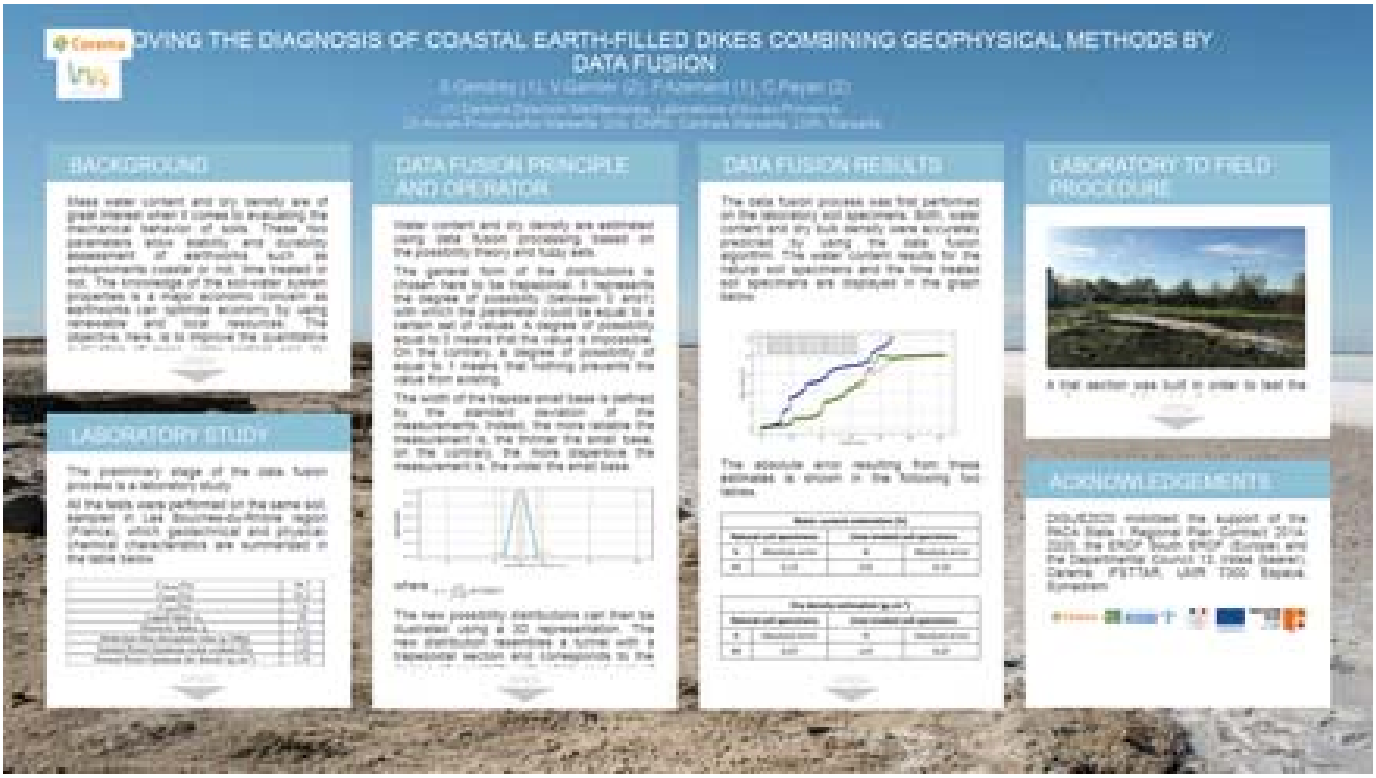
IMPROVING THE DIAGNOSIS OF COASTAL EARTH-FILLED DIKES COMBINING GEOPHYSICAL METHODS BY DATA FUSION



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PRESENTED AT:

BACKGROUND

Mass water content and dry density are of great interest when it comes to evaluating the mechanical behavior of soils. These two parameters allow stability and durability assessment of earthworks such as embankments coastal or not, lime treated or not. The knowledge of the soil-water system properties is a major economic concern as earthworks can optimize economy by using renewable and local resources. The objective, here, is to improve the quantitative evaluation of mass water content and dry density using the combination of non-destructive techniques: electrical resistivity, radar and ultrasonic testing.

Furthermore, this study aims to simultaneously estimate water content and dry density. These estimations are obtained from data fusion processing based on one possibility theory and fuzzy sets.

The performance of the proposed approach was investigated at three different scales:

1. A set of earth samples were produced in laboratory conditions by varying two physical states (or indicators): water content and dry bulk density at the optimal normal Proctor. The lime and salt contents were respectively fixed at 0 and 2%, and 30g.L-1. This parametric study established a collection of observables, which were divided into three groups: electrical (apparent resistivity), seismic (compressional and shear wave velocities), and electromagnetic (relative permittivity). Both, water content and dry bulk density were accurately predicted by using the data fusion algorithm.
2. Synthetic electrical and seismic data were produced on a 2D finite element model using commercial software. After post-processing the data, the resulting probability map makes it possible to highlight when the pair (mass water content, dry density) does not exist, and thus to highlight the potential existing pathologies.
3. In order to move from the laboratory to the field, the models will be recalibrated using a test platform. Seismic and electrical data were collected on field conditions, where defects, such as low-density areas and small voids were already present. This latter experimental campaign included information about temperature and moisture sensors.

In the scope of the CPER FEDER Digue 2020 project, the proposed method shows promise for evaluating the mechanical integrity of earth filled dikes.

LABORATORY STUDY

The preliminary stage of the data fusion process is a laboratory study.

All the tests were performed on the same soil, sampled in Les Bouches-du-Rhône region (France), which geotechnical and physical-chemical characteristics are summarized in the table below.

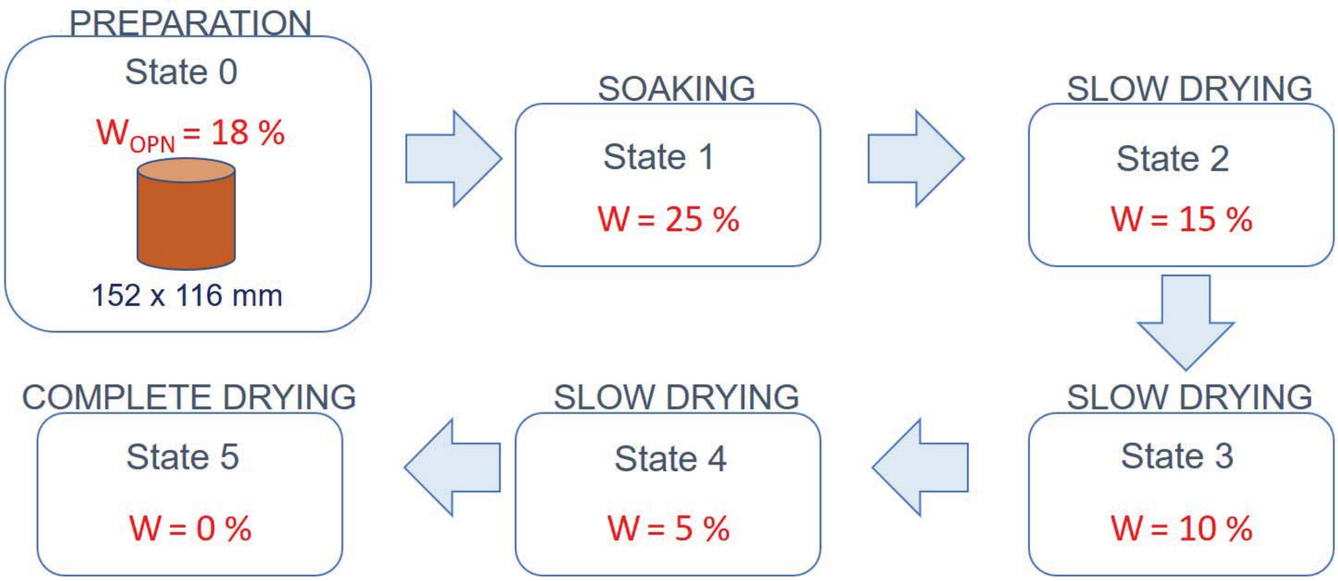
$C_{400\mu m}$ (%)	99,7
$C_{80\mu m}$ (%)	85,5
$C_{2\mu m}$ (%)	7,6
Liquid limit, w_L	30
Plasticity Index, I_p	4,3
Methylene blue absorption value (g/100g)	1,12
Normal Protor Optimum water content (%)	1,65
Normal Protor Optimum dry density ($g.cm^{-3}$)	1,74
Normal Protor Optimum quicklime treated water content (%)	1,82
Normal Protor Optimum quicklime treated dry density ($g.cm^{-3}$)	1,70
Organic matter (%)	2,3
Sulfate content (% SO3)	0,07
Chloride content (%Cl)	0,27

36 cylindrical soil specimens (152 x 116 mm) were made :

- 3 sets of 7 lime treated soil samples
- 3 sets of 5 natural soil samples

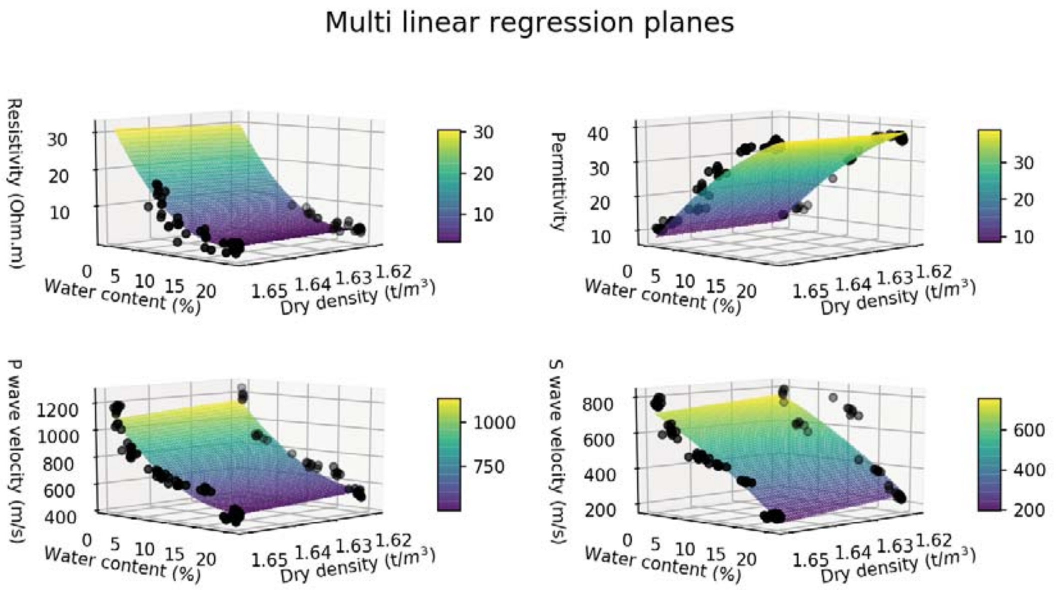
	Lime treated soil samples	Natural soil samples
	Dry density ($g.cm^{-3}$)	
LOT 1	1,62	1,57
LOT 2	1,65	1,67
LOT 3	1,65	1,72

Once the specimens were produced, they were they soaked into synthetic seawater. Each specimen was slowly oven-dried and measurements were made on each set of different dry density with water content ranging from 25% to 0%.

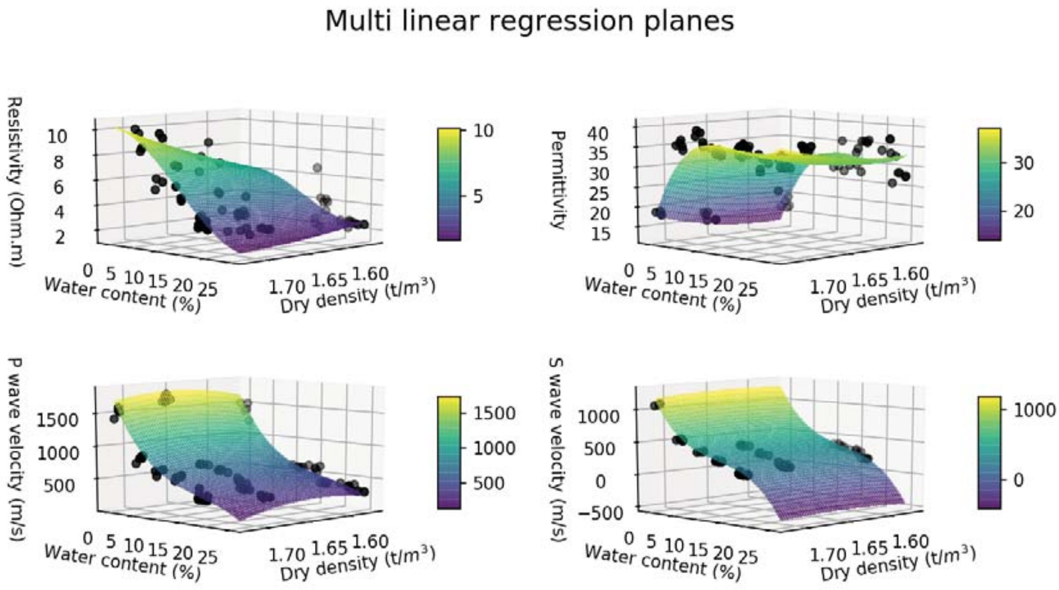


Electrical (apparent resistivity), seismic (compressional and shear wave velocities), and electromagnetic (relative permittivity) measurements were performed at each state. The results are then represented in the form of cubic regression planes for each case :

1. the lime treated soil :



2. the natural soil :

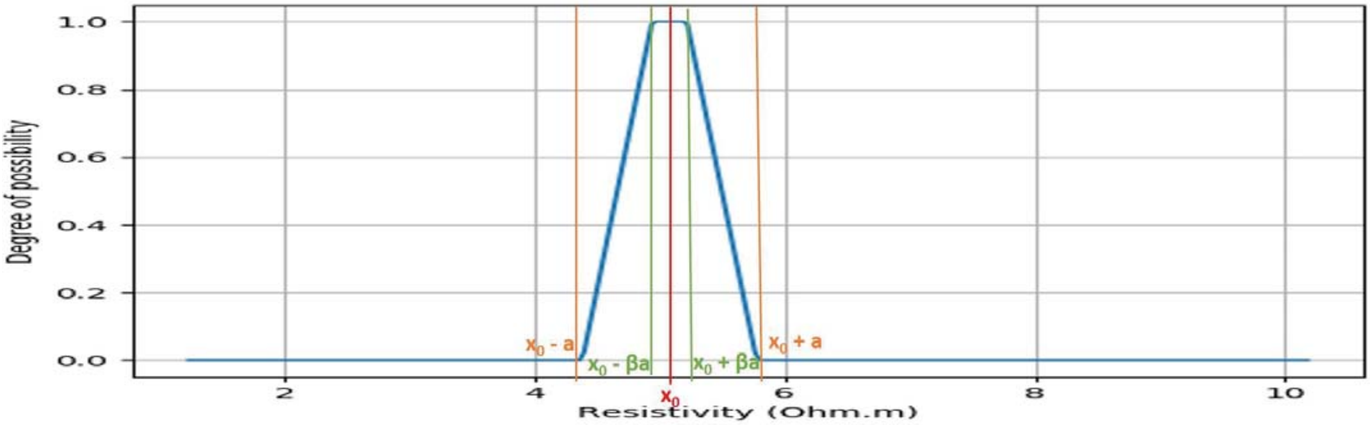


DATA FUSION PRINCIPLE AND OPERATOR

Water content and dry density are estimated using data fusion processing based on the possibility theory and fuzzy sets.

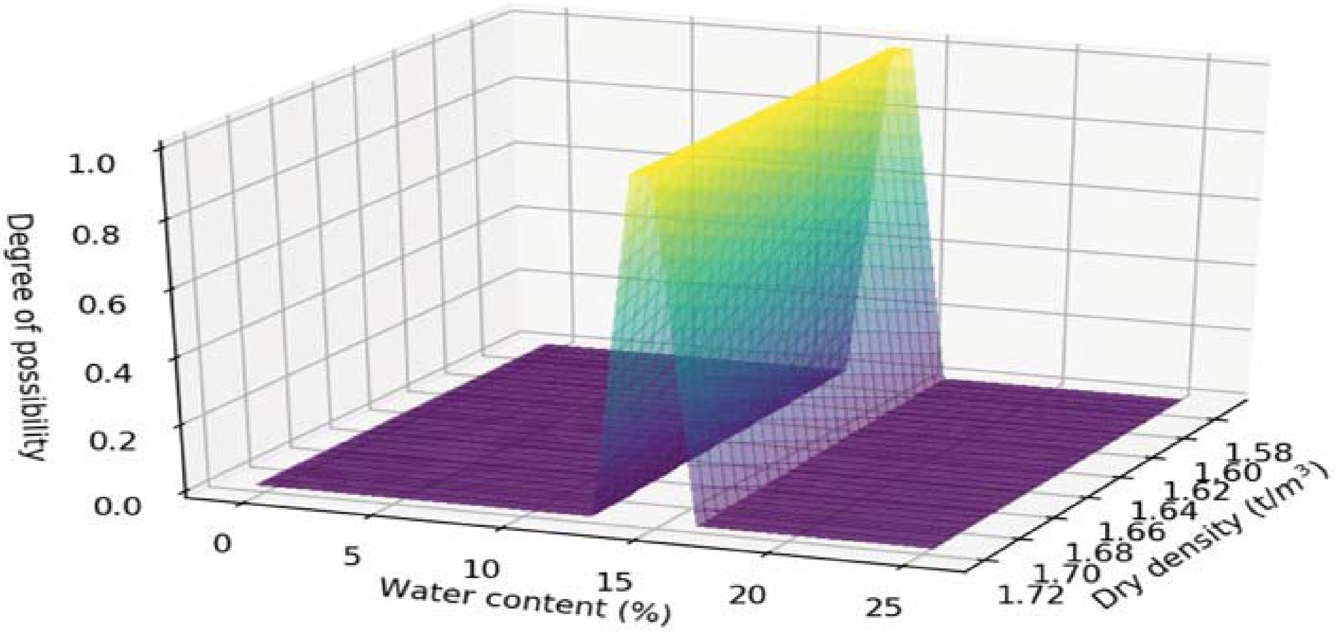
The general form of the distributions is chosen here to be trapezoidal. It represents the degree of possibility (between 0 and1) with which the parameter could be equal to a certain set of values. A degree of possibility equal to 0 means that the value is impossible. On the contrary, a degree of possibility of equal to 1 means that nothing prevents the value from existing.

The width of the trapeze small base is defined by the standard deviation of the measurements. Indeed, the more reliable the measurement is, the thinner the small base, on the contrary, the more dispersive the measurement is, the wider the small base.



where $a = \frac{\sigma\sqrt{6}}{\sqrt{1+\beta^2}}$ et $0 \leq \beta \leq 1$

The new possibility distributions can then be illustrated using a 3D representation. The new distribution resembles a tunnel with a trapezoidal section and corresponds to the degree of possibility with which each pair of water content and dry density values could be true.



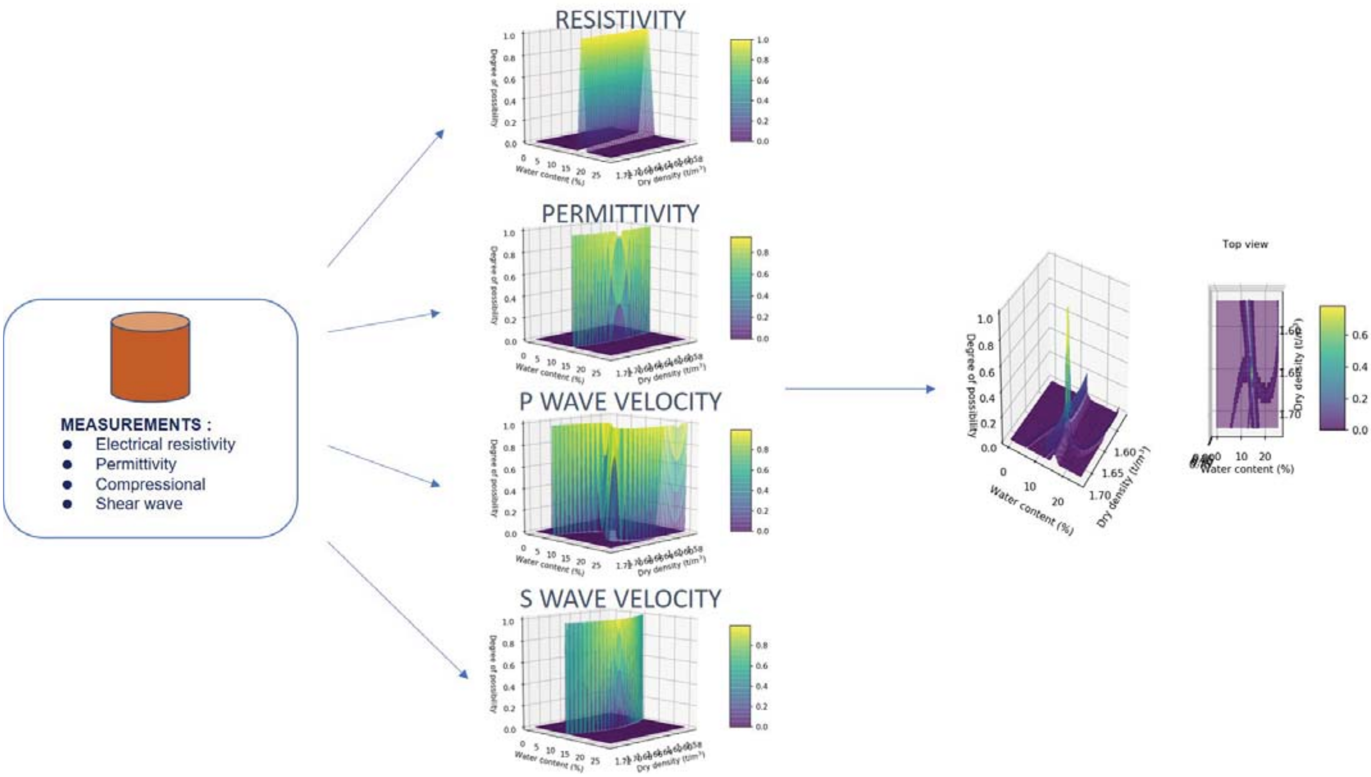
The data fusion operator was chosen because it's an adaptative operator. It adapts its behavior (disjunctive or conjunctive) according to the level of conflict or the reliability of the sources.

$$\pi_0(\rho d_{OPN}, w) = (1-\alpha^2) max_i\left(t_i \pi_i(\rho d_{OPN}, w)\right) + \alpha^2 min\left[min_i(1 - t_i + t_i \pi_i(\rho d_{OPN}, w), max_i(\pi_i(\rho d_{OPN}, w))\right]$$

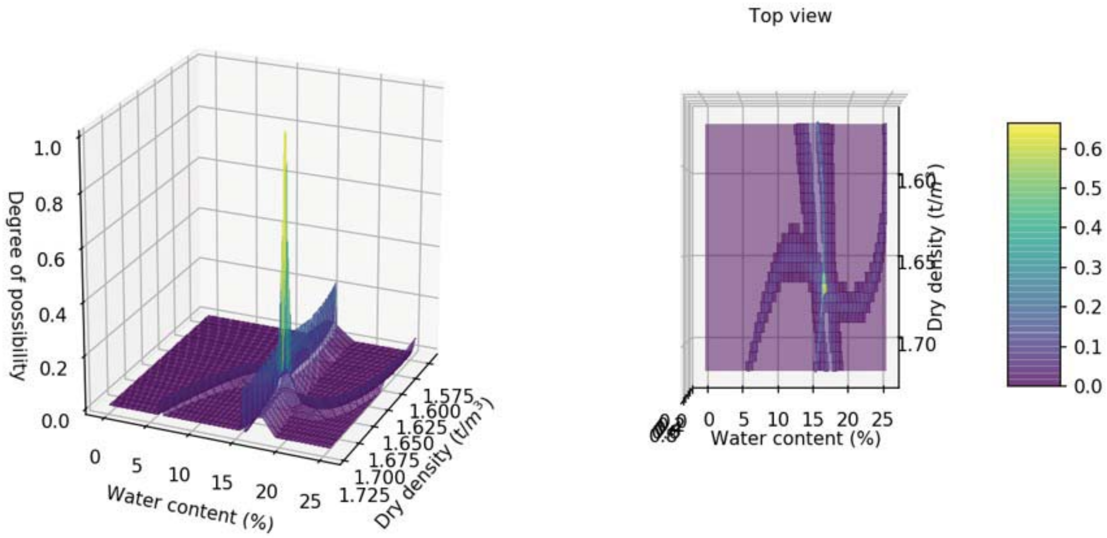
where π0 represents the possibility distribution provided by
the ith source, in terms of the water content and dry density,ti is the ith source's global reliability and $\alpha = \frac{1}{n}\sum_{i=1}^{n} t_i$ is the average reliability overall of thesources.

In fact, its definition implies that its predominant behavior will be disjunctive (‘‘max’’) if only a few sources are reliable, and on the contrary, conjunctive (‘‘min’’), if most of the sources are reliable.

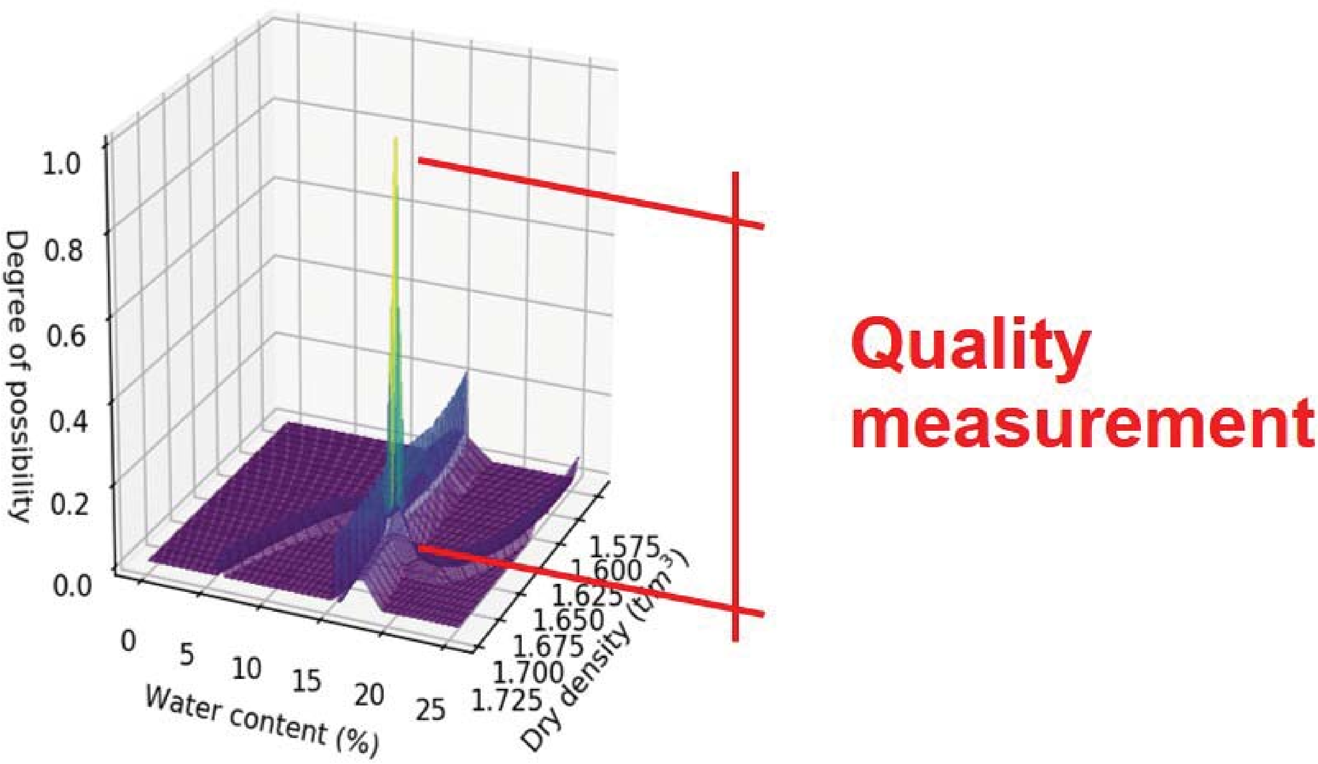
Since the chosen operator adapts its behavior according to the global reliabilities of the sources, this global reliability needs to be defined. The reliability corresponds to the general ability of the source to evaluate unknown parameters and is directly related to a quality index obtained from the statistical analysis of the measurement campaign.



Data fusion

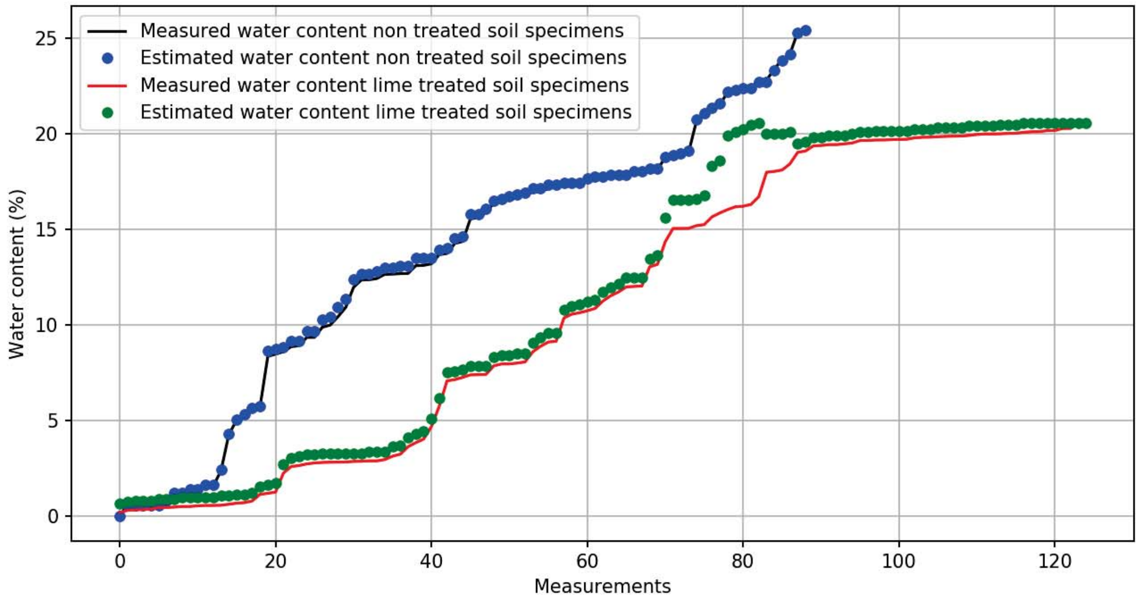


The solution from the possibility distribution resulting from a combination, in terms of the indicators is the values of the indicators for which the degree of possibility of the distribution reaches a maximum.


1.0
0.8
0.6
0.4
0.2
0.0
Degree of possibility
0
5
10
15
20
25
Water content (%)
1.575
1.600
1.625
1.650
1.675
1.700
1.725
Dry density (t/m³)
Quality
measurement

DATA FUSION RESULTS

The data fusion process was first performed on the laboratory soil specimens. Both, water content and dry bulk density were accurately predicted by using the data fusion algorithm. The water content results for the natural soil specimens and the lime treated soil specimens are displayed in the graph below.

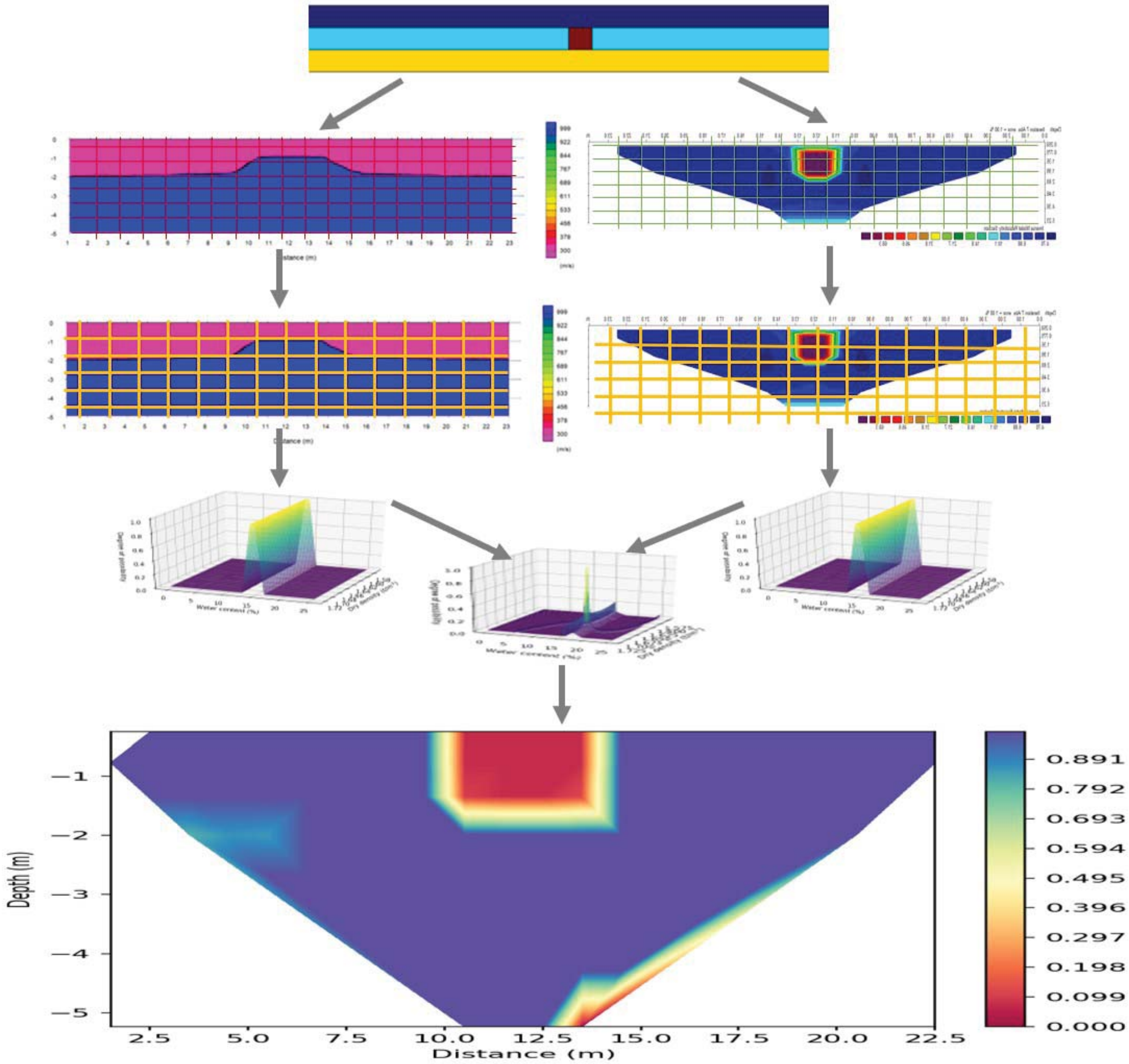


The absolute error resulting from these estimates is shown in the following two tables.

Water content estimation (%)			
Natural soil specimens		Lime treated soil specimens	
N	Absolute error	N	Absolute error
89	0,15	125	0,19

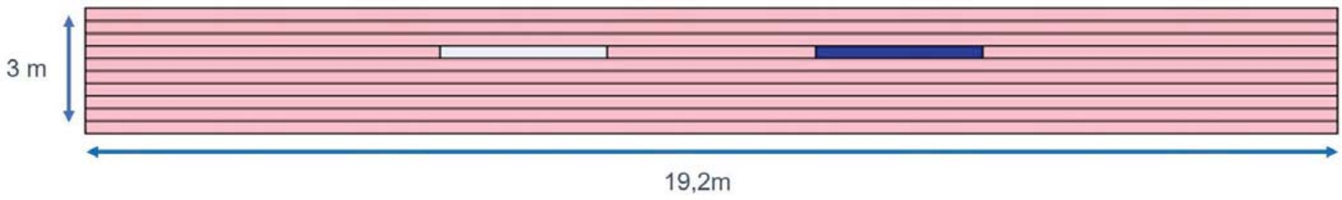
Dry density estimation ($g.cm^{-3}$)			
Natural soil specimens		Lime treated soil specimens	
N	Absolute error	N	Absolute error
89	0,07	125	0,07

This study aims at improving the diagnosis and extends the capability of such geophysical characterization by combining the physical observables issued from any of these three techniques (aka data fusion). The performance of the proposed approach was investigated on synthetic electrical and seismic data that were produced on a 2D finite element model using commercial software. After post-processing the data, the resulting probability map highlight when the pair (mass water content, dry density) does not exist, and thus to highlight the potential existing pathologies.

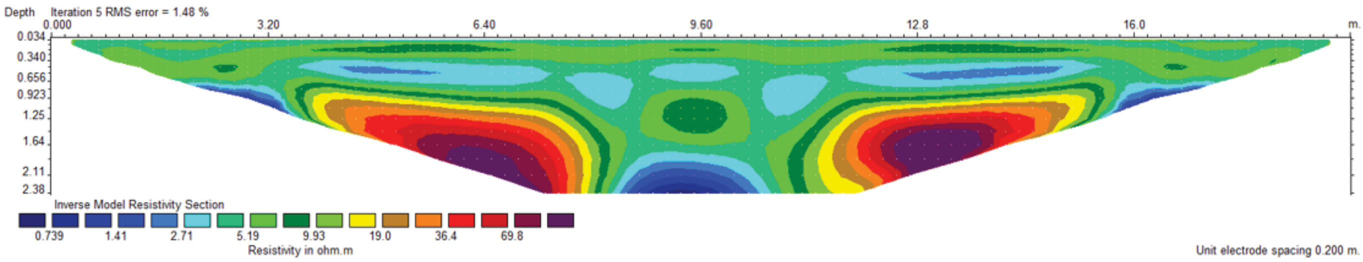


Synthetic data :

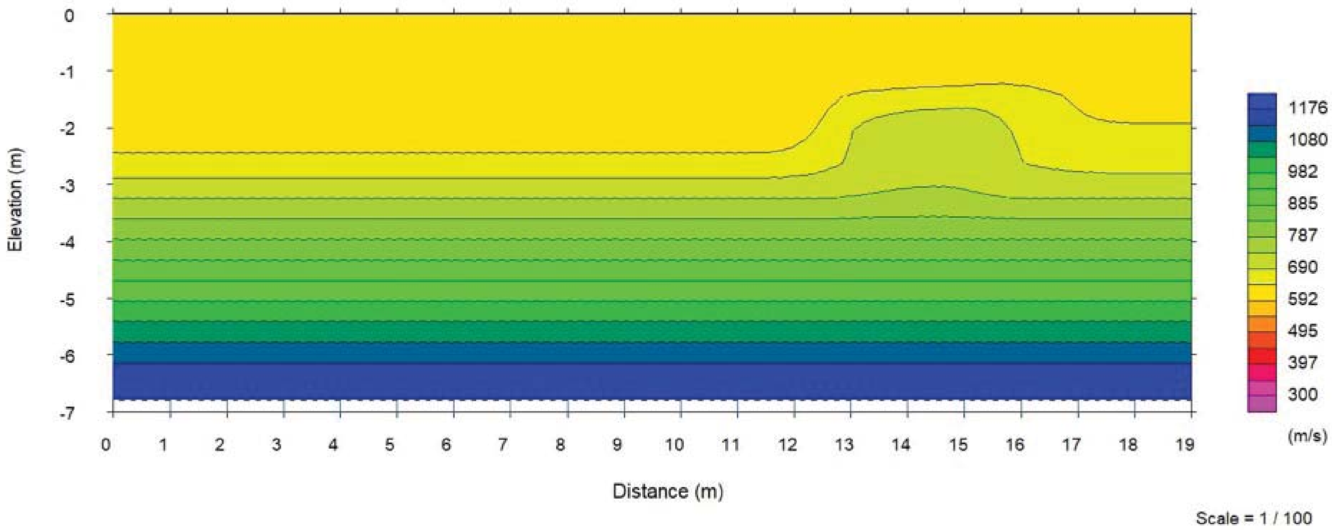
- 96 probes
- dx = 0,2 m
- L = 19,2m
- 10 layers
- 2 defects :
  - void (burrow)
  - plastic (pipe)



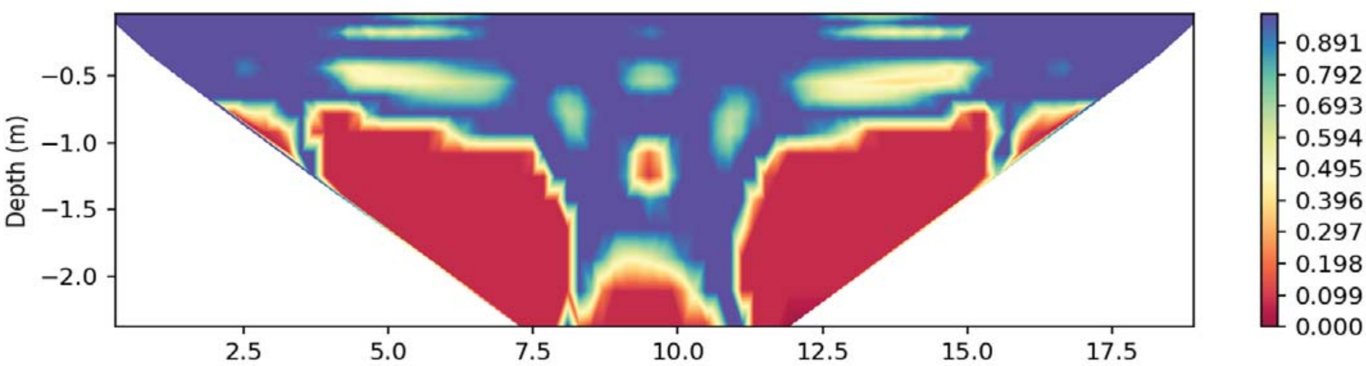
Resistivity model :



Velocity model :



Probability map for the pair mass water (25,4 %) content-dry density (1,72 g.cm^{-3}) :

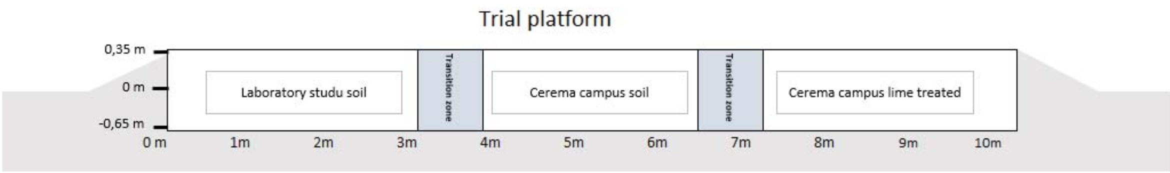


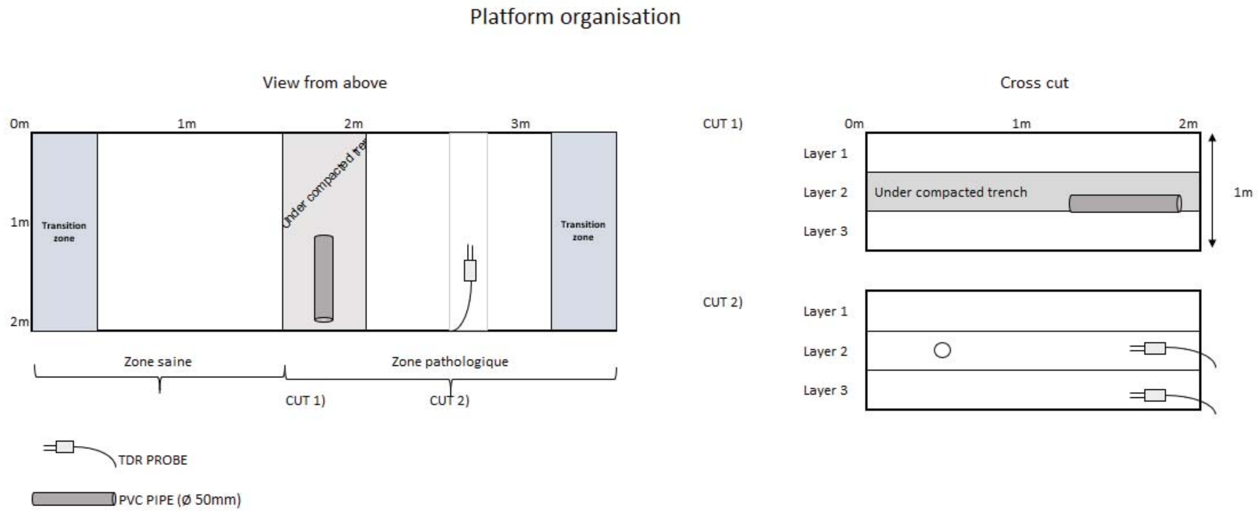
LABORATORY TO FIELD PROCEDURE

A trial section was built in order to test the performance of the data fusion process on-field results and also aims to recalibrate the models established in the laboratory.

The platform consists of 3 different sections:

1. One was made of the lime treated soil used in the laboratory study
2. One was made of the soil of the excavation of the pit in which the platform was built.
3. The last was made of the lime treated excavation soil.





The recalibration will be done by taking samples out of the first section of the platform. Using these samples, we will be able to establish the scale factor between laboratory measurements and field measurements. And thus test the model on real data.

ACKNOWLEDGEMENTS

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Sorry but time is up!

ABSTRACT

With 40% of the world population living on coasts and with climate changes extreme weather to be more frequent, the durability assessment of dikes is major concern, since structural failure might entail environmental catastrophes and human losses.
The diagnosis of coastal earth-filled dike (CEFD) using geophysical methods like seismic methods, ground-penetrating (GPR), and electrical resistivity tomography (ERT), are commonly used to detect and locate pipeline networks or defects, such as large voids. However, small-sized voids or low-density areas, which might eventually be filled by water, are usually undetected when using a single geophysical method. This study aims at improving the diagnosis and extend the capability of such geophysical characterization by combining the physical observables issued from any of these three techniques (aka data fusion). The performance of the proposed approach was investigated on three scenarios.
First, a set of earth samples were produced in laboratory conditions by varying two physical states (or indicators): water content and dry bulk density at the optimal normal Proctor. The lime and salt contents were respectively fixed at 0 and 2%, and 30g.L-1. This parametric study established a collection of observables, which were divided in three groups: electrical (apparent resistivity), seismic (compressional and shear wave velocities), and electromagnetic (relative permittivity). Both, water content and dry bulk density were accurately predicted by using the data fusion algorithm.
Second, synthetic electrical and seismic data were produced on a 2D finite element model using a commercial software. After post-processing the data, the resulting density map matches that set on the numerical model.
And finally, third, seismic and electrical data was collected on field conditions, where defects, such as low-density areas and small voids were already present. This latter experimental campaign included information of temperature and moisture sensors. In the scope of the CPER FEDER Digue 2020 project, the proposed method shows promise for evaluating the mechanical integrity of CEFD.

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SWITCH TEMPLATE