Cathodic protection of precast, prestressed multistory car park slabs, using a surface applied galvanic zinc layer anode.

Roberto Giorgini [1], *Frédéric* Souchal [2], *Michel* Grill [3], *Christophe* Michaux [4], *Leon* Thyes [5]

[1] CorrPRE - Special anodes Manufacturing, Moordrecht - Netherlands
[2] 4m Group, Battice - Belgium
[3 4 5] Sixence In-Situ / Vinci - Livange - Luxembourg

ABSTRACT. A surface applied galvanic Zinc Layer Anode (ZLA) system was installed on a multistory carpark structure to provide cathodic protection to the soffits of the prestressed hollow concrete slabs, which were suffering from chloride induced corrosion deterioration. This paper evaluates the cathodic protection system performance against the international standard for Cathodic Protection of Steel in Concrete, ISO 12696 [13], 17 months after commissioning.

A surface applied galvanic Zinc Layer Anode was selected to provide cathodic protection, as this offered a low risk of exceeding the hydrogen embrittlement potential and provided a unique application approach, which was compatible with the hollow slab construction.

During the pilot phase, a total of 40 m^2 of ZLA was applied into two anode zones and monitored for a month, to prove concept and system performance. Following the pilot phase the remainder of the cathodic protection works were completed, extending to a total concrete area of 320 m^2. The installed system was provided with embedded reference electrodes and wired to enable full performance evaluation as per the requirements of ISO 12696. Three battery powered web-based monitoring devices were used for remote system monitoring and performance assessment.

The initial performance data following 17 months of operation, identified that all 12 reference electrodes installed across the 6 anode zones all met the 100mV depolarization criteria within a 24-hour period, as per the requirements of clause 8.6b of ISO 12696. The anode to cathode current was also recorded continuously over this operational period and used to evaluate environmental effects and predicted actual anode service life.

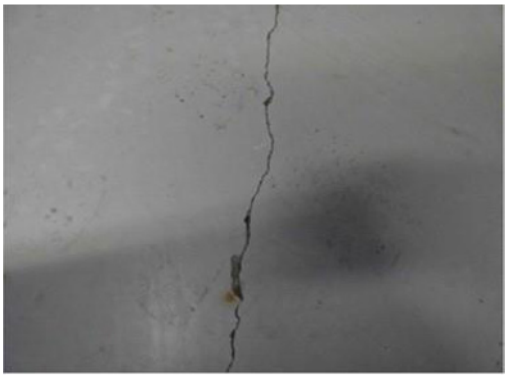
1 Introduction

The object in question concerns a steel reinforced concrete car park located at Contern in the southern part of Luxembourg. The carpark construction consisted of precast prestressed hollow concrete slabs installed in a transverse beam-column configuration, which resulted in an expansion joint being formed between individual precast slabs. The joints had been leaking for many years, which resulted in chloride contaminated water dripping through the joint onto the slab soffits, leading to corrosion of the prestressed tendons and subsequent concrete deterioration around the joint.

During inspections performed in early 2020 it became clear that the years of leakage at the central transverse beam-column joint had penetrated into the bridge deck initiating corrosion of the prestressed steel tendons. Figure 1 shows a general view of the car park interior.

Fig 1: General view of the car park.

* Corresponding author: r.giorgini@corrpre.com



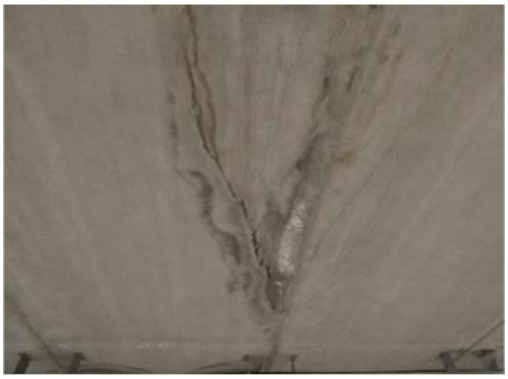


Fig. 2, 3, 4 and 5. Due to leakage of the central beam-column joint, moisture could easily penetrate inside the hollow slabs causing cracks all over the slab.

Fig. 6 and 7. During the verifications, corroded tendons were found.

As an economic remediation solution it was recommended to apply a cathodic protection (CP) system preferably a surface-applied galvanic CP system [2] as this would pose no risk of hydrogen embrittlement of the prestressed tendons, and as specified by the owner would allow for at least 10 years of corrosion control [6] [7] [9] [10] [12].

2 Description

The car park, constructed in 2005, consists of a beam-column structure with transversely placed prestressed hollow concrete slabs shown in Fig. 8 with a 1,20m width.

Two types of slabs were placed of which on one side of the joint in zones 1, 3 and 5, hollow slabs with 12mm diameter tendons as shown in Fig. 9, and on the other side of the joint in zones 2, 4, and 6 hollow slabs with 5mm diameter tendons as shown in Fig. 10. The total steel surface area of the slabs located in zones 1, 3 and 5 having 7x tendons with a diameter of 12mm and 1 tendon with a diameter of 14mm is : 0,31 m^2 steel/m^2 concrete and the total steel surface area of the slabs located in zones 2, 4 and 6 having 12x tendons with a diameter of 5mm and 1 tendon with a diamater of 14mm is : 0,23 m^2 steel/m^2 concrete

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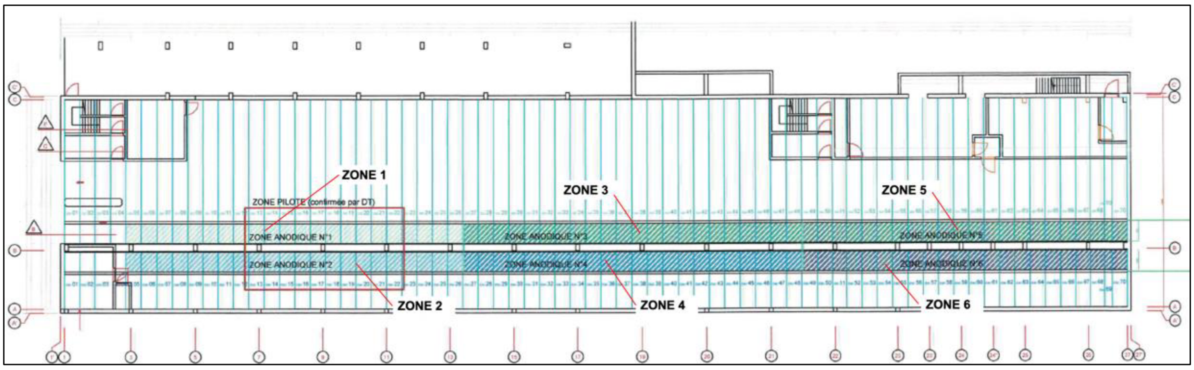

Fig. 8. Sketch of the car park structure

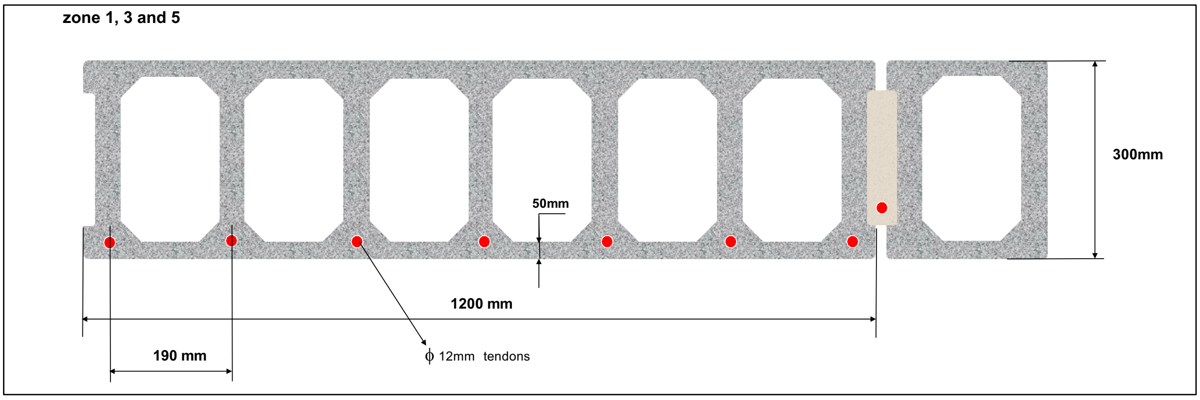

Fig. 9. Slabs located in zones 1, 3, and 5

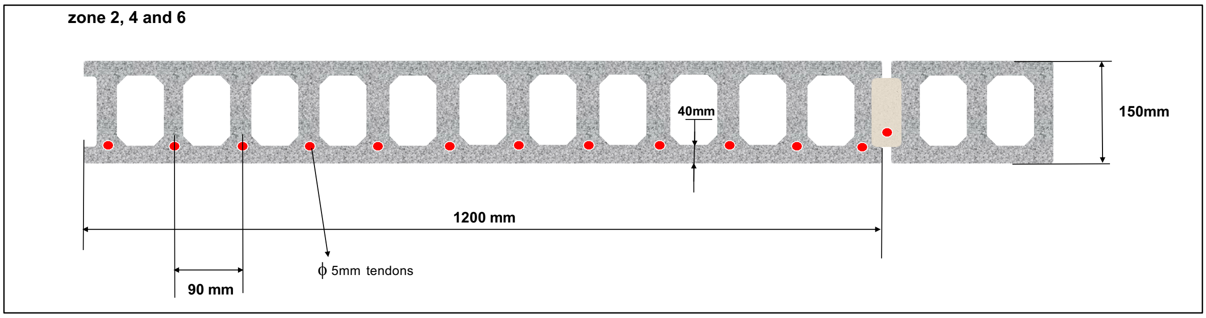

Fig. 10. Slabs located in zones 2, 4 and 6

3 Application

The Zinc Layer Anode system used for this project consists of a high purity zinc foil, complete with an ion-conductive, auto moistening, humectant/activator/adhesive layer, which is designed to be surface mounted onto the surface of concrete structures.

Based on previous inspection results it was decided to apply the ZLA on an area on both sides all along the main joint with a width of 1,67m (Fig.11 and 12) covering a total of 320 m^2 surface area. The 320 m^2 ZLA was devided in 6 equal zones of each appr. 53 m^2. In total, three battery powered web-based monitoring devices were installed together with 12 ERE reference electrodes.

4 Results

Parameters like potential decay values and current outputs were measured, recorded and sent through a SIM card to a main server. Every individual with valid login codes had access to these monitoring readings which have been logged since start-up and are presented online through tables and graphs. Instant-off potentials and potential decay scans can be programmed in advance through the website. In total 3 monitoring devices have been installed of which

- Device 1 : monitors zone 1 and 2,
- Device 2 : monitors zone 3 and 4,
- Device 3 : monitors zone 5 and 6

* Corresponding author: r.giorgini@corrpre.com

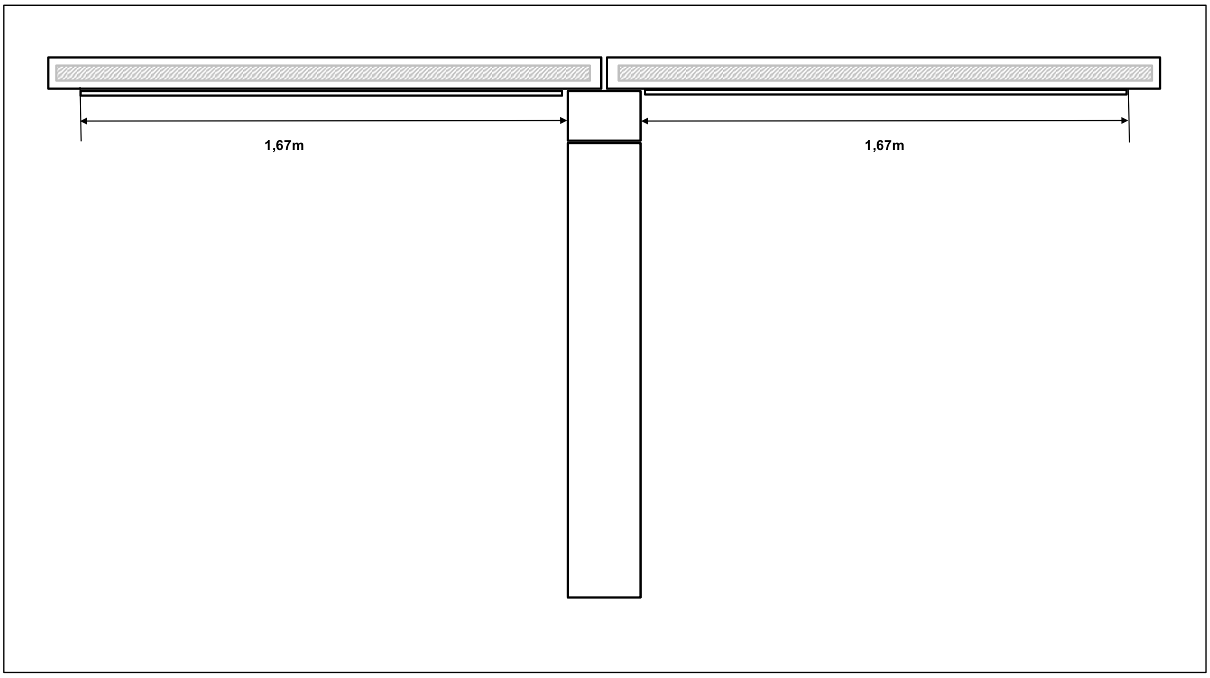

Fig. 11. ZLA applied up till 1,67m on both sides of the joint all along the joint

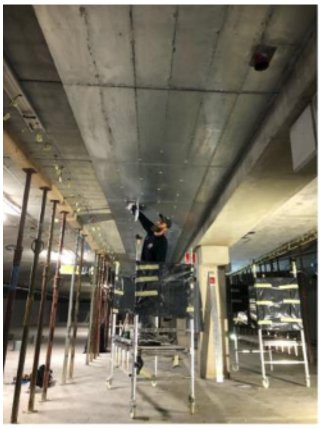

Fig. 12 ZLA application in zone 2

Fig. 13 Steel (negative) connections

Fig. 14 ZLA (positive) connections

Table 1 Details of Monitoring Devices

	Anodes	Reference electrode channels			
Monitoring device	**channels**	**1**	**2**	**3**	**4**
1	channel 1 : zone 1	Ref 1	Ref 2		
	channel 2 : zone 2			Ref 3	Ref 4
2	channel 1 : zone 3	ERE 1	ERE 2		
	channel 2 : zone 4			ERE 3	ERE 4
3	channel 1 : zone 5	ERE 1	ERE 2		
	channel 2 : zone 6			ERE 3	ERE 4

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The internal channels of the monitoring devices are linked in the following way:

Monitoring device nr 1 (zone 1 and zone 2) The monitoring devices can be pre-programmed to switch off the current on any date and time. The tables and graphs below show the current and potential decay readings of all 6 zones and 12 Reference electrodes.

Fig. 15. One of three remote monitoring devices

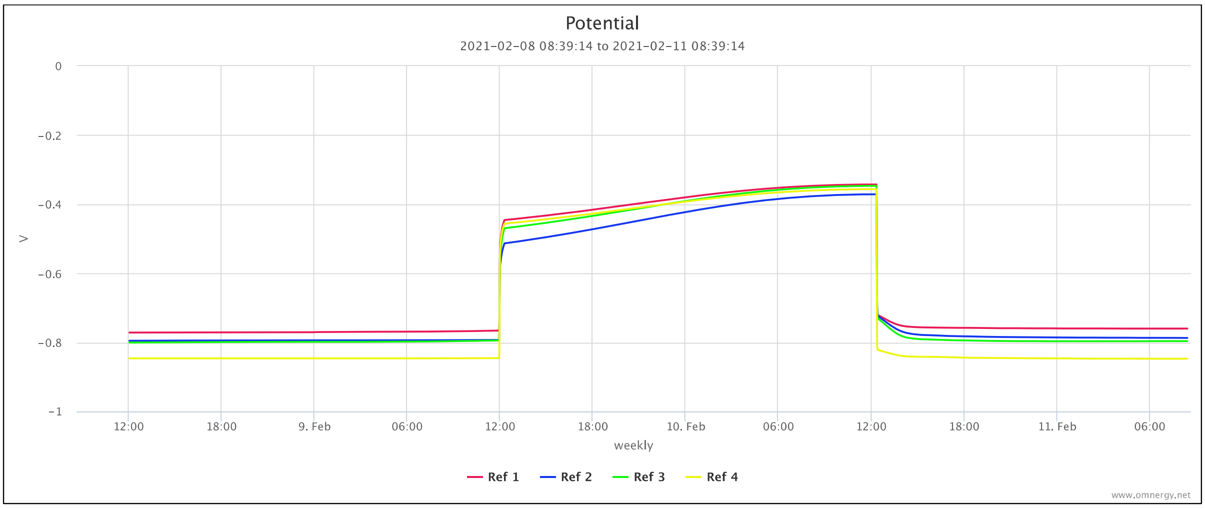

Fig. 16. Potential decay curves of zone 1 and zone 2 performed in Febr. 2021

Table 2 Instant-off potential decay over <24hr for each Ref. electrode of zone 1 and zone 2 acc. ISO12696

Monitoring device 1								
Ref. electrodes	on		Instant off		mV / 24hr off		depol <24hr	
Ref 1	-0,7703	V	-0,708	V	-0,3429	V	365	mV
Ref 2	-0,7942	V	-0,724	V	-0,3714	V	353	mV
Ref 3	-0,7986	V	-0,74	V	-0,3468	V	393	mV
Ref 4	-0,8463	V	-0,758	V	-0,3562	V	402	mV

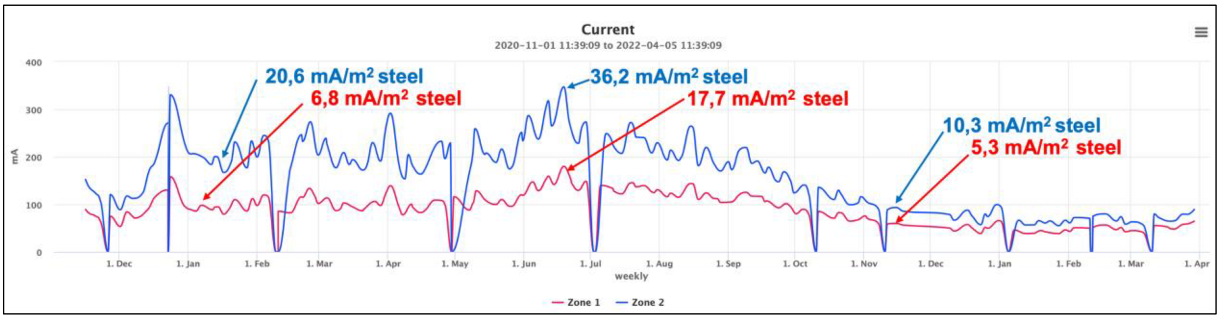

Fig. 17. GACP current output zone 1 and zone 2 over almost 17 months

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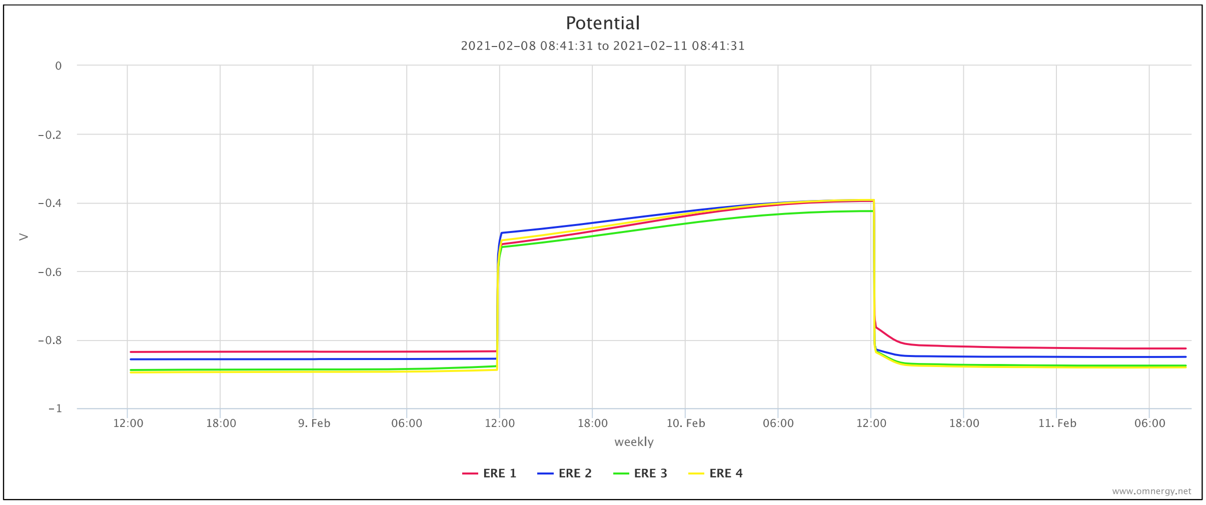

Fig. 18. Potential decay curves of Monitoring Device No. 2, zone 3 and zone 4 performed in Feb. 2021

Table 3 Instant-off potential decay over <24hr for each Ref. electrode of zone 3 and zone 4 acc. ISO12696

Monitoring device 2									
Ref. electrodes	on		Instant off		mV / 24hr off		depol <24hr	
ERE 1	-0,834	V	-0,7835	V	-0,3951	V	388	mV
ERE 2	-0,8555	V	-0,7576	V	-0,3925	V	365	mV
ERE 3	-0,8772	V	-0,7774	V	-0,4247	V	353	mV
ERE 4	-0,8882	V	-0,7823	V	-0,3919	V	390	mV

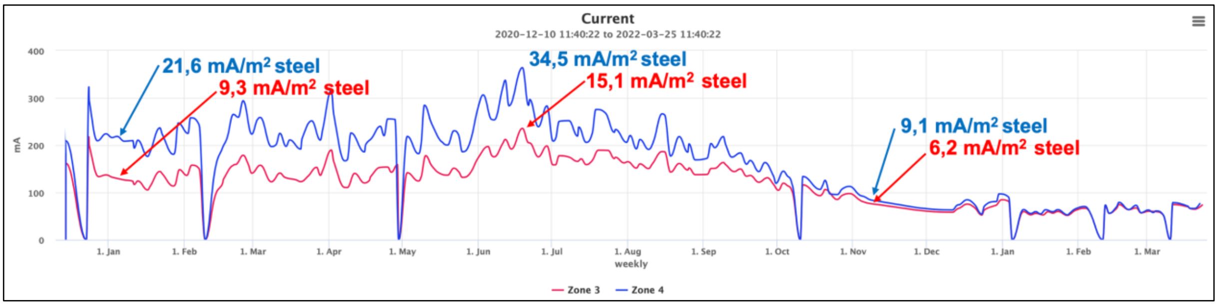

Fig. 19. GACP current output zone 3 and zone 4 over almost 17 months

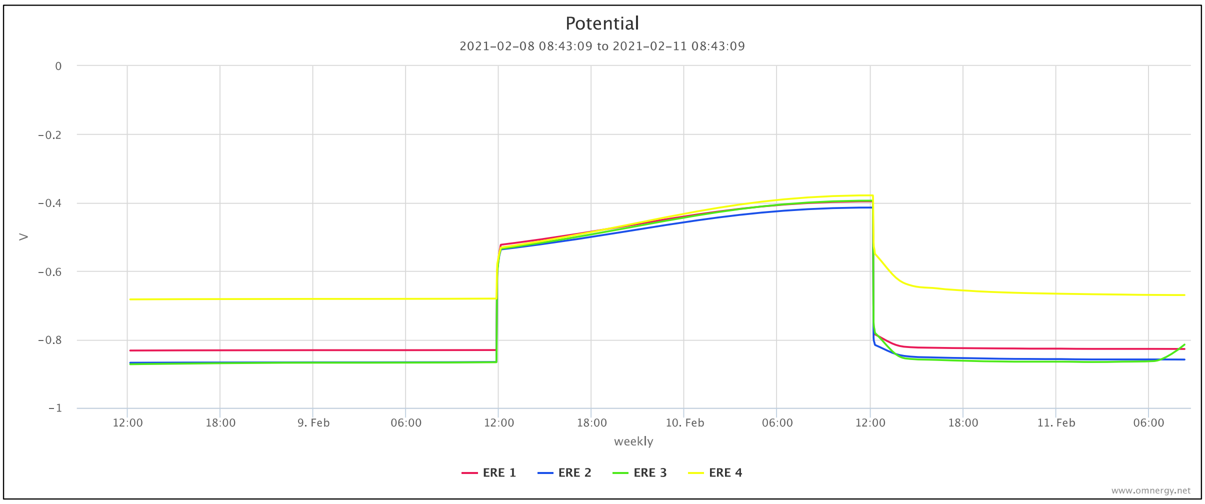

Fig. 20. Potential decay curves of Monitoring Device No. 3 zone 5 and zone 6 performed in Febr. 2021

Table 4 Instant-off potential decay over <24hr for each Ref. electrode of zone 5 and zone 6 acc. ISO12696

Monitoring device 3								
Ref. electrodes	on		Instant off		mV / 24hr off		depol <24hr	
ERE 1	-0,8312	V	-0,7581	V	-0,3959	V	362	mV
ERE 2	-0,8662	V	-0,7541	V	-0,4142	V	340	mV
ERE 3	-0,8667	V	-0,7678	V	-0,394	V	374	mV
ERE 4	-0,6805	V	-0,6599	V	-0,3785	V	281	mV

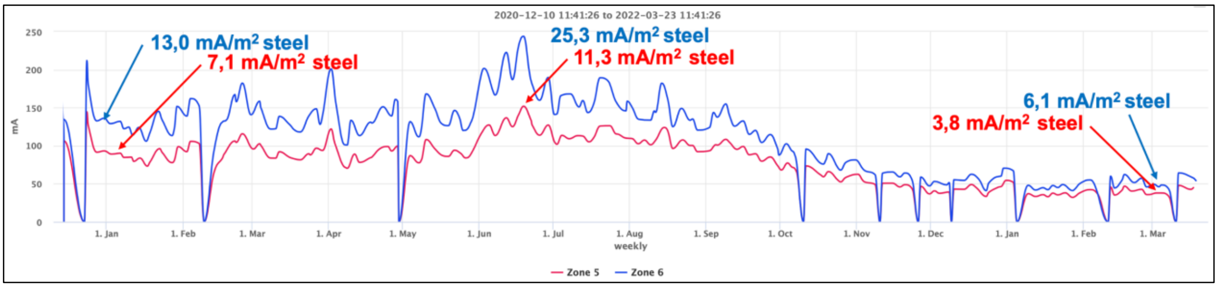

Fig. 21. GACP current output zone 5 and zone 5 over almost 17 months

Table 5 below shows the potential decay readings performed in Nov. 2021.

Table 5 Potential decay readings in Nov 2021

	on [mV]	Instant off [mV]	24hr off [mV]	depol. < 24hrs
zone 1	-606	-576	-296	280
	-558	-534	-316	218
zone 2	-693	-655	-294	361
	-745	-711	-327	384
zone 3	-773	-727	-409	318
	-750	-700	-375	325
zone 4	-836	-748	-388	360
	-687	-632	-352	280
zone 5	-764	-722	-353	369
	-663	-619	-350	269
zone 6	-738	-678	-326	352
	-522	-514	-348	166

Considering an avarage current ouput for each zone, we are able to calculate the anode and steel current densities :

Zone 1 : with an average of appr. 89 mA, an anode surface area of 54,76 m^2, and steel surface area of 13,17 m^2, will give an avarage anode current density of 1,63 mA/m^2, and a steel current density of 6,8 mA/m^2 .

Zone 2 : with an average of appr. 162 mA, an anode surface area of 54,86 m^2, and steel surface area of 9,26 m^2, will give an avarage anode current density of 2,95 mA/m^2, and a steel current density of 17,5 mA/m^2 .

Zone 3 : with an average of appr. 142 mA, an anode surface area of 58,09 m^2, and steel surface area of 15,33 m^2, will give an avarage anode current density of 2,44 mA/m^2, and a steel current density of 9,3 mA/m^2 .

Zone 4 : with an average of appr. 203 mA, an anode surface area of 54,84 m^2, and steel surface area of 10,42 m^2, will give an avarage anode current density of 3,70 mA/m^2, and a steel current density of 19,5 mA/m^2 .

Zone 5 : with an average of appr. 94 mA, an anode surface area of 52,49 m^2, and steel surface area of 13,28 m^2, will give an avarage anode current density of 1,79 mA/m^2, and a steel current density of 7,1 mA/m^2 .

Zone 6 : with an average of appr. 128 mA, an anode surface area of 49,87 m^2, and steel surface area of 9,88 m^2, will give an avarage anode current density of 2,57 mA/m^2, and a steel current density of 13,0 mA/m^2 .

The erratic pattern over time of the current outputs of each zone as seen in the above figures 17, 19 and 21 can be attributed to the seasonal and daily ambient temperature fluctuations. These phenomena have been noticed in several other projects [8].

Fig. 22 shows the ambient temperature vs. current output of ZLA installed on carpark slabs and supports at ARC 2000 in France. The direct relation between the ambient temperature and the current output can be clearly seen.

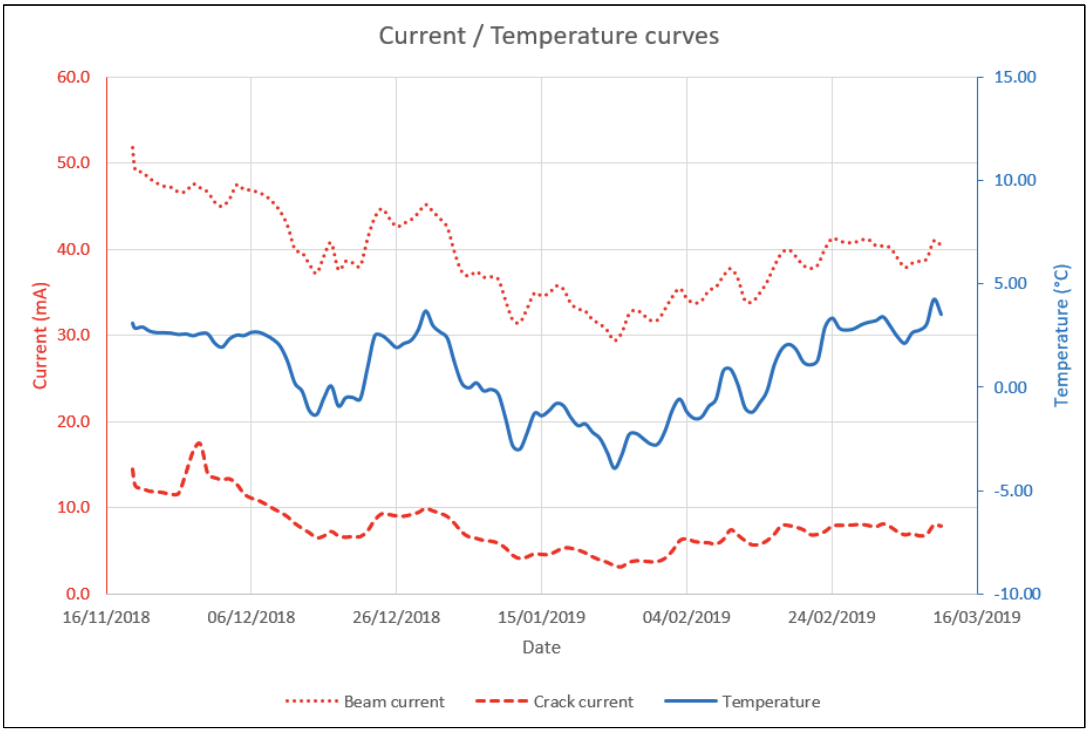

Fig. 22. ZLA current output vs. ambient temperature

Table 6 Instant Off Potential Values from Monitoring Devices

Monitoring device			**2nd week Febr. 2021**	**2nd week Nov. 2021**
1	zone 1	Ref 1	365 mV	280 mV
		Ref 2	353 mV	218 mV
	zone 2	Ref 3	393 mV	361 mV
		Ref 4	402 mV	384 mV
2	zone 3	ERE 1	388 mV	318 mV
		ERE 2	365 mV	325 mV
	zone 4	ERE 3	353 mV	360 mV
		ERE 4	390 mV	280 mV
3	zone 5	ERE 1	362 mV	369 mV
		ERE 2	340 mV	269 mV
	zone 6	ERE 3	374 mV	352 mV
		ERE 4	281 mV	166 mV

5 Conclusions

ISO12696 [13] indicates the 3 criteria which a CP system should meet for satisfactory steel in concrete corrosion protection. Basically ISO12696 says "For any structure, any representative steel in concrete location shall meet any one of the criteria given in items 1 to 3 :

1. an “Instantaneous OFF” potential more negative than −720 mV with respect to Ag/AgCl/0,5 M KCl; or
2. a potential decay over a maximum of 24 h of at least 100 mV from “Instantaneous OFF”; or
3. a potential decay over an extended period (typically 24 h or longer) of at least 150 mV from the instant off subject to a continuing decay and the use of reference electrodes (not potential decay probes) for the measurement extended beyond 24 h.

We can pick out one of the three choices and normally for CP of steel reinforced concrete structures we use criteria nr. 2 which is a potential decay over a maximum of 24hrs from instant-off [1]. Using the readings from the 3 monitorings devices above we will get instant-off potential decay values over a maximum of 24hrs :

We can conclude that :

1. The CP system fully complies with the international code based criteria ISO12696 for satisfactory corrosion protection of steel reinforcement in concrete which is a potential decay of more than 100 mV from Instant-off over a maximum of 24hrs [4] [11].

2. Considering the ON potentials of the ERE reference electrodes between -800mV and -900mV which is in the range of -625mV to -725mV SCE which is well above the -850mV SCE (-1025mV ERE) criteria as a limit for prestressing steel according ISO12696, there should be no risk for hydrogen embrittlement [2] [12] .

3. Due to high initial steel current densities over a period of almost 1 year it can be ascertained that the prestressed tendons will be re-passivated within a relatively short period [3] [5].

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* Corresponding author: r.giorgini@corrpre.com