Reinforced concrete demo-wall illustrating service life extension through cathodic protection

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Goal

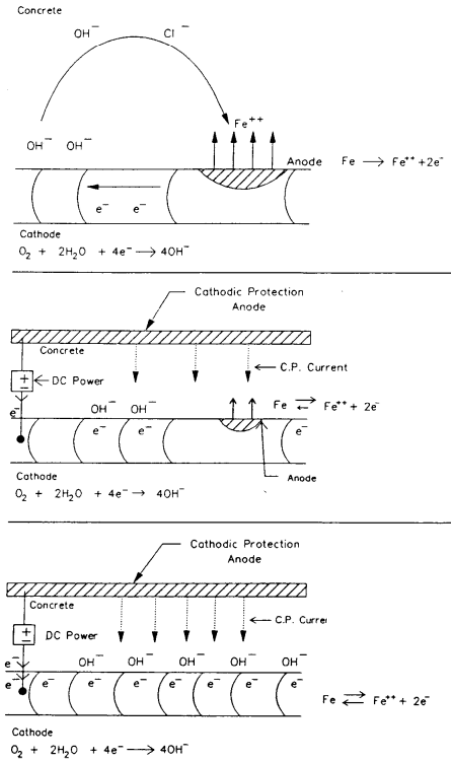
- Demonstrations for students and stakeholders within the concrete renovation sector
- Displaying of the various cathodic protection (CP) systems on ‘damaged/corroding’ concrete structures to create a realistic demo setup
- Continuous remote & sensing control monitoring of temperature, relative humidity, resistivity, corrosion current and steel potential
- Promote CP as a full-fledged and efficient concrete repair technique
- Secondary: further research on the current and potential distribution generated by the CP system

Problems within the Belgian CP sector (2021-2022)

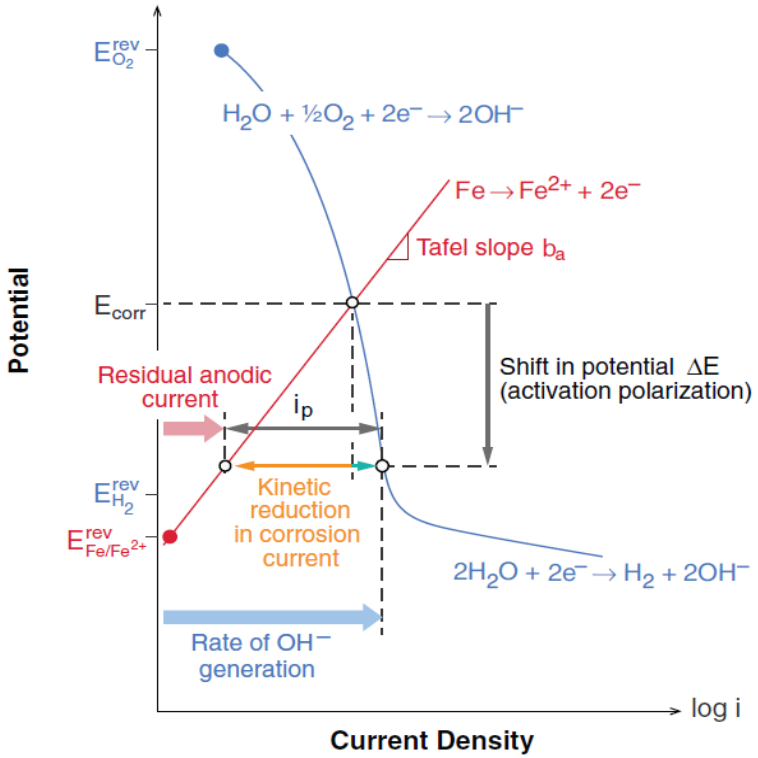
- Limited number of companies within the Belgian market → has changed over the last few years
- Failure of or not enough reference electrodes
- System deregulated by water leakage
- Oxidation of the copper anode cables
- Power supply interrupted due to renovation works or ignorance
- …
- **Need for knowledge and experience!**

Introduction on cathodic protection of steel in concrete

- Increasing the service of the concrete structures where reinforcement corrosion is the main cause of the damage (chloride ingress/mixed vs carbonatation)
- Timing is crucial



Source: Funahashi, M., & Bushman, J, *Corrosion*, **47**, 376-386 (1991)



Source: U. M. Angst, Corrosion, **75**, 1420-1433 (2019)

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Demo-wall set-up

- Six reinforced concrete elements: 1000 mm x 1000 mm x 200 mm (±500kg)
- Four ICCP elements for four ICCP systems:
  - TiMMO mesh
  - TiMMO strips
  - Conductive coating
  - Ceramic-TiMMO discrete anodes
- One GCP element with three systems:
  - Zinc foil
  - Zinc discrete anodes
  - One hybrid system (first phase via internal power source)
- One reference-element:
  - Outdoors

Demo-wall set-up

- Two layers of reinforcement per test piece (electrically separated) and one lifting anchor
- Concrete cover 2 cm
- Per reinforcement layer 1 m² steel per m² concrete surface :Ø 16 mm with a rebar length of 950 mm and a spacing of 100 mm:

$$\frac{\pi \cdot 0{,}016 \cdot 0{,}95 \cdot 20\ m^2 st}{1\ m^2 concrete} = 0{,}96\ m^2 st\ per\ m^2 of\ concrete$$

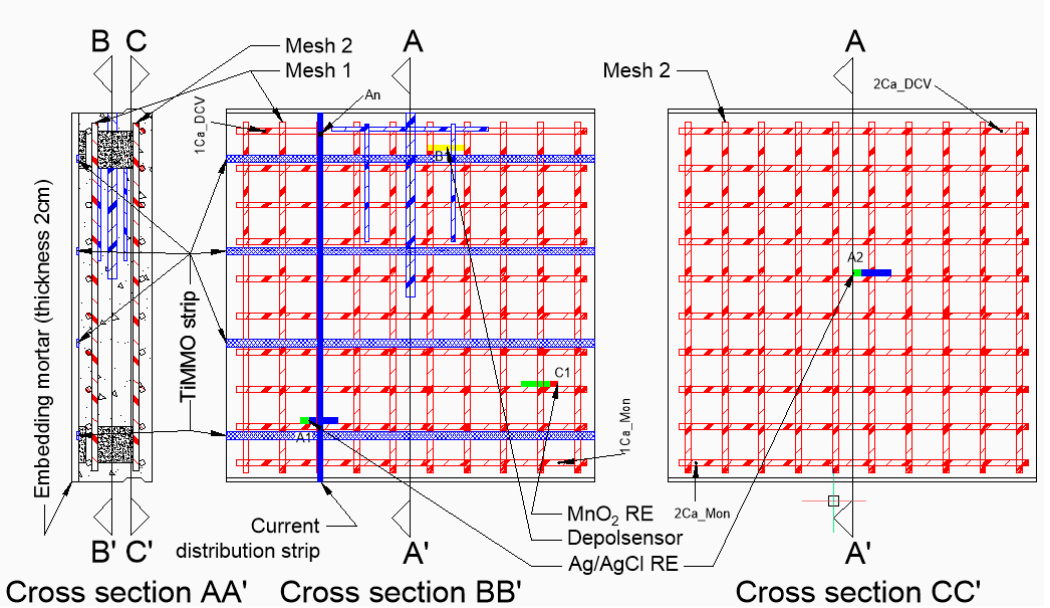
- GCP element less heavily reinforced : Ø 8 mm with a rebar length of 950 mm and a spacing of 100 mm:

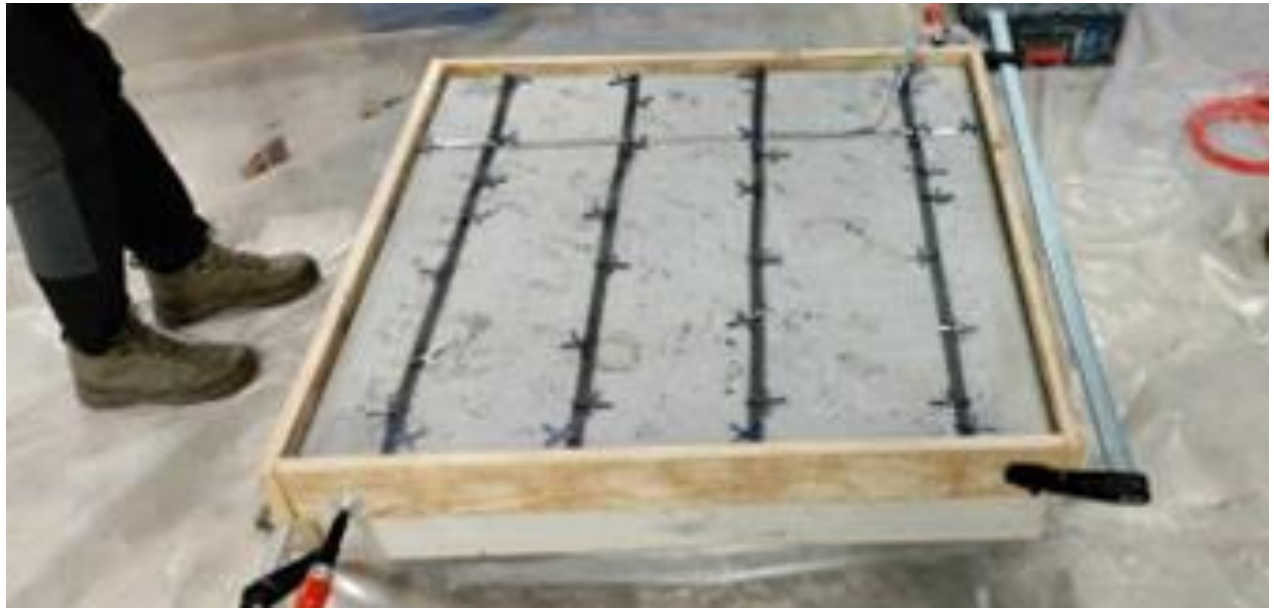
$$\frac{\pi \cdot 0{,}08 \cdot 0{,}95 \cdot 20\ m^2 st}{1\ m^2 concrete} = 0{,}48\ m^2 st\ per\ m^2 of\ concrete$$

Demo-wall set-up

- Sufficient corrosion current:
  - Carbonation
  - **Chlorides** (ingress vs **mixed-in**)
  - Cracks
  - Accelerated corrosion
- Concrete composition:
  - CEM I 52.5 R: 280 kg cement per m3 concrete
  - W/C factor: 0,62
  - Superplasticiser: 0,8 m% relative to cement weight
  - 2 m%Cl relative to mass of cement
  - Granulates: sea sand 0/2, rhine sand 0/7, Limestone 6/14 and recycled granulates are used with a weight of resp. 378 kg, 489 kg, 623 kg, 49 kg per m^3 concrete
- Belgian conditions: temperatures in between [-7°C;42°C] (annual average 11°C) and a RH in the range of [51%;96%] (annual average 78%).

Demo-wall set-up: example TiMMO strips





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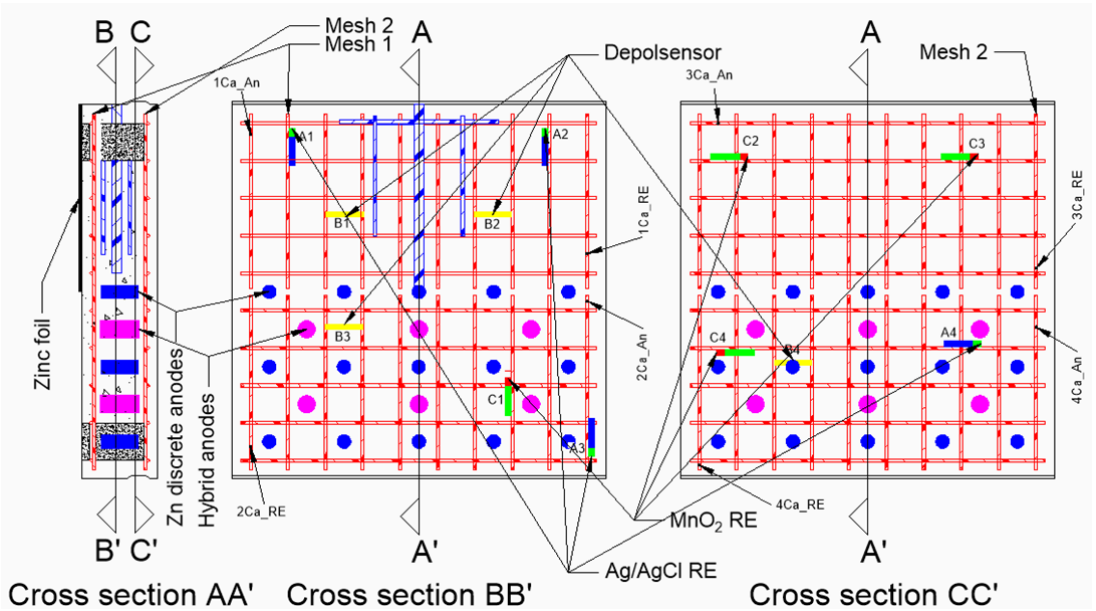
Demo-wall set-up: example GCP element



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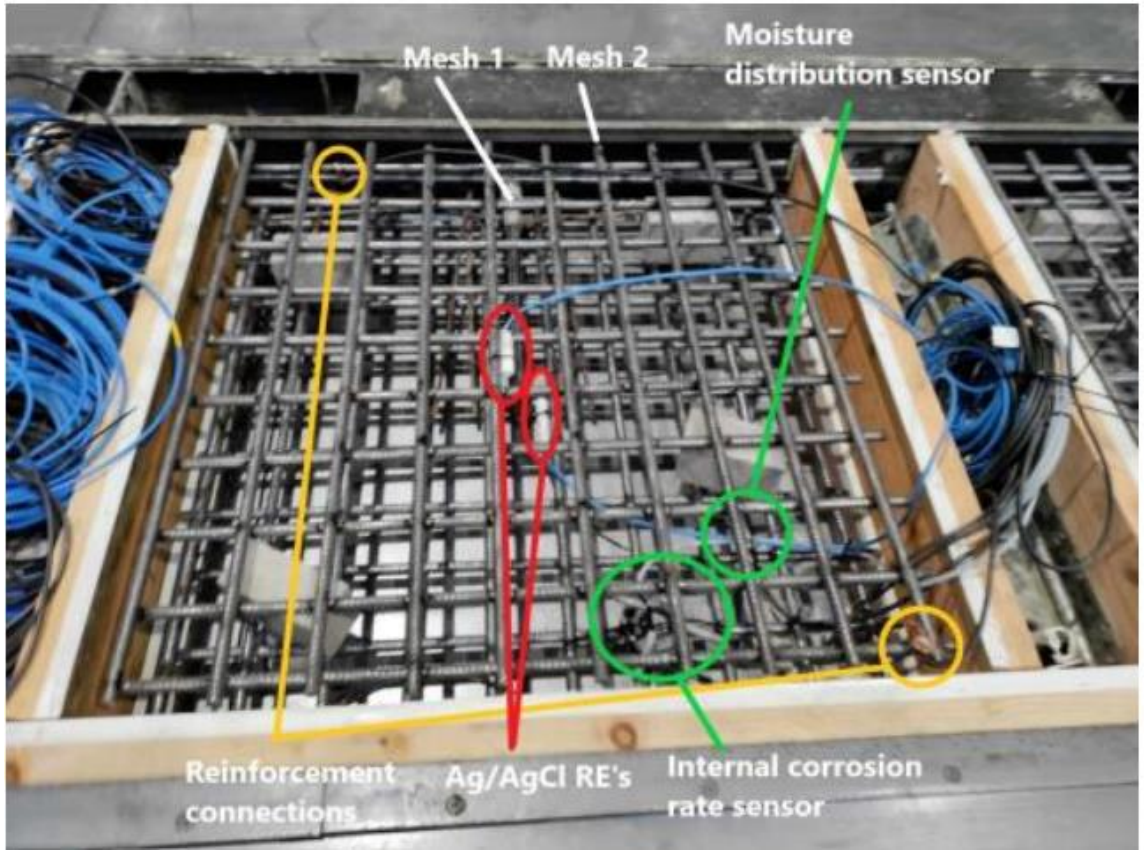
Demo-wall set-up: example reference element



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System monitoring

- Initial control measurements (81 days after pouring the concrete)
- CP start-up and parameter measurements (91 days after pouring the concrete)
- Depolarization measurement (105 days after pouring the concrete)
- LPR measurement (90 and 106 days after pouring the concrete)

Initial control measurements

TiMMO mesh element	Potential difference [mV]	Resistance [Ω]
Source1 – RE1	0,0	0,144
Source2 – RE2	0,0	0,107
RE1 – RE2	-27,2	8,240
TiMMO mesh – RE1/RE2	-319	2,801

TiMMO mesh element	Potential difference [mV]
RE A1	-272
RE B1	-247
RE C1	-532
RE A2	-261

Potential, mV vs SCE	Potential, mV vs Ag/AgCl	Probability of Corrosion (%)
More –ve than -275	More –ve than -255	.> 90 (active)
Between -275 to -125	Between -255 to -105	Uncertain
More + ve than -125	More + ve than -105	< 10 % (passive)

(ASTM C 876 - 09, 2001)

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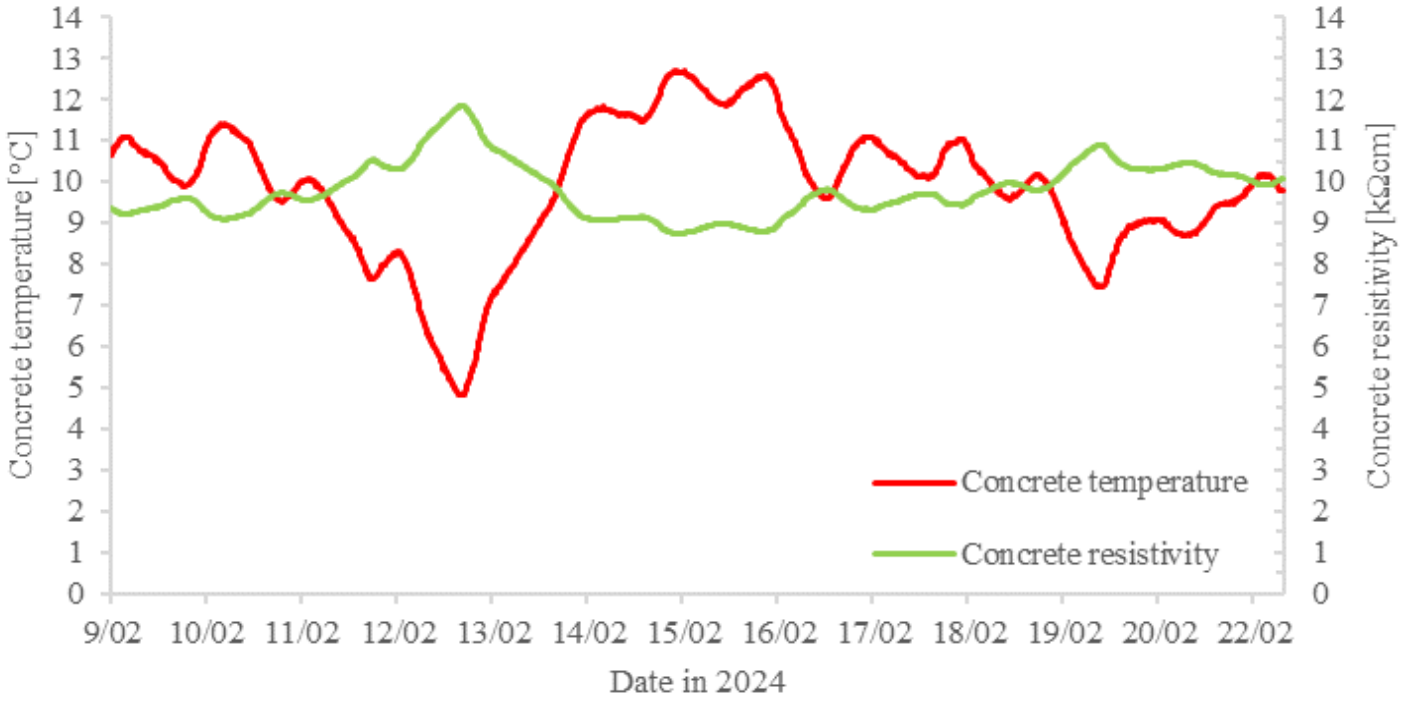
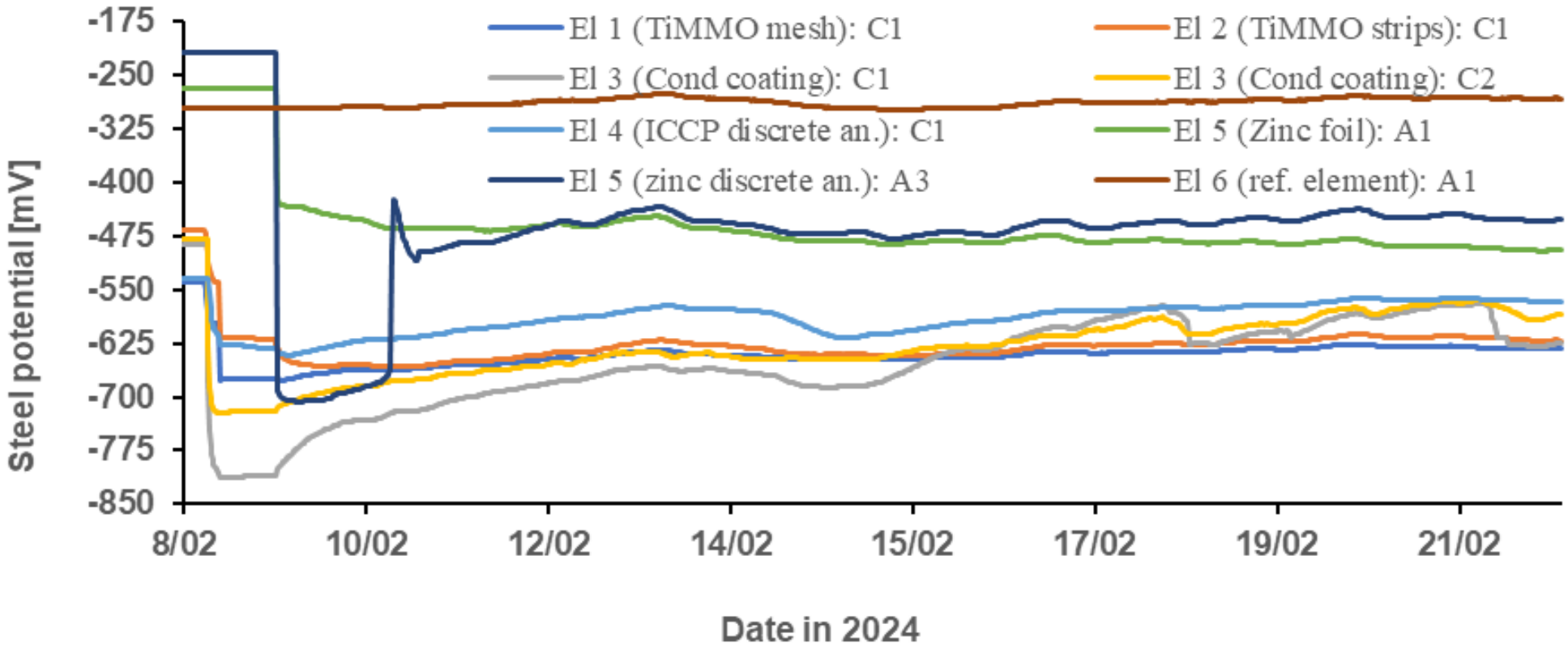
CP start-up and parameter measurements

TiMMO mesh element (2V) (current peak of 102 mA)	Potential difference: OFF [mV]	Potential difference: 40 min ON [mV]	$\Delta E: OFF - ON$
RE A1	-272	-465	193
RE B1	-247	-493	246
RE C1	-532	-675	143
RE A2	-261	-303	42



CP start-up and parameter measurements



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CP start-up and parameter measurements

- Over the week study period → decrease in current output → Increase in uniformity

Element	Total current after two weeks [mA/m²concr]	Current to mesh 1 [mA/m² steel]	Current to mesh 2 [mA/m² steel]
Element 1 (TiMMO mesh)	36	25 (69%)	11 (31%)
Element 2 (TiMMO strips)	37	24 (65%)	13 (35%)
Element 3 (Cond. coating 1)	40	36 (90%)	4 (10%)
Element 3 (Cond. coating 2)	38	32 (84%)	6 (16%)
Element 4 (ICCP discr. an.)	27	16 (59%)	11 (41%)
Element 5 (Zinc foil)	26	40 (77%)	12 (23%)
Element 5 (Zinc discr. an.)	42	44 (52%)	40 (48%)

Depolarization measurement and LPR measurements

Relative to RE for mesh 1	24h depol. [mV]	Relative to RE for mesh 2	24h depol. [mV]
El1 (TiMMO mesh): C1	107	El1 (TiMMO mesh): A2	62
El2 (TiMMO strips): C1	171	El2 (TiMMO strips): A2	106
El3 (cond. coating): C1	157	El3 (cond. coating): A3	53
El3 (cond. coating): C2	128	El3 (cond. coating): A4	56
El4 (ICCP discr. an.): C1	84	El4 (ICCP discr. an.): A2	56
El5 (zinc foil): A1	225	El5 (zinc foil): C2	73
El5 (zinc discr. an.): A3	235	El5 (zinc discr. an.): A4	135

Element	iCORR [µA/cm2] before start	iCORR [µA/cm2] after two weeks
TiMMO mesh	4,86	4,56
Reference element	3,29	3,18

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Conclusions

- The different components and different types of CP systems are addressed, compared and discussed → theory converted into practice
- Create sufficient insight for stakeholders → focus on design, execution and monitoring
- A negative correlation can be observed between the concrete temperature and resistivity
- An increase in potential and decrease in current can be noticed for an increment in concrete resistivity
- Current of 14 mA/m²st not sufficient due to the high corrosion degree
- The results of a 24h depolarization measurement can be evaluated based on the distance to the anode

Website: https://www.odisee.be/Kathodische-bescherming-beton/demo-wall-kathodische-bescherming

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Thank you for listening!

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