A NEW APPROACH TO CATHODIC PROTECTION OF CORRODING CONCRETE HARBOR STRUCTURES

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Abstract

For many years, both research and practical experience have shown that cathodic protection (CP) is the most efficient and very often the only way of getting chloride induced corrosion in concrete structures under control. For most CP-systems, however, the installation is both time consuming and expensive. For corroding concrete structures in moist environments where the visual appearance is not important, a more simplified and cost-efficient CP-system has been developed. In principle, the new CP-system consists of impregnated wooden laths on which a porous and acid-resistant felt, impregnated with a moist absorbing agent, is attached. Between this felt and the wooden lath, there is a MMO-coated titanium ribbon, and these constituents a cassette unit that is firmly applied to the concrete sub-base. Before installation, some preliminary measurements have to be carried out in order to find the most efficient locations for the cassette units. Subsequently, the various titanium ribbons are welded together. As the felt turns wet, electrolytic contact between the anode and the concrete body is established, thus providing cathodic protection to the corroding steel.

In the present paper, the development and installation of the new CP-system to a heavily corroding concrete harbor structure are briefly described. The installed CP-system has been electrochemically monitored for approximately two years, some results of which are also briefly presented and discussed.

1. Introduction

Recently, a heavily corroding concrete harbor structure in Norway was going to be repaired. The harbor structure, which was an open structure consisting of a concrete deck of 132 m × 17 m on top of tremie-cast concrete pillars, was constructed in 1964. The deck consisted of 3 longitudinal main beams and 18 transversal secondary beams

with two-ways slabs in-between. The main beams and the secondary beams had dimensions of 90 × 120 cm and 70 × 70 cm, respectively, while the top slab was 25 cm thick including a 6 cm top layer. The mechanical loads on the deck consisted mainly of two heavy loading cranes, 60 tons and 100 tons, respectively, moving on top of the three longitudinal main beams.

After a service period of 37 years, the general condition of the structure was very poor due to an advanced stage of chloride-induced corrosion. A structural assessment had confirmed that the load-bearing capacity of the main beams would only be acceptable for a continued operation of the cranes for a very short period, but the rate of corrosion in the beams was so high that an immediate repair was needed. The concrete pillars were in fairly good condition, but the deck slabs had reached such a high degree of deterioration that all traffic on the deck by car had already been forbidden. Of the various technical solutions for repair considered, one option was simply be to construct a new concrete deck on top of the old deck. However, since both the crane facilities and the structure would not be needed for a continued service and further operation for more than approximately 15 years, the construction of a new deck would have been a very expensive solution. Therefore, all efforts were made to reduce or prevent further deterioration of the main and secondary beams by use of cathodic protection in order to extend the service life of the deck beams for a limited period of time. During this process, a specially designed system for cathodic protection (CP) was developed and installed [1], a brief description of which is given in the following.

2. Design of CP system

2.1 Limitations and problems
Although cathodic protection has proved to be the most efficient and very often the only way of getting a chloride induced corrosion in concrete structures under control, the installation of a CP-system is typically both elaborate and quite expensive. Normally, the CP-system has to be custom designed for each structure, taking a number of factors into account such as necessary amount of protective current, anode geometry and type of anode system. For the harbor structure in question, the safest approach would have been to apply a continuous anode system on the surface of the beams after the establishing of electrical continuity and patch repairing. Although such an approach would have been technically possible, this would also have been a very expensive solution. In order to come up with a more simplified and cost-efficient CP system that could be used only for a limited period of time, a new approach was taken, which required very little both manpower and equipment compared to that of a more traditional CP-installation.

2.2 Design and preliminary investigations
In the approach of designing the new CP-system, some preliminary investigations were carried out both in the laboratory and in the field. These investigations included anode design such as type of felt, acid resistivity and moist-absorbing agent as well as anode

distance. After some preliminary tests in the laboratory, a small test area on the structure was selected, where surface electrodes were mounted for electrochemical potential measurements.

After the above preliminary investigations, an anode system was finely selected, which consisted of surface-mounted anode ribbons mounted along the various beams. On impregnated wooden laths of cross-section 20 × 90 mm, a porous and acid-resistant felt, impregnated with a moist absorbing agent, was attached. Between this felt and the wooden lath, there was a 13 mm broad MMO-Titanium (Ti) ribbon, and this made up a cassette unit, which was firmly applied to the concrete sub-base [2]. At the end of each lath, the Ti-ribbons were protruding by approximately 20 cm. These prefabricated cassette units were mounted onto the beams with the felt facing the concrete by use of stainless steel bolting. For the bolting which was done at a lateral distance of approximately 60 cm, it was important to do this on each side of the Ti-ribbons in such a way that electric contact was avoided. Finely, the loose ends of the Ti-ribbons between the neighbouring laths were point-welded, and the anode circuit established by drawing the connecting wires through the deck slab to the electric cables (Fig. 1). The final CP-installation was applied to the structure through eight anode-zones with one transformer/rectifier unit for each zone (Fig. 3), the separate control of which was done remotely.

Fig. 1. Layout of the cassette-anode system.

Before the final installation, however, one question of concern was how high the voltage drop along the Ti-ribbons would be. Since the electrical resistance of 1 m Ti-ribbon was 0.39 Ω, it was clear that the voltage drop in the anode would be high, especially when the current discharge per unit meter was also high. The average voltage drop over the length of the anode was calculated by:

$$\Delta E = \frac{(x \cdot i_a) \cdot (x \cdot \rho_a)}{2} \tag{1}$$

where:
    $x =$ the length of anode from power feed to the point furthest away from the power feed ($2x =$ distance between power feed point)

    $i_a =$ the average current discharge per linear meter of anode segment

    $\rho_a =$ the resistance per linear meter of anode segment

ZONE 1   ZONE 2

⊏⊐ Anode-laths
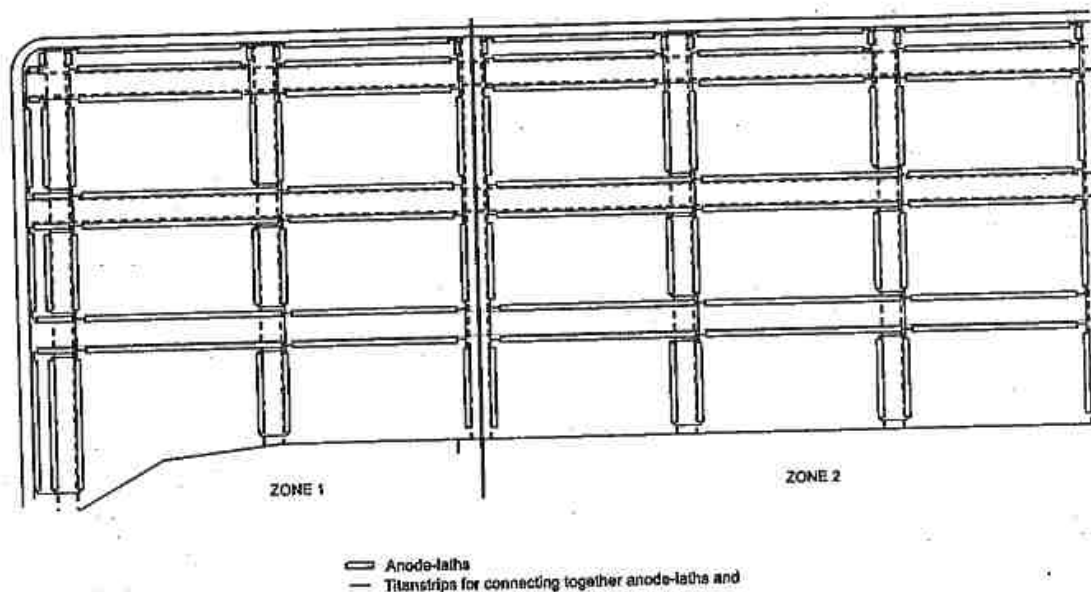— Titanstrips for connecting together anode-laths and

Fig. 2. Layout of the cassette-anode system for Zone 1 and Zone 2.

Assuming that the current discharge per unit meter was 20 mA, a voltage drop of 390 mV could be expected over 10 m anode. It was assumed that 300 mV voltage drop would be tolerable within one anode zone. In this case, the drop would give the steel furthest away from the electrical feed not less than 80 percent of the average current [3]. Using this 300 mV criterion in combination with eq. 1, a maximum anode length away from the feed would be approximately 8.8 m at a current discharge of 20 mA/m. From some previous trial measurements, it was estimated that the current discharge per anode meter could be estimated to approximately 20 mA at an applied voltage of 7.5 V. As a first approximation, therefore, the concrete resistance per linear meter was assumed to be 7.5 V/0.02 A = 375 Ω.

It was also necessary to find out how frequent the various anode ribbons should be interlinked, and how many power-feeds would be needed in order to guarantee a system with as little voltage drop in the anode system as possible. For this reason and in order also to properly simulate the current discharge over each anode zone, a small network model was made in the laboratory by use of 0.5 Ω and 374 Ω resistors (Fig. 3). The 0.5 Ω resistor and the 374 Ω resistor should reflect the resistance of 1 m Ti-ribbon and the concrete resistance per linear meter, respectively. The reinforcement was not simulated by resistors but only by use of a copper wire. The feeds and circuits for the cables feeding the anode were simulated by wires as assumed for the design (Fig. 4). Finally, a voltage of 5 V was applied and the voltage difference to the feed measured at several points. Actually, only a voltage of 0.5 V was applied in order not to burn the resistors, and all measured values were therefore multiplied by a factor of 10 in order to simulate the actual field conditions. 5 V was also assumed to be a representative value for U_{app}.

The average voltage over the 374 Ω resistor was approximately 4.6 V, which means that the model simulated an approximate current discharge of 12.3 mA per linear meter of anode.
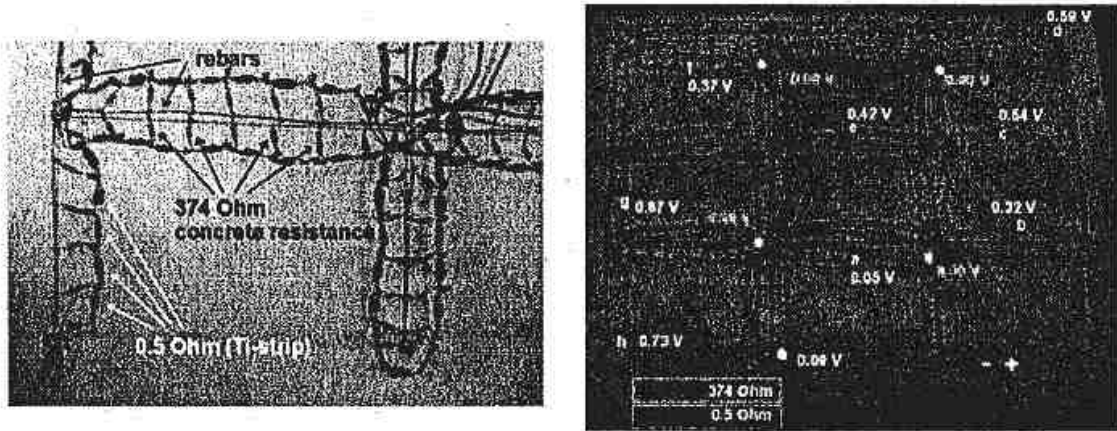
Close-up of the electric network model.

Voltage differences between feed and measurement points. U_{app} = 5.00 V, I_{app} = 3.47 A (i_{app} = 12.3 mA/m)

Fig. 3. Electric network model made in the laboratory for simulating current consumption for one anode zone and voltage drop in the Ti-ribbons.

The measurements of voltage drop performed on the network model were correlated with the results predicted by eq. 1. As can seen from Table 1, the predicted values were in qualitative agreement with the measurements obtained from the model. For three of the measurement points, however, the predicted values were far too low compared to that of the measured values. Measurements of voltage drops performed on the final field installation of the CP-system showed similar values as that obtained from the network model, thus proving a certain reliability basis for the model.
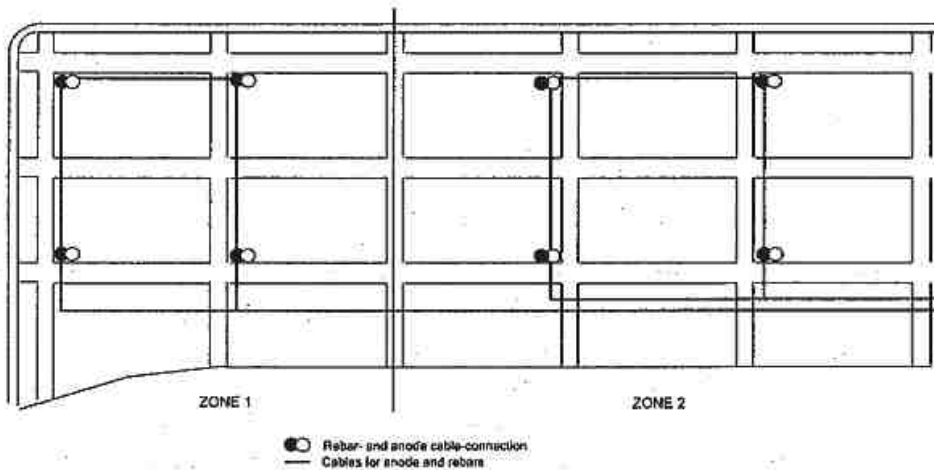

Fig. 4. Design of power feeds for Zone 1 and Zone 2.

Table 1. Calculated and measured values of the voltage drop in the cassette-anode system at various locations of the anode.

Measurement point (Fig. 3)	Distance from feed [m]	ΔE calc. (using eq. 1) (i_{app} = 12.3 mA/m)	ΔE measured (resistor-model) (i_{app} = 12.3 mA/m)
a	4	0.05 V	0.05 V
b	11	0.37 V	0.59 V
c	9	0.25 V	0.42 V
d	13	0.52 V	0.73 V

3. Final installation and operation of the CP system

Based on the preliminary investigations carried out, the above cassette-anode system was installed to all the main and secondary beams of the harbor structure by eight anode zones. For each zone, eight MnO_2-reference electrodes were also embedded for further control (Fig. 5). The CP-installation was completed by use of a control cabinet consisting of a logging system with 96 channels for the electrodes, which are separately controlling the transformer/rectifier units for each anode zone. The remote control is performed by use of telephone lines.
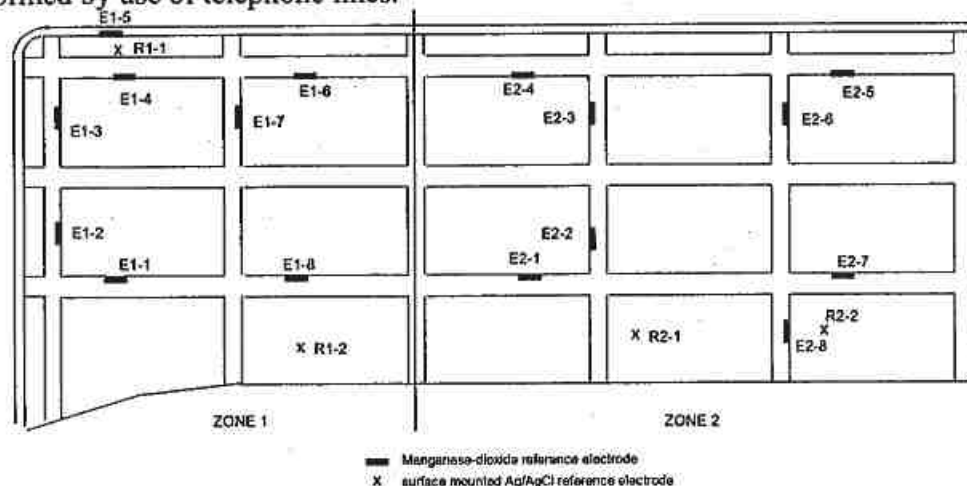

Fig. 5. Placement of reference electrodes in Zone 1 and Zone 2.

For cathodic protection of embedded steel under atmospheric conditions, the 100 mV decay is the most commonly used criterion, while for completely submerged concrete, a protection potential of $E_{inst.-off}$ = -870 mV to −1280 mV vs. MnO_2 (-720 mV to − 1130 mV vs. Ag/AgCl/0.5M KCl) is a most commonly used criterion. For concrete in the tidal zone, however, practical criteria and guidelines for CP are missing [4]. During installation, it was observed, however, that when the electrode location was lowered towards the sea level, the duration of the decay period should be increased. Since a tidal

variation will influence the potential decay dramatically, it has been suggested that the shape of the decay period should also be recorded [5].

For the harbor structure in question, all the beams of the concrete deck are mostly located in the splash-zone, but occasionally, they are also located in the tidal zone during stormy weather and very high tidal periods. For the evaluation and future control of the protection efficiency, therefore, it should be necessary to observe both the depolarization values and the protection potentials at the same time.

So far, the CP-installation has only been in operation for approximately two years, but some typical measurements of protection potential and depolarization are shown in Fig. 6. As can be seen from these measurements, the CP-system is working fairly well, but a sufficient protection potential is not reached for all of the measurement locations, while others are slightly overprotected. This overprotection is not considered harmful, since neither pre-stressed nor post-tensioned steel has been used for the concrete structure in question. The depolarization of the reinforcing steel occurs rather slowly. It appears that the depolarization values observed 24 hours after current interruption might not exceed 75 % of the final value. It appears, therefore, that the 100 mV criterion may also be adopted for concrete in the tidal zone.
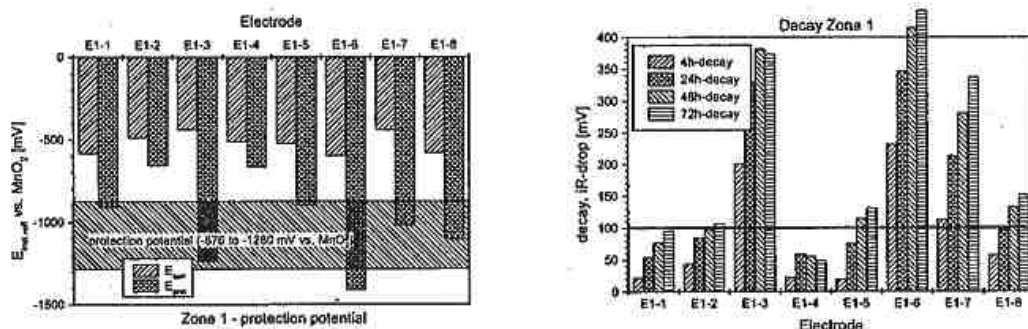

Fig. 6. Measurements of protection potential and depolarization for Zone 1 ($i_{app} = 44$ mA/m).

Due to the special acid resistivity of the felt used, it is expected that the service life of the new CP-system will be comparable to that of CP-installations based on Ti-ribbon anodes mounted inside the concrete. Since the new CP-system is based on a simple surface installation, it is also expected that it will be easy to control and maintain it by regular inspections.

4. Conclusions

The new CP-system which was developed and applied to the heavily corroding concrete harbor structure described in the present paper, has not been in operation for more than

approximately two years. Based on the experience obtained so far, however, the following conclusions appear to be warranted:

1. For moist environments where the visual appearance of the structure is not important, the new cassette-anode system appears to give a simple and cost-efficient CP of corroding concrete structures.

2. As a preliminary step in the design of the new CP-system, it was useful to simulate the current, voltage and polarization conditions by moving surface mountable anodes along the concrete sub-base in order to obtain optimal cassette placements. In this way, optimal polarization of the corroding steel was obtained.

3. Although it appears that the 100 mV criterion for CP may be adopted for concrete in the tidal zone, better criteria and guidelines for CP under such environmental conditions are needed.

5. Acknowledgement

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