Abstracts and powerpoints online meeting EWG-IE 2020

Internal erosion at the field scale

Thursday February 4th, 2021

4.00-7.00 pm CET

1 An experimental earthfill embankment dam with built-in defects in the core - detection and time dependent evolution of defects - *Johan Lagerlund, Peter Viklander, Christian Bernstone (Vattenfall)*

2 Progression of backwards erosion piping estimated from field scale pore pressure measurements - *C. Bocovich (Colorado School of Mines / USBR), W. Kanning (Deltares / Delft University of Technology), M. Mooney (Colorado School of Mines)*

3 Backward Erosion piping in tidal sands – *Marc Hijma (Deltares), Gert-Ruben van Goor (Fugro)*

4 Can we hear the backward erosion piping (BEP)? Proof of concept for fiber optics DAS based BEP monitoring - *J.P. Aguilar López (Delft University of Technology), T.A. Bogaard (Delft University of Technology), A. Garcia Ruiz (Universidad de Alcalà), M. Gonzàles Herràez (Universidad de Alcalà)*

5 The effect of subsurface heterogeneity on well discharges - *W.J. Dirkx, T.G. Winkels (Utrecht University)*

6 Application of the coarse sand barrier at pilot-site Gameren: 3D flow aspects - *André Koelewijn, Esther Rosenbrand, Vera van Beek (Deltares)*

7 Length-effects in reliability analysis of internal erosion in earthen dikes - *Jochem Caspers (HKV)*

8 Field measurements on a natural sand boil along the Po river (Italy) - *Michela Marchi, Guido Gottardi, Laura Tonni (Universita di Bologna)*

9 Case studies in using internal stability criterion to characterize piping, softening and dispersive soils - *Emoke Imre (Óbuda University), Daniel Barreto (Edinburgh Napier University), János Szendefy (BME), Levente Kovács (Óbuda University)*

10 The sand boil generator and a new technique to control sand boils - *Axel Montalvo-Bartolomei (U.S. Army Corps of Engineers)*

An experimental earthfill embankment dam with built-in defects in the core – detection and time dependent evolution of defects

Johan Lagerlund[1,3], Peter Viklander[2,3] and Christian Bernstone[1]
[1]Vattenfall AB, R&D; [2]Vattenfall Vattenkraft AB; [3]Luleå University of Technology

Abstract

The purpose of this experimental dam research is to enhance the capability to detect damages in impermeable cores of fine-grained till of earthfilled embankment dams. A scaled embankment dam with embedded artificial defects, to be detected by geophysical methods and to learn about internal erosion, has been built at Vattenfall's laboratory facilities in Älvkarleby, Sweden. The 4 meter high, 16 meter wide, and 20 meters long dam was built as a conventional earth embankment dam where the impermeable core is supported by two connecting filter zones and gravel support fill (Figure 1). The dam was built into a reinforced concrete support structure to be fully controlled. The bottom plate of the concrete structure was founded on sand and the supporting side walls had a slope of 1:8.

The built-in well defined defects in the core, representing faults that eventually can evolve to a dam failure are:

1. Wooden cube with sides of 0.4 m.
2. Horizontally rectangular permeable zone passing through the core (0.1 m high and 0.5 m wide).
3. Vertically loose zone (elongated zone with a diameter of 0.3 m and a height of 2.5 m).
4. Cube of solid concrete with sides of 0.5 m.
5. Permeable horizontal zone through the core at one abutment (0.2 m x 0.2 m).
6. Separated filter on the upstream side.

These defects were, based on previous synthetic modelling, designed to be realistic in size, and large enough to be detected by geophysical measurements. The water reservoir was filled up with a velocity of 0.2 m/day in the early summer of 2020. Evaluations of the results from the measurements will continue throughout 2021.

The dam site has been given a weather shelter to provide full control of the water balance into the upstream reservoir. Leakage-water through the dam is being physically divided into seven sections and the flows are measured separately at Thomson weirs. As can be seen from the reservoir level and corresponding total leakage flow, the dam exhibits self-healing of the core (Figure 1).

The geophysical and geotechnical research is a collaborative work of several research organizations, with research groups working on the electric-resistivity imaging, seismics, temperature and geotechnical monitoring respectively. At the workshop, more details and experiences of the test dam will be presented together with the scientific program of the project.

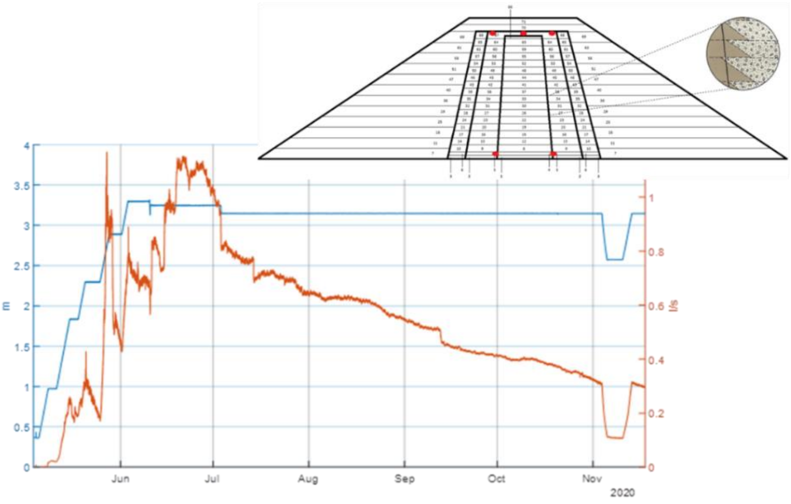


Figure 1. A cross section through the dam, and data on the reservoir filling with the corresponding total leakage.

An experimental earthfill embankment dam with built-in defects in the core

Detection and time dependent evolution of defects

Johan Lagerlund (Vattenfall AB)
Peter Viklander (Vattenfall AB)
Christian Bernstone (Vattenfall AB)

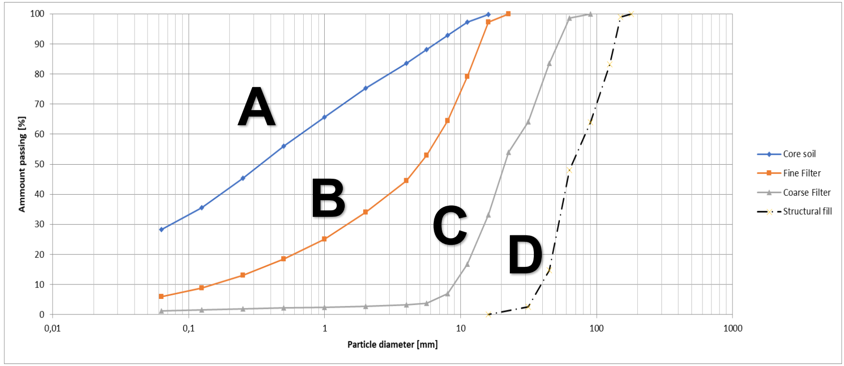
Introduction and objective of project

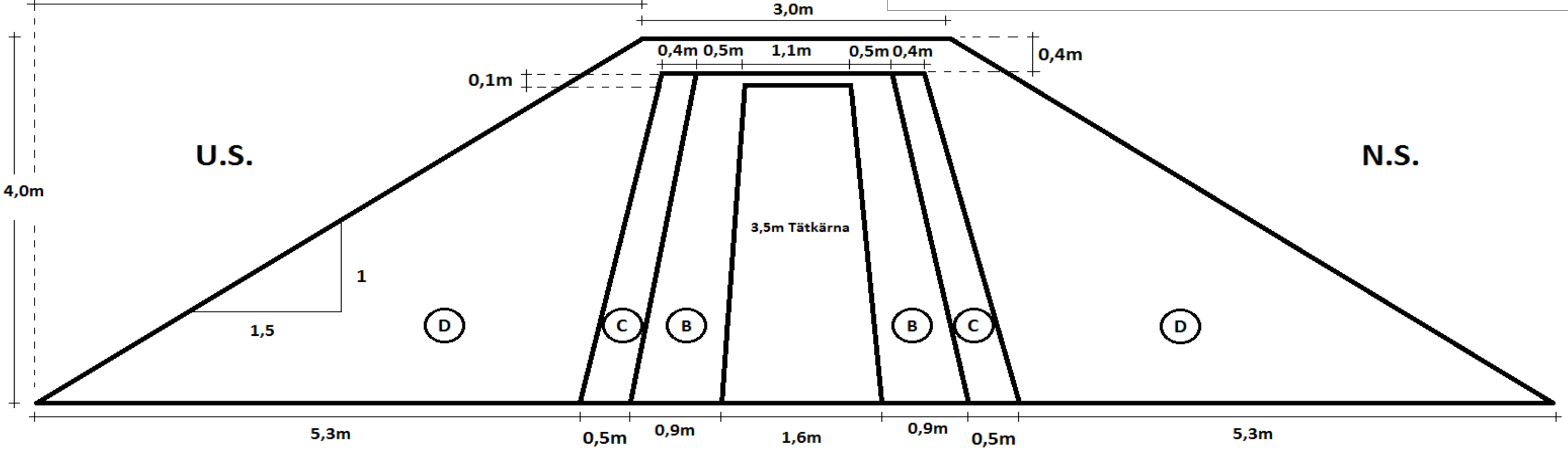
The purpose is to enhance the capability to detect damages in embankment dams caused by internal erosion in impermeable cores of fine-grained till.

- Build an experimental embankment dam with artificial defects in a protected environment.
- None-destructive methods to localize defects.

Earthfill embankment dam design

A. ***Core soil*** (till, 0/16mm)
B. ***Fine filter*** (crushed rock, 0/22mm)
C. ***Coarse filter*** (crushed rock, 8/64mm)
D. ***Structural fill*** (crushed rock, 16/150mm)



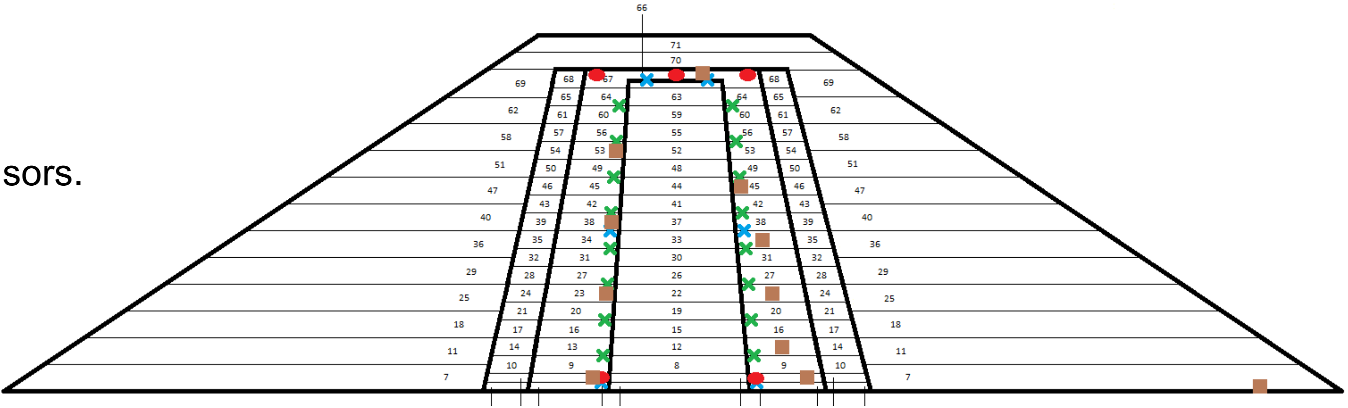


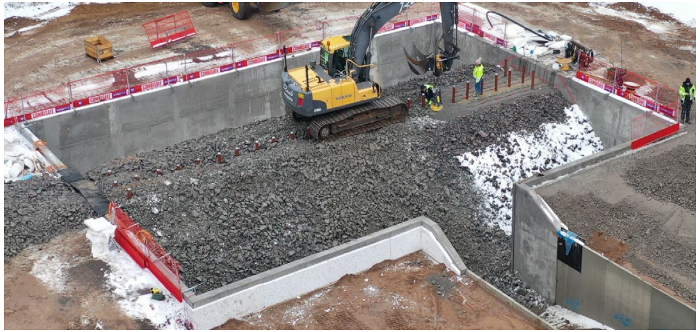
2021-02-04

VATTENFALL

Earthfill embankment dam design

- 6 artificial defects.
- Geophysical sensor cables.
- “Classical” geotechnical sensors.





Abutments and seepage

- Leaning (1:8) abutments.
- Sectionized seepage

Built-in defects

- 6 different defects in total that may be caused due to internal erosion, large enough to be detected by the detection methods.

1 and 2 - Horizontal permeable zone

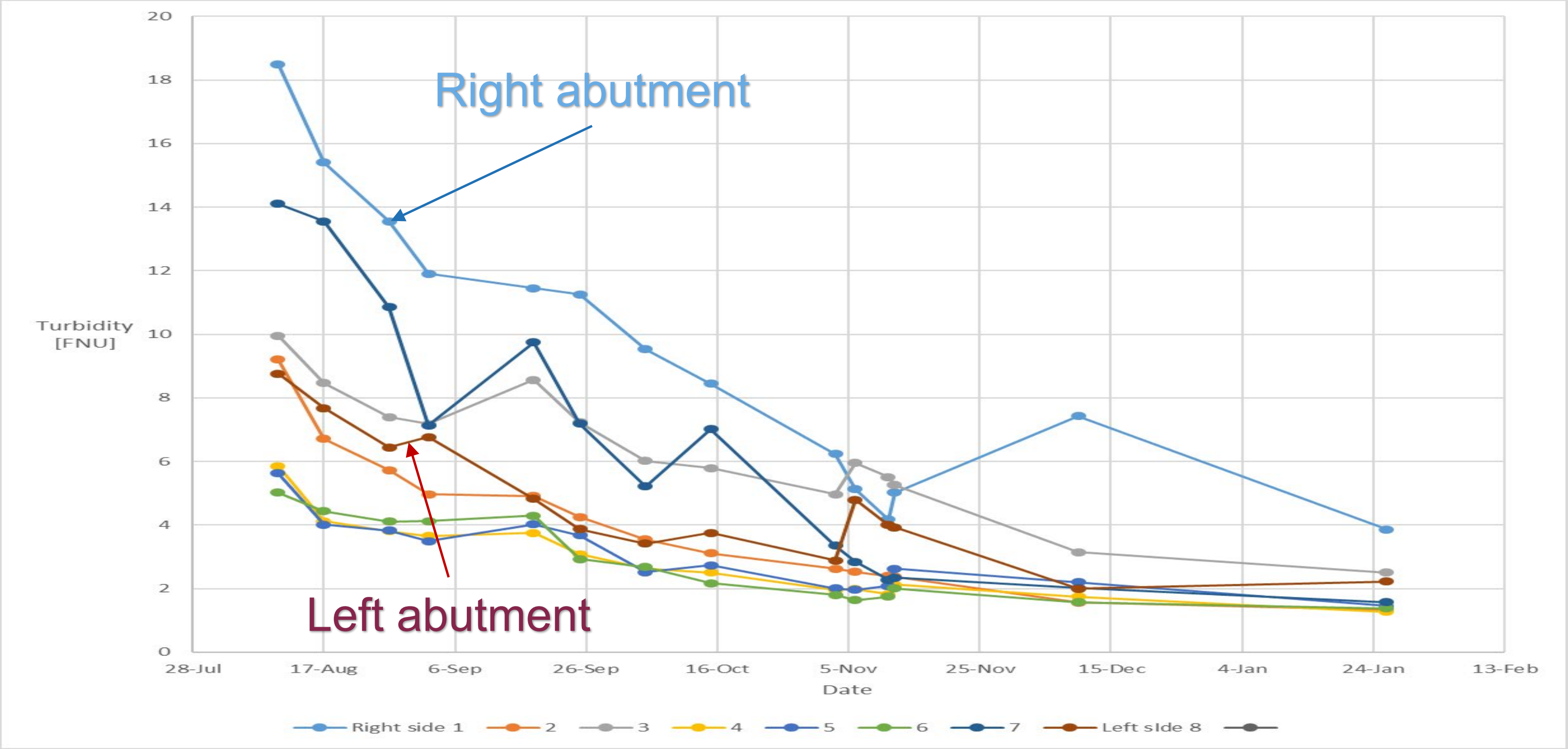
Built-in defects

3 and 4 – “Cavity” and ***Lump of concrete***

Built-in defects

5 and 6 - Vertical loose zone and *Filter defect*

Turbidity


Right abutment
Left abutment
Turbidity [FNU]
20
18
16
14
12
10
8
6
4
2
0
28-Jul
17-Aug
6-Sep
26-Sep
16-Oct
5-Nov
25-Nov
15-Dec
4-Jan
24-Jan
13-Feb
Date
Right side 1
2
3
4
5
6
7
Left side 8

Forensics

What can we learn and how will the dam look after the project?

Final words

Data and analysis will be available with time!

QUESTIONS?

johan.lagerlund@Vattenfall.com

Progression of backwards erosion piping estimated from field scale pore pressure measurements

C. Bocovich
Colorado School of Mines (2013-2019), Bureau of Reclamation

W. Kanning & M. Mooney
Deltares, Delft University of Technology, Colorado School of Mines

This presentation will demonstration the spatial and temporal progression of backwards erosion piping estimated by inverting pore pressure measurements collected during the IJkdijk 2009, Test 2 experiment.

The IJkdijk experiments included a series of full-scale tests conducted to better understand the progression and monitoring of backwards erosion piping. Under these conditions, direct observation of the progression of backwards erosion piping is not possible, unlike small and medium-scale experiments with glass coverings, due to a clay dike overlaying the sandy aquifer. To address this issue, densely spaced pore pressure measurements were inverted to estimate spatial changes in hydraulic conductivity at consecutive time steps.

Comsol *Multiphysics* version 5.2a, a finite element software, was used to create a 3-dimensional model of the IJkdijk 2009, Test 2 experiment and model fluid flow assuming a transient Darcy equation. The 2-dimensional, gradient based inversion was restricted to a single layer of elements at the top of the aquifer, immediately beneath the clay embankment. The 2-dimensional area allows for backwards erosion to progress longitudinally and transversely, however, assumes that progression in depth is negligible. The inversion estimates spatial increases in hydraulic conductivity, based on the spatial distribution of measured pore water pressures. The areas of increased hydraulic conductivity were assumed to be locations of erosion due to backwards erosion piping.

The estimated backwards erosion channels compare well with direct observations and measurements taken during the IJkdijk 2009 experiment, including those of: pore pressure trends, the embankment collapse pattern, sand boil observations, measured flow rates, and the time and location of breach at the upstream reservoir. Although this inversion is highly non-unique and non-uniform, these agreements demonstrate confidence in the estimated results.

Results indicate that backwards erosion progression, at the field scale, is highly non-uniform in space and in time. Multiple channels are estimated, progressing both longitudinally and transversely. This highlights that backwards erosion progression is not linear and should be assumed to progress in multiple directions under multiple channels.

Common predictive models assume backwards erosion piping progresses in a straight, 1-dimensional pattern. To address this assumption, the maximum length of the channel system estimated by this inversion was calculated and compared with both predictive models and a 1D linear regression of IJkdijk 2009, Test 2 data.

BUREAU OF RECLAMATION

Backwards Erosion Piping

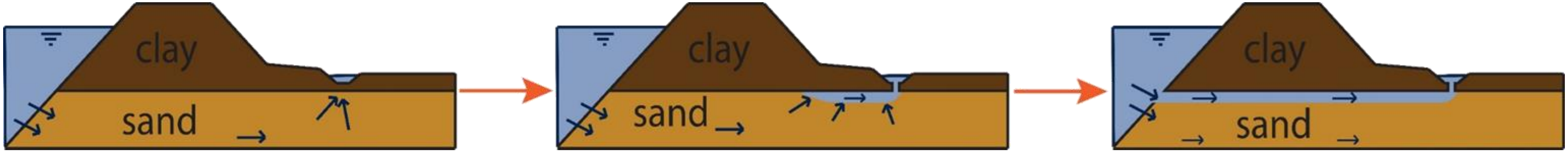
Understood through data driven modeling

Carolyne Bocovich

Acknowledgments

- Wim Kanning and Mike Mooney (PhD Advisor)
- Colorado School of Mines, Deltares
- National Science Foundation: NSF IGERT SmartGeo Program (DGE-0801692) and NSF PIRE Program
- United States Society of Dams

Backwards Erosion Piping (piping)



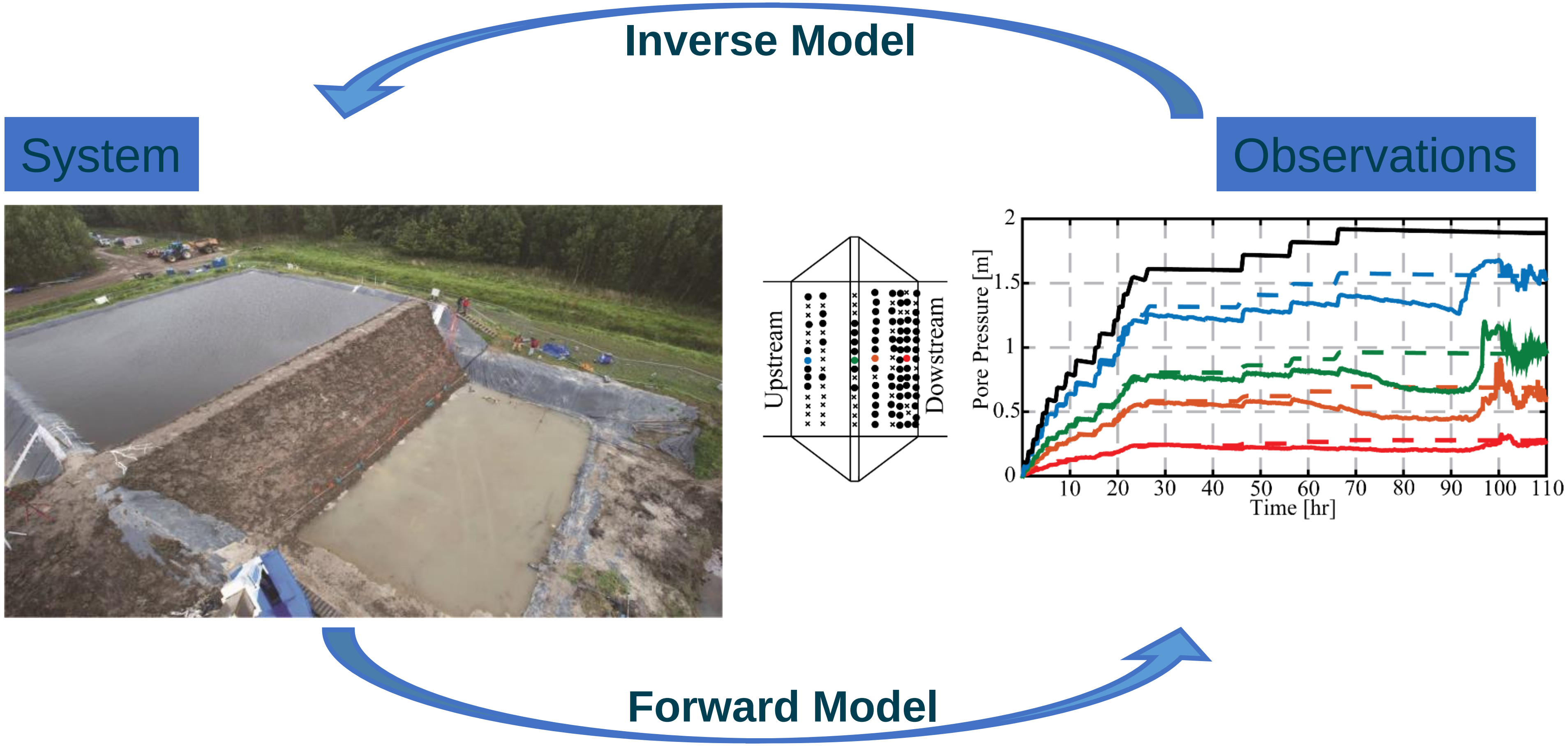
- Initiates at the downstream toe
- Progresses toward the upstream source (reservoir, river, …)
- Erodible soil underlying a material that will support the pipe (such as cohesive soil)
- Occurs internal to the structure, can not observe directly

IJkdijk Experiments

- better understand piping mechanism
- ability to monitor piping progression

Figures from or modified from van Beek, 2015

IJkdijk inversion



Inverse Model

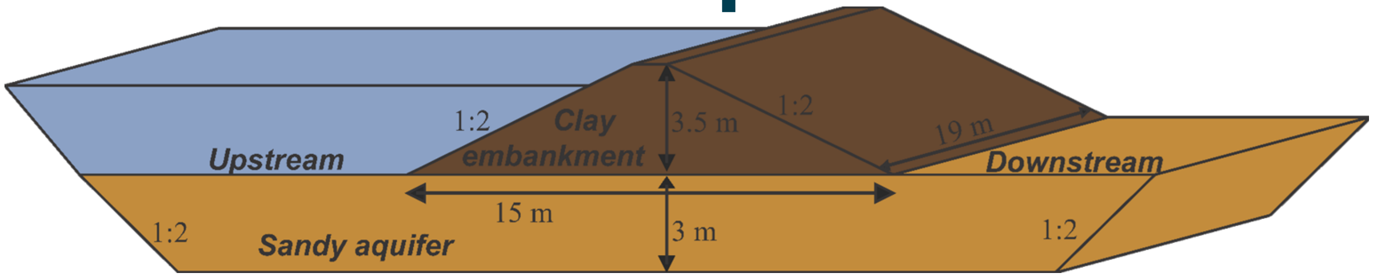
System

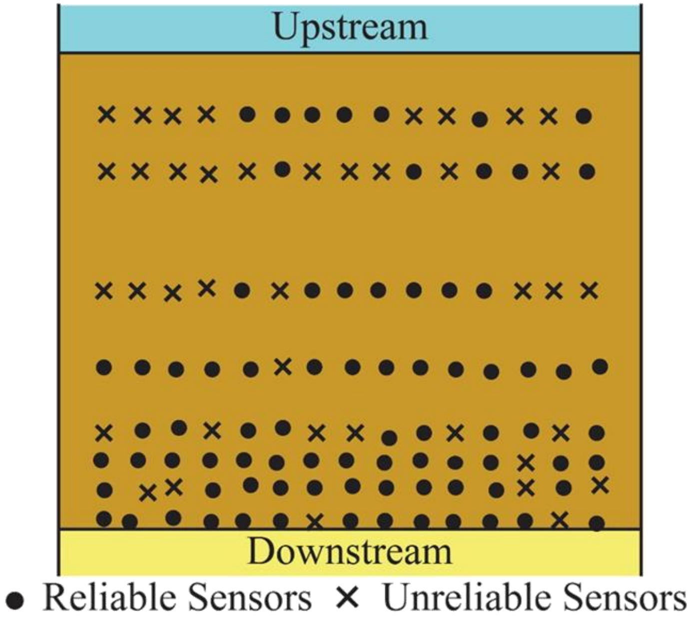
Observations

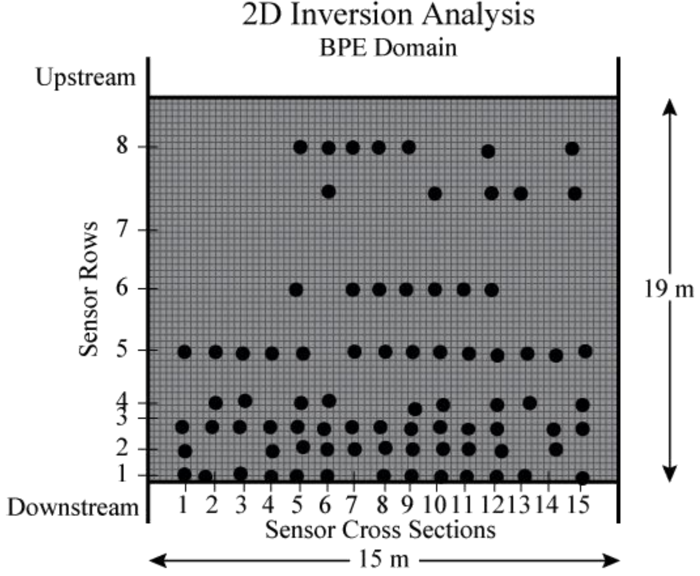
Forward Model

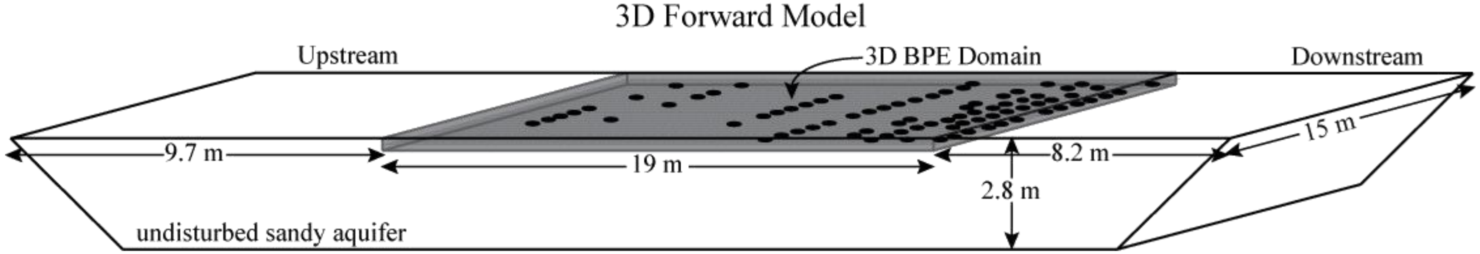
- Use pore pressures collected during the IJkdijk experiments to inform estimates of the hydraulic conductivity.

Full Scale Experiment: IJkdijk 2009, Test 2



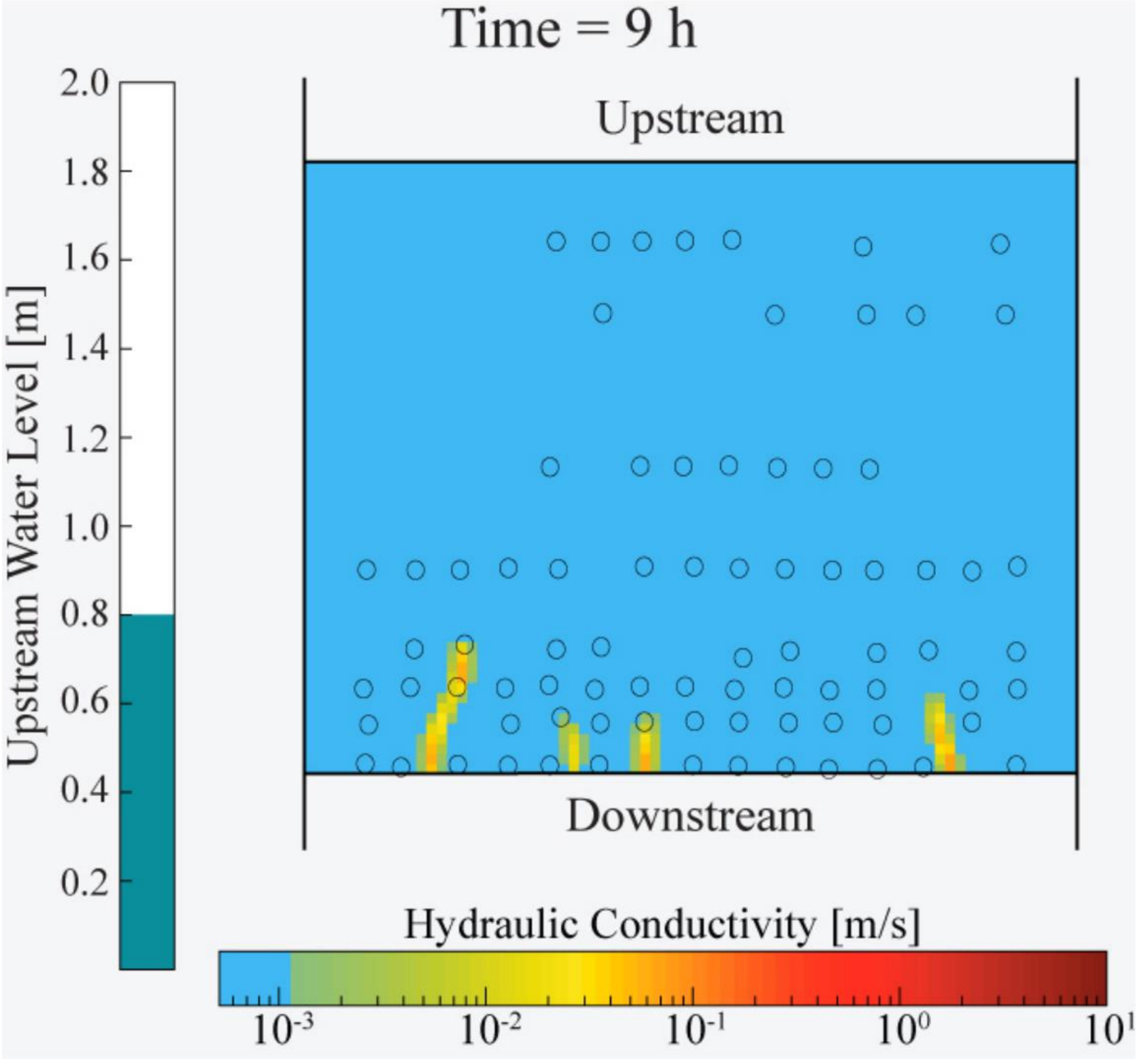




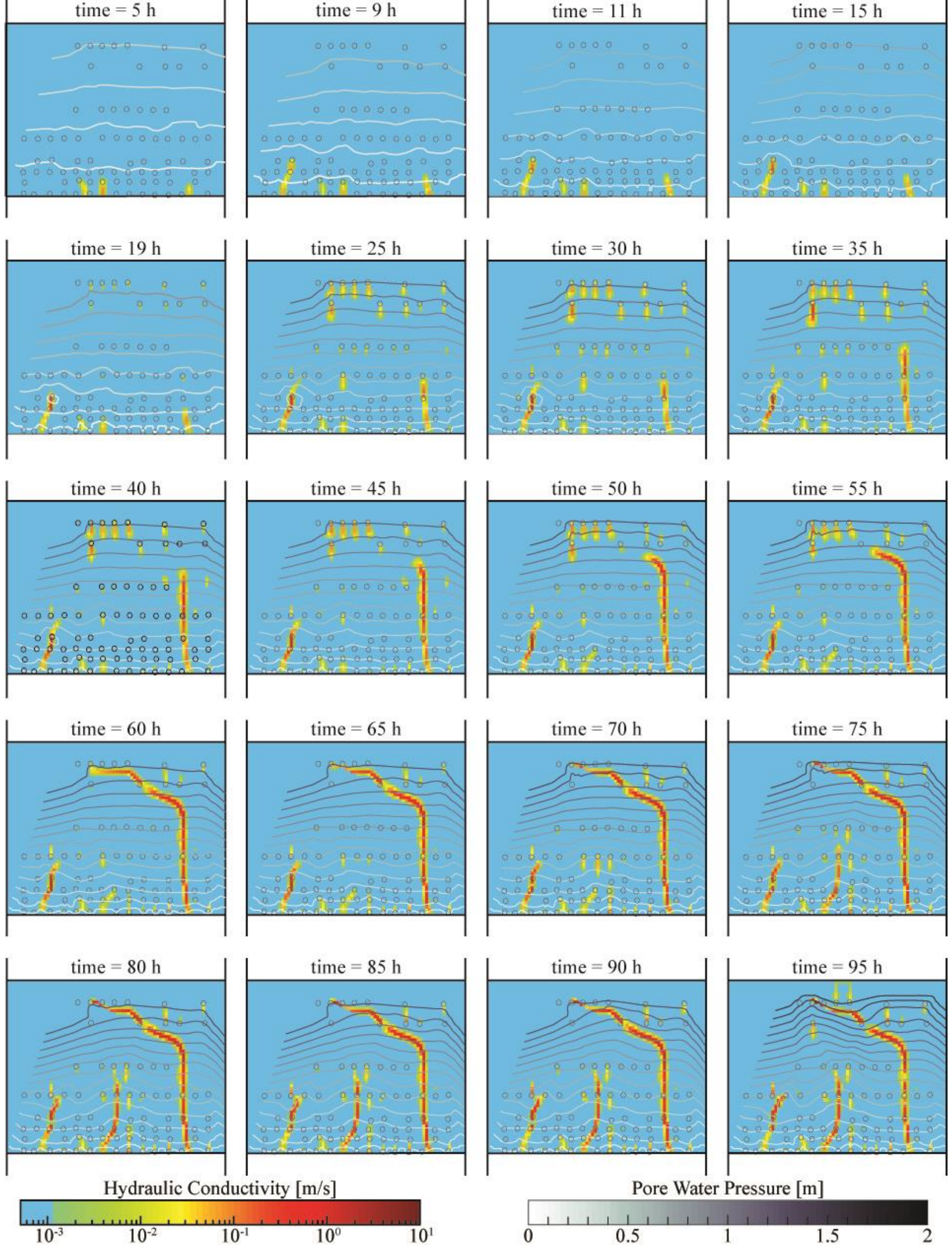


- Finite element model based on IJkdijk 2009, Test 2 using COMSOL Multiphysics
  - Forward model: 3D Transient Darcy Flow
  - Inverse model: 2D based on Guass-Newton

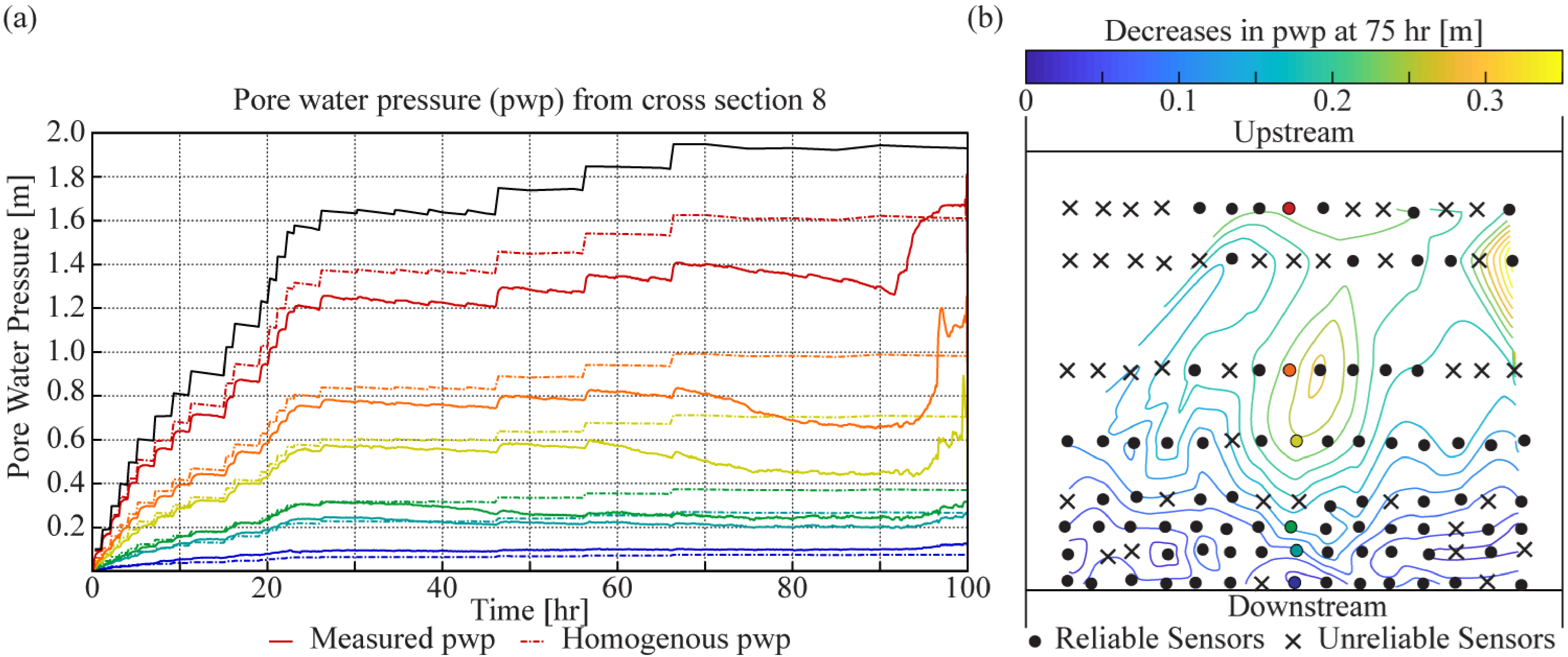
IJkdijk Inversion



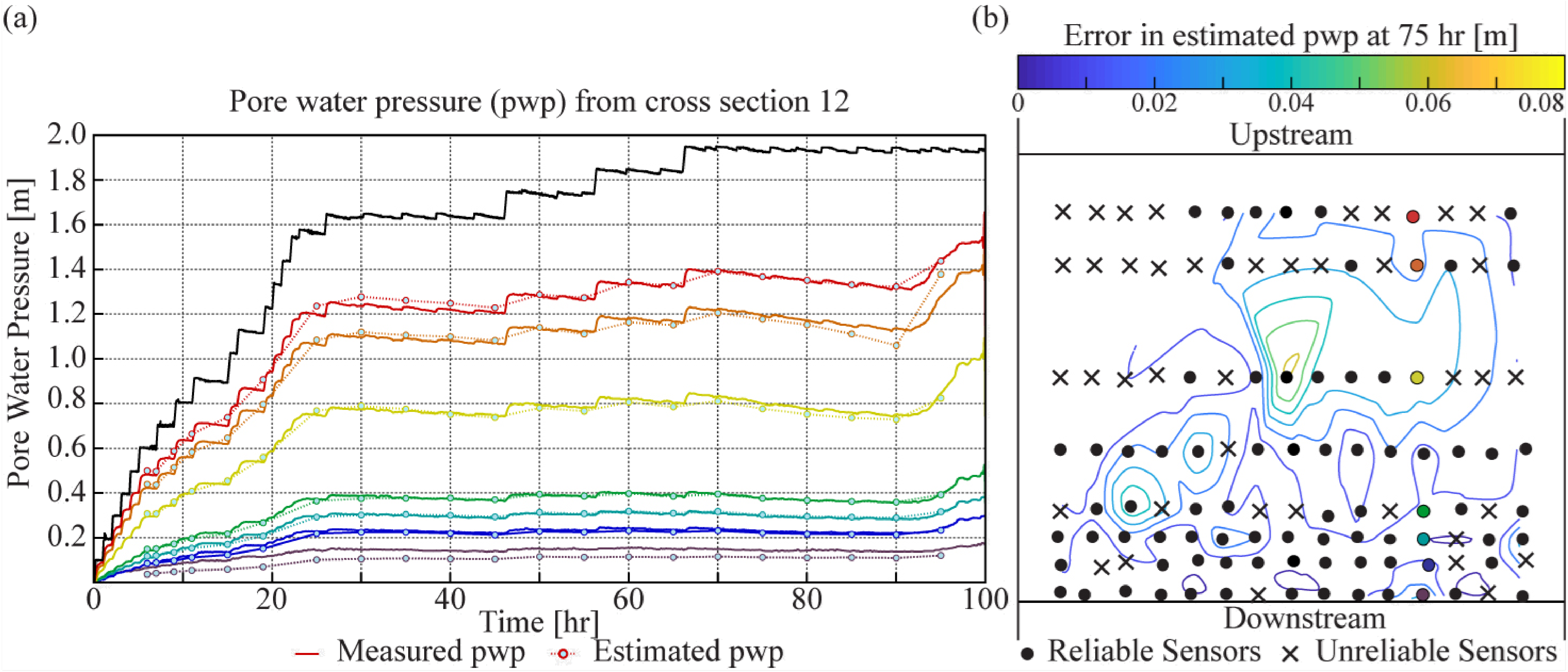
IJkdijk Inversion time lapse



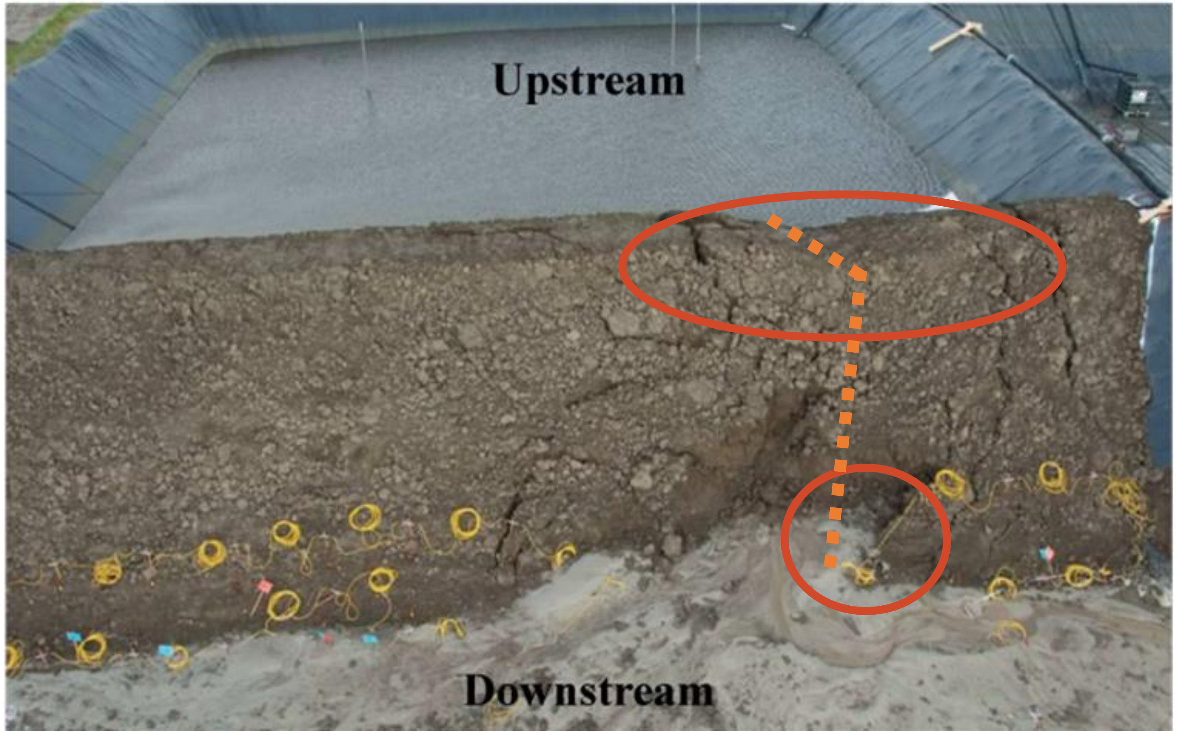
Comparing PWP: before inversion

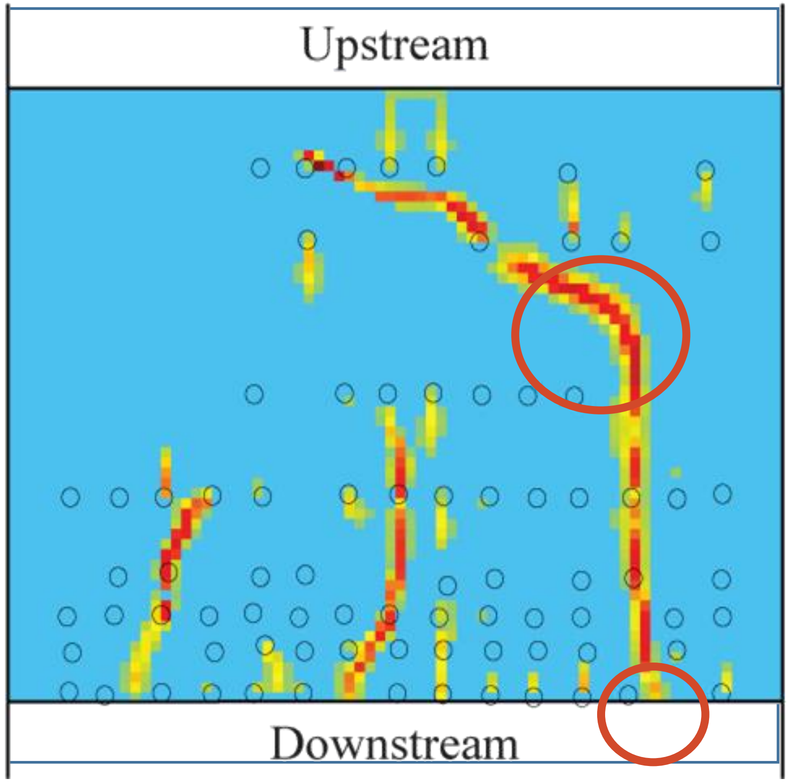


Comparing PWP: Post Inversion



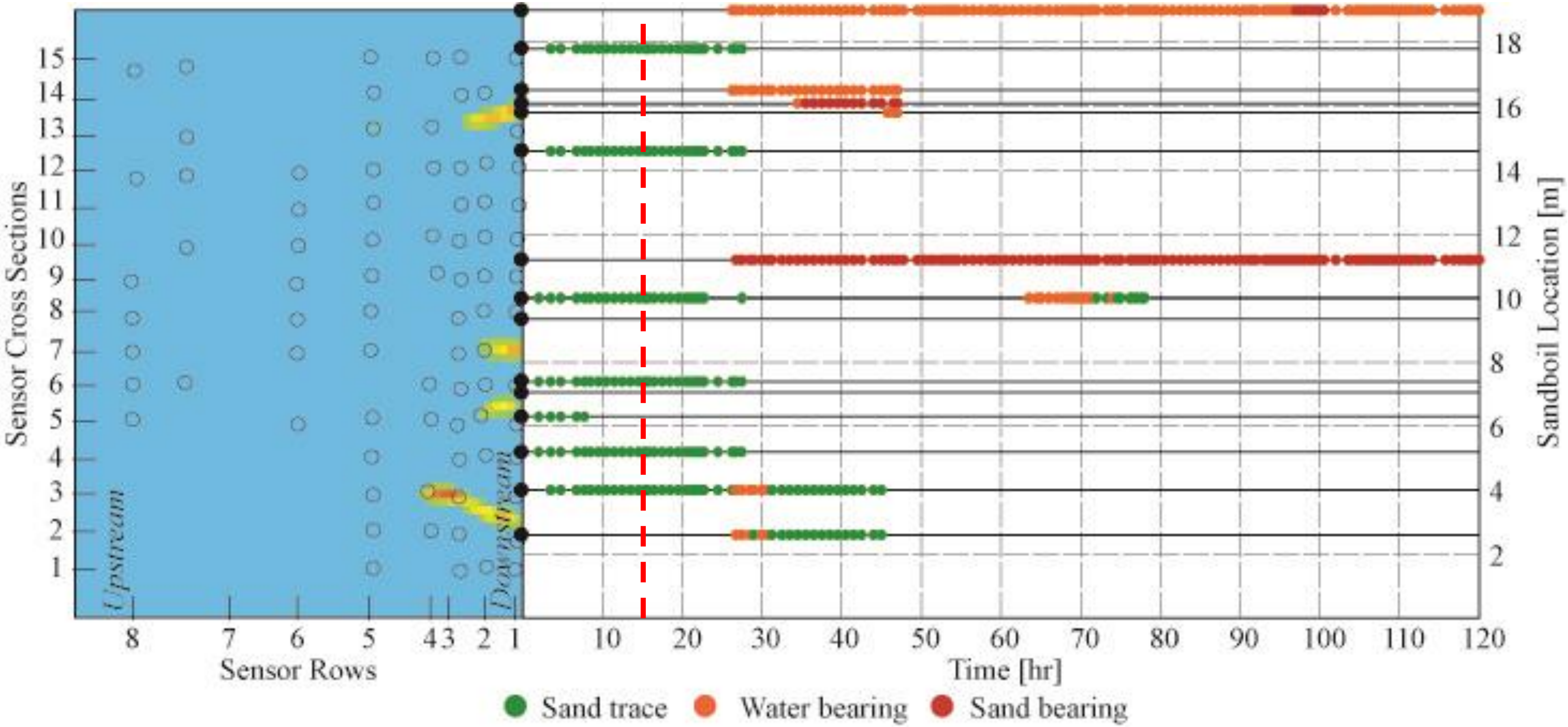
Comparing Embankment Collapse



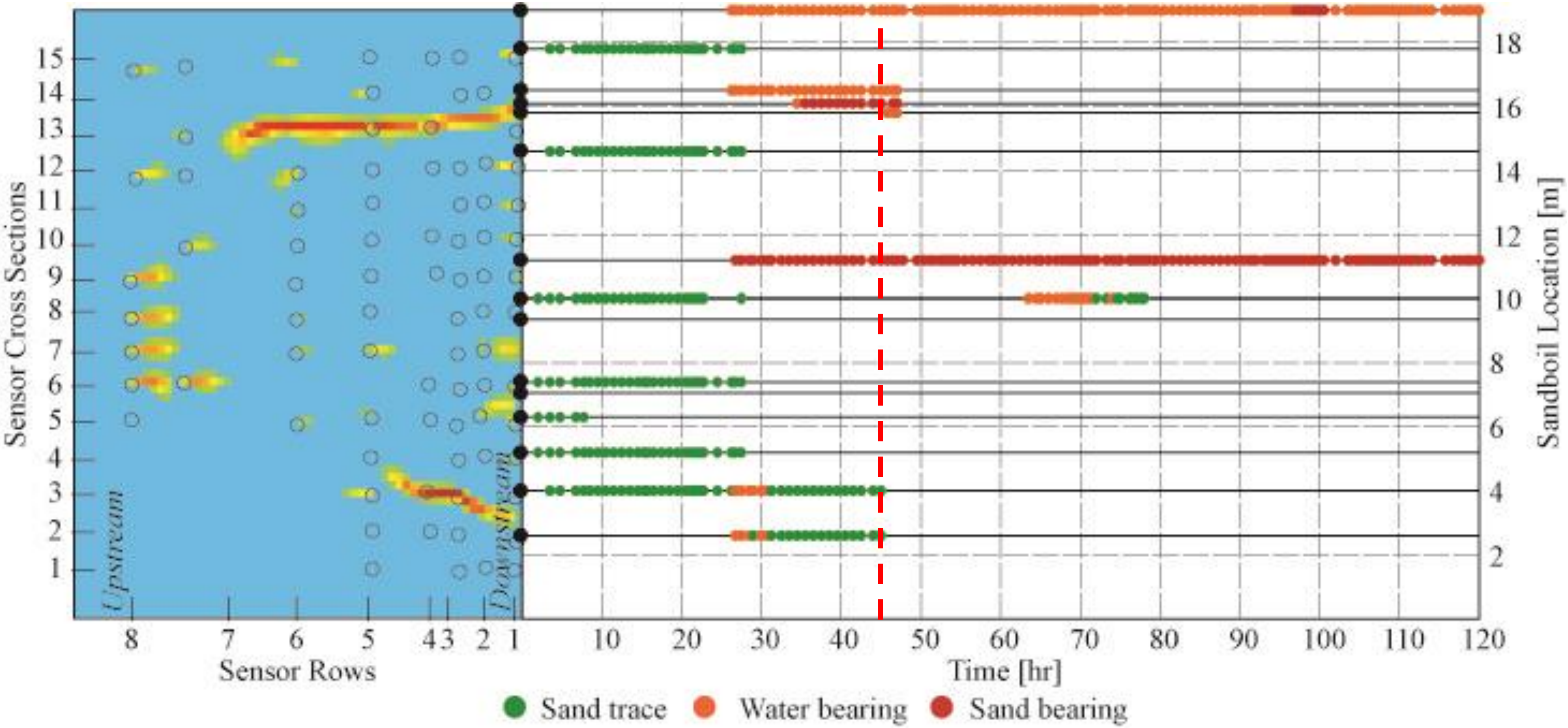


- IJkdijk embankment collapse correlates with inversion BEP patterns
  - Initiation location
  - bend in channel
  - Breach location

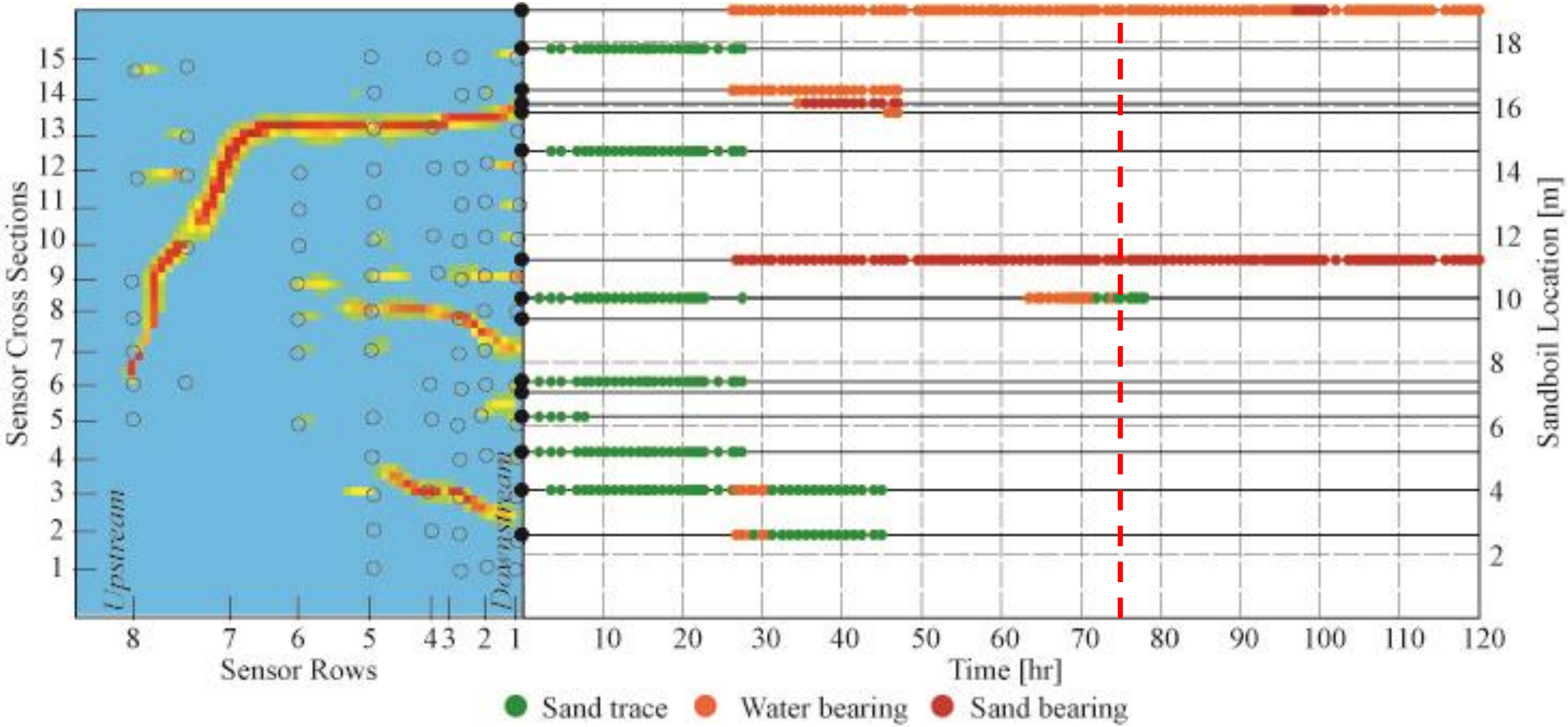
Comparing Sand Boil Locations: 15 hr



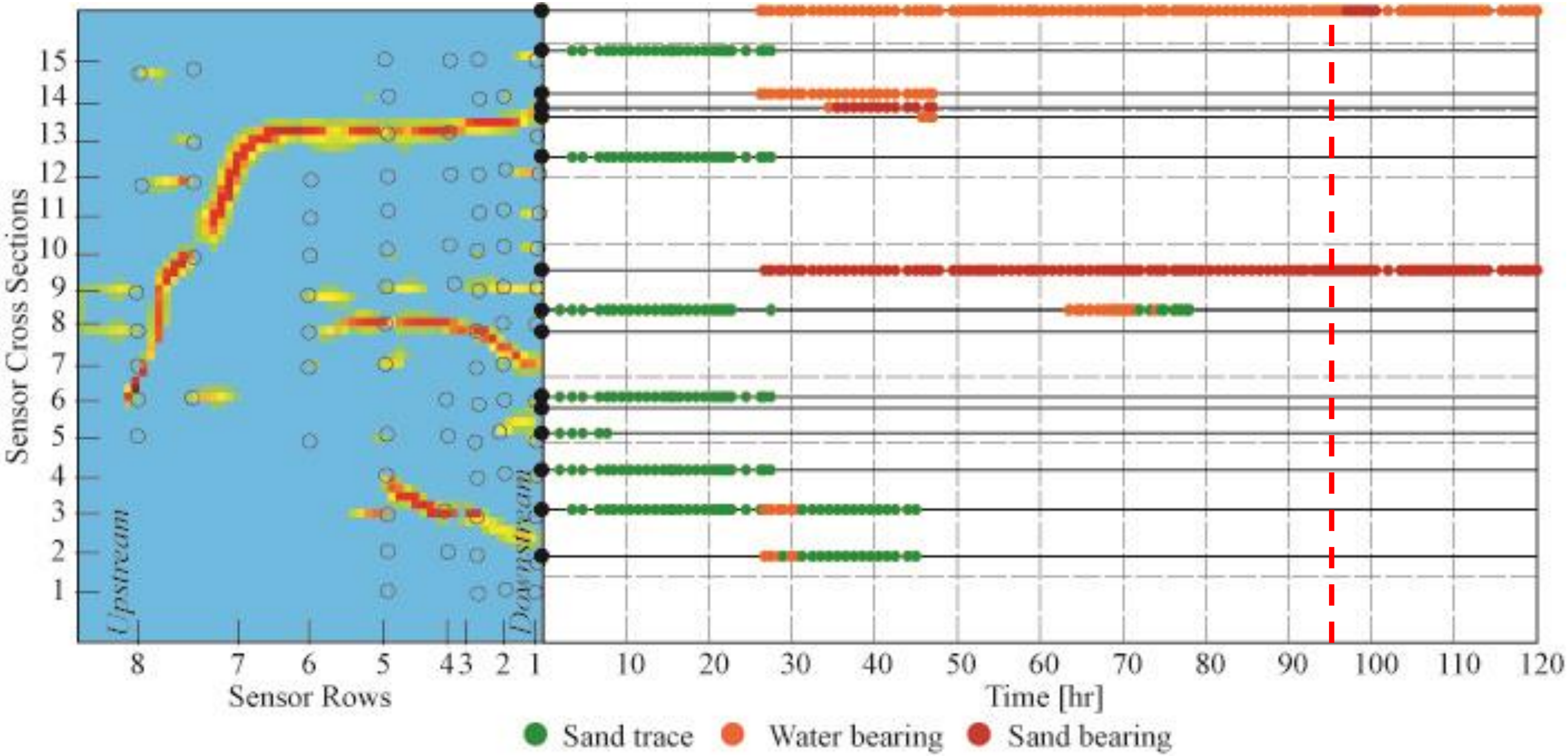
Comparing Sand Boil Locations: 45 hr



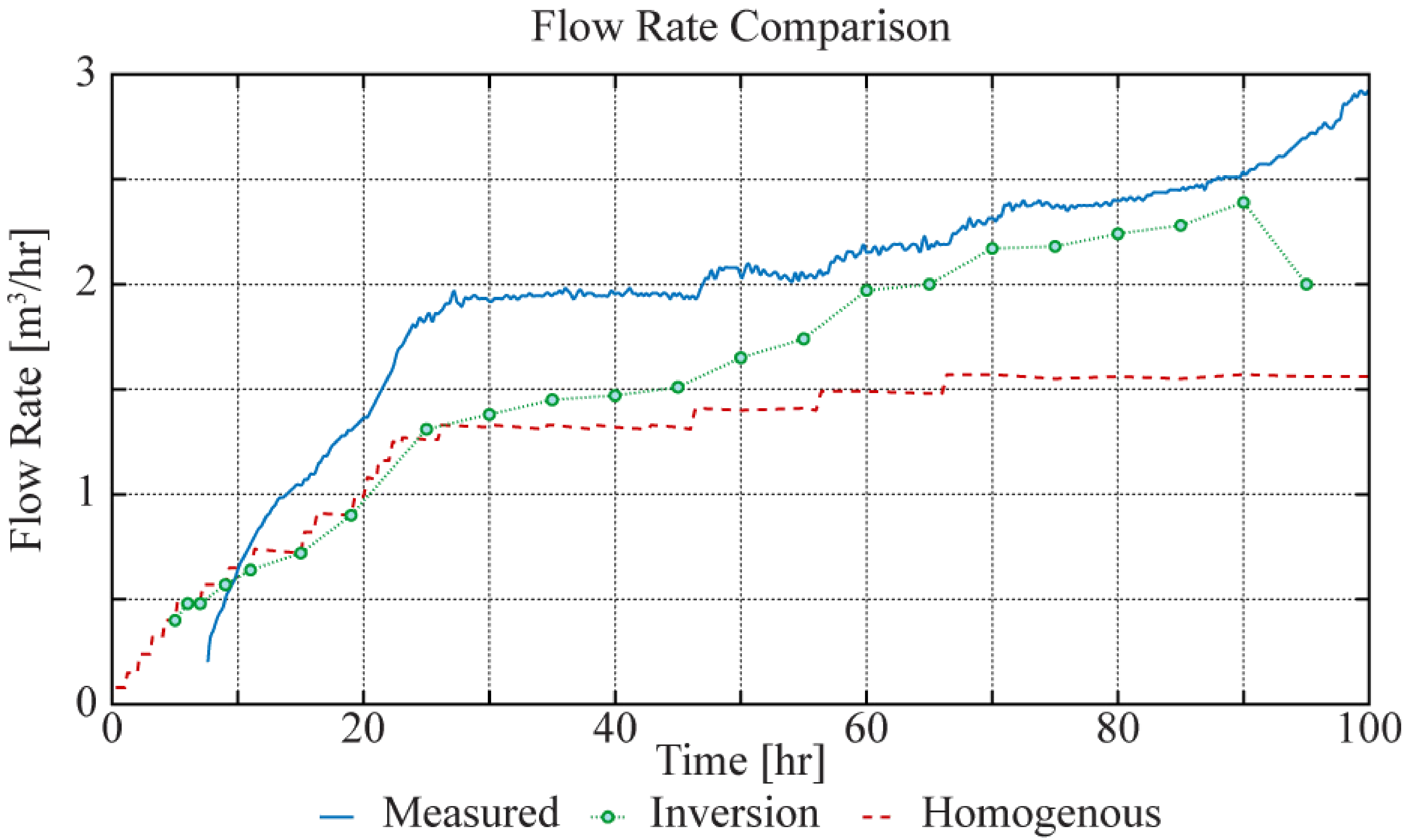
Comparing Sand Boil Locations: 75 hr



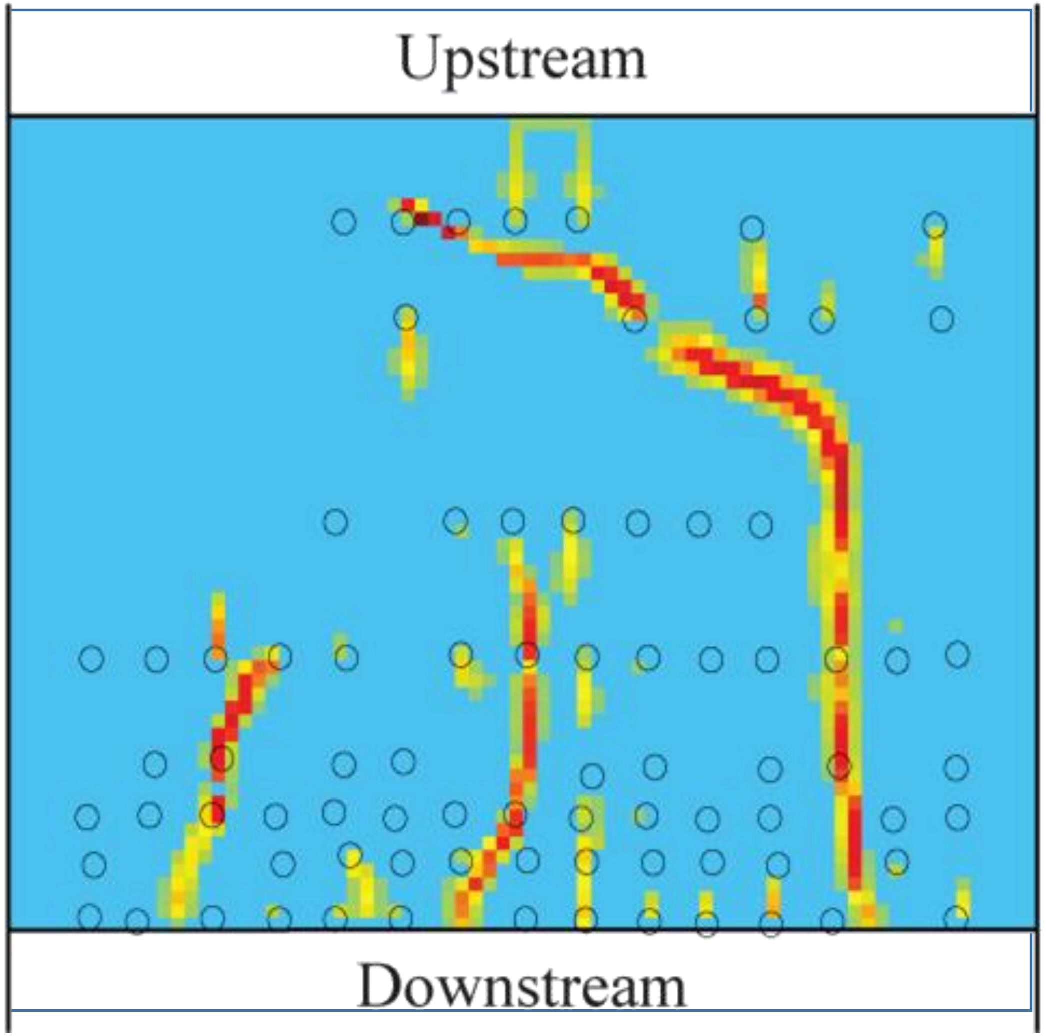
Comparing Sand Boil Locations: 95 hr



Comparing Flow Rates



Conclusions



- Complex progression
- Multiple channels
- Longitudinal and transverse progression

cbocovich@usbr.gov

Thank you for listening.
Any questions or comments?

— BUREAU OF —
RECLAMATION

Backward erosion piping in tidal sand

Marc Hijma[1] and Gert-Ruben van Goor[2]

[1] Deltares, [2]Fugro

In The Netherlands about 2500 km of our primary flood-defense system is built upon fluvial deposits and about 1000 km upon tidal deposits. The sandy fluvial and tidal deposits, however, have distinctly different properties: fluvial sand is much coarser, contains relatively low percentages of silt and clay, has higher permeabilities and lower anisotropy. In addition, tidal sand can contain numerous clay layers and is most likely more ‘sticky’ due to the presence of biofilms. This difference in properties makes it likely that tidal sand is less sensitive to BEP than fluvial sand. This hypothesis is strengthened by the observation that hardly any BEP-phenomena have been reported from the tidal areas in the Netherlands. In 2017 Deltares started a research line on BEP in tidal sand that includes modelling and many small to large scale tests. In this presentation we will give you an update about this research with focus on the recent and upcoming large-scale tests.

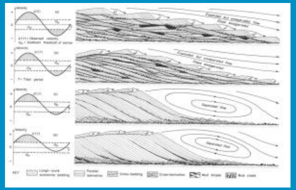
Enabling Delta Life

Backward erosion piping in tidal sand

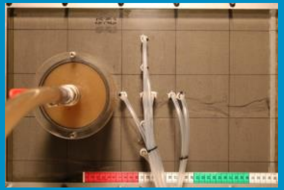
Marc Hijma

Gert-Ruben van Goor/Rick van Tilborg (Fugro)

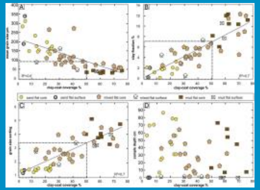
Outline



Background



Small-scale tests



Important processes

Large-scale tests

Why study backward erosion piping in tidal sand

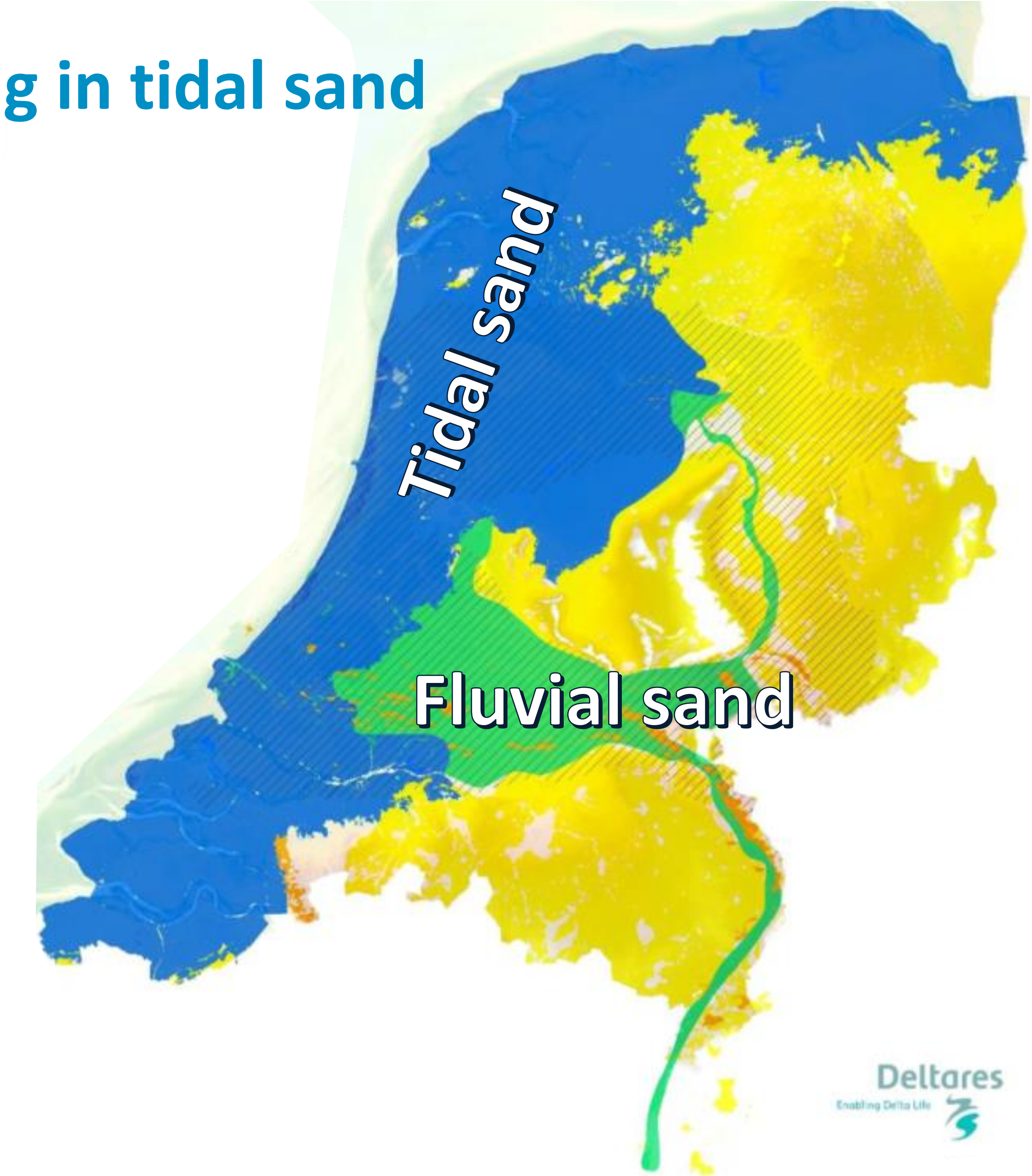
1. Most, if not all, research on BEP has focused on fluvial sand. But tidal sand is a different material

1. Much finer
2. Much larger silt and clay fraction
3. Many more (thin) clay layers

Why study backward erosion piping in tidal sand

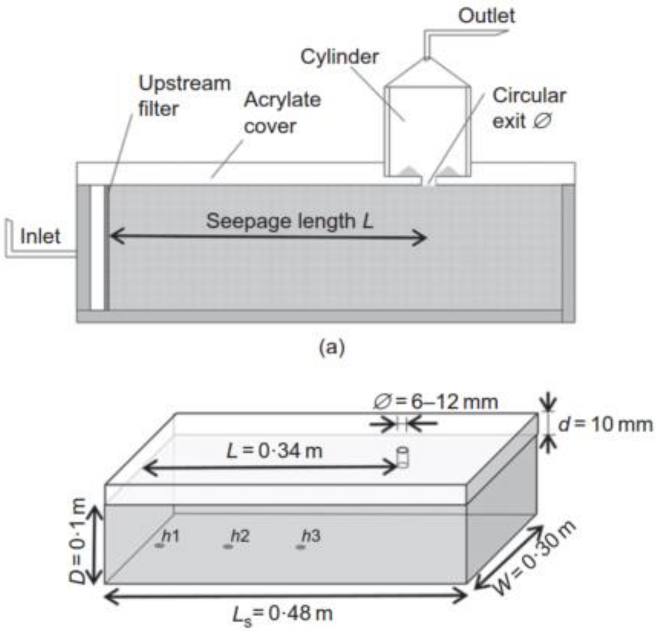
2. They have a large spatial distribution
   ~1/3 of primary levee system of The Netherlands

3. Hardly any BEP phenomena reported



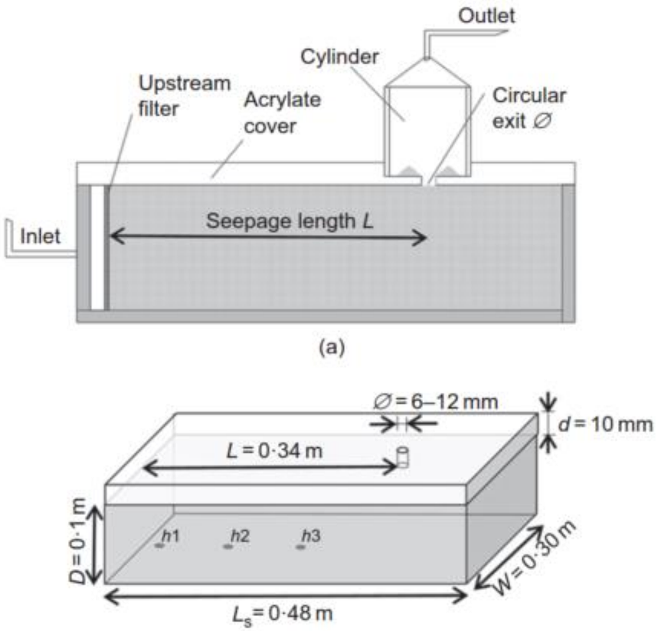
Smalle-scale tests

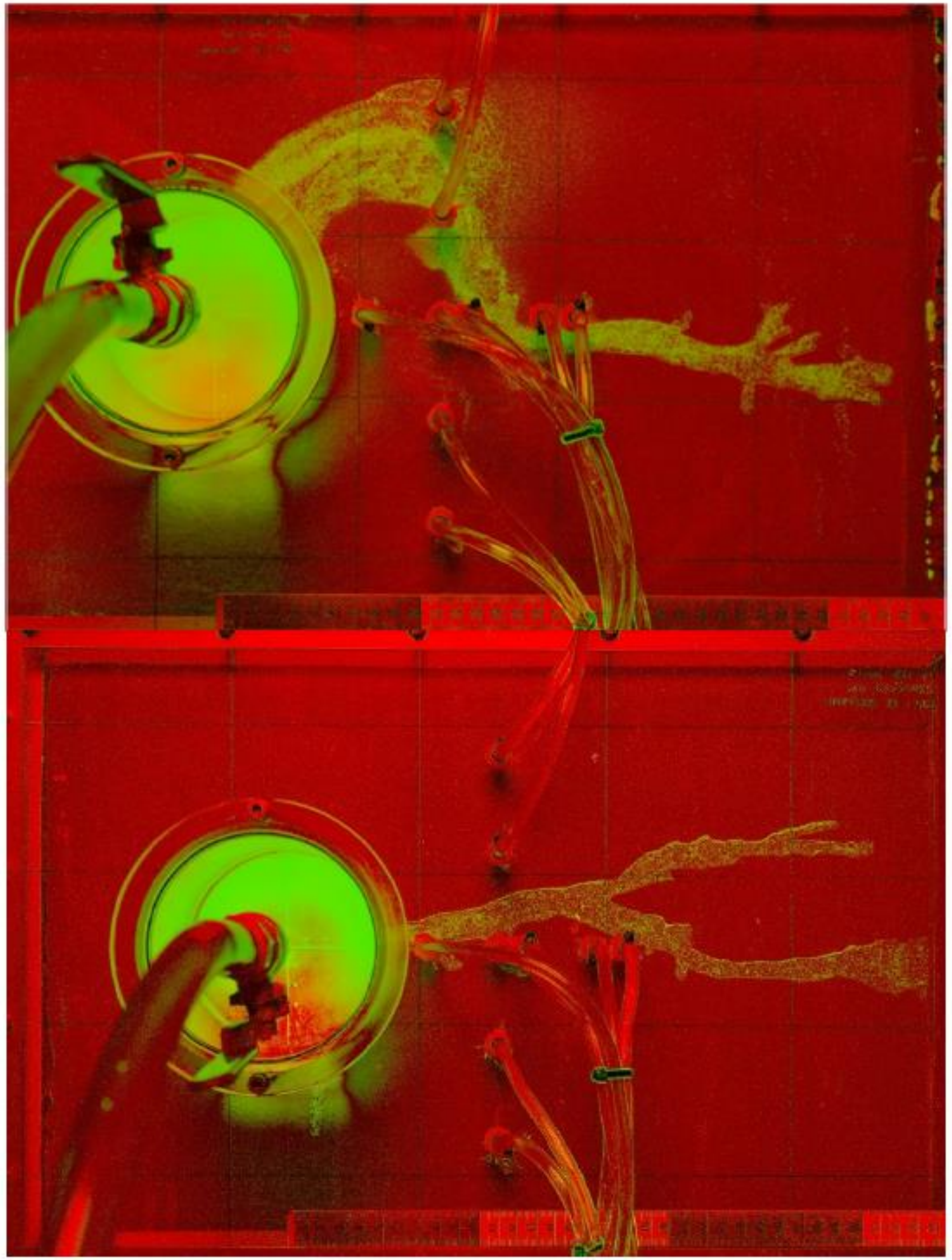
1) ***Is tidal sand less sensitive to BEP than fluvial?***
    1) ***Obtained sand from the field***
    2) ***Use exact same set-up as for fluvial sand***
    3) ***Homogeneous build-up, no clay layers***



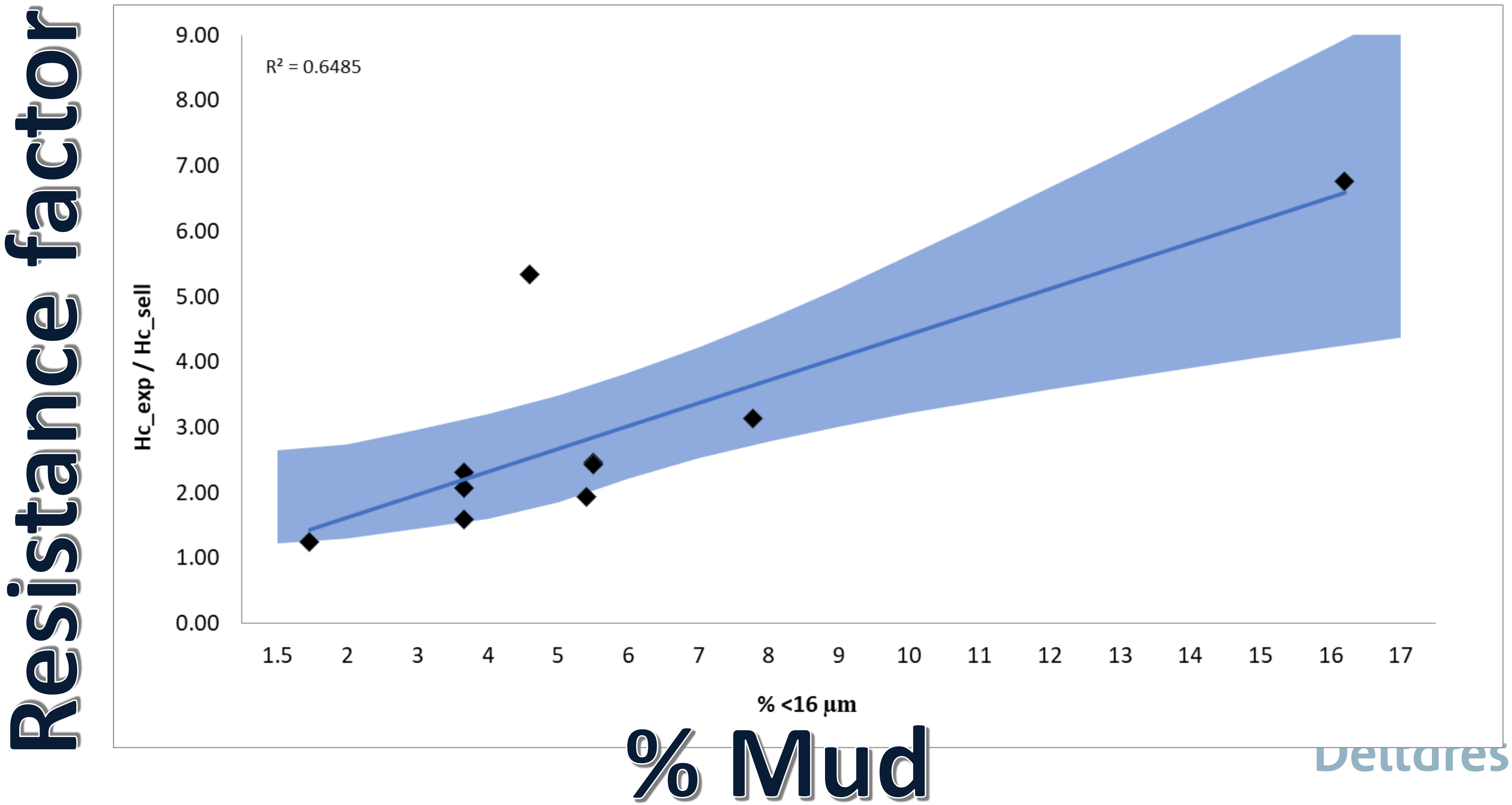
Smalle-scale tests

1) *Is tidal sand less sensitive to BEP than fluvial?*
    1) *Obtained sand from the field*
    2) *Use exact same set-up as for fluvial sand*
    3) *Homogeneous build-up, no clay layers*





Small-scale tests



Why is tidal sand less sensitive to BEP than fluvial sand?

Pressure

1. **More frequent multiple layering**
   results in permeability contrasts and less pressure build-up;
2. **Anisotropy in permeability within layer**
   due to presence of clay layers, results in lower bulk permeabilities and very low vertical permeabilities;

Resistance

3. **Cohesion**
   between clay particles, possibly due to presence of biofilms;
4. **High percentages silt and clay**
   Increase of critical shear stress
5. **Labyrinth**
   complex structures that the pipe has to pass, predominantly due to the presence of multiple clay layers

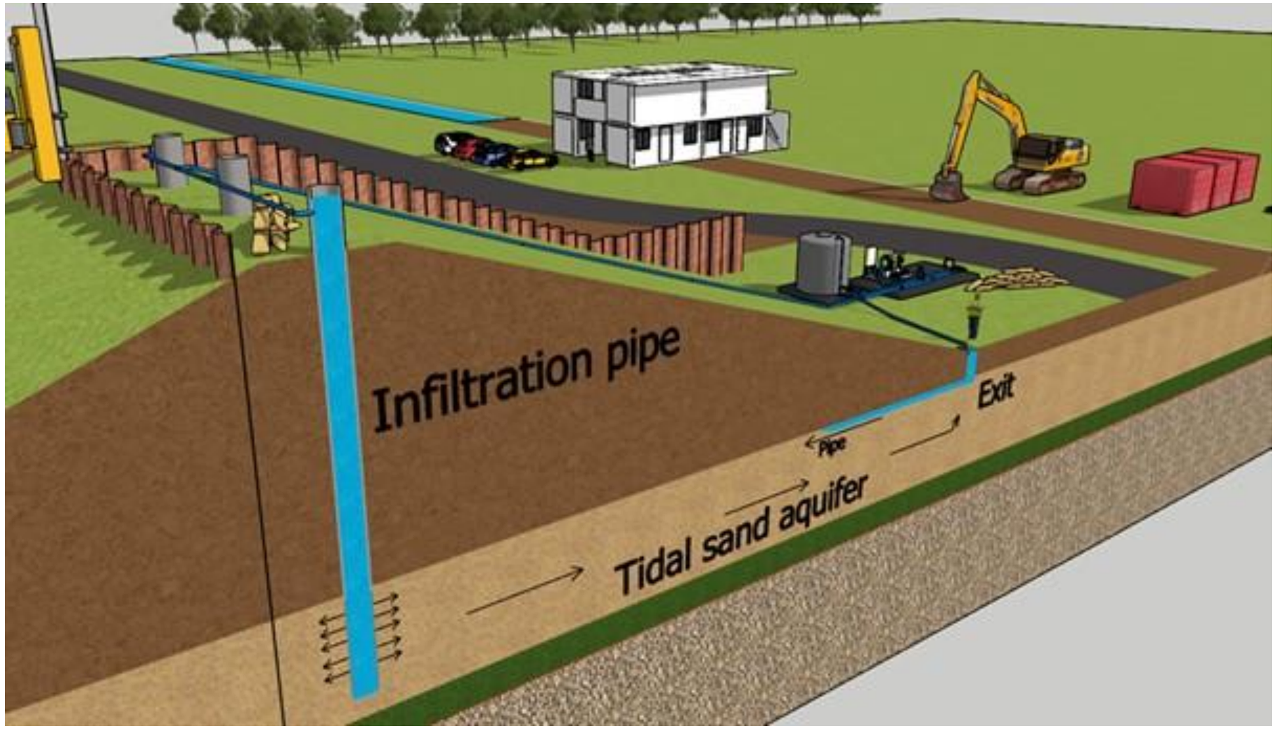
Set-up tests

Prerequisite

Enclosed tidal-sand deposit

Set up:

- Sheet piles for enclosure
- Infiltration tubes
- Create exit hole



Monitoring and observing:

- Gradients
- Electrical conductivity
- Discharges (in and out)
- Sand transport

One done, one to go

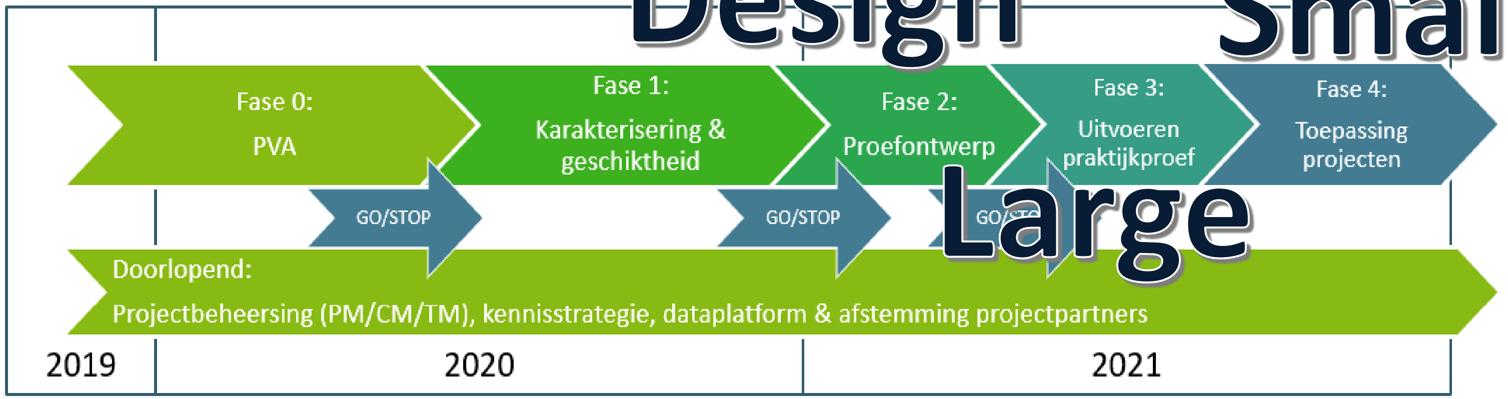
First findings

1. Sand boils occurred;
2. No horizontal pipe growth;
3. The resistance factor was at least 2: no BEP when maximum pressure was reached
4. Flow velocities were very low: heave could not have occurred

July 2021 2 large tests in Zeeland

Design

Small+implications



Fase 0:
PVA

Fase 1:
Karakterisering & geschiktheid

Fase 2:
Proefontwerp

Fase 3:
Uitvoeren praktijkproef

Fase 4:
Toepassing projecten

GO/STOP

GO/STOP

GO/STO

Doorlopend:
Projectbeheersing (PM/CM/TM), kennisstrategie, dataplatform & afstemming projectpartners

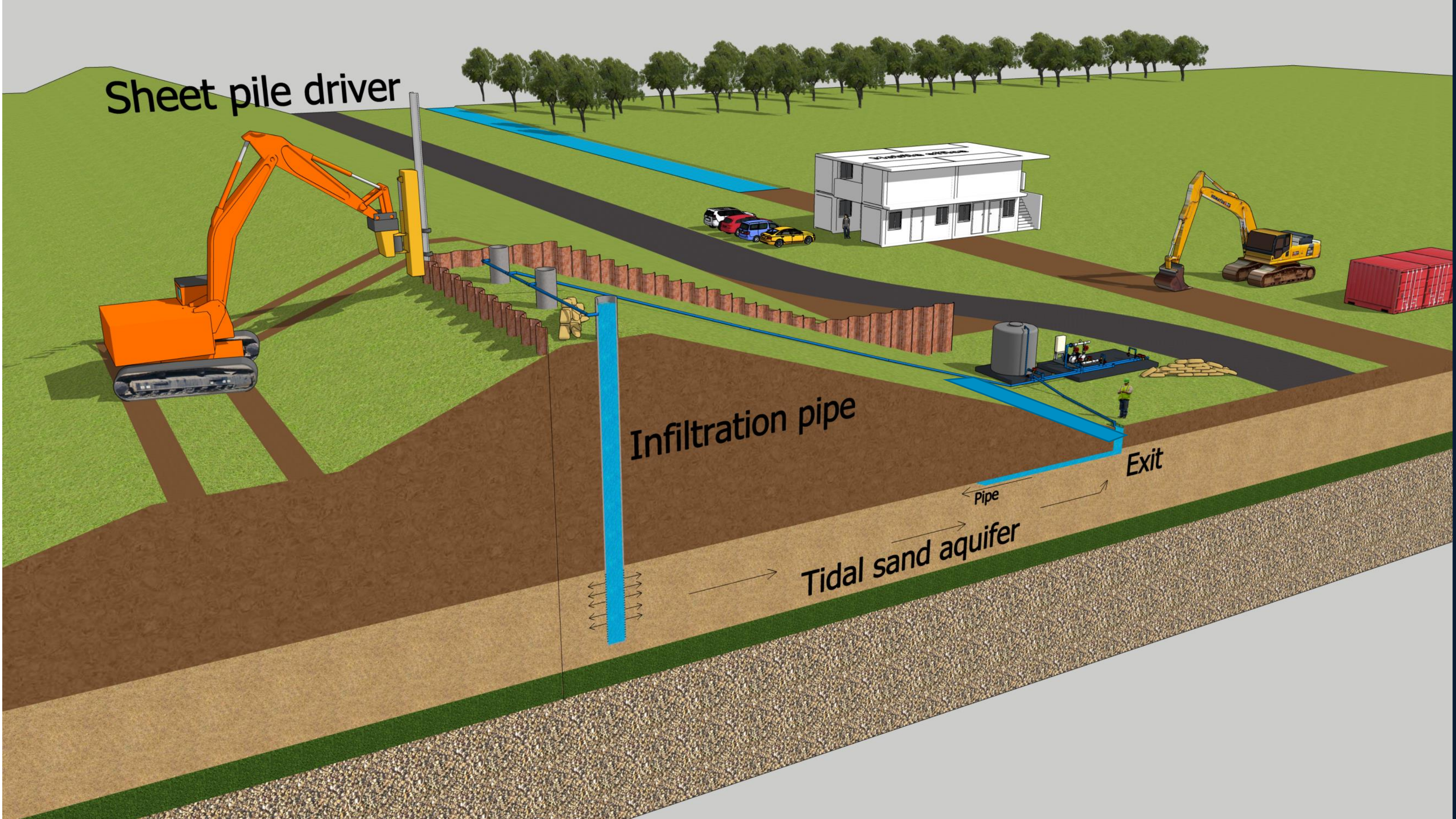
2019

2020

2021

Large

Deltares


Sheet pile driver
Infiltration pipe
Exit
Pipe
Tidal sand aquifer

Take home messages

1. Tidal sand is much more resistant to BEP than fluvial sand
2. Caused by the combined effects of fines, anisotropy, labyrinth structures, cohesion and biofilms
3. The resistance factor is frequently more than a factor 2
4. After implementation of the new knowledge in the assessment of dikes: 100+ million euros will be saved

Any questions? Marc.Hijma@deltares.nl

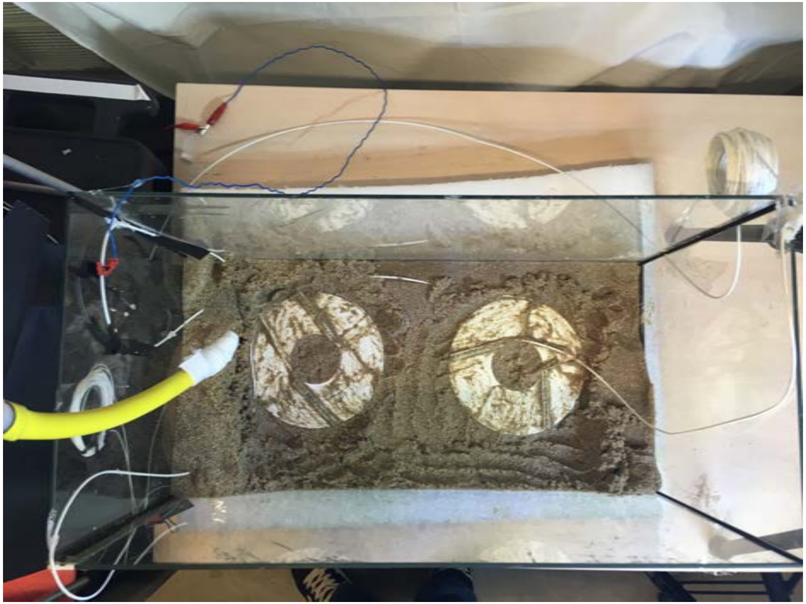
Can we hear the backward erosion piping (BEP)? Proof of concept for fiber optics DAS based BEP monitoring

J.P. Aguilar López (1,2), T.A. Bogaard (1), A. Garcia Ruiz(3), M. Gonzàles Herràez(3)
(1) Water resources section, Faculty of civil engineering, Delft University of Technology.
(2) Hydraulic structures and flood risk section, Faculty of civil engineering, Delft University of Technology.
(3) Department of electronics, Polytechnic School, Universidad de Alcalà

Backward erosion piping (BEP) represents the largest threat for most dikes founded over highly heterogenous aquifers due to its almost unpredictable nature in time and space. While sand boils are often used as the most reliable evidence of BEP occurrence, they just tell little about the location of the erosion paths and their evolution in time. In addition, the dendritic nature of the evolving channeling patterns makes it even more difficult to locate the eroded paths in space. Previous attempts for BEP monitoring have envisioned the detection process as a function of changes in either pore pressure (piezometric semi-distributed approach) or temperature changes (fully distributed fiber optic-based temperature change sensing) inside the aquifer. In theory, both methods directly relate the process to the main drivers of BEP (pressure gradients and advective transport) but in practice, diffusion processes of pore-pressures and heat makes them only applicable under conditions in which the groundwater stratigraphy and temperature are well known beforehand. Given the latest advances in the fiber optics distributed acoustic sensing technologies (DAS), it is now possible to capture a broad range of acoustic perturbations inside a medium in a spatially dense manner along fiber optic cables. The present study aimed to test if we can use the DAS technology to 'hear' the onset of BEP and to try to characterize its unique acoustic signature (combination of frequencies) so that it can be detected in time and space. The experiment consisted in embedding few in-house made fiber optics 'microphones' and to record the signals emitted during the BEP process while also capturing it with video camaras. These last ones to allow to pinpoint the time of occurrence of BEP events such as initiation and breakthrough. The obtained results show that BEP can be recorded inside a frequency band between 1200 and 1600 Hz for our specific sand and that the amplitude of the signal is largely amplified at the exact moment of the breakthrough event. The next stage is to build a controlled larger lab set-up so that different types of sand and pore pressure measurements are also included in the experiments.

Can we hear backward erosion piping (BEP) ?

Proof of concept for FO-DAS based BEP monitoring



Juan Pablo Aguilar-López[1], Thom Bogaard[1],
Andres Garcia-Ruiz[2], Miguel González-Herràez[2],

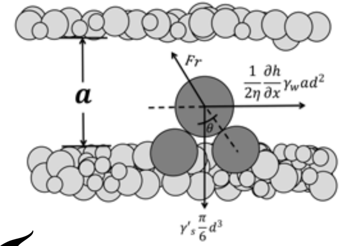
1) Water Resources Section - Faculty of Civil Engineering and Geosciences – Delft University of Technology
2) Department of Electronics, Universidad de Alcalá de Henares

Experimental hypothesis

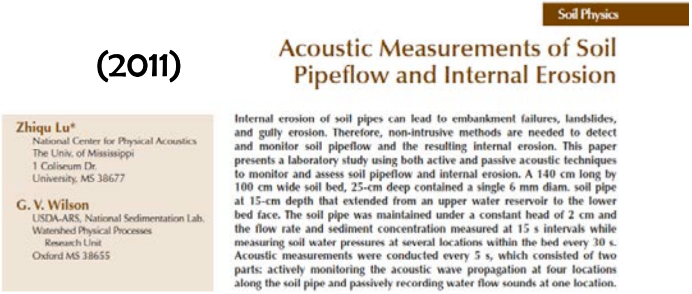
PIPING EROSION ACOUSTIC SIGNATURE:

During all stages of BEP, the collision between grains and water erosion related processes will generate acoustic emissions.

If this is true, a sensing (monitoring) strategy can be acoustic based and might even be able to detect one or more phases of BEP like onset, progression and breakthrough.



(2011)



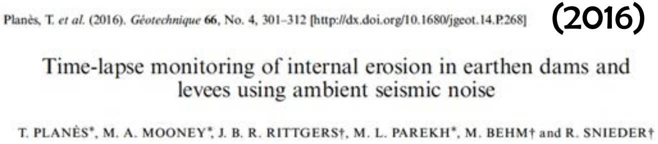
Soil Physics

Acoustic Measurements of Soil Pipeflow and Internal Erosion

Zhiqu Lu*
National Center for Physical Acoustics
The Univ. of Mississippi
1 Coliseum Dr.
University, MS 38677

G. V. Wilson
USDA-ARS, National Sedimentation Lab.
Watershed Physical Processes
Research Unit
Oxford MS 38655

Internal erosion of soil pipes can lead to embankment failures, landslides, and gully erosion. Therefore, non-intrusive methods are needed to detect and monitor soil pipeflow and the resulting internal erosion. This paper presents a laboratory study using both active and passive acoustic techniques to monitor and assess soil pipeflow and internal erosion. A 140 cm long by 100 cm wide soil bed, 25-cm deep contained a single 6 mm diam. soil pipe at 15-cm depth that extended from an upper water reservoir to the lower bed face. The soil pipe was maintained under a constant head of 2 cm and the flow rate and sediment concentration measured at 15 s intervals while measuring soil water pressures at several locations within the bed every 30 s. Acoustic measurements were conducted every 5 s, which consisted of two parts: actively monitoring the acoustic wave propagation at four locations along the soil pipe and passively recording water flow sounds at one location.



Planès, T. *et al.* (2016). *Géotechnique* **66**, No. 4, 301–312 [http://dx.doi.org/10.1680/jgeot.14.P.268]

(2016)

Time-lapse monitoring of internal erosion in earthen dams and levees using ambient seismic noise

T. PLANÈS*, M. A. MOONEY*, J. B. R. RITTGERS†, M. L. PAREKH*, M. BEHM† and R. SNIEDER†

ELSEVIER

Contents lists available at ScienceDirect

Particuology

journal homepage: www.elsevier.com/locate/partic

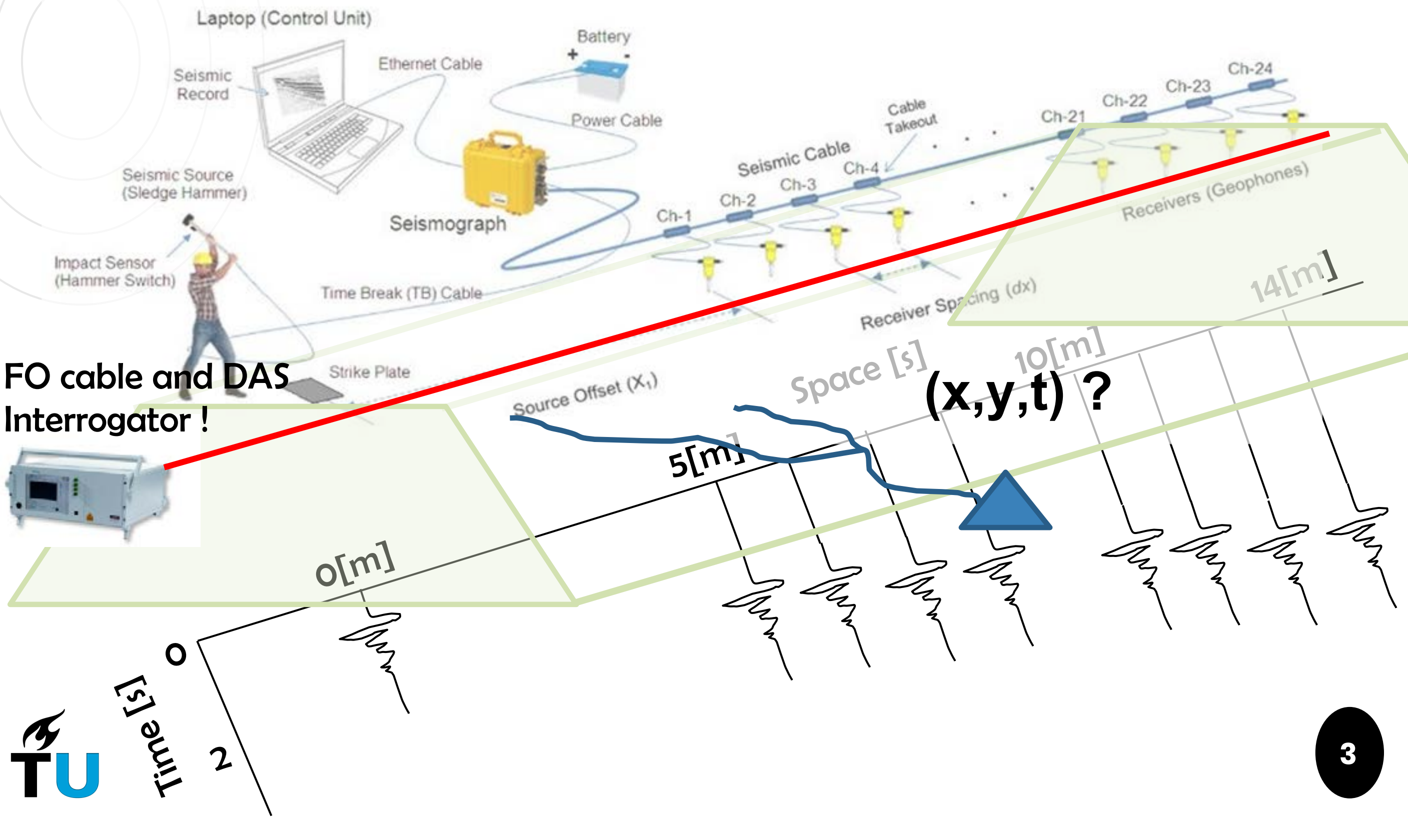
(2018)

Frequency–amplitude behavior in the incipient movement of grains under vibration

Karina A. Valenzuela Aracena[a], Jesica G. Benito[a], Luc Oger[b], Irene Ippolito[c], Rodolfo O. Uñac[a], Ana M. Vidales[a,*]

[a] INFAP, CONICET, Departamento de Física, Facultad de Ciencias Físico Matemáticas y Naturales, Universidad Nacional de San Luis, Ejército de los Andes 950, D5700HHW, San Luis, Argentina
[b] Institut de Physique de Rennes, UMR UR1-CNRS 6251, Université de Rennes 1, 263, Avenue du Général Leclerc, Campus de Beaulieu, CS 74205, 35042 Rennes Cedex, France
[c] Universidad de Buenos Aires, Facultad de Ingeniería, Grupo de Medios Porosos, Paseo Colón 850, 1063, Buenos Aires, Argentina

Monitoring challenge



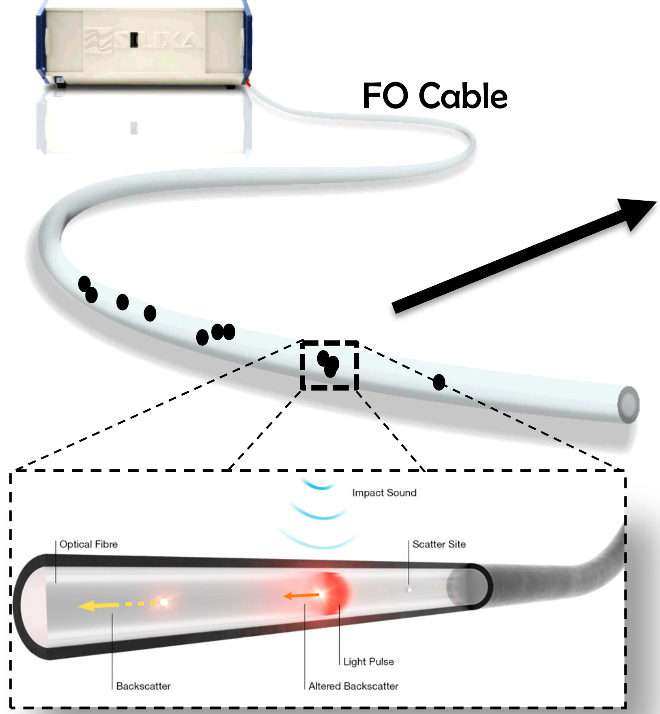
FO cable and DAS Interrogator !

(x,y,t) ?

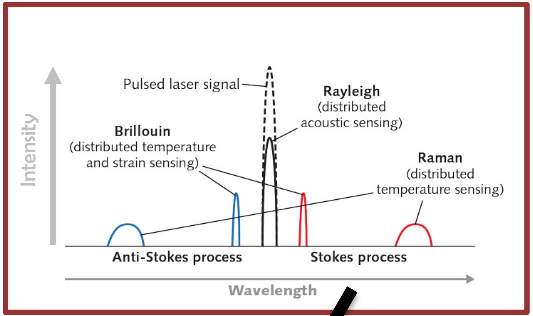
How does Distributed acoustic sensing (DAS) works?

DAS Interrogator

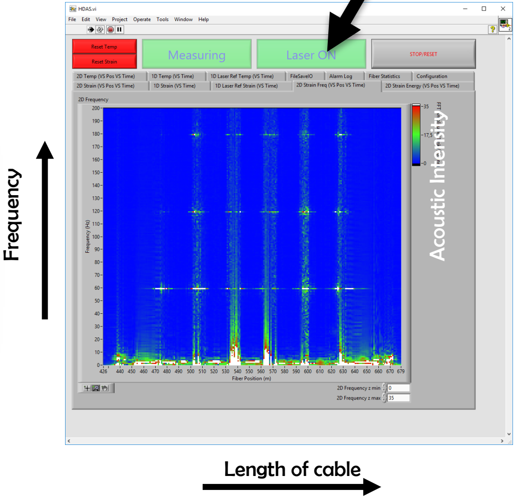
FO Cable



Backscatter Spectrum



Frequency Spectrum



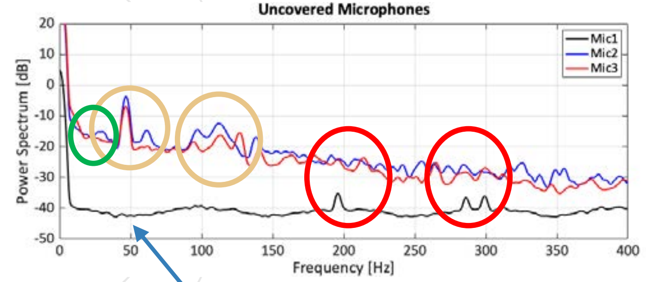
2D Frequency z min 0

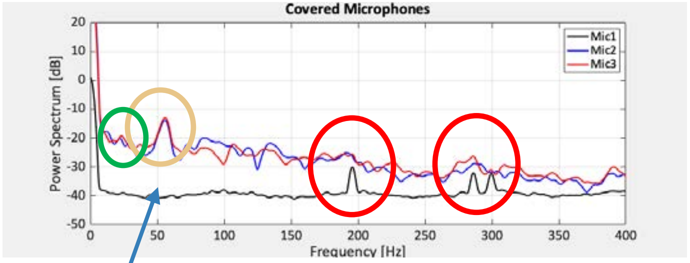
2D Frequency z max 35

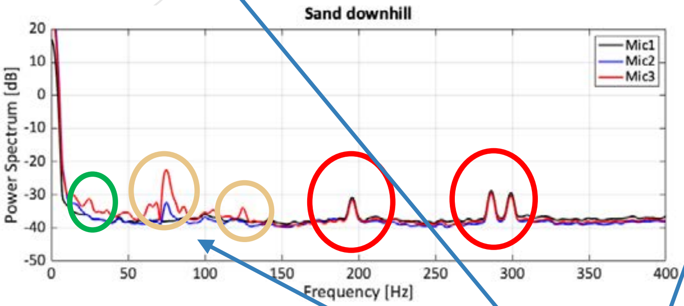
Animation borrowed from: https://silixa.com/resources/what-is-distributed-sensing/

4 ‘Simple’ tests

Results of simple tests


Uncovered Microphones


Covered Microphones


Sand downhill

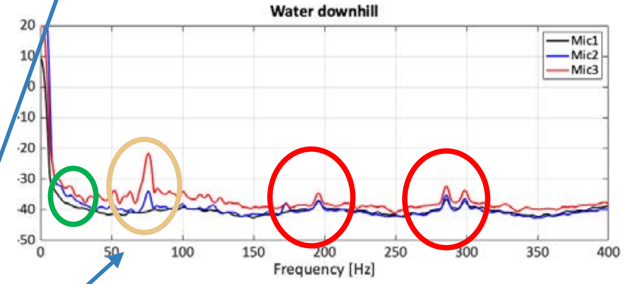
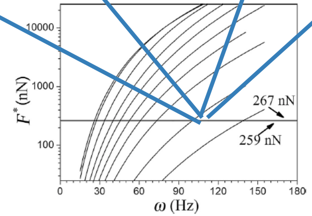
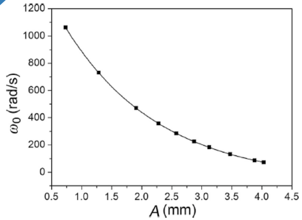

Water downhill

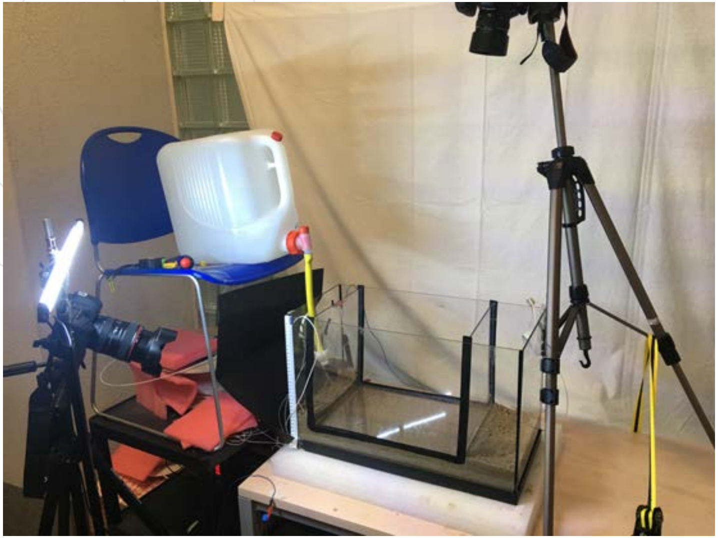
Figure extracted from:

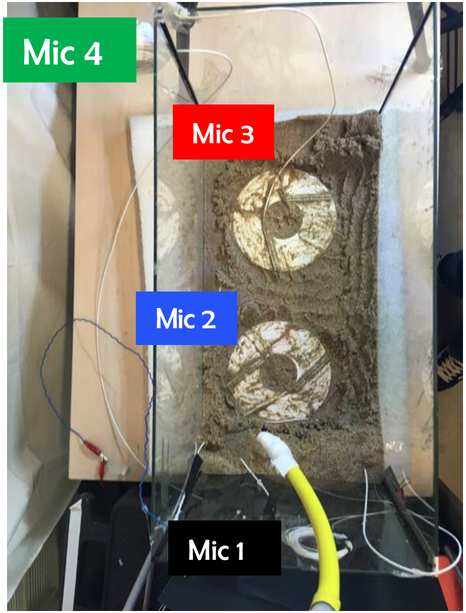
Aracena KA, Benito JG, Oger L, Ippolito I, Uñac RO, Vidales AM. Frequency–amplitude behavior in the incipient movement of grains under vibration. Particuology. 2018 Oct 1;40:1-9.
https://doi.org/10.1016/j.partic.2017.11.009





DAS for BEP Experiment





BEP fish tank experiment (speed X 2)

Power spectrum signal of BEP

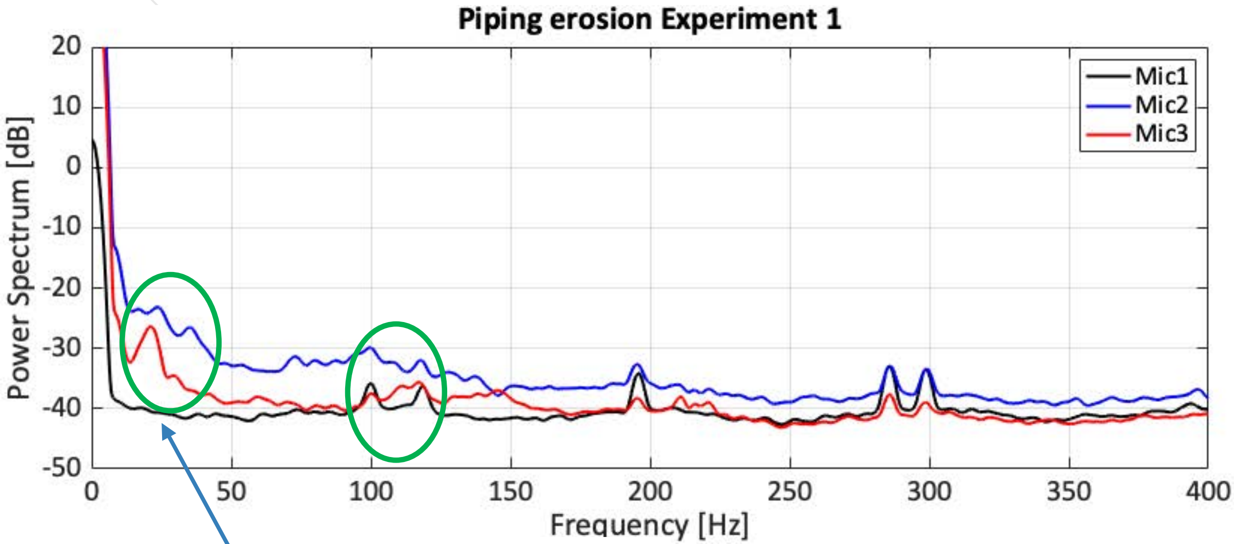


Figure extracted from:
Aracena KA, Benito JG, Oger L, Ippolito I, Uñac RO, Vidales AM. Frequency–amplitude behavior in the incipient movement of grains under vibration. Particuology. 2018 Oct 1;40:1-9.
https://doi.org/10.1016/j.partic.2017.11.009

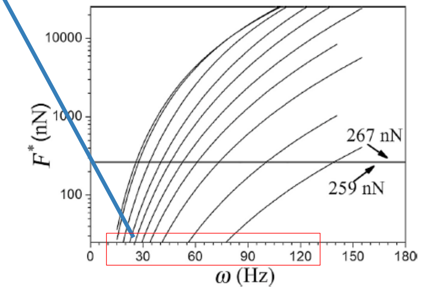
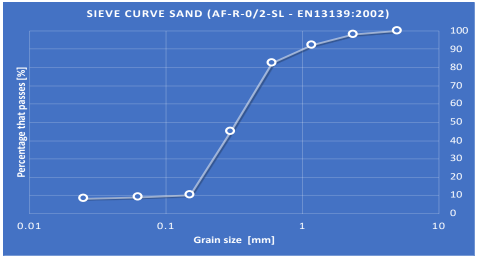


Fig. 6. Calculated forces experienced by the particle deposited on the oscillating surface for different amplitudes, which (from left to right) are: 0.73, 1.28, 1.91, 2.28, 2.58, 2.87, 3.12, 3.47, 3.88, 4.03 mm. Note that the force is plotted on a logarithmic scale. The two horizontal lines correspond to the detaching forces for each glass-beaded surface: 250 μm (upper) and 500 μm (lower).



Signal in time of BEP (actual speed)

Conclusions:

- **YES** ! We can hear ‘something’ when piping happens but is still not clear which phase of the process.

- DAS is sensitive enough to record the process despite the low amplitude. Yet, this is only true for 20 [cm] of sand.

- Grain acoustic signature seems to occur in a band between 10 and 40 Hz for the sand used in the experiment.

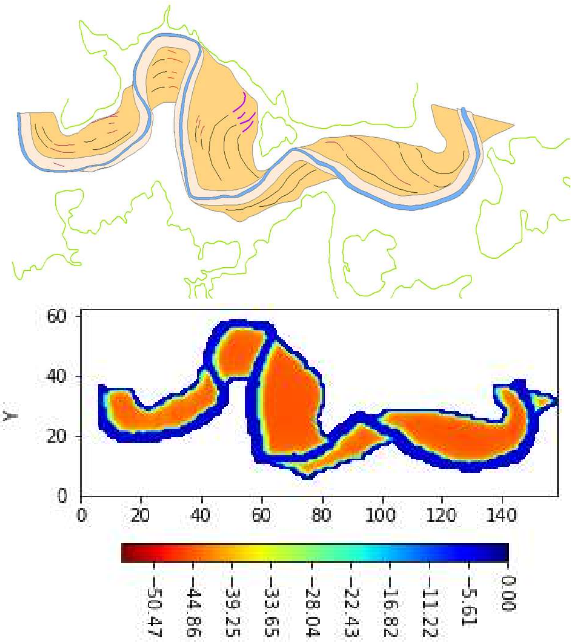
- Signal amplitude significantly increases in time during break trough which may prove the DAS sensing potential for monitoring but maybe too late for emergency reaction (according to this experiment).

- There is enough evidence to upscale to a real lab experiment. We will build a robust BEP box with larger dimensions. Specially, in the horizontal direction to better test the applicability and spatial resolution of DAS.

The effect of subsurface heterogeneity on well discharges

W.J.Dirkx*, T.G. Winkels* *Utrecht University, department of physical geography*

Of possible failure mechanisms affecting levees, piping, i.e. the formation of small pipes along preferential seepage pathways immediately below dikes, is seen as a key failure mechanism. During high water events water levels rise in the embanked floodplain, driving groundwater flow through shallow-depth sandy aquifers underneath dikes. In locations where a coverlayer is present, these pressure gradients can lead to localized hydraulic fracturing, causing a concentrated outflow point. Once vertical outflow velocities exceed the threshold for particle-entrainment, soil particles these can be transported up through the coverlayer layer (heave). This is a precondition for the initiation of the backward erosion process, threating the stability of dikes (Van Beek, 2015). The Dutch subsurface is however notoriously heterogenous. Generalised, the Rhine-Meuse delta is built up out of sandy deposits of Pleistocene age which are overlain by a deltaic wedge of Holocene age. This deltaic wedge is a complex confining layer (Weerts, 1996), composed of aquitard clays and peats, dissected by channel-belt sand bodies (Cohen, 2002). It is these sand bodies in which the piping process mainly takes place. Within the current Dutch directives on dike safety assessments variability in subsurface build-up is captured by multiple 2D subsurface scenarios (Hijma & Lam, 2015). However, reducing subsurface variability to stochastic 2D subsurface realizations potentially overlooks the spatial effects of subsurface variability on flow patterns (Colombera et al., 2017). Thus, the Stuivenberg channel-belt was chosen as a case study area, since detailed subsurface reconstructions available for this site have allowed for a high resolution 3-dimensional modelling of well discharges (Winkels, in prep). Since this channel has been abandoned, theoretical dike positions were set-up to study the spatial effects of configuration of deltaic sands on outflow discharges across multiple scenarios.



Top: Reconstruction of the Stuivenberg channel belt with point bar system (orange), abandoned channel (beige) and residual channel (blue). Bottom: composite map of potential well discharges (m^3/d) across the channel belt.

Van Beek, V. M. (2015). Backward erosion piping: initiation and progression. TUDelft repository

Cohen, K. M., Stouthamer, E., & Berendsen, H. J. A. (2002). Fluvial deposits as a record for Late Quaternary neotectonic activity in the Rhine-Meuse delta, The Netherlands. Netherlands Journal of Geosciences/Geologie en Mijnbouw, 81(3-4).

Weerts, H. J., & Mol, J. A. (1996). Complex confining layers: architecture and hydraulic properties of Holocene and late Weichselian deposits in the fluvial Rhine-Meuse delta, The Netherlands (Vol. 213). Koninklijk Nederlands Aardrijkskundig Genootschap.

Hijma, M., Van der Meij, R., & Lam, K. S. (2015). Grasping the Heterogeneity of the Subsurface: using Buildup Scenarios for Assessing Flood-Protection Safety.

Colombera, L., Mountney, N. P., Russell, C. E., Shiers, M. N., & McCaffrey, W. D. (2017). Geometry and compartmentalization of fluvial meander-belt reservoirs at the bar-form scale: Quantitative insight from outcrop, modern and subsurface analogues. Marine and Petroleum Geology, 82, 35-55.

Winkels, T.G. (in prep) Internal architecture, meander evolution and grainsize variability of a deltaic channel belt in the Rhine-Meuse delta, the Netherlands.

Application of the coarse sand barrier at pilot-site Gameren: 3D flow aspects

André Koelewijn[1], Esther Rosenbrand[1] & Vera van Beek[1]
[1]Deltares

Recently, the coarse sand barrier (CSB) has been proposed as a solution against backward erosion piping. After a significant number of laboratory tests at various scales and a few trials by different contractors, it will be applied as part of a levee along one of the main rivers in the Netherlands.

The CSB will be applied near the village of Gameren over a length of 1 km in an area with various clay pits at the landside and a large, mainly refilled sand pit at the riverside. For a proper application, the safety of the CSB must be proven first by calculations.

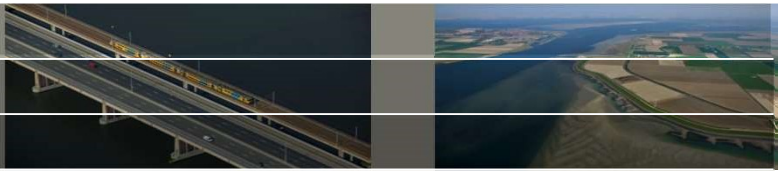
One of the main factors influencing the safety is the concentration of flow when an undetected hydraulic obstacle prevents the usual erosion processes around a CSB from occurring. Because of numerical and practical constraints, three different 3D finite element models have been applied to arrive at an estimate for the amplification factor for the hydraulic gradient occurring at design conditions. This has been done for the part along the levee with the worst hydraulic configuration regarding the various pits, i.e. at other parts of the pilot stretch, a more favourable value for this 3D-factor will be obtained.

Deltares
Enabling Delta Life

Application of the Coarse Sand Barrier at pilot-site Gameren

André Koelewijn, Esther Rosenbrand & Vera van Beek
EWG-IE 2020, February 4, 2021

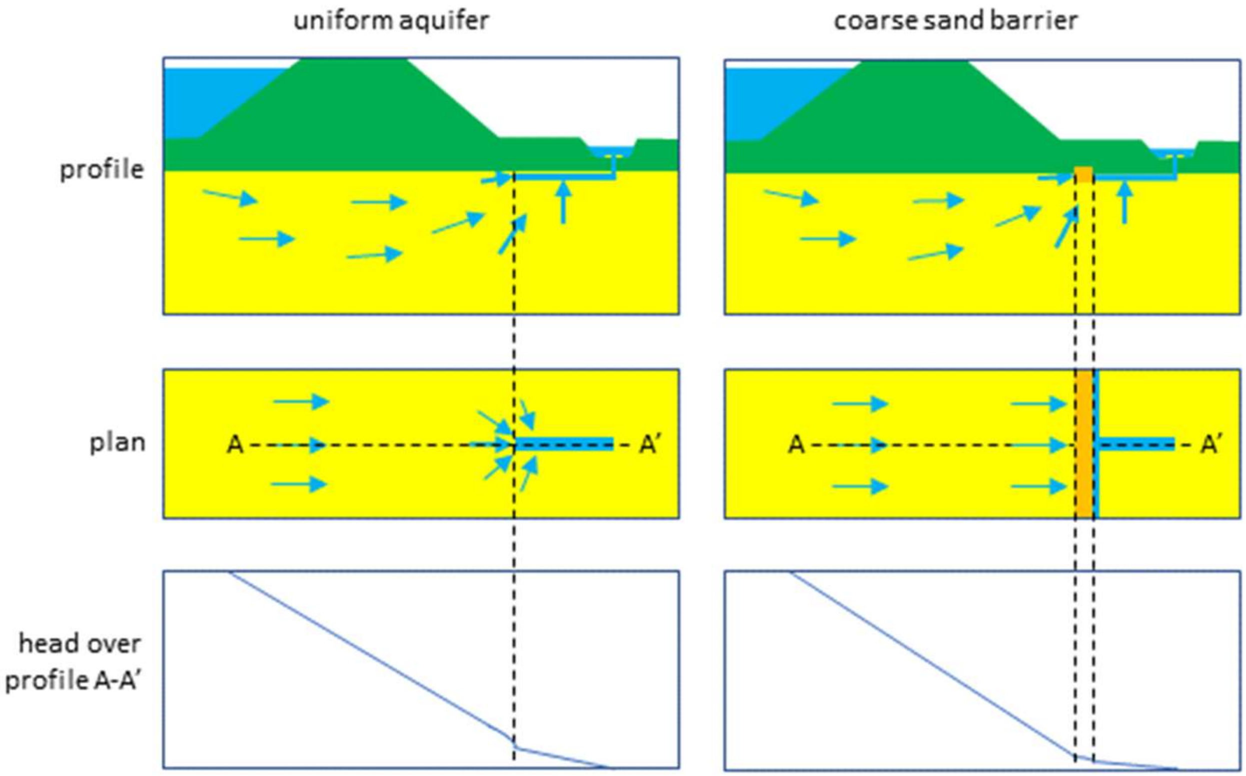
Overview



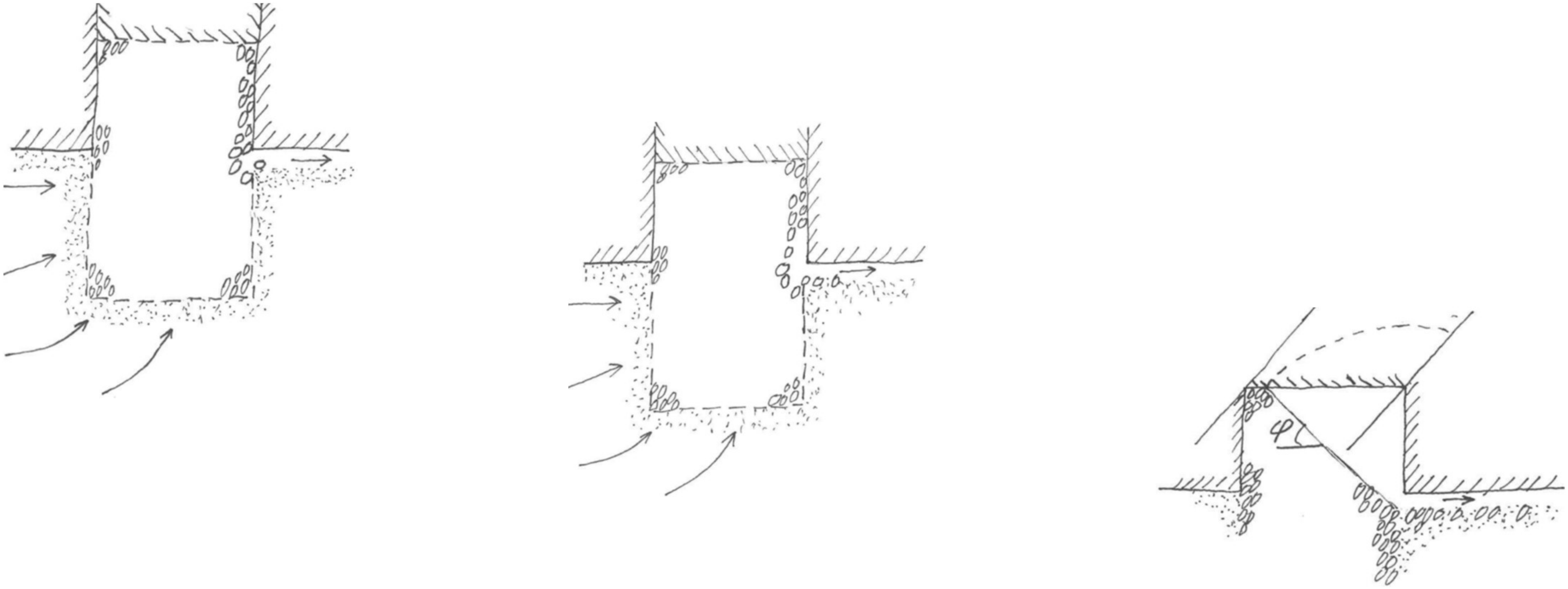
- Principle of the Coarse Sand Barrier
- Processes towards failure
- Pilot site Gameren
- 3D factor
- Other partial safety factors
- Conclusions

Principle of the Coarse Sand Barrier

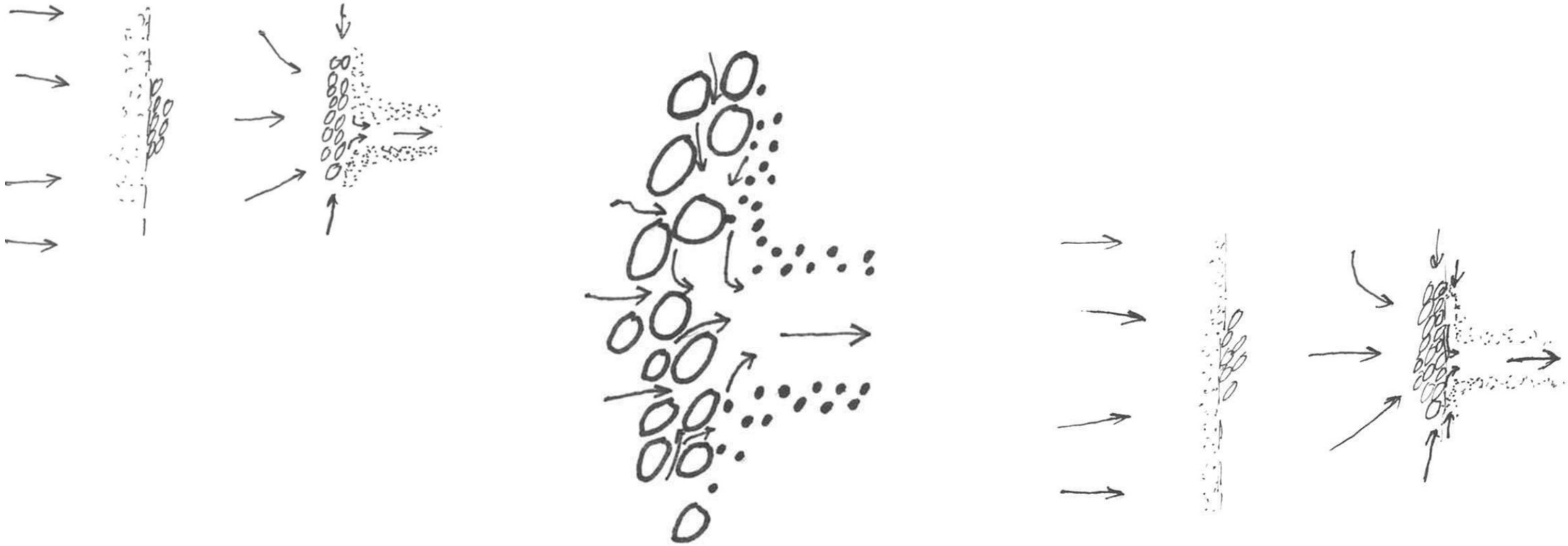
- Downstream pipe provides drainage
- Low hydraulic gradient inside the barrier
- Larger grain size of the barrier is more resistant against erosion



Downstream pipe reaching the barrier (in cross-section)

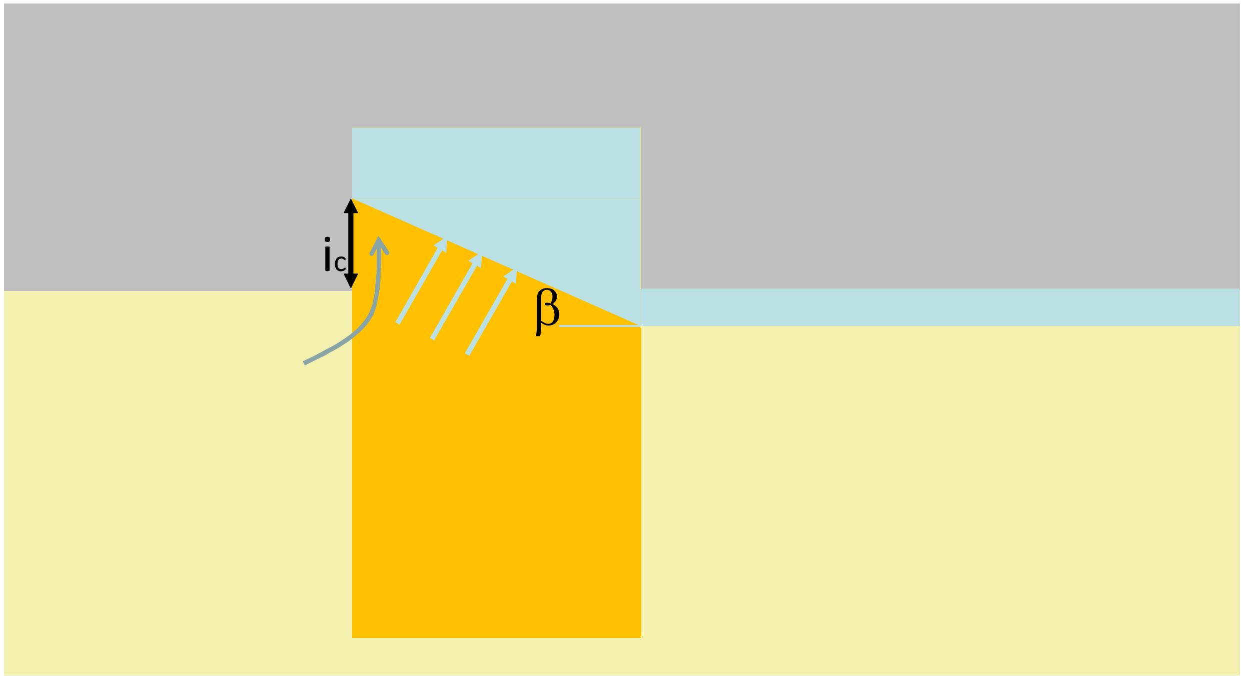


Lateral pipe growth (top view)



Ultimate strength and failure of the barrier

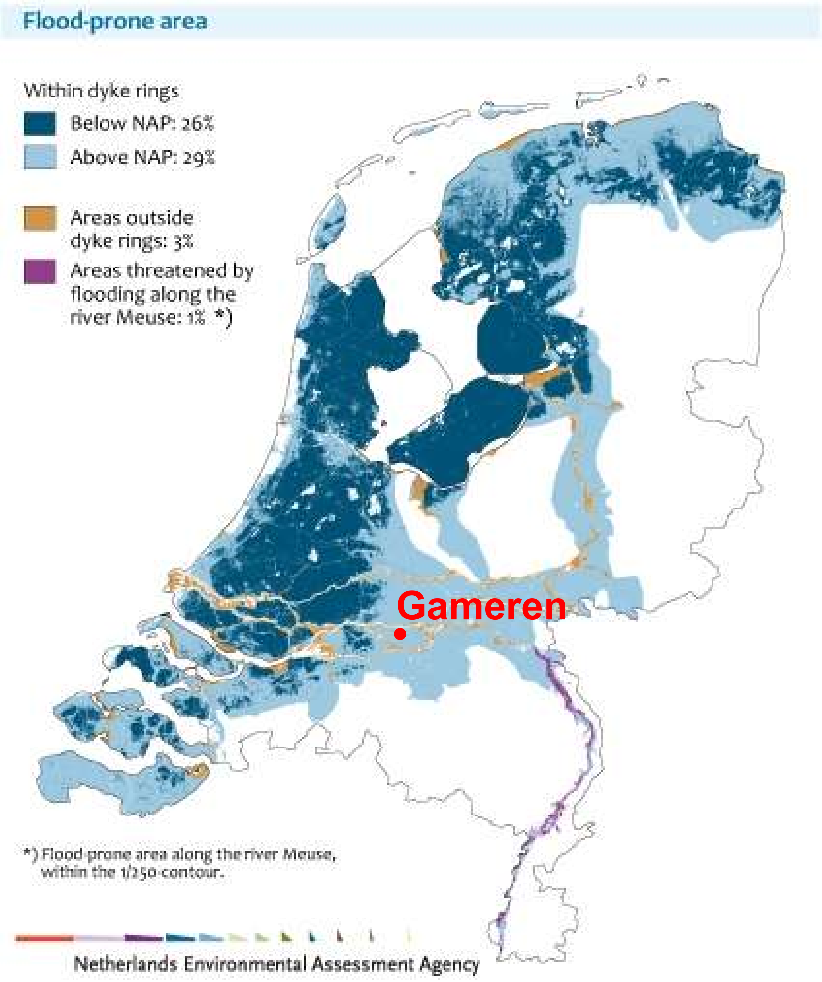
Failure consists of instability of the remaining slope, caused by the strong outward flow



Pilot application at Gameren (Netherlands)

Gameren is a small village along the Waal river, part of the Rhine river system.

By Dutch law, the acceptable annual probability of flooding for this part of the Netherlands has been set to 1/10,000.



*) Flood-prone area along the river Meuse, within the 1/250 contour.

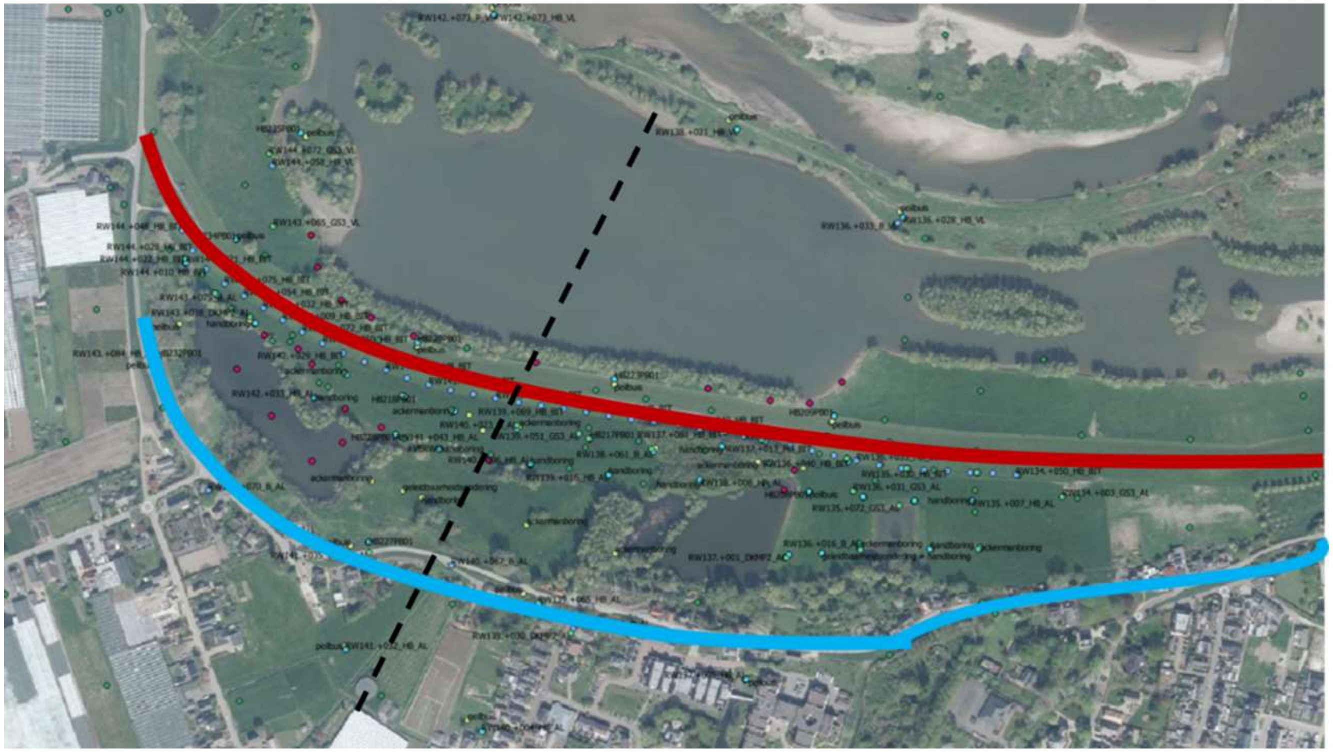
Netherlands Environmental Assessment Agency

New and old levee at Gameren

The old levee dates back to around 1400 A.D.

In 2005, a new levee was built. Its safety against backward erosion piping appeared to be insufficient.

A stretch of approx. 1 km was selected for the pilot application of the Coarse Sand Barrier.



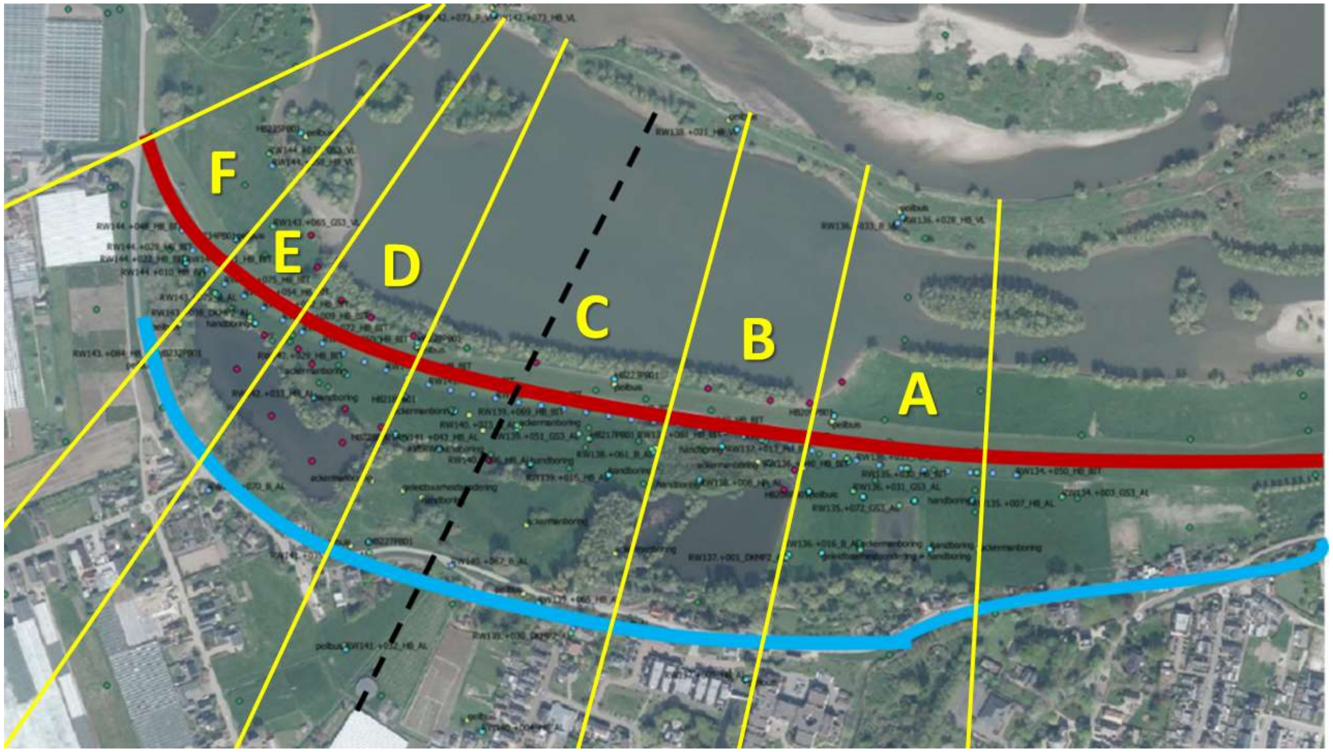
Deltares

Non-uniformity

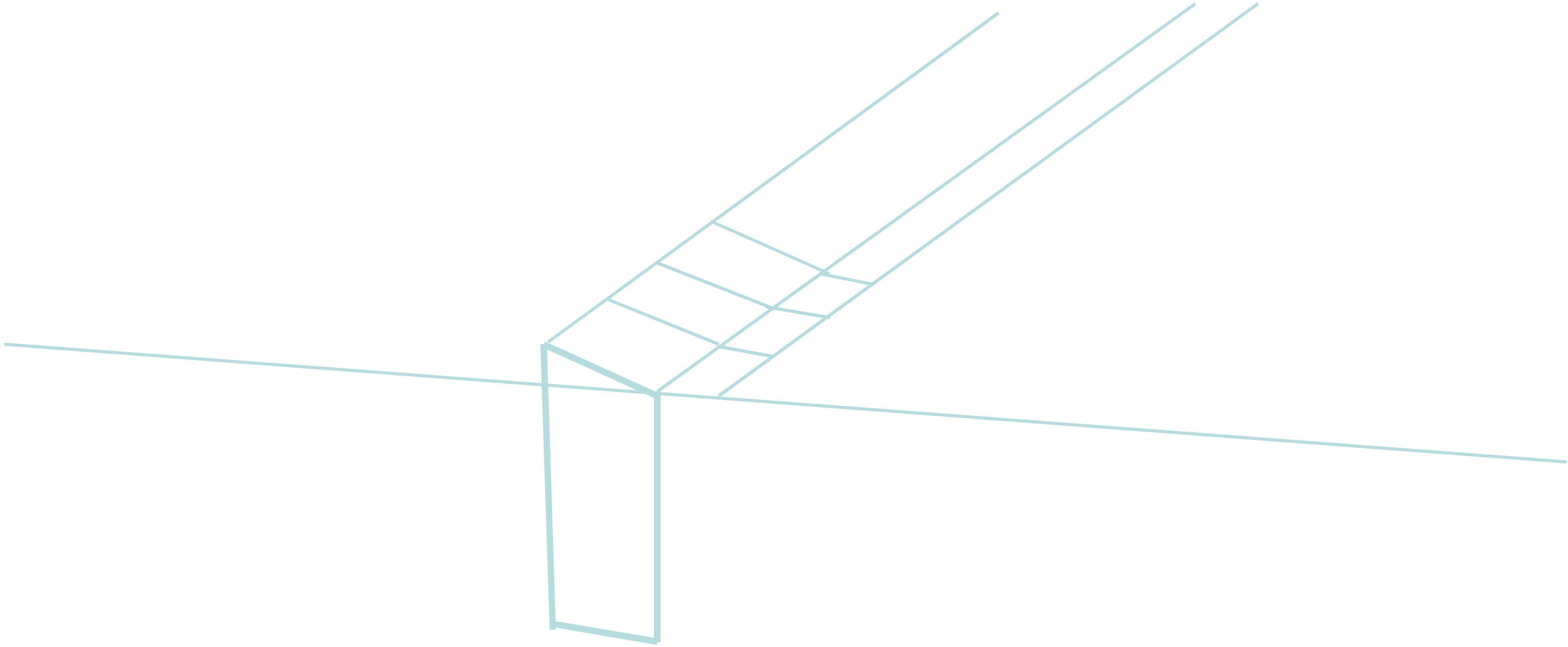
At the waterside, a large re-filled sandpit in the local side branch of the main river complicates the analysis.

At the land side, there are several clay pits between both dikes, visible as ponds.

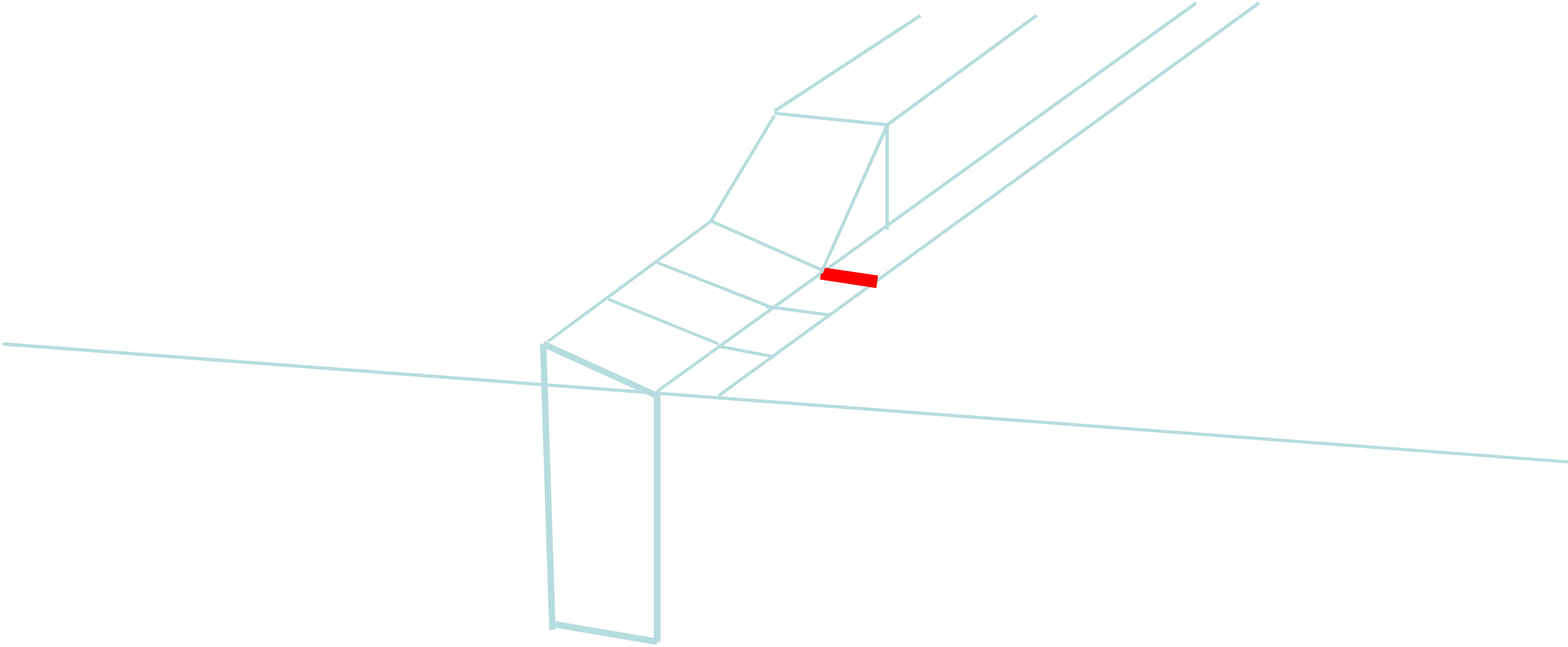
Sections B and D are roughly equal to each other, resulting in five different geohydrological parts.



Infinite growth of lateral pipe?



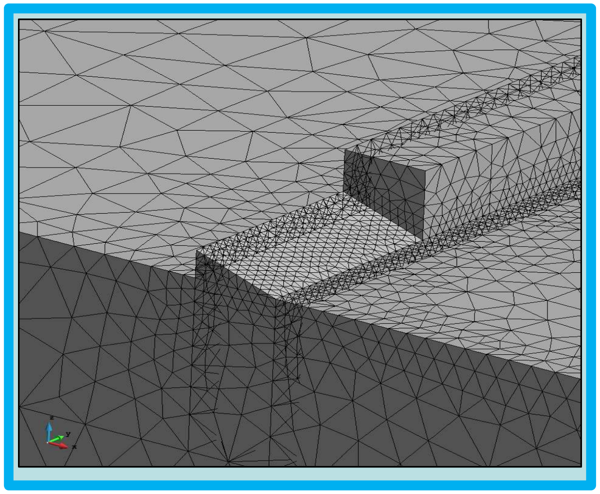
Reality: no infinite lateral growth because of random obstacles

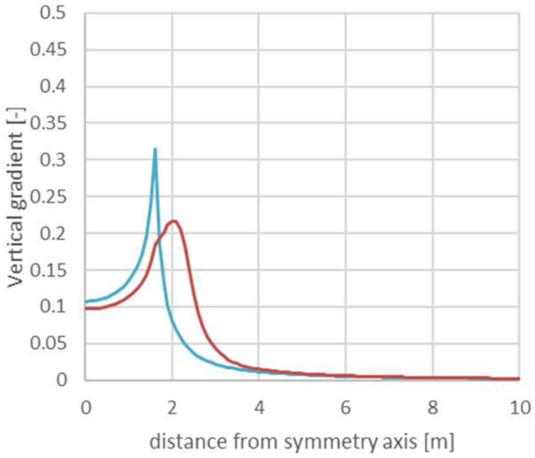


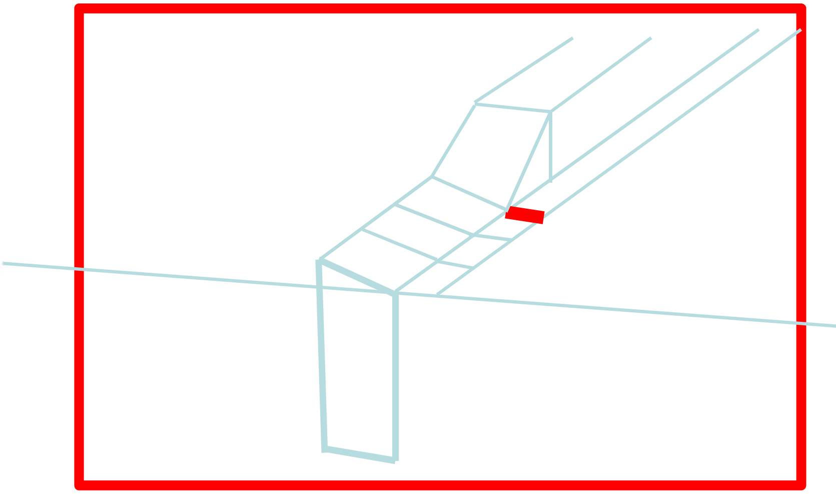
3D analysis – Finite element models used

- Flat barrier: determine influence of large-scale geometrical variations and conductivity parameters
  - long model, including the village
  - short model, ending at the old levee
- Barrier extending into the blanket layer
  - Vertical side edge
  - Inclined side edge

Influence of shape of edge on calculated 3D factor







Other partial safety factors

- Model factor – to account for simplifications made in the conceptual failure model
- Modelling factor – to account for imperfections in reality
  - clay lenses
  - a more permeable part of the aquifer
  - holes in the blanket layer
- damage factor – to translate the result of one section
  to the safety of a longer levee stretch (here: 28.8 km),
  with only a part of the failure probability reserved for backward erosion piping
  and an overall probability of failure of 1:10,000 per year

Conclusions

- the Coarse Sand Barrier is still a promising concept
- Faced with reality:
  - 3D factor – ‘bad flow conditions’
  - Model factor – ‘simple model’
  - Modelling factor – ‘reality is different’
  - Damage factor – ‘part of a larger system’

… the safety margins may be fully required.

Thank you for your attention!

No progress is possible without a dedicated team…

Vera van Beek

Dennis Peters

Ulrich Förster

Adam Bezuijen

Marc Hijma

Esther Rosenbrand

Bernard van der Kolk

Sepideh Akrami

Aron Noordam

André Koelewijn

Jarno Terwindt

Leo Voogt

Deltares

Workshop Internal Erosion at the field scale

Length-effects in reliability analysis of internal erosion in earthen dikes

Jochem Caspers (MSc), graduated at the Technical University of Delft, currently working at HKV

As a master student at the TU Delft I performed a researched on the Dutch method of combining failure probabilities at different spatial scales from September 2019 to June 2020. This researched has been conducted in order to achieve the Master of Science degree in Hydraulic Engineering.

The current method for combining failure probabilities at different scales ('assemblage') is used in the Dutch flood risk analysis of earthen dikes to assess the probability of flooding. Currently, probabilities of flooding for geotechnical failure mechanisms are obtained which are not considered to be realistic. To obtain more realistic results the following steps are researched; the assessment of cross-sections, scaling to dike sections and combining sections to a dike trajectory. The increase of failure probability over increasing length, known as the length-effect, is of importance in the current Dutch method of combining failure probabilities. This method is known as the assembly procedure.

This research is based on a case study of dike trajectory 48-1 along the Dutch Rhine for the geotechnical failure mechanism internal erosion (or piping). If during high water events the flow of ground water underneath the earthen dike entrains sand, the dike can fail due to internal erosion. With a flood risk analysis of this geotechnical failure mechanisms the assembly procedure is researched. The objective is to answer the main research question:

Can the current Dutch assembly procedure of combining failure probabilities of geotechnical failure mechanisms be improved, and if so, how?

The scaling from cross-sectional to sectional failure probabilities using the length-effect within sections is based on a Continuous Model of the Outcrossing Method. This method results in conservative scaling factors because (i) the nationwide calibrated length-effect parameters (a and b) are a conservative choice, (ii) the method is in most cases not applied to intervals much larger than the independent equivalent length, (iii) the method is not applied to intervals with statistically constant reliability and (iv) the method is based on the upper bound of the outcrossing method which is only a good approximation for small failure probabilities and outcrossing rates.

Based on the case study data, new field calibrated length-effect parameters are derived which reduce the length-effect significantly compared to the current length-effect parameters according to the WBI. Moreover, since these field calibrated length-effect parameters still include conservatism resulting from the mismatch between the theoretical assumptions and practical reality, the length-effect within sections approaches one. This indicates no length-effect within dike sections if the assessment is based on the normative cross-section (or 'weakest link') within dike sections of lengths not much larger than the equivalent independent length.

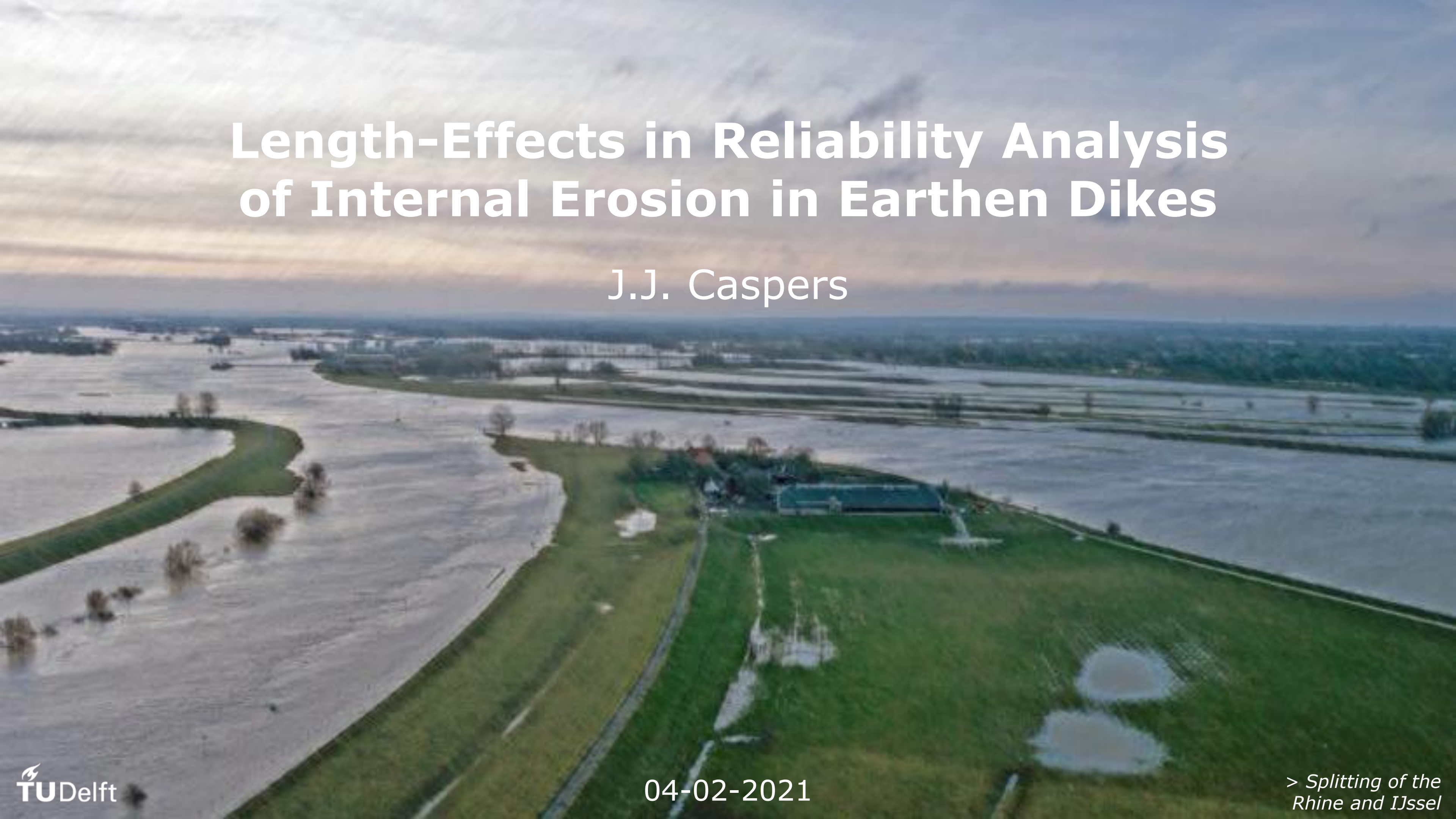
The combination of sections to a trajectory failure probability using the length-effect between sections is currently based on the fundamental independent upper boundary. In other words, the independent summation of the sectional failure probabilities. This is a conservative method because (i) the correlation between dike sections, mainly introduced by the load (or water level), is not negligible and (ii) knowledge about fluvial deposits is not taken into account.

Taking the correlation of consecutive dike sections into account reduces the trajectory failure probability. Therefore, the fundamental independent boundary is not a good approximation for dike trajectories. An efficient method to include the correlation between dike sections is the Equivalent Planes Method based on a probabilistic assessment.

Finally, when applying the field related assembly procedure to the case study of trajectory 48-1 leads to a lower trajectory failure probability of the failure mechanism piping compared to the current assembly procedure of the WBI 2017. The more realistic result is based on a probabilistic assessment, without the length-effect within sections (but the selection of the critical cross-section as representative) and with the length-effect between sections using the equivalent planes method.

Length-Effects in Reliability Analysis of Internal Erosion in Earthen Dikes

J.J. Caspers



TUDelft

04-02-2021

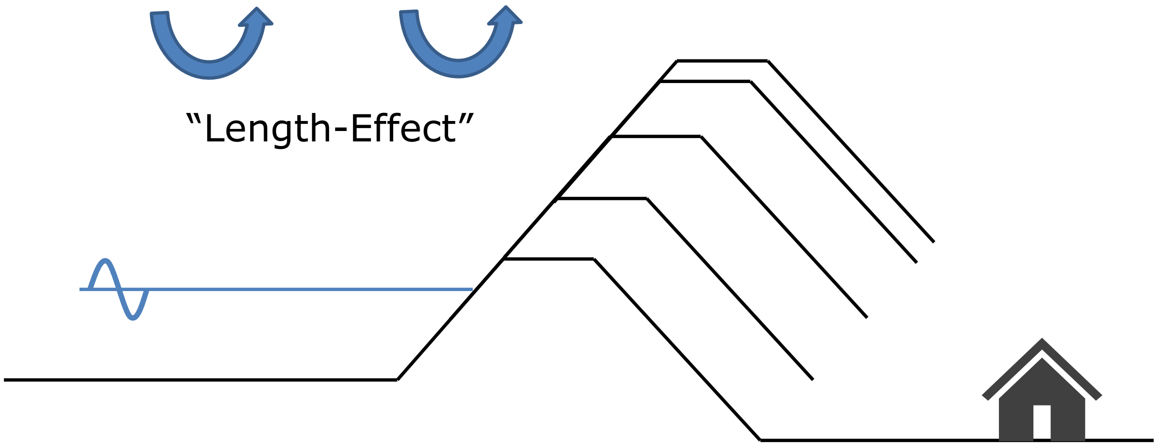
> Splitting of the Rhine and IJssel

Introduction

- The greater the length of a dike, the more likely there will be a weak spot

- Safety Assessment
  - Probability of flooding
  - Cross-Sections -> Sections -> Trajectory

- Safety Standards (2017)
  - Risk evaluation
  - Trajectory



“Length-Effect”

Case Study

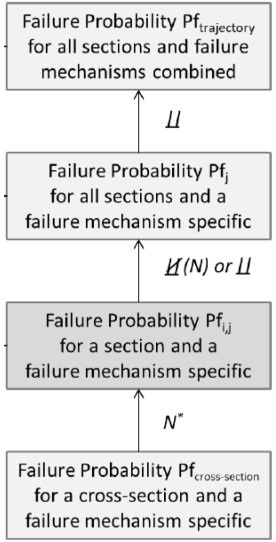
- Flood risk analysis (48-1)
  - Internal erosion failure mechanism
  - Unrealistic result not reported by expectations and knowledge
- More realistic assessment?
  - Calculation of cross-sections
  - Scaling to dike sections
  - Combination to a trajectory

Source: Waterboard Rijn & IJssel

Research

- Calculation
  - Reliability Analysis
- Scaling
  - Outcrossing Method
- Combination
  - Equivalent Planes Method

WBI Approach



Failure Probability $Pf_{trajectory}$ for all sections and failure mechanisms combined

$\coprod$

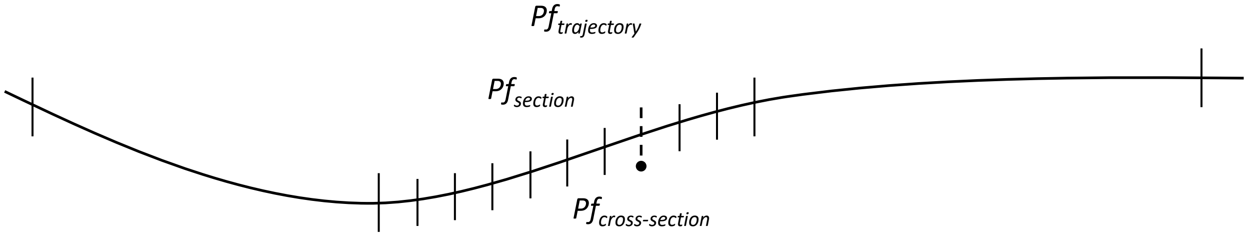
Failure Probability Pf_{j} for all sections and a failure mechanism specific

$\cancel{\coprod}(N)$ or $\coprod$

Failure Probability $Pf_{i,j}$ for a section and a failure mechanism specific

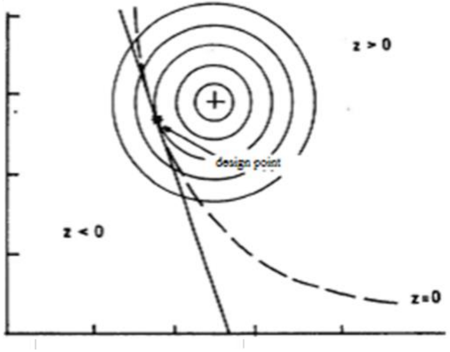
N^{*}

Failure Probability $Pf_{cross\text{-}section}$ for a cross-section and a failure mechanism specific

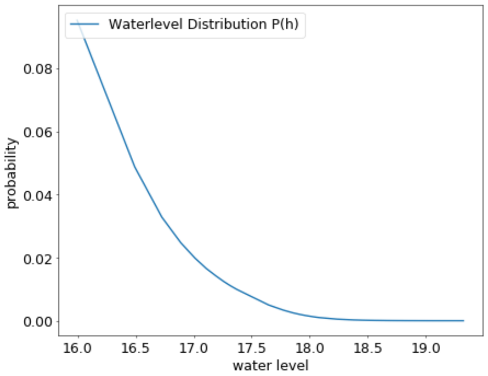


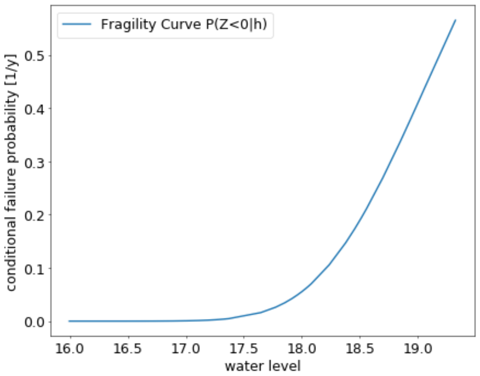
Reliability Analysis

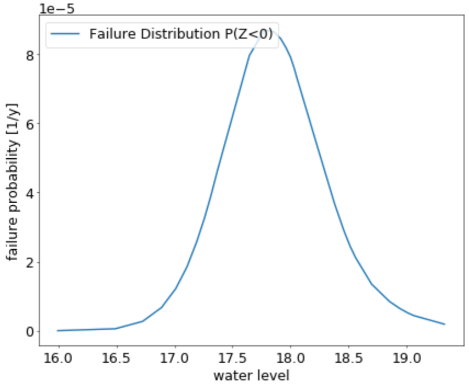
- Semi-Probabilistic Assessment
  - Characteristic Values
- Probabilistic Assessment
  - First Order Reliability Method (FORM)
  - Fragility Curves



Source: SienceDirect

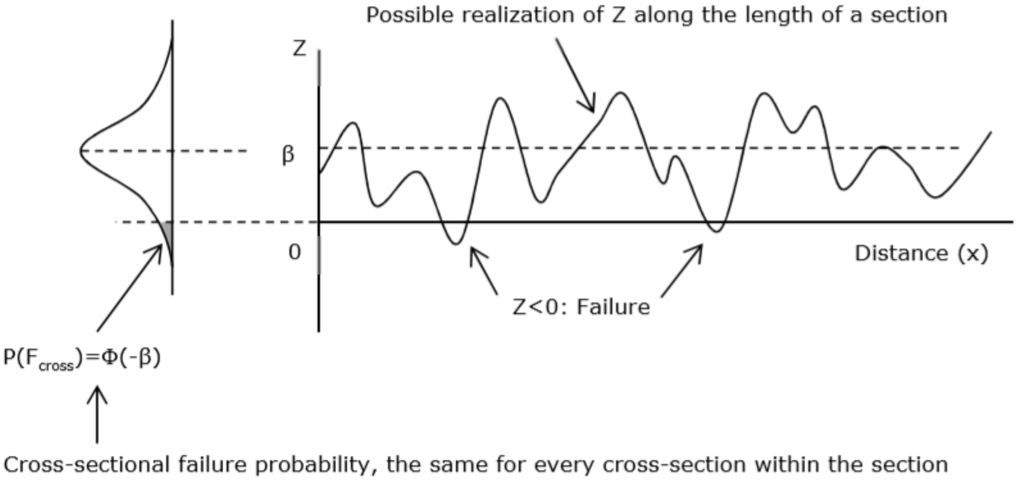






Length-Effect within Sections

- Continuous Model of the Outcrossing Method



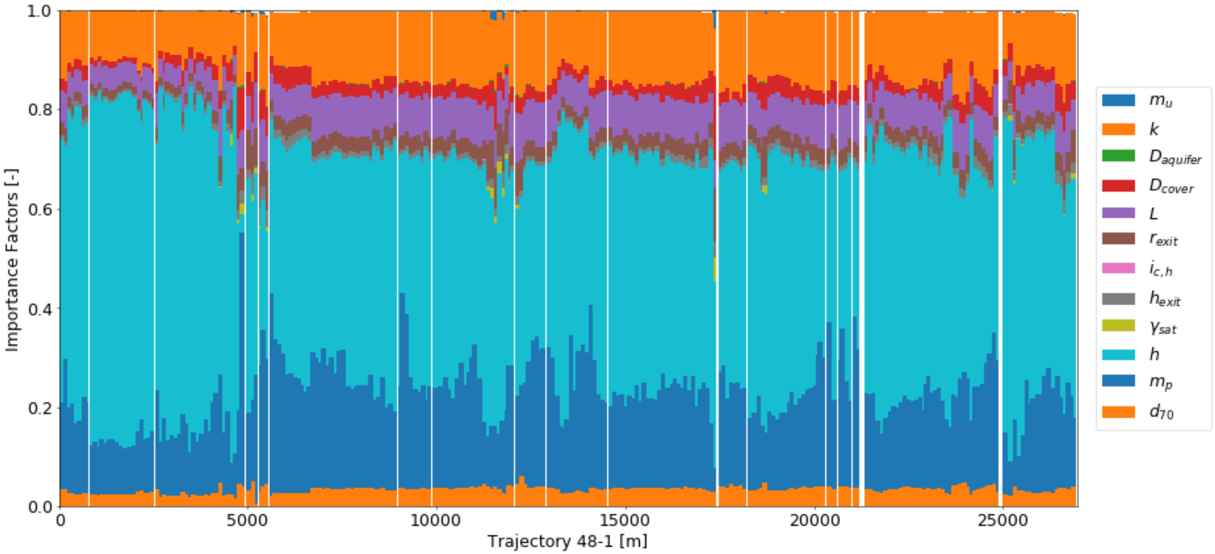
Source: Code Calibration WBI 2017 – Length-effect

$$\boxed{\rho''_z(0) = -\sum_{i=1}^{N} \frac{2\alpha_i^2(1-\rho_{0,i})}{D_i^2}}$$

$$Pf(0,L) = Pf(0) + \upsilon \cdot L = Pf(0) + \frac{L}{2\pi} exp(-\frac{1}{2}\beta^2) \cdot \sqrt{-\rho''_Z(0)} \qquad (9.12)$$

Length-Effect within Sections

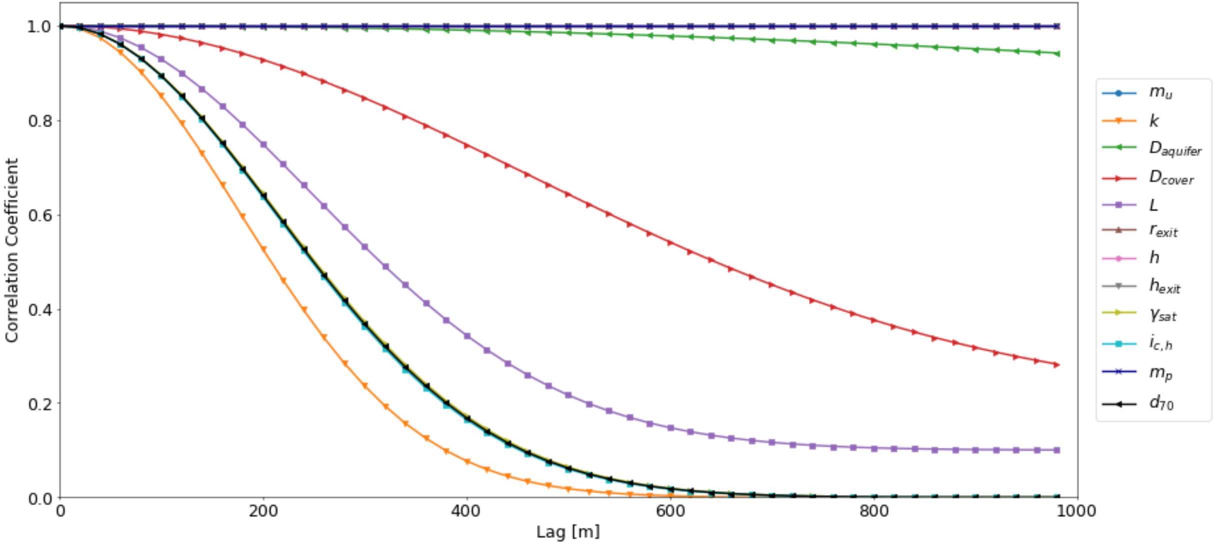
- Continuous Model of the Outcrossing Method
  - Importance factors (α)



$$\rho_z''(0) = -\sum_{i=1}^{N} \frac{2\alpha_i^2(1-\rho_{0,i})}{D_i^2}$$

Length-Effect within Sections

- Continuous Model of the Outcrossing Method
  - Autocorrelation functions (ρ,D)



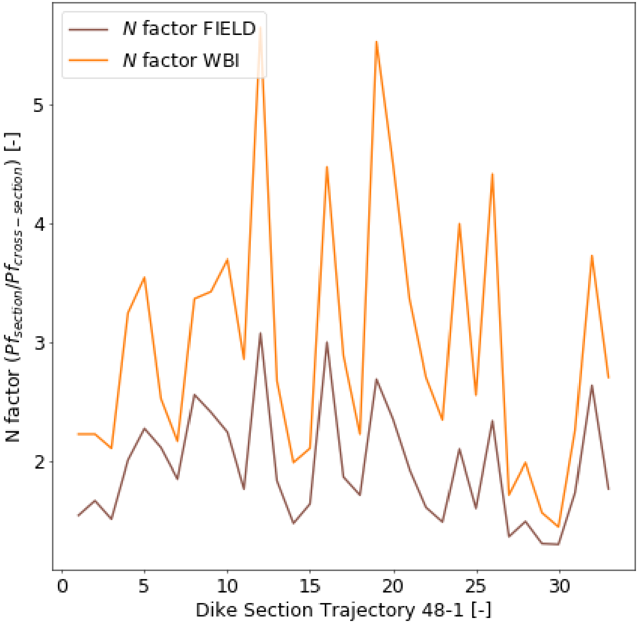
$$\rho_z''(0) = -\sum_{i=1}^{N} \frac{2\alpha_i^2(1-\rho_{0,i})}{D_i^2}$$

Length-Effect within Sections

- Comparison of the Continuous Model of the Outcrossing Method (FIELD) and the current definition of the length-effect (WBI)

$$N^*_{WBI} = 1 + \frac{a * L_{vak}}{b}$$ (WBI 2017)

$$N^*_{FIELD} = 1 + \frac{L_{vak}}{l_{eq}}$$ (Calibration Study)



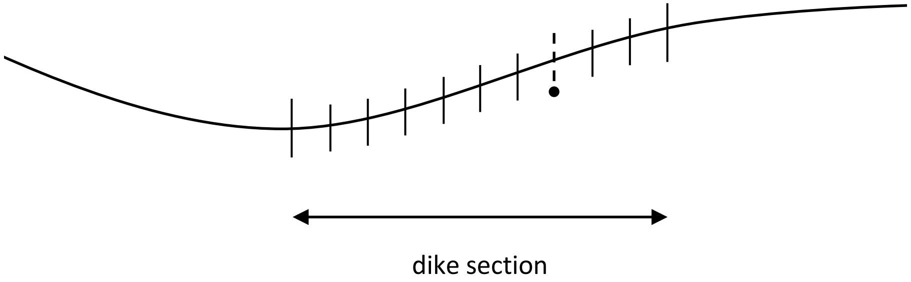
Length-Effect within Sections

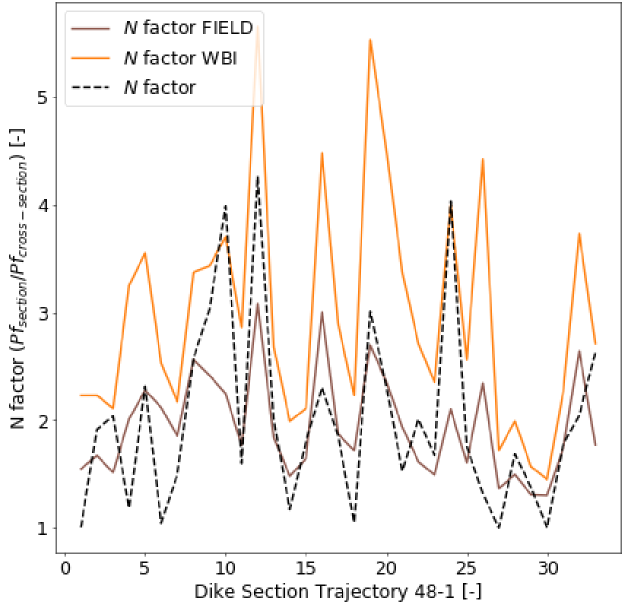
- Comparison to the ratio between the independent summation and maximum probability of failure within sections

$$N^*_{WBI} = 1 + \frac{a * L_{vak}}{b} \quad \text{(WBI 2017)}$$

$$N^*_{FIELD} = 1 + \frac{L_{vak}}{l_{eq}} \quad \text{(Calibration Study)}$$

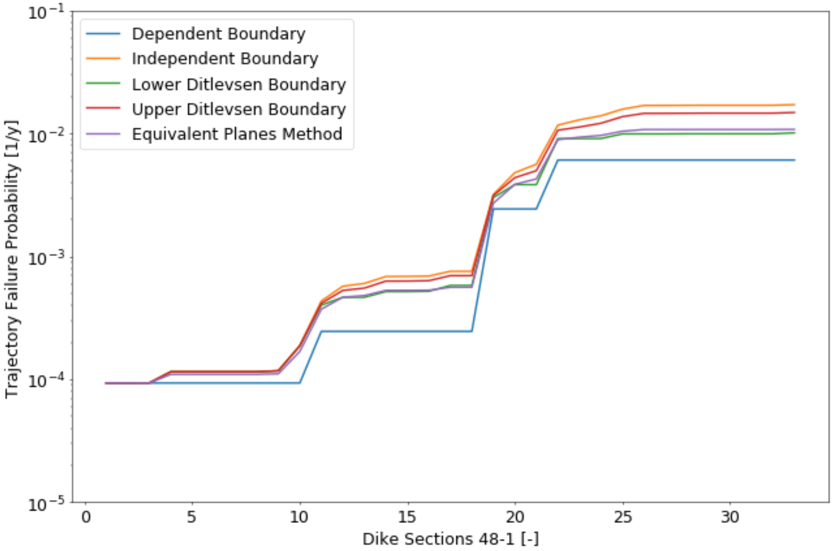
$$N^* = \frac{\sum(Pf_i)}{\max(Pf_i)} \qquad i \in L_{section}$$





Length-Effect between Sections

- Equivalent Planes Method
  - Method for combining sections to an equivalent section by taking the mutual dependence into account (Theory of Hohenbicker and Rackwitz)



Conclusions

- Can the current Dutch method of combining failure probabilities of geotechnical failure mechanisms be improved, and if so, how?
  - Scaling to dike sections
    - No length-effect within sections if the assessment of sections is based on the ’weakest link’ of a dike section with variable or small reliability and sectional lengths not much larger than the equivalent independent length.
  - Combining to a dike trajectory
    - With the Equivalent Planes Method mutual dependence between dike sections can be accounted for. Including field related importance factors and autocorrelations results in a more realistic failure probability

Thank you!

Questions?

Digital version of this master thesis available at the TU Delft repository

http://resolver.tudelft.nl/uuid:315c6eb4-066c-4377-b412-dcaa849a7a5b

Jochem Casper

caspers@hkv.nl

Field measurements on a natural sand boil along the Po river (Italy)

Michela Marchi [a], Guido Gottardi [a], Laura Tonni [a]

[a] University of Bologna, DICAM, Bologna, Italy

* corresponding author: michela.marchi@unibo.it

Abstract: This study presents a set of field measurements carried out on a large sand boil reactivated near the toe of an embankment along the river Po (Italy). Hydraulic heads, velocity and discharge, concentration and pipe geometry were measured as a function of the water level in the river during the November 2018 flood. The collected data are compared to predictions of a theoretical model which provides the head loss in the vertical pipe. Furthermore, the local exit gradients, as deduced from measurements, are discussed, together with the operational critical gradients adopted in current design practice.

The most significant outcomes can be listed as follows:

1) A valuable piece of information has been obtained for the investigated natural sand boil, in terms of pipe diameter and depth, particle size of both fluidized and ejected sediments. These data, which are not routinely obtained in practice, are of crucial importance for the calibration of piping models.

2) A novel way of measuring concentration into the pipe during reactivation has been introduced and its effectiveness demonstrated by comparison with independent determinations from discharge and velocity data.

3) The observed evolution of excess water head into the pipe suggests that during the monitoring period, which can be interpreted as a sequence of equilibrium stages characterized by different water heads imposed by the river, the variation of hydraulic load governing underseepage is very likely to have been partly absorbed by fluidisation of the sand bed in the pipe and partly dissipated in the aquifer along the seepage length.

4) Good agreement has been found between measured head loss in the vertical pipe and that deduced from the application of Robbins *et al.* (2019) model. When applied to the river Po case, the model provides trends of hydraulic gradients similar to the values predicted for the Dutch sand boil described in the same study.

5) The vertical exit gradients computed for the river Po section have been compared with those observed in the river Mississippi and described in USACE (1956). In spite of the differences in the calculation procedure adopted for the two different datasets, the values turn out to be in good agreement.

Robbins, B.A., Stephens, I.J., Van Beek, V., Koelewijn, A.R. and Bezuijen, A. 2019. Field measurements of sand boil hydraulics. *Géotechnique*, **70** (2), 153-160.

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Field measurements on a natural sand boil along the Po river (Italy)

Michela Marchi, Guido Gottardi, and Laura Tonni

Department of Civil, Chemical, Environmental, and Materials Engineering (DICAM),
University of Bologna

EWG-IE 2020 - Internal erosion at the field scale – 3rd Online meeting
February 4th, 2021

130 HISTORIC SAND BOILS «FONTANAZZI» OF THE PO RIVER

Po river basin in the northern Italy

MARCHI et al (2020) https://doi.org/10.1144/qjegh2020-097

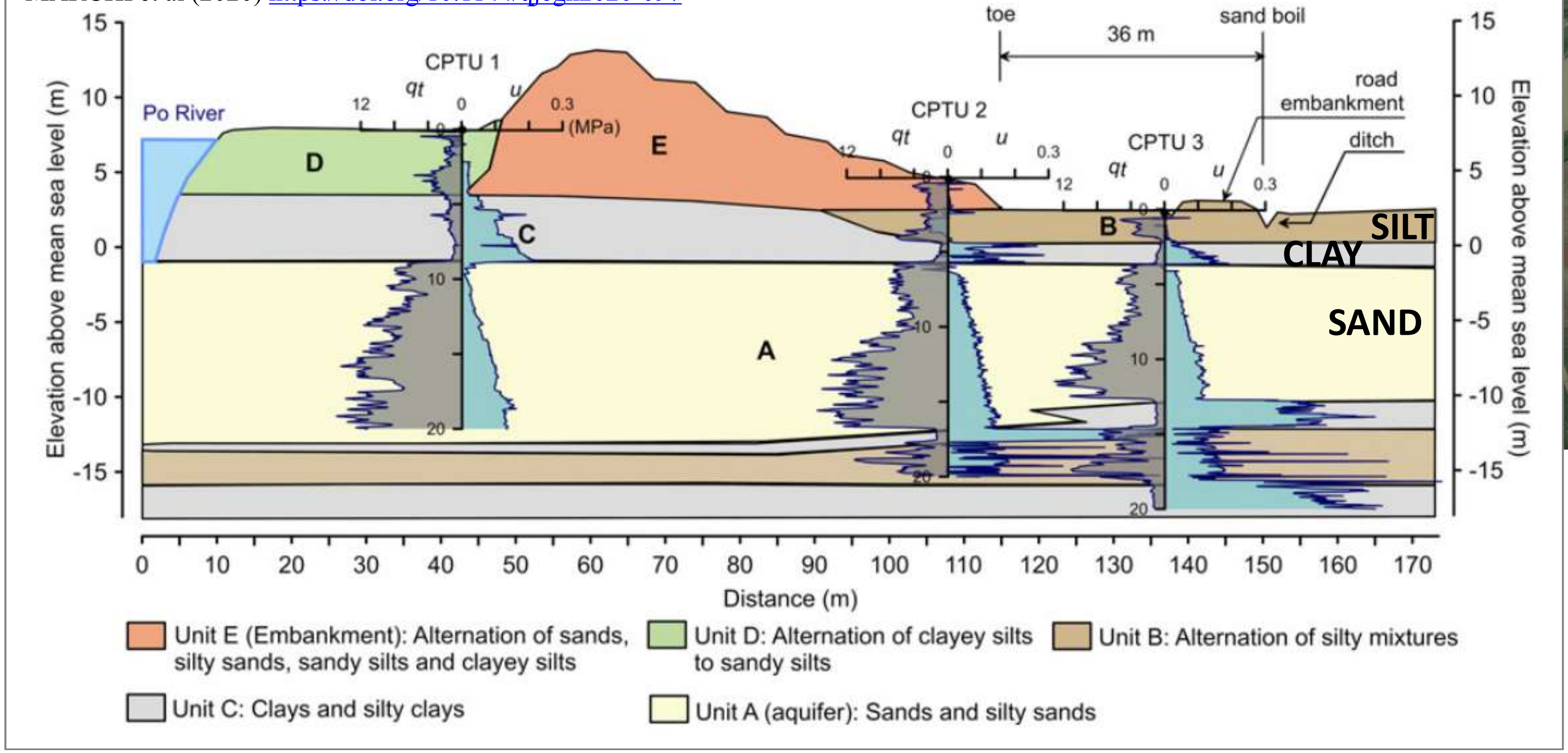
Field measurements on a natural sand boil along the Po river (Italy)

Michela Marchi, María Fernanda García Martínez, Guido Gottardi, and Laura Tonni

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Case study:
sand boil in Guarda Ferrarese

MARCHI et al (2020) https://doi.org/10.1144/qjegh2020-097



🟧 Unit E (Embankment): Alternation of sands, silty sands, sandy silts and clayey silts

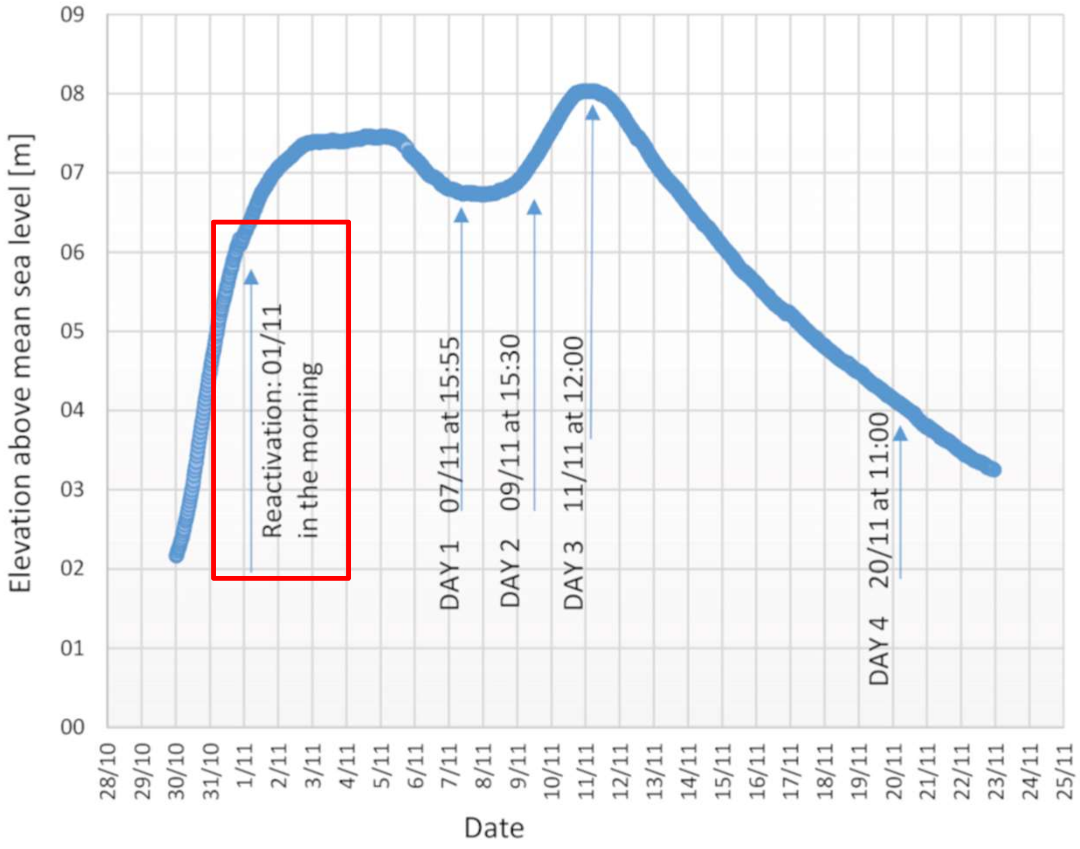
🟩 Unit D: Alternation of clayey silts to sandy silts

🟫 Unit B: Alternation of silty mixtures

⬜ Unit C: Clays and silty clays

🟨 Unit A (aquifer): Sands and silty sands

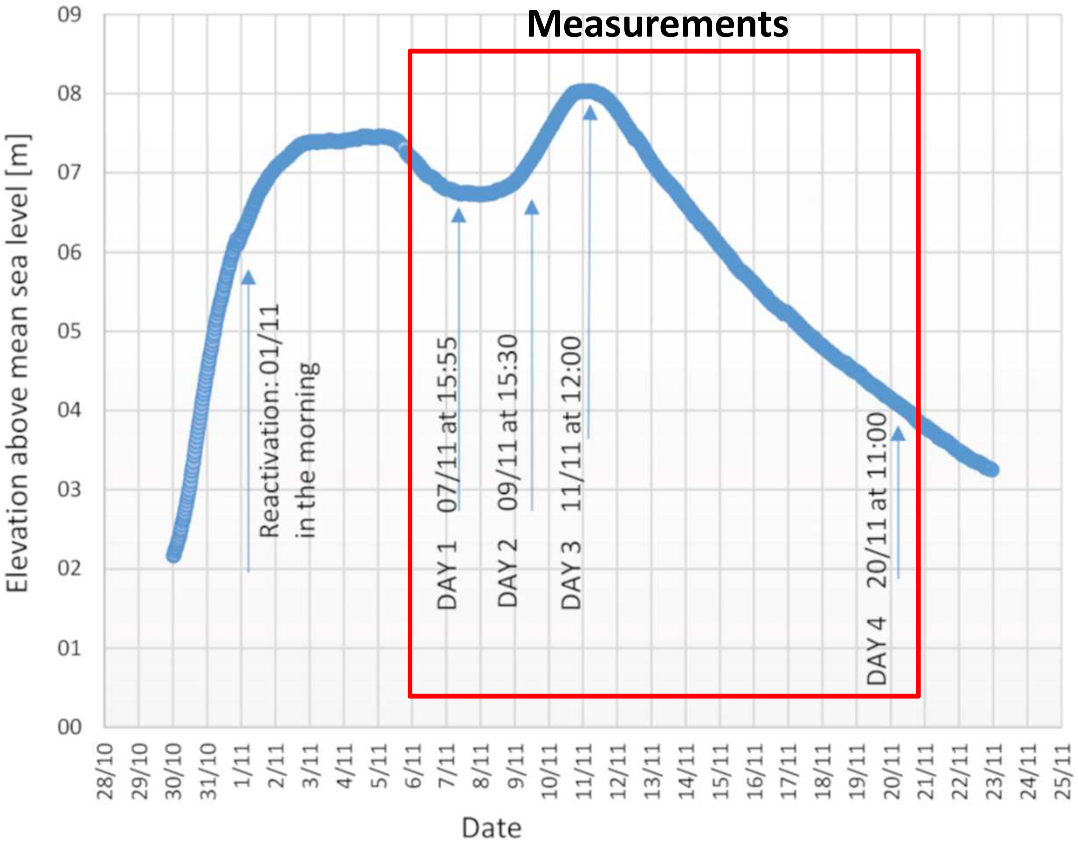
Novembre 2018 reactivation



Hydrograph of November 2018 flood

Picture of the sand boil at the initial stage of the reactivation

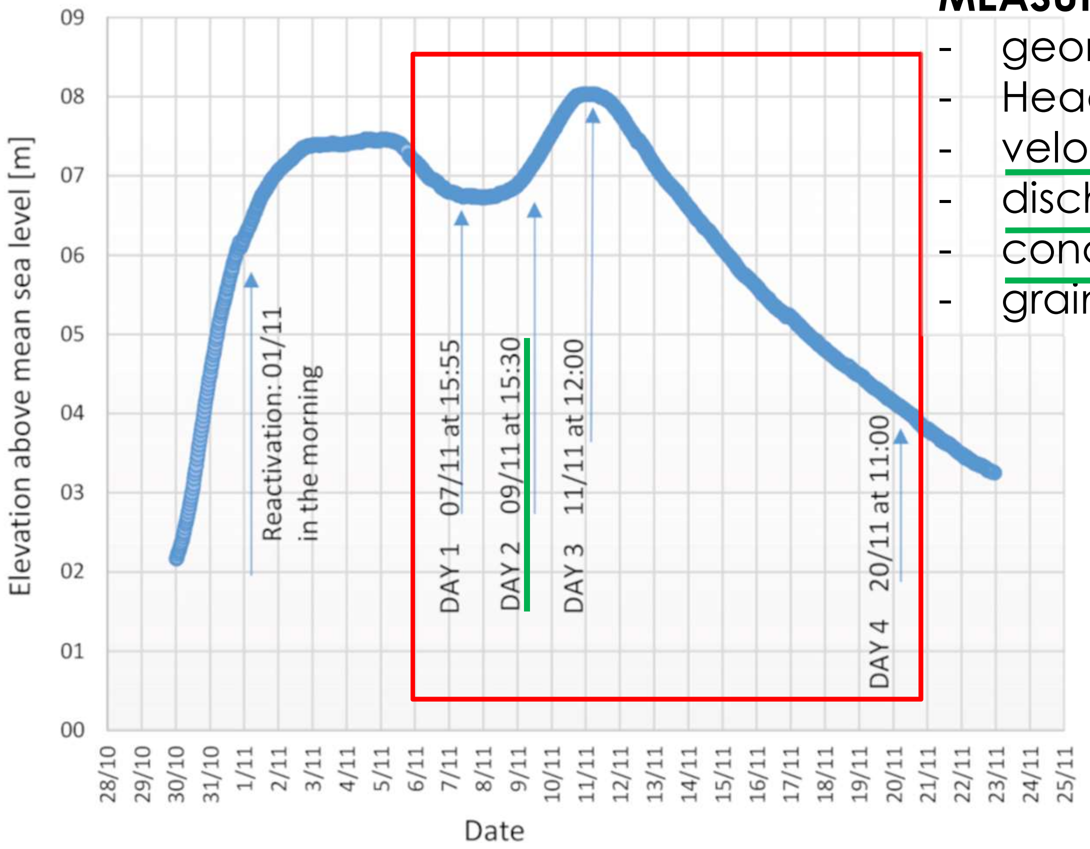
Measurements during Novembre 2018 reactivation



Hydrograph of November 2018 flood

Picture of the sand boil in equilibrium condition, after sandbagging

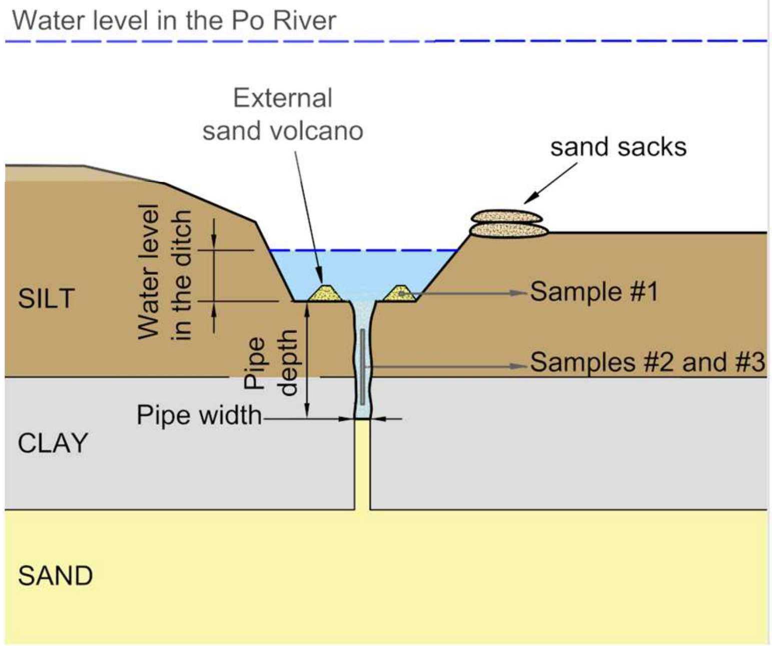
Measurements during Novembre 2018 reactivation



Hydrograph of November 2018 flood

MEASURED PARAMETERS:

- geometry;
- Head loss along the vertical pipe
- velocity;
- discharge;
- concentration;
- grain size distribution



Scheme of the pipe geometry and sample positions
MARCHI et al (2020) https://doi.org/10.1144/qjegh2020-097

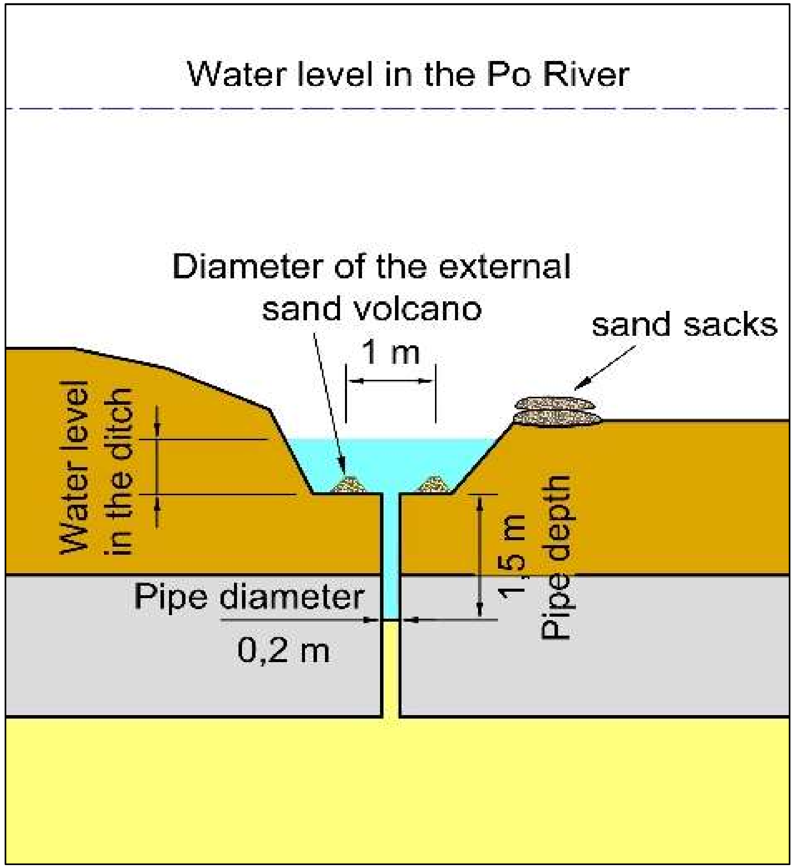
Measurements during Novembre 2018 reactivation

Vertical pipe geometry:

EXTERNAL VOLCANO
diameter of about 1 m at the top of the rim and was c. 15 cm high

HORIZONTAL SECTION
increases from 20 cm at its bottom to c. 35 cm near the exit

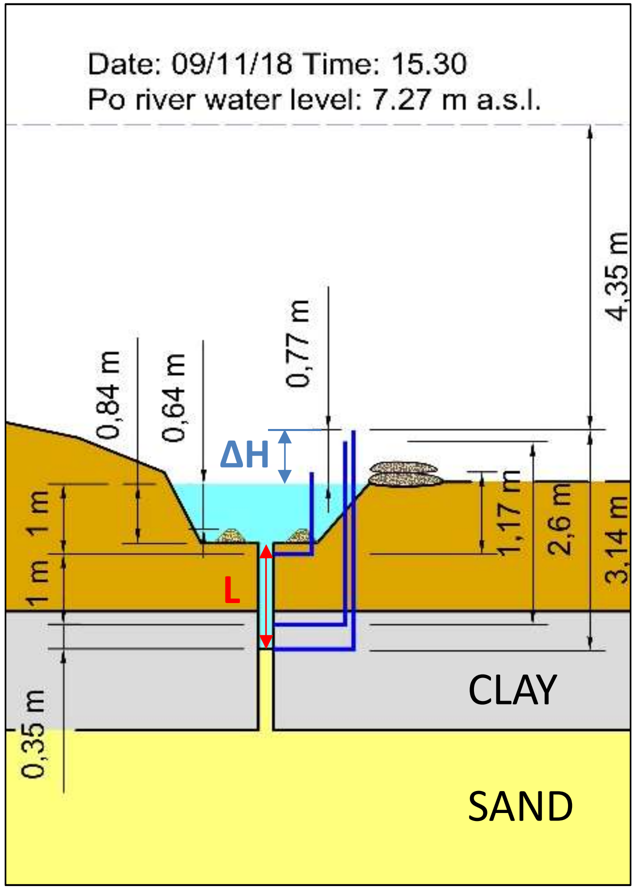
DEPTH
varies from a maximum of 1.54 m to a minimum of 0.73 m



Measurements during Novembre 2018 reactivation

Water head in the vertical pipe

Detail of the filter placed at the lower end of the PE tube used for the measurement of water heads



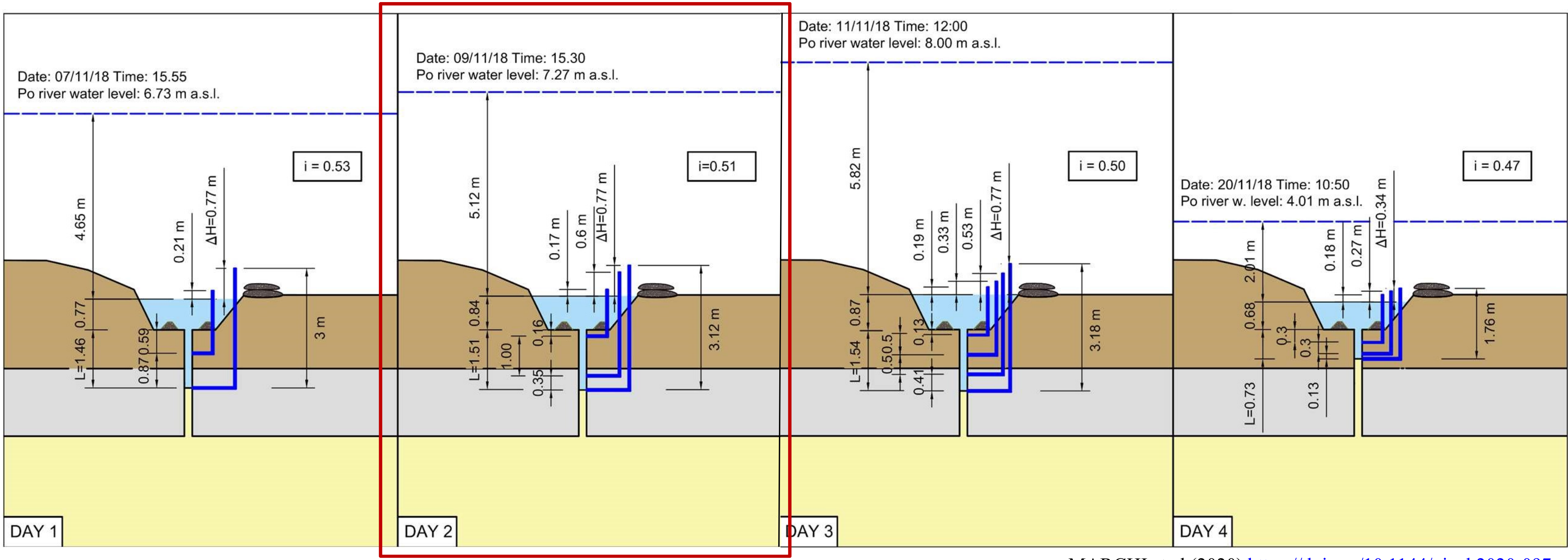
Date: 09/11/18 Time: 15.30
Po river water level: 7.27 m a.s.l.

Average hydraulic gradient into the vertical pipe

$$\frac{\Delta H}{L} = 0{,}51$$

Measurements during Novembre 2018 reactivation

Water head in the vertical pipe



Date: 07/11/18 Time: 15.55
Po river water level: 6.73 m a.s.l.

Date: 09/11/18 Time: 15.30
Po river water level: 7.27 m a.s.l.

Date: 11/11/18 Time: 12:00
Po river water level: 8.00 m a.s.l.

Date: 20/11/18 Time: 10:50
Po river w. level: 4.01 m a.s.l.

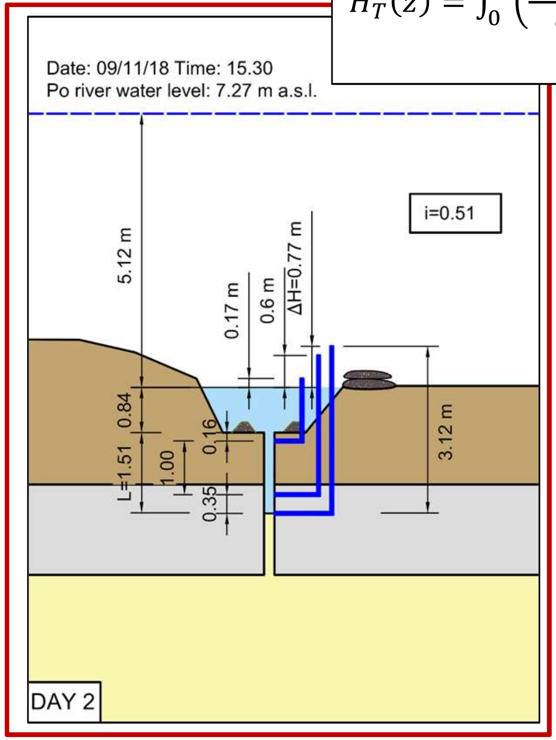
MARCHI et al (2020) https://doi.org/10.1144/qjegh2020-097

Measurements during Novembre 2018 reactivation

Water head in the vertical pipe

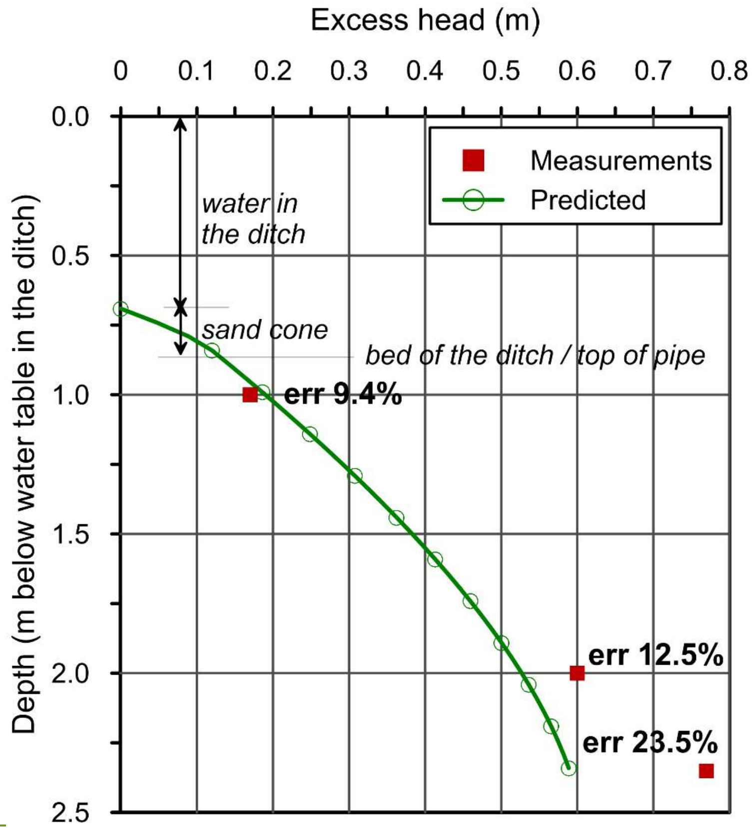
Interpretation of hydraulic loads in the sand boil with the analytical model by Robbins et al. (2019)

$$H_T(z) = \int_0^z \left(\frac{\partial H_L(z)}{\partial z} + \frac{\partial H_D(z)}{\partial z}\right)\partial z = \int_0^z \left[\left(\frac{32\mu v(z)}{\rho_w g D(z)^2}\right) + (G_s - 1)C_V(z)\right]\partial z$$



Input parameter	
$n_{\min}$	0.40
G_s	2.65
d_{98} (mm)	0.35
ρ_w (kg m^{-3})	1000
ρ_s (kg m^{-3})	2650
g (m s^{-2})	9.81
μ (Pa s)	1×10^{-3}
D_{top} (m)	0.35
D_{base} (m)	0.20
α (deg.)	15
Q (m^3 s^{-1})	2×10^{-4}

Input parameters



Measurements during Novembre 2018 reactivation

Flow velocity and discharge

Portable digital flow meter

v < 0.1 m/s
(rate was lower than the instrument sensitivity)

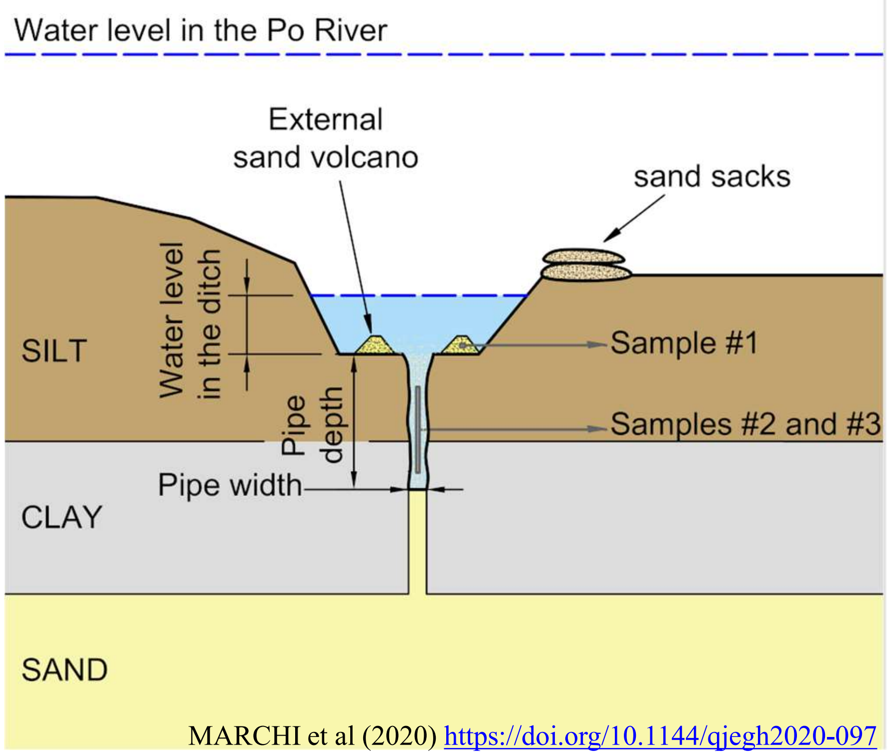
Dye injections (Robbins et al. 2019)

v ~ 0.1 m/s

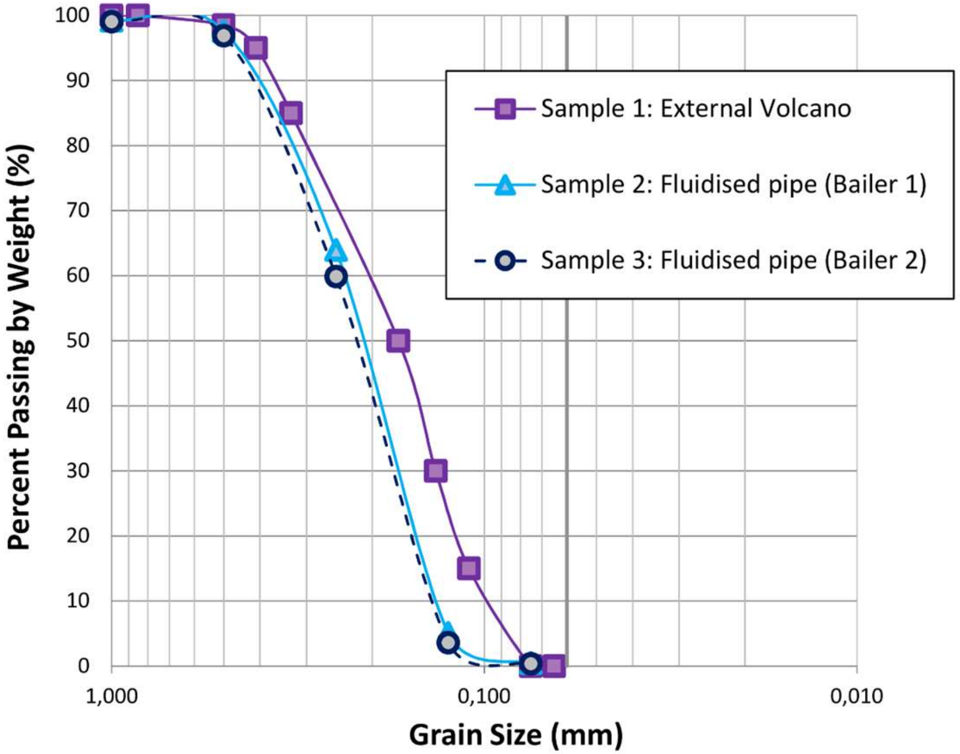
Graduated buckets
Q =2 l/s → v ~ 0.06 m/s

Measurements during Novembre 2018 reactivation

Sample collection and laboratory tests → Particle size distribution

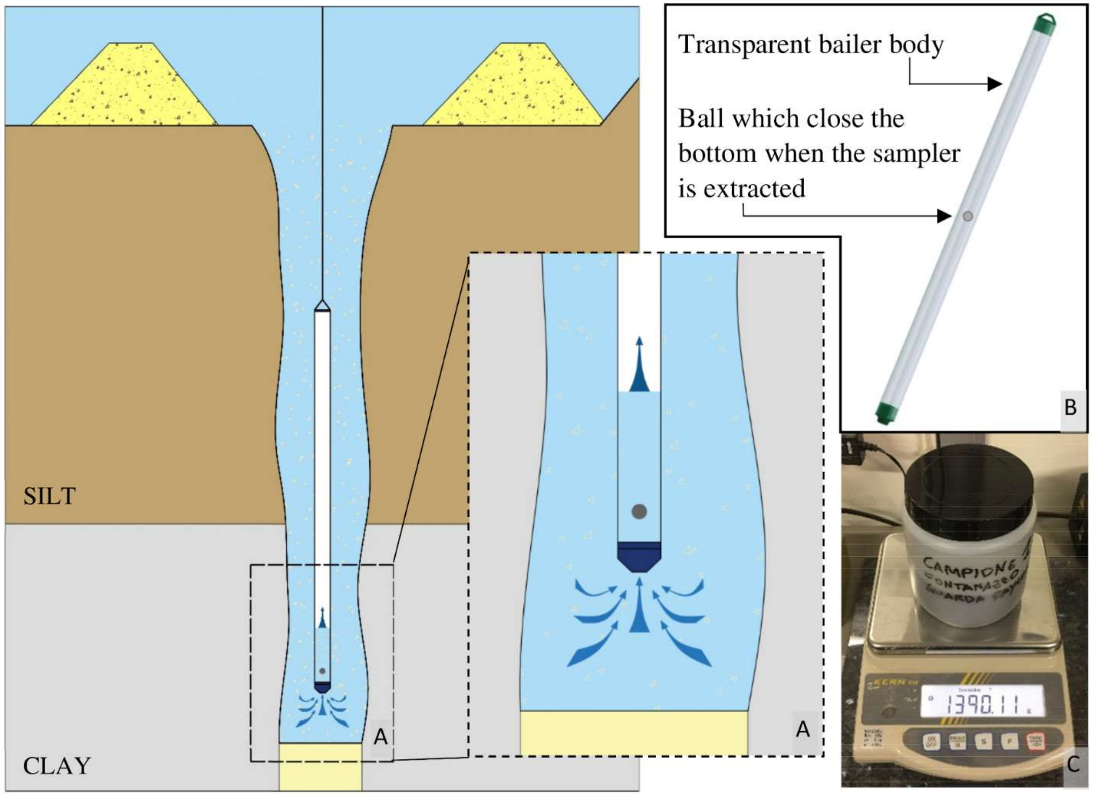


MARCHI et al (2020) https://doi.org/10.1144/qjegh2020-097



Measurements during Novembre 2018 reactivation

Sample collection and laboratory tests → Concentration



MARCHI et al (2020) https://doi.org/10.1144/qjegh2020-097

$$C_{vol}=V_{solid}/(V_{solid}+V_{water})=1-n$$

$$C_{vol}=\mathbf{31.6}\ \%$$

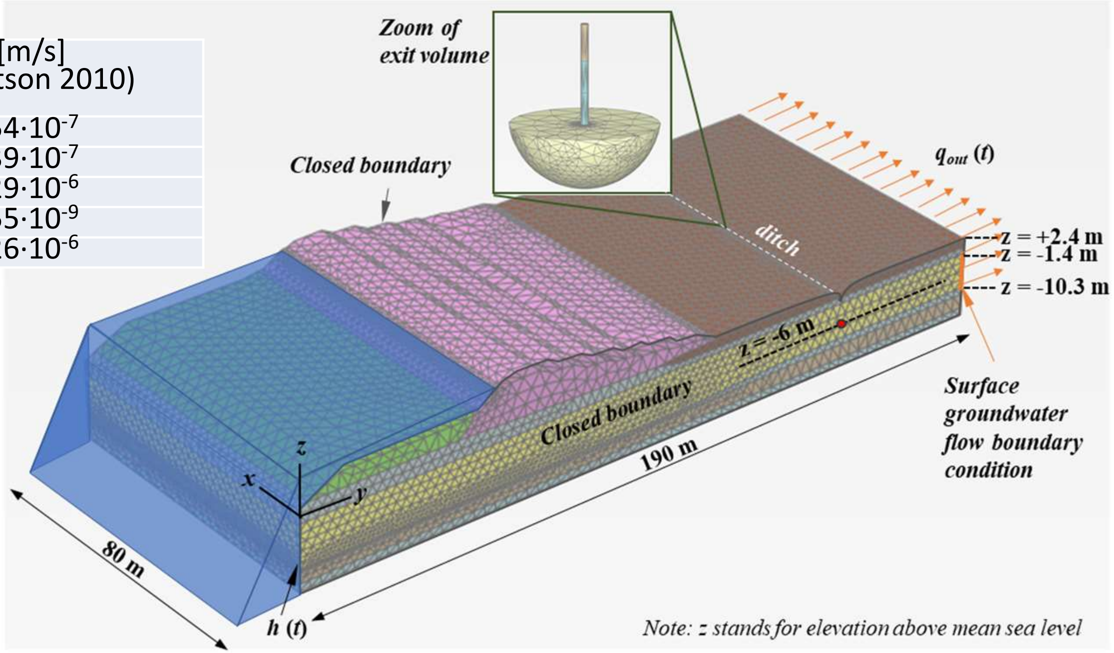
Indirect determination of Cv (Vandenboer, 2019):

$$\boxed{\Delta H = C_v \cdot L \cdot \frac{\rho_s-\rho_w}{\rho_w} \rightarrow 0.309}$$

Final remarks

- **Collected data**, not routinely obtained in practice, are of crucial importance for the calibration of piping models and then **reduce model uncertainties**

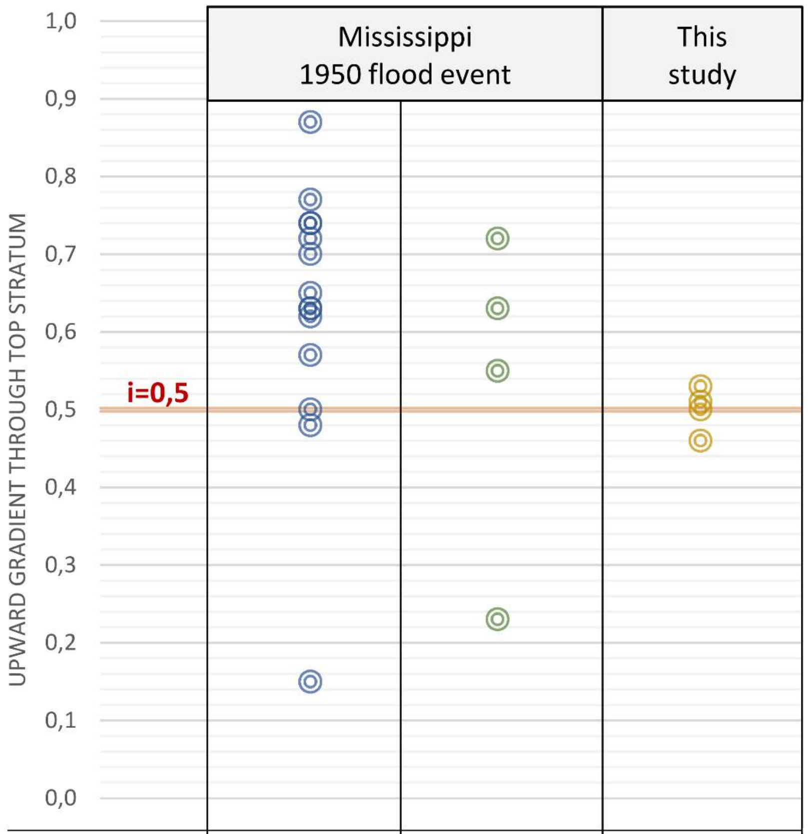
Layer	k [m/s] (Robertson 2010)
D1	$1.54 \cdot 10^{-7}$
Ar	$2.39 \cdot 10^{-7}$
B (upper)	$4.29 \cdot 10^{-6}$
C (upper)	$5.55 \cdot 10^{-9}$
A	$9.26 \cdot 10^{-6}$



GARCÍA MARTÍNEZ, M.F., TONNI, L., MARCHI, M., TOZZI, S., GOTTARDI, G., Numerical Tool for Prediction of Sand Boil Reactivations near River Embankments, *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 146(12) **9/2020. https://doi.org/10.1061/(ASCE)GT.1943-5606.0002380**

Final remarks

☐ Comparison between the **average hydraulic gradients in the vertical pipe** with the **maximum upward gradients through the top stratum** observed in 1950 along the Mississippi river (data from USACE 1956)



Severity of the sand boil	numerous and/or large sand boils	numerous pin boils or several small boils	single large sand boil
Condition of the sand boil when the gradient was measured	onset of activation	onset of activation	Equilibrium phase
New activation or reactivation	Not specified	Not specified	Reactivation

MARCHI, M., GARCÍA MARTÍNEZ, M.F., TONNI, L., GOTTARDI, G. (2020). Field measurements on a large natural sand boil along the river Po (Italy). *Quarterly Journal of Engineering Geology and Hydrogeology* 12/2020. https://doi.org/10.1144/qjegh2020-097

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Field measurements on a natural sand boil along the Po river (Italy)

Authors: Michela Marchi, Guido Gottardi, and Laura Tonni

Department of Civil, Chemical, Environmental, and Materials Engineering (DICAM), University of Bologna

***Oral presentation:* Michela Marchi**

michela.marchi@unibo.it

Examples – case studies in using internal stability criterion to characterize piping, softening and dispersive soils

Emoke Imre[1], Daniel Barreto[2], János Szendefy[3], Levente Kovács[4]

[1]*Óbuda University, EKIK HBM Systems Research Center, Budapest, Hungary, imre.emoke@uni-obuda.hu*
[2]*Edinburgh Napier University, U.K.*
[2]*BME, Civil Engineering, Budapest, Hungary*
[4]*Óbuda University, AIAM Doctoral School, Budapest, Hungary*

SYNOPSIS:
Lőrincz (1986) gives grading entropy criterion for the borderline when the structure of a cohesionless soil is unstable and, consequently, the soil is prone to internal erosion. Case studies are analysed. The starting of the piping process is related to the stress state (shear and normal stresses) around the dike.

In detail: dispersive and piping soils known from the literature are categorized unstable on the basis of the particle migration criteria of Lőrincz (1986) elaborated for granular soils in terms of the normalized entropy coordinates. The examples shown here support the hypothesis that erodible soils may be identified with the use of grading curves. The particle migration criteria are usable for dispersive and saline/dispersive soils as well. Lime modification is found to cause a state improvement in terms of non-normalized entropy coordinates.

The picture of the internal erosion (piping) is visualized in Figure 1 in the work of Galli (1955). The internal stability criterion was fully supported by these criteria in the presented Dunakiliti, Dunafalva and Bolcske case studies: over a permeable layer a finer unstable cover layer is found which is erodible (using data of Fehér, 1973; Szepessy et al, 1973). The examined case studies support the hypothesis that internal stability criterion can be used for the identification of not only the piping but also the dispersive soils.

.

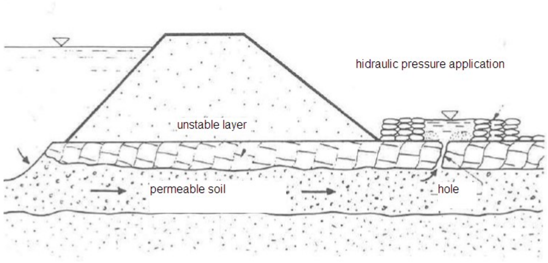


Figure 1. The piping phenomenon (Galli 1955)

REFERENCES

Galli, L. (1955). Seepage phenomena along flood protection dams (in Hungarian). *Vízügyi Közlemények* 1-2.

Fehér, Á. (1973). Improvement of river dyke stability. B.209.2. Piping (in Hungarian). *VITUKI research report 7631/ 6-5*.

Imre, E., Réthári, L. (1991). Complex geotechnical examination of river dykes FTV no 86/86/XXIX OTKA

Imre, E. (1995). Characterization of dispersive and piping soils. *Proc. of XI. ECSMFE, Copenhagen,* Vol. 2. 49-55.

Imre, E.; Nagy, L.; Lőrincz, J.; Rahemi, N.; Schanz, T.; Singh, V.P.; Fityus, S. Some Comments on the Entropy-Based Criteria for Piping. *Entropy* **2015**, *17*, 2281-2303.

Lőrincz, J. (1986). Grading entropy of soils (in Hungarian). Ph. D. Thesis, TU Budapest.

Szepessy, J.; Bogárdi, I.; Vastagh, G (1973). Literature review about river dyke failures (in Hungarian). *VITUKI research report 7631/6-5.*

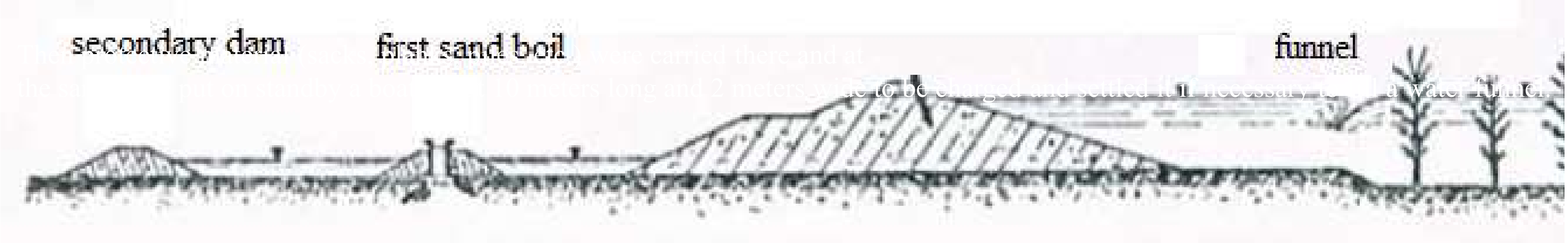
Examples – case studies in using internal stability criterion to characterize piping and dispersive soils

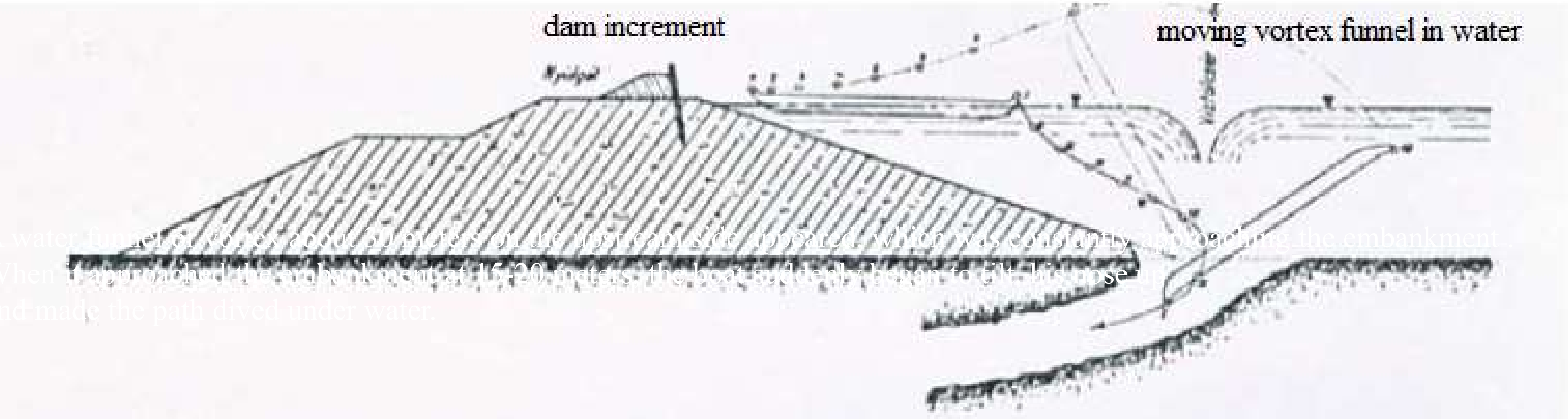
Emoke Imre[1], László Nagy[2], János Lőrincz[2], Daniel Barreto[3],
János Szendefy[2], Ágnes Bálint[1], Edina Koch[4], Maria Datcheva[5],
Levente Kovács[6], Stephen Fityus [7], Vijay P. Singh[8]

[1]*Óbuda University, EKIK HBM Systems R. C., Budapest, Hungary*
[2]*BME, Civil Engineering, Budapest, Hungary*
[3]*Edinburgh Napier University, U.K.*
[4] *Széchenyi István University, Győr, Hungary,*
[5] *Institute of Mechanics, Bulgarian Academy of Sciences, Bulgaria*
[6]*Óbuda University, AIAM Doctoral School, Budapest, Hungary*
[7] *University of Newcastle, Australia*
[8] *Texas A& M University, USA*

Piping in Hungary

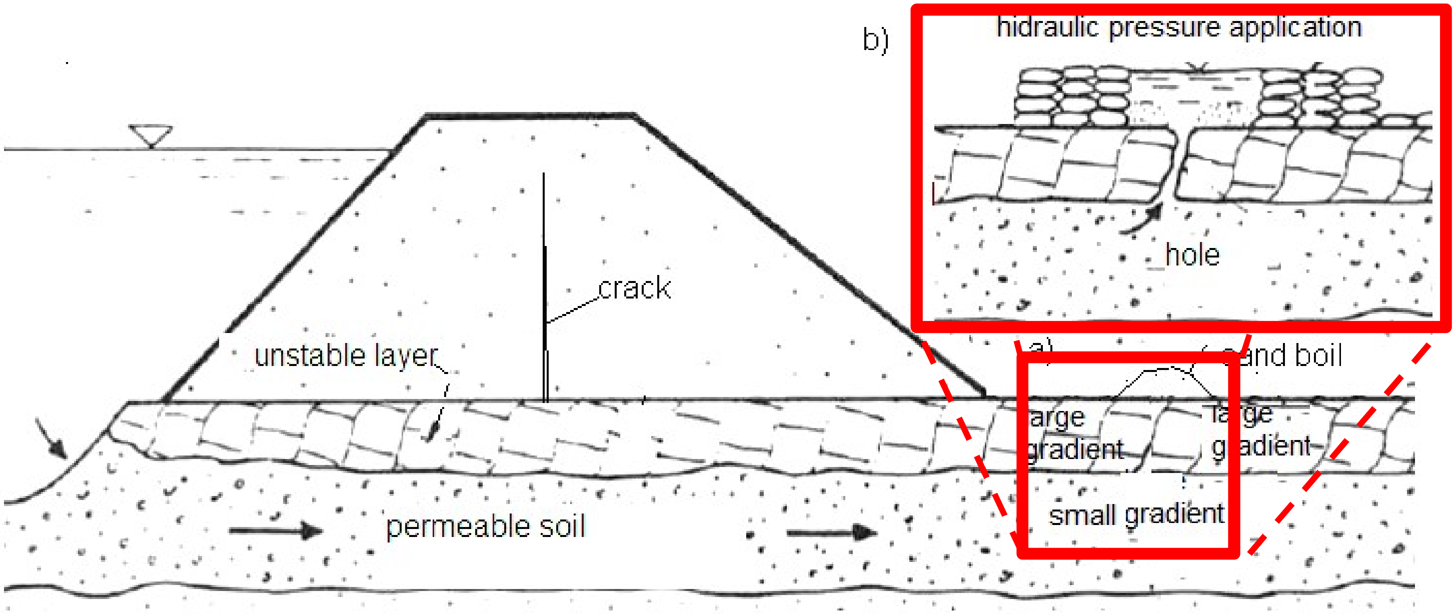
The defence against piping has a great tradition in Hungary. Measurement of the size and path of the pipe using sinking boats, as well as management by controlling water level.





Thin erodible layer* - Slow piping

Failure within a few days

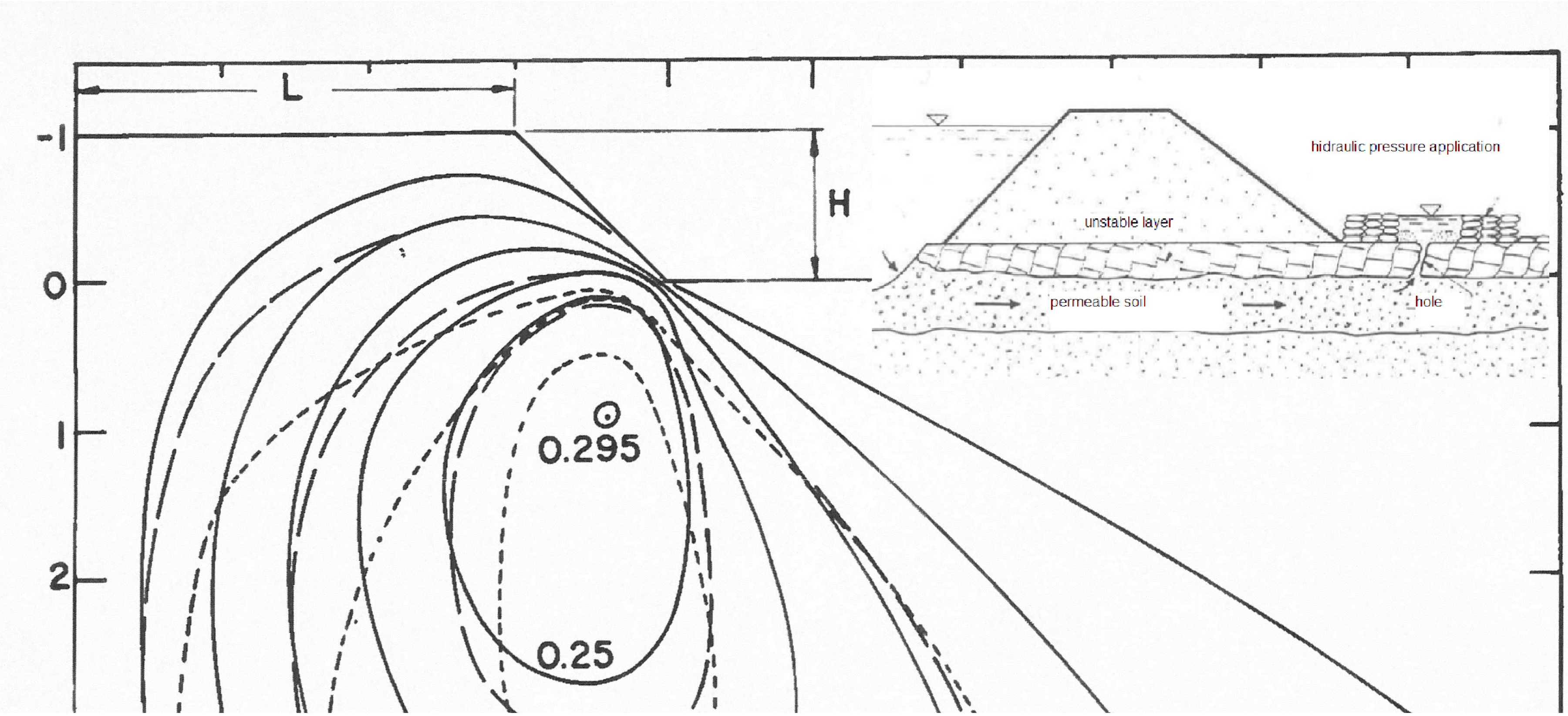


The sand boil is the first stage of a piping failure of river dikes – can be related to equlibrium of single surface grain.

*Lörincz criterion

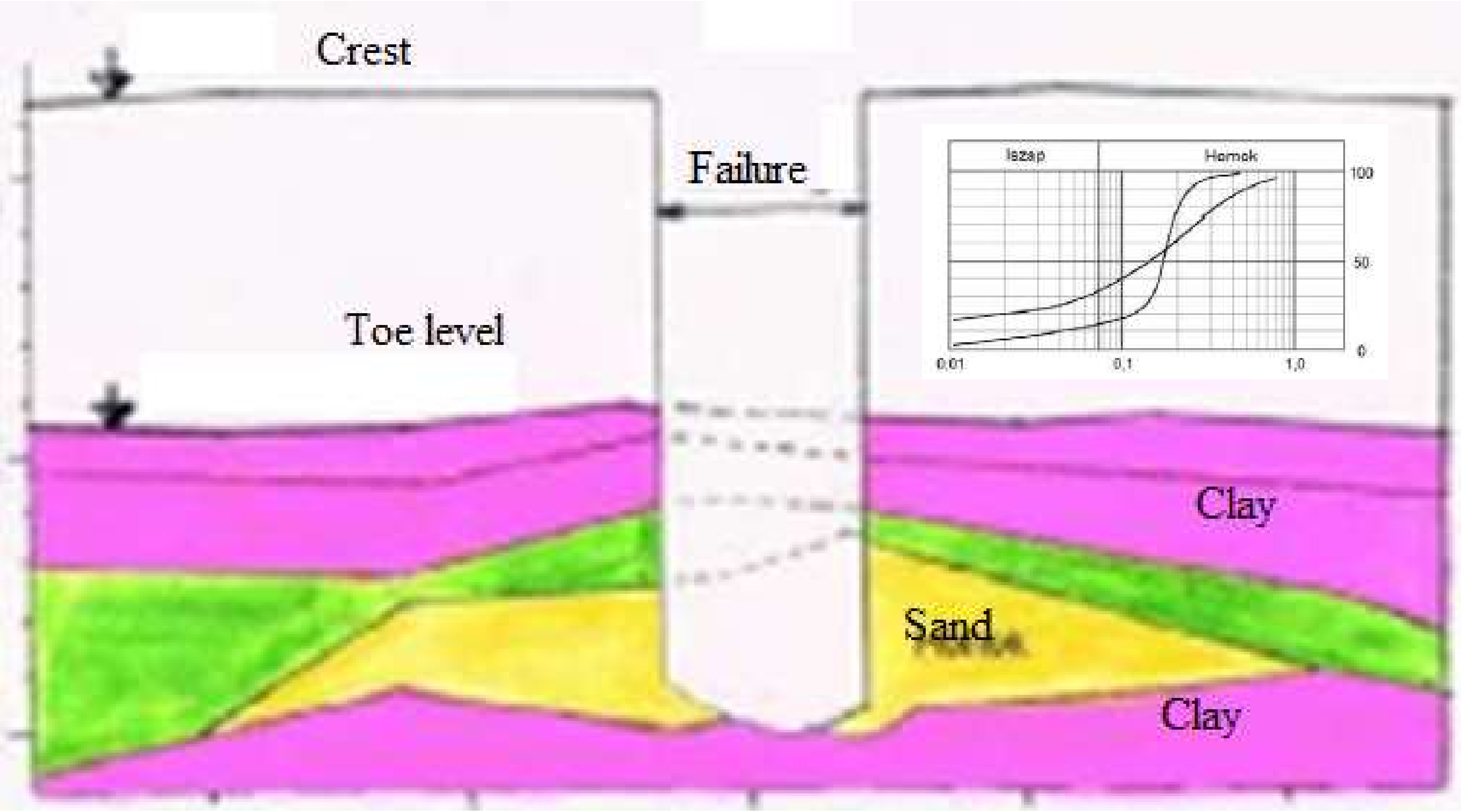
Piping & shear stresses

On the basis of elastic stress analysis, piping formation can be related to shear stresses, as well as the displacement of dam.

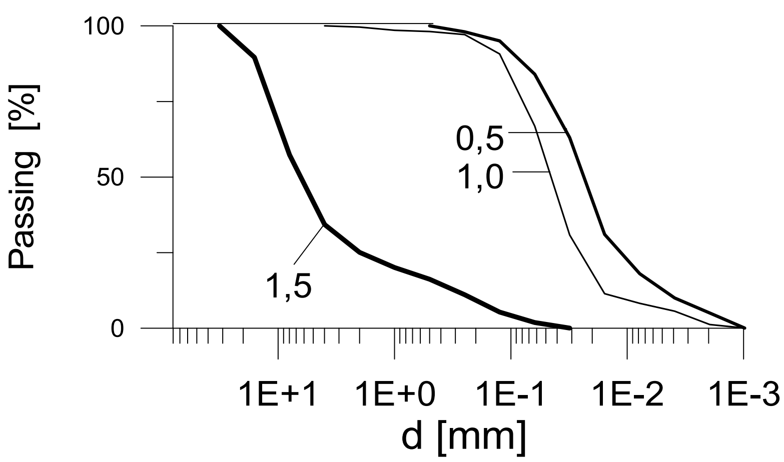


Thick, very loose erodible* layer - Fast piping

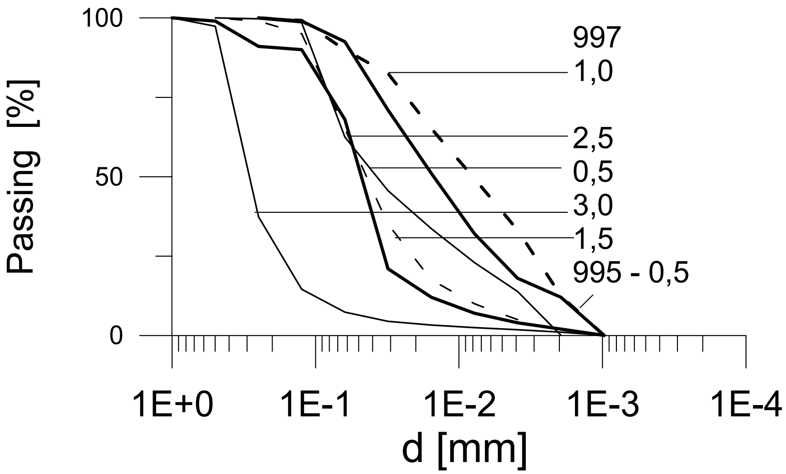
Hosszúfok failure (1980) - Failure in 5 minutes



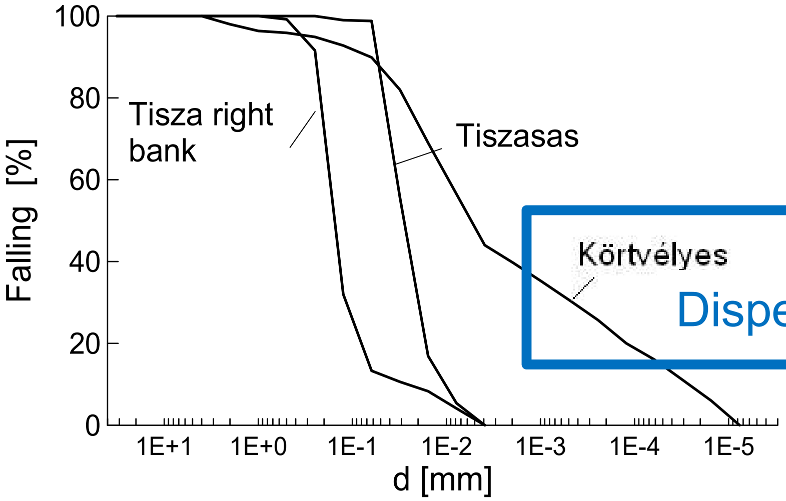
Grading characteristics



(a) Dunakiliti soils



(b) the Dunafalva soils



(c) Tisza (washed-out) soils

Sand-boil soils very similar to erodible layers – not suffosion

Dispersive soils

Some background – filter criteria

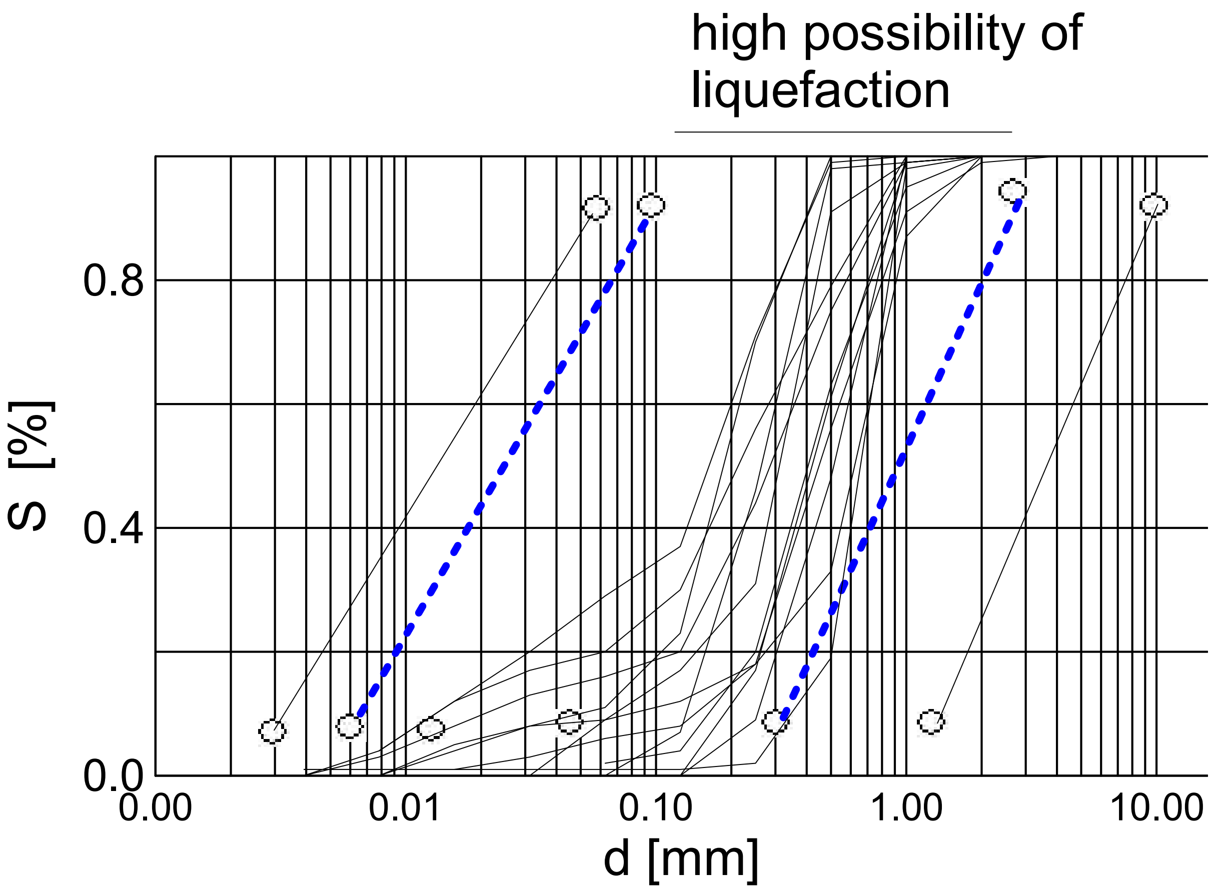
$$\frac{D_{\min}}{d_{\max}} \leq 4$$

- *D* and *d* refer to the filter and the base soil, resp. If there are more than two empty fractions, the base soil cannot be filtered. (Terzaghi’s filter criterion for uniform filters)

- Kezdi’s self-filtering theory states on the basis of this filter rule that if the ratio between the minimum particle diameter of the filter and the maximum particle size of the base soil is between 1 and 4, then particle migration from the base soil is prevented.

- *Suffosion may occur only in case of near gap-graded mixtures with 3 empty fractions.*

Some note on liquefaction criteria



The grading curves of the washed-out soils with the linear part of several liquefaction criteria

Grading entropy coordinates

The grading entropy *S* is the sum of the `non-normalised entropy coordinates` base entropy S_0 and entropy increment ΔS

$$S = \Delta S + S\text{o}$$

$$\Delta S = -\frac{1}{ln\,2}\sum_{i=1}^{N} x_i \, ln\, x_i$$

$$B = \frac{\Delta S}{\ln N}$$

$$S_o = \sum_{i=1}^{N} x_i S_{oi}$$

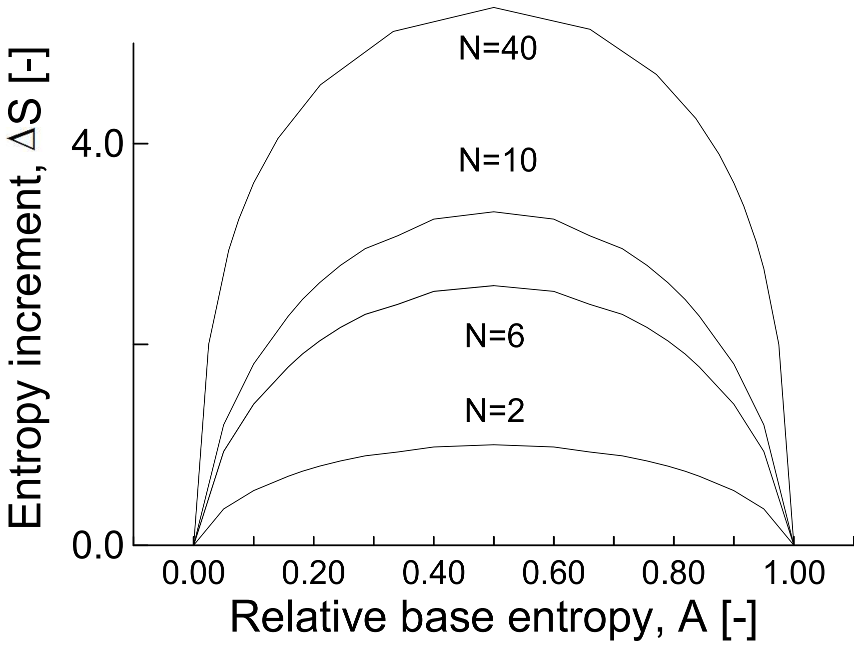
$$A = \frac{S_o - S_{o\,min}}{S_{o\,max} - S_{o\,min}}$$

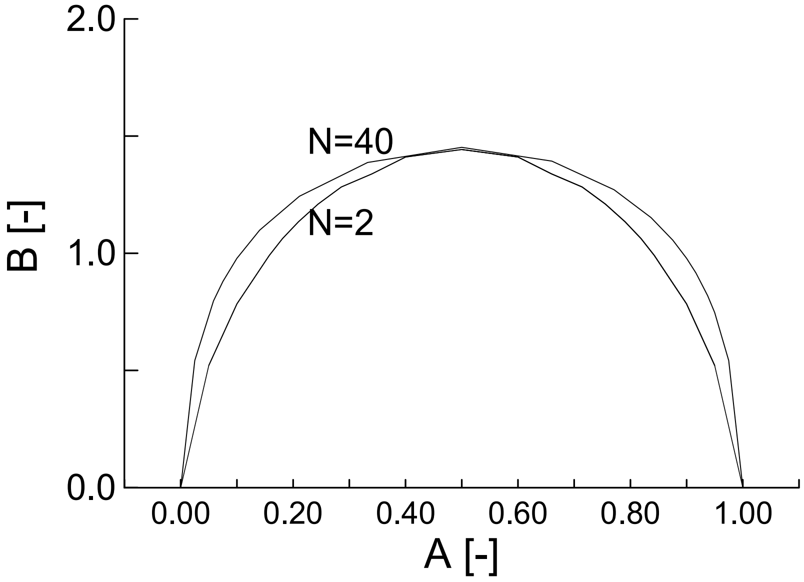
Non-normalised

Normalised

where *N* is the number of the fractions between the finest and coarsest ones, x_i= relative frequency of fraction *I* and S_{0i} =*i-1* are fraction entropies (i.e. a sieve identifier).

Entropy diagrams

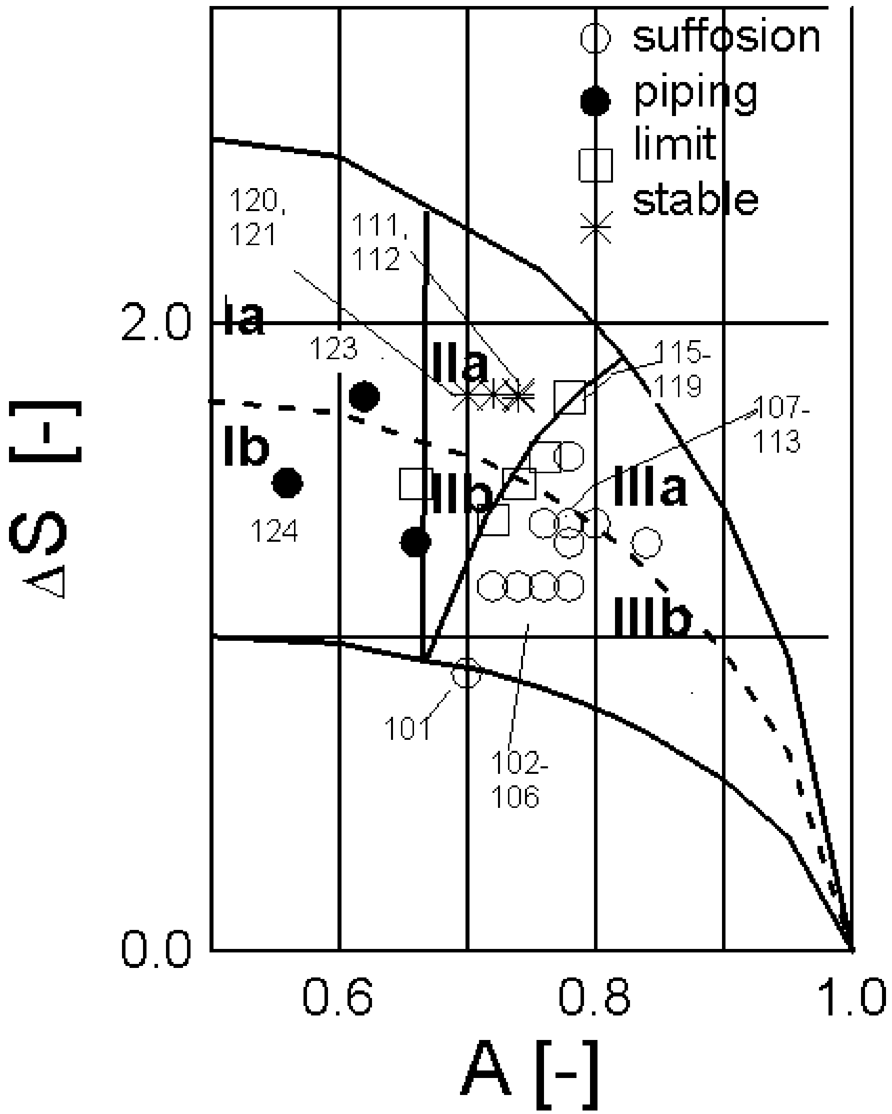


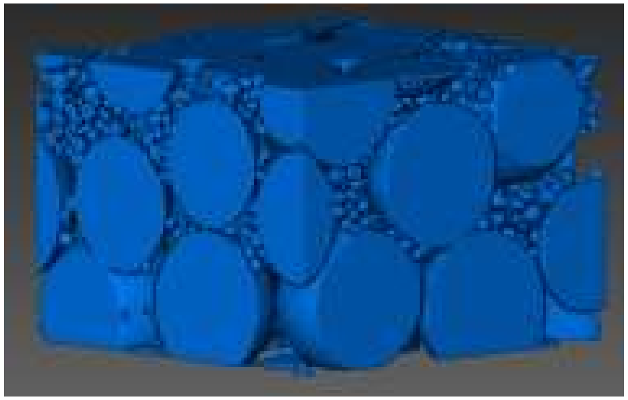


Grading entropy coordinates can be represented in fully normalised, partly normalised or non-normalised manner. Upper boundary lines are also related to fractal gradings

Particle migration (Lőrincz 1992b), granular filter criteria (Lőrincz 1992a), and segregation rules (Lőrincz, 1996) have been proposed.

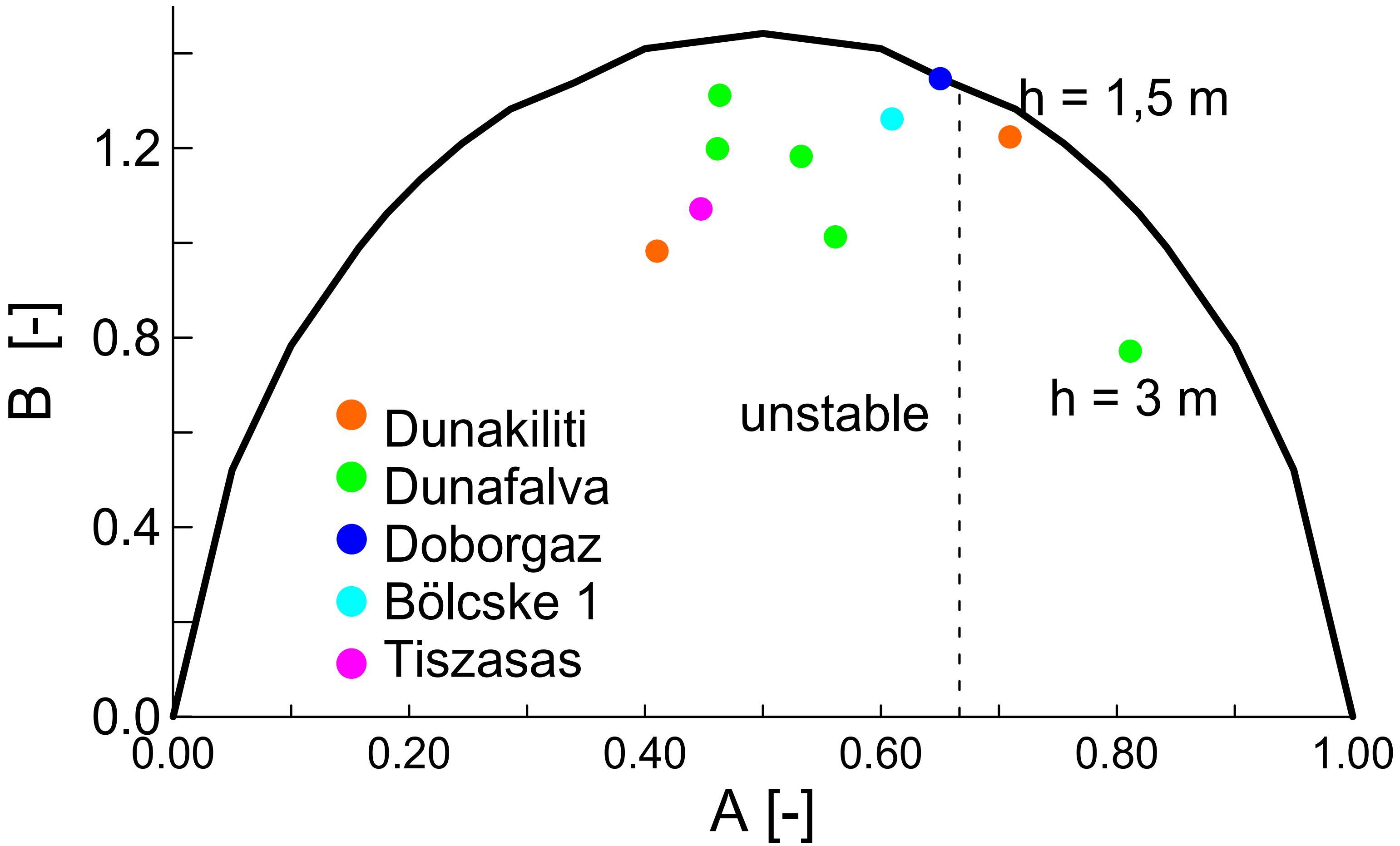
Particle migration rule - internal stability and internal structure



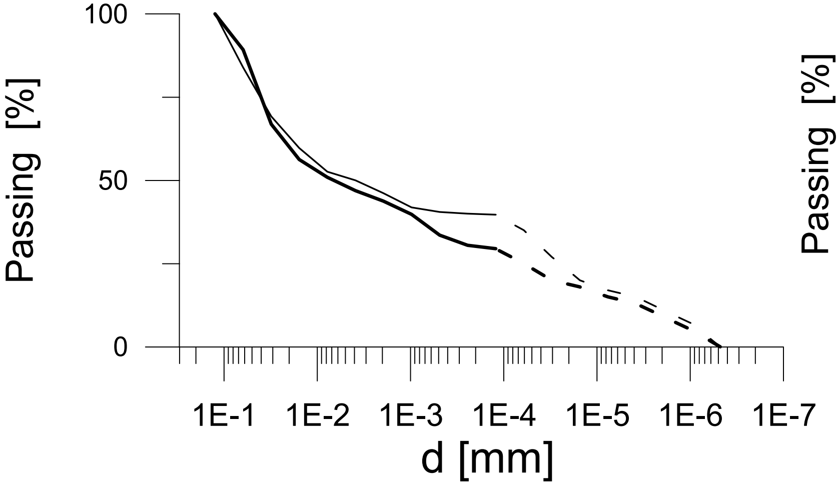


Zone I (A < 2/3): soil is internally unstable - coarse particles float in a matrix of fines. Unstable when fines are removed by water flow. For A >=2/3 Zone II (stable) coarse particles in contact have stable structure with continuous force chain In Zone III (transition, the stable structure builds up, elongated gradings)

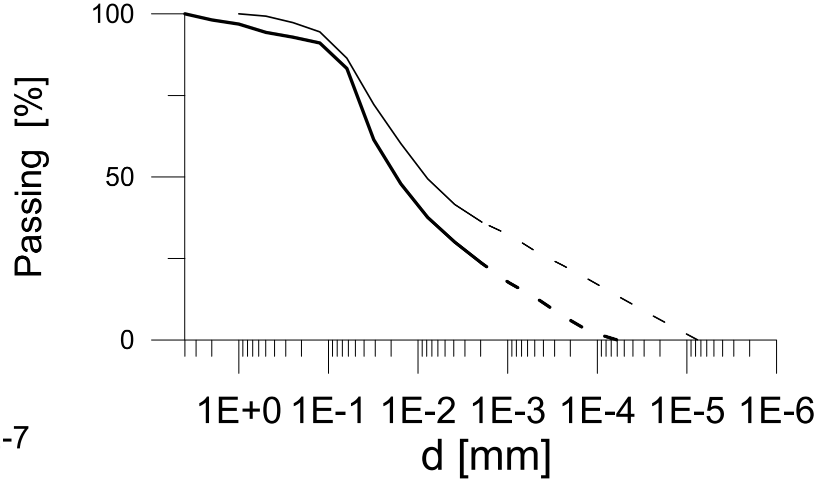
Entropy diagram – Hungarian data



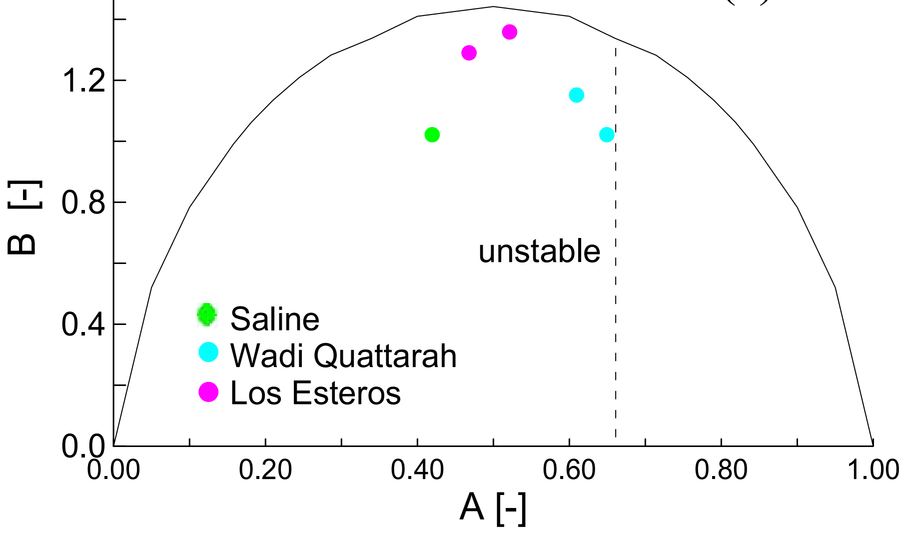
Entropy diagram – Dispersive soils in large dams around the world



(a) Wadi Quattarah dam

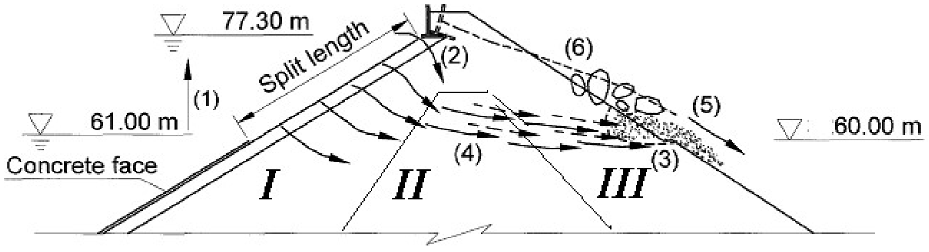


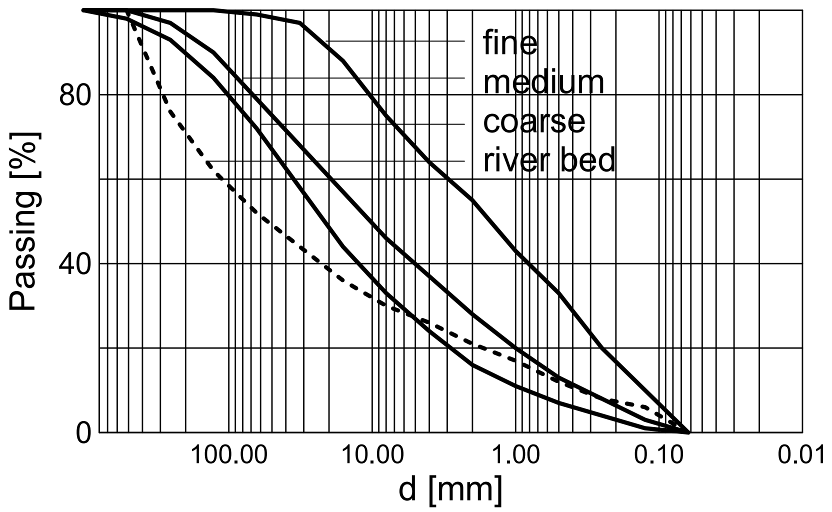
(b) Los Esteros dam.

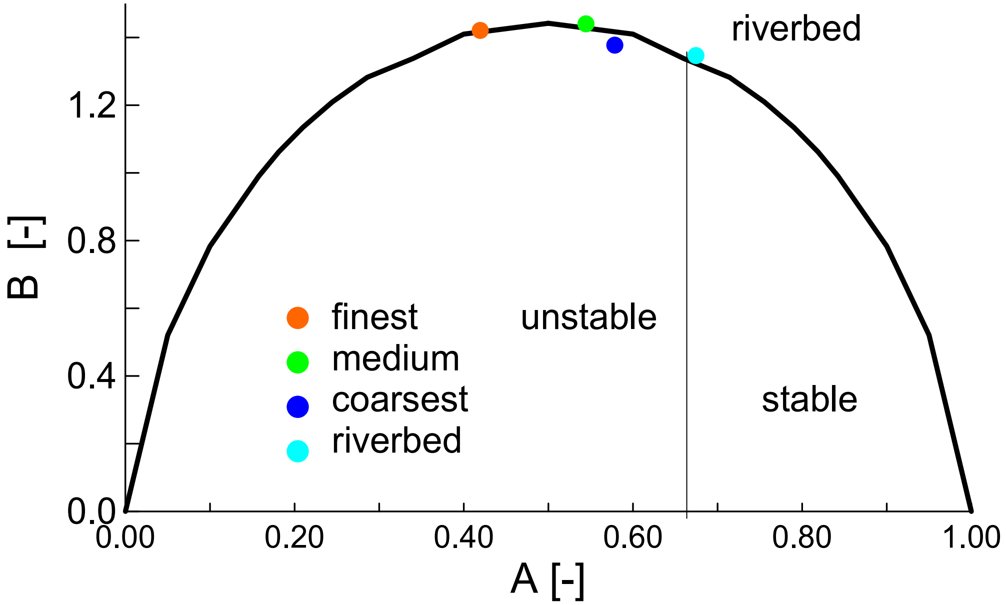


Entropy diagram
– Potentially useful for other “problematic” soils

Gouhou dam failure (crushed stone)







Some conclusions

On the basis of case studies:

1. Piping cases with a thin or thick erodible layer (fine sand) in the base of the dyke. The washed out soils from sand-boils seemed to be very similar to it. These soils are both erodible (internal stability criterion) and prone to liquefaction, whilst the permeable river bed gravel is internally stable. The effect related to the shear stress during piping has been apparent.

2. Similar results in case of piping / internal erosion of large dams, irrespective of grain size and soil type. Grading entropy based internal stability criterion seems useful even for crushed stone, saline and dispersive silty soils.

3. Grading entropy based internal stability criterion accounts for suffusion that may occur in both stable and unstable soils. Similarity of gradings for sand-boils and erodible layer indicate no suffusion.

The sand boil generator and a new technique to control sand boils

Axel Montalvo-Bartolomei[1]
[1]U.S. Army Corps of Engineers

Abstract:
One of the most common techniques to control a sand boil during flood emergency operations usually involves the use of sand bags to form a ring around the sand boil and raise the hydraulic head at the seepage exit. This technique helps to decrease the head difference and flow rate until erosion is slowed or stopped. A new technique was developed at the U.S. Army Engineer Research and Development Center (ERDC) to control sand boils in a quicker and more efficient way. Full-scale testing of this new method was possible in a laboratory environment by using the sand boil generator. This new laboratory equipment was created such that new mitigation techniques could be tested without relying on natural flood events. The conditions of the full-scale sand boils such as flow rate, grain size of the sand, and throat diameter can be adjusted while water pressures can be monitored at different locations. The new technique for controlling sand boil consists of inserting a conical-shaped filter at the sand boil exit. The cone of the sand boil filter is made of a polymer mesh and has a clear PVC tube with a series of holes to control the height of the water that exits. As sand and water are forced to come out from the holes in the vertical tube, the hydraulic head increases at the exit and has the same effect as the sand bag ring. Kits with the new tool will be distributed to Districts of the U.S. Army Corps of Engineers to evaluate this technique in the field during future flood fighting events.