Cathodic Protection of Precast, Prestressed Multistory Carpark Slabs, using a Surface Applied Galvanic Zinc Layer Anode.

ABSTRACT

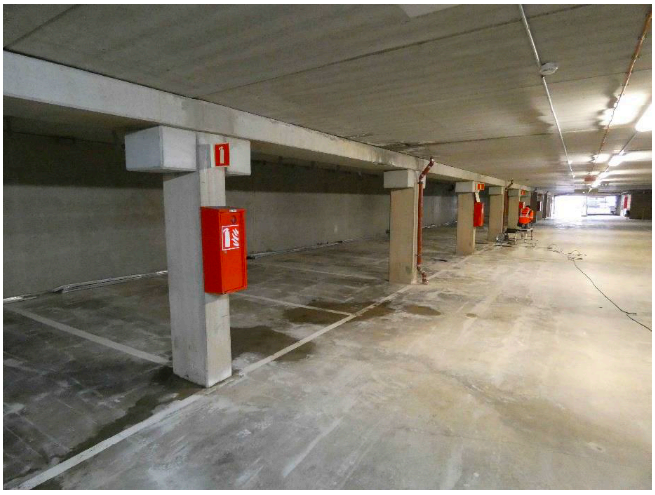
A surface applied galvanic Zinc Layer Anode (ZLA) system was installed onto a multistory carpark structure to provide cathodic protection to the soffits of the prestressed hollow concrete slabs, which were suffering from chloride induced corrosion deterioration. This paper evaluates the cathodic protection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

The carpark construction consisted of precast prestressed hollow concrete slabs installed in a transverse beam-column configuration, which resulted in an expansion joint been formed between individual precast planks. 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.

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

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 3 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.



INTRODUCTION

The object in question concerns a steel reinforced concrete car park located in the southern part of Luxembourg. During inspections performed in early 2020 it became clear that years of leakage at the central transverse beam-column joint allowed chlorides originating from the de-icing salts in winter periods carried by vehicles entering and leaving the car park penetrated into the bridge deck initiating corrosion of the prestressed steel tendons. As an economic remediation solution it was recommended to apply a cathodic protection (CP) system preferably a surface-applied galvanic CP system as this would pose no risk of hydrogen embrittlement of the prestressed tendons, and as specified by the owner would give for at least 10 years of corrosion control.

DESCRIPTION

The car park constructed in 2005 consists of a beam-column structure with transversely placed prestressed hollow concrete slabs shown in Fig. 2 with a 1,20m width.

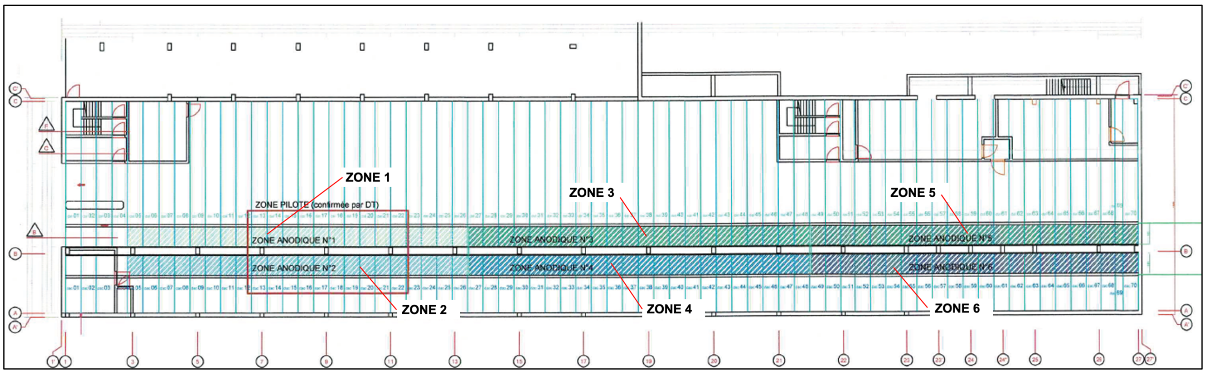


Fig. 2 Sketch of the car park structure

Two types of slabs were placed of which on one side of the joint in zone 1, 3 and 5 hollow slabs with 12mm diameter tendons as shown in Fig. 3, and on the other side of the joint in zones 2,4, and 6 hollow slabs with 5mm diameter tendons as shown in Fig. 4.

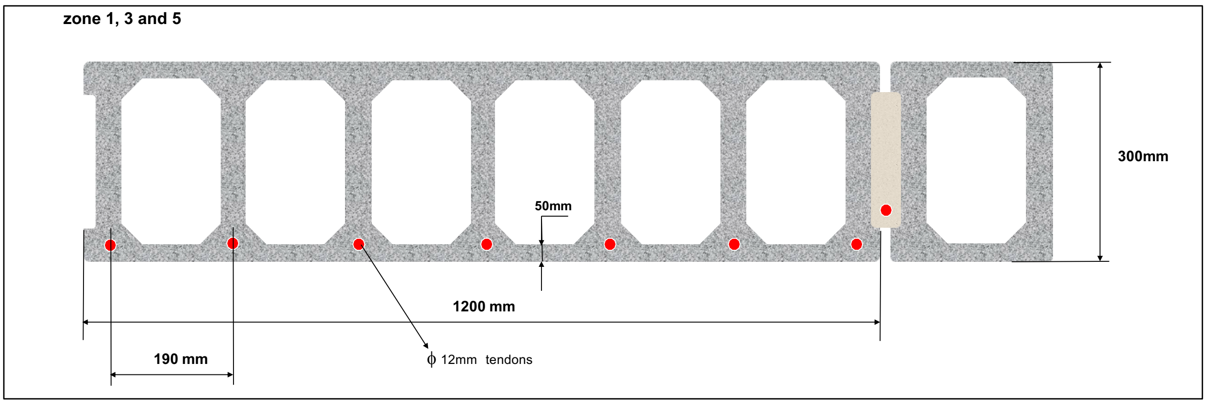


Fig. 3 Slabs located in zones 1, 3, and 5

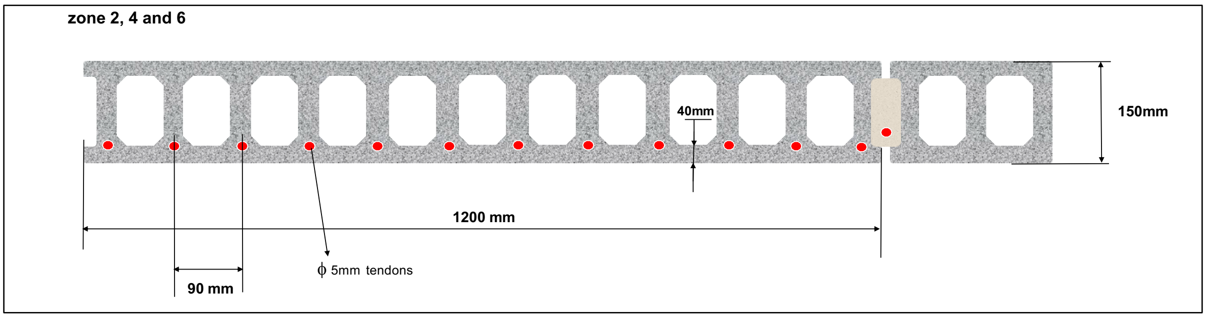


Fig 5 Slabs located in zones 2, 4 and 6

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 dimater 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 dimater of 14mm is : 0,23 m^2 steel/m^2 concrete.

APPLICATION

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. 6 and 7) covering a total of 320 m^2 surface area.

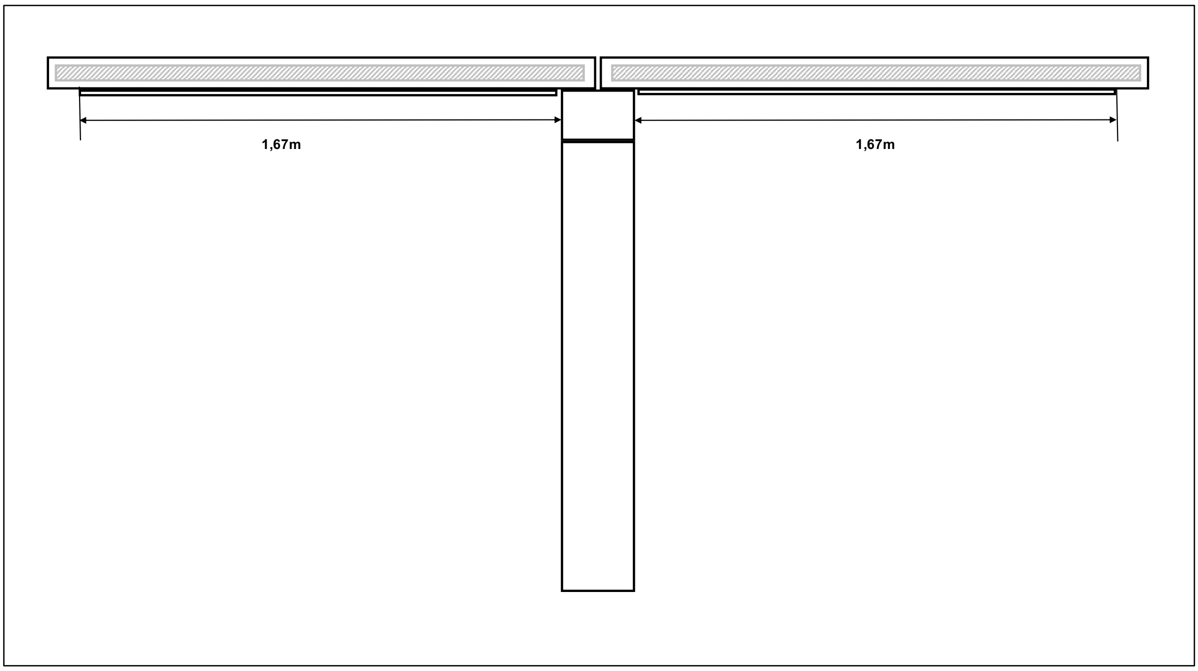


Fig. 6 ZLA applied up till 1,67m on both sides of the joint all along the joint.

Fig. 6 ZLA application in zone 2.

The 320 m^2 ZLA was devided in 6 equal zones of each appr. 53 m^2.

RESULTS

In total three battery powered Web-based monitoring devices were installed together with 12 ERE reference electrodes. Parameters like potential decay values and current outputs are measured, recorded and send through a SIM card to a main server located in the UK. Every one with valid login codes have access to the these monitoring readings which are logged since start-up presented online through tables and graphs. Instant-off potentials and potential decay scans can be programmed in advanced through the Website.

In total 3 monitoring devices are installed of which :

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

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

TABLE 1

	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

Fig. 7 One of three remotely monitoring devices

All three monitoring devices were pre-programmed to switch off the current of all monitoring devices on dd. 9th Febr. 2021 at noon. The Tables and Graphs below show the current and potential decay readings of all 6 zones and 12 ERE reference electrodes.

Monitoring device nr 1 (zone 1 and zone 2)

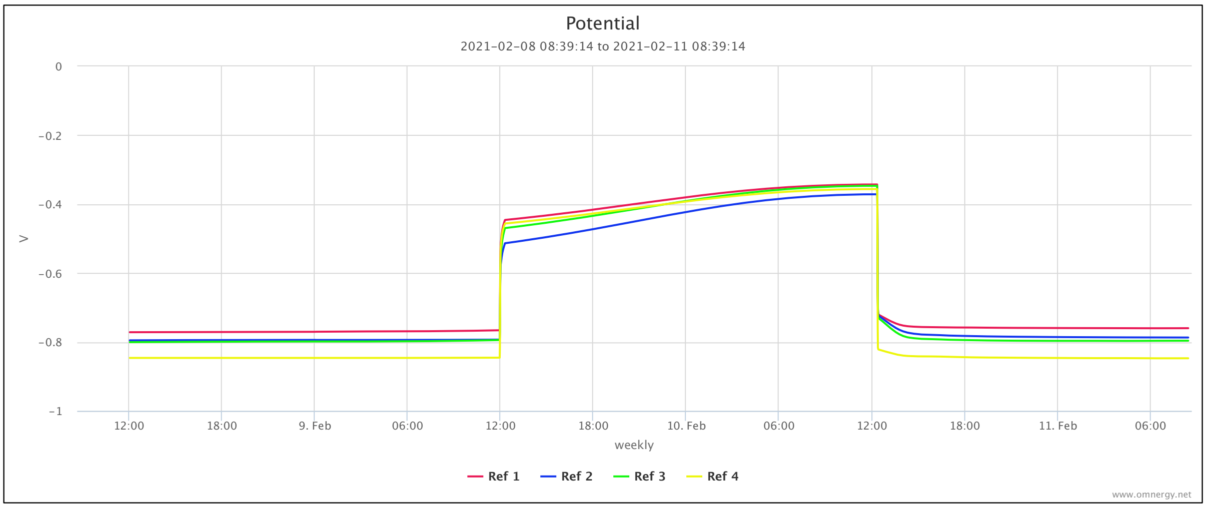


Fig. 8 Potential decay curves of zone 1 and zone 2

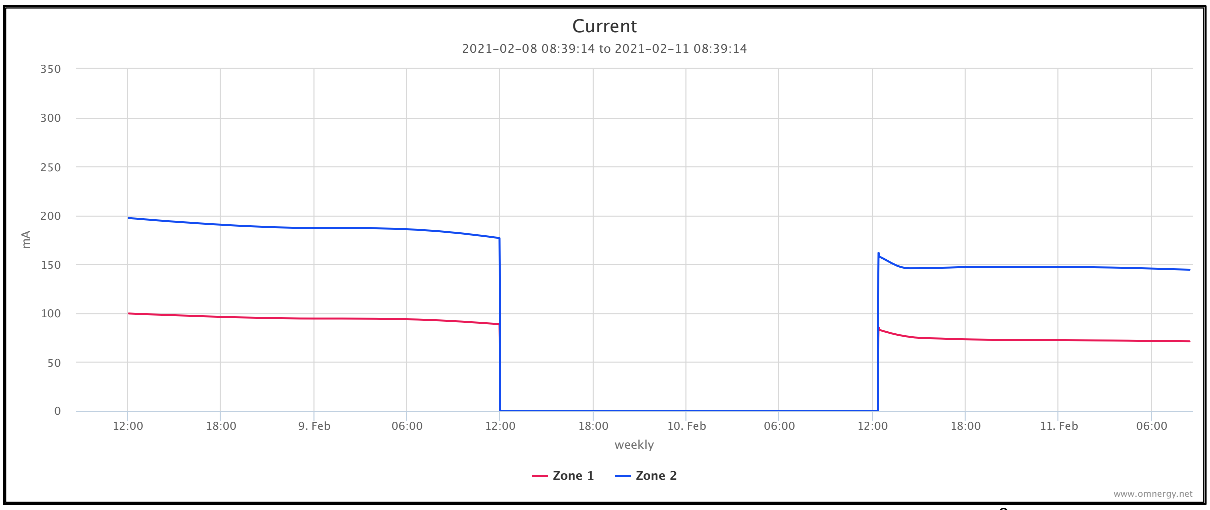


Fig. 9 GACP current output of zone 1 and zone 2 each appr. 53m^2 ZLA

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

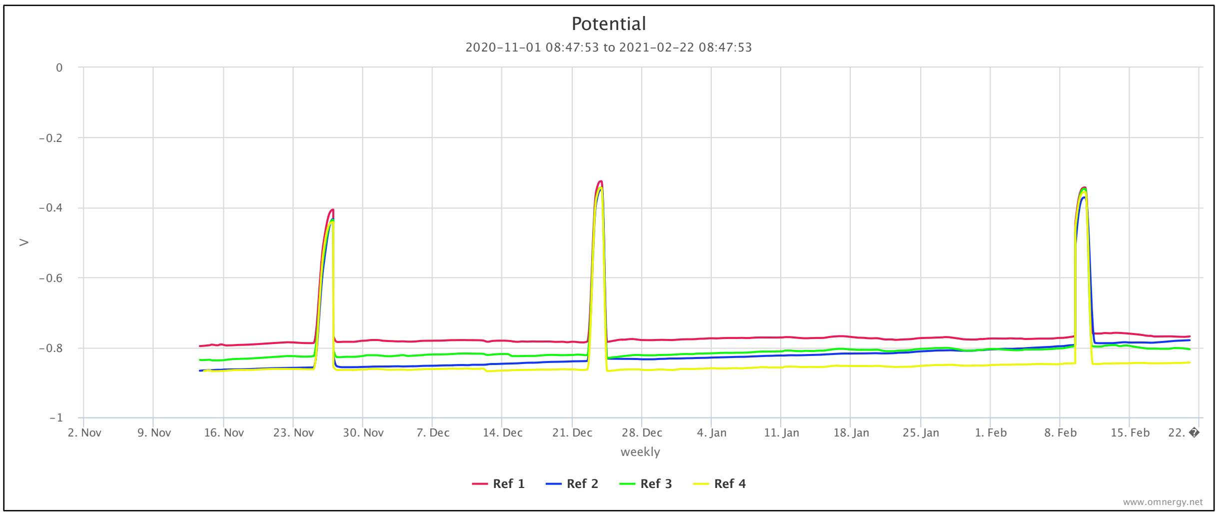


Fig. 10 Potentials since start-up of zone 1 and zone 2

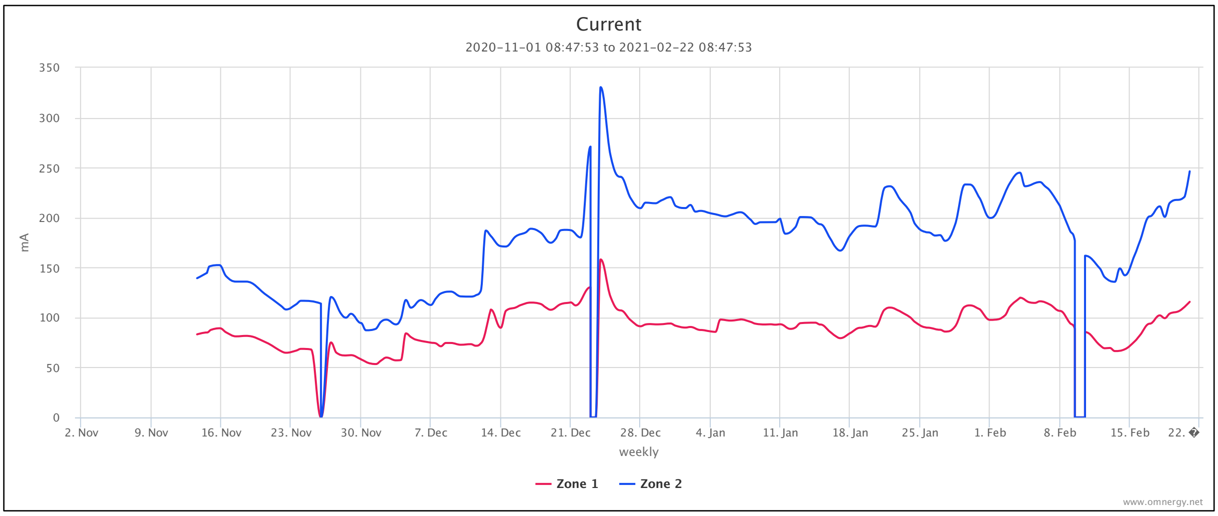


Fig.11 GACP current output since start-up of zone 1 and zone 2

Monitoring device nr 2 (zone 3 and zone 4)

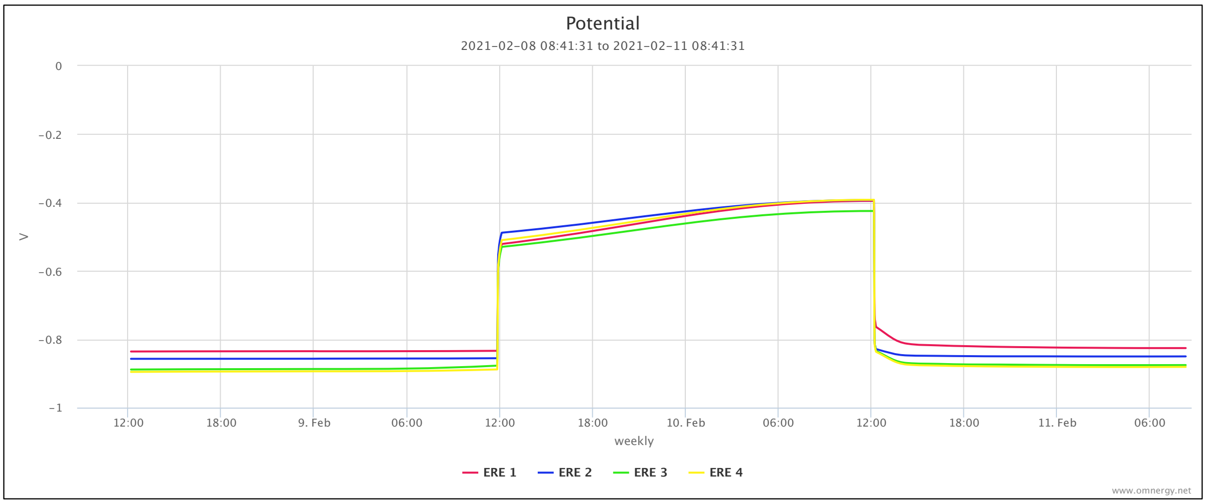


Fig. 12 Potential decay curves of zone 3 and zone 4

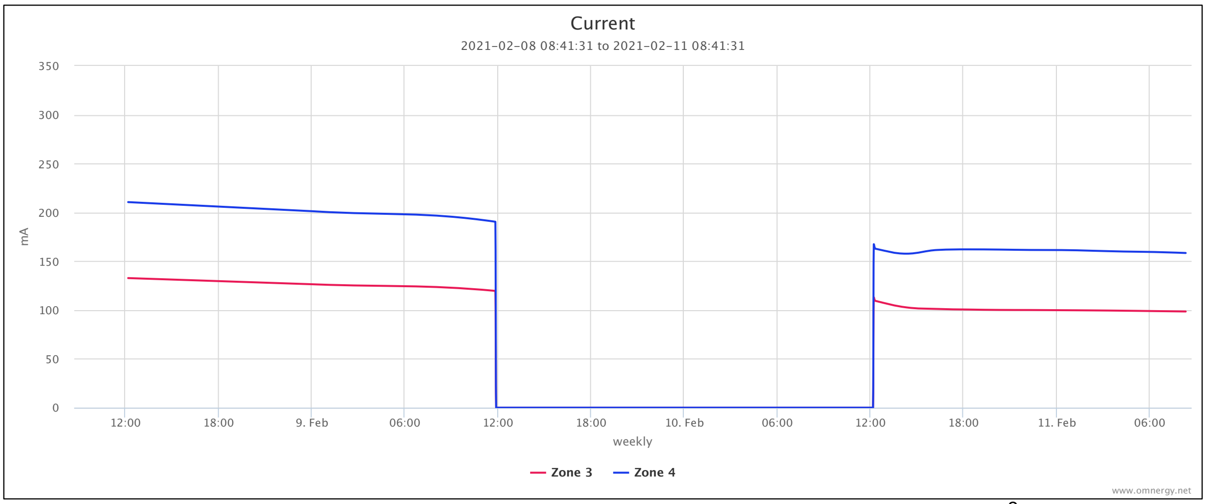


Fig. 13 GACP current output of zone 3 and zone 3 each appr. 53m^2 ZLA

TABLE 2 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

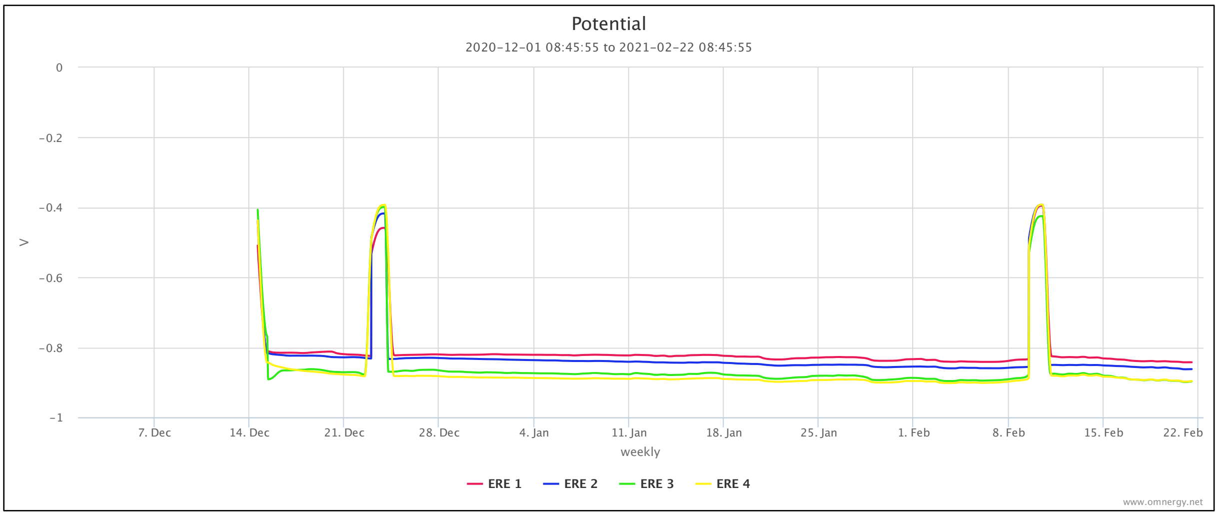


Fig. 14 Potentials since start-up of zone 3 and zone 4

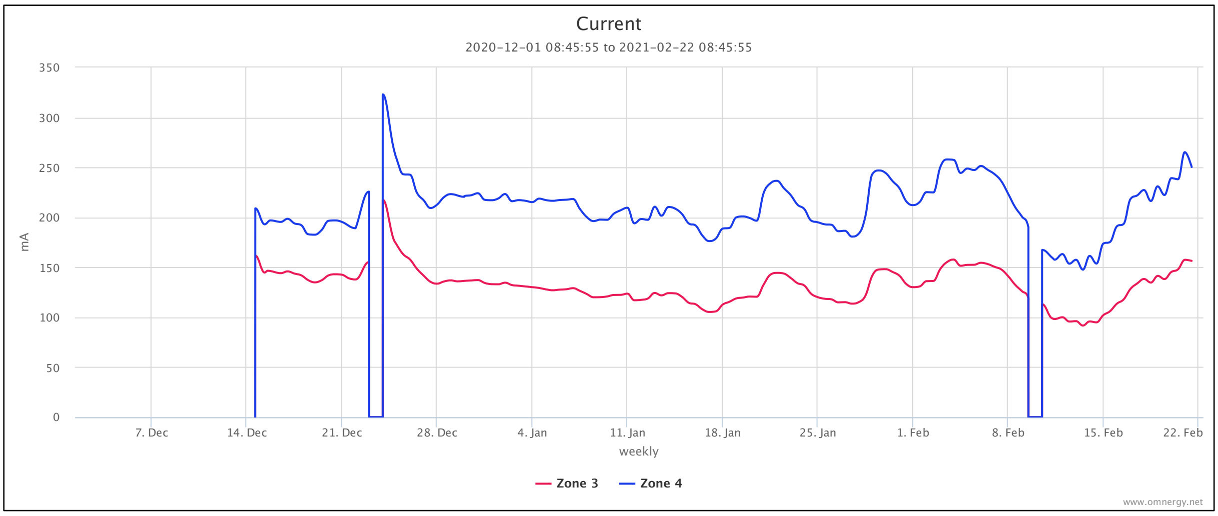


Fig.15 GACP current output since start-up of zone 3 and zone 4

Monitoring device nr 3 (zone 5 and zone 6)

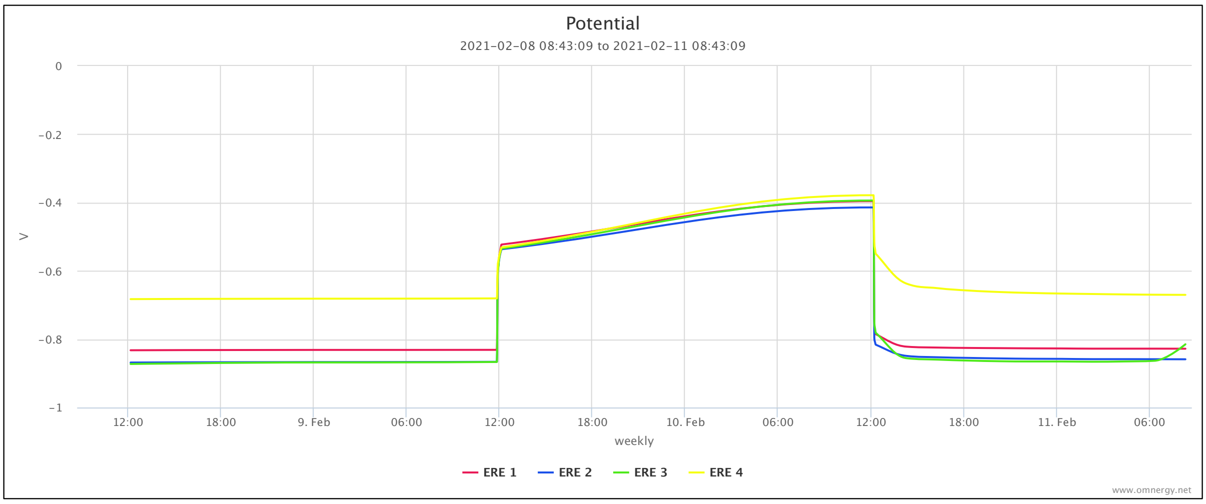


Fig. 16 Potential decay curves of zone 5 and zone 6

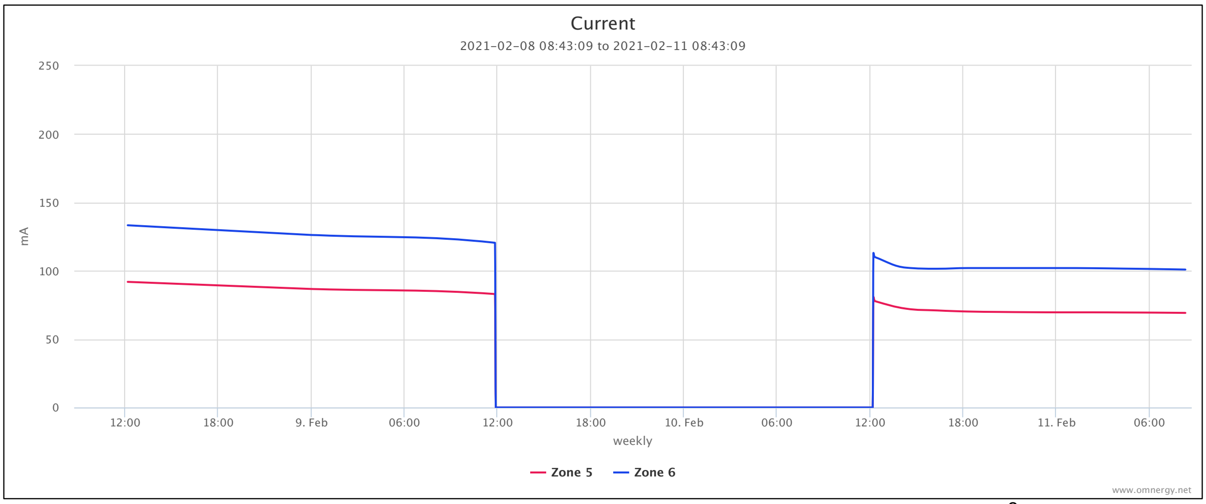


Fig. 17 GACP current output of zone 5 and zone 6 each appr. 53m^2 ZLA

TABLE 2 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

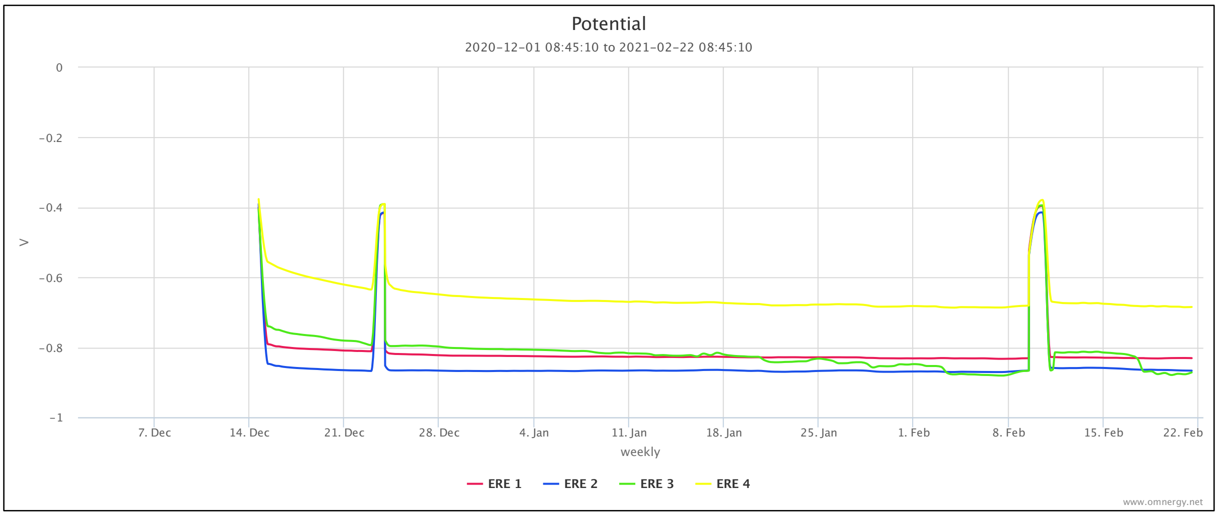


Fig. 18 Potentials since start-up of zone 5 and zone 6

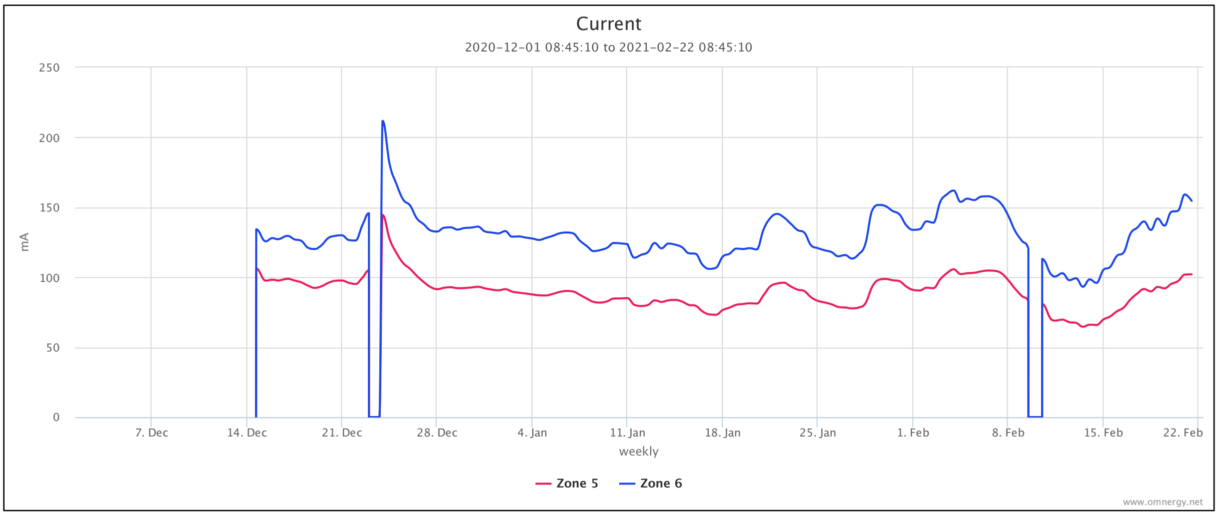


Fig.19 GACP current output since start-up of zone 3 and zone 4

Considering an avarage current ouput over 3 months for each zone :

Zone 1 : 89 mA, which will give with a anode surface area of appr. 53m^2 an avarage of 1,68 mA/m^2 ZLA, and a steel current density of : 1,68/0,31 = 5,42 mA/m^2 .

Zone 2 : 162 mA, which will give with a anode surface area of appr. 53m^2 an avarage of 3,06 mA/m^2 ZLA, and a steel current density of : 3,06/0,23 = 13,3 mA/m^2 .

Zone 3 : 142 mA, which will give with a anode surface area of appr. 53m^2 an avarage of 2,68 mA/m^2 ZLA, and a steel current density of : 1,68/0,31 = 8,65 mA/m^2 .

Zone 4 : 203 mA, which will give with a anode surface area of appr. 53m^2 an avarage of 3,83 mA/m^2 ZLA, and a steel current density of : 3,83/0,23 = 16,6 mA/m^2 .

Zone 5 : 94 mA, which will give with a anode surface area of appr. 53m^2 an avarage of 1,77 mA/m^2 ZLA, and a steel current density of : 1,77/0,31 = 5,72 mA/m^2 .

Zone 6 : 128 mA, which will give with a anode surface area of appr. 53m^2 an avarage of 2,42 mA/m^2 ZLA, and a steel current density of : 2,42/0,23 = 10,5 mA/m^2 .

CONCLUSION

ISO12696 indicate the 3 criteria of 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 <u>any one</u> 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.

Using the readings from the 3 iGAL's above we will get as <u>instant-off</u> potential decay values over a maximum of 24hrs :

- iGAL 1
    - Ref 1 : 365 mV
    - Ref 2 : 353 mV
    - Ref 3 : 393 mV
    - Ref 4 : 402 mV

- iGAL 2
    - ERE 1 : 388 mV
    - ERE 2 : 365 mV
    - ERE 3 : 353 mV
    - ERE 4 : 390 mV

- iGAL 3
    - ERE 1 : 362 mV
    - ERE 2 : 340 mV
    - ERE 3 : 374 mV
    - ERE 4 : 281 mV

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.

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.