OPTIONS FOR EXTENDING THE LIFE OF CONCRETE STRUCTURES

BY STIG STROMBECK AND CHRIS BALL

The functional life span of a reinforced concrete structure is dependent on several key factors. An important consideration is the structure's resistance to corrosion of the reinforcing steel. Due to the potential impact that corrosion may have on the serviceability and long-term maintenance cost, there has been an increase in industry-wide awareness and use of corrosion management in recent years. This article provides an overview of technologies that are being used to mitigate steel corrosion of existing concrete structures. There are several solutions, each with specific uses, advantages, and limitations that allow for the mitigation of corrosion, resulting in the overall life extension of the structure.

CORROSION AND CONCRETE REPAIR

Corrosion damage can occur on many different types of structures, such as bridges, parking garages, and marine structures. Repairing these areas of concern, once steel corrosion has become apparent, should take place in a very well-defined way. For example, the recently issued ACI 562-13, "Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings,"[1] provides evaluation procedures and material and design requirements for the repair and rehabilitation of structural concrete members.

Today, it is well-known that the corrosion of steel in concrete is primarily due to exposure to chloride via roadway deicing chemicals, salt water, soils or contaminated aggregates, or mix water when the structure was built. Corrosion can also occur without the presence of chloride when the concrete pH around the steel drops due to exposure to atmospheric carbon dioxide, a process known as carbonation.

If a concrete structure requires repair, it is useful to include corrosion evaluation to gain an understanding of the magnitude and extent of the corrosion problem. If the corrosion problem is addressed by the repair process, such as removal

Fig. 1: Examples of steel corrosion on bridge structures

of all chloride-contaminated concrete in a bridge deck replacement, then a durable repair can be achieved without further measures.

More commonly, the concrete is repaired leaving significant portions of the original concrete in place. If a corrosion-damaged structure is repaired, but the underlying corrosion issue is not addressed, there can be a recurring corrosion issue in the concrete adjacent to repaired areas, known as patch-accelerated corrosion, or the halo effect. This subsequent corrosion damage takes place due to the reinforcing steel being exposed to the variation in chemistry between the new repair mortar or concrete and the remaining chloride-contaminated concrete. The environment left by the repair process may lead to a new or accelerated electrochemical reaction resulting in the corrosion of the steel that is encased in the original concrete outside of the repair, as well as the eventual breakdown of the original concrete surrounding the repair.

For these reasons, many engineers and owners are opting for longer-term solutions that provide ongoing corrosion prevention, as well as solutions for mitigating the corrosion issues entirely. These solutions include electrochemical treatments, impressed current systems, and galvanic systems.

ELECTROCHEMICAL TREATMENTS

Electrochemical treatments are used to passivate the active corrosion within the structure by changing the environment around the reinforcing steel. The two types of electrochemical treatments are chloride extraction and realkalization. These techniques are typically implemented on beams, columns, and pier caps, but can also be performed on concrete structures with accessibility for the treatment system, such as buildings. These treatment systems each have a specific purpose, but both have the benefit of being nondestructive, globally applied, and low-maintenance while also providing long-term protection.

Chloride extraction is a treatment that uses an applied electrical field between the reinforcement in the structure and an externally mounted temporary anode to passivate corrosion by moving chloride ions away from the steel and restoring a high pH environment through electrolysis. A majority of the chloride ions are transferred out of the concrete and removed at the end of the treatment with the end result being that the structure is left in a passive, noncorroding condition without the need for ongoing monitoring or maintenance of a cathodic protection system.

Realkalization is similar to chloride extraction in that it also uses a temporarily applied electric field, but the purpose is to increase the alkalinity of a carbonated concrete structure by using a highly alkaline electrolyte during the treatment process. Through electro-osmosis, this externally applied electrolyte is pulled into the structure, sufficiently

Fig. 2: Chloride extraction performed on historic viaduct

increasing the pH of the concrete directly around the reinforcing steel to maintain a long-term passive condition. In effect, realkalization turns back the clock on carbonated concrete structures.

IMPRESSED CURRENT CATHODIC PROTECTION

Impressed current cathodic protection (ICCP) systems can provide long-term protection to reinforcing steel in aggressive environments. This protection is provided through a constant supply of DC current from a permanent power source. The current flows from permanently installed anodes to the reinforcement (the cathode). ICCP systems are commonly designed with inert anodes such as mixed metal oxide (MMO)-coated titanium and ceramic materials that do not require replacement over the design life of the system. A properly designed and installed ICCP system will reduce or eliminate corrosion of the reinforcing steel by maintaining the steel in a more passive state.

In addition to providing long-term protection, an ICCP system also offers a high level of control for the user by providing a means for adjusting the applied voltage to achieve the level of protection that is required. During its life, the system will need regular monitoring and maintenance to ensure that it is functioning properly and fulfilling its intended purpose. When not maintained properly, the performance of ICCP systems may be impacted with the possibility of losing all functionality; but when maintained properly, they have been shown to have a high level of effectiveness.

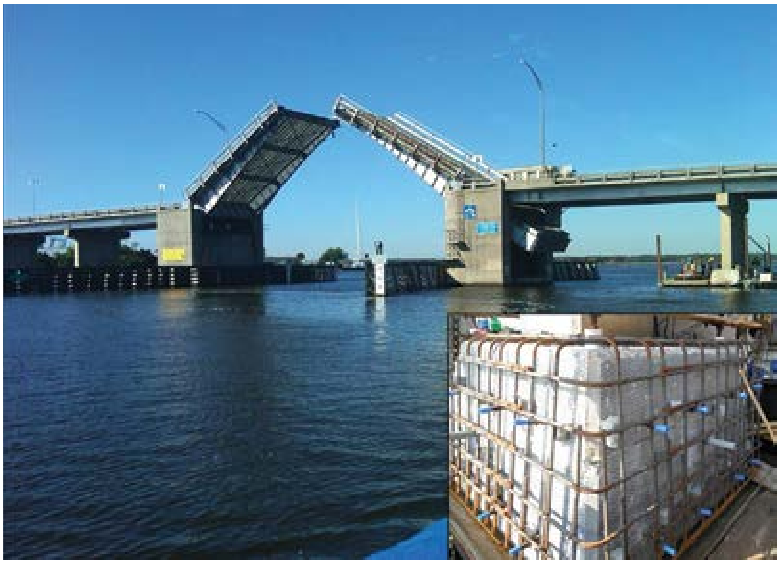


Fig. 3: ICCP system on bridge footing in marine environment

Fig. 4: Type 1A embedded galvanic anodes on bridge pier

GALVANIC PROTECTION

Galvanic protection systems are used to increase the usable life of a structure by mitigating corrosion with a reduced level of maintenance and monitoring. This type of system provides protection through an electrochemical process in which a sacrificial metal is consumed preferentially to the reinforcing steel within the structure. For concrete structures, zinc is the most commonly used metal in galvanic protection systems, particularly for anodes embedded in concrete.

The sacrificial anode has a higher (more negative) potential relative to the reinforcing steel. When the anode is connected to the reinforcing steel in concrete, the steel functions as the cathode and is protected by the current generated from the corrosion of the anode. Due to this propensity for the anode to naturally decay, galvanic protection systems are typically designed to have a service life of 10 to 30 years. Once the anode service life is exceeded, the anodes can be reinstalled if necessary, although the structure may be relatively passive due to positive effects on the reinforcing steel that occurred while receiving decades of protective current.

There are several different types of galvanic anode systems that can be applied for various situations. These systems consist of embedded anodes, surface-applied anodes, and anodes specific to marine environments.

EMBEDDED GALVANIC ANODES

Embedded galvanic anodes are the most common galvanic anode, encompassing both discrete galvanic anodes and distributed galvanic anodes. The ACI publication "Repair Application Procedures (ACI RAP) Bulletin 8—Installation of Embedded Galvanic Anodes,"[2] includes useful nomenclature that can be used to define the various types of embedded galvanic anodes.

Discrete galvanic anodes are available in a range of sizes and shapes to account for various corrosion conditions, steel density, and uses. Type 1 anodes are attached to the reinforcing steel during repairs at the interface between new and old concrete to mitigate halo effect corrosion. Type 2 anodes are placed into holes drilled on a grid pattern in sound concrete. These anodes can be particularly useful to address corrosion "hot spots" that have been detected by a half-cell corrosion potential survey.

Embedded galvanic anodes contain chemicals in the specialized mortar that surround the zinc core and allow the anode to continue to produce protective current over time. Type A anodes (alkali-activated) have a high pH environment around the zinc core and Type H anodes (halide-activated) use chloride or bromide salts.

Distributed galvanic anodes are customized for specific applications and provide a high level of protection. For protection of large areas, such as decks, abutments, and columns, elongated anodes are distributed across the surface of the structure and embedded in a concrete overlay. Distributed anodes are also used for targeted protection such as at the interface between new and old concrete resulting from the extension or replacement of a structure.

SURFACE-APPLIED GALVANIC ANODES

There are two main types of surface-applied galvanic anodes: metalized anodes and preformed zinc sheets with conductive adhesive. These systems do not require an additional power source, are simple to visually inspect, and require little maintenance. The most common surface-applied galvanic anode is installed by a metalizing process that takes wires of the anode material (for example, zinc or aluminum alloys) and sprays the molten metal onto the surface of the concrete structure. When this metal is connected directly to the reinforcing steel, it acts as a sacrificial anode. After the anode is installed, a humectant solution is commonly used to attract moisture to the anode-concrete interface, thus increasing the system performance. Surface-applied galvanic anodes are generally used to mitigate corrosion in larger, non-traffic-bearing areas.

GALVANIC PROTECTION FOR CONCRETE PILES

Concrete piles in marine environments are very susceptible to corrosion, particularly due to cyclic wetting and drying in the tidal zone. The most common protection strategy is to use galvanic encasements specifically designed for this harsh environment. There are two types of galvanic anode systems used for this application: zinc mesh jackets and distributed galvanic anodes, both of which are encased in concrete.

The zinc mesh jacket design allows for salt water to enter the bottom of the jacket (which remains submerged), keeping the zinc active so that it can perform as the anode for the reinforcing steel. Because the anode is dependent on saltwater exposure to stay active, drier elevated sections of the pile away from the tidal zone may receive inadequate protection.

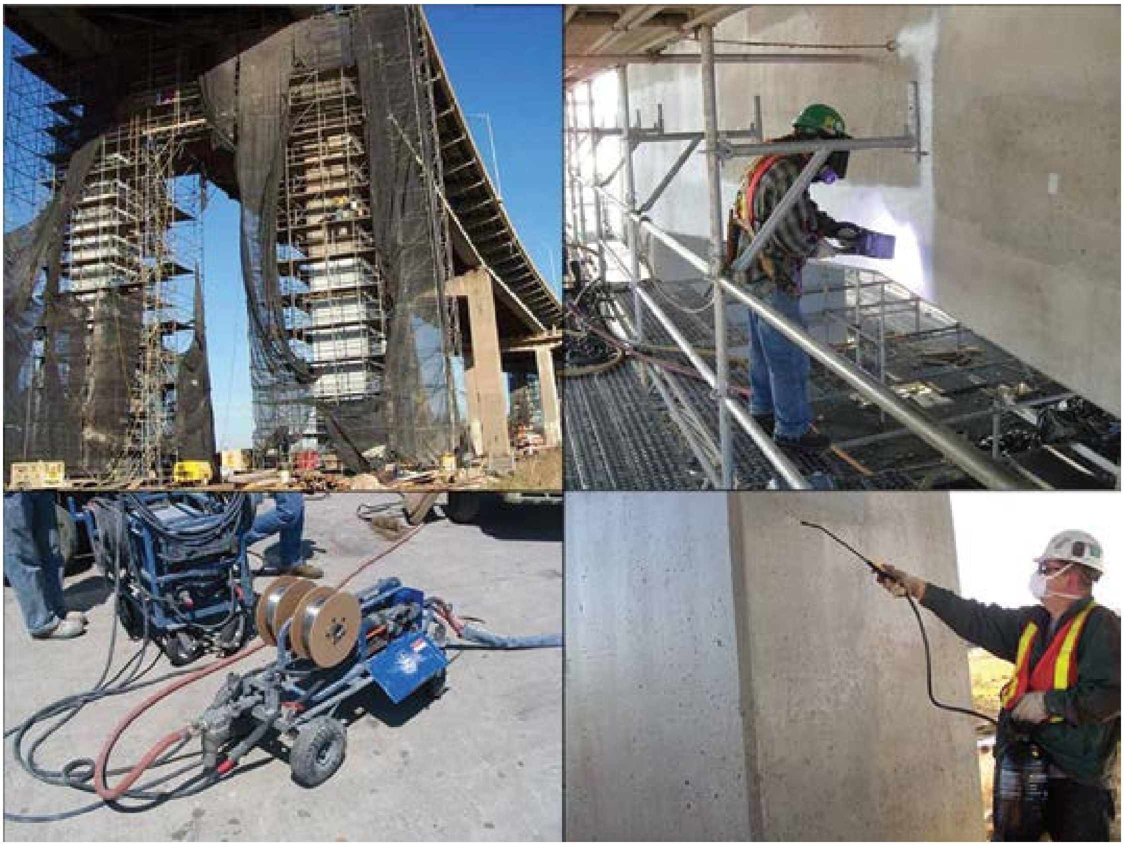


Fig. 5: Humectant-activated arc-sprayed zinc metalizing on bridge substructure

Fig. 6: Marine pile protection with self-activated distributed anodes inside FRP jacket

The marine-distributed galvanic anode system is a system in which an elongated anode is surrounded by a self-activated mortar. Once the galvanic anode is secured to the concrete surface, it is encased in concrete using a stay-in-place fiber-reinforced polymer (FRP) jacket or removable formwork. The anode is not reliant on saltwater exposure for activation and therefore offers protection in both wet and dry areas of marine piles. This is particularly useful if the system is intended to protect sections of the pile above the high-tide area. Both of these systems use bulk zinc anodes below the tidal zone to protect the submerged section of the pile.

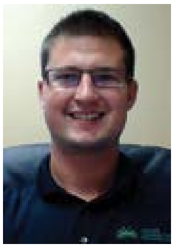
CONCLUSIONS

There are many corrosion mitigation solutions available. The large range of options allows for the global protection of the entire structure (or relatively large areas of the structure) or for protecting targeted areas of the structure to mitigate localized corrosion issues. When deciding on which system to use, it is recommended to consider the existing structure condition, the environmental conditions in which the structure resides, the desired or expected service life, the possibility for required monitoring and maintenance, and the budget. When all of these factors are taken into account, the proper corrosion protection system can be selected, resulting in the extension of the life of reinforced concrete structures.

Further information on electrochemical techniques used to mitigate the corrosion of steel in reinforced concrete structures is available in ICRI Technical Guideline No. 510.1-2013.

REFERENCES

1. ACI Committee 562, "Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings and Commentary (ACI 562-13)," American Concrete Institute, Farmington Hills, MI, 2013, 59 pp.
2. ACI RAP Bulletin 8, "Installation of Embedded Galvanic Anodes," American Concrete Institute, Farmington Hills, MI, Reapproved 2010, 7 pp.
3. ICRI Technical Guideline 510.1-2013, "Guide for Electrochemical Techniques to Mitigate the Corrosion of Steel for Reinforced Concrete Structures," International Concrete Repair Institute, Rosemont, IL, 2013, 24 pp.



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