A study on ERT and IP measurements, and seepage modelling of the Älvkarleby test dam

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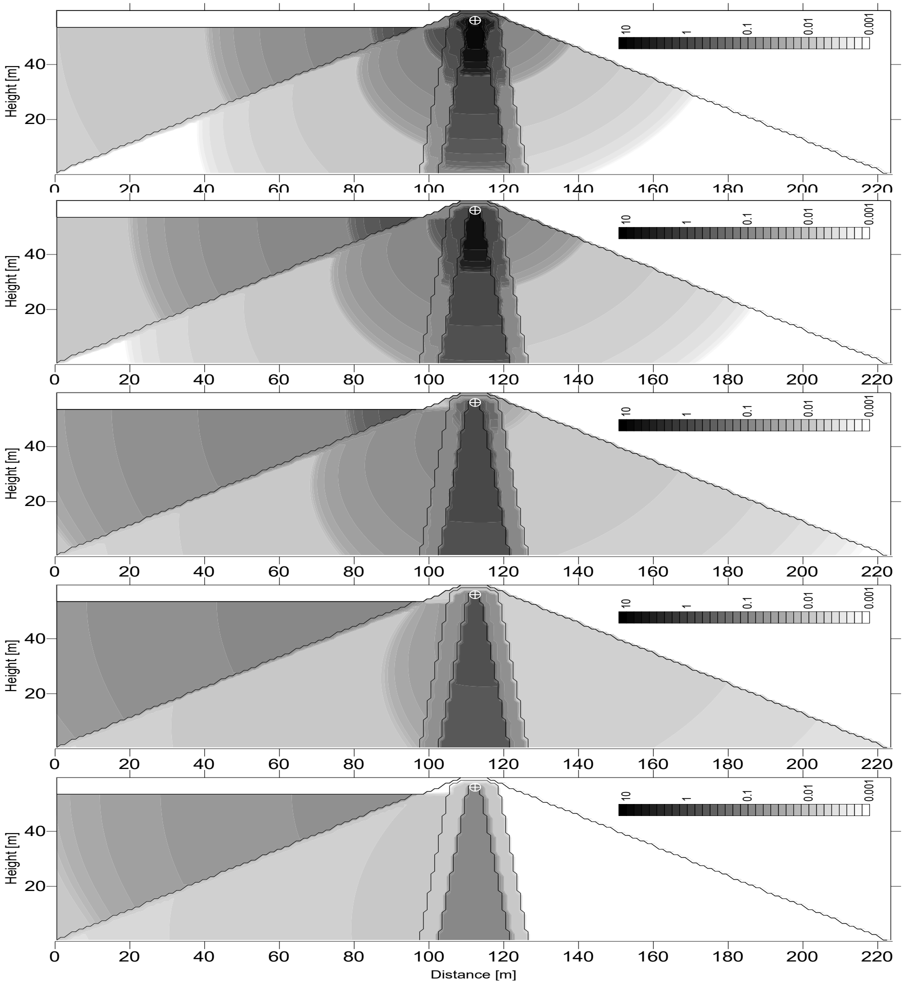
Resistivity of geological materials (embankment dams)

- Resistivity (ρ) depends on:
  - Water content
  - Fine material content
  - Temperature
  - Ion content
- Washout of fines ⇒ increase in ρ (Bergström 1998)
- Internal and external dam geometry leads to 3D effects
- Dam core most conductive part (lowest ρ)

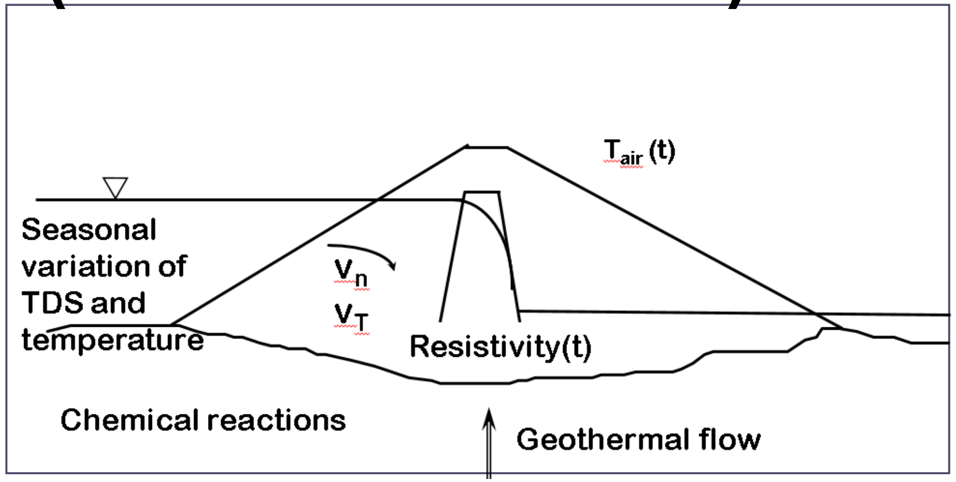


Current density in mA/m^2 at 1A transmitted current

From: Sjödahl, P., Dahlin, T. and Zhou, B. (2006) 2.5D Modelling to Assess 3D Effects in Resistivity Imaging on Embankment Dams, Geophysics, 71(5), G107-G114.

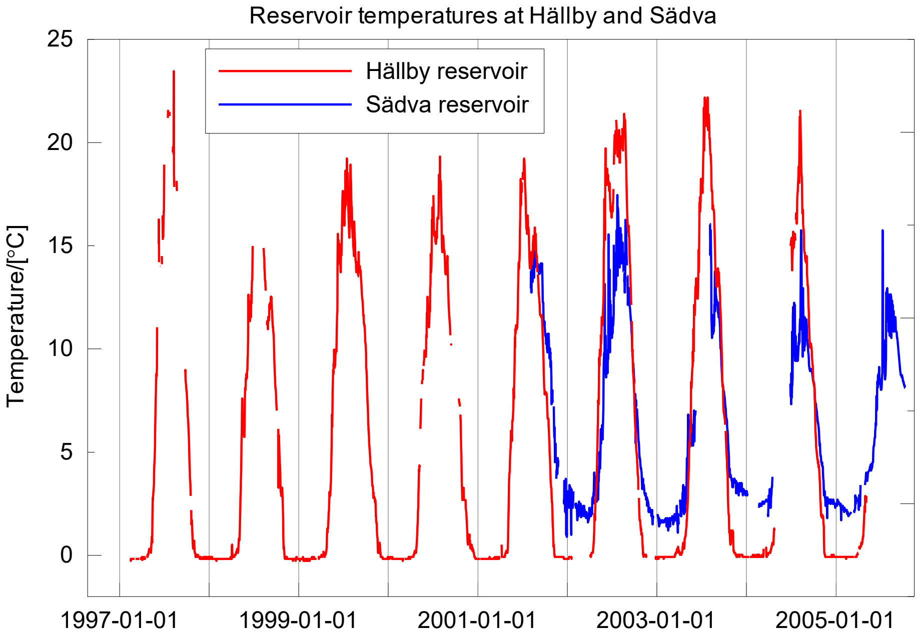
Resistivity of geological materials (embankment dams)

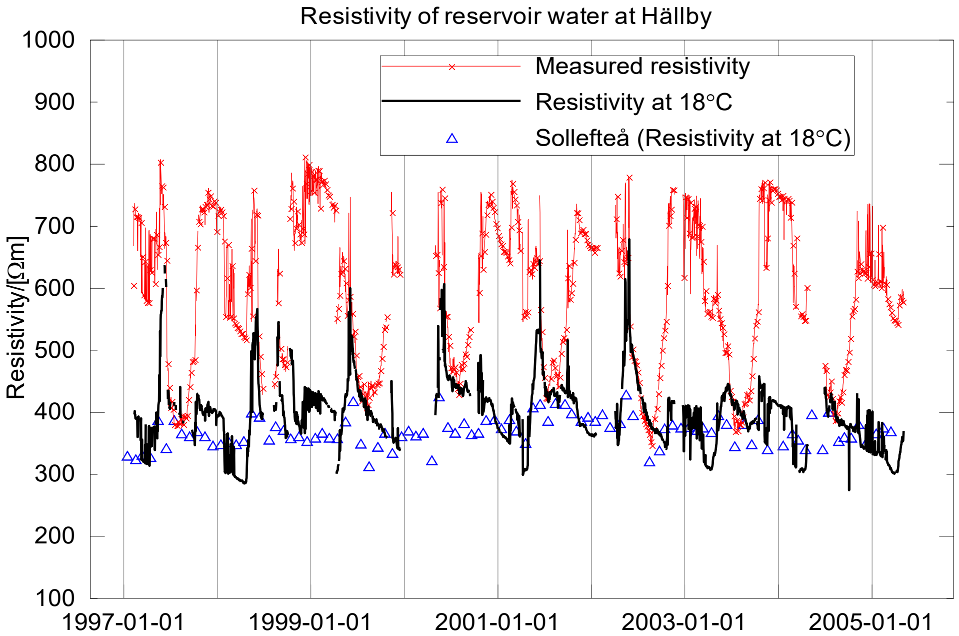
- Water flow ⇨ temperature variation ⇨resistivity variation



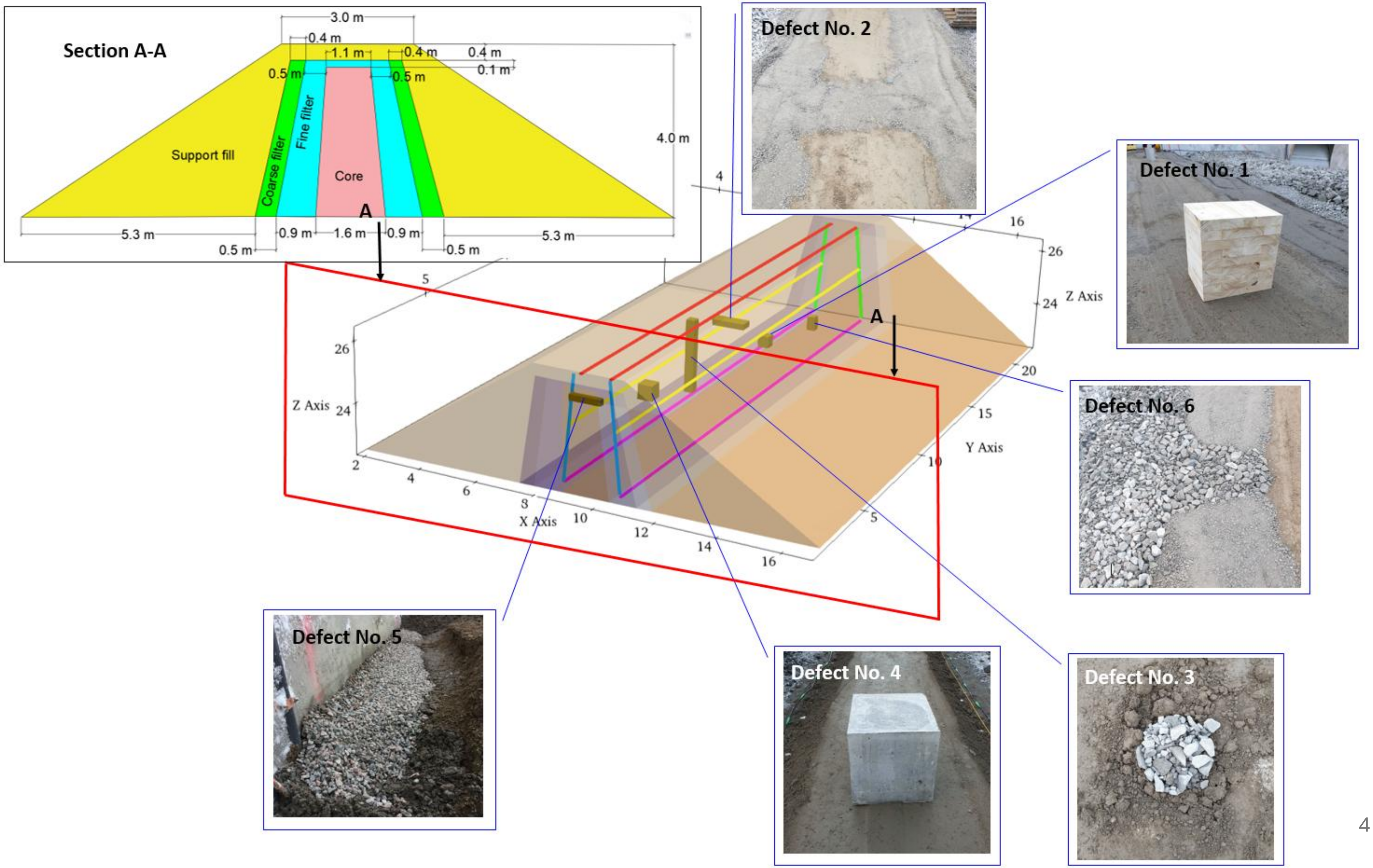
(Johansson 1997)

Reservoir water temperature and resistivity variation



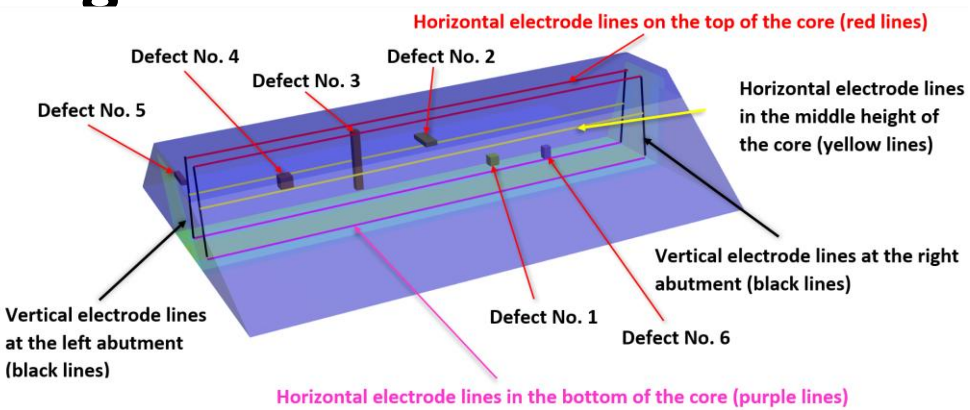


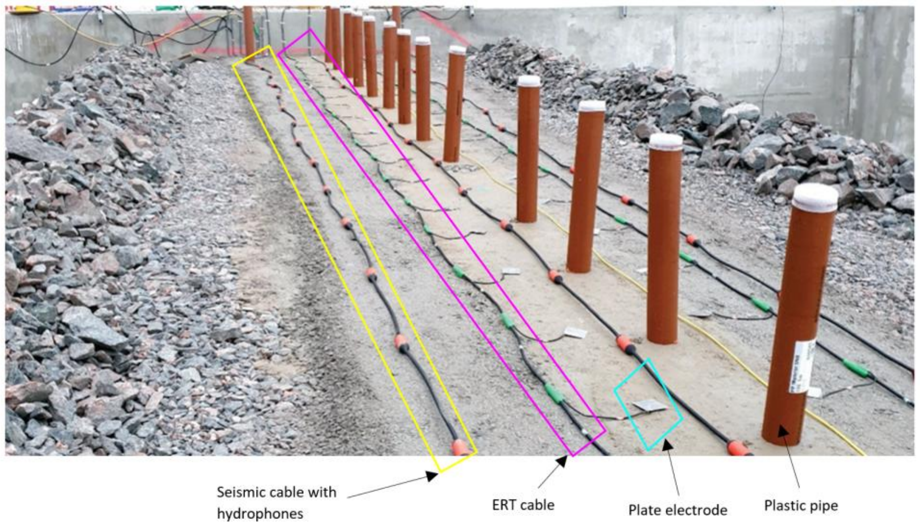
Älvkarlebytest dam



ERT/DCIP data acquisition / monitoring

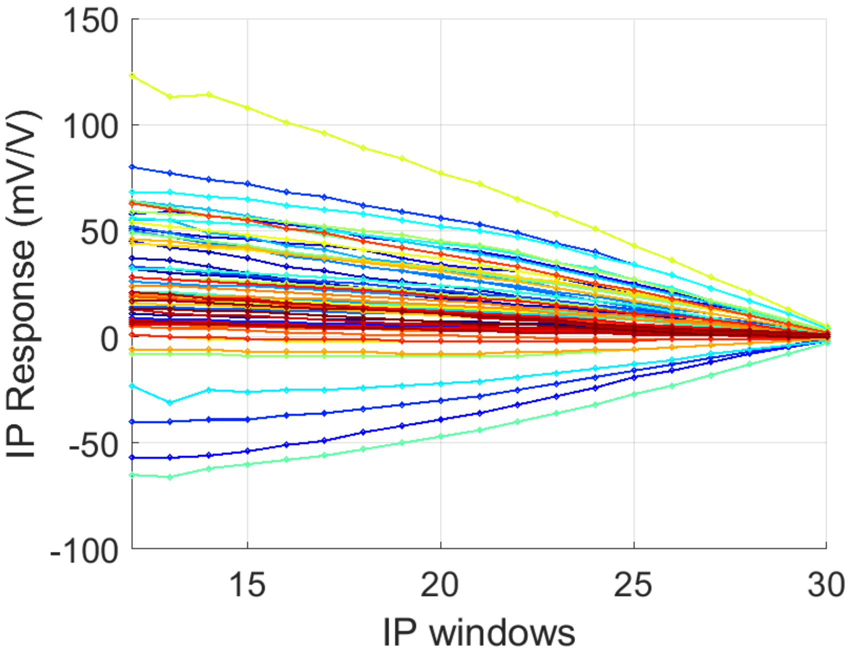
- Direct Current resistivity and time-domain Induced Polarization tomography (DCIP)
- In total 224 electrodes (80 mm x 80 mm stainless steel plates)
- 6 horizontal profiles: 32 electrodes with 61 – 63 cm (nominal) spacing
- 4 vertical profiles: 8 electrodes with 50 cm vertical spacing
- In-line & between-line measurements to cover the core volume (extended gradient, equatorial dipole-dipole, corner array).
- Initially around 7 000 data points collected, increased to 14 000.
- Monitoring daily November 2019 – August 2024

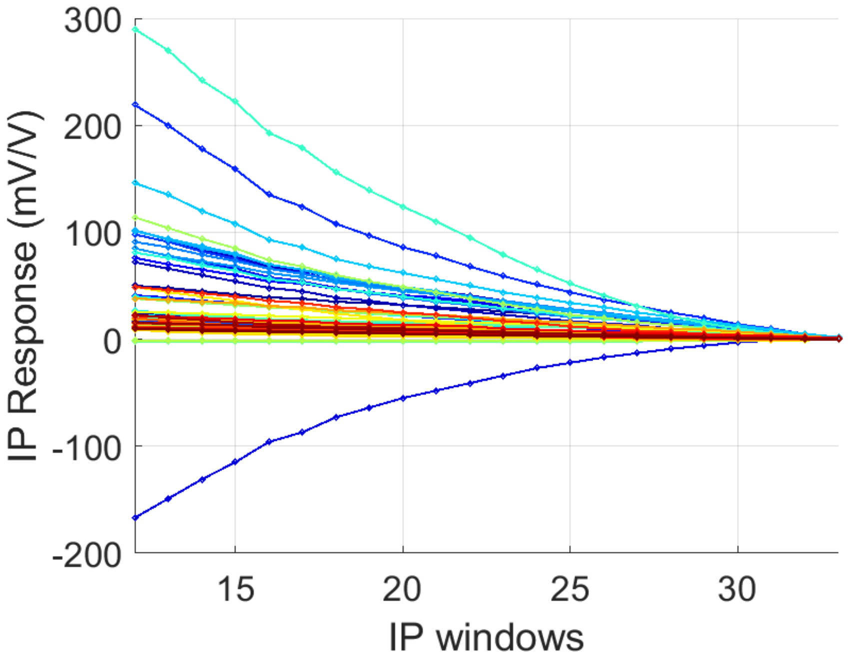


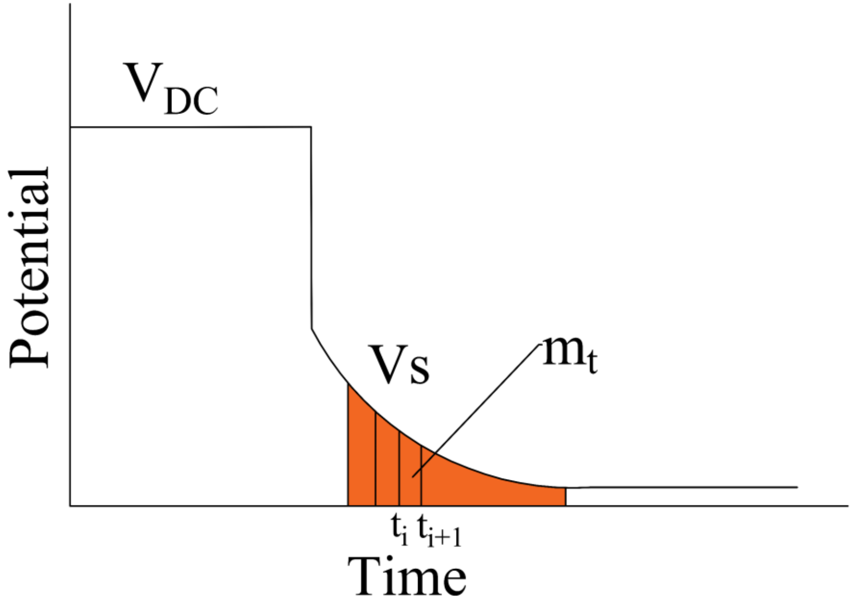


Induced Polarization (IP)

- IP measures the ability of soils and rocks to store electrical charge.
- Depends on water content and clay - useful for detecting internal erosion?
- TDIP data from gates 12–33 (after July 2022) and 12–30 (before July 2022) were used.

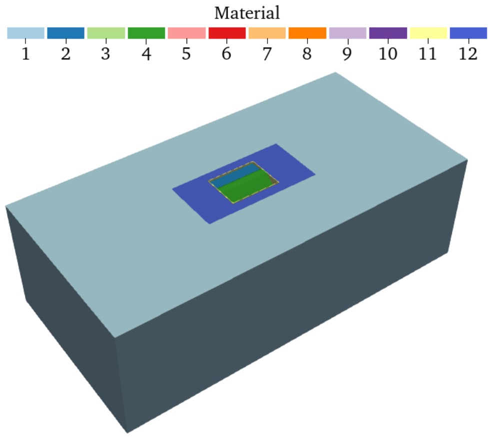


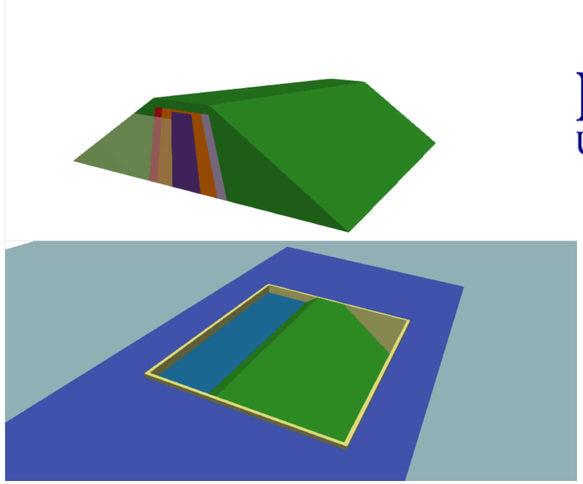


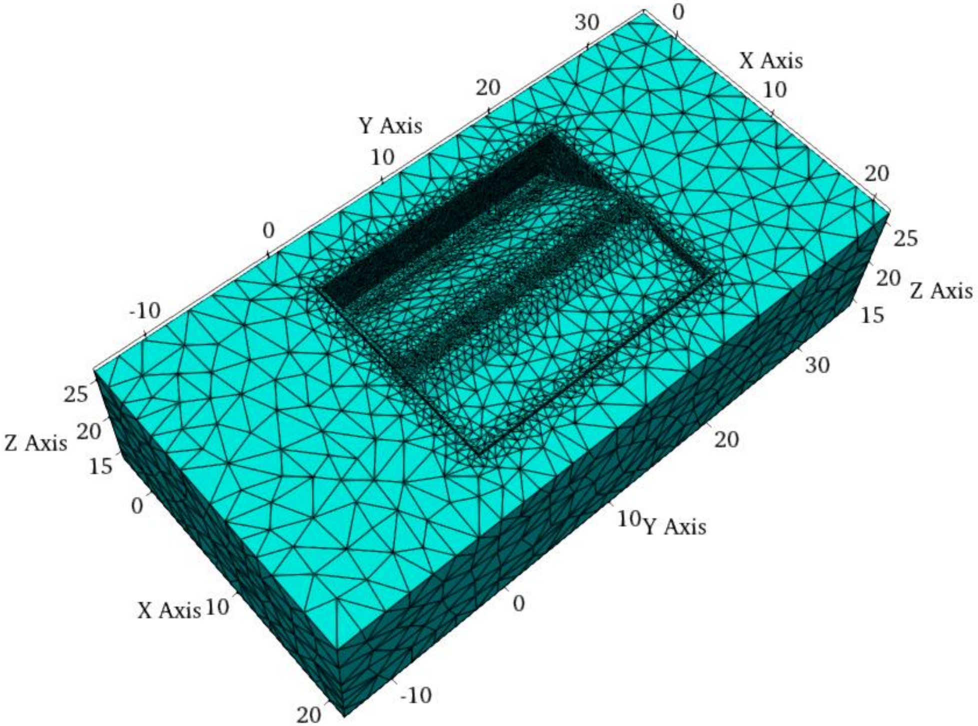


Inversion model

- pyBERT/pyGIMLi software package (Rücker et al, 2017)
- 3D model
- Mesh design with internal structure based on known material boundaries
- Smoothness constrains broken at material boundaries (12 regions)
- ~200’000 cells generated using TetGen (Si, 2015)

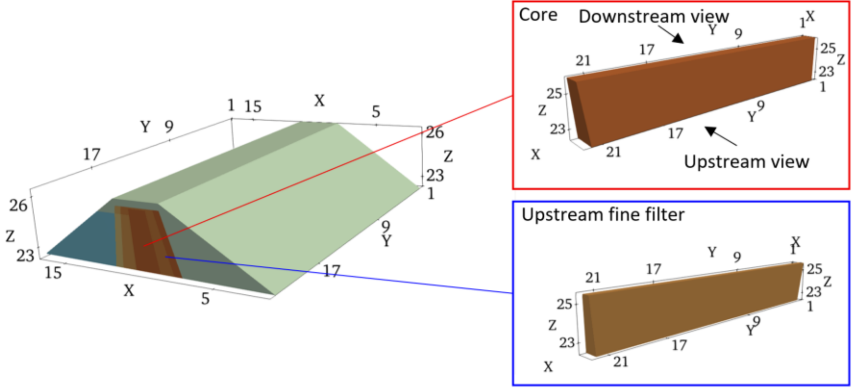


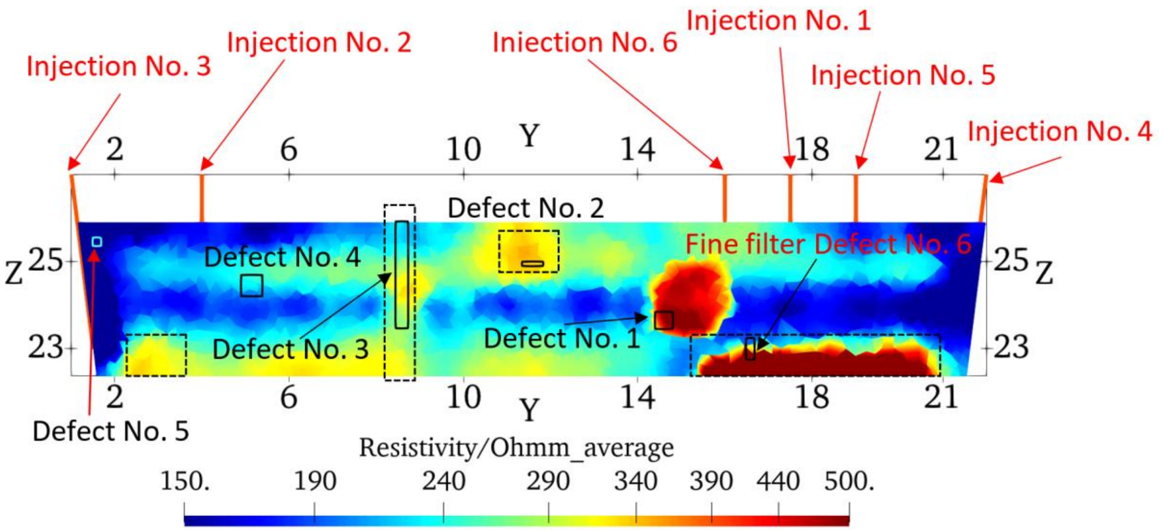


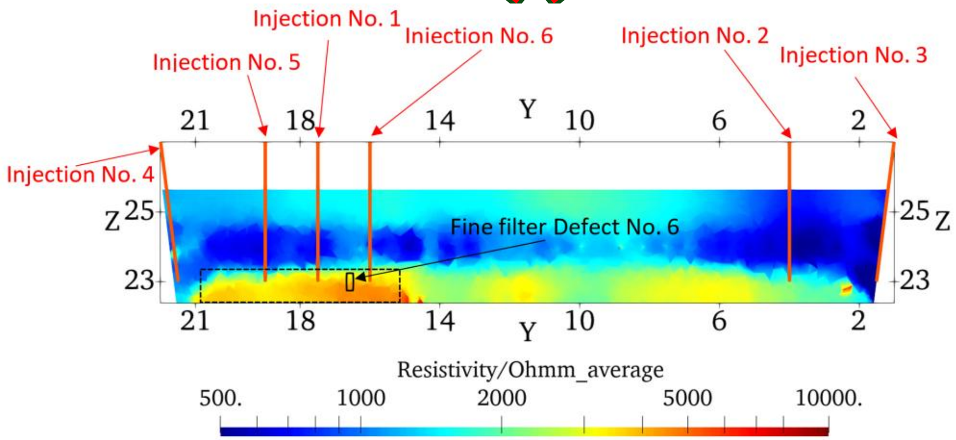


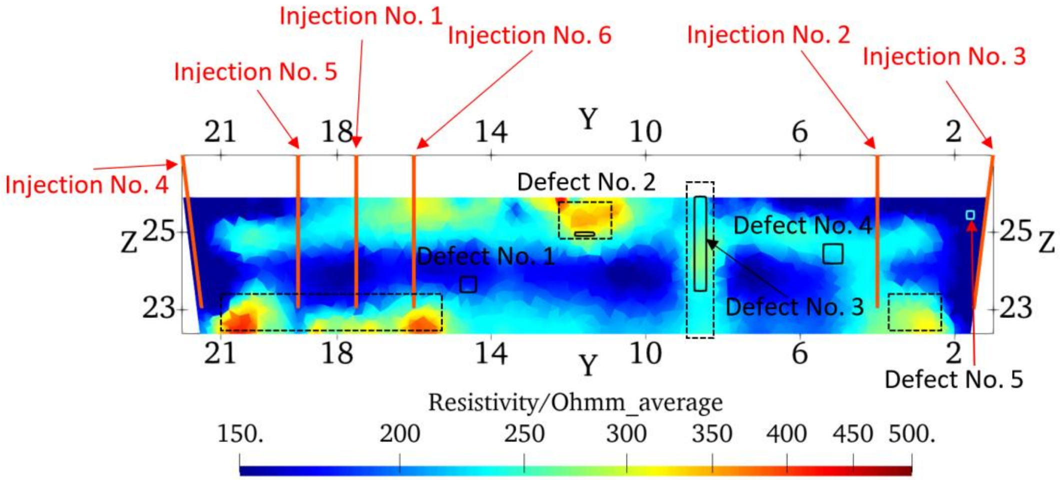
Resistivity data analysis

- Defect No. 1 and 5
- Defect No. 2
- Defect No. 3
- Defect No. 4
- Defect No. 6
- Injections



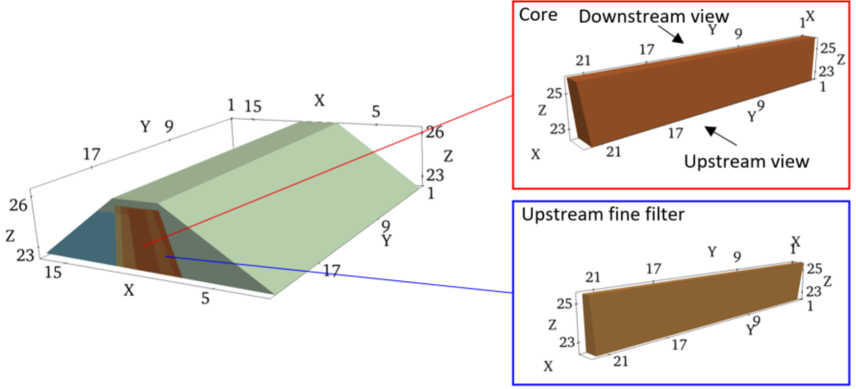


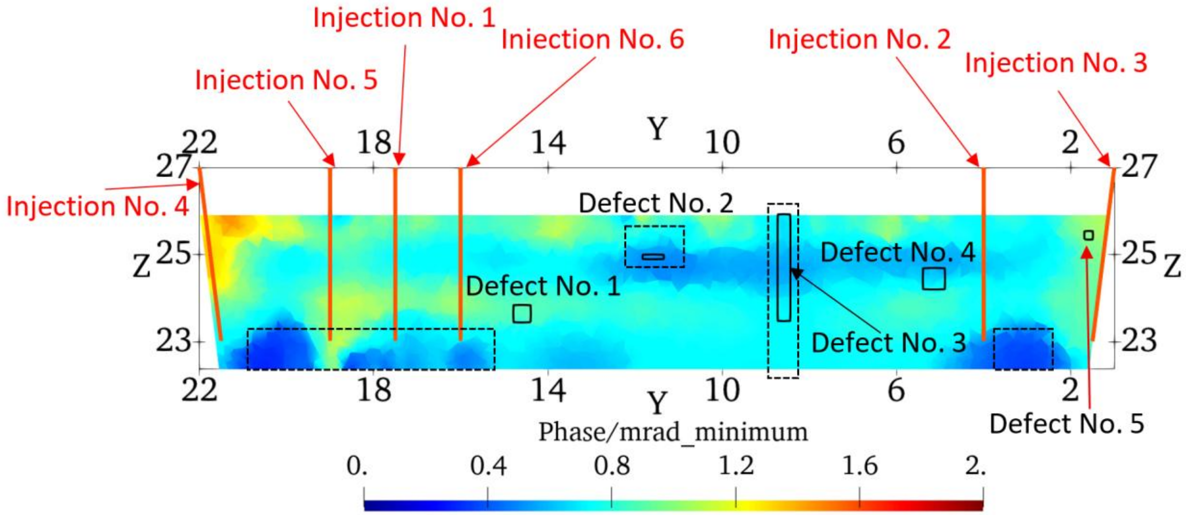


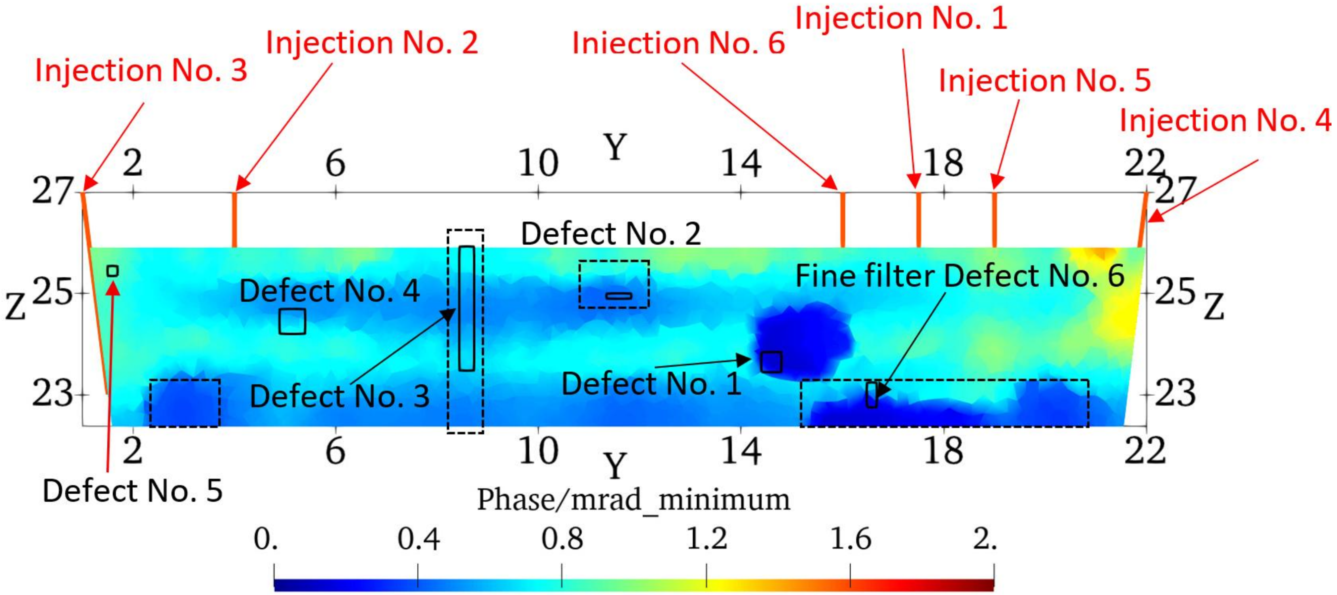


IP data analysis

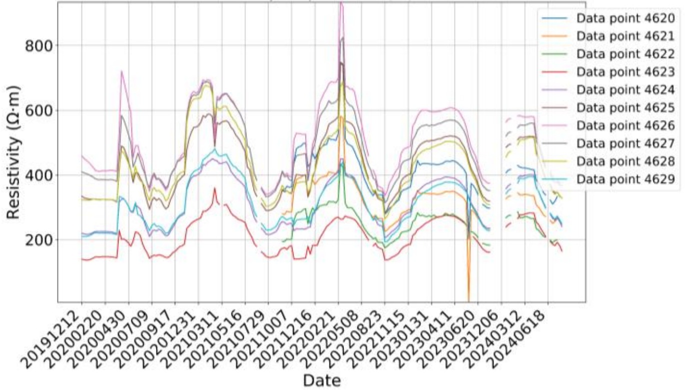
- Defect No. 1 and 5
- Defect No. 2
- Defect No. 3
- Defect No. 4
- Defect No. 6
- Injections

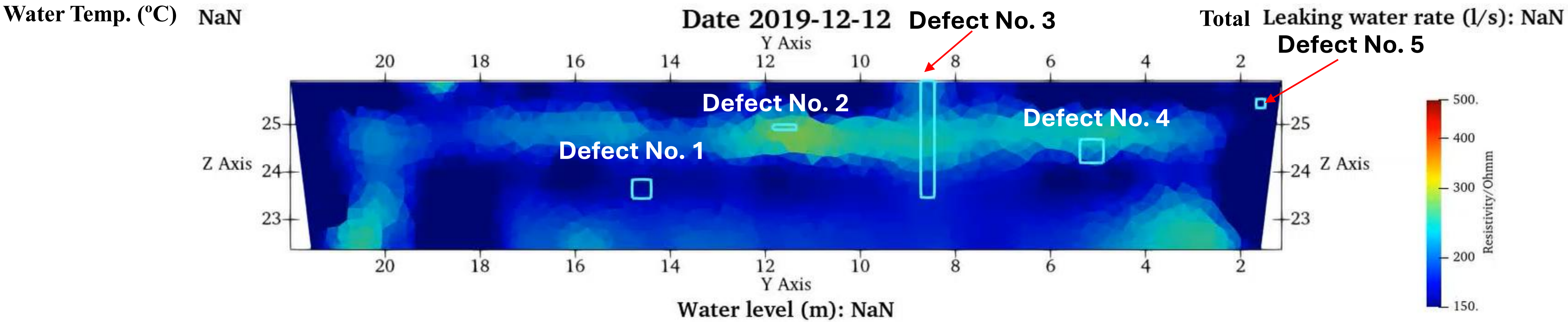


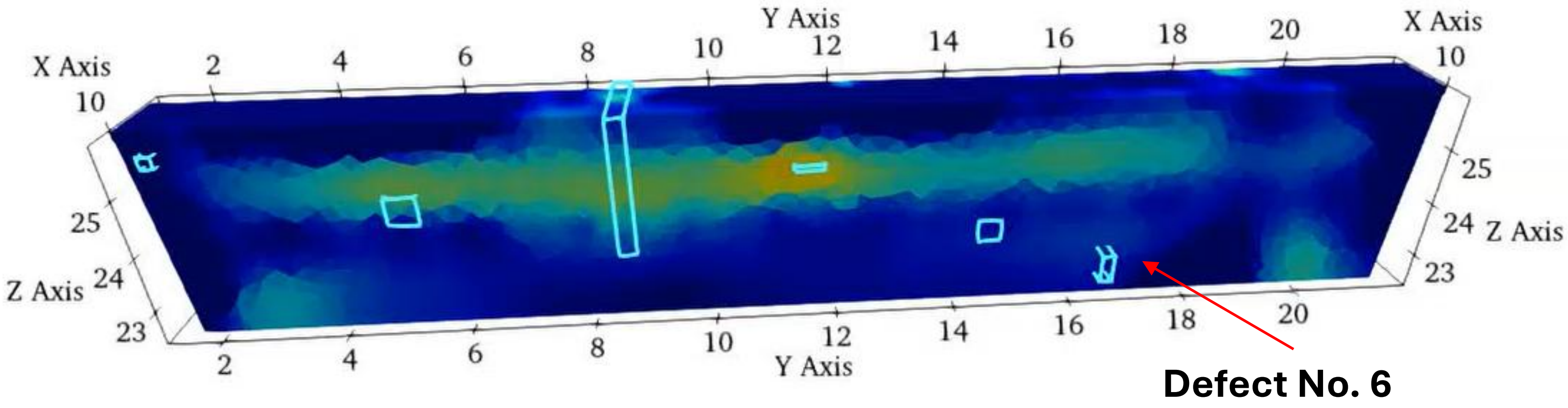




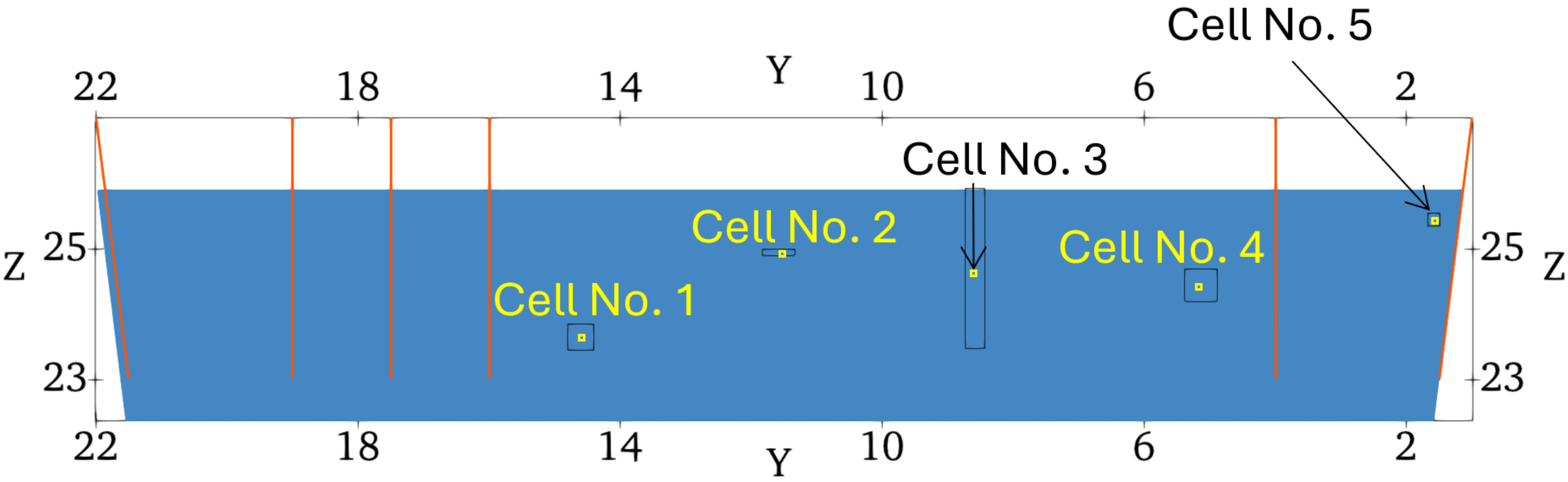
ERT inversion results



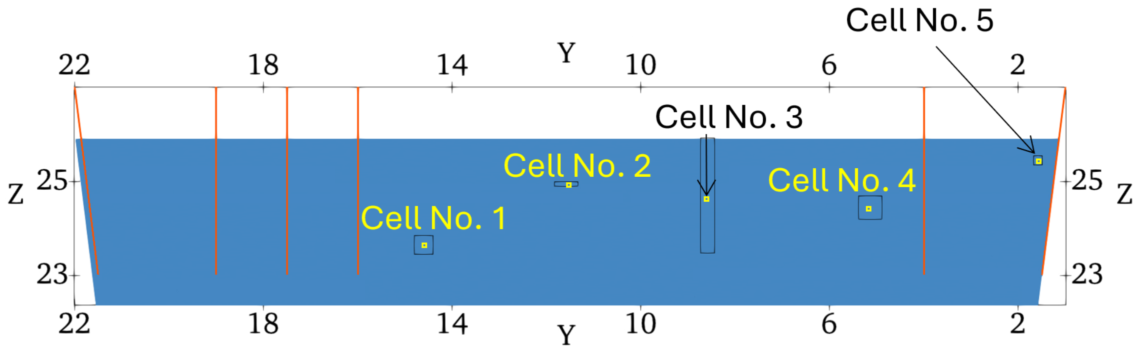




Resistivity of the cells versus time

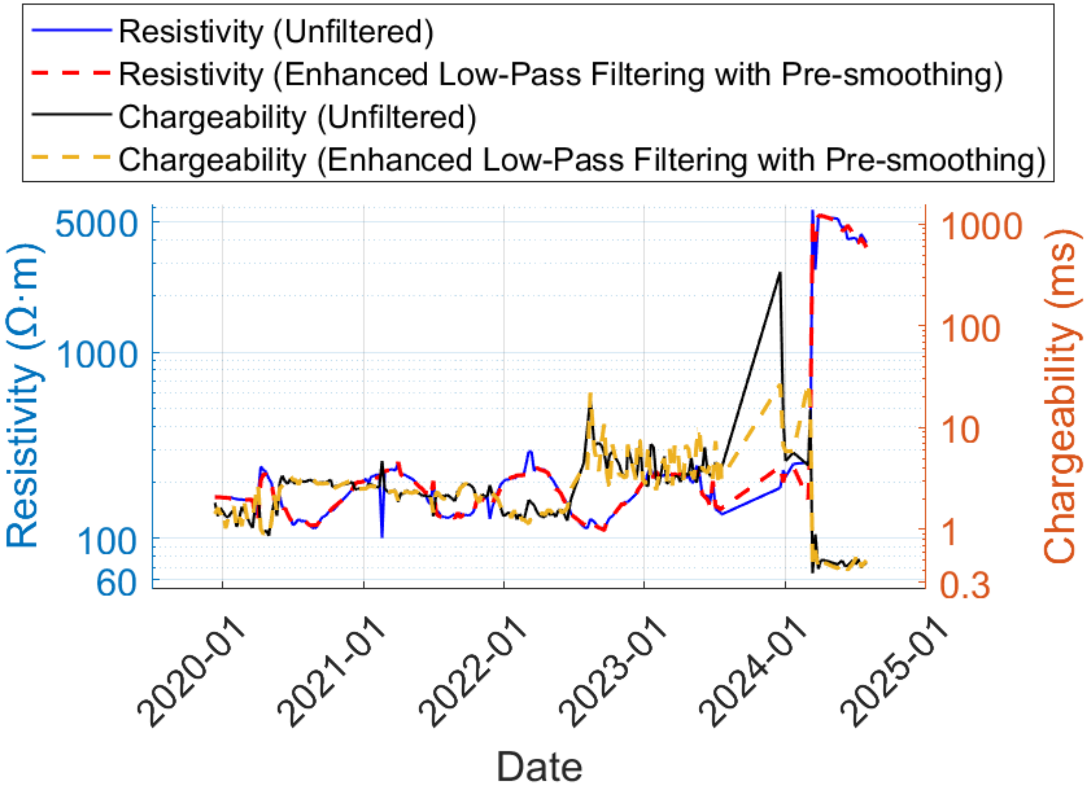


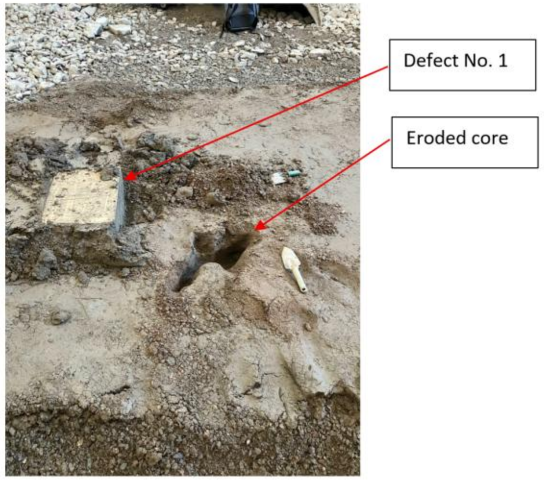
Resistivity of the cells versus time

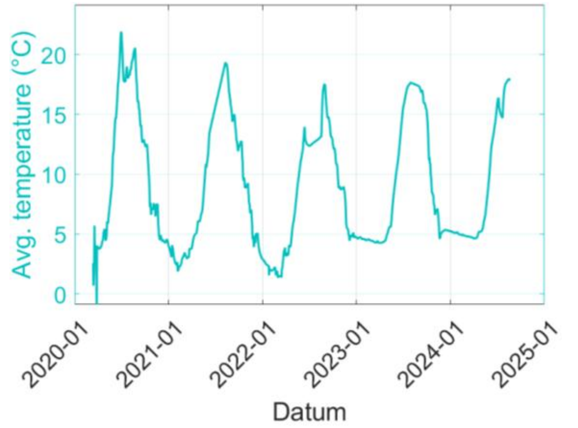


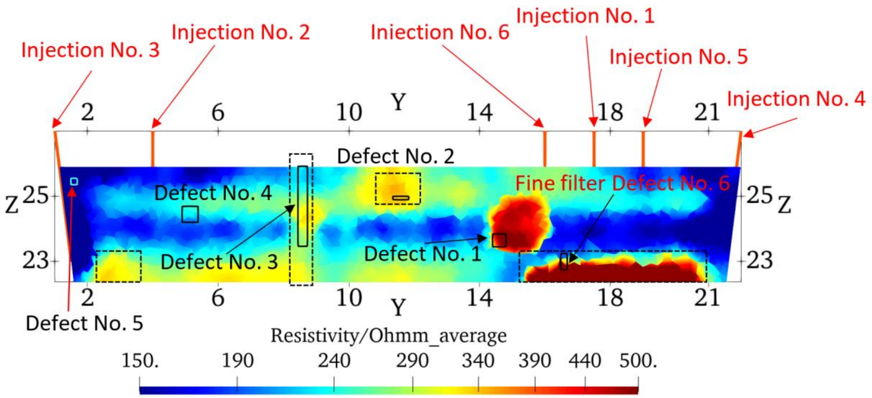
Cell No. 1

- After Feb 2024, high resistivity and low chargeability → washed-out fines and increased water flow.
- Resistivity values in Cell No. 1 prior to February 2024 → relatively low compared to the other cells.
- Resistivity values fluctuate with temperature.
- Less pronounced spikes in filtered results.



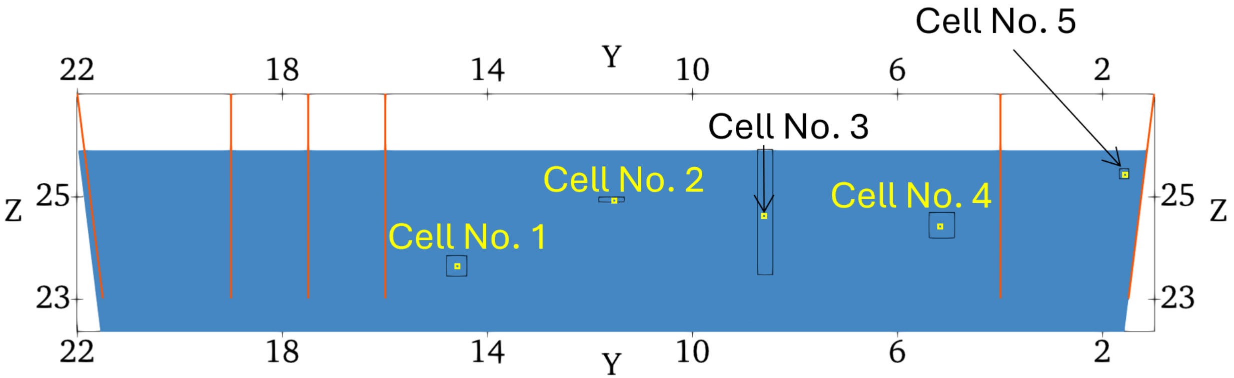




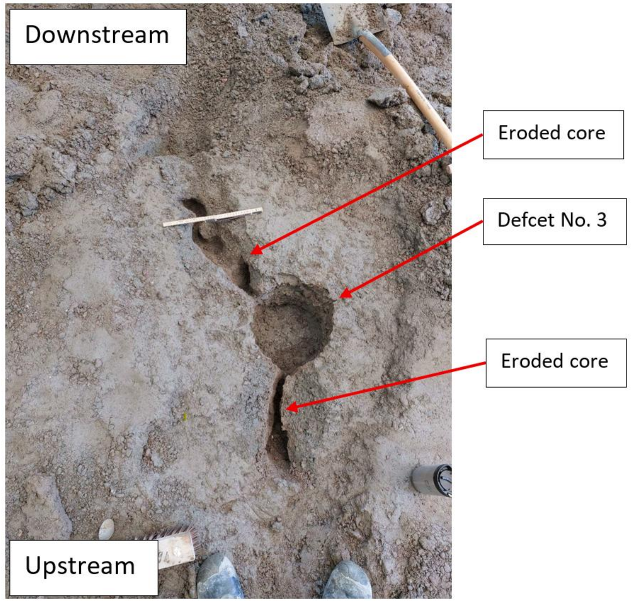


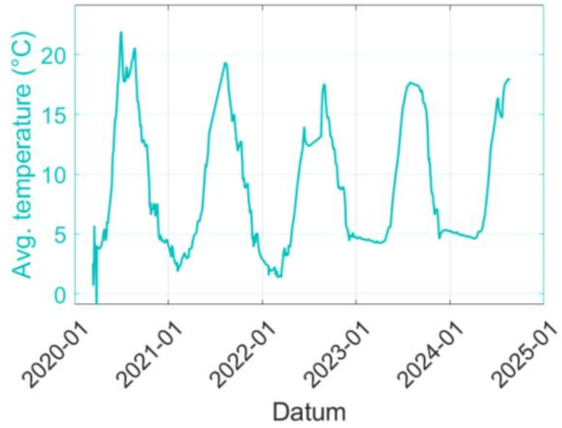
Resistivity of the cells versus time

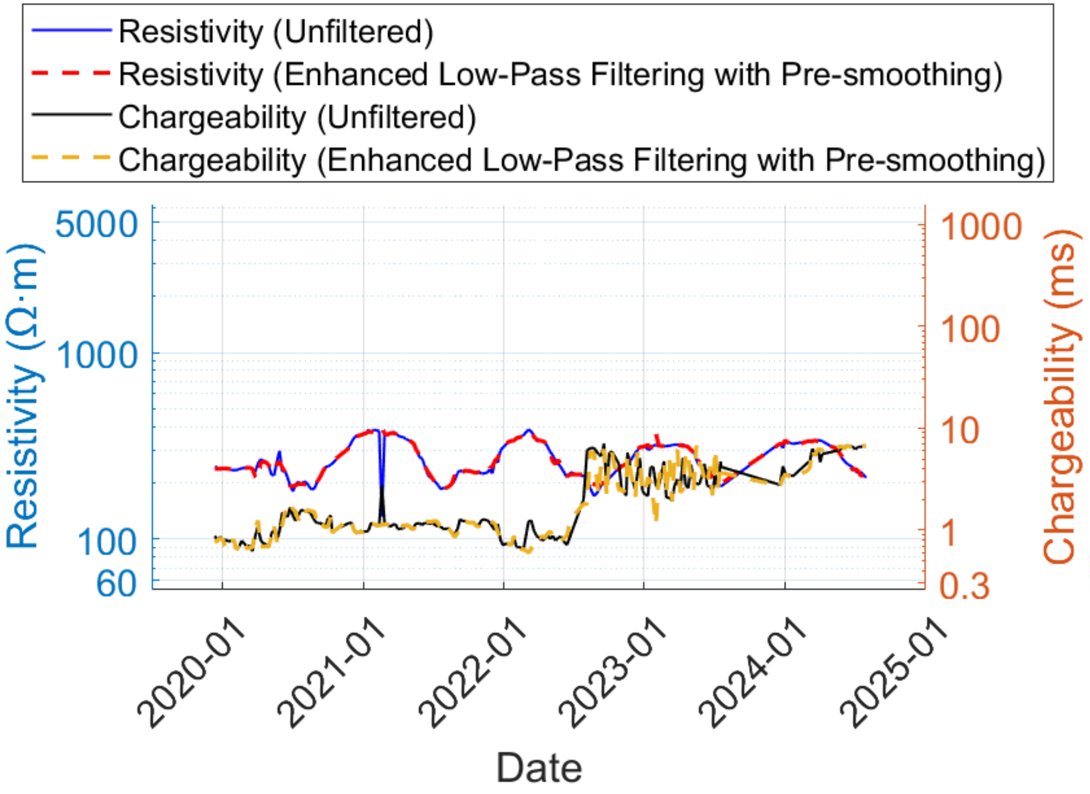
Cell No. 3

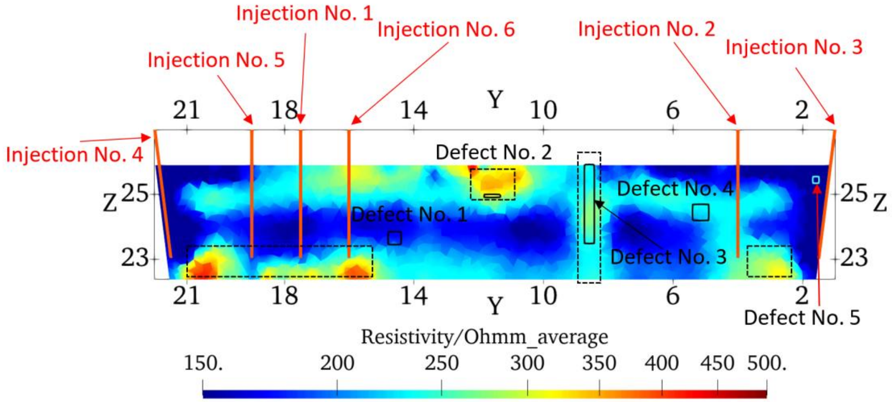


- Cell No. 3 → higher resistivity values→ easy to detect
- Resistivity values fluctuate with temperature.
- Less pronounced spikes in filtered results.







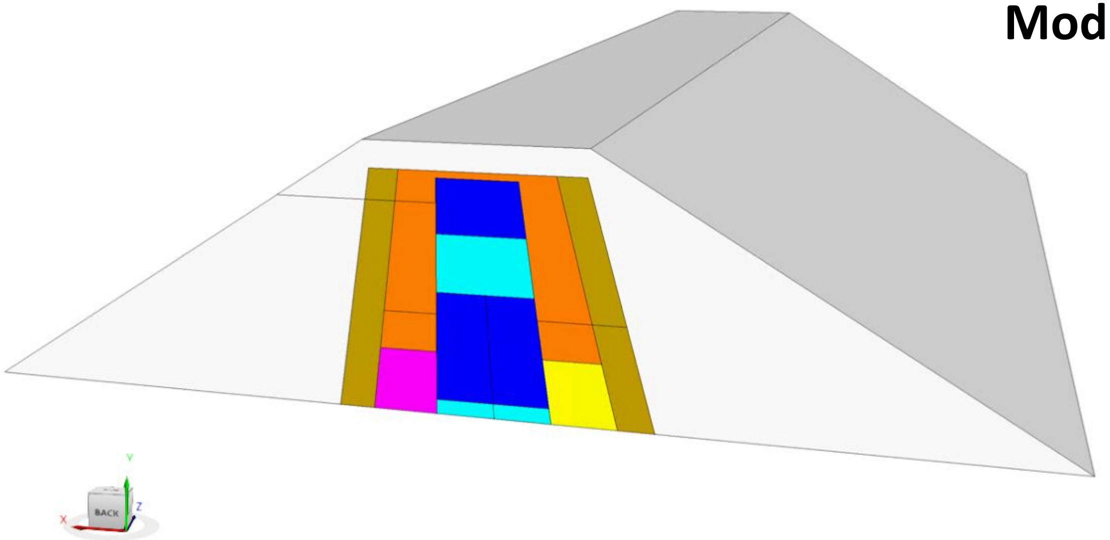


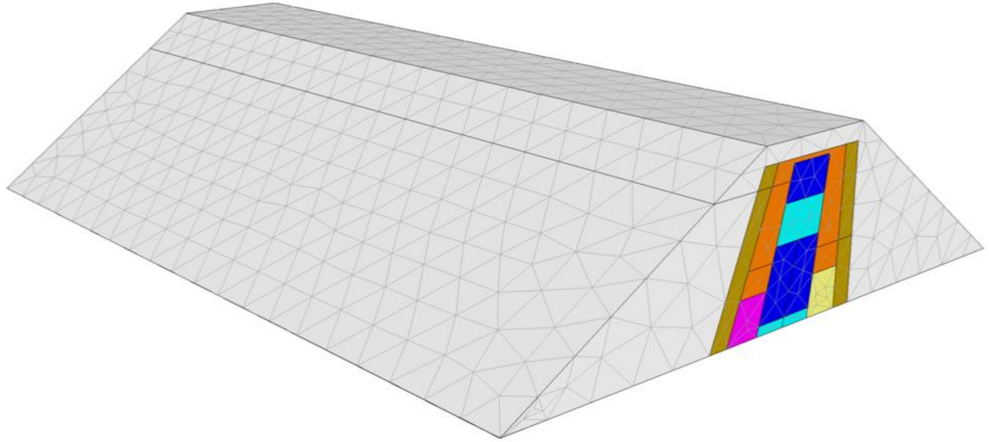
3D seepage model

- SEEP 3D used for the transient seepage flow modelling.

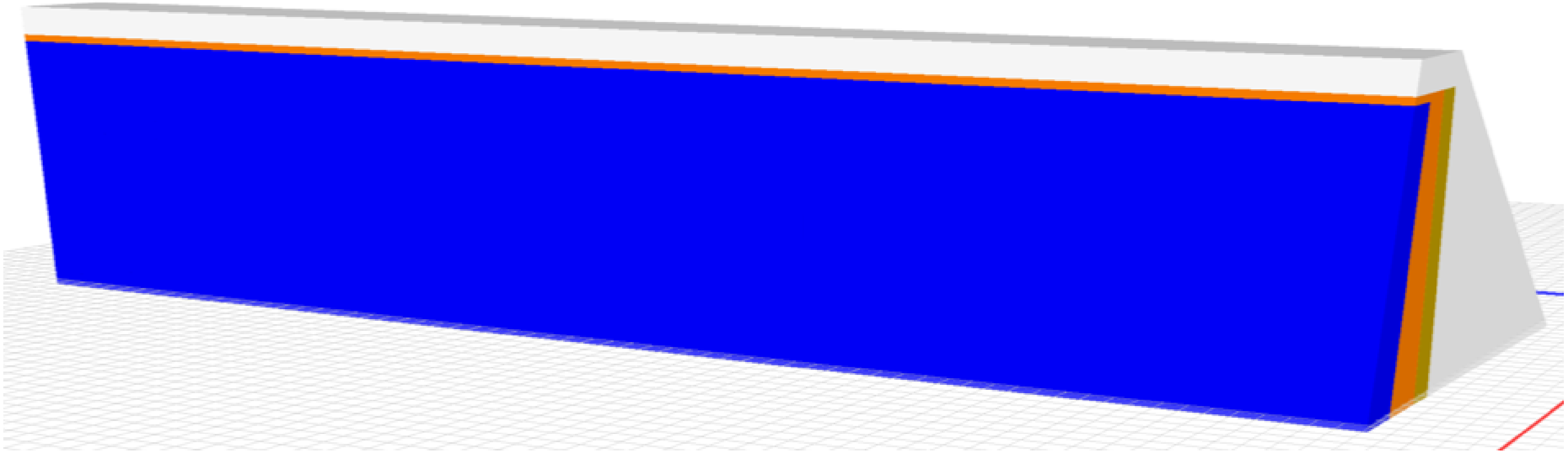
No.	Specifications
Model No. 1	Homogeneous core and filters
Model No. 2	Model including the intentional defects
Model No. 3	Model with intentional defects plus anomalous zones and layering detected by ERT

Model No. 3

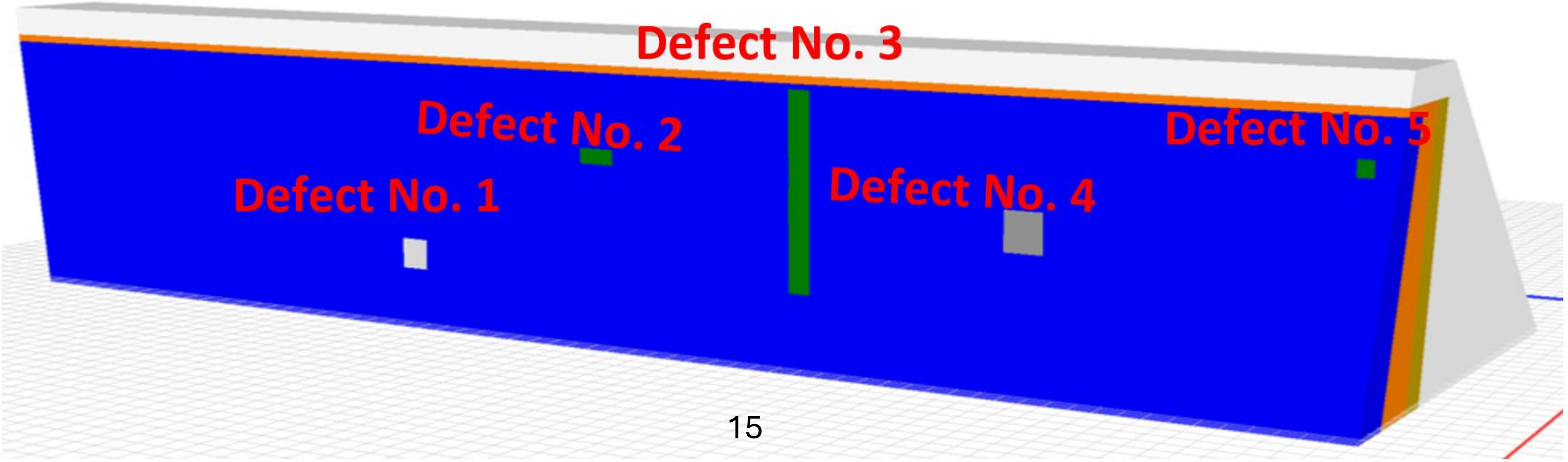




Seepage model No. 1

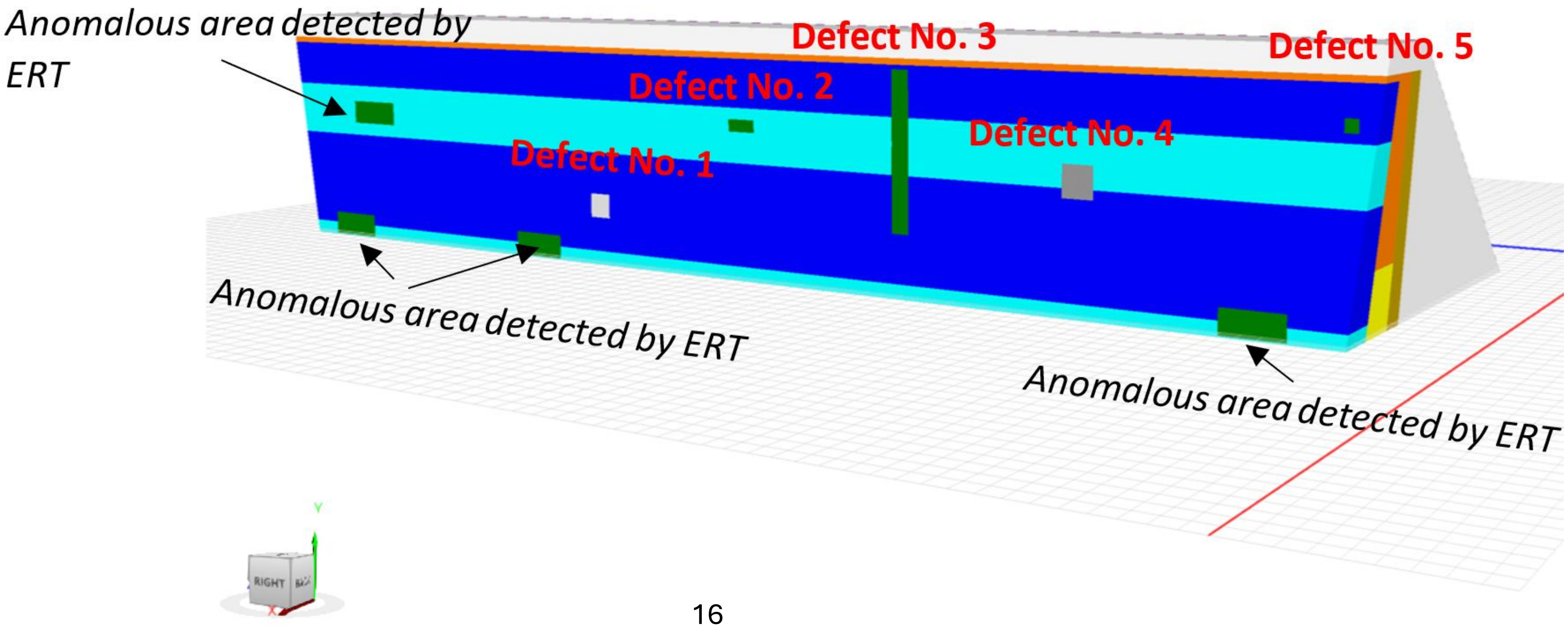


Seepage model No. 2



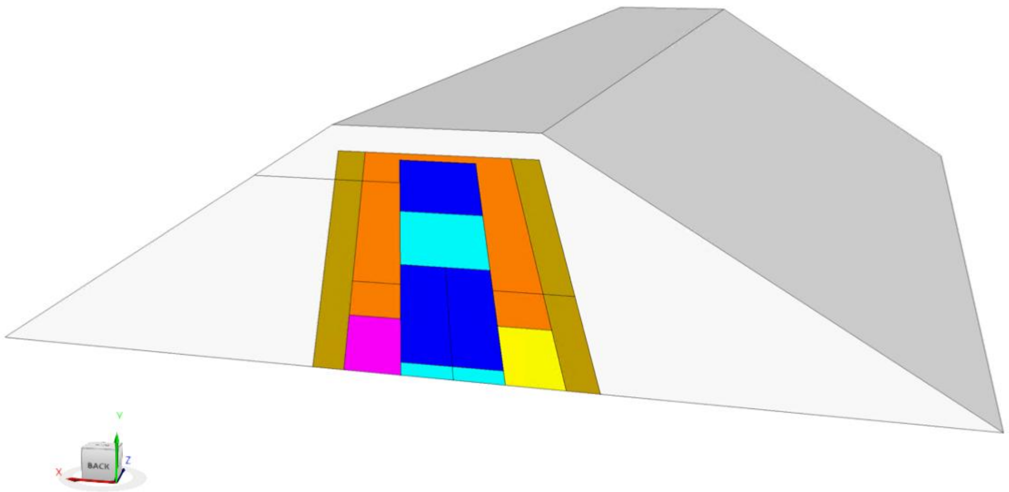
Seepage model No. 3

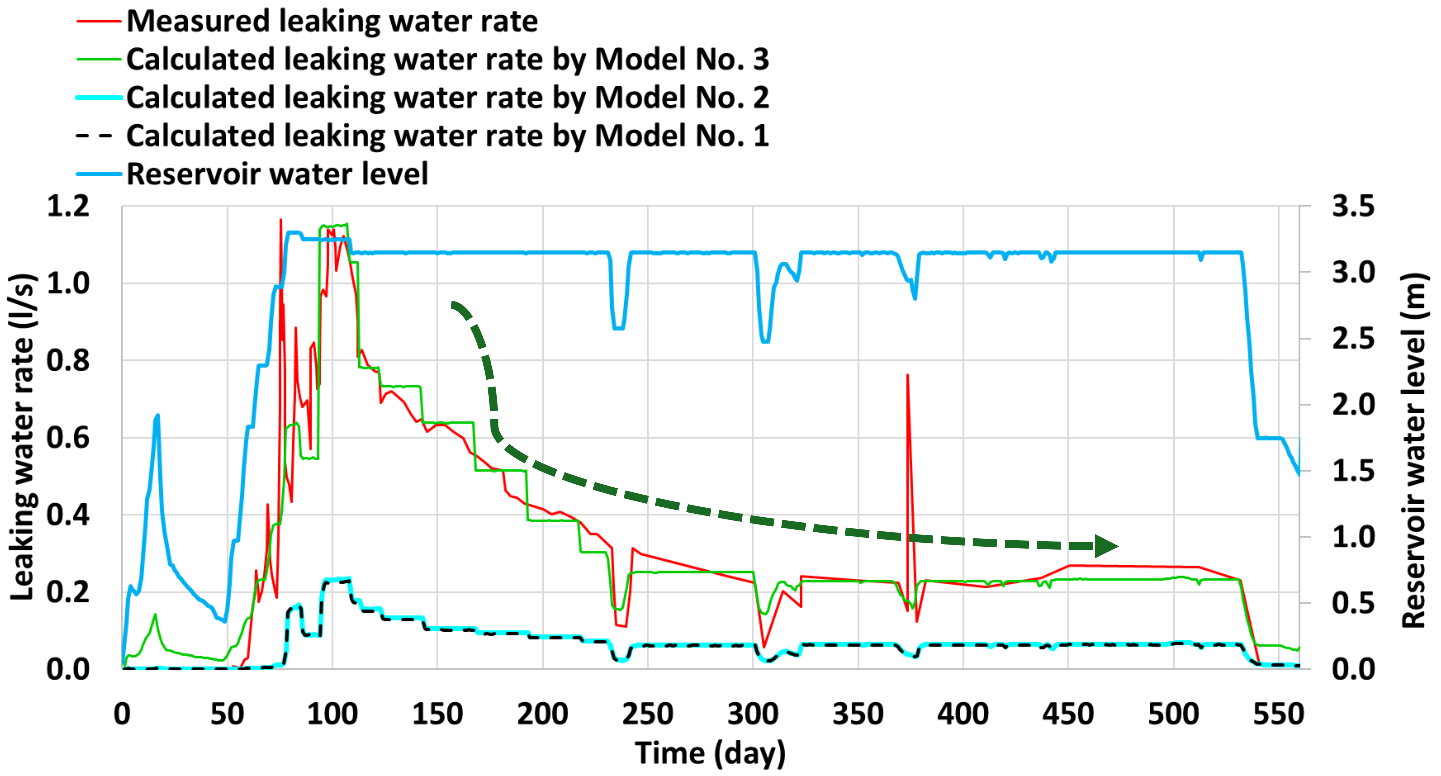
Model with intentional defects plus anomalous zones and layering detected by ERT.



Seepage modelling - measured and calculated flow

- Materials settle gradually → lower hydraulic conductivity→ lower leakage → healed defects
- Homogeneous core model and core with intentional defects only – no agreement
- Core with intentional and unintentional defects → good agreement

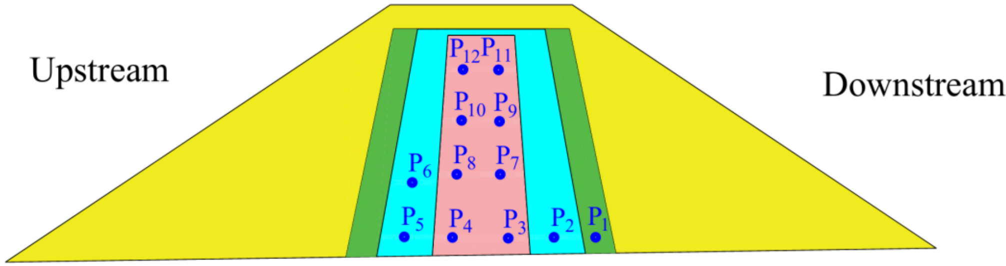


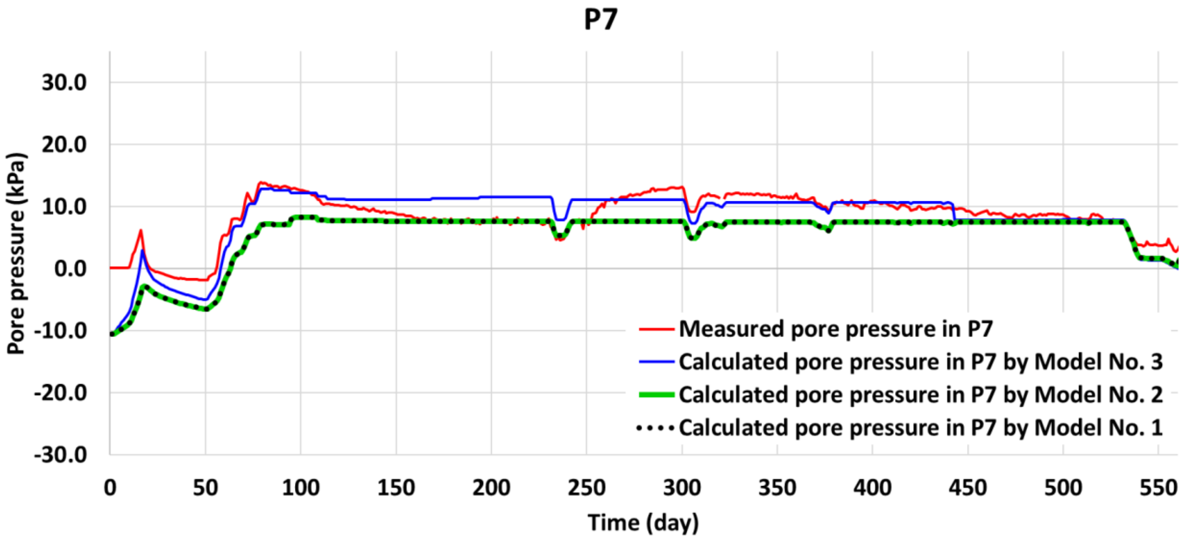


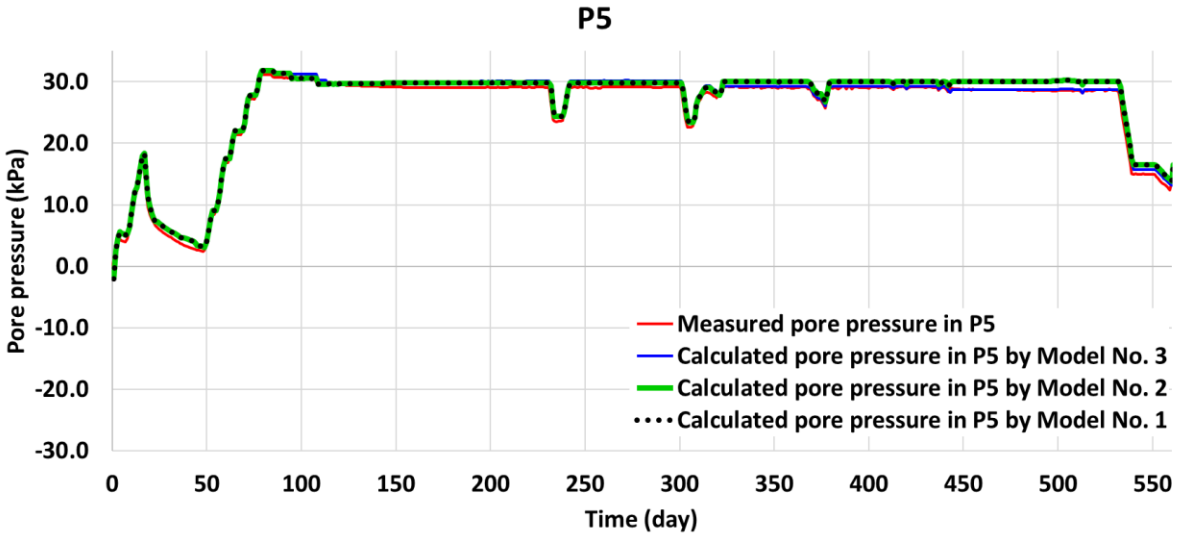
Seepage modelling - measured and calculated pore pressure

- Homogeneous core model and core with intentional defects only – no agreement

- Core with intentional and unintentional defects → better agreement

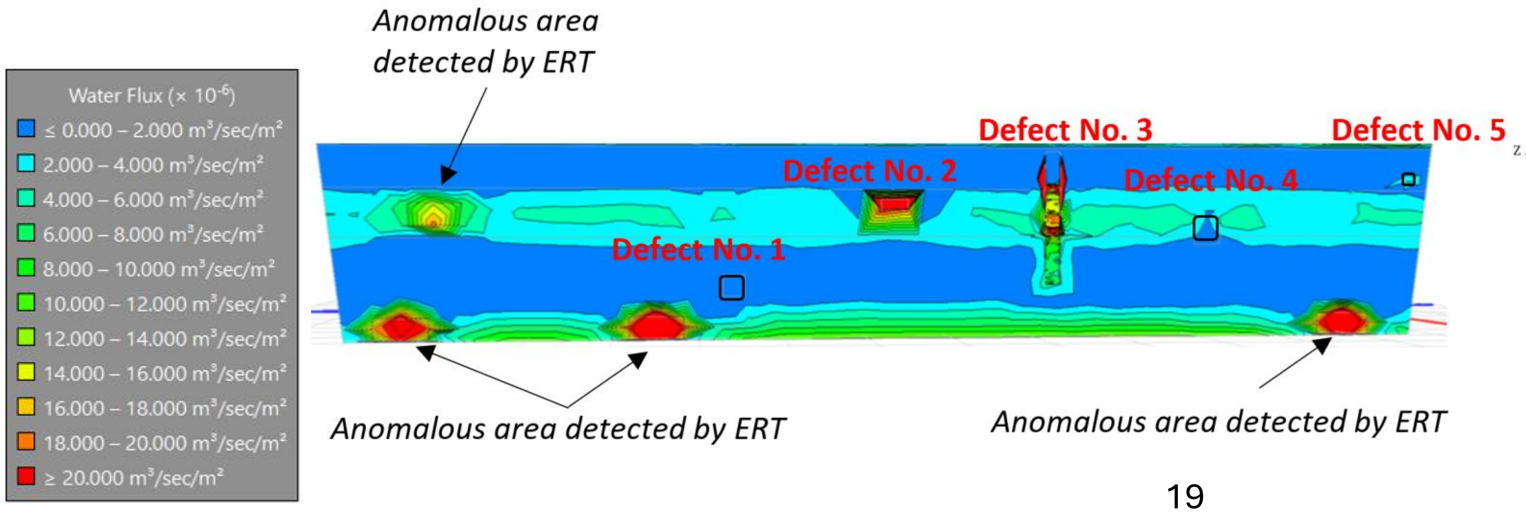


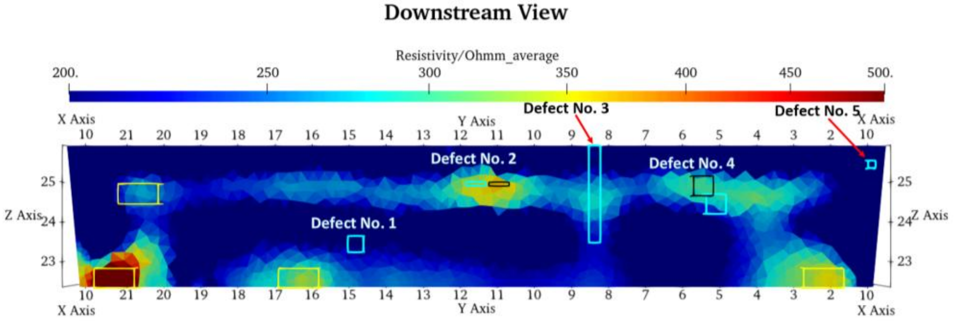




Calculated water flux by Model No. 3

- High water flux through the unintentional anomalous areas
- Water seeps through Defect No. 2 (and the surrounding areas?)
- Defect No. 3 also shows considerable water flow
- Defects No. 1, 4, 5 and 6 → very little or no water flow





Conclusions

- ERT → identified Defects No. 2 and 3 (crushed rock) early, and high-resistivity anomalies around Defect No. 4 → washed-out fine material.
- Defects No. 1 and 6 were only detected in 2024, suggesting progressive material loss
- Defect No. 5 undetected → limited data coverage and small size.
- IP results generally agreed with ERT, detecting Defects No. 2 and 3 early, and Defects No. 1 and 6 in 2024
- IP data interpretation more challenging due to unstable data.
- Enhanced seepage modelling by integrating geophysical data, which improved the representation of hydraulic properties and water content distribution.
- Long-term monitoring valuable, as time-lapse data revealed delayed changes and additional defects.

Thanks for your attention!

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Integration of seepage modelling and electrical resistivity monitoring data for the Älvkarleby test embankment dam, Sweden

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ORIGINAL PAPER

Monitoring of Älvkarleby test embankment dam using 3D electrical resistivity tomography for detection of internal defects

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Received: 17 March 2023 / Accepted: 25 February 2024

Abstract

Electrical resistivity tomography (ERT) is a potential-based method for detecting internal erosion in the core of embankment dams using the electrodes installed outside. This study aims at evaluating the practical capability of ERT monitoring for detecting internal defects in embankment dams. A test embankment dam with in-built well-defined defects was built in Älvkarleby, Sweden, to assess different monitoring systems including ERT and the defect locations were unknown to the monitoring teams. Between 7500 and 14,000 ERT data points were acquired daily, which were used to create the distribution of electrical resistivity models of the dam using 3D time-lapse inversion. The inversion models revealed a layered resistivity structure in the core that might be related to variations in water content or unintentional variations in material properties

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A geoelectrical pre-study of Älvkarleby test embankment dam: 3D forward modelling and effects of structural constraints on the 3D inversion model of zoned embankment dams

Reyhaneh Norooz [a], Per-Ivar Olsson [b,*], Torleif Dahlin [b], Thomas Günther [c], Christian Bernstone [d]