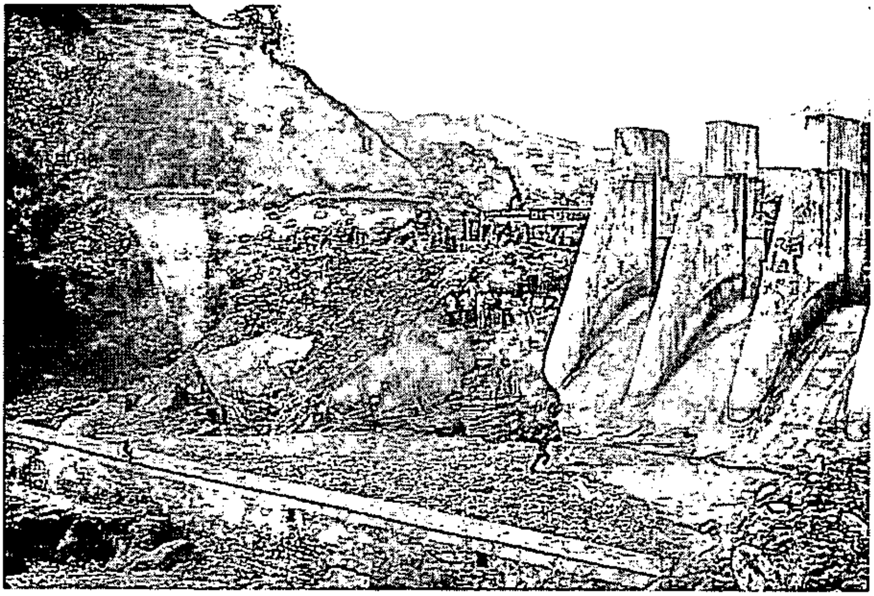


Figure 4.9 Phewa dam.

little enquiry as to the engineering geology as we would expect today, particularly if we have assembled a suitably multidisciplined team. The USBR guidelines of the time pay scant regard to this aspect. As a result, the engineer examining a concrete or masonry dam more than 50 years old is fortunate if there is evidence that the grout curtain is continuous, effective, or even present.

Internal erosion is a common ageing scenario and one with which British inspecting engineers are familiar. Table 4.2 was developed by EDF to take account of internal erosion and the poor engineering of the foundations of old dams. It gives a useful insight into the continuing performance of a foundation.

	Seepage increasing	**Seepage decreasing**
Piezometric head increasing	Unfavourable. Rehabilitation may be needed urgently	It may be necessary to clean or enlarge the drains.
Piezometric head decreasing	Surveillance required. Risk of internal erosion, hence advisable to check whether the seepage water contains fines.	Safe. No action is necessary.

Table 4.2 Aid to monitoring foundation behaviour

4.3.2 Further trends from Bulletin 119

The bulletin reports on some 20 case studies of rehabilitation of foundations and the following are among the trends observed.

Computers will be used more extensively to control of foundation grouting. The owner of the Logan Martin dam in the US has had a battle for more than 30 years to hold the leakage through the foundation of the dam in karstic terrain to acceptable levels. Williams et al (1994) report on efforts to reduce the leakage flow through the foundation which has exceeded 20m^3/s. The rock is so extensively karstic that grouting is required at a depth of 150m below the 30m high dam. Already some 113 000m^3 of grout solids have been injected. The owner has installed an automated centralised high capacity grout plant capable of instantaneous response to changes in conditions using a selection from 40 mixes and a range of pumps.

It was considered that the repairs to the foundations at El Chocon dam in Argentina could more economically be undertaken by gaining close access to the problem areas rather than by drilling from the surface (Aisiks, 1991). A 3.4m diameter shaft 107m deep and access galleries was excavated through the problem area. Blasting was not permitted and the entire access system was lined with 500mm thick concrete. A pressure regulation device and appropriate valves in the borehole collars were mandatory when drilling against reservoir pressure. Computers controlled the operating systems to monitor and to ensure safety.

Close working with a specialist contractor together with a multi-disciplined engineering team was important in both these spectacular pieces of work.

4.4 Include maintenance in the design

4.4.1 Introduction

Concentration on rehabilitation works has inevitably drawn attention to the omissions of the original designers in not taking account in their work of maintenance and rehabilitation. It is important that the designer of new works should make generous provision for the needs of those responsible for looking after their structures e.g.

- Access to confined spaces for maintenance. These spaces include tunnels and pipelines and also canals. A surprisingly large number of tunnels have been designed incorporating relatively small vertical sections, presumably to follow the better quality rock, but which make it impossible for convenient access even by pedestrians.
- Means of isolation of components that will be replaced during the life of the main civil structures. This implies consideration of the different rates of ageing of the components of the works.
- Provision of robust lighting and drainage in access ways.
- Provision of clear marking to show the location.

If the designer considers the needs of the rehabilitation team at an early stage, provision can usually be made at little incremental cost. Two examples follow. The first illustrates how access to a long unlined tunnel was introduced at low cost. The second describes the considerable ingenuity required by the rehabilitation team because no stop logs were provided.

4.4.2 Carhuaquero tunnel

The headrace tunnel of the Carhuaquero project in the Peruvian Andes is 13km long and was designed to be nominally unlined (Rossinelli et al, 1994). It is inevitable that steady maintenance will be required as the unlined rock spalls from time to time. The owner accepted that he would need to pay more attention to maintenance than if the tunnel were fully lined with concrete. A sloping access way is incorporated into the large desander structure and is big enough to allow a medium sized loader to enter (Figure. 4.10). Once it is inside the tunnel, the loader can turn in one of the places where the overbreak was enlarged.

4.4.3 Kotri barrage

It is difficult not to criticise the designers of the many structures built up to the 1960s who made no provision for stoplogs to isolate steel hydraulic elements. Considerable expense and ingenuity have been demanded to overcome this deficiency on a number of projects. An example is the work carried out at Kotri barrage on the River Indus in Pakistan (Figure 4.11). Padgett and Morrison (2002) have reported on the design of the self-contained buoyant bulkhead gate. The

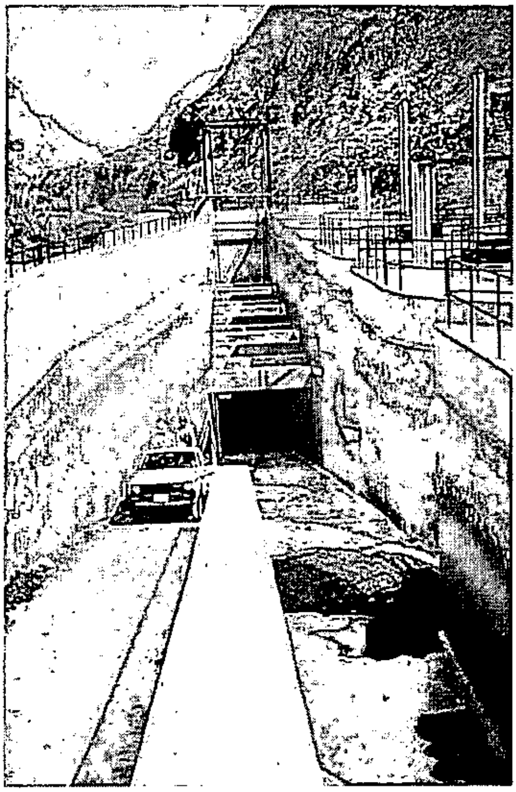


Figure 4.10 Carhuaquero, maintenance access to tunnel.

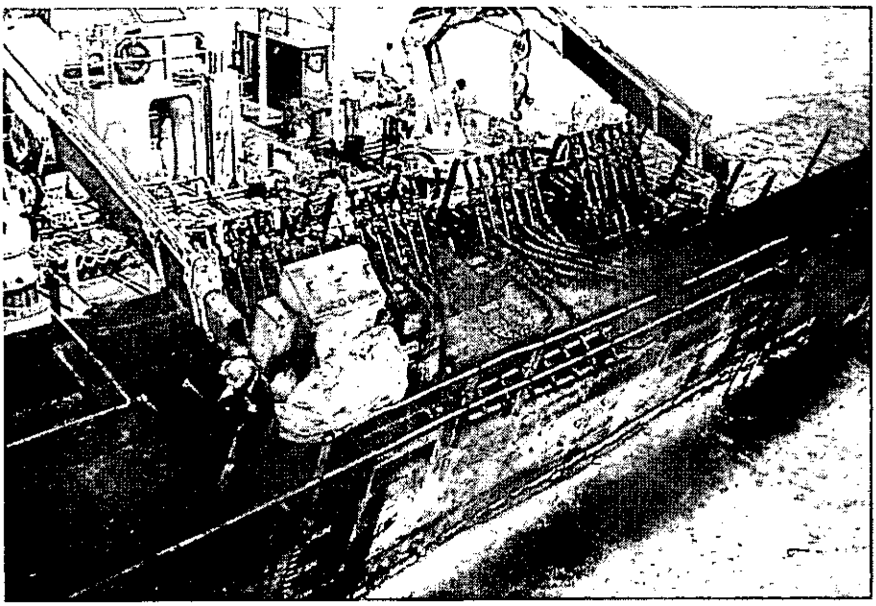


Figure 4.11 Kotri barrage, upstrem face.

challenge was formidable:

- 88 gates each 13m wide with no possibility of economic dewatering of the reservoir.
- The masonry surfaces have a roughness of several tens of mm, requiring a large, soft seal.
- The bottom seal required special attention because the concrete slab below the gate is too thin to resist the uplift pressure if it were dewatered.

The solution was a purpose-built rig (Figure. 4.12). The bulkhead gate was designed by the contractor to the Engineer's original scheme and to his approval. A pontoon and a tug carried the bulkhead gate to the sluice to be isolated. Once in position water ballast was adjusted so that the gate moved from a horizontal manoeuvring orientation to a vertical sealing position. The hydrostatic load on the gate was carried by thrust arms to the massive piers. Once the gate was in position, jacks were used to press the seals into place. It is pleasing to report that despite the difficulties, the bulkhead gate worked well and was a complete success.

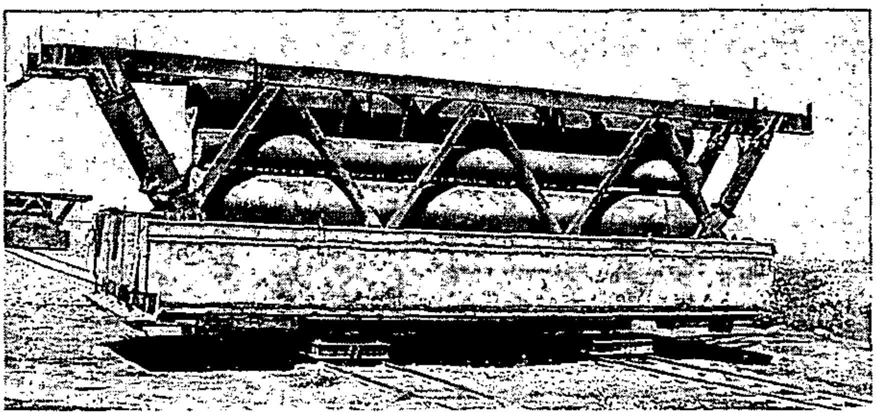


Figure 4.12 Kotri Barrage, bulkhead gate.

5 THE BRITISH DAM SOCIETY

5.1 British Dam Society

The British Dam Society is a unique body of technical wisdom, deeply experienced in its primary role as a technical facilitator. As members we are proud of the Society and its achievements and we must cherish it. It was to help us to consider what BDS is for and how to make it prosper that we prepared the Strategy that was recently described in *Dams & Reservoirs*. BDS's role has expanded with regard to the Reservoirs Committee and its ability to provide CPD for dam engineers is recognised. We seek a place on the steering groups for research projects so that society can benefit from the breadth of experience in the country that might otherwise be ignored in the competitive scramble to do the work.

BDS is a society of volunteers. Its success depends on the enthusiasm of individuals. It is to our credit that we provide as much continuity of manpower as does for example the Department of the Environment, Farming and Rural Affairs (DEFRA) or its predecessors. As the UK national committee of ICOLD we have serious long-term commitments.

The key outcomes of our strategic review reflect our view of the role of the dam engineer within a European and international context. Thus, we have developed a web site. We have a high status technical co-ordinating committee. My discussions with European dam engineers confirms that it would be helpful for all the European National Committees to share their experiences of seeking to improve their communications with the wider public, to find out what is acceptable, and what has proved to be effective. Therefore I recommend the routine circulation of the BDS journal *Dams & Reservoirs* to European national committees.

Following on from this work, I develop four themes for consideration for the future organisation of the Society.

- The nature and structure of the membership of BDS.
- Database of dam incidents

- Archive of older construction data
- Training of future generations of dam engineers.

The BDS was praised in the ICE Annual Review for 2001 (p6) for our organisation of the meeting in February 2001 to discuss the WCD Report. This is the meeting to which environment minister Chris Mullen was invited and is a good example of what we should be trying to do.

Acknowledging our primary role as a technical facilitator, I do no more than mention the importance of BDS as a commercial entity. It must be able to react quickly and be reasonably democratic. It must be able to manage the risk of being sued as a result of issuing technical guidelines. We should think of ourselves as a lobby group, willing and able to forestall inappropriate legislation.

5.2 Membership of BDS

At present the membership of the British Dam Society comprises civil engineers with a specialist interest in the design, construction and maintenance of dams. It is overwhelmingly technical in nature. Membership of non-specialist engineers or even of non-technical people has not been encouraged.

One of WCD's recommendations is that the national committees of ICOLD should include a consultative group of non-governmental organisations (NGOs), environmental scientists and affected peoples groups. They recommend setting up joint activities to learn from past experience. BDS should therefore encourage membership of non-engineers, so often the objectors to dam projects. The author Arundhati Roy is an example. Apparently totally opposed to the Narmada project in India, she appears blind to the potential benefits of reservoirs. We must surely share the work of explaining these benefits. If it is true that energetic opponents of dams are the children of middle-class parents with the time to argue the case against development projects, but without the need to propose alternatives, then this should be exposed too.

5.3 European database of dam incidents

Introduction

Work is already being considered for a UK database. Coxon (1986) and Cullen (1990) have supported the concept and I wish to support the initiative as far as I can. For it to be successful it will be important that it should be funded by the government. It is easy to start the tiger running with an idea like this. It is less easy, but essential, to control it once released.

I am not the first to propose harmonisation of the collection of data from the operation of dams on a Europe-wide basis. My proposal is that BDS accepts responsibility for pressing for and developing a European database of incidents to dams of all types. WCD is specific in its recommendations - *We should monitor our dams so that we can justify both them and our stewardship of them. We should seek to turn the data into knowledge, the basis of wisdom.* (WCD, 2000, see for example page 314). In this way our dam projects will not only operate more efficiently, but more safely.

It is important to realise however, that not everyone accepts that a database would be worthwhile, at least for now. Some feel that the enterprise is expensive and not good value for money. They prefer to emphasise good quality engineering judgement in assessing the likelihood of failure and the priority of rehabilitation works.

Two recent pieces of work in particular have encouraged me in thinking that such a database will be of value to the profession. The first is the preparation of Bulletin 119, the ICOLD Bulletin on Rehabilitation. In collaboration with BRE we started to collect data on incidents relating to rehabilitation to give guidance to engineers on what had proved successful already in a given set of circumstances. It did not take too long for us to realise the difficulty of the task we had set ourselves. Despite being the most popular of our activities, we did not succeed in producing anything of value.

The second was the DEFRA research into an integrated approach to risk management for dams and reservoirs. Here the benefit soon became clear as we sought to develop a quantitative approach to risk assessment. With a comprehensive database of incidents to dams it will not only be possible to assess the probability of an incident of a given type for a given kind of dam, but it will also be possible to judge the hazard posed to society by dams and reservoirs. We will be able to compare this with the probabilities found in other industries and those already found acceptable by the public at large. Already it is clear that the existing databases in the UK are as yet inadequate in their organisation and scope. There is already an argument to work together with European colleagues to develop a wider database.

Purpose of a database

A database provides information about the past. The future experience will be different as our understanding of ageing and climate change improves with our practice in carrying out upgrading and rehabilitation. The database would store data that could be processed to identify and quantify many aspects of the safety and engineering of British dams, including for example how the ageing process varies for dams of all types and conditions. ICOLD have discussed the role of databases in reducing uncertainty under Question 76 *The Use Of Risk Analysis To Support Dam Safety Decisions And Management.* Fell et al (2000) were among those who discussed the methods currently available to provide input to quantitative risk assessments. They point out that the assessment of the numerical probability of failure by some mechanisms, such as internal erosion, has so far proved resistant to analytical techniques. It is clear that a good quality database will help future generations with this type of analysis. With a mature database it should be possible to retrieve the statistical frequency of incidents of a given type at a dam of a specific type, age and condition as quantification of probability of an incident and for use in calibrating analytical techniques. It is important to encourage the database to hold data on incidents as well as failures. This is important because there are more incidents than failures, making the statistics more reliable, and because they can be used for reporting near misses.

Such a database would assist with the assessment of alternative rehabilitation options and for this reason alone would be worthwhile (Tedd et al, 1994). But there are many other potential benefits.

The importance of the human aspects of dam engineering that I have referred to in the first part of this lecture would be revealed.

The processed data would provide vital input to the current research into the procedures of Quantitative Risk Management. It would help in determining research priorities in the field.

Economic optimisation becomes possible with numerical data, leading the way to cost effective programmes of maintenance and rehabilitation, particularly of portfolios of dams.

In the British context, the database would provide DEFRA, OFWAT and owners with the basis for estimating the likely expenditure levels for the proper maintenance of the national dam-related infrastructure.

The data base would inform public policy once it proved capable of giving numerical data that could be used to compare dam safety for example, with levels of safety accepted by the population in connection with other industries.

Existing databases

The databases that exist worldwide vary in terms of scope, quality and availability.

It is often reported that there are three British databases. Best known is that organised by BRE (Tedd et al, 1992 and Tedd et al, 2000). This was set up in response to recommendations following the Carsington failure (Coxon, 1986). The University of Newcastle has maintained a database in connection with its dam research, and a third, referred to by Moffat as an *overtopping* database, emerged from research carried out at Newcastle twenty years ago. Moffat suggests that the data captured comprise the service history of some 25% of UK dams.

ICOLD itself has several collections of international data. They are of considerable value, but have several drawbacks when considered from a British viewpoint. First is that the data will not have been collected for projects where the dam is lower than 15m or the other ICOLD size criteria have not been met. However, Bulletin 109 deals specifically with dams less than 30m tall and is helpful in this regard. Second, much of the data comes from a small number of countries where the culture encourages revelation. Little comes from China or from those countries of the developing world where democracy has not yet taken deep root.

There are reports of databases in Europe (Vogel, 1998 for example). It is understood that the French have made progress not only with a database, but also with obtaining financial support for it from the European Community. We have a working precedent in the USA where the US National Performance of Dams Program was set up in 1994 at Stanford University under the Federal Emergency Management Agency (McCann, 1998).

There are great engineering research institutes throughout Europe: BRE, Delft, LNEC, EDF, ENEL, ICH, MOPT, NGI, Vattenfall, and the Universities; Aachen, Lausanne, Imperial College and Bristol to name but a few. Should we consider whether one of these institutions could work with BDS to set up and operate a data base on dam related matters, including incidents and failures? It would be a tool of unrivalled value.

Linke (2001) has described the way in which the USBR manages the maintenance and rehabilitation of its portfolio. It is not credible that USBR is alone among major operators of dam projects in collecting data. The challenge will be to work with such owners to gather what data is available with regard to the behaviour of their dams and appurtenant works.

Insurance companies may have information that is relevant.

Essential features of a successful database

From these remarks it can be seen that a strong case can be made for setting up a first class database for British dams. The British Dam Society should respond to this challenge. There will be debate as to whether the contents should be publicly available and whether owners should be legally obliged to provide the data concerning incidents. This is an important argument and there can be little doubt that a voluntary and confidential database would be of less value to the profession.

We have an effective means of collecting data about our dams through the work of Supervising and Inspecting Engineers. The Reservoirs Act 1975 allows us to collect useful incident data. The Act requires all reports containing recommendations in the interests of safety to be copied to the Enforcement Authority. Currently it appears that this information is simply filed. But it could be used to augment a database. Such augmentation would be simplified if the Enforcement Authority role were to be accepted on a UK-wide basis by one body. The Bibliography of British Dams (Charles & Tedd, 1996) will also provide useful data.

The database will have to be designed and then operated by a competent team whose work is supervised by a steering committee. It is difficult to imagine an effective database that is not run by a paid team. It will be important to optimise the time period for which any team is in charge, and to provide a regular opportunity to check that value for money is being maintained.

British data may be tainted by national considerations. Our 2600 dams are smaller and older than many other national collections. Such distortions have to be assessed by those who are knowledgeable of the statistical aspects of using collected data.

Immediate tasks include

The first stage of the work will be to plan the database. Answers will be needed to such questions. The nature of these questions confirms that the first stage of the work should be done in close collaboration with the DEFRA.

- The economic justification for the database. In view of the opposition of some experienced engineers, is it really worth the effort in setting it up and maintaining it?
- How would the database support dam safety and fit in with the primary legislation in the field?
- How it is to be funded, by whom, over what time scale?
- How is it to be managed? Will the manager will be selected following a bidding process and if so at what frequency?
- What will be the scope of the database, whether and how it will include data from foreign countries?
- How it is to be used? How will it deal with confidential or sensitive data? What access is planned? What reports are appropriate and practical?
- What software is most appropriate, its life span and the ease of transferring data from existing data bases, both in the UK and elsewhere?

The second stage will be to set up the database itself and the third stage would be to operate the database under close surveillance for an initial period.

5.4 Archive of older construction data

Introduction

My third proposal is that BDS should support the assembly of an archive of documents demonstrating the construction of dams in the UK and by British engineers overseas. Experience shows that often data of this type is freely available for a short time only, particularly as businesses and offices merge. Once the data has been destroyed the office is certainly tidier but a link with those whose work is to be rehabilitated is lost.

Purpose of an archive of construction documents.

A national archive will allow us to highlight some of the key developments of improving design and construction over the last century, a period chosen to cover the dams that the current and future generations of engineers will be rehabilitating. No doubt the developments to be covered will include uplift, internal erosion, concrete chemistry, soil mechanics and the big machines, rock mechanics and the use of the natural strength of the foundation. Thus a major benefit of the archive is to demonstrate that good understanding and observation, together with the effective use of science and management are essential to good engineering of rehabilitation. In interpreting history, context is everything. Papers of which Sims (1994) and Scott et al, (2001) and ICOLD Bulletin 109 are typical and are useful in discovering the stage of evolution of the design and this is most helpful to the engineer responsible for the design and management of a rehabilitation programme.

Existing archives

An important part of the task will be to coordinate with the holders of existing archives. The larger owners of dams in the UK hold archives of construction photographs. The ICE carries an archive of documents given to them on the retirement or death of members.

Key features of a good archive

The archive should be accessible on easily available software, and with a good index. It may be appropriate to charge for providing information from the archive.

Immediate actions

The first requirement is to prepare a feasibility study to determine whether it is an economically and technically feasible project. The second is to secure funding.

5.5 Future training of dam engineers

The present rate of appointment to Panels of Reservoir Engineers is two new Panel AR Engineers per year and ten Supervising Engineers. As we all know there are fewer new dams being built by British engineers, either in the UK or overseas. Perhaps as a result, the average age of Panel AR engineers is rising, albeit slowly. If this continues, there may prove to be an issue of long-term dam safety in the UK involved.

The required skills for British engineers in future will encompass broad issues of operation and maintenance including risk management and rehabilitation. It is no coincidence that these are recurrent themes in this lecture. It is not clear how these skills are developed in the industry at present. But it is certain that BDS plays a vital facilitating role.

One quarter of respondents to a recent survey of civil engineers receive no training and 47% say that they are not appropriately trained (NCE 13 Dec 2001).

It seems that the problem is not limited to Britain. Linke (2001) refers to a study in the United States which showed that between 33% and 80% of the senior staff of a selection of hydropower companies intend either to leave or to retire within 5 years. It is worthy of debate whether there is a demand for a centre of dam engineering excellence in the UK, or in Europe, now or in the future. Bristol and Newcastle universities in the UK deal explicitly with dam engineering. To what extent do their courses meet the demand for post-graduate training? Is the role of commercial trainers such as Water Training International adequate for present purposes? To what extent should the British Dam Society involve itself with the Quality Assurance of such a course?

If there is a demand for a British or European centre of excellence, what is the best way of developing it and funding it? It is worth noting that the International Centre for Hydropower in Trondheim, Norway has been developed at least partially as a vehicle for

Norwegian aid in this field to developing countries. There are considerably more questions than answers in this area at present and my recommendation is that BDS should commit itself to a study of the position with a view to providing advice to DEFRA at an appropriate time.

I have been struck by the lack of emphasis in risk management discussions about the psychological aspects of dam safety. We take account of internal erosion but not why monitoring and maintenance are skimped if they are done at all. As an example I have in mind the vandalised and inoperative instrument house at an important water supply dam which was built about fifty years ago and at the time it absorbed the attention of some of the best civil engineering minds in the world. If this dam were to fail, a major African city might well descend into anarchy as the inhabitants struggled to find water to drink. We must get to the bottom of the thinking that allows this vandalism to happen in the first place and does not see the point of repairing it. A possible way of doing this is through appropriate funding, and through training of the key staff at the British Centre for Dam Management.

6 CONCLUDING REMARKS

In conclusion let me summarise briefly some of the key points of this lecture.

We have a unique resource available to maintain and rehabilitate our stock of British dams. We should do all we can to identify and develop inspirational behaviour among our colleagues. It is difficult to exaggerate the importance of forming multidiscipline teams for rehabilitation projects. We have a particular role in communicating with those who are opposed to dams.

We should look ahead to the future of rehabilitation engineering for dams. Research and development will be valuable in the areas of:

- Working on the dam with the water at its service level
- Rehabilitation of deep foundations

- Designing for maintenance.

The British Dam Society is a world-class group, deeply experienced in its primary role of technical facilitator. There are four major tasks ahead that will benefit from the active interest and intervention of BDS.

- Widening the membership of the society
- Supporting a national or European data base for dam incidents
- Supporting a national or European archive of engineering data for dams
- The future training of the engineers we need.

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Alan Johnston writes:

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