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Impressed current cathodic protection of reinforced concrete in ATEX-zones – Case study: concrete slab in an industrial building

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Abstract. Electrochemical repair by means of impressed current cathodic protection (ICCP) was adopted as a repair strategy for a reinforced concrete slab, severely damaged by chloride induced reinforcement corrosion. Since the slab is located within an ATEX-zone (i.e. a zone with a potentially explosive atmosphere), strict safety regulations regarding the maximum current output through the cables had to be taken into account in the design of the ICCP system. Therefore, the anode in the zones of the CP system was subdivided into small fields (subzones), each individually connected to the power supply and provided with an electrical fuse in the circuit in order to avoid exceedance of the maximum allowed current. Performance assessment of the ICCP system, based on 24-hour depolarization measurements at regular time intervals, showed that complete protection of the steel reinforcement was obtained, according to the 100 mV depolarization criterium in the European standard EN ISO 12696, while the current output was kept well below safety limits. During a monitoring period of about one year, a decreasing required current density with time was observed, which was found to be 4 to 5 times lower than the adopted design value of 20 mA/m² at the start-up of the system and up to 10 times lower after 11 months of continuous application.

1 Introduction

The subject of this case study is a reinforced concrete floor slab with an area of about 230 m² in a 50-year old two-storey building on an industrial site in Belgium. The building is a production hall with numerous reactor installations used for the fabrication of raw materials for the production of photographic films. The floor slab, at the first level of the building, is supported by a framework of concrete beams, subdividing it into 13 smaller parts. The middle area of the floor contains openings for the reactors. Therefore, each floor part is supported by beams on 3 sides, leaving the side at the border of the openings unsupported. A plan view of the floor slab, indicating the 13 parts is given in Fig. 1. The areas indicated with a cross in Fig. 1 are the openings in the floor slab.

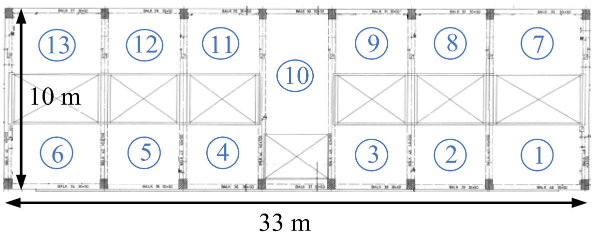

Fig. 1. Plan view of the floor slab.

The concrete slab has a thickness of 15 cm in the outer parts (i.e. parts 1, 6, 7 and 13) and 13 cm in the other parts. On top of the slab there is a layer of screed and a tile floor finishing. The bottom of the slab is coated with a white paint.

Due to the presence of reactor installations inside the building, the concrete floor slab is located within a so-called ATEX-zone (i.e. a zone with a potentially explosive atmosphere).

2 Condition assessment

The condition assessment of the concrete floor slab was performed in two phases: a first phase to determine the cause and severity of the damage and a second phase in which the extent of the damage was determined and the necessary parameters for the design of a cathodic protection (CP) system were obtained.

2.1 First phase investigation

The first phase investigation included a visual inspection of the damage to the concrete slab, the extraction of concrete core samples for laboratory testing and non-destructive measurements of the concrete cover depth of the steel reinforcement.

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2.1.1 Visual inspection

The damage, visible at the bottom of the concrete slab, was mainly characterized by cracking, spalling and delamination of concrete due to corroding steel reinforcement (see Fig. 2a). Pitting corrosion of the reinforcement was noticed (Fig. 2b), which at some locations had led to breaking of rebars (Fig. 2c). Also, deposition of corrosion products in the surrounding concrete matrix was detected (see Fig. 2b) and damage (cracking) of previously executed patch repairs was observed.

Next to the damage phenomena related to reinforcement corrosion, visual traces of leakages were observed at the edges of the floor slab (Fig. 2d).

Fig. 2. Examples of damage phenomena at the bottom of the concrete floor slab.

2.1.2 Core sampling and in-situ measurements

At three different locations where the most severe damage was noticed (in slab parts 2, 3 and 7), concrete cores with a diameter of 50 mm were taken from the slab to determine the carbonation depth and chloride concentration in the concrete (see parts 2.1.3 and 2.1.4). At these locations, the concrete cover depth of the reinforcement was measured non-destructively by means of an electromagnetic scanner. The results of the mean cover depth of the main and secondary reinforcement at the bottom of the slab are shown in Table 1.

Table 1. Concrete cover depth of reinforcement.

Slab part	Reinforcement	Cover depth (Mean ± St. Dev.)
2	Main Secondary	23 ± 6 mm 37 ± 11 mm
3	Main Secondary	24 ± 2 mm 40 ± 10 mm
7	Main Secondary	17 ± 4 mm 38 ± 10 mm

2.1.3 Carbonation

The carbonation depth at the bottom of the concrete slab was measured by spraying phenolphthalein on a freshly sawn surface of the extracted cores, according to the standard EN 14630:2007 [1].

The mean carbonation depth at the measurement locations ranged from 4 to 6 mm, with a local maximum measured depth of 10 mm.

When comparing the measured carbonation depths to the cover depth of the reinforcement at the measurement locations, the risk for carbonation induced reinforcement corrosion in the current state was negligibly small.

2.1.4 Chloride content

A chloride concentration profile was determined by measuring the (total) chloride concentration in the concrete of the extracted cores at 3 different depths from the bottom of the slab: 0-10 mm, 30-40 mm and 60-70 mm. The results are shown in Fig. 3.

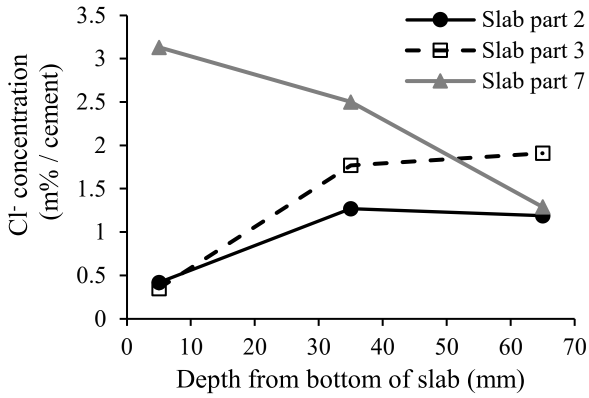

Fig. 3. Chloride concentration profiles.

In slab parts 2 and 3, an increasing chloride profile from the bottom of the slab was detected. As the cores in these parts were taken near the middle area of the slab, this suggests a chloride ingress from the top of the slab.

For slab part 7, the chloride concentrations decreased from the bottom of the slab, which can be explained by the fact that the core in this part was taken near the unsupported edge of the slab where traces of leakage were noticed. It can thus be assumed that the chloride ingress at this position mainly occurred from the bottom due to leakage of chloride containing solutions at the edge of the slab.

For all three locations a very high chloride concentration, ranging from 1.3 to 2.7 % by mass of cement, was measured at a depth of 30-40 mm from the bottom of the slab. This indicates a very high risk for chloride-induced reinforcement corrosion.

2.1.5 Recommendations regarding repair and further investigation

Based on the results of the first phase investigation, the visual damage at the bottom of the floor slab can be linked to chloride induced reinforcement corrosion.

Considering the very high chloride concentrations in the concrete close to the damaged areas and the poor

accessibility of (the bottom of) the concrete slab due to numerous technical installations, a 'traditional' concrete repair by removal and replacement of all contaminated concrete was not feasible. Consequently, electro-chemical repair by means of cathodic protection (CP) was suggested as the most suitable and economical method to obtain a durable concrete repair.
In order to confirm the feasibility and provide design information for the CP system, a second phase investigation was performed.

2.2 Second phase investigation

During the second phase investigation, electrical continuity of the steel reinforcement was verified, half-cell potential measurements over the concrete slab were performed and powder samples were taken to perform additional chloride concentration measurements.

For this investigation, only the slab parts 1 to 7 and 10 were (partly) accessible. Slab parts 8, 9, 11, 12 and 13 were completely inaccessible due to the presence of technical installations.

2.2.1 Electrical continuity of steel reinforcement

In order to verify the feasibility of the installation of a CP system, the electrical continuity of the steel reinforcement in the concrete slab was checked by locally exposing steel reinforcement bars at two locations in each of the accessible parts of the concrete slab and measuring the electrical resistance between the exposed rebars by means of an LCR meter.

The electrical resistance between exposed rebars, both within one slab part and between adjacent slab parts, ranged from 0.05 Ω to 0.50 Ω, indicating electrical continuity of the reinforcement over the complete concrete slab.

2.2.2 Potential mapping

On the accessible parts of the bottom of the concrete floor slab, half-cell potential measurements were performed by means of a $Cu/CuSO_4$ reference electrode [2] in an orthogonal grid with dimensions of 0.5 m x 0.5 m. The results are visualized in a colour plot in Fig. 4 (inaccessible parts are indicated in grey).

The potential mapping colour plot (Fig. 4) qualitatively shows that in general more positive half-cell potential measurements are obtained for the left half of the floor slab (slab parts 4, 5, 6 and 10) compared to the right half of the floor slab (slab parts 1, 2, 3 and 7).

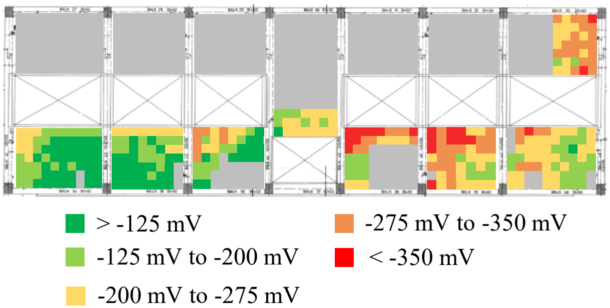

Fig. 4. Half-cell potential mapping.

A quantitative analysis of the measured half-cell potential values in both halves of the floor slab is represented by the box plot in Fig. 5. A significant difference in half-cell potential was obtained between the left and right half of the floor slab, indicating a significantly higher risk for reinforcement corrosion in the latter half of the slab.

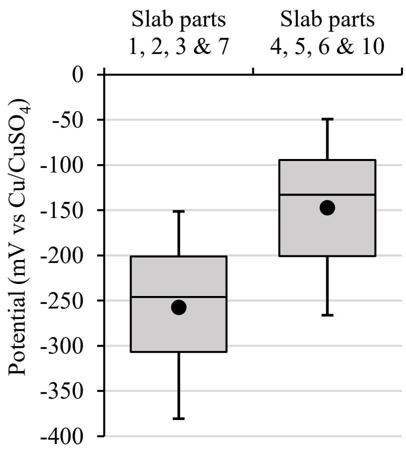

Fig. 5. Box plot of the half-cell potential data (● = mean value).

Next to the general difference between the left and right half of the slab, more negative values of the half-cell potential near the edge of the slab parts adjacent to the openings in the middle area can be observed (Fig. 4). The higher risk for reinforcement corrosion near the edges of the slabs can be linked to the visually observed leakages (see Fig. 2d).

2.2.3 Chloride content at reinforcement

Additional measurements of the (total) chloride concentration at the level of the (bottom) reinforcement were performed by extracting concrete powder samples at a depth of 15-35 mm from the bottom of the slab at several locations in the accessible parts of the slab.

The measured chloride concentrations (expressed in % by mass of cement) are denoted on the plan view of the concrete slab at the respective locations where the powder samples were taken (Fig. 6).

Fig. 6 shows that the chloride concentrations at the reinforcement for all locations in the left half of the slab (i.e. slab parts 4, 5 and 6) were close to 0.40 % by mass of cement, which is commonly considered as the critical chloride concentration (cf. standards EN 1504-9:2008

[3] and EN 206:2013 [4]). For the measurement locations at the right half of the slab, 6 out of 10 measured chloride concentrations were higher than 1.00 % by mass of cement, indicating a very high chance for initiation of corrosion.

Generally, the chloride concentration measurements showed a good correlation with the half-cell potential measurements in the sense that the risk for chloride induced reinforcement corrosion was significantly higher in the right half of the floor slab compared to the left half.

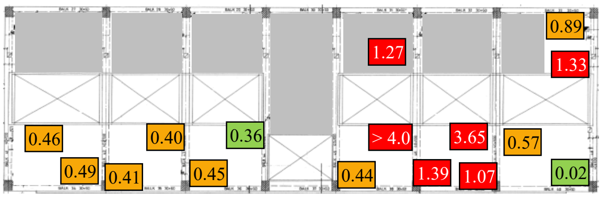

Fig. 6. Chloride concentration (m% / cement) at the level of the reinforcement.

2.3 Conclusions of the condition assessment

Corrosion of steel reinforcement caused by ingress of chlorides due to leakage of solutions from industrial processes was identified as the main cause of the damage to the concrete slab.

Half-cell potential mapping at the bottom of the slab and chloride concentration measurements at the bottom steel reinforcement showed a significantly higher risk for chloride induced reinforcement corrosion at the right half of the slab (slab parts 1, 2, 3, 7, 8 and 9) compared to the left half of the slab (slab parts 4, 5, 6, 10, 11, 12 and 13). This correlates well to the visual inspection, where the most severe damage due to reinforcement corrosion was detected at the right half of the slab.

Electrical continuity of the steel reinforcement in the concrete slab was verified by means of electrical resistance measurements, making cathodic protection a feasible repair method.

For the right half of the concrete slab, repair by means of cathodic protection was considered as absolutely necessary to obtain a durable concrete repair, since the removal of all contaminated concrete was not possible.

For the left half of the slab, the risk for chloride induced reinforcement corrosion was relatively low at the time of survey, but future initiation and propagation of corrosion is possible. Therefore, two options can be considered as preventive repair actions:

- Installation of reference electrodes in the concrete slab to continuously monitor the half-cell potential, combined with periodic visual inspection of the slab, in order to detect initiation of corrosion and possible occurrence of damage in an early stage.
- Installation of cathodic protection as a preventive measure to completely avoid future propagation of reinforcement corrosion.

3 Electrochemical repair by means of impressed current cathodic protection

3.1 Design and implementation

3.1.1 Extent of the CP system + zones

Based on both technical and economical considerations regarding future maintenance of the concrete slab, it was decided to install the CP system on the complete slab (all 13 slab parts). The decision to install the CP system not only on the right half, but also on left half of the slab was to limit future interventions as much as possible, as they may cause interruptions of the production processes which would lead to considerable unexpected costs.

As the condition assessment showed a considerable difference in the severity and risk for reinforcement corrosion between the right half and left half of the concrete slab, the two halves were divided into two separate zones in the CP system, further referred to as zone A and zone B (see Fig. 7) with a surface of 100 m² and 130 m², respectively.

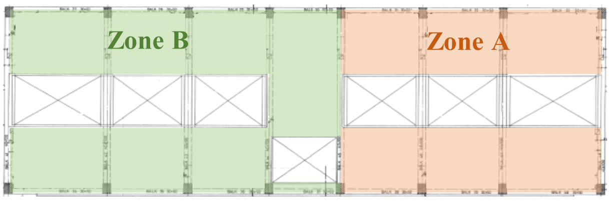

Fig. 7. Zones of the CP system.

3.1.2 Choice and design of the anode system

The main durability issues and damage to the concrete slab were related to corrosion of the bottom layer of reinforcement in the slab. Hence, the main objective of the CP system was the protection of the bottom reinforcement against further propagation of corrosion.

Therefore, the anode of the CP system should be installed at the bottom of the slab (i.e. as close as possible to the steel reinforcement to be protected). However, due to the very limited accessibility at the bottom of the slab because of technical installations which cannot be removed, installation of the anode at the bottom of the slab was not feasible. Consequently, one of the only viable options was the installation of an anode at the top of the slab (after removal of the floor finishing layers at the top). As the thickness of the slab was limited to 15 cm, the application of a sufficient protection current to the bottom reinforcement remained feasible. Moreover, possible corrosion of the top reinforcement layer will also be efficiently stopped by the CP system.

The design of the anode system is based on the density and assumed design current demand of the steel reinforcement in the slab, the latter depending strongly on the steel corrosion state [5].

Considering the very high chloride concentrations in the concrete and severe corrosion of steel, a required current density of 20 mA/m² steel was adopted [5, 6].

The density of the steel reinforcement was calculated based on the available plans. Next to both the bottom and top reinforcement in the slab, also the top reinforcement of the concrete beams and top part of the stirrups in the beams were considered for the calculation of the steel reinforcement density, as all this reinforcement would receive protection current from the CP system.

For the parts of the concrete slab in between the beams, the steel reinforcement density varied from 0.43 to 0.85 m^2_{st}/m^2_{con}. Above the beams and at the unsupported edge of the slab, the reinforcement density was higher, ranging from 0.74 to 1.57 m^2_{st}/m^2_{con}.

Based on the adopted design current density and the calculated steel reinforcement densities, a TiMMO mesh with a nominal current density output of 20 mA/m² concrete/anode surface was selected as a (basic) anode for the complete slab. At the floor surfaces crossing beams and at the unsupported edge of the slab, an additional TiMMO ribbon anode with a nominal current density output of 6.5 mA/m was placed to account for the local higher reinforcement density.

3.1.3 Adapted anode design considering additional requirements due to ATEX-zone regulations

As the concrete slab was located in a zone with potentially explosive atmosphere (ATEX-zone), additional requirements for the application of an ICCP system were imposed by specific safety regulations on the industrial site. The main requirements are:

- The current output through each of the cables of the ICCP system had to be limited to a maximum of 100 mA.
- All cables of the ICCP system inside the building within the ATEX region had to be embedded inside a cementitious mortar overlay.
- The power supplies and monitoring unit of the ICCP system had to be placed outside of the ATEX area.

The first requirement had a large impact on the design of the ICCP system in the sense that the two zones of the system had to be subdivided into smaller subzones or so-called ‘fields’ in order to limit the current through the individual cables of the system.

The general weighted average of the reinforcement density in the slab amounted to 0.75 m^2_{st}/m^2_{con}, which resulted in an average current demand of 15 mA/m^2_{con}. Considering the maximum current requirement of 100 mA, the maximum area of each field (subzone) of the CP system was limited to 6.7 m².

Practically, zone A of the CP system was divided into 18 fields and zone B was divided into 22 fields. A detailed layout of the design of the anode fields in slab parts 1, 2 and 3 of zone A is shown as an example in Fig. 8.

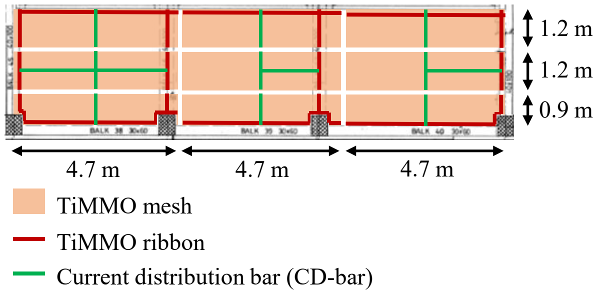

Fig. 8. Detail example of the anode field design for slab parts 1, 2 and 3 (one anode field = TiMMO mesh + ribbons at locations above beams and at the unsupported edges of the slab).

As shown in Fig. 8, slab parts 1, 2 and 3 were divided into 9 separate fields (6 fields with dimensions of 4.7 m x 1.2 m and 3 fields with dimensions of 4.7 m x 0.9 m). Each field contained a titanium current distribution bar (CD-bar), welded to the TiMMO mesh and ribbons within one field in order to distribute the current from the power supply to the TiMMO anode. Each field also contained an anode connection by means of a copper wire which was connected to the current distribution bar. A photo of the installed anodes is shown in Fig. 9.

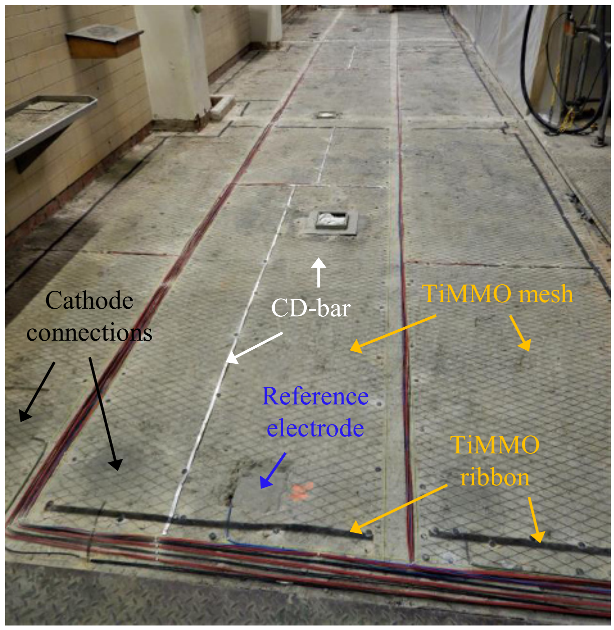

Fig. 9. Installation of the ICCP system.

All cables from anode fields, reinforcement (cathode) connections and reference electrodes (see 3.1.4) were placed on top of the concrete slab in between anode fields (see Fig. 9) and guided to a central point outside of the ATEX-zone (through the wall at slab part 1).

After installation of all system components and cables, a cementitious overlay was applied on the top surface of the slab with a mortar grout, embedding the TiMMO anode system and all cables within the

ATEX-zone. Lastly, a chemical resistant industrial flooring was applied on top of the cementitious overlay.

3.1.4 Reference electrodes

For the monitoring of the ICCP system, a total of 12 manganese dioxide (MnO_2) reference electrodes were installed (6 in each zone). The locations of the reference electrodes (RE's) are shown in Fig. 10. For both zones, the RE's are numbered from 1 to 6.

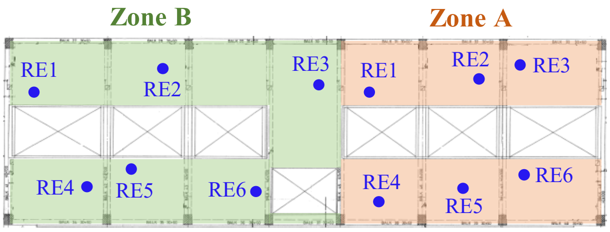

Fig. 10. Location of reference electrodes.

The reference electrodes were installed at a varying depth in the concrete slab to provide information regarding the protection of all steel reinforcement in the slab: in each zone, 3 RE's were installed near the bottom reinforcement, 1 RE near the top reinforcement and 2 RE's in the middle of the thickness of the slab.

3.1.5 Monitoring unit

Outside of the ATEX-zone, all cables from anode fields, reinforcement (cathode) connections and reference electrodes were connected to a central rectifying unit (CRU) containing 2 power supplies (one for each zone) and a modem for remote data logging and management of the system.

In order to ensure that the current output to one anode field never exceeds the maximum value of 100 mA, fuses were installed in the electrical circuit of each individual anode field within the CRU.

3.2 Commissioning and initial assessment

3.2.1 Initial steel potential + control measurements

Before energizing the ICCP system, initial potentials of the steel reinforcement with respect to all installed reference electrodes were measured (see Table 2).

Table 2. Initial potential of steel reinforcement.

	Steel potential (mV vs MnO_2)	
	Zone A	**Zone B**
RE 1	-360	-329
RE 2	-448	-306
RE 3	-397	-324
RE 4	(*)	-251
RE 5	-377	-260
RE 6	-343	-301
Mean ± St. Dev.	-385 ± 41	-295 ± 33

(*) RE 4 of zone A is dysfunctional.

Generally, more negative values of steel potential were measured in zone A (right half of the slab) compared to zone B (left half of the slab). The average potential of the steel reinforcement at the 6 measurement locations was 90 mV more negative for zone A compared to zone B. This was in agreement with the condition assessment of the slab, where a higher risk for reinforcement corrosion was found for the right half of the slab.

3.2.2 Initial energizing and assessment

The start-up (initial energizing) of an ICCP system is generally accompanied by a high peak in current, which decreases relatively fast in the first few hours. To ensure that the current to each anode field in the system did not exceed the limit value of 100 mA, the ICCP system was energized at a low initial voltage of 1.0V and the current to each individual field was measured manually. After about half an hour, the voltage was increased to 1.6V and the currents were measured again.

The results of the minimum, maximum and mean measured current to the individual fields in both zones during initial energizing of the ICCP system are shown in Table 3. At an applied voltage of 1.0V and 1.6V, the maximum current output to an individual anode field was 32.8 mA and 56.5 mA, respectively. This shows that the current to each field remained well below the limit of 100 mA at the applied voltage levels.

Table 3. Minimum, maximum and mean current to the anode fields in both zones during initial energizing of the ICCP system at 1.0V and 1.6V.

	Current (mA)			
	Zone A		**Zone B**	
	1.0V	**1.6V**	**1.0V**	**1.6V**
Min.	15.9	32.8	13.4	25.4
Max.	25.6	48.0	32.8	56.5
Mean ± St. Dev.	20.1 ± 2.5	39.9 ± 4.4	22.7 ± 5.7	40.4 ± 9.5

After checking the current output to all anode fields, the applied voltage to both zones of the ICCP system was set to 1.2V during the first day, subsequently increased to 1.6V the next day and finally increased further to 1.8V.

About 9 days after the start-up of the system, a first 24-hour depolarization measurement was performed to assess the protection level of the steel reinforcement, according to the standard EN ISO 12696 [6]. After the depolarization measurement, the voltage was again applied gradually from 1.2V to 2.0V (both zones) in order to avoid high peaks in current. About 12 days later (a total period of 3 weeks after start-up), a second 24-hour depolarization measurement was conducted after which the voltage was again gradually applied up to 2.0V. The stepwise applied voltage and measured total current to all fields in one zone during the first 5 weeks since the start-up of the ICCP is shown in Fig. 11 (example for zone B).

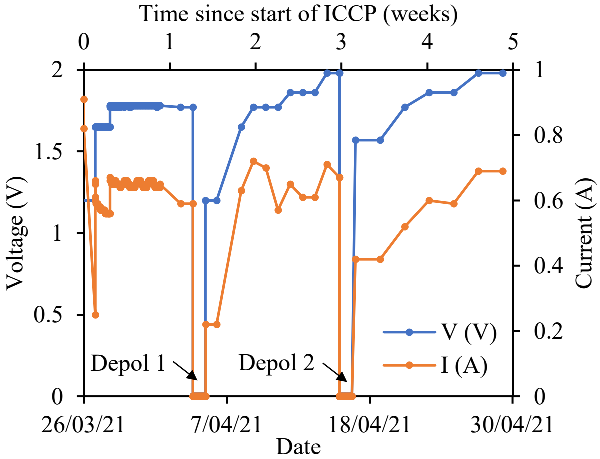

Fig. 11. Applied voltage and measured current of the ICCP system in zone B during the first 5 weeks (commissioning period).

Table 4 and Table 5 show the results of the 24-hour depolarization measurements on day 9 (04/04/2021) and day 21 (16/04/2021), respectively. An example of the depolarization curves obtained during the 24-hour measurement period is given in Fig. 12.

Table 4. Depolarization measurement results (day 9 – 04/04/2021)

	24-hour depolarization (mV)					
Zone	**RE1**	**RE2**	**RE3**	**RE4**	**RE5**	**RE6**
A	270	158	207	-	263	173
B	260	196	198	266	274	315

Table 5. Depolarization measurement results (day 21 – 16/04/2021)

	24-hour depolarization (mV)					
Zone	**RE1**	**RE2**	**RE3**	**RE4**	**RE5**	**RE6**
A	297	177	226	-	298	175
B	269	201	208	278	281	334

At all measurement locations in both zones of the ICCP system, a minimum depolarization (i.e. potential decay over 24-hours) of 100 mV was obtained, indicating that the steel reinforcement was sufficiently protected against corrosion (cf. the ‘100 mV depolarization criterium’ given in the European standard EN ISO 12696 [6]).

As the measurement results indicated a sufficient protection of the steel reinforcement, the applied voltage of 2.0V was maintained for both zones of the ICCP system.

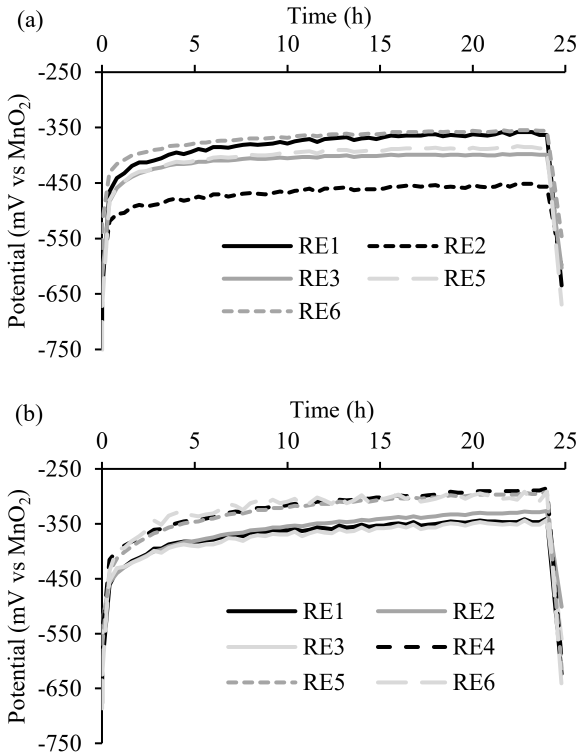

Fig. 12. Depolarization measurements for (a) zone A and (b) zone B at day 21 (16/04/2021).

3.3 Performance assessment

After the initial energizing of the system, further monitoring and performance assessment of the system were performed at 3 month intervals as prescribed in the standard EN ISO 12696 [6]. The performance assessment comprised of:

- The measurement of the applied voltage and current delivered to both zones of the CP system.
- 24-hour depolarization measurements, i.e. measurement of the potential decay with all installed RE’s during a 24-hour switch off of the CP system.

3.3.1 Current density

The applied voltage to both zones of the CP system was kept constant at 2.0V during the whole monitoring period. The total current delivered to each zone was measured at every performance assessment. Considering the total area of the zones (100 m² for zone A and 130 m² for zone B) and the weighted average reinforcement density of 0.75 m^2_{st}/m^2_{con}, the current density in each zone was calculated and is shown in Fig. 13.

The current density is higher for zone A compared to zone B, which can be linked to the higher corrosion activity at the reinforcement in the former zone.

Fig. 13 also clearly shows that the current density decreases with time for both zones, which can be attributed to a decreasing current demand of the reinforcement due to continued polarization of the steel. Furthermore, the difference in current density between zone A and zone B also decreases with time, indicating that the high corrosion activity in zone A is effectively countered by the CP system, as the current demand becomes more similar to zone B.

Lastly, the current density lies within a general range of 1.9 to 5.3 mA/m² steel. This is much lower than the adopted design current density of 20 mA/m² steel, indicating that the design was conservative.

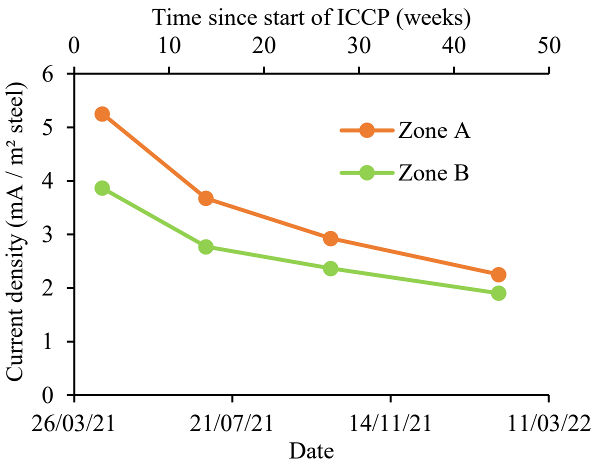

Fig. 13. Evolution of current density.

3.3.2 Depolarization measurements

So far, during the first year since the start of the ICCP system, three depolarization measurements have been performed with an interval of 3 to 4 months. The resulting 24-hour depolarization values at each measurement time are given in Table 6, Table 7 and Table 8.

Table 6. Depolarization measurement results (14 weeks – 01/07/2021)

	24-hour depolarization (mV)					
Zone	**RE1**	**RE2**	**RE3**	**RE4**	**RE5**	**RE6**
A	279	171	204	-	297	166
B	250	209	201	278	264	321

Table 7. Depolarization measurement results (27 weeks – 01/10/2021)

	24-hour depolarization (mV)					
Zone	**RE1**	**RE2**	**RE3**	**RE4**	**RE5**	**RE6**
A	286	182	195	-	287	179
B	245	210	182	272	254	316

Table 8. Depolarization measurement results (45 weeks – 02/02/2022)

	24-hour depolarization (mV)					
Zone	**RE1**	**RE2**	**RE3**	**RE4**	**RE5**	**RE6**
A	288	183	193	-	281	183
B	243	207	183	258	252	310

The data of the depolarization measurements shows that, although the current density is decreasing in time, there is very little to no change in depolarization at the different measurement times and all values are well above the minimum level of 100 mV. Consequently, it can be concluded that the steel reinforcement in the concrete slab is fully protected against further propagation of corrosion.

4 Conclusions

Thorough condition assessment of a concrete floor slab in an industrial building revealed a severe case of damage caused by chloride induced reinforcement corrosion. Due to the severity and extent of the chloride contamination and considering the poor accessibility of the concrete slab due to numerous unremovable technical installations, impressed current cathodic protection (ICCP) was found to be the most efficient repair method to obtain a durable, long-lasting concrete repair.

The design of the ICCP system contained specific challenges as the concrete slab is located within an ATEX-zone. The most important challenge being the limitation of the current output through the cables of the ICCP system to a maximum of 100 mA. Due to this limitation, the TiMMO mesh and ribbon anodes of the ICCP system had to be divided into multiple small ‘fields’, each with their own separate connections. On top of this, fuses were installed in the electrical circuit of each individual anode field as an extra safety measure.

Commissioning and performance assessment of the ICCP system showed that an applied voltage of 2.0V was sufficient to provide full protection of the steel reinforcement, judged by the 24-hour depolarization measurements, while the current output to each individual anode field remained well below the maximum limit.

Based on the measured current densities in each zone of the ICCP system over the course of one year, a design current density of 20 mA / m² steel was found to be conservative, in spite of the severe chloride contamination of the concrete. After 11 months of continuous application of the CP system, the required current density to achieve sufficient protection was 10 times lower than the adopted design current density. The relatively low current density of the ICCP system can possibly be explained by the fact that the concrete slab is located in a relatively dry indoor climate and leakage of solutions from industrial processes is avoided by the application of a chemical resistant industrial flooring.

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