ICOLD Bulletin 164: Internal Erosion Workshop
Friday June 14, 9h00-12h45

Internal erosion is a major cause of embankment dam failures and incidents. ICOLD Bulletin 164 on internal erosion in existing dams, dikes and levees and their foundations provides practical guidance on dealing with the threat of internal erosion in existing water-retaining embankments. Presentations in this workshop will cover the four modes of internal erosion as well as applications of Bulletin 164 to explain incidents and target remediation. Case studies and the latest research will be presented by prominent international practitioners, researchers and academics.

This workshop is aimed at dam engineers and technical specialists, regulators and dam owners involved in the design, construction and operation of dams, levees and tailings dams. Participants will gain improved understanding of internal erosion mechanics and how to make engineering assessments to limit the risks related to this phenomenon.

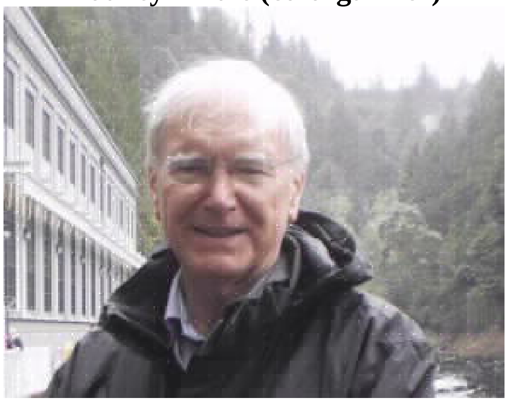
ICOLD OTTAWA INTERNAL EROSION WORKSHOP Friday June 14, 9h00-12h45
Shaw Centre (level 2) room 208 (check with app for possible last minute changes)

15 minutes presentations, start at 9h00

start	end	speaker #	Speaker	Country	Title of presentation	IE mechanism	Other topic	Field
9h00	9h05		Marc Smith		Welcome, logistics			
9h05	9h10		Rodney Bridle		Intro on ICOLD Embankment Dams Committee, ICOLD IE Bulletin, EWGIE			
9h10	9h25	1	Rodney Bridle	UK	Overview of internal erosion mechanisms	Overview		Intro
9h30	9h45	2	Jonathan Fannin	Canada	Developments in research and practice: a Canadian perspective	Suffusion		Research
9h50	10h05	3	Thibaut Mallet	France	Quantitative Risk Assessment for flood protection embankments using ICOLD Bulletin 164: the Symadrem experience	Concentrated leak	Risk	Practice
10h10	10h25	4	David Paul	US	Remediation against internal erosion through foundations – selection and installation of cut-off walls		Remediation	Practice
10h30	**11h00**		**BREAK, Parliament Foyer (level 3)**					
11h00	11h15	5	Esther Rosenbrand	Netherlands	Backward Erosion Piping: a multi-scale investigation of a novel remediation technique	Backward erosion	Remediation	Research
11h20	11h35	6	Marc Smith	Canada	Contact erosion detection and rehabilitation : a case study	Contact erosion	Detection	Practice
11h40	11h55	7	Florian Landstorfer	Austria	Using European research to investigate the potential for suffusion at a dam in Austria	Suffusion		Practice
12h00	12h15	8	Rémy Tourment	France	Levee failures and internal erosion mechanisms: the role of risk analysis		Risk	Practice
12h20	12h35	9	Des Hartford	Canada	An owner's view of assessing and managing internal erosion risk		Risk	Practice
12h40	12h45		Rodney Bridle		Wrap-up			
12h45	**13h30**		**LUNCH, Parliament Foyer (level 3)**					

Presenters and Presentations

Rodney Bridle (co-organizer)



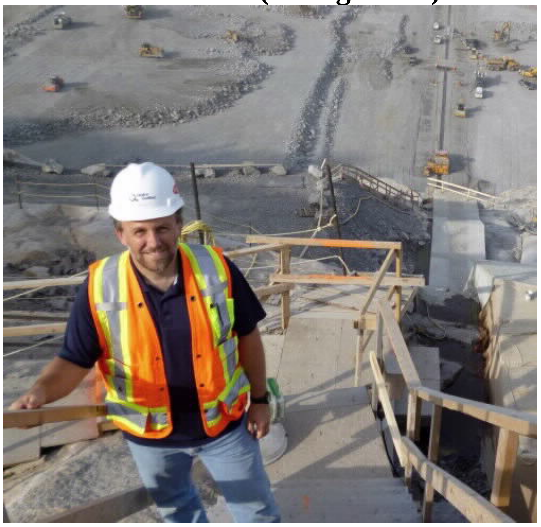
Rodney Bridle, Civil engineer, Dam Safety Ltd, specialist consulting engineer in earth and earth-rock dams, internal erosion and risk. UK Member, ICOLD Technical Committee on Embankment Dams. Editor and part-author of the two volumes of ICOLD Bulletin 164 on Internal Erosion. Regular attendee at ICOLD and ICOLD Internal Erosion Working Group (EWGIE) meetings. Former Chair, British Dam Society. More information at www.damsafety.co.uk.

Overview of internal erosion mechanisms

Internal erosion is a process of erosion in which the hydraulic forces imposed by water flowing through openings or seeping through the pores in soils in water-retaining embankments and their foundations are sufficient to overcome the resistance to erosion of those soils. It has parallels to scour and erosion on river beds. The hydraulic forces are usually greatest when water levels are high as floods pass through reservoirs or along waterways, consequently the probability of the water level causing failure can be estimated from the flood hydrology for use in risk analysis (because risk = probability x consequences). If internal erosion initiates, progress to failure will likely be rapid, unless the erosion is stopped by filters – in designed filter zones or in fill zones of a grading capable of filtering - trapping eroded particles and preventing the continuation of erosion after no-, some- or excessive erosion. Unzoned (often called 'homogeneous') embankment dams and levees are more vulnerable to internal erosion than zoned embankments because there are no more-or-less vertical zones that might arrest erosion.

ICOLD Bulletin 164 provides a comprehensive qualitative understanding of internal erosion and the means to quantify the hydraulic forces that will cause failure through the four internal erosion mechanisms: concentrated leak erosion, suffusion, backward erosion and piping, and contact erosion. It gives methods to assess the filtering capability of filters and fills; guidance on investigations and engineering analyses, and on remediation and surveillance. Recent research has added to the usefulness of the Bulletin, notably in backward erosion and piping, as a case history shows. An important conclusion is that it is not possible to anticipate the onset of internal erosion to failure through surveillance and monitoring; and as failure occurs rapidly, the critical hydraulic load, water level, should be predicted by investigations and engineering analysis, and remediation completed if necessary, before large floods occur.

Marc Smith (co-organizer)



Marc Smith, P.E., Ph.D., is a geotechnical engineer with Hydro Québec. He has more than 34 years of experience in the design and construction of embankment dams as well as in their monitoring during the impoundment and operation phases. He has carried out many specialized dam safety analyses in Québec, Latin America, Africa and Asia. He is also an Associate Professor at Laval University as well as part-author of ICOLD Bulletin 164.

Contact erosion detection and rehabilitation: a case study

An embankment dam with a central impervious core was constructed in 1971 perpendicular to another embankment dam constructed in 1915 to create an intermediate reservoir for environmental purposes. The older dam is comprised of random rockfill with an upstream clay core. After impoundment of the intermediate reservoir, total seepage at the junction of both dams was increasing steadily. Contact erosion in the random rockfill was suspected to be the main cause of these observations. Identification of the variable flow patterns was deemed necessary to design optimal remediation works to reduce seepage quantities.

A global survey of the seepage area was completed using an electromagnetic method to detect and map main flow patterns. Based on these global findings, optical televiewer surveys from boreholes were used to assess the rockfill stratigraphy in more detail. Active temperature monitoring using fibre optics as well as passive temperature monitoring using thermistors helped detect a zone of preferential seepage and estimate flow velocities.

The random rockfill was grouted shortly after these investigations. The contact erosion phenomena was stopped thus reducing significantly the seepage quantities.

Jonathan Fannin

J.Fannin : top-left with UBC research team

Dr. Jonathan Fannin, P.Eng., F.E.I.C., is a Prof. of Civil Engineering at the University of British Columbia. He has more than 25 years experience in teaching, research, and specialist consulting on matters of seepage and internal erosion in zoned earthfill structures. His research advancements are recognised with an IGS Award for laboratory and field contributions to design practice, a CGS Award for the best paper in the Canadian Geotechnical Journal, and a Distinguished Visiting Fellow Award from the U.K. Royal Academy of Engineering. Jonathan has provided specialist technical consulting advice on dams and dikes in Canada, the USA, and South America.

Developments in research and practice: a Canadian perspective

There is longstanding appreciation for the three most significant modes of dam failure being slope instability, overtopping, and internal erosion. The state-of-practice for assessing the susceptibility of a zoned earthfill dam to internal erosion is described with reference to current CDA, ICOLD, and USBR-USACE guidance. An application of the state-of-practice is described, with reference to materials testing and assessment for a dam in Canada. Consideration is then given to the state-of-art in Canada, and the role and contribution of university-industry research to advancing the state-of-practice, most notably with reference to BC Hydro sponsored research at the University of British Columbia.

Thibaut Mallet

Thibaut Mallet is a hydraulic engineer having 24 years of experience. After working in Sri Lanka and Mali from 1995 to 1998, he joined the Agricultural Ministry as a civil engineer. Following the 2002 flood in the Gard province and the Rhône flood of 2003, he became Project Director for the construction of small dams and reconstruction of levees (Aramon, Comps...). In 2006, he became Deputy General Manager of SYMADREM, a public institution in charge of the management of river and sea levees in the Rhône Delta River (240 km). He is now implementing a 400M Euros program to reinforce the Rhône levees. As part of the French regulation related to levees, he developed a model to evaluate breach probability following the guidelines of ICOLD bulletin 164. He presented his work at ICOLD annual meetings in 2014, 2016 and 2018.

Quantitative Risk Assessment for flood protection embankments using ICOLD Bulletin 164: the Symadrem experience

David Paul

David B. Paul, P.E., is a Senior Technical Advisor for Dams and Levees for HDR Inc., Denver Office. He retired from the US Army Corps of Engineers (USACE) at the end of 2018 after 42 years of Federal service, as the Dam Safety Officer for the Mosul Dam Task Force which is providing technical assistance to the Government of Iraq in to mitigate dam safety issues associated with Mosul Dam. He also served as Special assistant for Dam Safety at the U.S. Army Corps of Engineers (USACE) headquarters in Washington, D.C., responsible for managing the USACE's portfolio of 715 dams. He is a national specialist on critical infrastructure design, dam design, levee design, construction engineering, engineering risk assessments, interim risk reduction measures (IRRM), and dam and levee safety modifications. He recently participated in the Risk Assessment for Oroville Dam. Mr. Paul is a Trustee of DFI, and a member of the United States Society of Dams (USSD), Association of State Dam Safety Officials (ASDSO) and American Society of Civil Engineers (ASCE). He is DFI Trustee for the Seepage Control and Grouting Committees and serves on the USSD Committees on Construction and Embankment Dams. He is the USSD Representative to the ICOLD Embankment Dams Committee.

Remediation against internal erosion through foundations – selection and installation of cut-off walls

Esther Rosenbrand

Esther Rosenbrand is a researcher and geotechnical advisor at Deltares, an independent institute for applied research in the field of water subsurface and infrastructure in the Netherlands. For the past two years, she has done research on a novel remediation measure against backward erosion piping, which is being developed in a multi-scale experimental program at Deltares.

Backward Erosion Piping: a multi-scale investigation of a novel remediation technique

In the field of flood defenses, Deltares develops knowledge for new assessment methods and technologies for reinforcing dikes. Backward erosion piping (BEP) poses a significant threat to the Dutch levees. Therefore, the coarse sand barrier (CSB) is being developed as a cost-effective nature-based measure to prevent a pipe from leading to embankment failure.

The concept of the CSB is based on a physical understanding of the mechanisms that cause the pipe to progress upstream below an embankment. The loosening of grains at the tip of the pipe due to the hydraulic forces, is the key factor to the effectiveness of the barrier. The progression of a pipe in the presence of a CSB was investigated by means of laboratory experiments at different scales (aquifer depths of 0.10 m and 0.40 m) to investigate effects of geometry, scale and different material combinations. Subsequently two larger scale experiments (aquifer depth 3.0 m) were conducted in the Delta Flume test facility at Deltares to develop further confidence in the measure.

The combination of laboratory experiments and numerical modelling was used in order to better understand the process, and to derive a strength criterion, which allows for design of reinforcement of embankments with the measure. Subsequent steps will involve tests by constructors to investigate the feasibility of placing the measure in the field, and a pilot test at a real embankment in the Netherlands.

Florian Landstorfer

Florian Landstorfer is a Dam Safety Engineer for VERBUND Hydro Power (Austria). He has 15 years of experience in project management, dam surveillance and dam safety. He is responsible of 6 dams (1 gravity, 1 arch and 4 embankment) having heights ranging from 19 m to 120 m,

Using European research to investigate the potential for suffusion at a dam in Austria

Eberlaste dam is a 28 m-high embankment dam with an asphalt core and a foundation cut-off wall. As the cut-off wall did not reach bedrock, under-seepage was expected. Significant foundation settlement, with a rate of 3–4 mm/year after 50 years of operation, suggested the presence of internal erosion in the foundation. According to a theoretical assessment of contact erosion, the various foundation soils can act as a filter for the particular base material. Hole erosion tests showed a low resistivity against piping. However, pipe collapse during these tests indicates that the likelihood of concentrated leak erosion is very low. Consequently, the main focus of the internal erosion assessment was suffusion. Various theoretical criteria were applied using a large number of gradation curves. In addition, laboratory suffusion tests were carried out.

A cooperative research project was established with Université de Nantes, Electricité de France, IMSRM (Ingénierie des Mouvements de Sol et des Risques Naturels) and VERBUND Hydro Power to investigate, among other things, the influence of suffusion due to hydraulic loading on the mechanical behaviour of soil specimens by also taking into account the various scalping processes. This project aims to improve the understanding of the mechanical process of suffusion and the interpretation of test results.

Rémy Tourment

Rémy Tourment is an engineer-researcher with the Hydraulic Works Research Unit of Irstea since 1989. He is an expert on dam and levee safety and is now coordinator for research and expertise. Since 2009, Rémy acts as project manager and major contributor for various research projects related to levee safety and performance assessments as well as flood risk analysis. These include the French project DIGSURE, the EU FP7 project FloodProBE, levee-related flood risk analyses as well as contributions to the International Levee Handbook (ILH). Rémy is also Chairman of the Levees Technical Committee of ICOLD.

Levee failures and internal erosion mechanisms: the role of risk analysis

Levee system risk analyses are becoming commonly used to inform decision making in terms of levee upgrading or maintenance, of protection systems management as well as of flood risk management. A framework for these analyses has been defined in the International Levee Handbook (ILH). Levee failure mode analysis is an integrated part of the levee system risk analysis. It allows the identification of different failure scenarios involving more than one mechanism.

ICOLD Bulletin 164 describes different phases in a dam or levee failure scenario as well as four different internal erosion mechanisms. After a brief overview of the ILH, this presentation will show different examples of levee failure scenarios involving one or more internal erosion mechanisms. Using experience from the FloodProBE project, this presentation will show how these mechanisms can interact. It will also show how to better integrate the available knowledge on internal erosion and failure modes analysis to improve levee sytem risk analyses for better decision making.

DR. D.N.D Hartford

Dr Des Hartford, is Principal Engineering Scientist at BC Hydro. He is an internationally distinguished expert in risk analysis and risk assessment for dams and hydropower systems, risk management policy and risk-informed decision processes in safety management. Des is a principal author of the authoritative text books *Risk and Uncertainty in Dam Safety* and *Operational Safety of Dams and Reservoirs,* and is a principal author of three ICOLD Bulletins.

An owner's view of assessing and managing internal erosion risk

Concerning internal erosion risk, dam owners have three fundamental questions that can be answered to varying degrees of satisfaction by engineers using best available practices. These questions are:

1. Is there a problem with internal erosion?
2. Where is it (in the dam)?
3. How much time is there to resolve the problem?

Not much else matters as the issue of "Tolerability of Risk of Failure by Internal Erosion" is debatable. It is debatable because the tolerability of the consequences of any dam failure is dependent on the context of the failure. If the failure occurs within the design envelope of the dam the owner can expect a different social and political response than would be the case if the dam were overwhelmed by an unprecedented natural event such as a flood or earthquake of magnitude that were to exceed the best practice design criteria.

This presentation will provide a basis for a complete re-set of the approach to Tolerability of Internal Erosion Risk and provide a rationale as to why research on internal erosion needs to advance from empirically based answers to Question 1 above and move to a physically-based approach to addressing Questions 2 and 3.