Ground Penetrating Radar in Archaeology
COST Action TU1208
"Civil Engineering Applications of Ground Penetrating Radar"

Use of GPR for monitoring and assessment of material properties in archaeological surveys

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The mission of Archaeology

“[..] Driven by a huge desire to see the world, I have consecrated and devoted all of myself, both to complete the investigation of what has long been the main object of my interest, i.e. to find the vestiges of antiquity all over the world , both to be able to entrust into writings those vestiges falling into disrepair for the long work of time ravages, because of human indifference [..]”

Ciriaco d’Ancona, 1391-1453/55

- *To find “the past”* → *Detection/Assessment*
- *To protect the “discovered past” from the threat of the “present”* → *Monitoring*

The threats (Natural factors)

Natural disasters (earthquakes, volcanism, hydro-geological events)

Coastal-erosive events

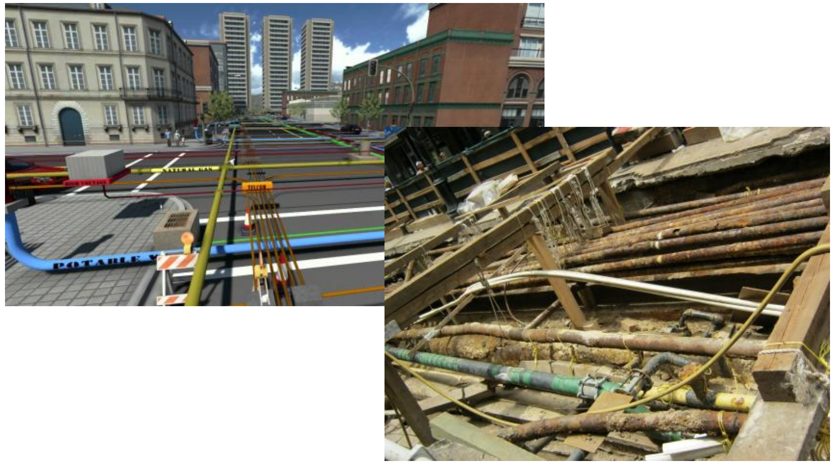
Water erosion

Climatic factors

Biological factors

The threats (Anthropic factors)

Complex environments



Genova, Italy

Pollution (air, water)

Medieval Castle

Glasgow, UK

The main challenge is to go a step forward..

Ancient Age	Middle Age	New Age
		?
Destructive archaeology	Minor-destructive archaeology	....

The main challenge is to go a step forward..

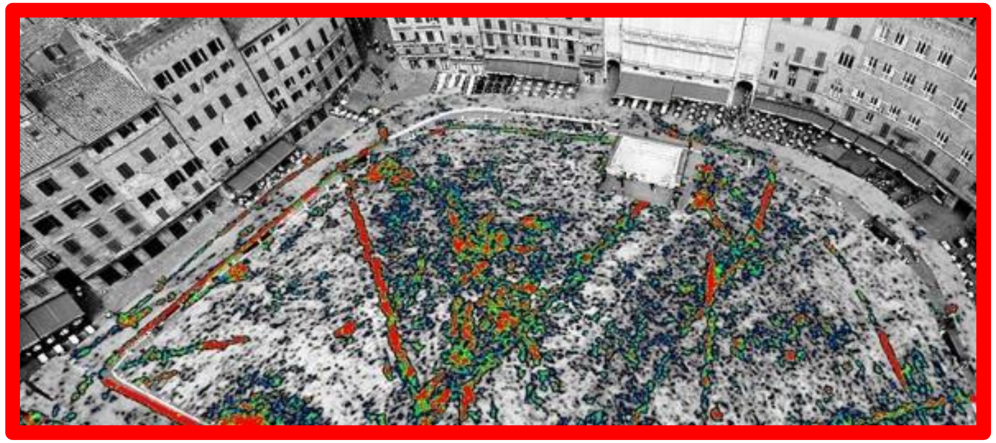
Ancient Age

Destructive archaeology

Middle Age

Minor-destructive archaeology

New Age



Non-destructive archaeology

..tackling the challenge!

Ground Penetrating Radar in archaeology

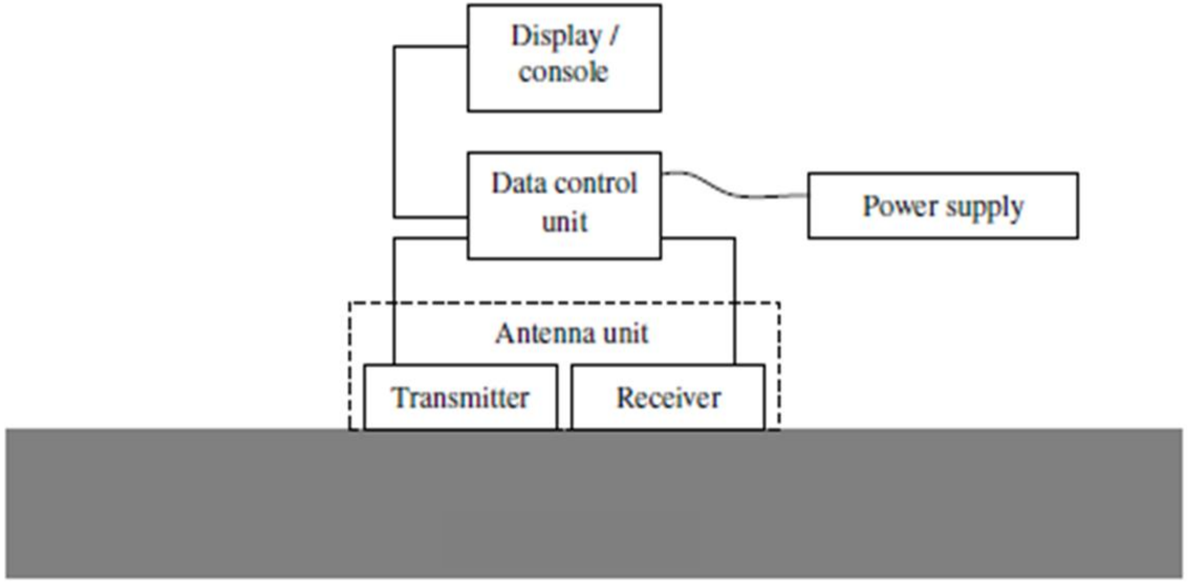
- non-destructive
- low cost
- easy to handle and rapid
- significant
- reliable

… but several issues …

- what can be expected? What can be done?
- how to extract practical information from GPR surveys?

How does GPR work?

Basics of the system



Key parameters

GPR characteristics (frequency, transmitted power)

Target characteristics (shape, EM properties)

Host material characteristics (EM properties)

Key parameters

√ √

GPR characteristics (frequency, transmitted power)

? ?

Target characteristics (shape, EM properties)

?

Host material characteristics, usually soil (EM properties)

→ *EM properties of materials are crucial for effective and reliable target detection!*

Two EM properties of importance for GPR

Electrical conductivity σ (inverse of resistivity)

- *σ is a measure of a material’s ability to carry an electric current*
- *The value is primarily controlled by water content and/or clay content*
- *Higher conductivity makes radar signal penetration difficult*

Relative dielectric permittivity ε (Dielectric constant)

- *Measures the capacity of a material to store charge when an electric field is applied*
- *The value ranges from 1 to 81 (1 = air, 81 = water); the value (for soils) is mainly controlled by water content*
- *Differences in dielectric properties between two adjacent materials through which the radar wave propagates will cause reflection of some of the radar energy back to the surface*
- *The strength of reflections is controlled by the contrast in the dielectric constants of the two adjacent materials.*

Investigation of soil EM properties (variable physical conditions)

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Investigation of material EM properties - *Roma Tre University, Italy (2010 – 2011)*

Survey protocols

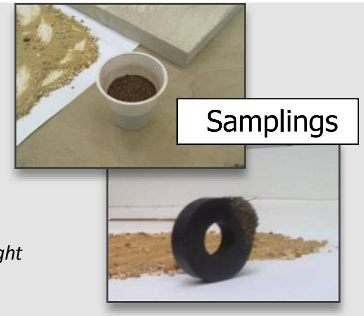
- *Mixing protocol*

Total

Comparison

% $_{Total\ weight}$ vs % $_{Sampled\ weight}$

Samplings



Definition of the minimum content of clay to ensure the homogeneity of the mixture

- *Compaction protocol*

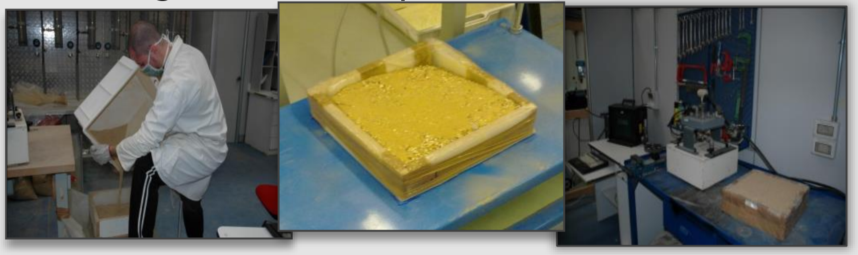
Proctor Test

Comparison $\gamma_d = \frac{m_d}{V}$

Vibrating table

Definition of the vibration time of soil samples when using a vibrating table

- *Radar signal detection protocol*



Impact analysis of relevant factors on signal noise

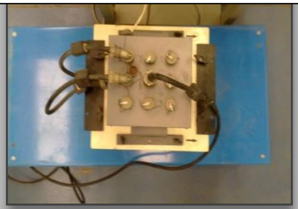
Clay content - Lab

Investigation of material EM properties - *Roma Tre University, Italy (2010 – 2011)*

Clay content - Lab

➢ *GPR device*

GPR TX/RX 600-1600 MHz



➢ *Main equipment*

Test box

Mixer

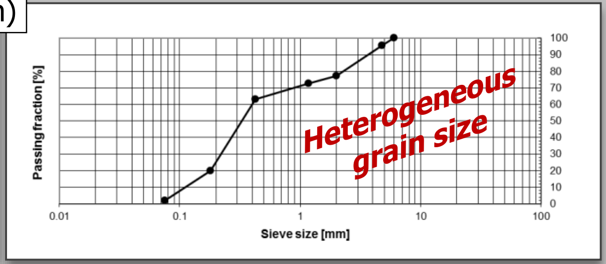
Vibrating table

Atterberg limits

➢ *Soil material*

M. Magliana (0-5 mm)

A1 AASHTO



Clay (Montmorillonite)

<u>17 tests in dry conditions</u>

- Range of clay content surveyed (0 - 30% clay)
- Survey steps (2% clay)

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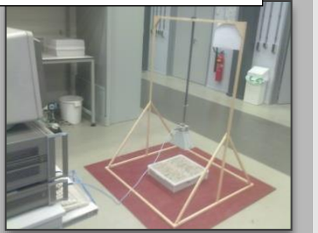
Investigation of material EM properties – *TUDelft, The Netherlands (October – November 2012)*

Clay content - Lab

➢ *GPR devices*

GPR TX/RX 500 MHz

VNA Ultra wide band



➢ *Main equipment*

Test box

Setting

Gas pycnometer

Mixer

➢ *Soil materials*

Gravel (4-8 mm)

A1 AASHTO

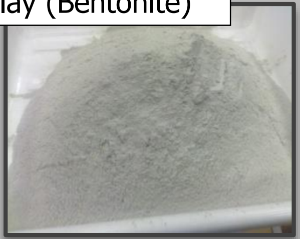
Sand (1-2 mm)

A2 AASHTO

Sand (0.125-0.250 mm)

A3 AASHTO

Clay (Bentonite)



54 tests in dry conditions

- Range of clay content surveyed (0-25% clay)
- Survey steps (2%; 5% clay)

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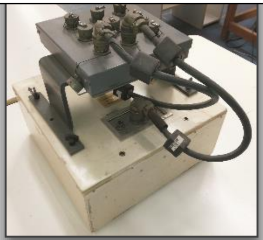
Investigation of material EM properties - *Roma Tre University, Italy (2010 – 2011)*

Water content - Lab

- *GPR device*

GPR TX/RX 600-1600 MHz



- *Main equipment*

Test box

Mixer

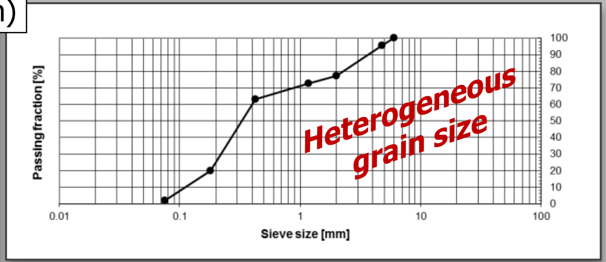
Vibrating table

Oven

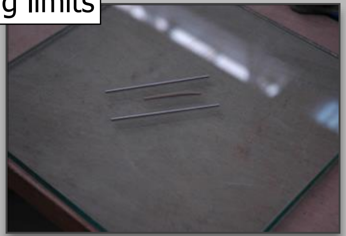
- *Soil material*

M. Magliana (0-5 mm)

A1 AASHTO



Atterberg limits



<u>*23 tests in wet conditions*</u>

- Three types of soil mixtures (5%; 10%; 15% clay)
- Survey steps (2% water)

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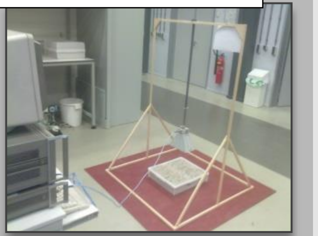
Investigation of material EM properties – *TUDelft, The Netherlands (October – November 2012)*

Water content - Lab

- *GPR devices*

GPR TX/RX 500 MHz

VNA Ultra wide band



- *Main equipment*

Test box

Setting

Gas pycnometer

Mixer

- *Soil materials*

Gravel (4-8 mm)

A1 AASHTO

Sand (1-2 mm)

A2 AASHTO

Sand (0.125-0.250 mm)

A3 AASHTO

<u>*104 tests in wet conditions*</u>

- Two mixtures per soil type surveyed (0%; 15% clay)
- Survey steps (2%; 5% water)

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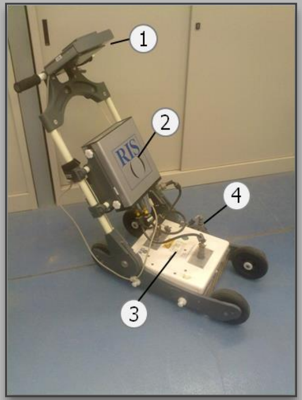
Investigation of material EM properties – *Università degli Studi di Milano, Italy (2012)*

➢ *Tools and equipment*



Georadar IDS RIS 99

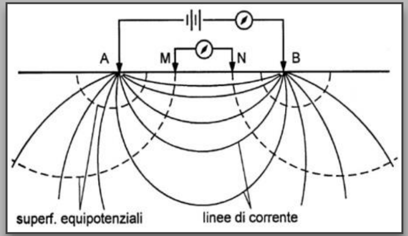
1. Signal acquisition unit
2. Signal generation unit
3. Multi-Frequency ground-coupled antennas (Tx-Rx 600-1600 MHz)
4. Wheel encoder

Capacitance probe Water Scout SM 100

- Range: 0% VWC to saturation
- Resolution: 0.1% VWC
- Sensing Area: 60 mm x 20 mm

Time Domain Reflectometer

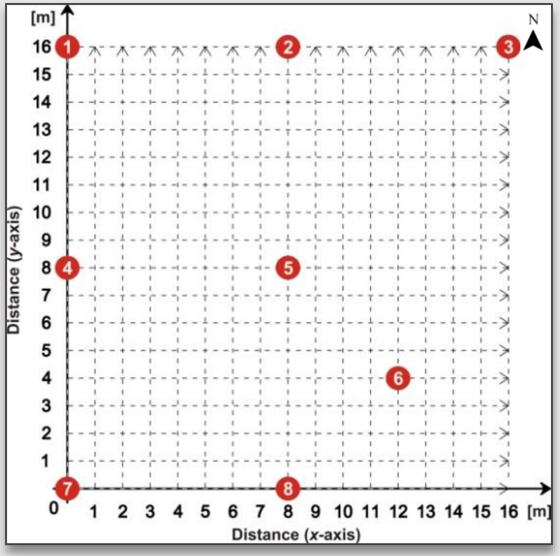
- Range span: 10 m to 3000 m
- Resolution: 1% range span



Geoelectrical tomography

- Two electrodes array

➢ *Experimental layout*



Test site 20m x 20m

(Useful area 16m x 16m)

Average elevation [m a.s.l.]: 88 m
● Capacitance probe
--- GPR acquisition

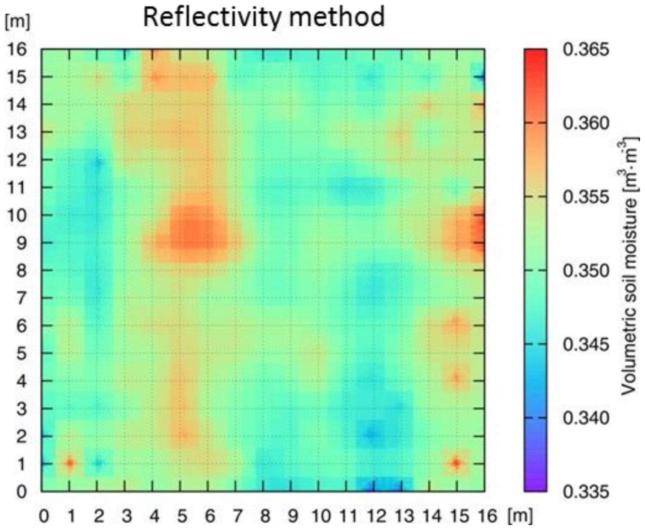
Water content – Test site

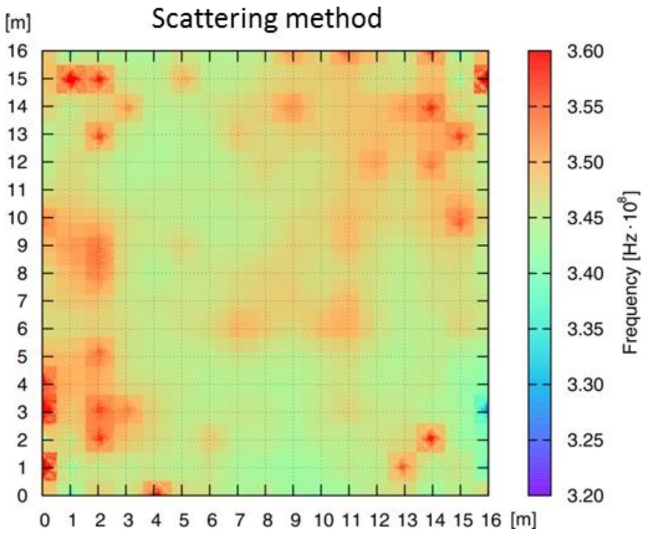
Investigation of material EM properties – *Università degli Studi di Milano, Italy (2012)*

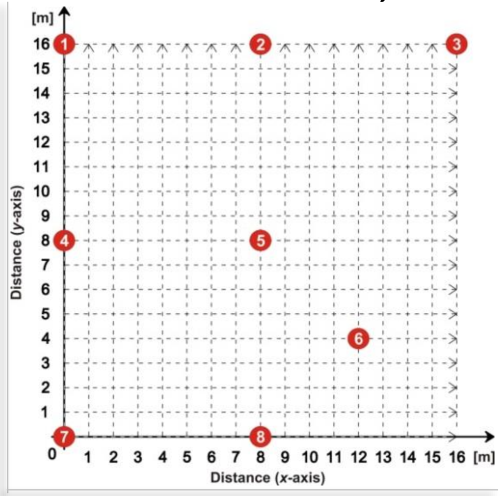
Water content – Test site

➢ Intermediate-scale VWC comparisons:

VWCs from GPR ‘reflectivity method’ *vs* VWCs spatial distribution from ‘Scattering method’







Main Statistics

- Field-average VWC:

$\theta_{f\,avg\,GPR} = 0.351\ m^3 \cdot m^{-3}$

- Field VWC standard deviation:

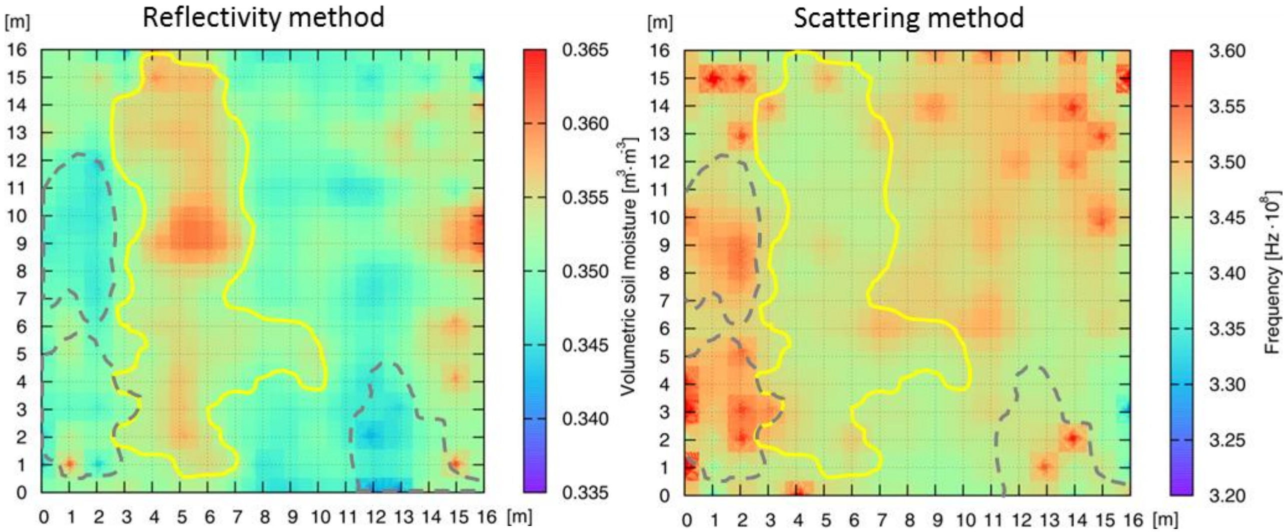
$\theta_{f\,std\,GPR} = 0.0304\ m^3 \cdot m^{-3}$

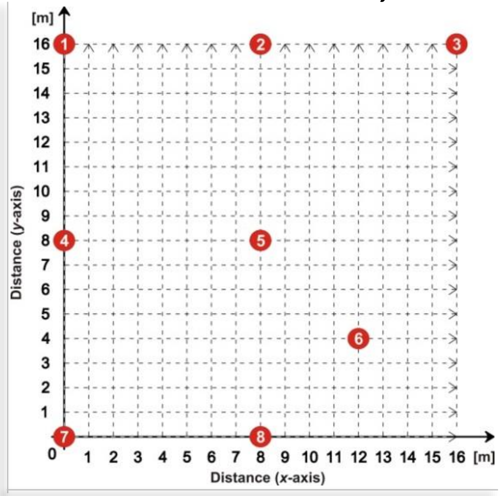
- *The comparison between the two maps shows a good agreement with the theoretical expectations*

Investigation of material EM properties – *Università degli Studi di Milano, Italy (2012)*

➢ Intermediate-scale VWC comparisons:

VWCs from GPR ‘reflectivity method’ *vs* VWCs spatial distribution from ‘Scattering method’





Main Statistics

- Field-average VWC:
$\theta_{f\ avg\ GPR} = 0.351\ m^3 \cdot m^{-3}$

- Field VWC standard deviation:
$\theta_{f\ std\ GPR} = 0.0304\ m^3 \cdot m^{-3}$

- *The comparison between the two maps shows a good agreement with the theoretical expectations*
- *In that respect, some clear matches can be found:*
  - *parallel to the y axis throughout the whole length of the area (e.g., yellow shape: high moisture contents and low frequency peaks)*
  - *in the middle-western edge and in the south-western corner of the maps*
  - *in the south-eastern corner of the figures*

(e.g., grey dashed shapes: low moisture contents and high frequency peaks)

Water content – Test site

Conclusions

- *The new challenge for archaeologists is to tend towards a non-destructive and self-consistent approach to increase target detectability and lower excavations*
- *To retrieve reliable info on the target, It is essential to have an a-priori comprehensive understanding of the EM properties of soil, under variable physical conditions*
- *Laboratory to full-scale investigations are suggested in order to achieve maximum reliability from (hosting) material characterisation*

Thank you for your time

and attention!