THE WORKING GROUP ON LEVEES AND FLOOD DEFENCES UNDER THE EUROPEAN CLUB OF ICOLD

ISSUE 09 - May 2022

lfd-eurcold.irstea.fr

LEVEES Working Group Newsletter

Aerial view of the Digues de la Mosson in Villeneuve les Maguelonne. Photograph from Claude Cruells (VINCI Group)

Note from the Chairman

Rémy Tourment

By comparison to my introduction of the last two issues of our newsletter, it looks like the COVID 19 pandemic situation is beginning to have less direct impact on our international community activities, even if the situation regarding our everyday life and our regular work is different from country to country and still can raise concerns.

However, we have some of the important international congresses and conferences happening again physically, or in a mixed format both physical and online, like the ISSMGE 20th international conference on soil mechanics and geotechnical engineering, in Sydney. More remarkable still for the ICOLD community, the 27th Congress and 90th annual meeting will take place in Marseille in a physical format. At least a thousand people, delegates from many ICOLD member countries will attend this event covering eight full busy days. After two years of no physical gathering, this is a really expected moment for our dams and levees family. As this ICOLD 90th annual meeting happens in a European country, I hope that a lot of the readers, and particularly our WG members, will have taken this opportunity for all to meet and create new links, or reinforce existing ones.

Different activities in direct relation to levees will happen in Marseille:

• **Friday 27 May:** short course "Risk analysis for levee systems" (8:30-16:15)

• **Saturday 28 May:** TC workshop "The world of levees and its significance for the work of ICOLD. Overview of two bulletins prepared by ICOLD Technical Committee LE" (10:30-12:30)

• **Sunday 29 May:** TC meeting (8:30-17:30)

• **Tuesday 31 May:** Technical visit: Levees in Camargue and Arles (SYMADREM), a levee system on Rhône River

and, of course, many presentations during the symposium and the sessions related to the four congress questions will relate indirectly or even directly to levees and flood defence structures.

Levees in ICOLD: involvement of other committees

Since 2015 with the creation of our own WG under the umbrella of the European Club, levees have clearly become a topic in ICOLD, and even more with the creation of the ICOLD Technical Committee on Levees in 2017 and the inclusion of Question 103 (Small dams and levees) at the program of the ICOLD 2018 Congress in Vienna, all this at an international level. Both former ICOLD President, Anton Schleiss, and current one, Michael Rogers, gave a strong support for the clear inclusion of levees in the work program of ICOLD, and I cannot thank them enough.

To ensure strong and explicit adoption of levees, not only inside the ICOLD TC and in EUCOLD LFD WG, but also by as many Committees as possible (both National Committees and other relevant ICOLD Technical Committees), the ICOLD President recommended that these Committees review for opportunities and formally include levees in their work program. Some National Committees are already considering technical issues relevant to levees in their country. This message is definitely a major step, let's hope it is heard and followed; check it here.

Could you help with our next new featured photo?

We're looking for exciting levee photos to feature on the front cover of our future newsletters! It could be something like an existing or construction or your favourite levee photo from all over the world.

Please email your pictures to lfd-eurcold@irstea.fr

IN THIS ISSUE

HYBRID MODELLING OF LEVEES

Development of a forecasting system of flood protection levees in an indoor real-scale experimental setup

By Dirk Fleischer, TU Dresden, DE

Long periods of drought or volatile rainfall have become a serious issue for water exposed slopes such as dams and levees due to climate change scenarios. Shrinkage of dry soil can cause deep cracks in the material structure. Furthermore, the risk of heavy rain is increasing, causing floods and direct surface infiltration amplifying hydraulic load on slope stability. A significant role is played by the processes in the partially saturated zone of a levee made by soil material. Earlier research by Prof. Aigner (TU Dresden) showed the beginning of the failure by loosing shear resistance in this zone. However, classic stability analysis is only capturing the fully saturated part.

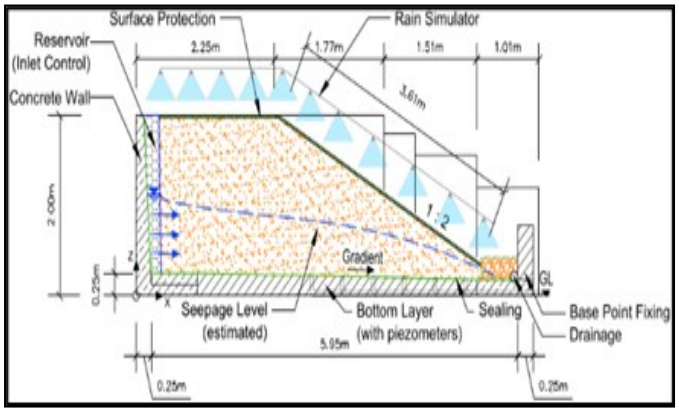

Figure 1: Cross-section of the experimental setup for development of physical and mathematical models to prevent levee failures in the VSDS-project, scenario GS01 (Fleischer et al. 2022a)[1]

The joint research project VSDS aims to support the development of a forecast system by experimental and mathematical modelling considering the geohydraulics in the partially saturated zone. The TU Dresden provides a real-scale levee model which is adaptable according to research objectives, like testing of low-cost, impedimetric soil sensors measuring the saturation and gaining experience about the interaction between impounding and simultaneously irrigation. In addition, the model facility was used to practically test the reinforcement of a levee by a liquid soil sealing system. Fig. 1 shows the basic elements of the experimental setup, including inlet control, piezometers, drainage and rain simulator.

Figure 2: Monitoring of the landward slope during the failure of scenario GS02 by laser scan and depth camera

For the first time, a depth camera (Intel RealSense) was used to monitor the controlled failure of the dike model by streaming the 3D-evolution of the surface, which has been loaded with a critical flood scenario. The setup and the failure pattern of the sandy, non-cohesive material is illustrated in Fig. 2. The time dependent 3D-pointclouds of the stream are extracted into cross sections in Fig. 3, where it shows the occurrence of large-scale backward erosion and soil liquefaction, but no total failure.

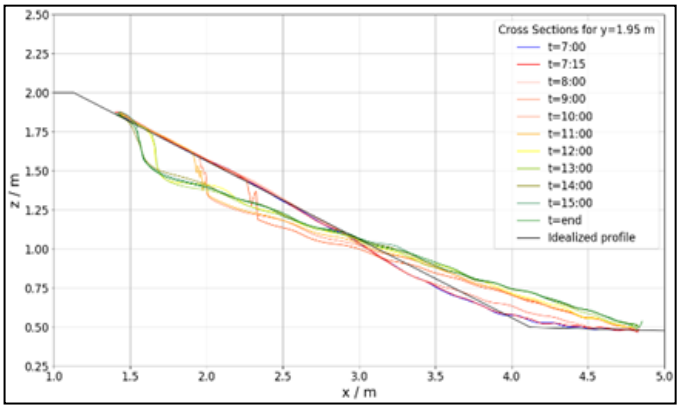

Figure 3: Evolution of cross sections of the landward slope during the failure monitoring of scenario GS02 (Fleischer et al. 2022b)[2]

The second part contains the efficient computer based mathematical modelling of geohydraulics and the resulting stability in flood protection embankments. The high end, numerical FEM-software PCSiWaPro was used to simulate the transient infiltration by irrigation and flooding scenarios, calculating hydraulic velocities, potential and saturation for each part of the dike. The output-data flows directly into a self scripted, advanced stability analysis tool, which efficiently finds the most likely failure body in the slope and its corresponding safety factor (see Fig. 4). The model chain can be used to quickly simulate unfavourable scenarios on levees, e. g. integrated in an early warning system, from combinations of irrigation and flooding.

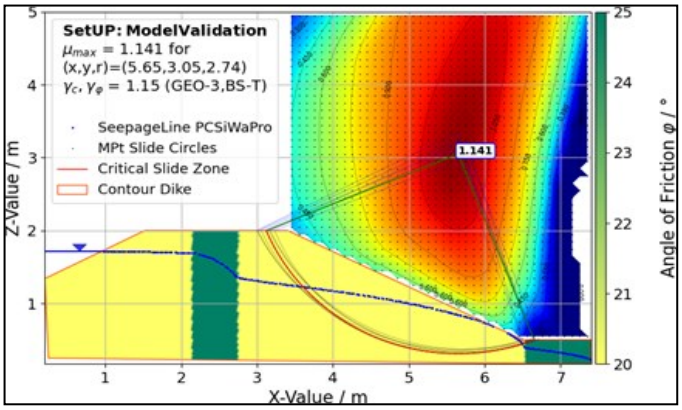

Figure 4: Test case output of the stability analysis based on PCSiWaPro-data and LEM-algorithm (Fleischer et al. 2022b)[2]

The hybrid modelling approach applied on levees is very suitable for the testing of new technologies under laboratory conditions, but requires profound experience with measuring and controlling systems. Furthermore, it supports the calibration or validation of mathematical or sensor based forecast systems and the deducing of recommendations for practical application.

[1] Fleischer et al. 2022a: (In: Proceedings of CIGOS 2021 in Ha Long, Vietnam), https://link.springer.com/chapter/10.1007/978-981-16-7160-9_30

[2] Fleischer et al. 2022b: (Proceedings of the 39th IAHR Congress 2022, Granada, Spain, paper submitted and accepted)

TRANSITIONS RESEARCH & DESIGN

Investigation, assessment and remediation of levee transitions

By Matthew Arthur, Environment Agency, UK

A transition is a single point or a zone in a flood defence structure where features such as structure type, material, geometry, subsoil or orientation change in a way that materially affects the performance of the structure during a flood. Evidence from historical floods is that most levee failures occur around transitions.

The UK Environment Agency commissioned a group of international experts, led by HRWallingford and supported by RHDVHaskoning to identify and consider the presence of transitions during flood defence condition assessment, quantify the effects of interfaces on flood defence performance (as expressed by fragility curves), and produce design guidance for fixing existing issues at transitions points. Four transition types were identified (Figure 5). Further analysis resulted in Type 2 transitions requiring bespoke investigation upon defect discovery due to the complexities in processes and failure mechanisms.

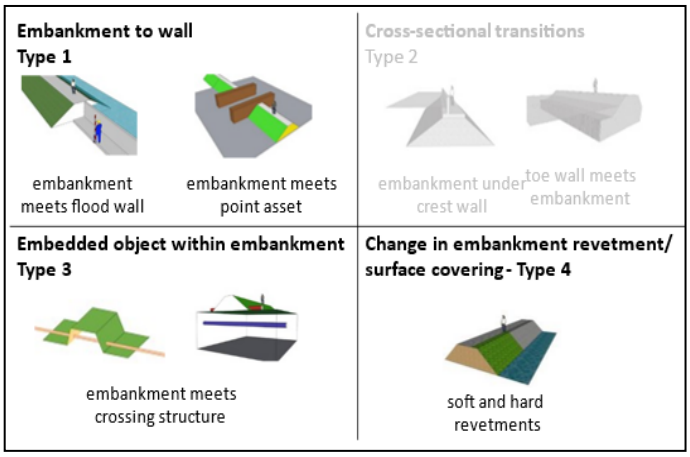

Figure 5: The four types of transition classified by project

1. The inspection and assessment guidance

The project developed a Guide which uses available data, field inspection and engineering judgement to determine whether a transition is weaker than the neighbouring defences. The Guide follows a tiered process (Tier 0, 1, 2 and 3) with each tier improving the accuracy and confidence in the assessment of transition performance (probability of failure) .

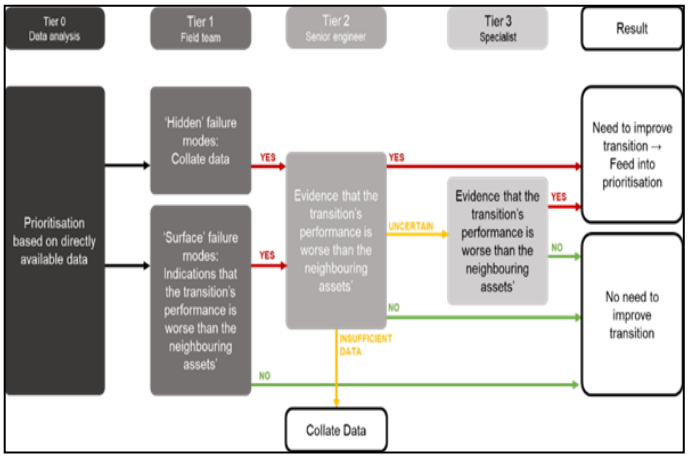

Figure 6: Transitions assessment process

2. The processes for evaluation of transition reliability (fragility curves)

Fragility curves were generated from one or a combination of Limit State Equations (LSEs) by expressing them in format z = F(R) – G(S). The new functionally built on the existing hrRELIABLE tool, to allow site data collected in the transition inspections, to be used directly in the generation of bespoke curves, for the two relevant failure modes.

3. Guidance on the design of remedial works for transitions

The guide is intended for the design of improvements to existing transitions, with the aim of achieving a situation where the transition is no longer the weakest point. The envisaged users are teams responsible for designing improvements, particularly senior engineers, in any flood defence asset management organisation. The intention throughout is that the guide is used alongside the existing guidance and standards, notably CIRIA (2013) principles 1-4.

What's next? The IT tools tested in the R&D combined with the design guide will form a valuable tool to inspect, assess and provide guidance for improvement methods and design approaches. A phased roll-out is planned to allow for iterative learning, with the initial focus being on a smaller number of higher risk transitions. The research reports will be available on the gov.uk website in late 2022. In the meantime, if you are keen to learn more about this R&D please see link to Public dissemination video.

ANNOUNCEMENT

EUCOLD WG Levee & Flood Defences – Webinar on temporary, mobile, demountable barriers (October 6, 11:00-13:00 CET)

When solid earthen embankments and concrete structures are no option, water and river authorities are choosing alternative flood protection measures, either being part of a permanent flood defence scheme, either applied as an emergency response.

The impact of extreme events such as rain bombs, with an increasing probability due to increasing development and climate change, failure of a water defence etc. can be reduced by the deployment of temporary solutions. Although sandbags have a long history, recent developments came up with easy to use, flexible and robust flood solutions for additional flood protection at unforeseen locations.

This webinar will focus on temporary, mobile and demountable flood barriers. These flood barriers provide a flood defence for a limited period (the duration of potential flood conditions), after which they are then removed until required again.

Water, river and coastal authorities are invited to share their experiences and thoughts with temporary, mobile and demountable flood barriers in practice: choosing a proper solution, installing during a flooding event, training (your) staff, maintaining the equipment.

Please let us know if you would like to participate as a presenter via lfd-eurcold@irstea.fr.

Don't hesitate to forward this announcement to those who are interested!
Adrian, Patrik & Rémy

DIGUE 2020 RESEARCH PLATFORM

First research device for coastal levees, made of soil-lime material.

By Laurent Peyras, INRAE, FR

INRAE, with its partners SYMADREM, Cerema, Gustave Eiffel University and Aix-Marseille University, inaugurated on October 13, 2021, the DIGUE 2020 research platform, located in the Camargue in the south-east of France.

This in situ laboratory, built against a hundred-year-old levee, aims to study the design and construction of an innovative concept of soil-lime levee, economically interesting and respectful of the environment. This platform, unique in France and internationally, will make it possible to assess the durability of this concept of coastal levee and to quantify the actions of the sea on the levees (swell, wave action).

Structured in several plots, the components of the research platform have received differentiated treatments. The performance of specific material compositions and the actions of the sea on the platform will be monitored and analysed over 20 years using high-tech instruments located at the heart of the structure.

This project was funded with the support of the Europe and received the support of the French state, the SUD Provence-Alpes-Côte d'Azur Region and the department of Bouches-du- Rhône.

Figure 7: DIGUE2020 research platform for coastal levees. Copyright INRAE

Local adaptation to climate change is a major challenge. For those located in coastal areas, the rise in sea level will lead to increased risks of flooding by marine submersion.

The south Provence-Alpes-Côte d'Azur Region has more than 2,700 km of river and coastal levees and nearly 250 managers. In France, there are almost 9000 km of levees. In this context and under the direction of INRAE, the maritime levee research platform DIGUE2020 has been considered and developed by several partners: SYMADREM (Interregional manager of levees in the Rhône delta and the sea), Aix-Marseille University, Cerema, and Gustave Eiffel University. It consisted in setting up a research platform on coastal levees in order to:

• reduce the risks of structural failure by breach caused by erosion, increase resistance to overflow, and quantify the effects of the actions of the sea on the levees;
• reduce the construction and maintenance costs of protection levees;
• reduce transport nuisances by limiting the supply of materials from distant deposits, and by using local soils considered mediocre compared to traditional techniques;
• better integrate the protection levees against marine flooding into the environment;
• enable the reinforcement of old dikes without deconstruction, using local resources and reducing the production of waste; and
• integrate an analysis of the management of the risk of marine submersion and the role of protection levees, by studying the perception and social representation of the risk of submersion.

This research platform DIGUE2020 studies 3 main questions:
• Design and construction of soil-lime levee in maritime context.
• Quantifying the consequences of the actions of the sea on levees.
• Quantifying the durability and performance of soil-lime levees and its material.

This research platform is intended to host other complementary research and development projects relating to maritime levees for protection against marine flooding, bringing together academic partners and the socio-economic sector (levee managers, industrialists, engineering offices), and over a target period of 20 years.

Do not hesitate to contact INRAE if you are interested in a collaboration!

Contact:
INRAE – Aix en Provence (France)
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sylvie.nicaise@inrae.fr

THE LEVEE TECHNICAL COMMITTEE (LE TC) UPDATE

By Adrian Rushworth, Environment Agency, UK

The origin of the LE TC was in 2015 when a Working Group on Levees and Flood Defences under the European Club was set up during the 25h Congress of ICOLD in Stavanger, Norway. This was followed by the initiation of an ICOLD technical committee on levees (TC LE) during the Prague meeting in 2017. The goals of the TC remain to address technical, governance and policy issues related to levees and flood defences. The committee currently includes more than 20 member countries.

The work of the TC is currently focused on two Bulletins:

- Levees around the world, Characteristics, Risks and Governance. A first version was produced by the ICOLD European Club (“European and US Levees and Flood Defences/ Characteristics, Risks and Governance”) in July 2018. This report is currently being expanded into a bulletin which includes more countries.

- Comparison of dams and levees; similarities, differences and recommendations.

It is anticipated that these will become cornerstone documents for the TC and for the role of levees within ICOLD and the wider industry.

The TC has also drafted a Position Paper that shows the importance of levees around the world. The paper will be a foundation for the future of the TC. It will demonstrate the relevance of levees to ICOLD and to other organisations and groups such as Governments, finding organisations, researchers.

Finally, the TC has been planning future activities and possible levee-related topics in ICOLD.

During the 27 Congress in Marseille the TC will meet to review progress and plan future work. Topics include,

- Discussion of how and when to update the levee situation bulletin.

- Timeline and activities for finalising dams levee comparison bulletin.

- Development of position paper, including additional topics for recommendations.

- Discussion of ideas for future work areas.

THE LEVEE SAFETY PARTNERSHIP

Sharing learning from Bellingham, 2022.

By Johnny Lyttle, UK; Alex Roos, NL & Jason Needham, US

The Levee Safety Partnership is a technical alliance between FCRM Engineers and Researchers from the Netherlands (Rijkswaterstaat), the United States (the US Army Corps of Engineers, USACE) and England (the Environment Agency). As the name suggests, the group is primarily focussed on levees, and has supported a wide range of levee research and standards, most notably the International Levee Handbook, which was published in 2013 and is still available online as a free download.
The group meets every six months, most recently in April 2022, where the meeting was hosted in Bellingham, USA.

The headline item at the Bellingham meeting was a comparison between the 3 organisations' technical methodologies when assessing the risks arising from the condition of a levee, and how this is affected by the legislative and governmental environments in which our organisations operate. For example:

- The Rijkswaterstaat approach is predominantly mathematical, driven by a legislative duty to keep the risk to life below a 1-in-100,000 probability per year. Water levels, levee design details, damage observations and receptor data all feed into equations and model simulations, which inform levee owners whether that standard of protection is achieved, or whether further work is needed.
- The US Army Corps of Engineers approach is more competency based, using teams of qualified experts to assess the challenges, assess options, and agree by consensus what action is required. They use event trees to conduct failure probability analyses for each relevant failure mode, which enables them to produce definitive risk assessments.
- The Environment Agency approach uses a two-tiered approach which utilises a simple mathematical scoring system for initial assessments, but when that score is indicative of a significant risk, the assessment is escalated to a qualified engineer who leads a more detailed assessment. Empirical 'fragility curves' are used to convert scores from the initial observation into probabilities of failure.

It is also worth noting that the decisions about interventions (i.e. repairs or improvements) are primarily driven by economics in the Environment Agency, which is a fundamental difference in philosophy from the Rijkswaterstaat and USACE approach, which are driven by meeting life risk standards with elements of economic efficiency.

At the meeting, we discussed the threats to levees arising from climate change, not only from changing water levels and wave dynamics, but also from higher temperatures and the effects that will have on levee water content and the resultant change in geotechnical behaviour.

We also discussed how we contribute to climate change with the carbon emitted from the construction and maintenance of levees. In future meetings, we're going to explore that further, considering options that could help us reduce our footprints, like reusing materials, reducing imports, reducing emissions from maintenance vehicles, etc.

We set up task groups to explore the high-priority technical issues of overtopping erosion (another hazard that we expect to see more of with climate change) and internal erosion/piping. We hope to work with the EUCOLD Levee Technical Committee to see how we can collaborate there.

And finally, we were given a tour of levees in the Nooksack Catchment in Washington State. During the floods in November 2021, there were several levee breaches which now have temporary fixes in place but are awaiting permanent repairs. We learned of new approaches to sealing a levee breach, both during the event (whilst water is gushing through the breach) and after. We also saw how the American governance arrangement allows local communities to take a proactive role in the supporting their levee repairs.

Figure 8: The Levee Safety Partnership, visiting levees in the Nooksack Catchment, Washington State

If you would like to find out more about the work of the Levee Safety Partnership, you can contact johnny.lyttle@environment-agency.gov.uk.

FORTHCOMING EVENTS

ICOLD 27th congress and 90th annual meeting takes in Marseille place from 27 May to 3 June 2021. The detailed program and the second bulletin are available on the dedicated web site https://cigb-icold2022.fr/en/.

Webinars

Following the success of the 2021 webinar on animal activity on levees the EUCOLD LFD WG will organise two more webinars.

October 6th, from 11:00 to 13:00 CET, on **temporary, mobile, demountable barriers (or defence structures)**. Please add the date in your calendar now with more details to follow later. The webinar will include different presentations and a large part of discussion involving the audience.

The WG hope to organise the second webinar before the end of the year.

Please let either Rémy Tourment, Adrian Rushworth or Patrik Peeters have suggestions for the topic we should cover.

FRANCE DIGUES

The French Association of Levee Managers

By Béatrice Tourlonnias, France Digues, FR

France Digues Association has been leading the **network of French levee managers** since its creation in 2013. The members of France Digues are public authorities in charge of levees management (and other flood protection structures). They are involved in a series of events and contribute to its actions. Today, it counts more than 100 French members from all over the country and overseas.

France Digues aims to represent and reinforce the levees management profession by facilitating knowledge sharing, technical visits and activities on levee practice.

Figure 9: Visit during a technical day on the coastal levee in Noirmoutier. Photograph from Beatrice Tourlonnias

In this context, many tools and activities are proposed to the members, specifically:

- Provide access and assistance to the SIRS Digues (Spatial Reference Information System) **[1]**, a software that can be used to centralize, capitalize and process data for the management of levees;
- Connect and support levee managers in their work duties (by providing access to a documentary resource centre on line, hosting a professional forum, answering to specific questions from members, sending newsletters, etc.);
- Organize Technical Days and webinars on different topics (geotechnics, hydraulics, day-to-day levees management, flood risk management, regulations, etc.) and partner events (Digues 2019, PREVIRISQ'Inondations Workshop, etc.); and
- Lead working groups, write and share technical and regulatory information and publications related to the flood defence assets (i.e., Explanatory note on technical and regulatory concepts related to levee systems, Provision of works: Transfers and Agreements).

Today, France Digues is well recognised by the French Ministry of the Environment as a major partner regarding the management of levees and flood defence assets.

[1] TOURMENT, R., TURPEAUD, B., MAUREL, P. - 2004. A SIRS for flood protection dikes management: from user`s needs to application. Selected problems of water engineering, Politecknika Krakowska Cemagref: results of cooperation, Krakow, POL, 9-11 October 2003. p. 167-180

It is based on a network of technical partners including the CFBR (French COLD, Committee on Large Dams). To facilitate technical development, it has recently signed a partnership agreement with CFBR. This is a two way process, CFBR keeps the members of the association informed on professional development and France Digues shares the managers knowledge and experience to contribute to this work.

France Digues wishes to expand these exchanges with French and international partners to enable levee managers to increase their skills and strengthen alliances in this sector. For example, in the past our members contributed in the development of the International Levee Handbook project.

Figure 10: Visit of a hydraulic facility in Steinbourg. Photograph from Beatrice Tourlonnias

For more information: www.france-digues.fr |contact@france-digues.fr | +33 (0)4 76 48 81 05

We are always looking for information from YOU to share in the newsletter and on our web site! We need diversity in terms of contributing countries, and are eager to learn from every member country. We welcome contributions from any countries, even non-European ones.

A CALL FOR CONTRIBUTIONS

- Information about levees and flood defences projects and works.
- News, media or press releases on current flood or storm events involving levees and flood defences.
- Current, ongoing or recently completed research projects.
- Documents related to levees or flood defences: handbooks, guidance, reports and regulations.
- Information on any event or conference relating to levees or flood defences.
- Links to informative / educational web sites and related organisations.
- Pictures to be used in the web site banner, randomly chosen every time a page loads (resolution has to be 1024x300)
- Contact the WG web site team: lfd-eurcold@irstea.fr

POLDER2C'S

Update on research activities for climate adaptation

By Francien Horrevorts, Communications Advisor Polder2C's

How well do our levees withstand continuous water overflow or wave overtopping? How can we improve our emergency response plans? And how can we make sure all experts have access to the latest knowledge and the next generation of water managers can be educated? These are the main questions the Polder2C's project tries to answer in the aim to adapt to climate change. In this article you will find an update on the Polder2C's research activities.

Living Lab Hedwige-Prosperpolder

For the last two years, many experiments and exercises have been done as part of the Polder2C's project. Most of these activities took place in the Living Lab Hedwige-Prosperpolder, exactly on the Dutch-Belgian border. The depoldering of this polder offered a 6 km^2 Living Lab environment, where current and innovative techniques, processes, methods and products were tested on existing levees.

Research activities

Numerous research activities and tests have been done in the Living Lab. During the experiments on the levees, various impressive machines were used, such as a continuous overflow generator, a wave overtopping simulator and a wave impact generator (Figures 11 and 12). In addition, portable devices were deployed for assessing erosion resistance, such as the Jet Erosion Test, the Grass Sod Pulling Instrument and the Fire Hose Method.

Figure 11: Overflow tests. Photograph from Mischa Keijser

Figure 12: Wave impact generator in action. Photograph from Mischa Keijser

The damages that were caused by these experiments, have been used for testing innovative repair measures, such as rock bags. Also, several inspection exercises took place on the levees using a new app to report damages, App2C. Furthermore, different techniques were used to explore the extent, size and frequency of animal burrowing in the levees. Finally, in the field of emergency response a number of mobile barriers were tested and a pilot study was executed using the BreachDefender. This is a pontoon used by the Dutch Ministry of Defence. It was studied whether the BreachDefender can be used to stop or slow down the breaching process (Figure 13).

Figure 13: Breachdefender pilot. Photograph from Mischa Keijser

Curious what these activities looked like? For an overview of last year's research, watch this video.

Turn data into tools

Most of the planned experiments have now been finalised and it is time to start interpreting all collected data. The partners of the project have gained a lot from participating in the project. They have broadened their national and international network of experts, they have exchanged knowledge and practice, look back on valuable collaborations and look forward to finalise the project together. Early next year outcomes and tools from Polder2C's will be presented during the closing conference in Antwerp.

Polder2C's on tour

Want to learn more on the Polder2C's project and meet in person? Polder2C's will participate in conferences near you. Come visit our booths to learn more and collect a Polder2C's souvenir at one of these events:

- ICOLD congress – Marseille, France - May 27 to June 3
- Flood & Coast 2022 – Telford, United Kingdom, June 7 to 9
- Knowledge Days Inspection Flood Defences – Arnhem, the Netherlands - June 29 to 30

Polder2C's is an Interreg 2 Seas project, a collaboration of partners from Belgium, England, France and the Netherlands. Together, they aim to adapt and protect the 2 Seas region against the effects of climate change, such as the rising sea level and the more frequent occurrence of heavy storms. Polder2C's receives a contribution of 3.9 million euros from the European Interreg 2 Seas program 2014-2020, co-financed by the European Regional Development Fund

Feedback Request!

We are always seeking for ways to improve this newsletter content and topical areas, and would welcome your feedback to lfd-eurcold@irstea.fr

FAILURE PATHS FOR LEVEES

A report from ISSMGE TC on Levees

By Rémy Tourment, INRAE, FR

Levee breaches are often the result of a combination of mechanisms, which may happen simultaneously, and/or successively. These interactions are complex and difficult to anticipate in design and assessment as well as during a forensic analysis of an actual breach. The ISSMGE TC201 has published a report on the failure paths (that can also be called failure scenarios). It is available on the ISSMGE Online Library.

The basis for this report is a compilation of case histories, and of failure paths used for assessment and design. **Part A** of the report provides an overview of the key concepts in this report and presents the proposed failure tree and overview of important aspects per event in the tree. The section finishes with a discussion and recommendations. **Part B** contains the collection of the contributed failure paths for case studies, these failure paths are illustrated in the framework (Figures 14 and 15).

Figure 14: Failure tree involving a sand boil (Rémy Tourment)

Figure 15: Sand boil near the Agly river levees (Rémy Tourment)

Part C contains the collection of contributed failure paths that are used for assessment and design (Figure 16). A glossary of key terms used is added at the end of the report.

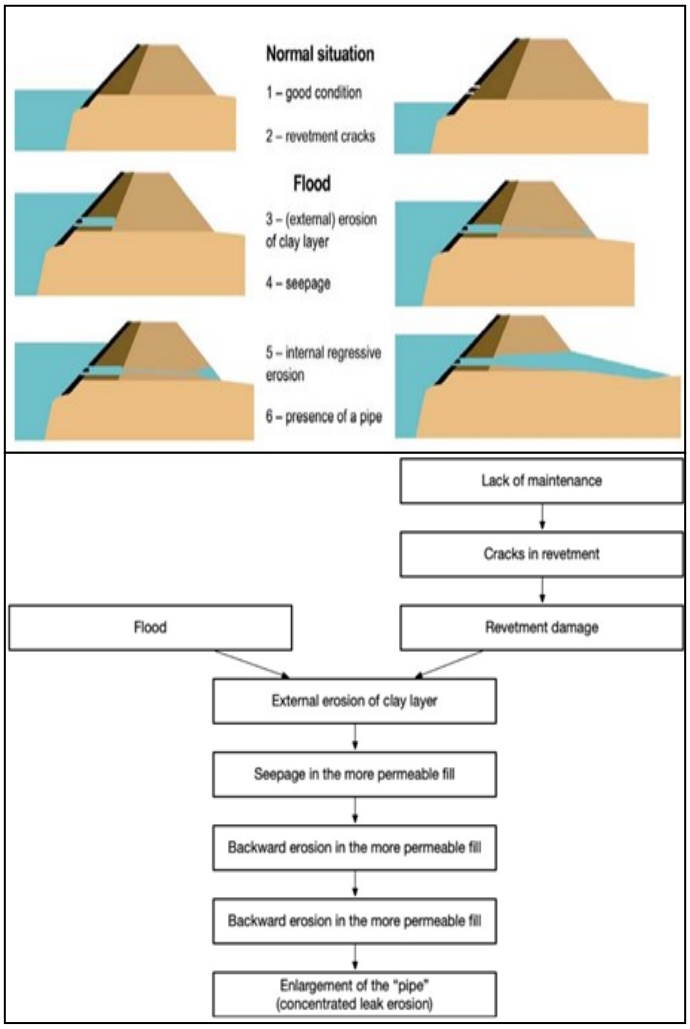

Figure 16: Failure path involving failure of a revetment, external erosion of a clay layer and internal erosion of a more permeable layer (Rémy Tourment)