

Internal Erosion News: Informal Report on ICOLD Prague, July 2017

The 'news' here will be published in due course in Dams & Reservoirs, the British Dam Society Journal, and this will provide formal references if needed.

1. ICOLD Embankment Dams Committee Meetings, Prague, Monday 3 July and Tuesday 4 July 2017

The ICOLD Technical Committee on Embankment Dams presented a Workshop on Asphalt Concrete Embankment Dams (ACED) and met with the Committee on Cemented Materials Dams on Monday; at the Committee meeting on Tuesday, we paid tribute to our Russian (originally USSR) member, Vadim Radchenko, who had retired from the Committee; received news of a publishing deal for Bulletins, received updates on new and on-going Bulletins; reports on the Oroville Spillway event and on progress at Mosul Dam; and made comments and agreed that two draft Bulletins should go forward for circulation and comments by national committees prior to formal approval by the Executive at ICOLD in Vienna, 2018.

2. Meeting with Committee on Cemented Soil Dams, Monday 3 July 2017

The new Committee deals with 'cemented' soils (treated with various binders, lime, cement, flyash, blast-furnace slag, etc). The discussion with the Embankment Dams Committee was based on a 2016 draft of the Bulletin on Cemented Soil Dams and related only to clay and loam treated with lime or cement. Cemented sand and gravel would be dealt with separately, updating Bulletin 54 of 1986 'Soil-Cement to Embankment Dams'. Treating clay with lime is a technique widely used in road construction to improve the workability of clay soils and provide strengthening against dynamic traffic loads on the top of embankments. There was a proposal to use it to build homogeneous cemented clay dams up to 50 m high.

Clay environments were limited internationally, but where encountered provided good fill materials for dams, particularly for low permeability cores. Clay foundations were sometimes difficult. High pore pressures resulting from loading in clay fill and foundations often necessitated slow construction rates or foundation drainage e.g. sand drains, to avoid instability. It was not known if treated clay fill would develop 'construction pore pressures'. Cemented clay fill would probably be more brittle than non-treated clay; consequently it may crack as the dam settled on clay foundations. The walls of a treated clay crack would be more resistant to internal erosion than in untreated soil, but tests had shown that, if initiated, erosion would continue at the same rate as in untreated clays. Treated clay might be used for cores in clay dams, but untreated clay would be at least as watertight and more flexible, consequently treated clay cores seemed to offer no advantage. Similarly, in clay environments cores in materials other than clay also offer no advantage.

In clay landscapes, rocks were not present, and treated clay soils may be useful, following research, for protection against wave damage on upstream slopes, or protection against scour by overtopping flows on downstream slopes.

Following the meeting, the Cemented Dams Committee would update the draft Bulletin, and ask for our further comments.

3. Meeting of ICOLD Technical Committee (E) on Embankment Dams, Tuesday 4 July 2017

3.1 Vadim Radchenko (Russia)

Vadim Radchenko had retired from the Committee. He was our Vice-Chairman and had been a member for many years; he is listed as a committee member in Bulletin 95 of 1994 and may have joined long before. He led an interesting life, playing a small part in international events in the world of dams. His father was a very senior engineer in the Russian Army, and became the senior officer commanding in the Russian Sector of (east) Berlin at the end of the World War II. His mother too was a senior Red Army officer, and Vadim showed us photos of family outings to the damaged Reichstag at weekends. Later, following the coups of General Naguib and Colonel Nasser, and the take-over of the Suez Canal, Egypt broke off relations with the 'west'

and developed them with the USSR, and Vadim's father was appointed as the Chief Engineer on the construction of the High Aswan Dam in Egypt. Vadim's early civil engineering experience included working as a young engineer on site at Aswan, alongside now very senior Egyptian engineers.

Vadim was a most enthusiastic supporter of our work on internal erosion. He worked hard to transfer Russian guidance on the subject, called 'seepage strength' in Russia, into the Bulletin because it had been successful in building dams resistant to internal erosion in USSR. He arranged a meeting of the ICOLD European Working Group to St Petersburg in 2010 where we visited the VNIIG laboratories and heard presentations from famous Russian engineers on their approaches to resist internal erosion. Some are included in ICOLD Bulletin 164 on Internal Erosion (ICOLD, 2015) but it was difficult to find translations from Russian into English. Professor Jaromir Riha (Czech Republic) hunted through Czech references, with little success; recently Florian Landstorfer (Austria) found references in an (east) German textbook and made an English translation. We are considering how to make this more widely available.

3.2 Internal Erosion Bulletin 164 on Internal Erosion in Existing Dams, Dikes and Levees
Volume 1 (ICOLD 2015) had long been completed in English and French, and is available as a final preprint from the ICOLD website. Volume 2 (ICOLD 2016) was complete in English on 6 May 2016, and is available as a preprint from the ICOLD website. Translation in to French is in progress by Dr Jean-Jacques Fry (France) and Valerie Frechette (Canada). It should be complete later this year.

Last year the possibility of keeping a database of internal erosion incidents was discussed, but Michel Poupart (France) already maintained a dam incident database. The Chairman would investigate how this could be accessed. Depending on the detail included, some case histories might be used for back-analysis to calibrate the present understanding of internal erosion mechanics.

Florian Landstorfer's discovery, mentioned above, of references in German to former-USSR 'seepage strength' analyses might also be used in back-analysis.

Papers on internal erosion topics were presented at the Symposium on Knowledge Based Dam Engineering on Wednesday, and there was a Workshop on Internal Erosion on Friday afternoon.

3.3 Bulletin on Geotextiles in Embankment Dams

Danie Badenhorst and Kelvin Legge (South Africa) had circulated the final draft of the update to Bulletin 55 of 1986 on Geotextiles as Filters and Transitions in Fill Dams for comments. Early comments from France had led to an important change in the title, which is now 'Geotextile Filters in Dams'. This highlighted the new recommendation to use geotextile filters as adjuncts to sand filters in critical situations, such as downstream of cores. The manufactured geotextile filters would provide a consistent filtering capability throughout, and the granular filter, of less consistent filter capability, would settle and adjust in the early years to leakage flows through any cracks or openings, or seepage through coarser more permeable parts of the core, and take over filtering duties if the geotextile filter deteriorated in the long term. This major change was mentioned but not highlighted in the conclusions.

The Bulletin gives comprehensive information and advice on all aspects of geotextiles and geofilters, including constituents and durability, and on positions and placement of geofilters and geotextiles in embankment dams. A coarse filter should be provided downstream of the sand filter if additional drainage capacity was needed. Comments had been received from Dr J-P Giroud, who delivered the 2010 Terzaghi Lecture, the prestige lecture of the ASCE Geoinstitute, (Giroud, 2010). The Chairman allowed any further comments until the end of August. He would ask at the Executive Meeting for agreement to circulate the final draft of the Bulletin to National Committees for approval, leading to approval of the final Bulletin at the Executive Meeting in 2018.

3.4 Bulletin on Granular Filters, Drains, Transitions and Slope Protection

Professor Antonio Soriano (Spain) made a full presentation of the proposed content of the bulletin on granular materials in embankment dams (primarily those with clay cores), as filters, transitions, drains and slope protection (rip-rap). This was based on drafts of Spanish guidance. The Bulletin would update Bulletin 95 of 1994 on Filters and Drains. It had been proposed partly because of suggestions to use very fine filters to protect cores in dispersive soils. Discrete Element Modelling had been used to model fluid flow through pore spaces between particles in transitions.

Dr Jean-Pierre Tournier (Canada), Chairman, noted that using the significant wave height (H_s) to derive the D_{50} size-weight of rip-rap results in the movement of smaller sizes when the significant (or larger) wave occurs. He had been active in producing guidance for the James Bay project in Canada (Levay et al, 1997; SEBJ, 1997), which had been widely used since, including for the La Romaine ACED dams. In this approach, which has been completely successful to date, the significant wave height is used to set the D_{min} size of the rip-rap.

The Bulletin would include case histories of internal erosion, resulting from filters not being taken to the top of the crest, and ineffective cut-offs and incorrect positioning of filters at an inlet tower and tunnel. The draft Bulletin in English would be circulated during 2018.

3.5 Oroville Dam, USA

John France (USA) gave a presentation on the damage to the spillway chute at Oroville Dam. He is the Chairman on the Board examining the causes of the extensive damage to the spillway as it passed flood flows. Another Board is advising on repairs to the spillway to restore it before floods in winter 2017-18.

Oroville Dam at 235 m (770-ft) is the tallest dam in the United States. It is an embankment dam, completed in 1967. The lower part of the spillway chute was extensively damaged as it passed flood flows in February 2017 following a long period of drought. When the damage was first seen the spillway gates were closed to limit further damage, and it was intended that the flood flows would pass over the emergency spillway at a higher level. However, there were leaks and back-cutting towards the emergency spillway weir, and much erosion on its unlined outlet chute, leading to fears of failure and the release of a 10 m high floodwave. This led to the evacuation of 180,000 people downstream. To reduce water level, releases once again had to be made through the damaged main spillway, damaging it further. Eroded materials (over one million m^3) partially blocked the river, raising water level at the power station upstream, making it inoperable and unable to release some of the flood flow. As the water level subsided, emergency work was put in hand to clear the debris, commence repairs and restore operations at the power house.

A report on the causes and lessons to be learnt, particularly whether the causes could affect many dams, is expected later this year. The cause is not immediately obvious because the spillway has passed substantially larger flows in the past without any damage. The dam is upstream of the spillway, and was not affected by the incident.

3.6 Mosul Dam, Iraq

David Paul (USA) gave a report on Mosul Dam, an embankment dam completed in 1985, where grouting to mitigate solutioning of gypsum and anhydrite from the foundations is now again in progress, having been interrupted by fighting nearby since about 2014. The team of the Iraq Ministry of Water Resources (MoWR), Trevi Group from Italy, and the U.S. Army Corps of Engineers (USACE), in the role of Engineer-of-Record, assisted by engineers from AECOM, is now mobilised on site. Dave Paul is Dam Safety Officer for the Mosul Dam Task Force which is providing technical support to MoWR to address dam safety issues. An inoperable gate on one of the two bottom outlets has been rehabilitated and both outlets can now be used to control reservoir water level, which is being operated at a lower elevation until re-grouting is complete. The Team are also considering options for the future including continuous grouting; a cut-off

wall; and the possibility of a replacement dam, or dams downstream to reduce the risk to the lives of the two million people in the flood zone.

Colonel Mike Farrell, a military engineer in the US Army Corps of Engineers (most of our USACE colleagues serve as civilians), who is the Officer Commanding, Mosul Dam Task Force, also gave a talk at the Symposium. He explained that his major military role, assisted by the internal security force of Italian Marines, is to ensure that supplies and people can reach the dam, and to keep the dam, working areas and accommodation secure, with absolutely no access allowed to any fighters, friend or foe.

We can note that the international task force at Mosul is fulfilling ICOLD's objectives for all dams - to keep them safe and able to play their role in maintaining peace and restoring prosperity to the people they serve.

3.7 New Bulletins

Suggestions for new or updated Bulletins included:

- Cofferdams: Dave Paul (US) would look out recent US guidance on this.
- Cracking in embankment dams: Dr Gavan Hunter (Australia) would consider cracking, he would consult Professor Robin Fell, who was active on this issue, particularly cracks on dam crests, potentially vulnerable to concentrated leak erosion during floods. Dr Didiek Djarwadi (Indonesia) had researched hydro-fracture for his PhD and may contribute.
- Dr J-J Fry (France) suggested that a further Bulletin on internal erosion case histories and analyses could be commenced in about 2020.
- Alberto Marulanda (past Chairman) emphasised that to produce a Bulletin, it was first necessary for a capable and knowledgeable author with time available to volunteer and commit to doing the writing.

References

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Symposium on Knowledge Based Dam Engineering, Wednesday 5 July 2017

Session 5: Advancements in analysis and design within flood protection reservoirs, levees and tailings dams

Twenty-nine papers were accepted on this topic. The subjects include internal erosion, flood management embankments and levees, including operation during floods, overtopping and breaches; tailings dams, including dambreak studies, seismic response and non-intrusive testing. Five presentations were made in the session, two on internal erosion and three on tailings dams.

Rodney Bridle (UK) presented his paper first (Bridle, 2017a). It described the mechanics of internal erosion as given in ICOLD Bulletin 164 on internal erosion (ICOLD, 2015; 2016). This is new knowledge and can be used for investigations and analyses to estimate the hydraulic load (usually expressed as water level) that will cause failure of embankment dams by internal erosion. It is necessary to make these investigations because surveillance and monitoring cannot give early enough warnings of the onset of internal erosion leading to failure. In response to a question, Rod confirmed that the Bulletin applied to tailings dams. He was not aware of examples but the mechanics of internal erosion applied to the 'soils' in tailings dams, and could be used to identify Probable Failure Modes, even in the unusual cross-sections of tailings dams.

Ingrid Silva (Sweden), a PhD student, presented Silva et al (2017) reporting on laboratory studies and tests on samples of moraine core material from a dam in Sweden where erosion leading to sinkholes had occurred. The samples were shown to be suffusive and the filters were too coarse to trap some of the fine particles. The core complied with guidelines current at the time of construction (1970), and with most of the requirements of recent guidelines. However, some samples showed fines content higher than specified in the construction specification (such details were not included in the guidelines). There were no specified criteria for filters at the time of construction, and the study recommends checking if the filters comply with current criteria.

Dr Andy Hughes (UK) presented Ulrich et al (2017) on non-intrusive testing to evaluate the condition of tailings dams. The paper gives examples of investigations at tailings dams and tailings storage facilities using the Willowstick method, a form of magnometric resistivity in which electromagnetic energy is introduced into the earth and the magnetic fields generated are measured and interpreted to identify seepage routes. It identified several seepage routes at each site and assisted in development of stabilisation and other changes at tailings facilities. In response to a question, it was pointed out that the method may not be applicable in situations where iron and other magnetic materials are present because the magnetic field is affected and this may over-ride the influence of water paths on the magnetic field.

References

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Tour TT2 to dams and town of Most in Ohre Mountains, Thursday 6 July 2017

Nechranice Dam (No 67, Czech National Committee, 2017)

Nechranice dam is 3.28 km long, the longest in Central Europe. It retains 288 Mm³, the fourth largest reservoir in the Czech Republic. It is used for flood control, hydropower, irrigation, recreation, water supply and other purposes. It is an embankment dam about 54 m high above foundation level, 47.5 m high above ground, constructed between 1961 and 1968. The foundations are layers of clays and claystones, several dozens of metres deep, below which are consolidated and unconsolidated sediments up to 350 m deep, including coal seams and sand layers saturated with artesian water.

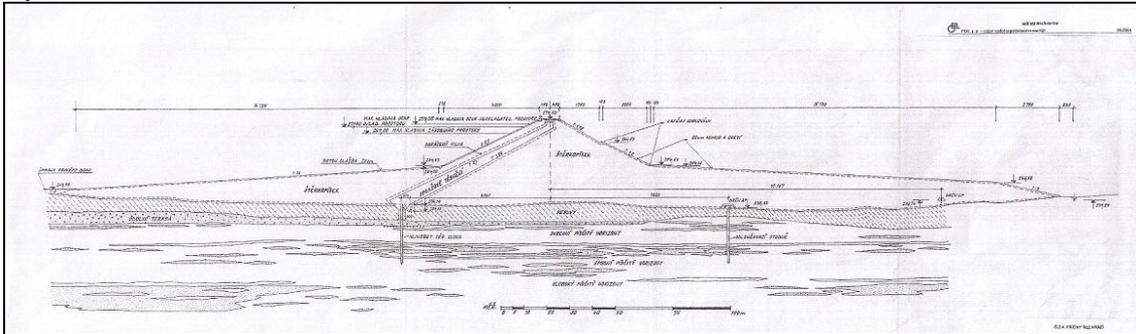


Figure 1 Nechrance Dam Section showing great width of dam, long berms and sloping core, and overburden in upper foundation with foundation strata below (from print provided by Povodi Ohre site staff)

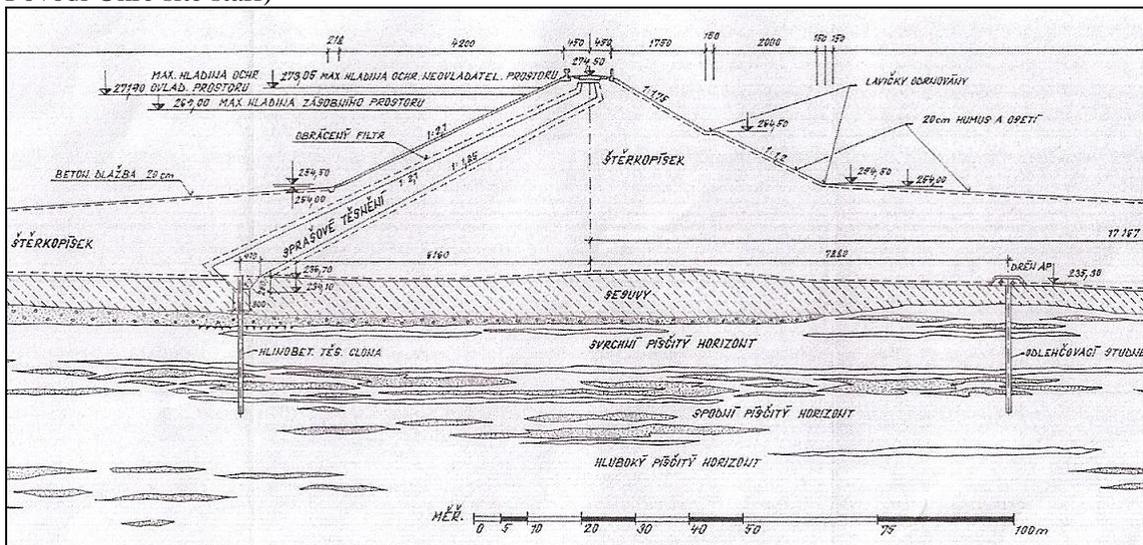


Figure 2 Nechrance Dam Central Section showing sloping core, filters, partial cut-off and relief well (from print provided by Povodi Ohre site staff)

As shown on the cross-sections, Figures 1 and 2, the dam fill is sands and gravels excavated from the reservoir basin, with an upstream sloping core of loess loams. The dam is up to 800 m wide at its highest part. The great width is a consequence of the weak foundation, a long length of foundation soil is required to provide sufficient resistance to the thrust from the core. The designers' solutions to the issues posed by the properties of the foundation soils are similar to those at Empingham Dam (Bridle et al, 1985), where the core also slopes upstream to reduce thrust from the central part of the dam, and keep the dam width as low as possible. There appear to be filters upstream and downstream of the core, and a partial cut-off into a less permeable layer below the core-foundation contact zone, with relief wells downstream.



Figure 3 Nechranice Dam: upper slope and downstream berm viewed across overflow

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Workshop on Internal Erosion, Friday afternoon, 7th July 2017

Seven speakers were invited to make presentations on various topics, as follows:

Dr Jean-Jacques Fry (France) presented risk assessments he and Thibaut Mallet had made on 200 km of flood embankments at the mouth of the Rhone in southern France, in which there had been failures and fatalities during floods. The analysis is described in Mallet et al (2014), Mallet and Fry (2015), ICOLD (2016) and Bridle (2017b). Almost all the failures were the result of internal erosion, mainly concentrated leak erosion, some from backward erosion. The risk assessment followed the process given in Chapter 9 on Volume 1 of Bulletin 164 (ICOLD, 2015). A range of different flood events provide varying water levels and probabilities. The concentrated leak erosion could occur along the walls of badger burrows which had been incompletely filled and could be opened at the upstream and downstream ends by hydraulic fracture where water pressure exceeded downward earth pressure. The flow of water through the open holes imposed hydraulic shear stresses on the walls, which were compared to the hydraulic shear strength (called the ‘critical shear strength’) determined by Hole Erosion Tests.

The results showed parts of the embankments to have a probability of failure as high as 1 in 5-years, i.e. the hydraulic load (water level) imposed by the 5-year flood level exceeded the ‘critical shear stress’ of the soil in the walls of the burrow. Similar analyses were carried out over lengths of the embankments on sand foundations, potentially vulnerable to backward erosion. The backward erosion analyses were carried out using the Sellmeijer and the Hoffman methods, both given in ICOLD (2015).

Dr Andre Koelewijn (Netherlands) who will be one of our hosts at the ICOLD European Working Group on Internal Erosion (EWGIE) Meeting in Delft, 3-7 September 2017, described research work in progress. It includes plans for a large scale test on an existing embankment into which a vertical gravel drain has been installed. The drain extends through the embankment and into the underlying sand foundation. Its purpose is to interrupt any backward erosion pipes as they work their way upstream below the embankment, and prevent them from reaching the waterway, thereby preventing an outrush of water which would cause settlement of the embankment and lead to failure.

Professor Jaromir Riha (Czech), one of our hosts at ICOLD 2017, who had organised today’s Workshop (and the 2011 EWGIE Meeting at his university in Brno), described the failure of the Bila Desna dam in 1916. The earth dam was founded on overburden above rock. It was damaged by flooding during construction. The culvert and other structures were founded on timber piles. The valley slopes were steep, with several springs. Compaction was limited, differential settlement up to 75 mm occurred, cracks formed, with water issuing from them. The dam operated for a few months, and then failed rapidly. There were 65 fatalities and extensive damage. The failure led to a loss of confidence in embankment dams in Czechoslovakia, and none were built for many years. A video reconstruction of the event was shown, available from: http://bursamusik.demamlagump3.download/sedot?v=doOY8uK_y8o

Rodney Bridle (UK) gave an overview of ICOLD Bulletin 164 on internal erosion in existing dams, dikes and levees and their foundations (ICOLD, 2016, 2015). The Bulletin presents new knowledge, defining the mechanics of internal erosion for the first time. Internal erosion initiates when the hydraulic forces imposed by water flowing or seeping through water-retaining earth embankments exceed the ability of the soils in the embankment to resist them. The highest hydraulic loads occur during floods when water level is high.

There are four initiating mechanisms: contact erosion at the interface between coarse and fine soils; concentrated leak erosion when flowing water erodes particles from the walls of cracks and openings; suffusion (also called internal instability), when fine soils are driven by water through the pores of the coarse matrix in gap-graded soils; and backward erosion when erosion pipes initiate at the downstream toe of embankments on sandy foundations, and work their way upstream (‘backwards’) towards the waterway or reservoir, when the rush of water released

enlarges the erosion pipes causing settlement and collapse of the embankment. The Bulletin makes it possible to estimate the hydraulic loads (usually expressed as water level) that will initiate internal erosion.

Internal erosion proceeds to failure in four phases: initiation; continuation or arrest by filtering; progression, and breach. Continuation or arrest is the most important phase. If the hydraulic load is sufficient to cause erosion to continue, it will progress to failure. It cannot usually be stopped because high hydraulic loads occur during floods, when it is not usually possible to control the water level in the reservoir or waterway. Consequently, internal erosion failures occur rapidly, and it is therefore recommended that investigations and analyses be carried out, as explained in the Bulletin, to estimate the ‘critical water level’ at which failure will occur. If this is too low, remediation will be necessary.

If the embankment is zoned with filter zones or downstream fills that are capable of arresting erosion by filtering, then the erosion process will be arrested and failure cannot occur. The Bulletin explains how to identify if fills are no-, some- or excessive-erosion filters, able to arrest erosion after increasing amounts of sediment laden leakage and damage, up to 1,000 L/s from the leak and sinkholes in the case of excessive-erosion ‘filters’. Homogeneous (unzoned) dams have no downstream zones, and therefore no filtering capability, consequently if erosion initiates, it cannot be arrested.

As the ‘critical water level’ causing failure can be estimated, and the annual probability of occurrence of that water level can be determined from the flood hydrology, the probability of occurrence of internal erosion failure can be estimated. Responding to a question regarding the number of dams that might require remediation to improve their resistance to internal erosion, Bridle referred to Figure 7 below. This showed results of quantitative assessments of internal erosion risk for a sample of UK embankment dams.

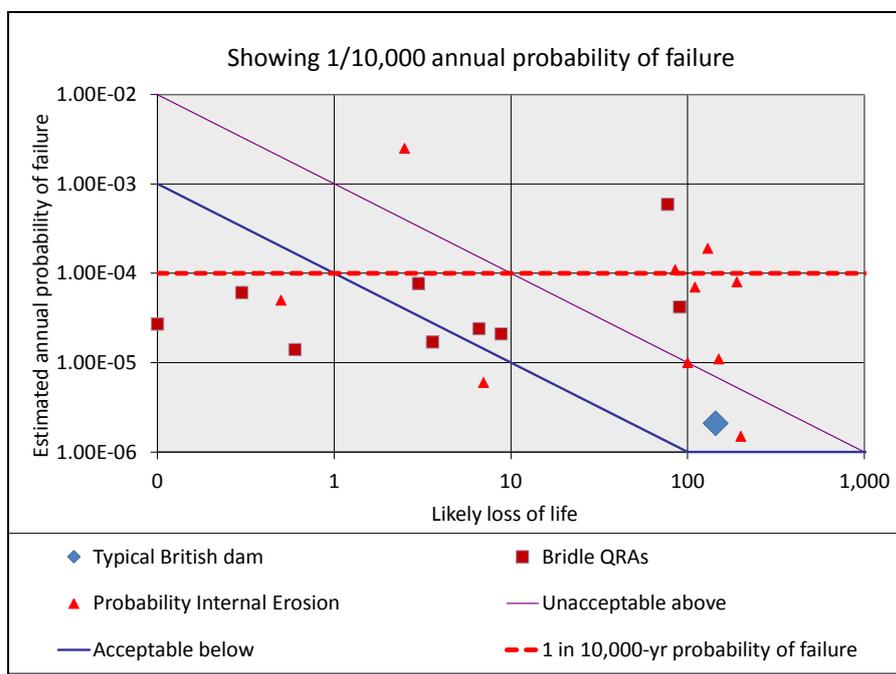


Figure 7 Probability of failure of a sample of British dams, estimated using Brown and Gosden (2004)

The results were not derived from application of the Bulletin, but from Brown and Gosden (2004) which projects results from records of many internal erosion incidents through to failure. As, unbeknown to the authors at that time, it was the hydraulic forces that would have caused failure, the probabilities from their method are also the probabilities of occurrence of particular water levels occurring during floods. The embankment dams on the plot include dams with puddle clay cores, and several are very old and without cores (i.e. unzoned). Only four of the 20

dams assessed show an annual probability of failure higher than 1 in 10,000-years, and a total of eight are in the 'unacceptable' zone. This sample of results suggests that, depending on what level of risk is acceptable to society, and bearing in mind the uncertainties in the estimates, between 20% and 40% of embankment dams might need remediation in order to improve their resistance to internal erosion.

Dr Remi Beguin (France), read by Dr Jean- Jacques Fry (France), reported on the influence of time on resistance to concentrated leak erosion. The 'critical shear stress' (hydraulic shear strength) of a silty soil (CL), compacted on the wet side to 88%-97% Proctor, kept under 'natural conditions', was 100 Pascals at one month, and had increased at three months and again at one year. The increase was thought to be the result of increasing pore suction in the samples.

Florian Landstorfer (Austria) had used guidance from the former East Germany to investigate erosion potential, particularly suffusion, at Durlassboden dam. The dam is 80 m high with an earth core and foundation underseepage, collected by relief wells. Seepage rates are measured. After 15 years operation (in 1985) sand boils occurred. Remediation followed, but seepage with a constant level of turbidity continued, and new springs developed. Suffusion was occurring, but there were no concentrated leaks or backward erosion. The reservoir was drawn down, but there was no sign of erosion on the reservoir floor. Tests showed that contact erosion could occur at very high gradients, and that holes and cracks would soon collapse and not allow concentrated leak erosion to continue. Suffusion of fines <5% (d_5) at low gradient continues.

Dr Krzysztof Radzicki (Poland) described the thermo-hydraulic temperature (and leak) monitoring system developed in Poland. He also described a strain detection system monitoring displacements by water injection. In combination the two systems give a quasi-3D geotechnical monitoring system. Full descriptions are given in Radzicki (2014). Combining with piezometer results he had completed finite element analyses of stability (and local instability) of a permeable fill embankment.

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