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Influence of different ways of chloride contamination on the efficiency of cathodic protection applied on structural reinforced concrete elements

J. Carmona Calero*, M.A. Climent Llorca, P. Garcés Terradillos

Civil Engineering Department, University of Alicante, PO. Box 99, 03080 Alicante, Spain

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ABSTRACT

Cathodic protection is a method to protect reinforced concrete structures located in saline environments against corrosion effect produced by Cl^- penetration. But there are significant differences among these aggressive environments. The aim of this article is to show how different ways of saline contamination can affect the efficiency of cathodic protection. For this research, a series of laboratory specimens representing structural elements were subjected to two versions of cathodic protection (cathodic protection strictly speaking, and cathodic prevention), while two different ways of saline contamination were applied (permanent immersion in a NaCl solution and periodic pouring of discrete amounts of a NaCl solution in atmospheric exposure). Depending on the saline environment, differences in the efficiency of cathodic protection were detected. Results can be useful to determine the specific features of the cathodic protection to be applied in each case, taking into account both the initial Cl^- content of the structural element and the particular saline environment where it is located.

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1. Introduction

Environments characterized by a significant presence of chlorides (Cl^-) are undoubtedly the most aggressive contamination danger for reinforced concrete. Cl^- ions can either be present in the concrete mix or penetrate through the pore network of the concrete protecting cover of the steel rebar. When Cl^- reaches the reinforcement surface and under normal conditions (presence of oxygen and water), corrosion can be triggered. Exceeding a certain Cl^- concentration threshold, and from a determined electrochemical potential of the steel (mainly related to the O_2 presence in its surface), its protective oxide film (passive layer) starts to be affected by pitting corrosion. The method called cathodic protection (CP) has been utilized for a long time to prevent the corrosion process or at least mitigate its effects. It is a system generally used to protect metals against the corrosion process. This procedure can be applied in two ways: by sacrificial anodes or by impressed current, although hybrid treatments have been also carried out [1]. CP principle consists in reducing the electrochemical potential of the metal to be protected [2]. This action allows the lessening of both the corrosion rate and the activity of the electrochemical corrosion cells. In the case of reinforced concrete exposed to a Cl^- environment, some valuable side effects are the barrier effect against Cl^- penetration, the Cl^- and O_2 removal together with the generation of OH^- ions. The conjunction of these consequences helps inhibit the corrosion process despite a serious Cl^- contamination. A clear and rigorous explanation about it was

exposed in previous research [3]. From the seventies of the past century, CP has been adapted for the protection of reinforced concrete steel rebar. R.F. Stratful was probably the first one in applying CP to bridge decks Cl^- contaminated by de-icing salts [4] and ever since, a broad investigation on this matter has been developed [5–7]. Regarding the impressed current version of CP, the anode system is perhaps the most complex element and therefore the subject of further investigations. Currently, a wide range of anode materials are being used: from oxide activated high conductive metals to a new generation of modified cementitious materials, generally with carbon-related products and composites [8–13]. Also, assemblies composed by metal-carbon cementitious material mixes are recently proposed as anodes for CP [14–16]. For the present research, the anode system was basically composed of a thin layer of graphite-cement paste (GC), as was carried out initially for electrochemical chloride extraction [17–19], and recently adapted to cathodic protection. [20].

Generally, two kinds of cathodic protection methods are known: cathodic protection strictly speaking (CP) and cathodic prevention (CPre), as was for the first time stated by Pedferri et al. [21,22]. CP is usually applied to structures that have developed corrosion. CP impressed current density is usually in the range of 8–20 mA/m². CPre is defined as a particular case of CP, able to maintain the steel of new reinforced concrete structures in passivation (maintenance of the passive layer protective effects), despite the increase of chloride content on the rebar surface due to Cl^- contaminations during their service life. CPre is commonly applied with 1–2 mA/m² of current density.

The Cl^- contamination pathways of reinforced concrete structures may be classified into two major groups, namely:

* Corresponding author.

E-mail address: jcarmona@ua.es (J. Carmona Calero).

- Location in aggressive saline environments (which the most common is the marine environment).
- Operating contamination, such as the use of de-icing salt in winter-time on road structures (bridges, parking buildings, etc.)

This work aims to determine how different routes of Cl^- contamination influence the efficiency of both types of cathodic protection. This efficiency was assessed analyzing the ability of CP treatments to keep or recover protective conditions of the steel reinforcement (100 mV and 150 mV decay criterion). Besides, it was determined that the reduction of Cl^- penetration caused by the treatments is the so-called “barrier effect” [20,21].

Both electrochemical treatments (CP and CPre) were applied to laboratory specimens, subjected at the same time to two different forms of Cl^- contamination:

- Contamination A: ponding of a 1 M NaCl solution onto the concrete surface coated by the GC anode.
- Contamination B: spraying 65 ml of 0.5 M NaCl solution once a week on the same location.

Prismatic shaped specimens to be treated with CP were manufactured with salt in the mixing water. In this way, the presence of a significant amount of Cl^- close to the rebar (2% of Cl^- relative to cement mass) was assured right from the beginning of the study. The aim was to check the capability of CP to keep and restore the steel protection conditions with such high chloride contents along the electrochemical treatment and the contamination process.

The other specimens to be subjected to CPre were free of salt, as in newly built and therefore not yet Cl^- contaminated structures.

The means to know how different kinds of Cl^- contamination affect the efficiency level of CP and CPre treatments were the study of the following aspects:

- Time during which the passivation (protective conditions) of reinforced concrete rebar was preserved by the CP electrochemical treatments in both kinds of contamination.
- Assessment of the CP and CPre barrier effect, based on the evolution of Cl^- content profiles in the mass of concrete samples during the processes.
- Ability of the CP to restore steel protective conditions after they were lost because of the suffered contamination.

The three considered aspects were always evaluated by comparing the specimens subjected to electrochemical treatment with their

reference specimens, which had the same composition and were equally contaminated, but without any electrochemical treatment.

2. Materials and methods

2.1. Laboratory specimens

Laboratory specimens were designed as concrete prisms with dimensions of $18 \times 18 \times 8 \text{ cm}^3$, with reinforcements of six steel bars 5 mm diameter soldered symmetrically forming squares of 5 cm side, and placed 2 cm under the closest external surface, where the anodic system will be placed. Rebar was connected to the negative pole of the electric source, using plastic isolated copper connectors (see Fig. 1).

The approach taken to prepare the laboratory specimens as reinforced slabs was to obtain a concrete with a minimum risk of shrinkage cracks, and a good workability due to the complex formwork. But at the same time, with the characteristics of a conventional concrete. Thus, we manufactured the samples with a low content of cement (250 kg/m^3), a high water/cement ratio (0.65) but with the addition of a superplasticizer. This special flowability assured a good compactness using a vibrating table and a high energy of compaction.

Concrete specimens were manufactured with a dosage as follows (Table 1).

Concrete samples manufactured in this way were moist-cured by means of a curing chamber at >95% relative humidity (RH) for 28 days. Under these conditions, concrete got standard quality properties: compressive strength 37.8 N/mm^2 , porosity 11.1% and bulk density 2380 kg/m^3 . Therefore, laboratory specimens manufactured in this way can rightly represent a structural element of conventional reinforced concrete.

To set up the anode system, a graphite-cement paste (GC) was prepared by mixing graphite powder and Portland cement at 50%–50% in mass, with a water to solid mix ratio of 0.8. On that subject, the criteria stated in previous researches based on this kind of anodic system [17–20] was followed. A 2 mm thick layer of this paste was applied on the top face of each specimen, and after that all of them were placed in the curing chamber for 10 days.

Test configuration and connections with the electric source were made up as shown in Fig. 2.

To connect to the positive pole of the electric source, two graphite rods were embedded in the GC layer as primary anodes, avoiding any contact between graphite rods and concrete. Rod ends protruded from the sample in order to attach the copper wires. A PVC receptacle was

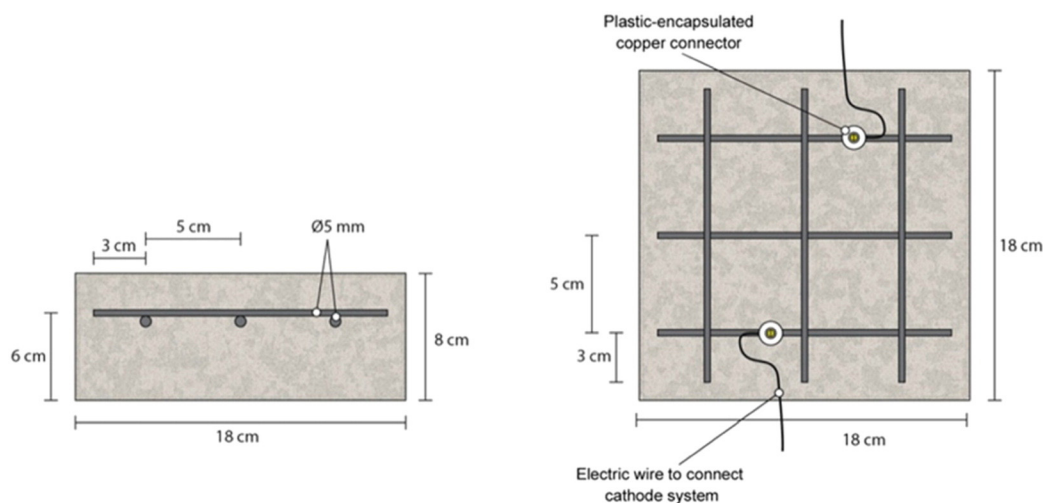


Fig. 1. Laboratory specimens. Dimensions and reinforcement. Adapted from [20].

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