



HAL
open science

Numerical Insights into the Ability of Indirect Galvanostatic Pulse in Wenner Configuration to Locate Corroding Areas in Macrocell Corrosion of Steel in Concrete

Romain Rodrigues, Stephane Gaboreau, Julien Gance, Ioannis Ignatiadis, Stéphanie Betelu

► To cite this version:

Romain Rodrigues, Stephane Gaboreau, Julien Gance, Ioannis Ignatiadis, Stéphanie Betelu. Numerical Insights into the Ability of Indirect Galvanostatic Pulse in Wenner Configuration to Locate Corroding Areas in Macrocell Corrosion of Steel in Concrete. EUROCORR 2023 - The Annual Congress of the European Federation of Corrosion, Aug 2023, Bruxelles, Belgium. . hal-04090786

HAL Id: hal-04090786

<https://brgm.hal.science/hal-04090786v1>

Submitted on 6 May 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Numerical Insights into the Ability of Indirect Galvanostatic Pulse in Wenner Configuration to Locate Corroding Areas in Macrocell Corrosion of Steel in Concrete

Romain Rodrigues¹, Stéphane Gaboreau¹, Julien Gance², Ioannis Ignatiadis¹, Stéphanie Betelu¹

¹ BRGM, Orléans, France

² Iris Instruments, Orléans, France



Introduction

Steel corrosion is the main cause of deterioration of reinforced concrete (RC) structures. Due to the **continuous ageing of structures**, the development of **monitoring techniques** that can detect an early stage of corrosion **without altering the integrity of the structures** is urgently needed.

The use of **indirect electrical techniques** is gaining interest for monitoring the corrosion of steel in concrete as they do not require any connection to the rebar.

These techniques are based on a **four-electrode configuration**, comparable to **concrete resistivity measurement**, but using low-frequencies to investigate steel corrosion.

The objective of this study is to provide insights into the ability of indirect GP for **locating highly corroding areas in non-uniform rebar corrosion**, as well as to estimate the sensitivity of this technique

Methods

Experiments

- Experiments were done on a mortar sample with one ribbed carbon steel rebar embedded at a cover depth of 33 mm
- Measurements were done on **passive state** using a potentiostat-galvanostat in **three and four-electrodes configuration** using **galvanostatic pulse** or **impedance**
- Determination of the influence of the **position of the monitoring device**, of the **probe spacing a** , of the **impressed current**

Simulations

- COMSOL Multiphysics using the second-current distribution module
- Main governing equations:**
- Parametric study** considering either uniform and non-uniform corrosion

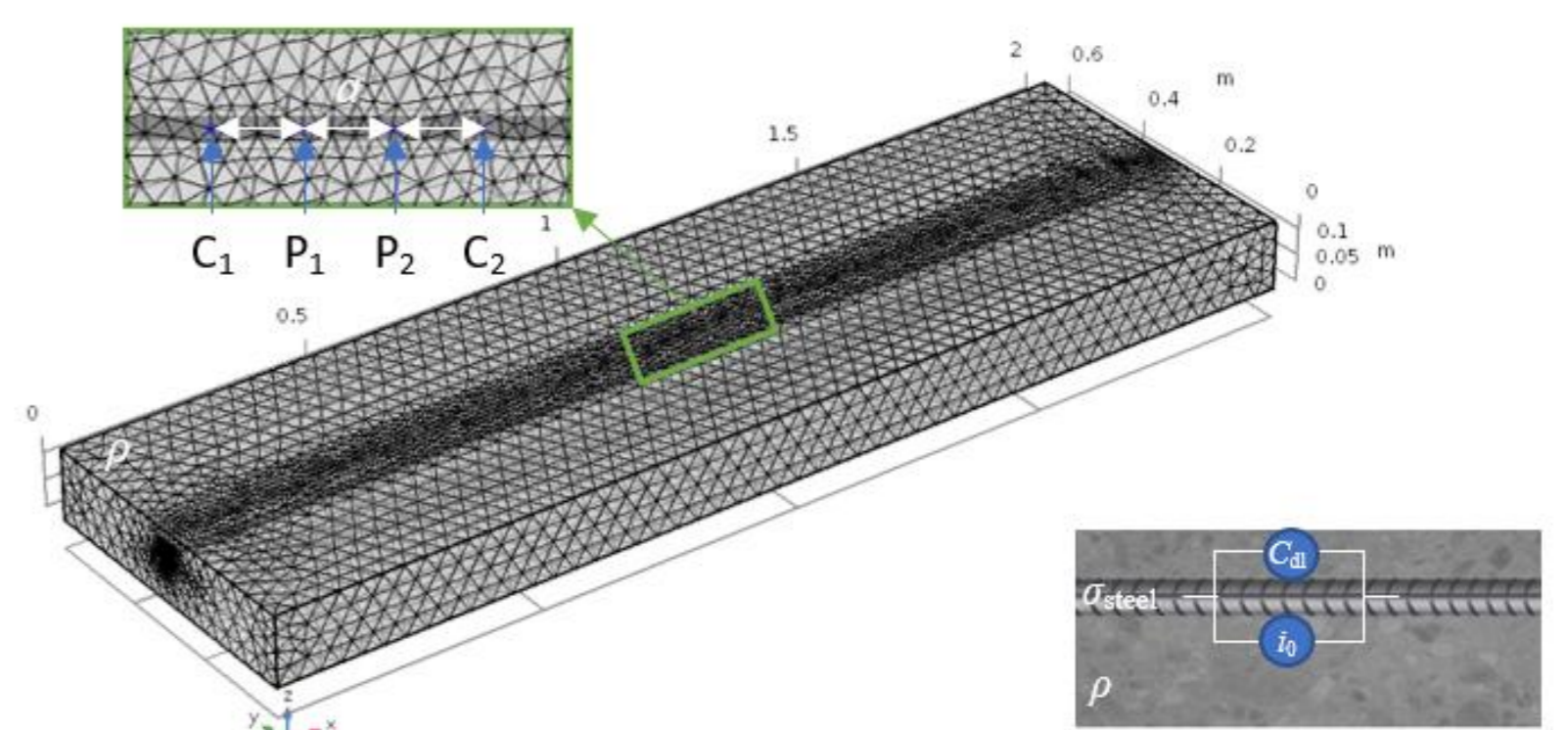
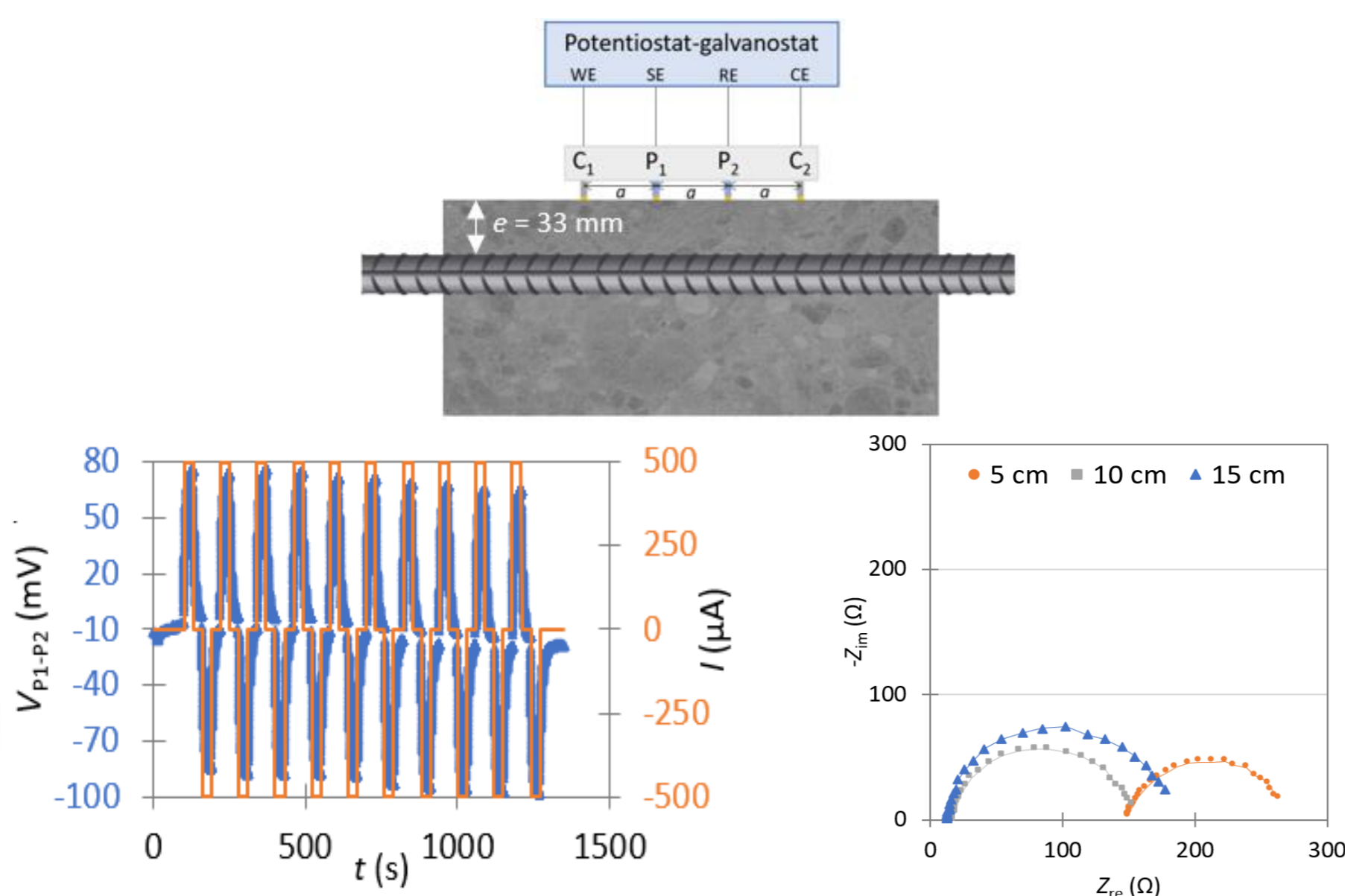
$$i = -\frac{1}{\rho} \nabla E,$$

$$\nabla \cdot i = 0,$$

$$i_{\text{tot}} = i_0 \left\{ \exp \left[\frac{\alpha_a F}{RT} (E - E_{\text{eq}}) \right] - \exp \left[-\frac{\alpha_c F}{RT} (E - E_{\text{eq}}) \right] \right\},$$

Input Parameters	Values	Input Parameters	Values
Current impressed on C1 I_{C1} (μA)	100, 300 or 500	Current impressed on C1 I_{C1} (μA)	100
Concrete resistivity ρ ($\Omega\text{ m}$)	100, 200, 500 or 1000	Concrete resistivity ρ ($\Omega\text{ m}$)	100, 200, 500 or 1000
Probe spacing a (cm)	2.5, 5, 7.5, 10 or 15	Anode length L_a (cm)	1, 3, 5, 7.5, 10, or 15
Cover depth e (mm)	20, 40 or 60	Probe spacing a (cm)	2.5, 5 or 15
Rebar diameter Φ (mm)	6, 12 or 25	Cover depth e (mm)	40
		Rebar diameter Φ (mm)	12
		Double-layer capacitance C_{dl} (F m^{-2})	0.2 or 2

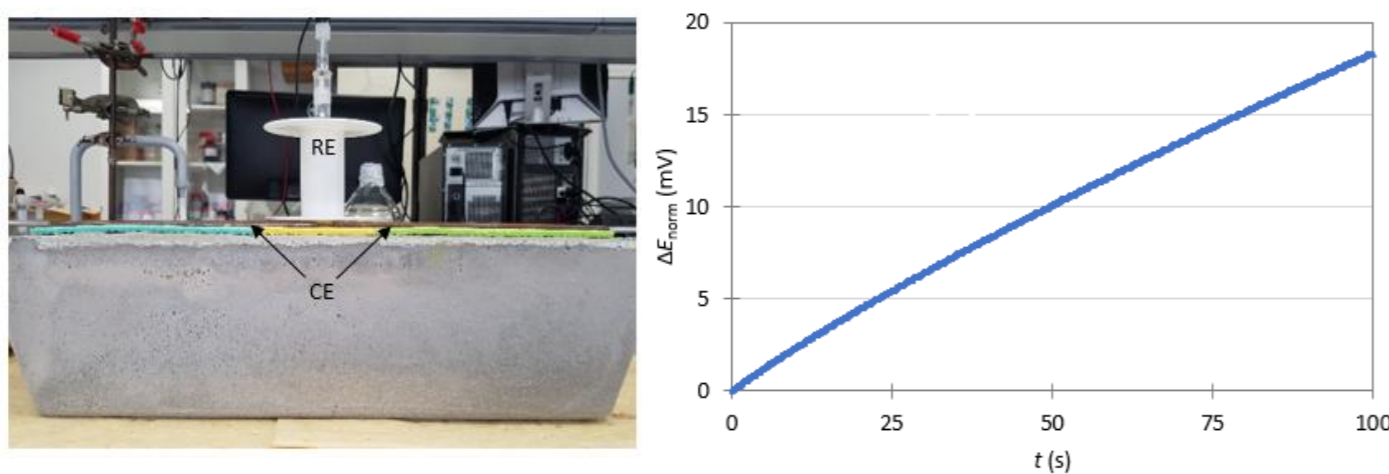
$$\Delta V(t) = V_{P1-P2}(t) \text{ for passive rebar} - V_{P1-P2}(t) \text{ for non-uniform corrosion.}$$



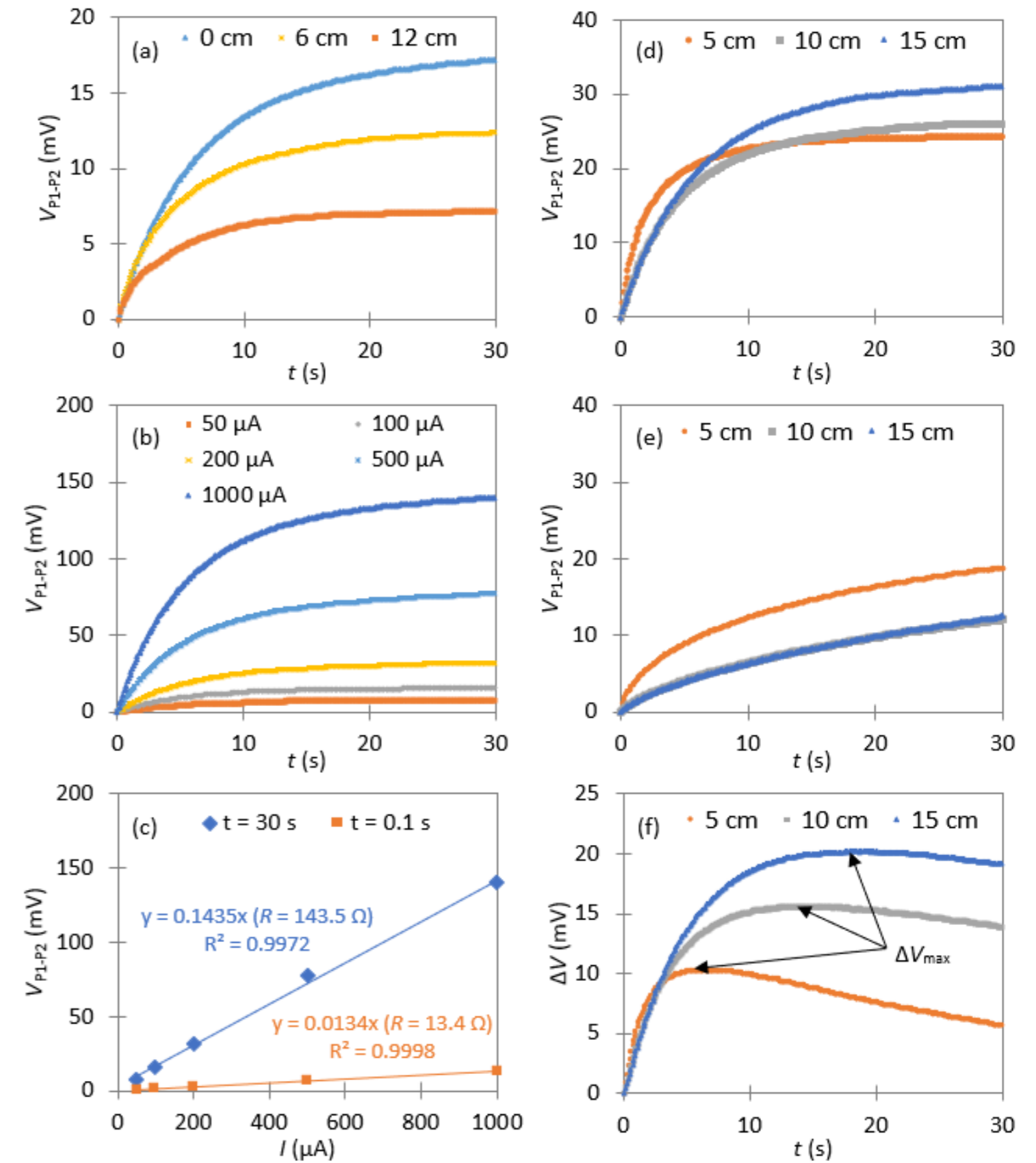
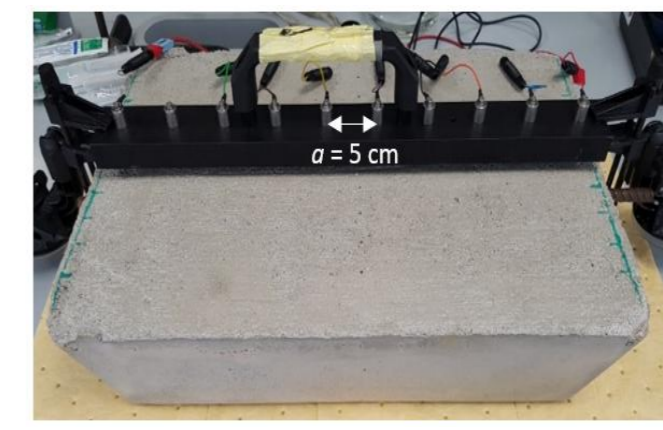
Experimental results

The main results indicate that:

- The rebar can effectively be polarized **without any connection** by applying a direct current between two probes located on concrete surface
- The further the monitoring device is from the rebar, the **higher the apparent concrete resistance** and the **lower the apparent polarization resistance**
- Comparable results of apparent resistivities are obtained **irrespective of the impressed current**, and increasing the current can help to obtain a **more significant variation** on the measured potential
- The **size of the specimen** affects the current distribution in the material
- The time required to reach the steady state is **much lower in four-electrode configuration**, and appears related to the **corrosion state of the rebar**



Three-electrode configuration

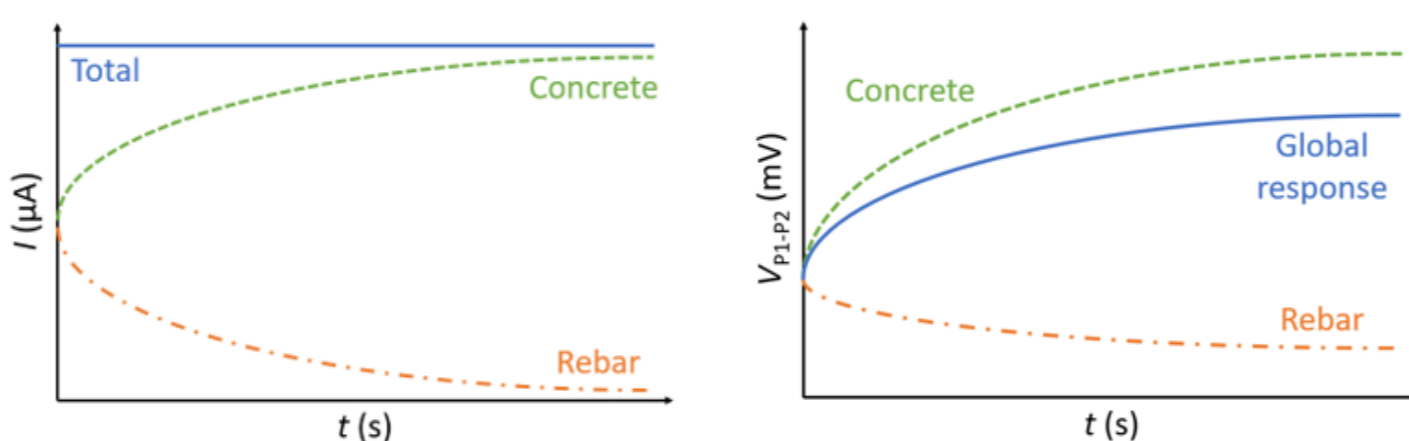


Four-electrode configuration

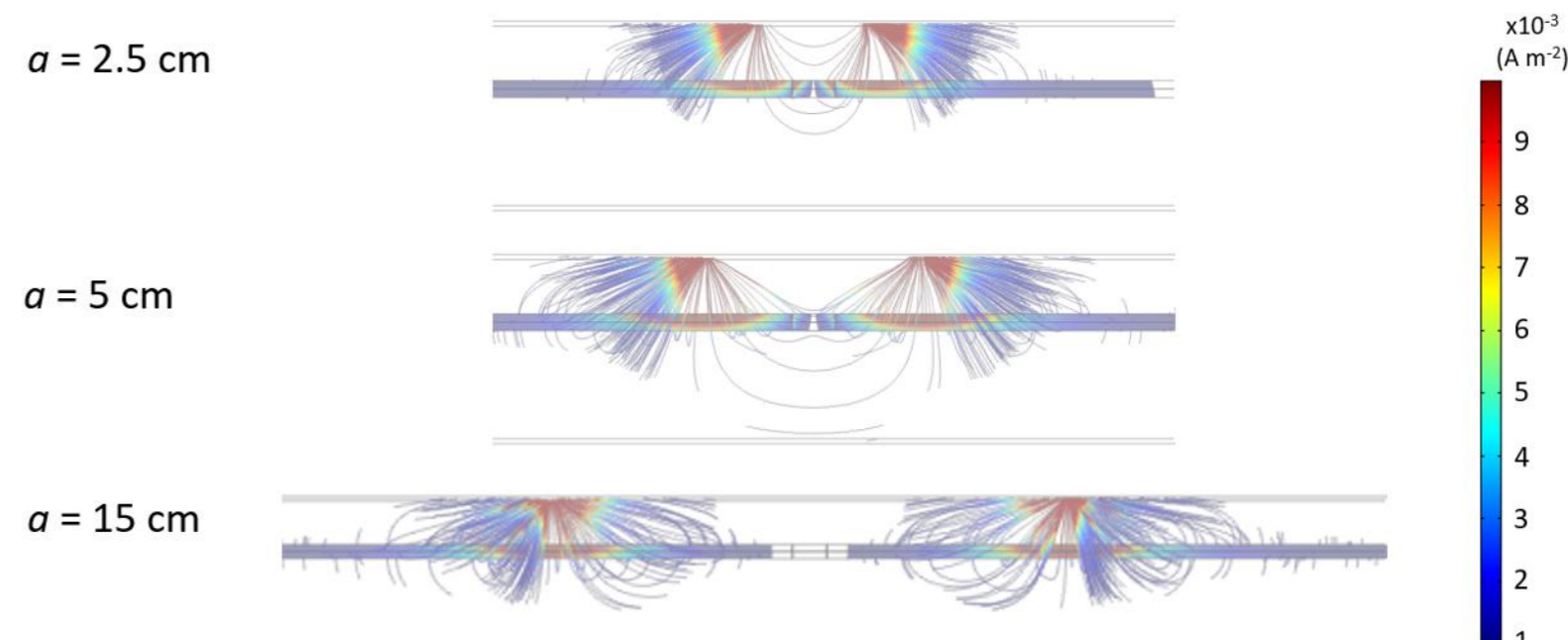
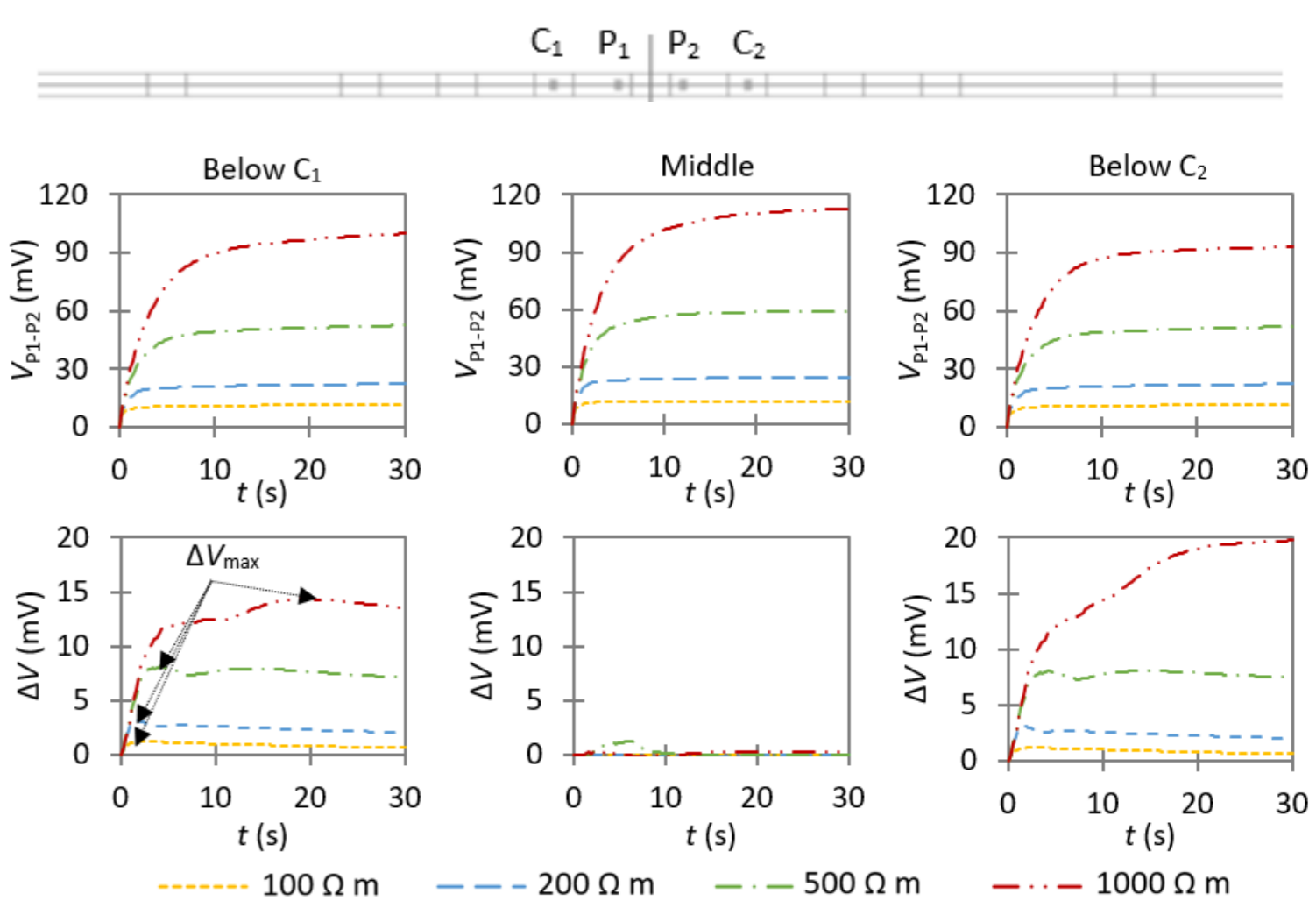
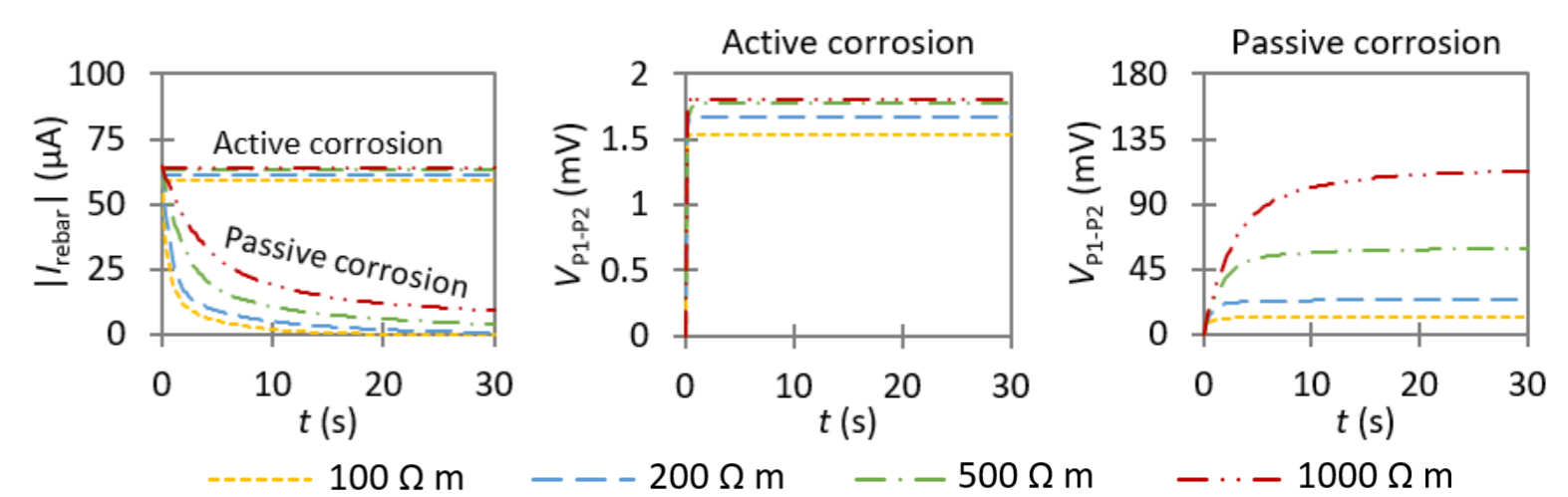
Numerical results in four-electrode configuration

The main results indicate that:

- Compared to conventional technique in three-electrode configuration, **only a fraction of the injected current polarizes the rebar**, depending on many parameters, in four-electrode configuration
- The temporal evolution of the potential difference is explained by the **increase of the potential difference related to concrete resistance** and the **decrease of the potential difference related to the rebar**



- The presence of an anode **disturbs** the current distribution in the entire material
- The time to reach the steady state when the anode is below one of the current electrodes increases with **increasing concrete resistivity**
- The sensitivity of the monitoring device is spatially limited as the anode is mainly observed when it is **located below or close to one of the current electrodes**.
- The **middle of the current probes** (and of the potential probes in Wenner configuration) corresponds to a point where the **total current on the rebar is null**
- An increase in the probe spacing **decreases the “internal” sensitivity** (between the current electrodes) and **increases the “external sensitivity”** (outside of the current electrodes) of the technique

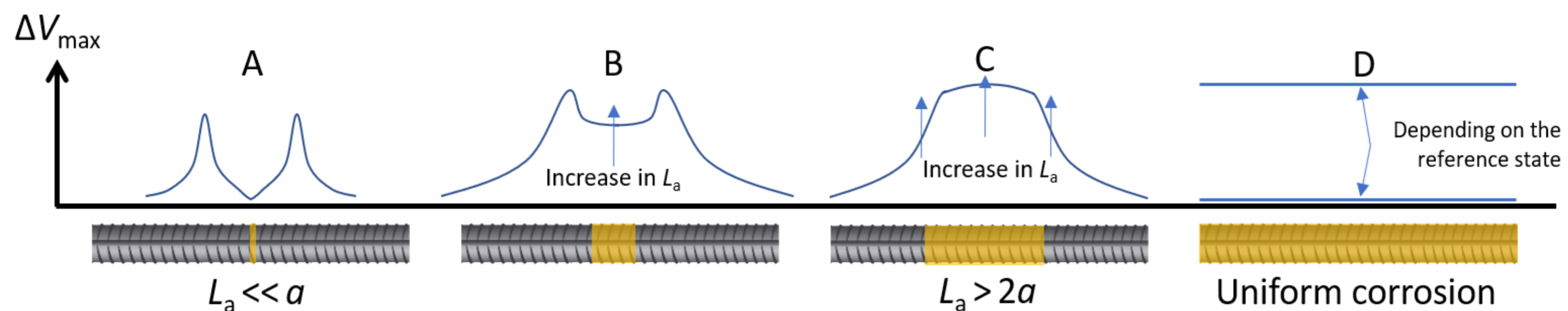


| Discussion

The instantaneous ohmic drop is largely affected by the presence of the rebar that acts initially as a short-circuit. This rebar effect decreases the value of concrete resistivity, especially when the measurement is done right above the rebar. It mainly depends on the probe spacing, the cover depth, and the geometry of the slab

However, it was also shown that the electrochemical state of the rebar has no influence on the rebar effect; thus, it is possible to calculate a corrective factor for an accurate determination of concrete resistivity irrespective of the corrosion state, which is the case when making measurements on RC structures

Based on all results, it seems possible to estimate the length of a localized corroding area by considering the difference in “internal” sensitivity depending on probe spacing



Schematic representation of the evolution of ΔV_{\max} as a function of the position of the monitoring device, allowing to estimate the position and size of the anodic area

| Conclusion and perspectives

- Sample geometry is an important parameter when performing any experiments or numerical simulations. An accurate **geometric factor** must be determined case-by-case, depending on specimen size and probe spacing, to convert concrete resistance into concrete resistivity
- If the steady-state potential can be reached rapidly considering uniform corrosion, either in active or passive conditions, **a longer time is required in non-uniform corrosion**. This is essentially due to the different capability of anodic and cathodic areas of consuming the impressed current
- As the anode has a **greater effect on the transient potential** than on the steady-state potential, it is preferable to examine the temporal evolution of the potential to **qualitatively detect the presence of a highly corroding area**
- The effect of the anode differs depending on its position relative to the monitoring device:
 - Corroding areas can mainly be located when they are **below or in the vicinity of the current electrodes**
 - The area below the center of the device is almost **not polarized** irrespective of concrete resistivity
- Further experiments are required to confirm the different scenarios observed numerically in this study and to determine the applicability and efficiency of the technique for everyday practice in real structures
- Future studies should be focused on the development of electrical tomography with inverse methods to quantify the corrosion rates, to spatially distribute both concrete resistivities and corrosion rates in the material to improve the diagnosis of RC structures

| References

- [1] R. Rodrigues, S. Gaboreau, J. Gance, I. Ignatiadis, S. Betelu, Reinforced concrete structures: A review of corrosion mechanisms and advances in electrical methods for corrosion monitoring, *Construction and Building Materials*. 269 (2021) 121240. <https://doi.org/10.1016/j.conbuildmat.2020.121240>.
- [2] R. Rodrigues, S. Gaboreau, J. Gance, I. Ignatiadis, S. Betelu, Indirect Galvanostatic Pulse in Wenner Configuration: Numerical Insights into Its Physical Aspect and Its Ability to Locate Highly Corroding Areas in Macrocell Corrosion of Steel in Concrete, *Corrosion and Materials Degradation*. 1 (2020) 373–407. <https://doi.org/10.3390/cmd1030018>.

| Related presentations at EUROCORR 2023

Benjarese Oniangue-Ongania, Julia Holzhauer, Romain Rodrigues, Stéphanie Betelu, Stéphane Gaboreau, Rachid Cherif, Ioannis Ignatiadis, Karim Ait-Mokhtar, Julien Gance, Non-invasive corrosion diagnosis of reinforced concrete structures: A sensitivity analysis using a multi-channel resistivity approach. Oral presentation at EUROCORR 2023

Julia Holzhauer, Julien Gance, Yannick Fargier, Christophe Chiaberge, Romain Rodrigues, Stéphanie Betelu, Inversion of non-invasive resistivity measurements in four-electrodes configuration for corrosion characterization in reinforced concrete samples. Oral presentation at EUROCORR 2023