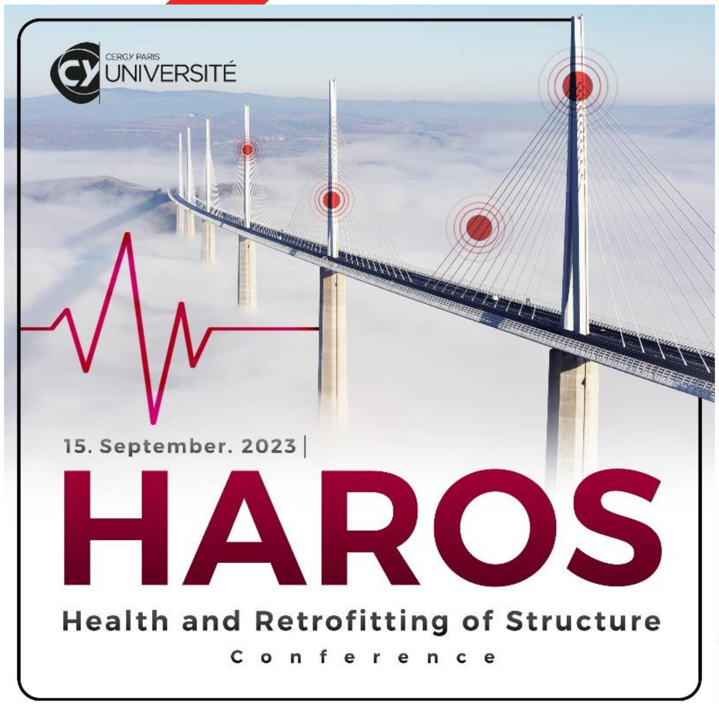

Electromagnetic and electric methods for monitoring concrete condition

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With:

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- B. Yven (Andra)
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Context

Civil Engineering Concrete Structures

Bridges

Nuclear plant confinements

Cooling Towers

Tunnels

- **Engineering needs:** calculation of residual lifespan by predictive models
- **Assessment of inputs or outputs of models**: **moisture content**, **mechanical stress**, elastic modulus, mechanical damage index, **corrosion**, etc…)

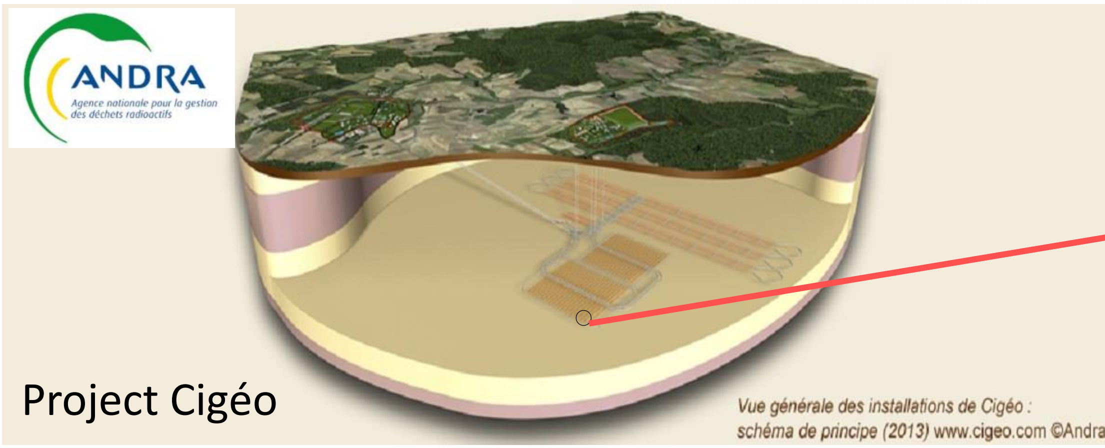
→ **SHM of properties and pathologies of concrete**

OUTLINES

- INTRODUCTION
- CONCRETE MOISTURE MONITORING
- REINFORCEMENT CORROSION MONITORING
- CONCRETE STRESS MONITORING BY EM WAVES
- CONCRETE MECHANICAL DAMAGE MONITORING WITH SELF-SENSING CONCRETE
- CONCLUSIONS/PERSPECTIVES

SHM AND MOISTURE

Moisture gradient assessment in concrete --> deep storage of radioactive wastes



- Reinforced concrete tunnels → in contact with the ground (argilite)
- Exothermic wastes → increase of temperature + tunnel ventilation → **important drying of concrete → risk of argilite drying which must be absolutely prevented**

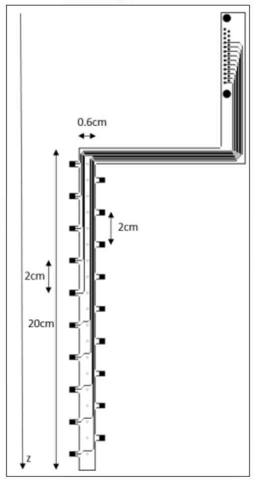
➡ **Monitoring of moisture gradient along concrete thickness by means of embedded resistivity sensors**

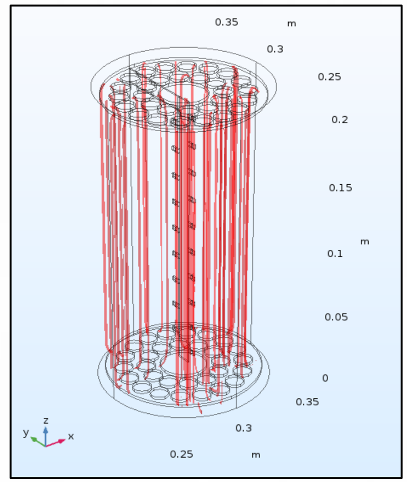
SHM and Moisture

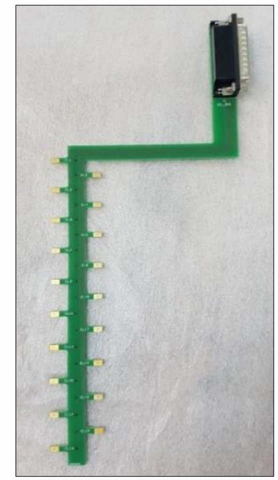
Design of embedded resistivity sensors

Sensor geometry | **Numerical experiments** | **Printed board**

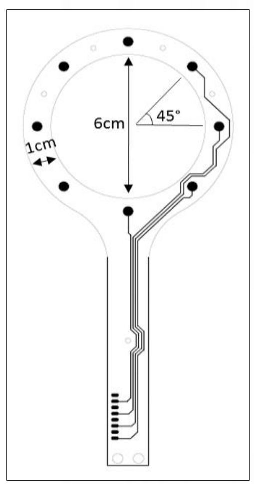
« Ladder »

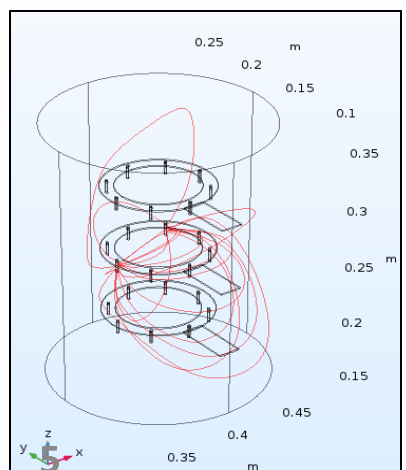






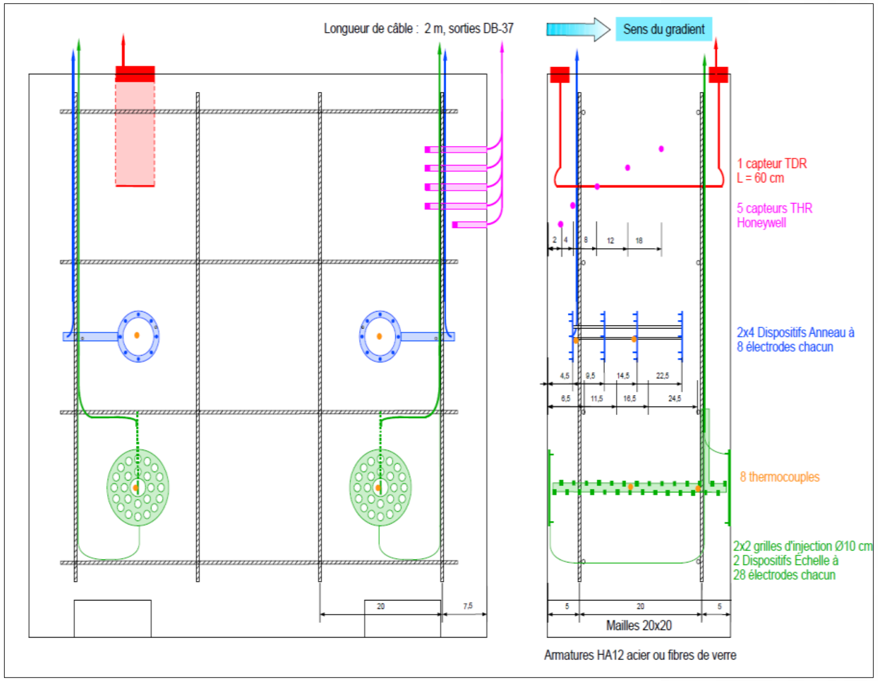
« Racket »



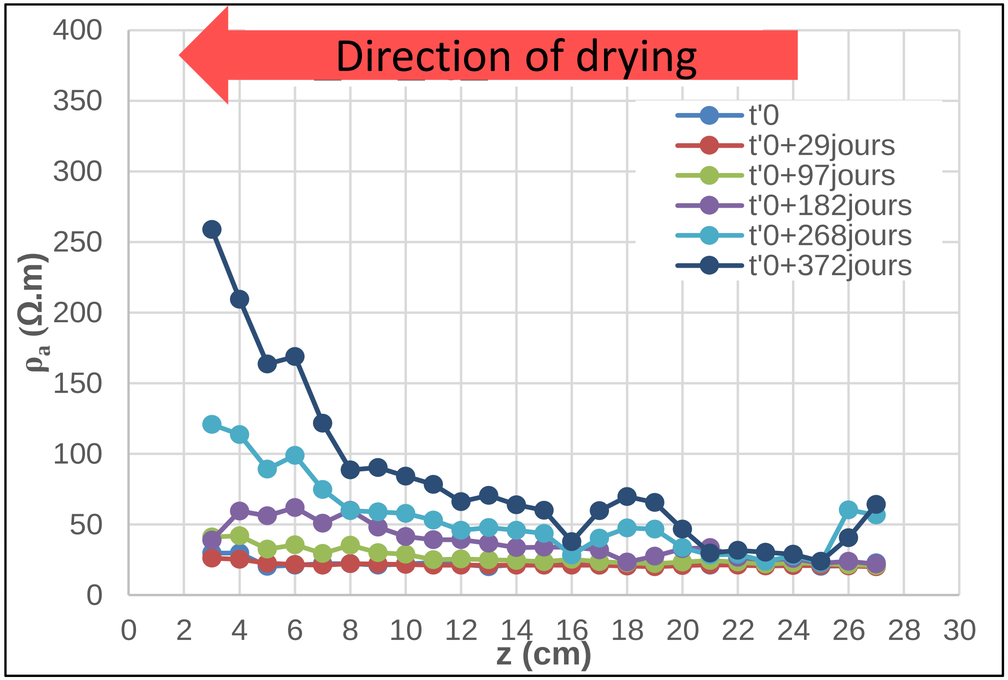


SHM AND MOISTURE

Results obtained on mockups (75cmx75cmx30cm)



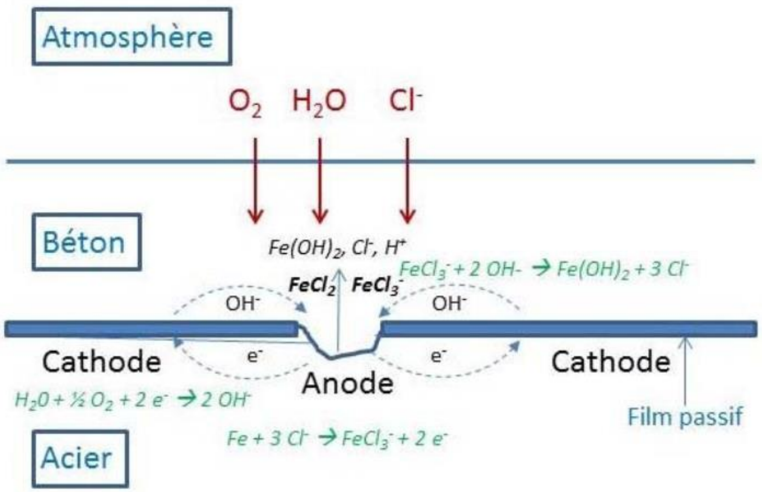
Sensors inside the mockup

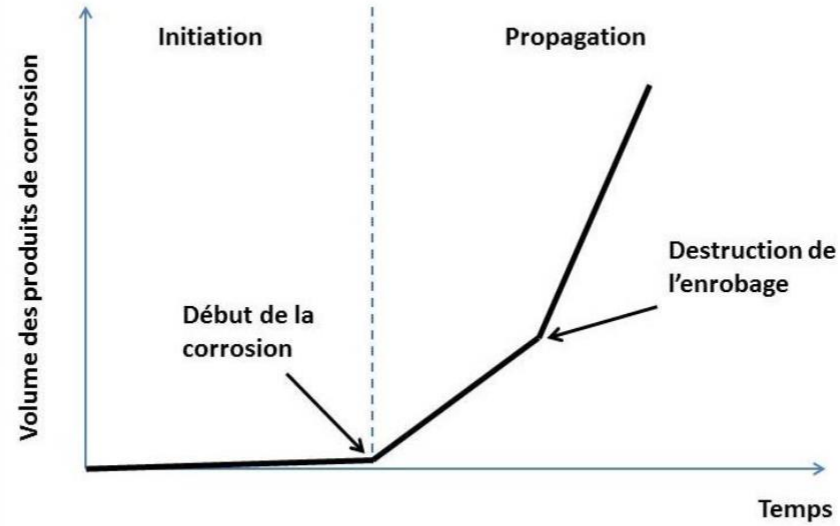


Resistivity versus thickness of concrete (Ladder sensor)

- Ladder sensor can detect the moisture gradient
- On site application planned in 2024 (ANR Scaning)

Corrosion of concrete steel reinforcement



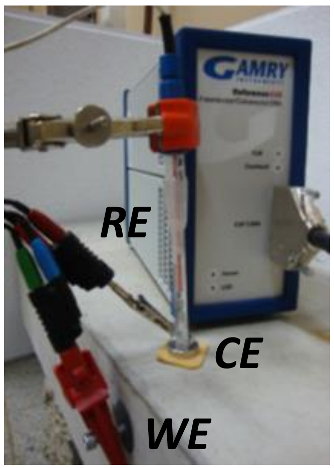


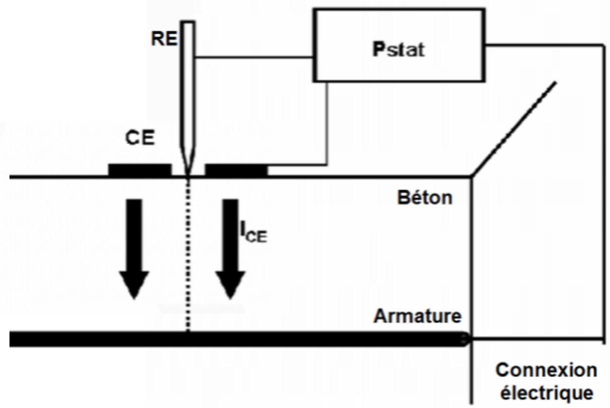
- Protection of steel by the high pH of concrete → **passivation layer**
- Due to CO_2 or/and chloride ingress through cover concrete → **destruction of passive layer**
- **Initiation and propagation of corrosion**

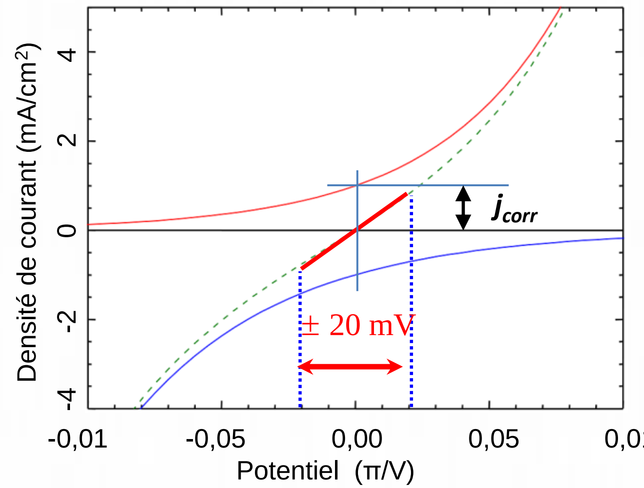
Very long process → SHM

Simplified configuration for the measurement of corrosion rate

➢ **Three-electrodes configuration for the measurement of polarisation resistance**







➢ Laboratory device → **on site application?**

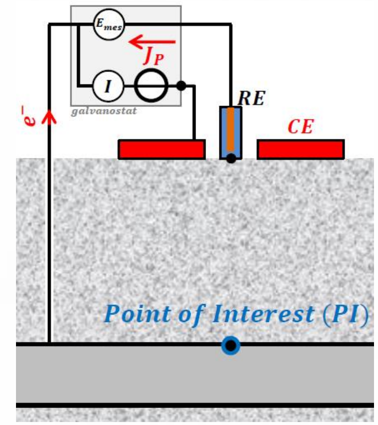
➢ Measurement processing → **engineering practice?**

SHM ET CORROSION

On site prototype of the measurement device

- Electrode and potentiostat gathered into a specific probe

Probe
« DIAMOND »



- Measurement processing via meta-models
- Driving and acquisition softwares in a portable tablet

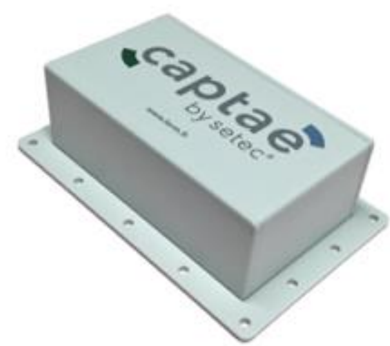
→ On site prototype used and validated by SETEC-LERM/EDF

Project FUI DIAMOND

Use of the probe for monitoring applications on cooling towers

- **CAPTAE® system designed and developed by SETEC-LERM**

Images LERM-SETEC©

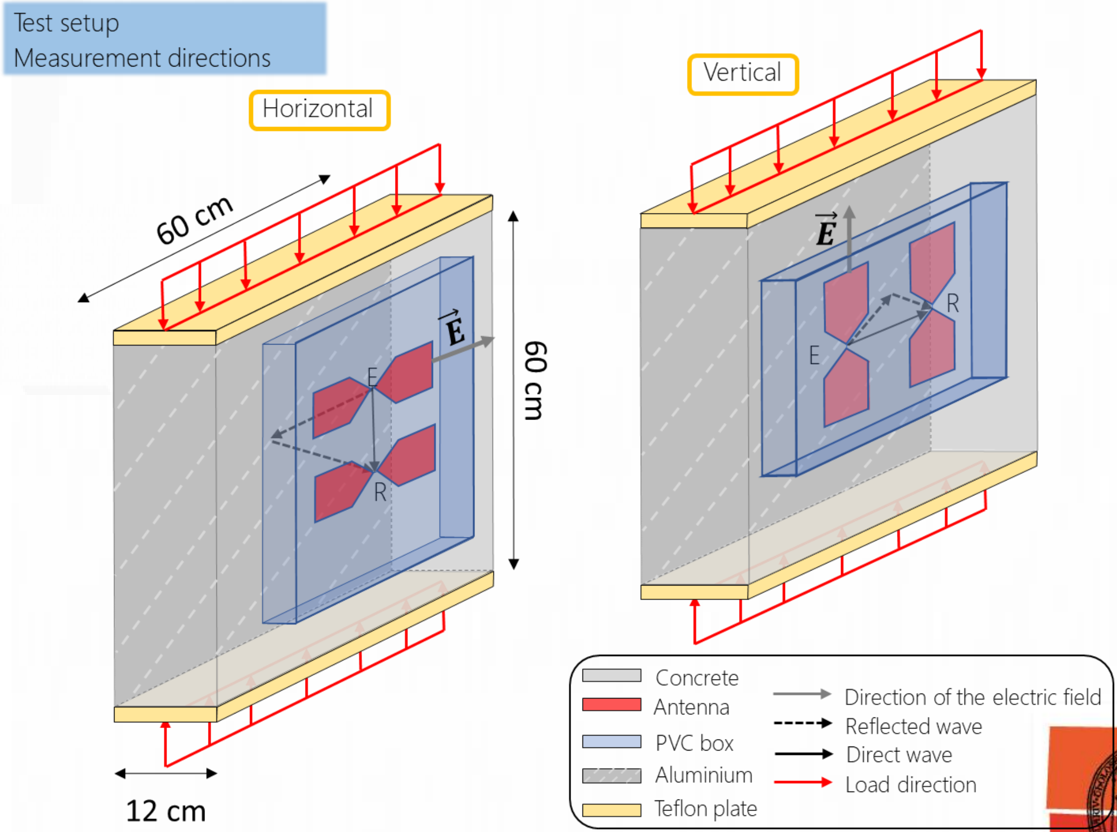


SHM AND STRESS

Concrete Stress Monitoring with electromagnetic (EM) waves

➢ **Use of Impulse and Step Frequency GPR with coupled antennas**

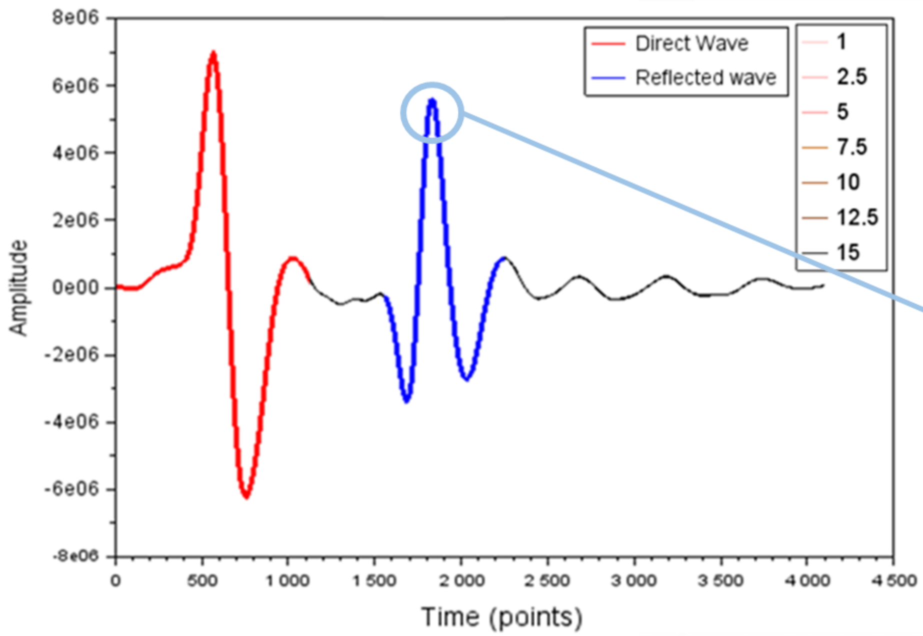
Compressive test

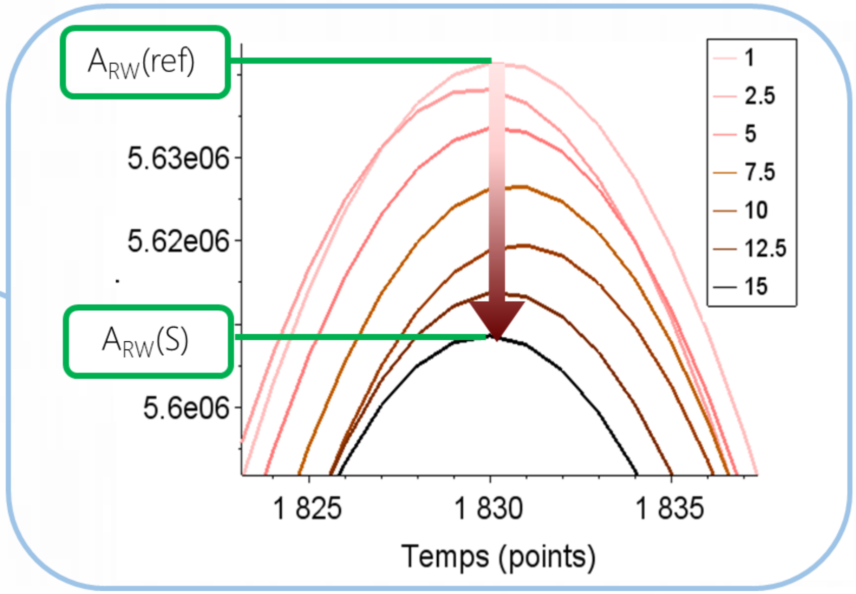


SHM AND STRESS

Concrete Stress Monitoring with electromagnetic (EM) waves

➢ **Effect of compressive stress on the amplitude of impulse GPR signals**

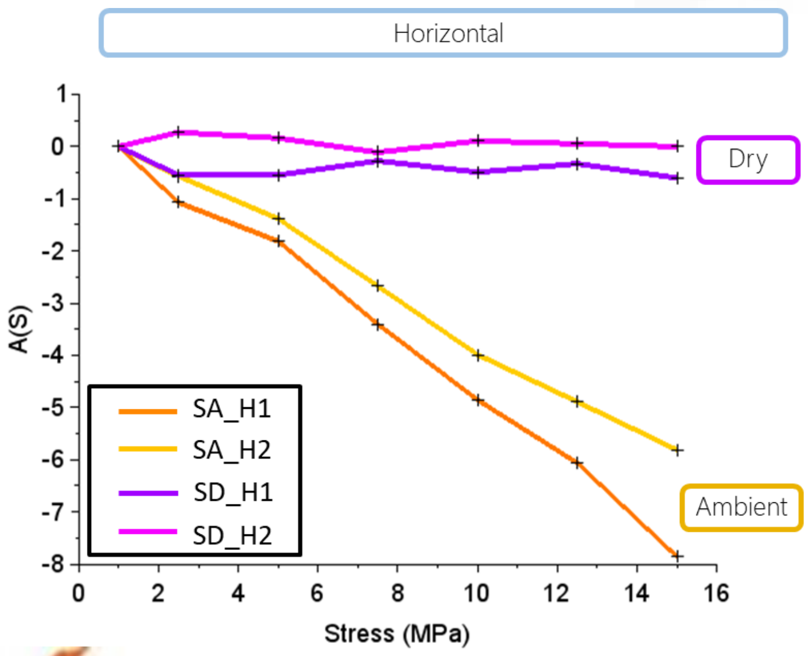


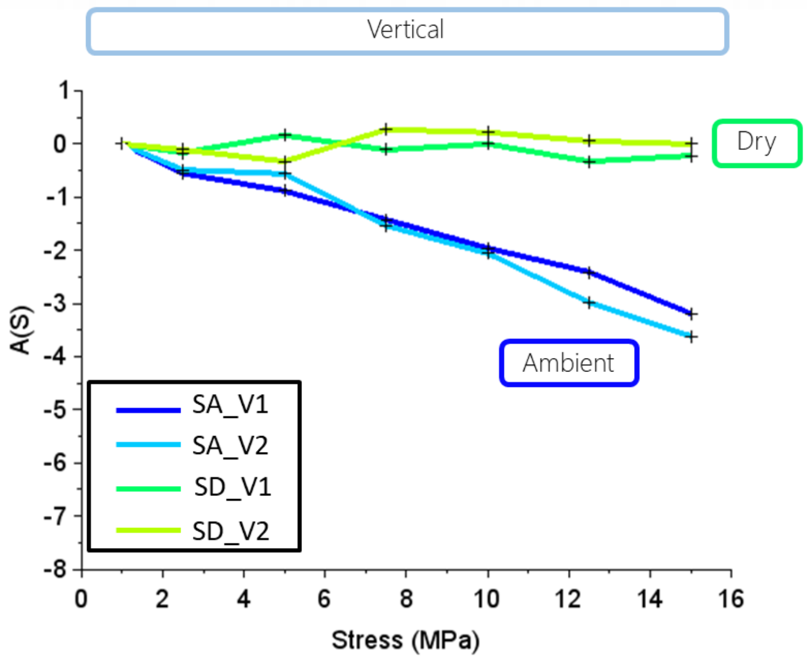


➢ The amplitude of the EM wave decreases with the increase of stress

Concrete Stress Monitoring with electromagnetic (EM) waves

➢ **Effect of antenna polarisation and moisture**





➢ The sensitivity of EM to stress is higher when the electric field is perpandicular to direction of stress

➢ The sensitivity is higher if moisture content is higher

Concrete Stress Monitoring with electromagnetic (EM) waves

- **Towards on site solution**

- Impulse GPR not adapted to SHM
- Use of step frequency GPR with Vivaldi antennas with portable VNA
- Higher resolution in particular for phase characterisation
- Lower cost

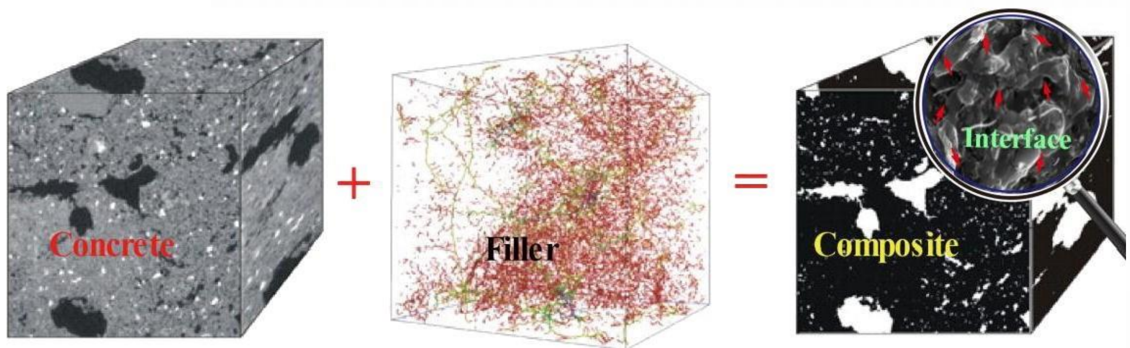
Compressive test with Vivaldi antennas

Concrete Mechanical Damage Monitoring with Self-sensing Concrete

➢ **Design of a self-sensing concrete**

Self-sensing concrete

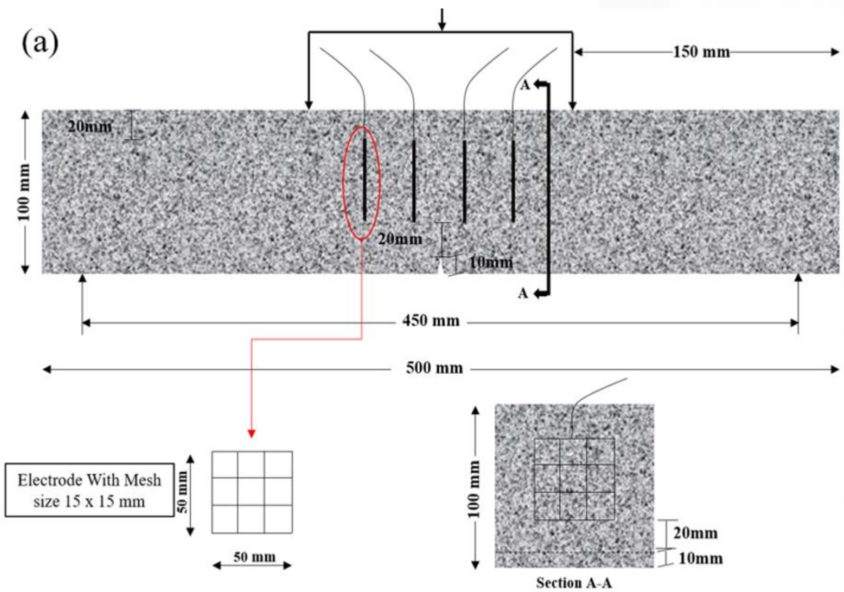
Highly conductive additions | Concrete

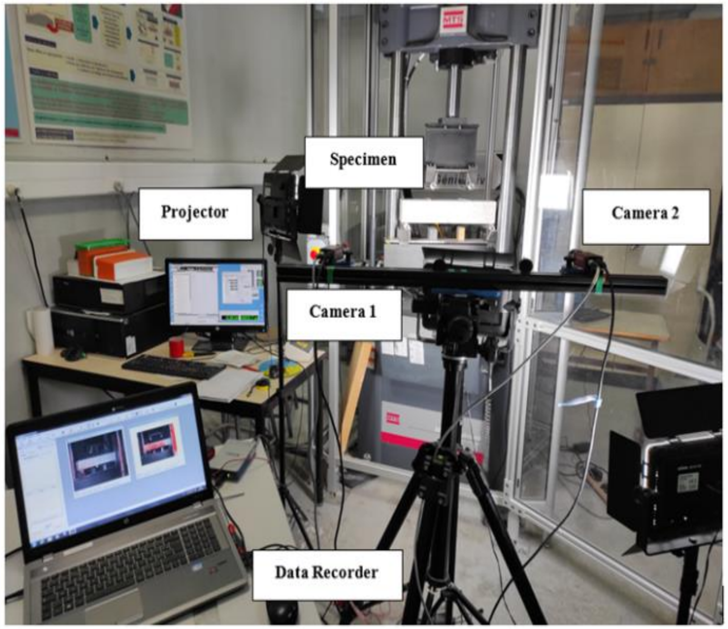


→ **Addition of carbon nanotubes**

Mechanical damage monitoring with Self-sensing concrete

➢ **Measurement principle**



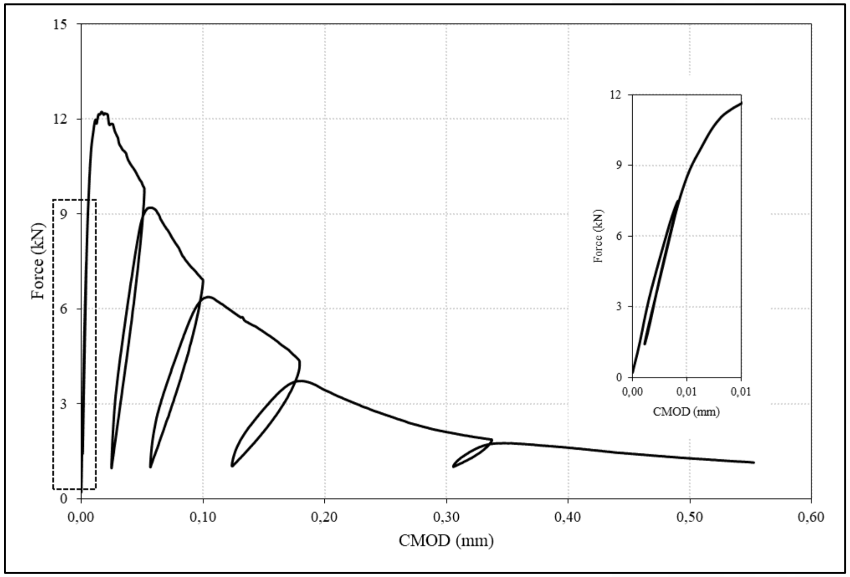


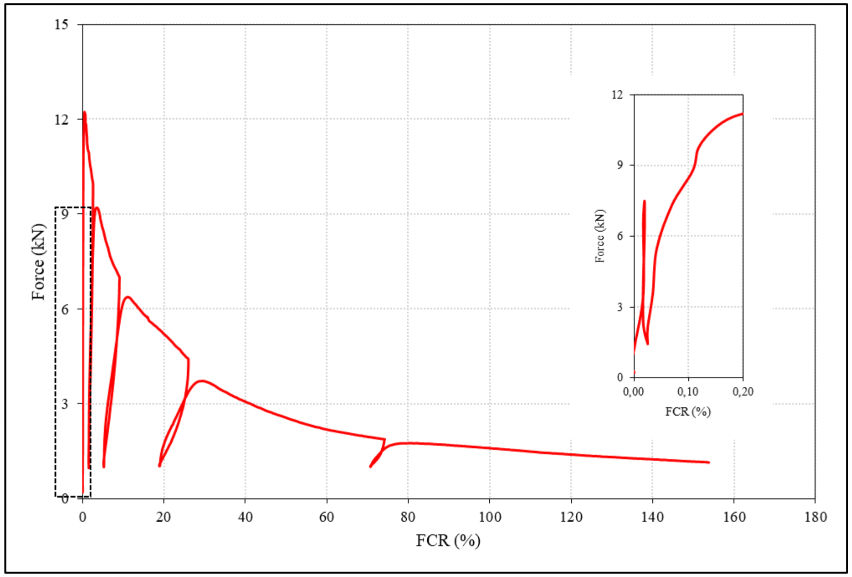
➢ Measurement of the fractional resistivity change (FCR) with embedded electrodes under four point bending test

SHM AND DAMAGE

Mechanical damage monitoring with Self-sensing concrete

➤ **Results**

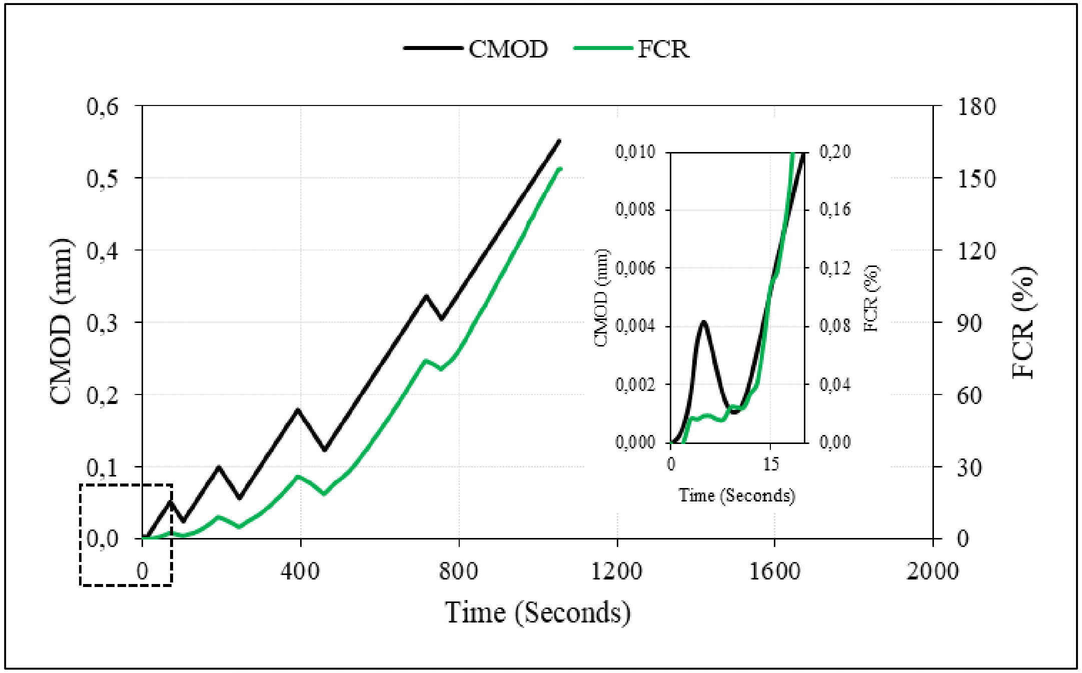




➤ FCR is able to reproduce the mechanical behaviour of the beam

Mechanical damage monitoring with Self-sensing concrete

- **Results**



- FCR is well correlated to crack opening (CMOD)

CONCLUSIONS
PERSPECTIVES

Monitoring of concrete condition is relevant for a relevant diagnosis and prognosis of structures

- **Monitoring of moisture** → embedded resistive sensors are available → rather low reliability for low moisture content → capacitive sensors

- **Monitoring of corrosion** → sensors and monitoring systems are currently being developed → what durability of electrochemical sensors for long term monitoring?

- **Monitoring of stress** → sensitivity of EM waves is demonstrated → necessity to discard the effect of water content variations

- **Mechanical Damage Assessment with Self-sensing Concrete** → the variation of resisitivity is well correlated to crack opening → problem with the cost of carbon nanotubes
  → use of metallic fibers to increase concrete conductivity

Thank you for your attention

Questions?