Sistemi innovativi di monitoraggio geotecnico mediante sensori in fibra ottica

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28 Giugno 2022

Monitoraggio della temperatura nelle strutture arginali per il riconoscimento dei flussi idraulici

(Temperature monitoring in the levees for detection of seepage)

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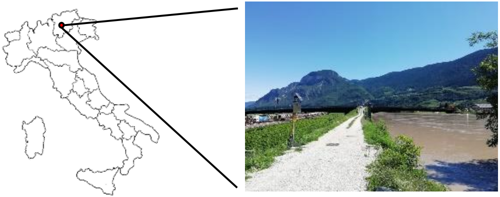
INGEGNERIA CIVILE, EDILE E AMBIENTALE
CIVIL, ARCHITECTURAL AND ENVIRONMENTAL ENGINEERING

Aim of project

The main aims of this research are the definition of safety degree of Adige river’s levees and testing new monitoring and survey strategies for seepage control in levees



Distributed monitoring:

- Optical fibre sensors for detection of internal temperature variation due to seepage
- Electrical tomography in vertical borehole

Punctual survey:

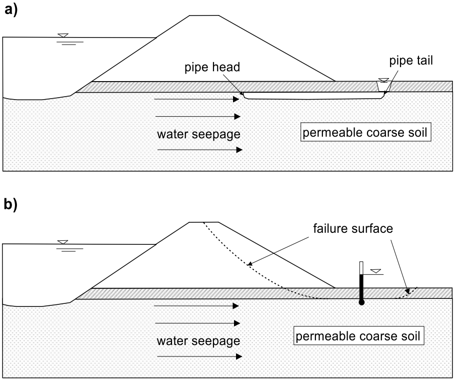
- New Gel Push Sampler for collection undisturbed samples in coarse soils
- New permeameter for testing coarse soils

Open questions

The river embankment safety assesment has to be checked for two main mechanisms:

a) Internal erosion

b) Global instability due to excess pore pressure in foundation or seepage in the levee body



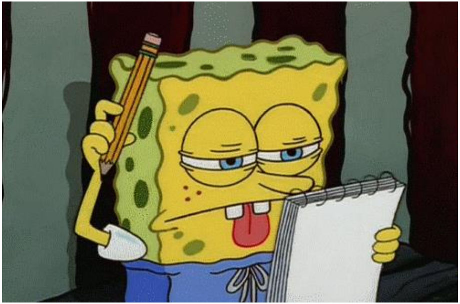
The difficulties relatively to the Adige rivers are::

- High stratigraphic heterogeneity
- No possibility to collect undisturbed samples in granular soils
- Not easy interpretation of in-situ measures and reliability of numerical models
- Too much expensive traditional monitoring devices in relation to the long profile of levees

Basic requirements for a monitoring system

Some aspects that a good monitoring system have to satisfy:

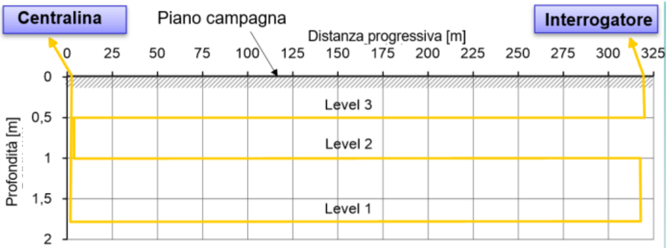
- Reliability
- Low cost
- Installation without reducing the geotechnical safety
- Coupling with traditional sensors for comparison
- Redundancy



1° test site in Salorno

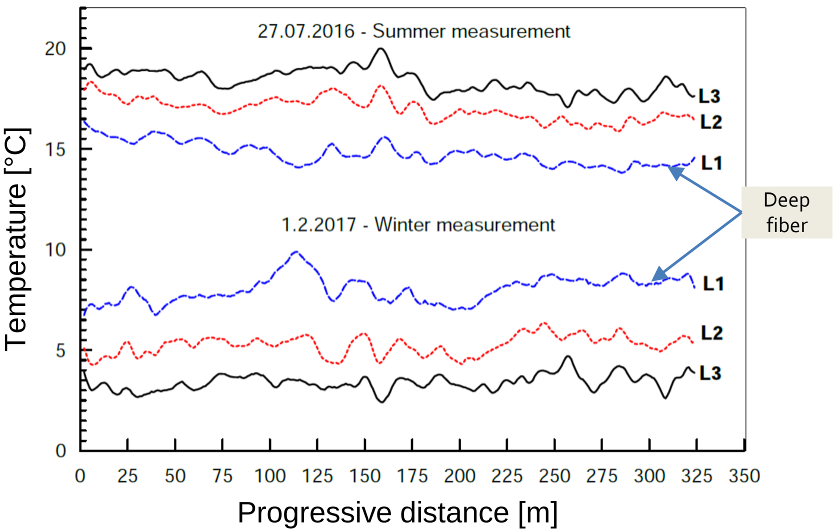
Aim: evaluate the potential of a DFOS-based monitoring system for identifying the piping occurrence or instability due to under pressure

- 1 single DFOS for temperature measurement placed on 3 levels at 50 cm of vertical interspace in a trench about 350m long at the foot of the embankment on the countryside side
- Installation minimizing possible disturbance
- Point pressure and temperature sensors in addition



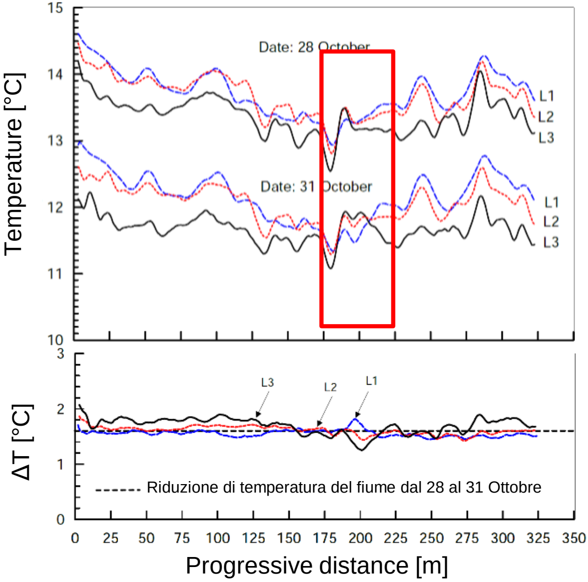
1° test site in Salorno

Temperature profiles in summer and winter



1° test site in Salorno

Records during «Vaia» flood (28-31/10/2018)



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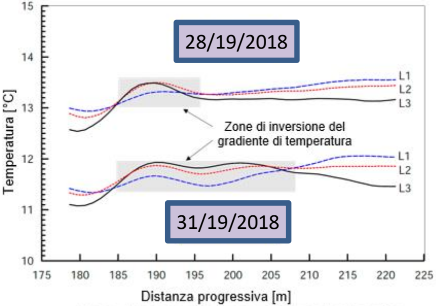
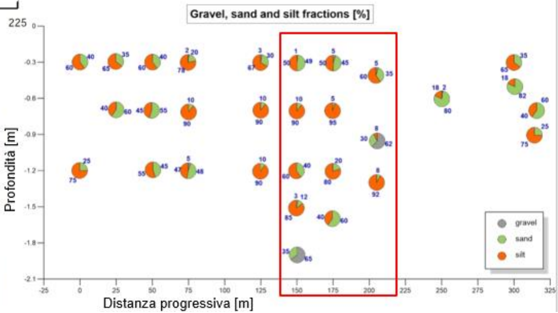


Temperature inversion due to a localized high seepage in the gravel lens



First remarks

Temperature variations detected by DFOS during the flood, although confirmed by measurements with traditional sensors, were very modest to draw definitive conclusions.

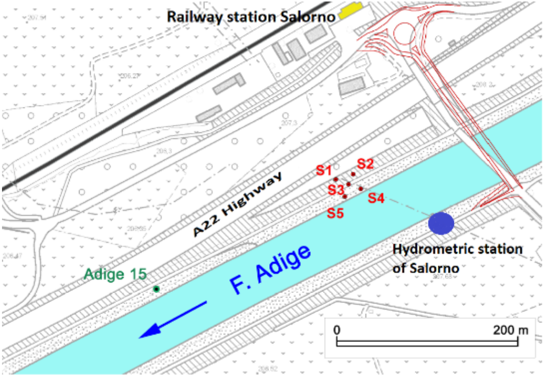
This is because:

- Due to the shallow position, the soil is mainly affected by seasonal temperature variation
- Damage to the soil texture for installation in the trench

It was therefore chosen a vertical DFOS installation closer to the river to evaluate the measuring capacity of the fibers

2° test site in Salorno

2° test site in Salorno

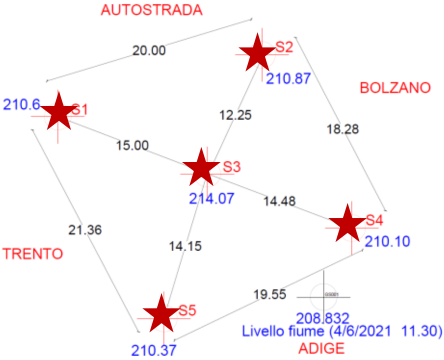


Highway parallel to the river

High risk

Investigations: geognostic surveys

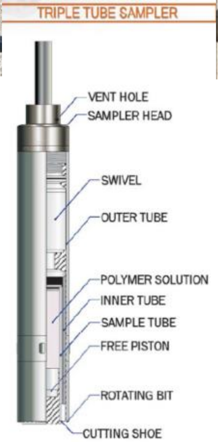
1. 5 surveys at the corners and center (corresponding to the axis of the embankment) of a square 20x20m².
   The depth of the surveys is about 25m for the corner ones and 30m for the central so as to reach about the same altitude.



Investigations: samples and laboratory tests

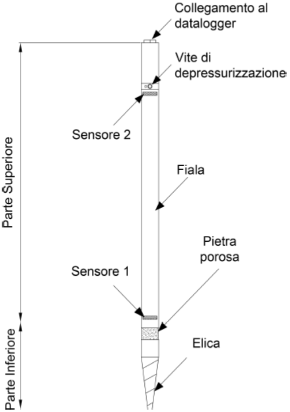
2. 11 undisturbed taken by Gel-Push Sampling in S3 + 10 undisturbed standard + 16 remoulded in S1, S2, S4 e S5.

3. Laboratory tests of classification, permeability and compressibility in Tx



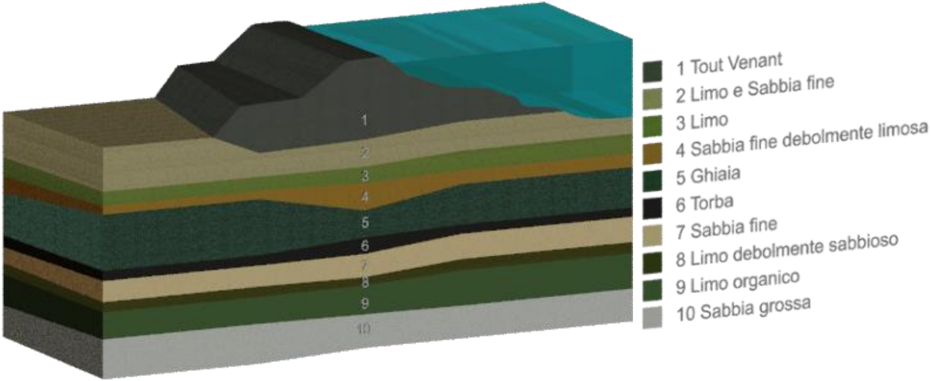
Investigations: in-situ permeability tests

4. SPT and Lefranc tests in coarse-grained soils
5. On-site permeability tests with a BAT type permeameter, specifically made for coarse-grained soils (sandy sands and gravels).



Investigations: stratigraphy model

Thank to all the information collected it is possible to reconstruct a 3D stratigraphic model of the embankment.

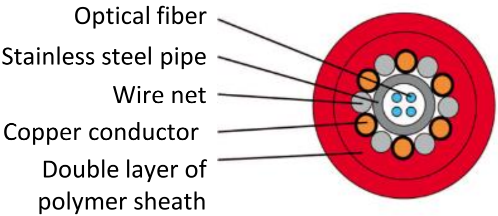


New monitoring system: **DFOS**

In each borehole:

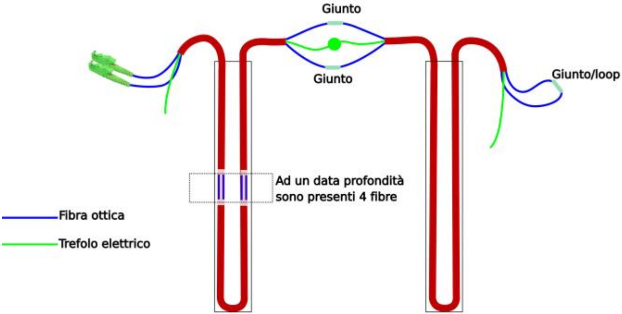
1. BRUsens® AHFO DTS with 2 multimode fibers to measure the temperature change along the depth.

   Fiber exploited with Raman mode with Oryx SR DTS of Sensornet (spatial resolution = 2m, accuracy = 0.1°C).



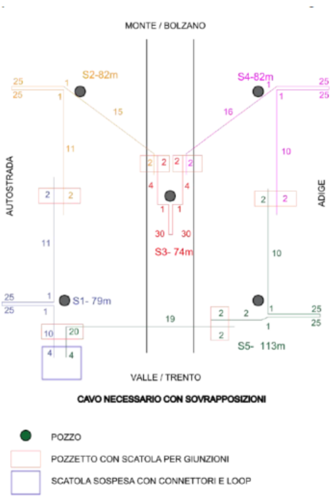
New monitoring system: **DFOS**

The DFOS is installed into the hole by fixing it to a micro-holed tube D=60mm taking care to protect the fiber optic cable at the bottom of the hole



New monitoring system: **DFOS**

Preparation of pieces of fiber, subsequently joined, to allow the removal of the coating of the coating of the sample

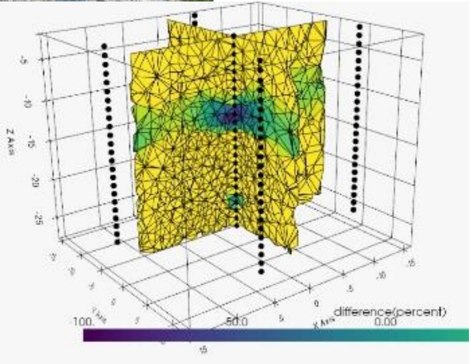


New monitoring system: **DFOS**

Tools to perform fiber optic lecture with thermal bath

New monitoring system: **ERT**

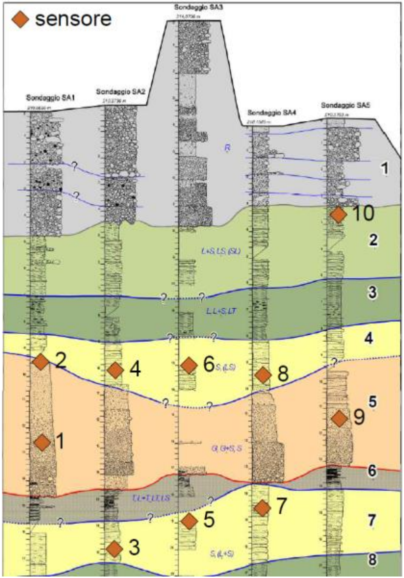
2. Cables for 3D ERT surveys of soils under the embankment, exploiting the sensors of three holes at a time;



Monitoring system: traditional sensors

3. Piezo/thermometric probes (2 per hole) with hourly measure. Accuracy: 2cm column H_2O and 0.1°C.

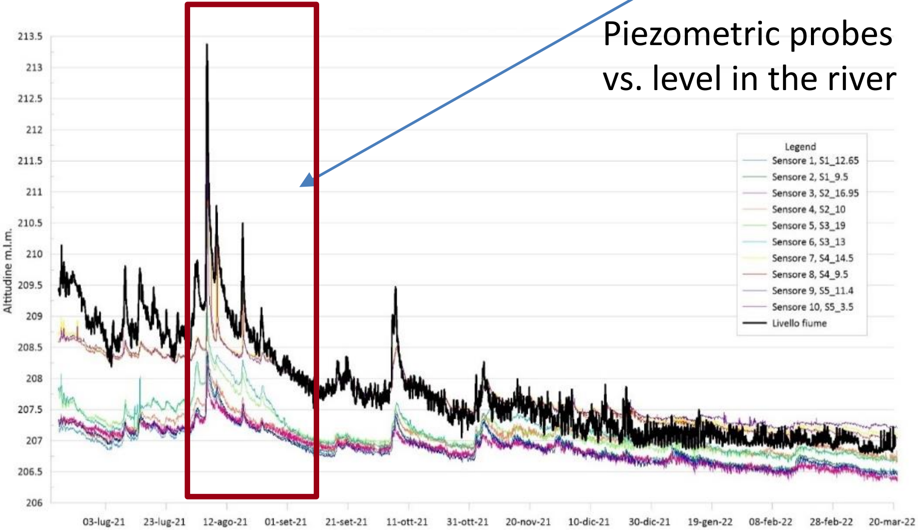
Laboratory calibration of thermometric probes



Monitoring results

Monitoring of about 1 year.

Interesting data observed in the full occurred on 5/8/2021.



Monitoring results

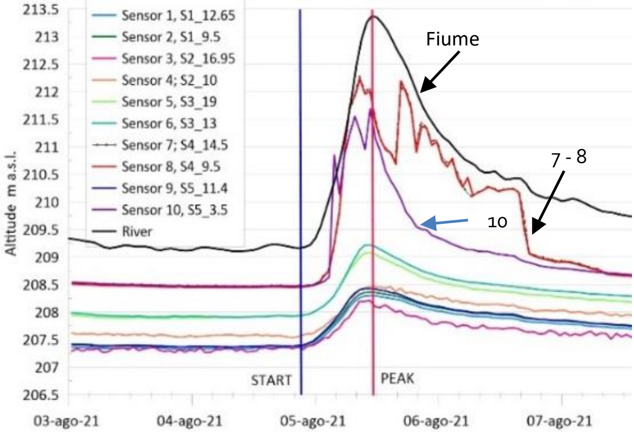
The hydrometric level in the river rose by 4.2 m in 11 hours, reaching an altitude of 213.4 m above sea level (70 cm above sea level) at 11.00 am on 5/8/2021.

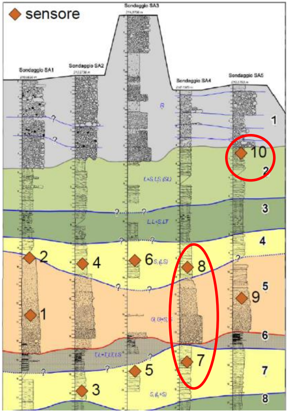
Numerous fountains were visible at the foot of the embankment on the countryside side.

Monitoring results

The most reactive sensors are the 7, 8 and 10, but the response of the 7 and 8 is anomalous because it is much faster than the others (1-2 hours against the 4-5 hours of the others).

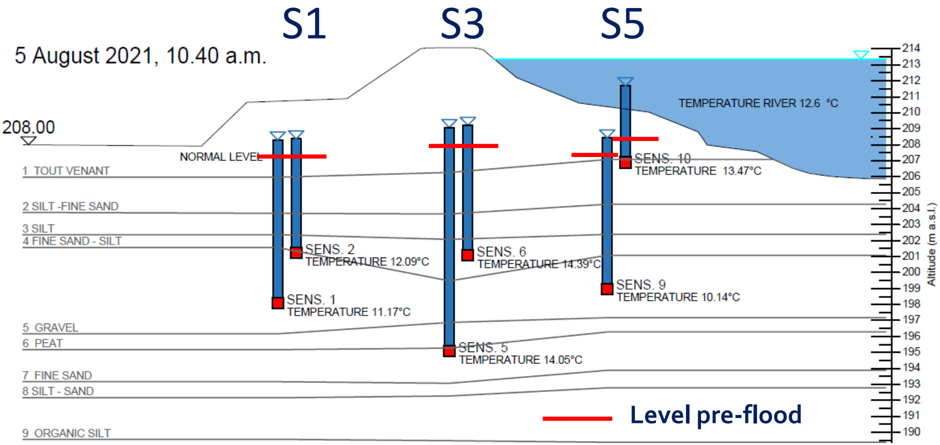
On the countryside side the variation is much smaller: only 1-1.2 m.





Monitoring results

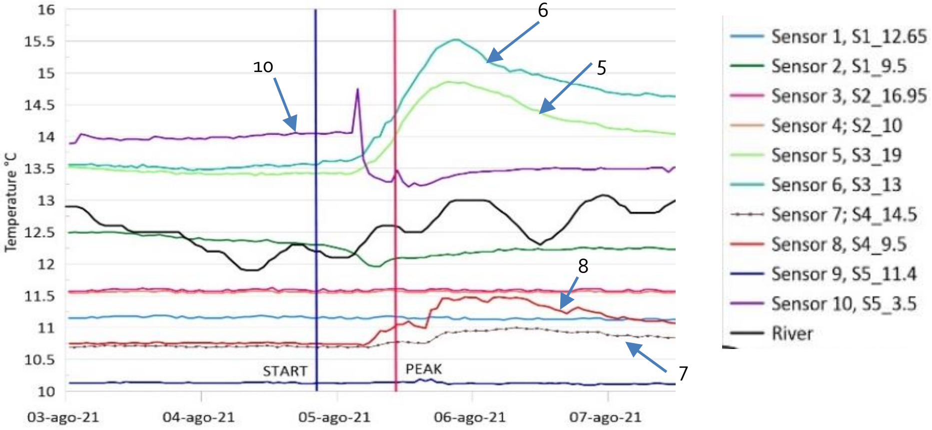
Piezometric levels at the flood peak



Monitoring results

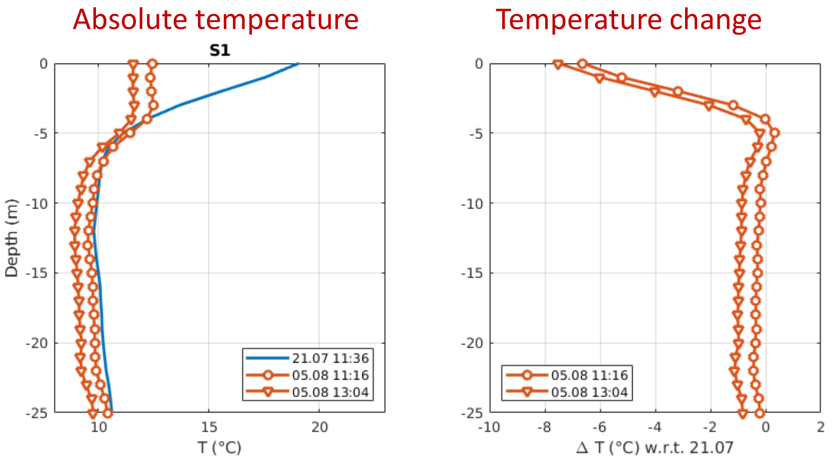
The water temperature in the river drops by about 1°C. Only sensor 10, the closest to the bottom of the river, records a drop of about 0.7°C.

Sensors 5, 6, 7 and 8, on the other hand, record an increase of about 0.5-2°C with a certain delay compared to the passage of the flood wave, probably due to the migration of warm waters already resident in the deep layers.



Monitoring results

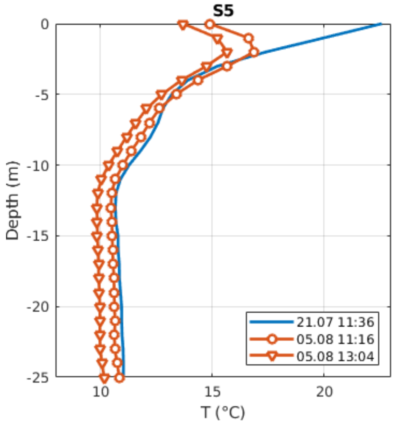
Comparison between temperature profiles measured by DFOS during flood and those measured during a normal flood.



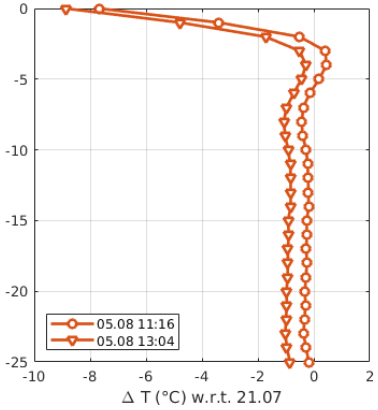
Monitoring results

Nei pozzi lungo il fiume si registra una diminuzione ΔT di 8÷9°C nei primi 2-3 m, forse a causa della sommersione delle teste pozzo che sono solo 2 m sopra il livello di morbida.

Absolute temperature



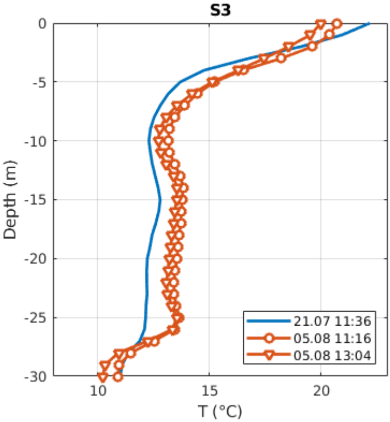
Temperature change



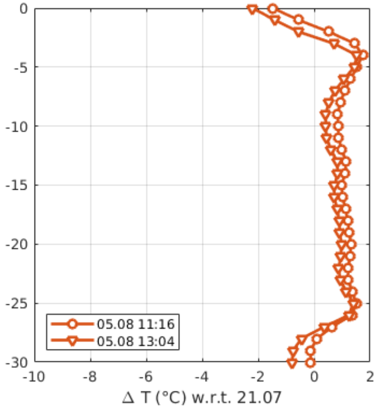
Monitoring results

In S3 the temperatures are higher because the microcracked tube was still open. In the deep layers at the passage of the flood a $\Delta T = 1°C$ confirms what recorded by traditional sensors.

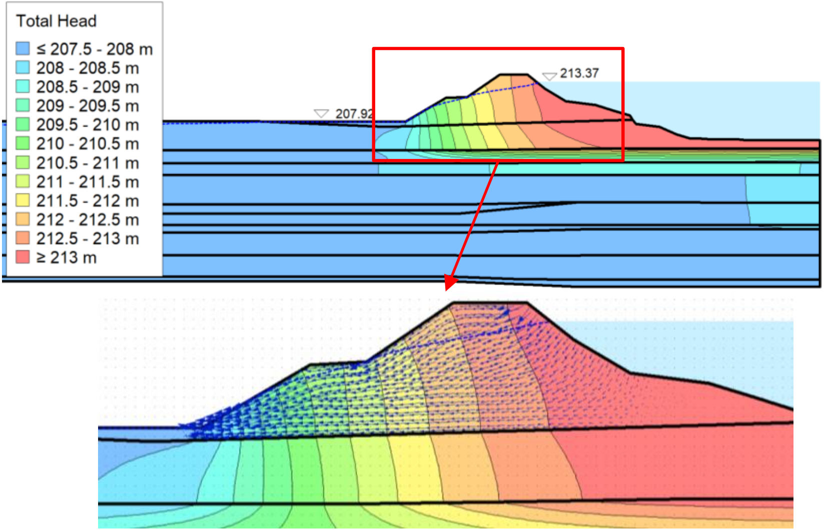
Absolute temperature



Temperature change

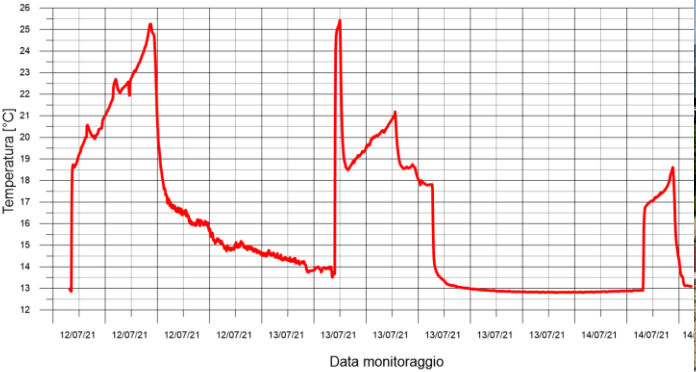


Seepage analysis



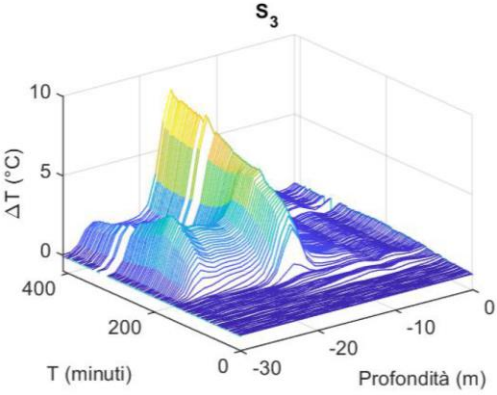
Injection test

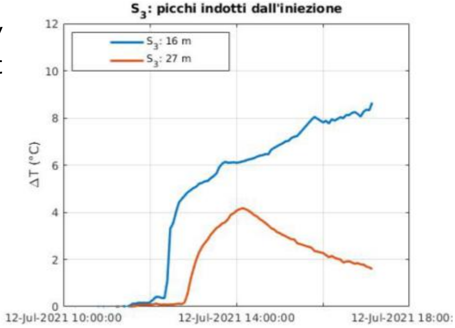
Dual packer system used in input tests



Injection test

ΔT in S3 on the 1st day of testing (12 July 2021), calculated with respect to the test start temperature





Evolution of the temperature variation at the two points of greatest variation during injection into the S3 well.

Final remarks

- The monitoring system used combines traditional sensors with distributed fiber optic sensor
- Traditional point sensors provide the temporal evolution of temperature and pressure in some predetermined points
- DFOS provide a distributed temperature measurement along the entire vertical profile of the well, but require an operator present for the querying of the fiber
- The combination of different measures is certainly advantageous because it allows to have a better picture of the phenomenon

Final remarks

Despite the significance of the observed flood wave, traditional sensors detect a modest increase in pressure, suggesting that filtration affects only the body of the embankment and the most superficial layers and does not concern the deeper layers.

The same conclusion can be deduced from the trend of temperatures, which also have variations of a few tenths of a degree, both if measured with traditional sensors and with fibers.

This response confirms predictions. In fact, this embankment was considered safe and chosen to have the photograph of a "healthy" embankment with regard to the hydraulic seal of the deep layers.

Conclusioni

- Advantage of DFOS it the monitoring of the entire vertical profile with a more detailed knowledge of temperature variations in the ground.
- Moreover, they do not require an a priori choice of the measurement position, as is the case for traditional ones.
- They allow you to observe even unforeseen local phenomena (see leakage during the input test).
- On the other hand, the declared accuracies with regard to thermal measurement do not seem to have been verified when operating on site. Here, in fact, the interrogator who is affected by the high/low temperatures, in turn influences the measurement.
- The results obtained provide some initial observations on the behavior of the structure of the survey, but further measurements and analyzes are needed to better define the response of the soils.

questions?

Thanks you!