

## **Cathodic Prevention/Protection of Marine Corrosion of Steel in Previously Cracked Concrete**

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### **ABSTRACT**

This paper presents the results of long term experiments with reinforced concrete blocks with controlled-width cracks placed along a central reinforcing steel bar. Ponding allows for cyclic or continuous exposure to a 5% NaCl solution to imitate a marine environment. Crack widths ranging from 0.25 mm to 1 mm (0.01 - 0.04 inch) and polarization levels ranging from -430 mV to -640 mV vs the Saturated Calomel Electrode (SCE) are used. Results suggest that cathodic protection with moderate polarization levels may be of limited benefit in the presence of cracks aligned lengthwise to the rebar independent of crack width. Specimens without protection experience corrosion after only a week of exposure. The 5.5-year-long tests revealed that current densities in the order of 8 - 19 mA/m<sup>2</sup> were required to achieve cathodic protection. Selected specimens were autopsied to examine their condition, revealing the presence of corrosion in the central bar at the crack location. The results are evaluated as to implications on the practical applicability of cathodic protection to marine structures.

Key words: cathodic protection, steel corrosion, cracked concrete, chlorides.

### **INTRODUCTION**

The chloride-induced corrosion of steel in reinforced concrete structures, especially in marine environments, can seriously limit service life. It is common today to design bridges to achieve a minimum 75- year service life, and the primary design approach to that end has been to improve the quality of concrete to make it less permeable and increase the clear concrete cover.<sup>1</sup> Both steps greatly extend the time to initiation of corrosion; however, the added cover places construction constraints, and some high performance concretes may be more susceptible to cracking, requiring special handling with associated risk and cost.<sup>2</sup>

These cracks in concrete structures can cause major localized durability problems because chloride ions' transport to the reinforcement is greatly enhanced. Chloride concentrations of about 2.4 kg/m<sup>3</sup> have been found at the steel/concrete interface in cracked concrete locations in some bridges built with low permeability concrete, compared to about 0.24 kg/m<sup>3</sup> or less steel/concrete interface in sound concrete locations.<sup>3</sup> Thus, early corrosion in high performance concretes is likely to develop mainly at crack locations with the resulting higher corrosion current densities.<sup>4</sup> For this reason, durability performance in cracked concrete and alternative corrosion control methods including cathodic protection (CP) and cathodic prevention (Cprev) are becoming a dominant concern in modern design.<sup>5, 6</sup>

Traditional CP merits consideration as a means of controlling corrosion in concrete with preexisting cracks. The negative shift in potential in CP systems is the main beneficial agent, which reduces the driving force for the anodic reaction and increases the resistance to the anodic process; consequently, corrosion cannot propagate, or the corrosion rate is minimal.<sup>6</sup> CP systems are successful but may require relatively high applied current densities, usually in the range of 2 mA/m<sup>2</sup> to 20 mA/m<sup>2</sup> on existing structures and between 2-5 mA/m<sup>2</sup> for new structures.<sup>7</sup> Cprev, where corrosion initiation is delayed by elevating the chloride threshold at more negative potentials, requires less polarization.<sup>3-6</sup> However, the case of steel in previously cracked concrete may pose a challenge to the application of CPrev because of the likely early presence of high local chloride contents on the steel surface where cracks intersect it.

In a previous publication, some of the characteristics of a CPrev system applied to cracked concrete specimens in a simulated marine environment have been established to determine applicability in cracked concrete structures.<sup>8, 9</sup> Here, additional findings from extended testing including autopsy are discussed considering the long-term (~5.5 years) corrosion outlook for a group of six specimens polarized to -540 mV, to determine whether cathodic protection can be useful for corrosion control in cracked concrete.

## EXPERIMENTAL PROGRAM

A total of 30 concrete prisms (35.6 cm-width x 40.6 cm-length x 12.7 cm-thickness) were constructed with three embedded reinforcement bars with 12.7 mm diameter (rebar #4) of 45.7 cm (18 in) length spaced 11.4 cm (4.5 in) (Figure 1). A crack was induced in each specimen by 3-point bending. Metal shims were used to set the crack width to one of the three values listed in Table 1. Ponding allows for cyclic or continuous exposure to a 5% NaCl solution to imitate a marine environment. Experimental details along with the initial results from this investigation can be found in a previous paper, so only a summary is presented here.<sup>7, 8</sup> Embedded reinforcement bars were normally interconnected. The polarization was applied to all three simultaneously in the CPrev system using an MMO activated titanium mesh ribbon anode connected to a multichannel potentiostat (Figure 1). Table 1 presents a summary of the test conditions regarding the crack width and potential level assigned to each specimen at the beginning of the test (-330 mV, -430 mV, and -540 mV (SCE)), as well as the degree of replication for each condition. The term "OC" means that the interconnected 3-bar assembly was not being connected to any external current source; macrocell currents flowed nevertheless between the bars themselves.

For OC specimens, activation was declared upon the development of a sudden potential drop. For polarized specimens, corrosion activation was declared by two alternative criteria. In the first criterion, used in our earliest work<sup>7</sup>, activation was deemed to occur when the total cathodic current demand of the 3-rebar group vanished, as the system had evolved to an active corrosion point where its open circuit potential equaled the appreciable negative polarization provided initially, clearly indicating active corrosion.<sup>7</sup> In a second, more stringent criterion (adopted in this paper), activation was declared when the central bar's current became anodic.<sup>8</sup>