fib Symposium2025
Antibes - France
Concrete Structures :
extend lifespan, limit impacts

16-18 June, 2025

3-years results on the corrosion of PerfDuB specimens exposed to chlorides on natural ageing site (PerfDuB project)

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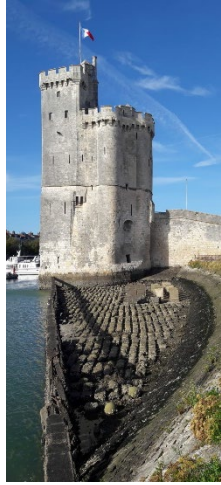
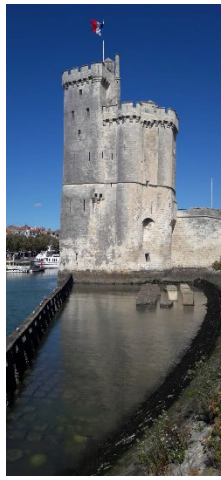
Objectives

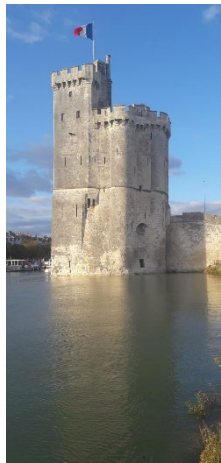
1. Detect the corrosion initiation
2. Evaluate the corrosion activity in the propagation phase
3. Improve the accuracy of the corrosion diagnosis
4. Provide data on new generation of concretes including low carbon footprint

Instant non- destructive electrochemical measurements

Permanent monitoring using embedded sensors





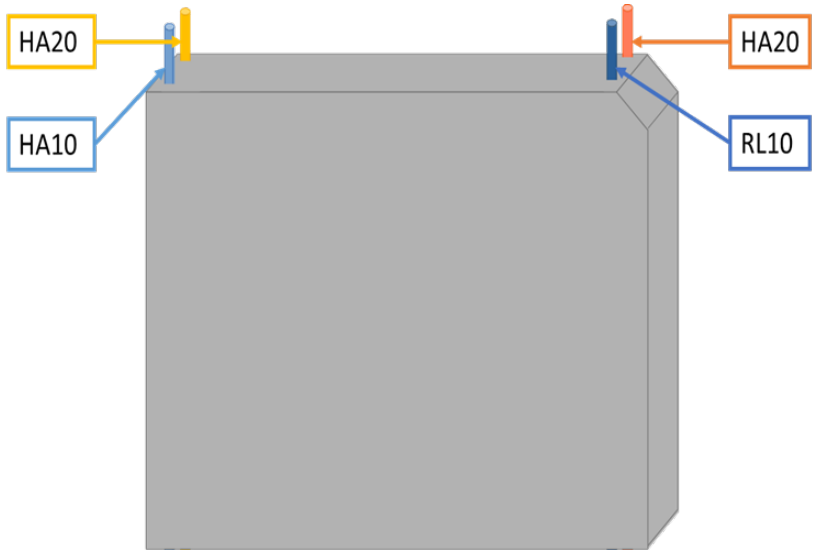


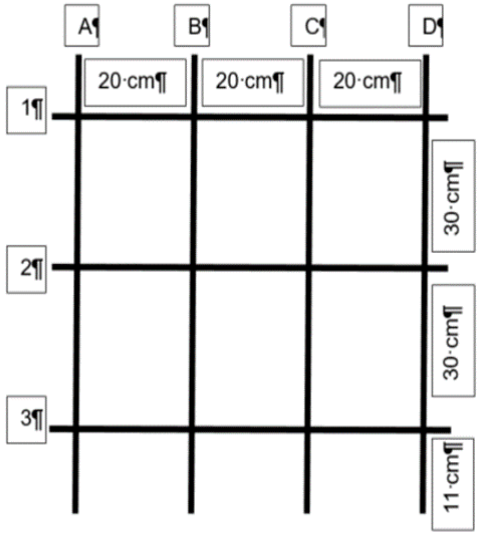
Experimental program

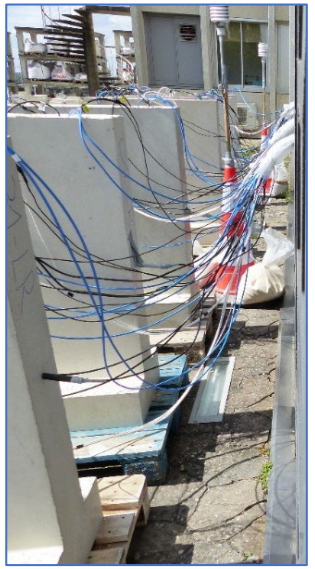
Specimens

- **11 specimens T-shaped**
  - Dimensions ➔ 0.16m-large, two 1x1m² faces, 0.4x0.15m foot (stability vs tide)
  - 2 types of steel bars ➔ RL : Smooth round shaped (RL) representative of ancient constructions + accurate surface determination for electrochemical calculations; HA: High-bond ribbed (HA) representative of modern constructions
  - Two concrete covers ➔ 10mm and 20mm for each type of rebar

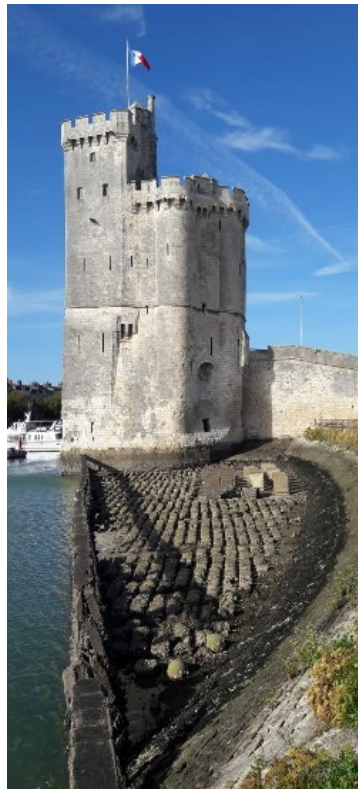
- **3 additional specimens T-shaped**
  - Reinforcing rebar network ➔ 30mm concrete cover
  - 1RL and 1 HA ➔ 15mm concrete cover







Exposure sites



- Specimens without sensors cast from December 2019 to January 2020
- 1 year of ageing in semi-rural environment
- Installation in La Rochelle harbor in December 2020 ➔ **XS3m**
- **Tidal zone** : 6 hours immersed, 6 hours in open air for every tide
- First set of NDT in October 2021 and annual follow-up examination

Exposure sites

- Specimens with sensors cast from June 2021 and August 2021
- 8 months of ageing in semi-rural environment
- Installation in La Pallice industrial harbor in May 2022 ➔ **XS3e**
- First set of NDT in May 2022 and annual follow-up examination

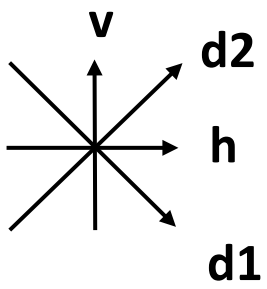
Instant non-destructive electrochemical measurements

- **Resistivity** ➔ Disc and Wenner 4-points methods
- **Potential mapping** ➔ Cu/$CuSO_4$ reference electrode
- **Polarization resistance** ➔ Gecor10 ©

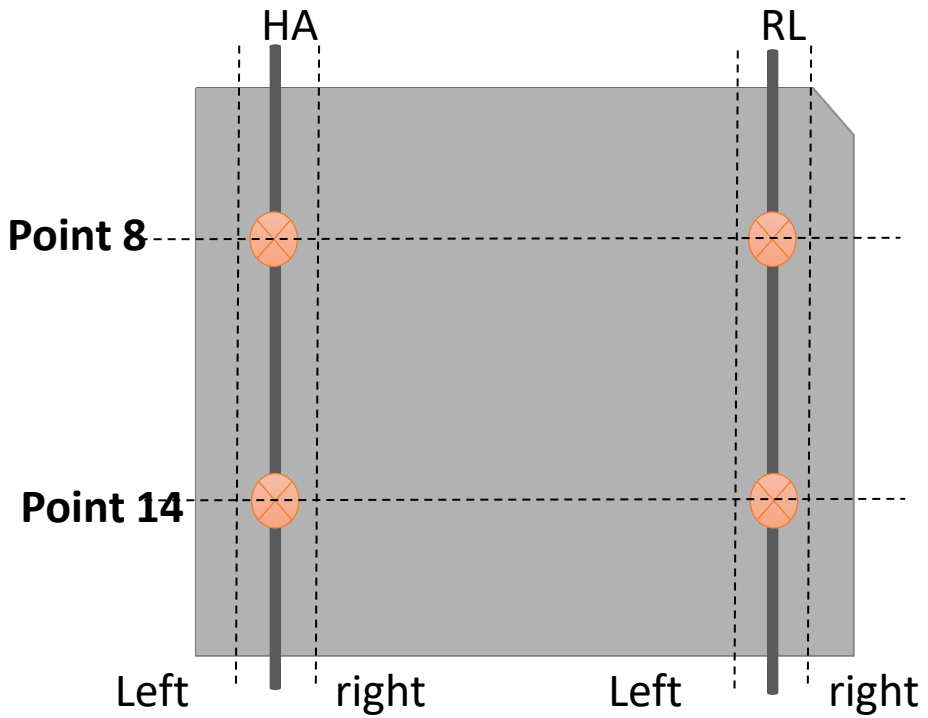



Instant non-destructive electrochemical measurements

- **Potential mapping** ⇨ 3 vertical lines 5 cm left, 5 cm right and on the rebar, every 5 cm from the top of the wall
- **Wenner** ⇨ ⊗ 2 points ➔ points 8 and 14
- **Disc** ⇨ ⊗ 4 points ➔ point 8 left and right, point 14 left and right from rebar
- **Rp** ⇨ ⊗ 1 point ➔ point 8 on the rebar

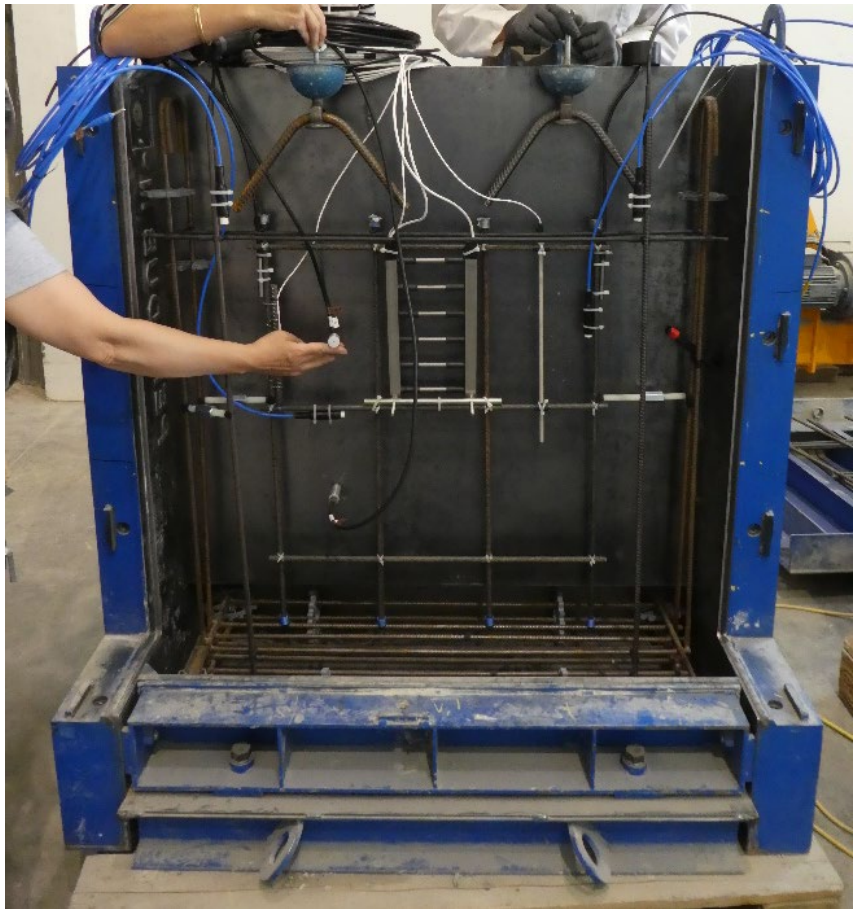


Wenner



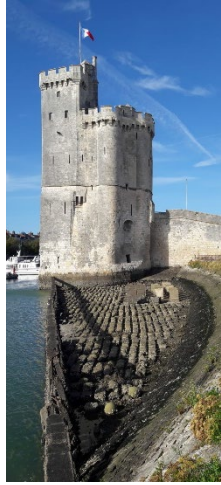
Permanent monitoring

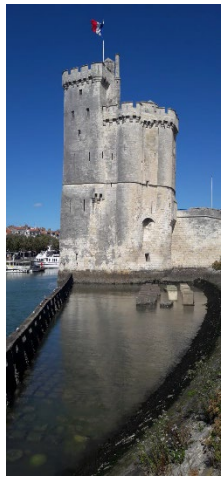
- **Sensors**
  - *Anode ladder© ➔ Resistance, potential and corrosion current*
  - *Multiring Electrode© ➔ Resistivity*
  - *ERE20 © ➔ Potential*
  - *HMP110© ➔ Temperature and relative humidity*
  - *Weather station close to the specimen ➔ Follow-up on environmental conditions*
- **Data acquisition system*** ➔ 1 acquisition per hour
- **Automatic database**
- **Remote control**



Only 3 mix designs ⇨ B01, B04, B31

** Data from the sensors collected through a multiplexer connected to an analyzer, connected to a computer ⇨ System designed by IBAC©.*

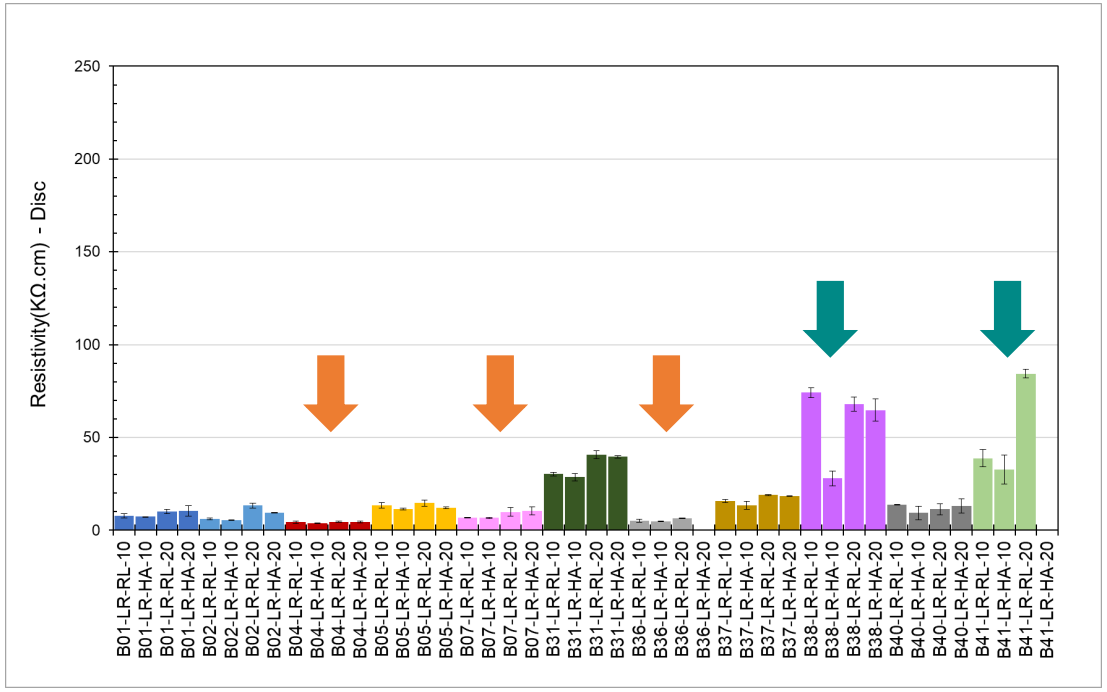


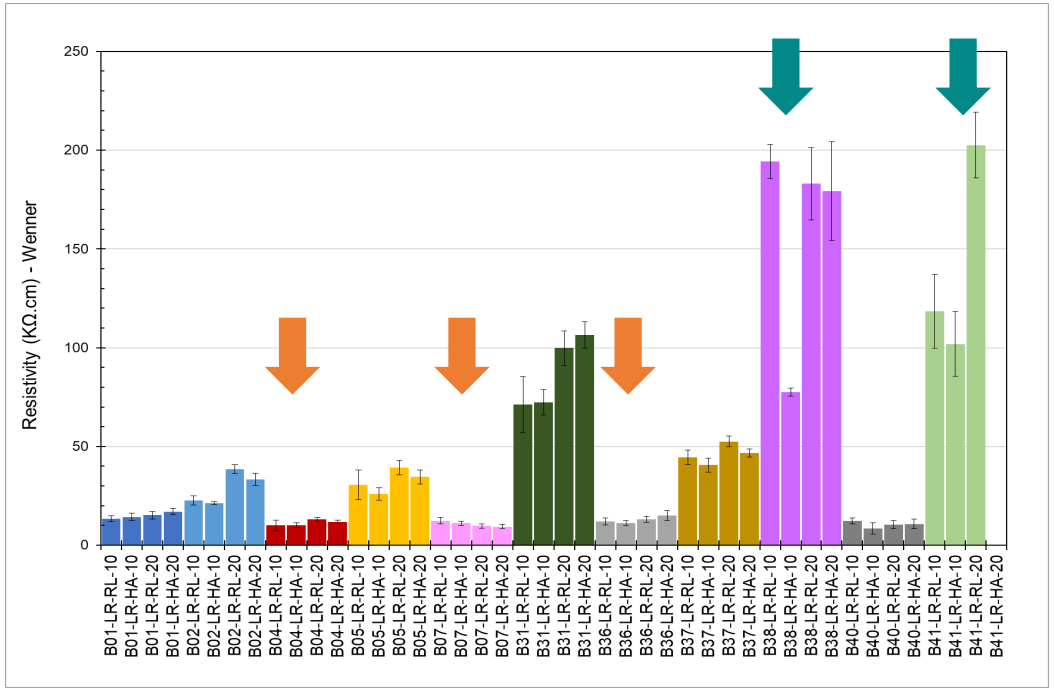


Results

Specimens without sensors

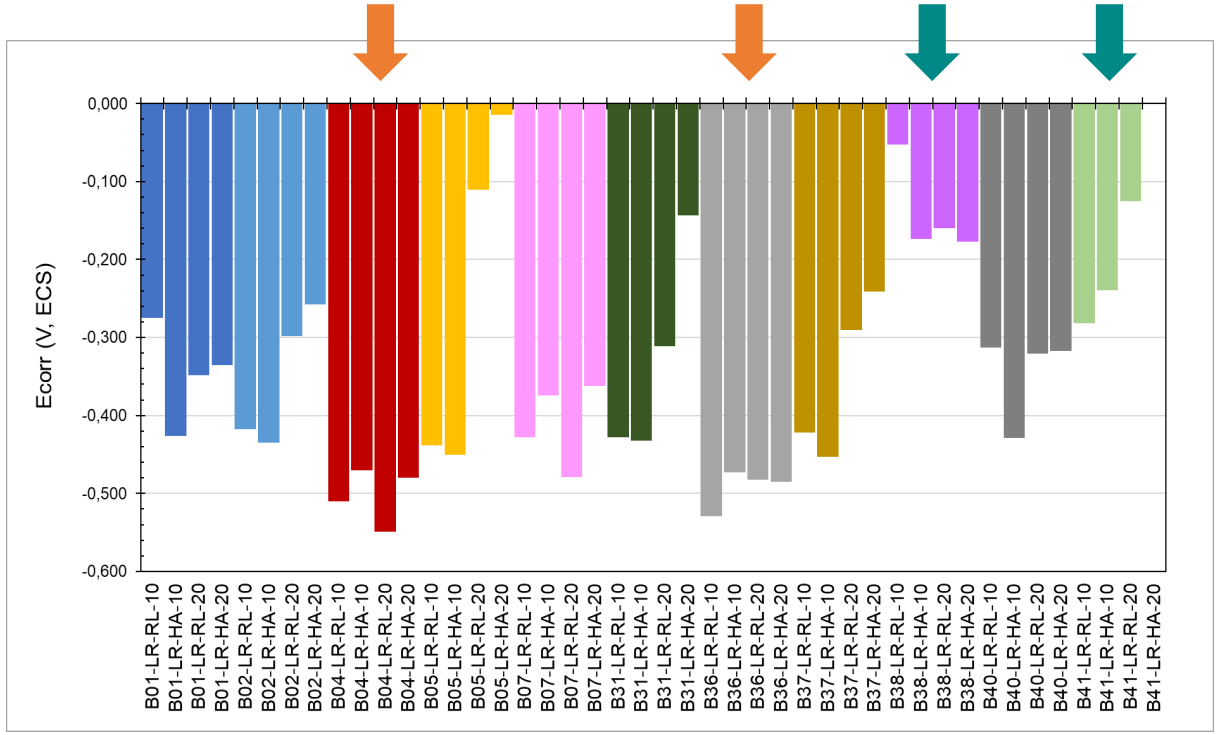
Resistivity





- **Disc method and 4-points method**
  - ⇨ In line, with slightly lower values for the disc method ➔ Already observed in previous studies ➔ Probable link with lower depth of concrete affected by the measurement with the Disc method
- **Highest** resistivities ➔ **B38, B41 and B31**
- **Lowest** resistivities ➔ **B04, B36 and B07**

Corrosion potential



5cm Left	Bar	5cm Right
-566	-564	-560
-575	-567	-560
-586	-577	-565
-592	-578	-570
-599	-582	-569
-594	-549	-574
-595	-582	-576
-603	-585	-585
-604	-597	-597
-613	-607	-604
-616	-613	-612
-620	-615	-620
-630	-628	-632
-632	-629	-632
-645	-633	-635
-642	-641	-640
-645	-640	-638
-646	-636	-636
-649	-641	-635

- **Corrosion potentials in line with resistivity**
  - ⇨ **Less electronegative** potentials observed for **B38 and B41**
  - ⇨ **Most electronegative** for **B04 and B36**
- **Potential mapping**
  - ⇨ Clear **tidal impact** with a potential gradient from the top to the bottom of the specimens
  - ⇨ Probable link with the duration of the tide's descent and to the tidal coefficient (at low coefficient, specimens not totally submerged)

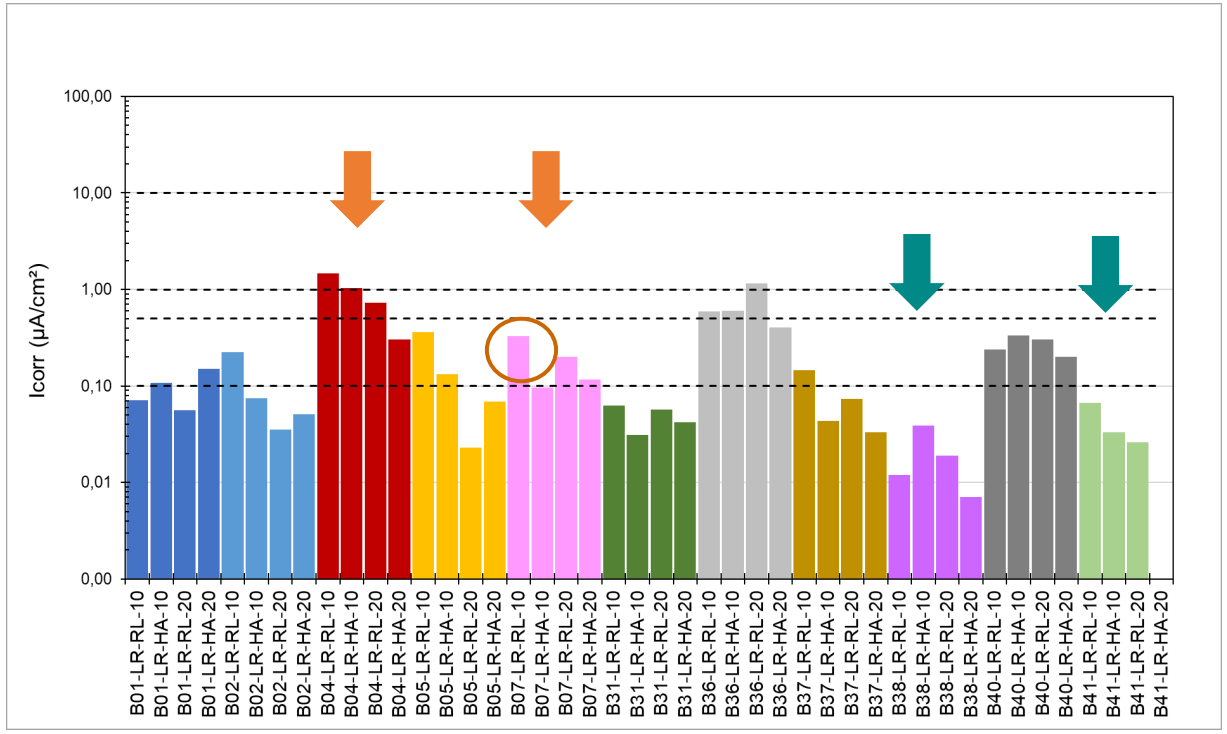
Corrosion potential

B36 – RL10

5cm Left	Bar	5cm Right
-508	-512	-493
-515	-504	-509
-524	-512	-515
-540	-529	-538
-563	-560	-559
-579	-570	-575
-588	-603	-596
-608	-616	-613
-613	-621	-620
-608	-605	-618
-603	-585	-606
-601	-599	-607
-600	-601	-600
-599	-601	-601
-602	-600	-591
-598	-598	-591
-594	-594	-578
-580	-579	-569
-566	-557	-556

- After three years for some specimen **significant gradients**
- Indicative of a **probable corrosion** according to the RILEM recommendation
- In the gradient zones clear correlation with the appearance of **rust stains and cracks**

Corrosion current density



RL10 -B07- 2024

RL10 -B07- 2025

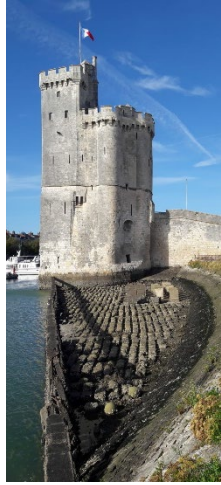
- In line with resistivity and potential measurements
- **Highest values** observed for **B04 and B07** ➔ Exceeding RILEM threshold for high corrosion (Jcorr ≥ 1 µA/cm²) ➔ corresponding to rust stains and crack opening
- **Lowest values** for **B38, B41 and B31** ➔ Corrosion current densities < RILEM threshold for negligible corrosion (Jcorr < 0.1 µA/cm²)

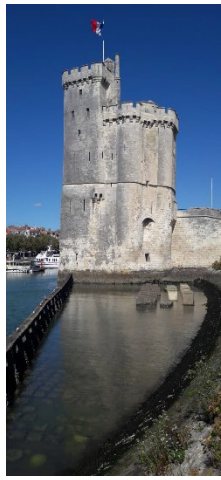
Discussion

- **Good corrosion performances ⇨ B38, B41 and B31**
  - ⇨ Consistent with low W/B ➔ 0.35 - 0.35 - 0.4
  - ⇨ Consistent with low open porosity ➔ 10.3% - 10.8% - 12.1% respectively
  - ⇨ Mixes designed to comply with XS3m environment

- **Poor corrosion performances ⇨ B04**
  - ⇨ High W/B ➔ 0.61
  - ⇨ High carbonation potential ➔ CEM III with low clinker content ➔ Possible carbonation of the concrete prior to its exposure in tidal zone ➔Just after casting specimens stored outdoors for one year in a semi-rural environment
  - ⇨ Not designed to resist to XS3m environment

- **Poor corrosion performances ⇨ B36**
  - ⇨ High open porosity ➔ 19.6%
  - ⇨ Noticeable sensitivity to chloride migration ➔ DRCM = 11.5 10-12m²/s

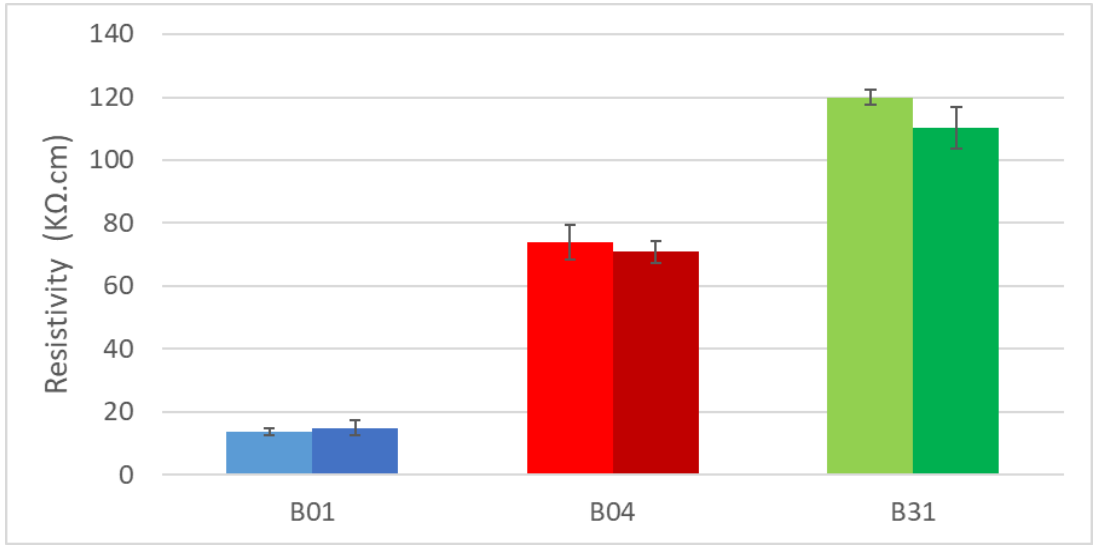


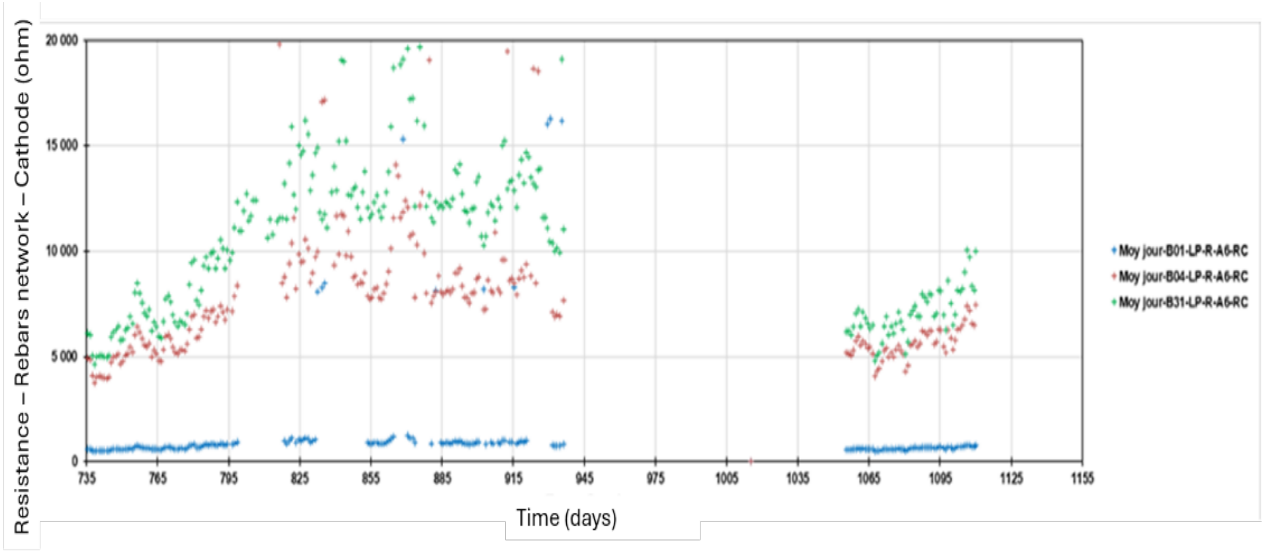


Results

Specimens with sensors

Resistivity - Resistance





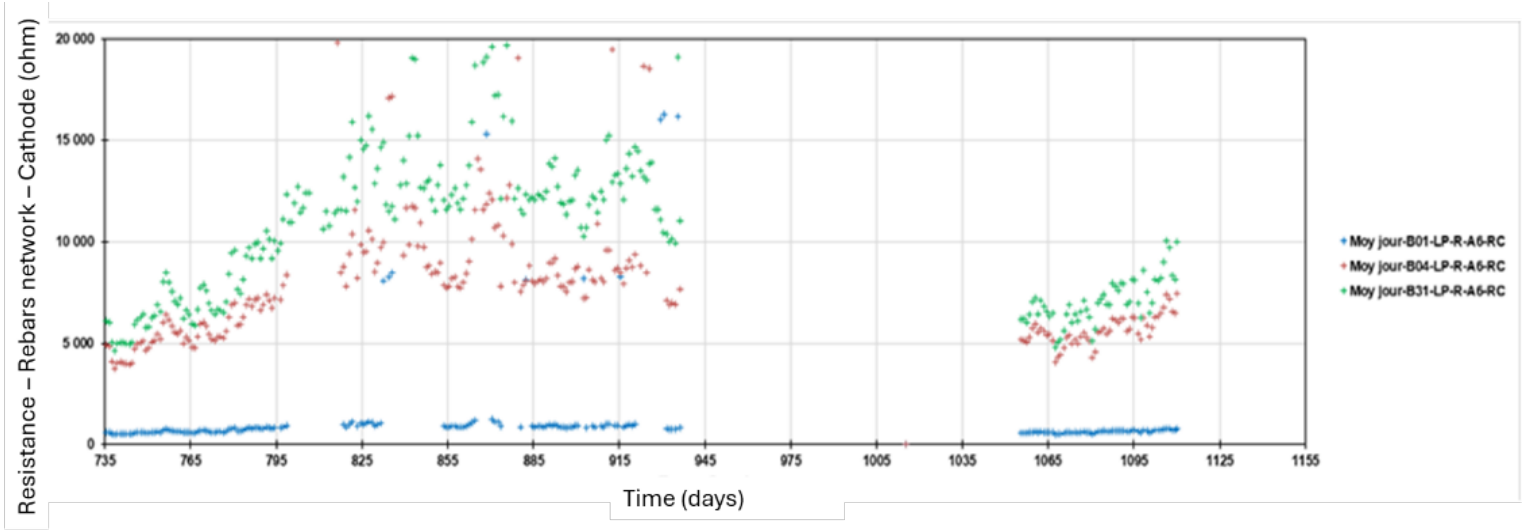
NDT Wenner technique ➔ B31> B04> B01

Resistance from the Anode ladders ➔ B31> B04> B01

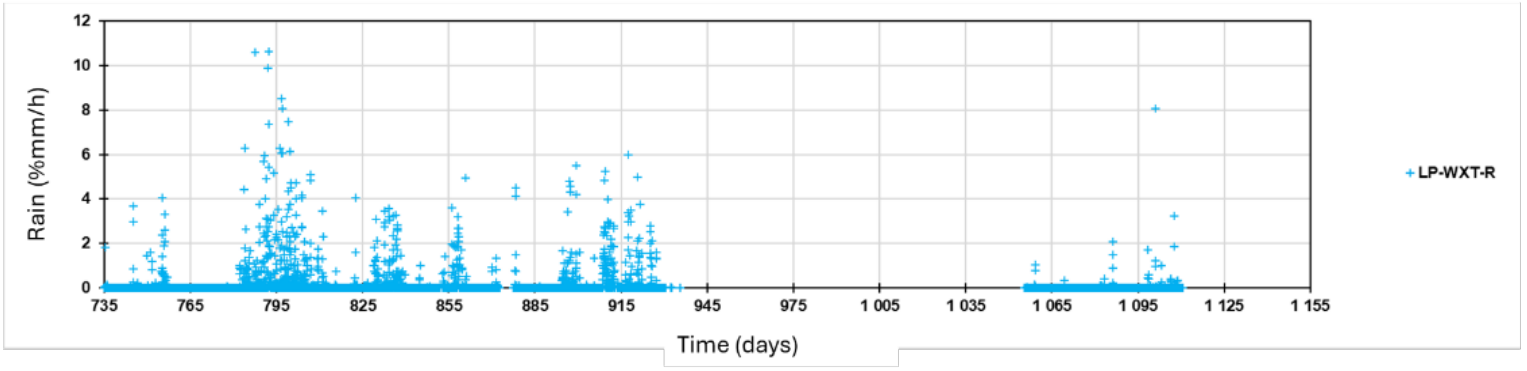
- **NDT-Resitivity and Monitoring-Resistance ⇨ In Line**
- **Results consistent with the binders**
  - B01 ⇨ Portland Cement
  - B04, B31 ⇨ Contain slag

Permanent monitoring

- Clear correlation between **rainfall** events and **resistance** evolution (Already evidenced by previous studies)



- **Highlights the limitations of instant non-destructive techniques**
- **And the contribution of permanent monitoring to a more precise understanding of corrosion risk evaluation and evolution**



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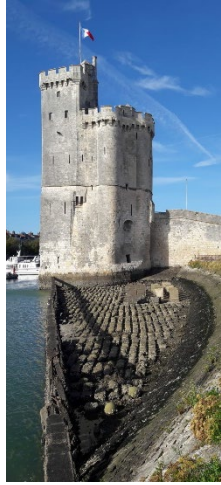

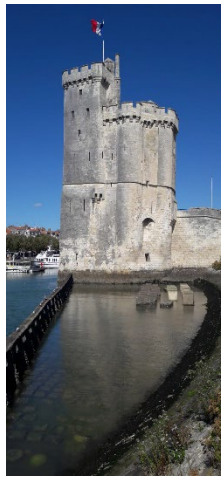

Conclusions and outlooks

Conclusions

- **Efficiency of electrochemical NDT** in identifying initiation and propagation phases of corrosion through the evolutions of resistivity, potential and corrosion current density
- Logically **initiation** started for **lowest concrete cover**
- **Propagation phase** for **B04, B07 and B36** ➔ In conjunction with the **appearance of rust stains and cracks** on the concrete surface
- **Consistency between corrosion and**
  - ⇨ **Concrete composition** ➔ High W/B, low clinker content…
  - ⇨ **Concrete initial performances** ➔ High sensitivity to chloride penetration or to carbonation, high porosity…
- Limits of NDT vs changes in climatic conditions confirmed ➔ **Clear input of permanent monitoring** using embedded sensors for more accurate diagnosis of corrosion.

Outlooks

- **Sampling and laboratory analysis**
  - ⇨ **Correlate electrochemical measurements** and **progression of chloride** through the concrete cover
  - ⇨ **Document** the **evolution of the binder matrix of low carbon footprint** concretes in marine environment.

- **Continuation of the study during the next 20 years**

Acknowledgements

- All the teams that contributed to design and casting of the specimens, installation in the exposure site, NDT and permanent monitoring…

- Financial support of IREX and all the contributors of the PN PerfDuB

And thank you for your attention