

## **Long-Term Case Studies of Cathodic Protection Along the Texas Gulf Coast**

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### **ABSTRACT**

Reinforced concrete bridges and other maritime infrastructure are at high risk for corrosion related damage over its service life. These assets are subjected to harsh exposures that will degrade ordinary protective measures for reinforced concrete over time. Sacrificial (galvanic) cathodic protection (CP) systems have been used successfully to protect bridge and other reinforced concrete infrastructure in Texas for approximately 30 years. As these systems age, owners are faced with decisions regarding timing and need to replace existing CP systems. This paper will present case studies from recent testing of sacrificial CP systems from several infrastructure projects along the Texas gulf coast, with ages up to 25 years old. Results from testing indicate many of the CP systems are still offering some level of cathodic protection. Considerations and options for continued monitoring, maintenance and repair, or replacement of the CP systems are presented.

Key words: reinforced concrete, cathodic protection, corrosion, sacrificial systems, bridges, gulf coast

### **INTRODUCTION**

Managing aging reinforced concrete infrastructure is a complex and capital-intensive task, particularly in harsh marine and coastal environments. Corrosion from saltwater, coupled with wet and dry cycles, are particularly problematic for long-term durability of reinforced concrete. The Gulf Coast presents a challenge for maintaining service life of concrete structures that are exposed to high levels of chlorides, either by direct contact with salty or brackish water or by indirect contact with salt spray. Chlorides induce corrosion of the steel reinforcement which initiates cracking and spalling of the concrete, reducing the service life of the structure. If left unmitigated, corrosion can result in section loss of the reinforcement and can create a potential for compromised strength and safety concerns.

Sacrificial (galvanic) cathodic protection (CP) systems are used to extend the service life of reinforced structures subject to harsh exposures such as bridges, ports, and other infrastructure. These systems have been used to protect bridge and other reinforced concrete infrastructure in Texas for nearly 30

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years.<sup>1</sup> As these systems age, owners are faced with decisions regarding timing and need to replace existing CP systems. This paper will present case studies from recent testing of sacrificial CP systems from four different infrastructure projects along the Texas gulf coast. General considerations and options for continued monitoring, maintenance and repair, or replacement of the CP systems are also presented.

## BACKGROUND

CP systems are primarily used where environmental conditions impact the integrity of a structure. Sacrificial CP systems work by providing protection from an anode to the cathode through a potential difference. These systems are easier to maintain as compared to an impressed CP system which requires an external power source. There are many different types of sacrificial CP systems used for reinforced concrete structures such as surface applied coatings, metallizing, variety of zinc anodes with stay-in-place FRP jackets, embedded anodes, and bulk anodes. NACE TR01105 provides information on several commercially available galvanic cathodic protection/prevention systems for reinforced concrete structures.<sup>2</sup> Coatings such as metallizing are thermally sprayed onto the concrete surface and provides a barrier between the substrate and environment while also providing cathodic protection. Zinc anodes are used with a stay-in-place FRP jacket and can be activated by either galvanic action, alkali-activated, or through a wicking material that supplies water to the anode. Choosing which method for activation of these zinc anodes depends on environmental and project specific conditions. Embedded anodes can also be drilled into the concrete structure and are connected directly to the reinforcement. Bulk zinc anodes are commonly used in conjunction with other sacrificial systems such as the FRP jackets. These anodes are typically made of aluminum, zinc, or magnesium and are connected and submerged near the structure being protected.

## DESCRIPTION OF CP JACKET SYSTEMS

The concrete substructure elements presented in this paper are protected by zinc mesh anodes with stay-in-place FRP jackets. Similar systems are used in marine environments for reinforced concrete columns, piles, web walls, and tie beams that are in the tidal or splash zone of coastal regions (salt or brackish water exposure). Sacrificial cathodic protection is achieved by supplying current, in this case produced by the dissimilar metal corrosion between zinc and carbon steel, to counteract the currents that develop in a typical corrosion cell. The current flows from an external anode (zinc mesh) through the electrolyte (grout and concrete) to the surface of the reinforcing steel, which becomes cathodic, and corrosion is mitigated. In addition, the stay-in-place jacket serves as a physical barrier against additional chloride penetration and limits oxygen availability to embedded steel.

These CP systems are often used in combination with submerged bulk zinc anodes. The size of the pile jackets varies based on the element being protected, however all jackets are tall enough to protect against the tidal and splash zone. The jackets consist of two C-shaped fiberglass stay-in-place forms installed around the piles connected at two longitudinal seams. Each jacket has a diamond-shaped zinc mesh adhered to the inside face of the stay-in-place form; this mesh serves as one of the system anodes of the sacrificial CP system in addition to the submerged bulk zinc anodes (when present). A 2-inch nominal annular space between the jacket and structure was filled with a sand-cement grout that serves as the CP system electrolyte. The top of the grout was sloped at a 45-degree angle to limit the propensity for water ponding and facilitate flow of water down the exterior of the jackets. Negative structure connections were made to the reinforcing steel, and positive anode connections were made to the zinc mesh and bulk zinc anodes. The system wiring was routed through PVC conduit into a junction box above the top of the jacket. Design intent for the pile jackets was for the structure and anode to be electrically discontinuous within the jacket and for the only electrical connection between the negative and positive leads to be made within the junction box to allow for routine monitoring.

Data compiled from CP systems for four different structures along the Gulf Coast are presented in this paper. Structure 2 used zinc mesh jacket systems while Structures 1, 3, and 4 used zinc mesh jacket

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systems in combination with submerged bulk zinc anodes. A total of 80 CP jackets were evaluated between all structures and the quantity of jackets tested at each structure is shown in **Table 1**. Each structure contained more jackets than presented herein, however a limited random sample of jackets were evaluated to give an estimation of the performance of all jackets.

**Table 1**  
**Ages of structure and CP systems at each structure.**

| Structure ID | Age of Structure | Age of CP System | Jackets Tested |
|--------------|------------------|------------------|----------------|
| Structure 1  | 58               | 10               | 21             |
| Structure 2  | 48               | 20               | 21             |
| Structure 3  | 51               | 18               | 21             |
| Structure 4  | 47               | 18               | 17             |

### VISUAL ASSESSMENT

A visual assessment of the CP elements and structure being protected was performed to record the existing condition and establish quantities for future repairs or maintenance needed to keep the system operating effectively. Elements that were observed and make up the CP system include: fiber glass jacket, grout material between jacket and pile, electrical junction boxes, PVC conduit, and electrical wiring.

Overall, the observed elements listed above were typically in good condition. Cracking of the fiber glass jackets was present on approximately 20 to 25 percent of jackets, mostly minor cracking (Figure 1) with the expectation of a few larger cracks exposing the underlying grout to the atmosphere (Figure 2). The grout at almost all locations was observed to be well adhered to the concrete pile, providing a path for the flow of ions for the cathodic reactions.



**Figure 1: Typical small cracks at jacket corners**



**Figure 2: Large vertical crack exposing grout to environment**

The grout above the jacket at a few locations was disbonded from the concrete pile (Figure 3), however this portion of the grout is not essential for performance of the CP. Junction boxes and PVC conduit were typically in fair condition with some boxes and conduit having severe cracking, exposing wiring to the environment. Screws holding the exterior face of the junction box were typically corroded, sometimes making it difficult to access the box. The condition of the electrical wiring varied between structures based on the method of protecting the connections, however some corrosion and loose connections were observed at all structures. Some connections were covered in a heat shrink wrap, which was generally poor at preventing corrosion of the connection (Figure 4 and Figure 5). Testing was also more time consuming and difficult due to removal of the wrap.



**Figure 3: Sloped grout topping removed by hammer sounding**



**Figure 4: Heat shrink sleeve over electrical connections**



**Figure 5: Corroded electrical connections inside junction box**

Concrete distress such as cracking and spalling was observed above some of the jackets, however the majority of piles with jackets did not show signs of concrete distress. Piles without jackets showed more concrete distress as compared to those with jackets. Typical types of distress above the jacket can be seen in Figure 6 and Figure 7.