Repair and Preservation of the Historic Rainbow Bridge

Valley County, Idaho

Submitted by Vector Corrosion Technologies

Fig. 1: The beautiful Rainbow Bridge

The Rainbow Bridge is the largest single-span concrete arch bridge in the State of Idaho and a landmark structure on the Payette River National Scenic Byway. Designed by Charles A. Kyle, the first Chief Bridge Engineer in Idaho, the structure was to blend in gracefully with its stunning surroundings (Fig. 1).

The structure is a reinforced concrete arch bridge approximately 410 ft (125 m) in length with a main span of approximately 210 ft (64 m) in length over the North Fork of the Payette River.

The federally funded bridge was completed in 1933 at a cost of $74,000 and provided a source of employment to the community.

Observed Problems

This historic bridge is located in a severe northern weather climate. Water runoff from the roadway is removed from the deck through drains, which allow water to fall unrestricted onto the bridge substructure.

In 1990, a previous rehabilitation of the bridge deck consisting of the removal of the top 2 in. (50 mm) of the original deck and removal of delaminated concrete was performed.

After decades of exposure to extended freezing-and-thawing cycles and application of deicing chemicals, severe corrosion of the reinforcing steel and subsequent deterioration of the concrete was occurring throughout the bridge (Fig. 2).

The Idaho Department of Transportation (DOT) determined that the historic bridge needed to be

Fig. 2: Chloride-induced corrosion damage

repaired and preserved. The two main objectives of the DOT were to:

1. Preserve and protect the historic structure for future generations, and
2. Improve safety for traveling motorists.

Corrosion of Steel in Reinforced Concrete

Corrosion of steel in reinforced concrete can be caused by the presence of sufficient concentrations of chloride ions, typically from deicing chemicals or saltwater exposure. Chloride ions can destroy the normal passive oxide protection that encases the reinforcing steel, leaving it vulnerable to corrosion. The corrosion by-product is expansive in nature and leads to concrete cracks, delaminations, and spalling.

While early damage is often not a serious structural concern, corrosion acts like a disease and must therefore be treated before it becomes a significant problem. In many cases, a chip-and-patch approach to concrete repair is adopted. This procedure entails removal of the damaged concrete, cleaning the reinforcing steel, and patching the repair area with concrete or a repair mortar. Repairs of this nature can accentuate corrosion in the reinforcing steel adjacent to the repair area. This phenomenon is often referred to as ring anode or patch-accelerated corrosion (Fig. 3).

Condition Evaluation

In May 2004, a condition evaluation of the bridge was completed by a structural engineering firm and a specialized corrosion consultant. This study assessed the extent of corrosion activity and evaluated alternatives for corrosion mitigation, preservation, and rehabilitation of the bridge (Fig. 4).

The corrosion evaluation consisted of electrical continuity testing, corrosion potential survey, chloride concentrations sampling, and delamination surveys. Upon completion of the survey, it was determined that the concrete arches and main piers around the deck drains and the joints had the most severe corrosion. The arches were particularly suffering along the chamfered edges where there was less concrete cover over the reinforcing steel (2 in. [50 mm] compared with 3 in. [76 mm] cover in other areas).

The corrosion potential testing indicated that the concrete arches ranged from approximately –0.100 V to –0.450 V relative to a copper-copper sulfate half-cell. Chloride testing from the arches ranged from 0.2 to 5.3 lb/yd^3 (0.12 to 3.1 kg/m^3) of concrete with 60% of the samples testing greater than the stated corrosion threshold of 1.2 lb/yd^3 (0.71 kg/m^3).

Selected Corrosion Mitigation Approach

As a result of the survey, railing and curbs were partially replaced and deck expansion joints were replaced to prevent future chloride contamination to the substructure. The substructure was partially patched and reconstructed, and long-term corrosion mitigation of arches was planned (Fig. 5).

After considering the various corrosion mitigation options, the corrosion mitigation scheme selected by the DOT was to use electrochemical

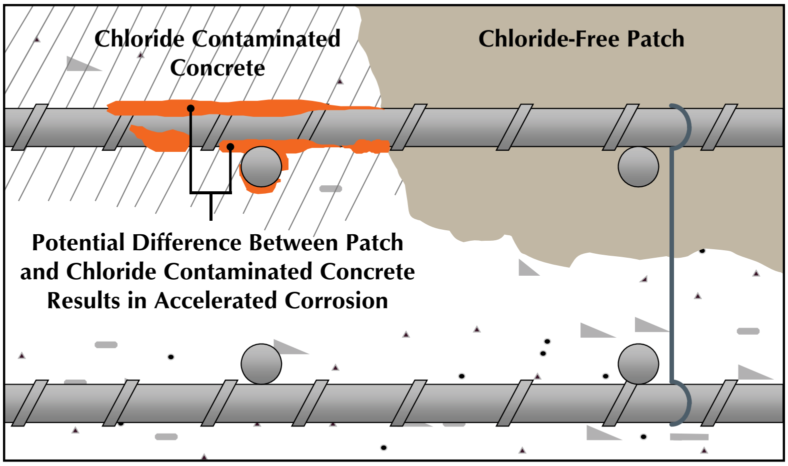

Fig. 3: Illustration of patch-accelerated corrosion

Fig. 4: Mapping grid for the corrosion potential survey

Fig. 5: Hanging platform access to the arches

Fig. 6: Work area enclosed to protect environment

Fig. 7: Reinforcing steel cover survey before ECE installation

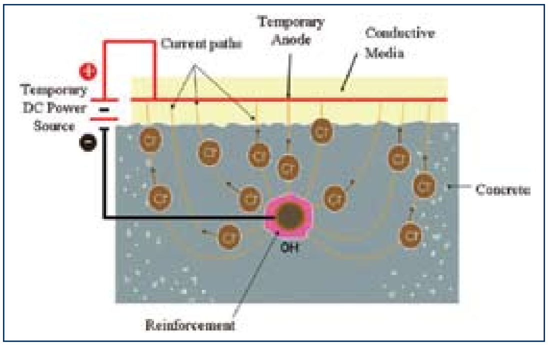

Fig. 8: Illustration of electrochemical chloride extraction

chloride extraction on the sections of the arches and main piers around the joints and to use embedded galvanic anodes in the concrete patch repairs in the nontreated areas (Fig. 6).

Electrochemical Chloride Extraction

Electrochemical chloride extraction (ECE) is a temporary electrochemical process used to mitigate reinforcement corrosion in salt-contaminated concrete structures (Fig. 7). By reducing the amount of chloride ions and generating higher alkalinity around the reinforcing steel, ECE has been found to reinstate the passivity of steel reinforcement. ECE was deemed to be one of the most promising technologies coming out of the FHWA Strategic Highway Research Program.

Unlike a cathodic protection system, the ECE system is a treatment process that directly addresses the cause of the corrosion from the concrete and no permanent system is left in place to be operated, maintained, and monitored for years into the future. ECE does not require any equipment or wiring to be left on the structure that can be vandalized or otherwise damaged, and maintains the original appearance of the structure.

ECE installation began on July 20, 2006, and the treatment was completed on September 14, 2006, in less than 2 months. Approximately 8000 ft^2 (745 m^2) of concrete surface was treated with ECE.

Installation of the ECE System

1. Cement slurry was used to seal off cracks and low cover areas on the structure. This prevented direct contact between the electrolyte and the reinforcing steel, hence reducing the possibility of an electrical short and ensuring a uniform treatment to the reinforcing steel (Fig. 8).
2. Loose and delaminated concrete was removed. Typically with ECE, the repairs are completed and allowed to cure before treatment. Due to the fast-track construction schedule, the exposed reinforcing steel was cleaned and coated in 100% solids two-part epoxy to prevent shorting of the system and the repairs were completed after the treatment.
3. Electrical contacts were established to the reinforcing steel (cathode) (Fig. 9).
4. Wood battens, approximately 1.5 in. (38 mm) thick, were attached to the surface of the concrete. The battens serve two purposes: they act as a spacer to keep the titanium mesh off the surface of the concrete, and as support for the temporary mesh anode.
5. A first layer of wet-spray-applied cellulose fiber/hydrated lime mixture was applied to the concrete surface to the level of the battens. The fiber acts as a conductive media that distributes the current uniformly over the surface of the

concrete. This was followed by hanging the titanium anode mesh from the battens. The anode mesh was then encapsulated by a second layer of cellulose fiber (Fig. 10).

6. To keep the cellulose fiber wet throughout the treatment, a system of drip hoses was installed on top of each pier cap. These hoses were connected to a central water supply that ran down the entire length of the bridge.
7. The entire system was then covered in 6 mil poly to prevent damage to the system and water evaporation from the electrolyte media.
8. The anode was installed into sections of approximately of equal area (subzones). The subzones were designed to cover between 100 to 150 ft^2 (less than 200 ft^2) (9.3 to 13.9 m^2 [less than 18.6 m^2]) of concrete surface area with at least two reinforcing steel connections per zone. Approximately 10 subzones (or 1000 ft^2 [92.9 m^2]) consisted of a single zone.
9. The anode mesh was then wired so that there were two leads running from the junction box to each sub-zone for redundancy.
10. A low-voltage DC rectifier was hooked to the system such that the reinforcing steel was negatively charged and the steel anode mesh was positively charged. Junction boxes were used to distribute power from the rectifiers to all subzones.

Startup and Monitoring of the ECE Treatment

1. Before the rectifier was turned on, the cellulose fiber was saturated by the irrigation system. The flow of water through the cellulose fiber was sufficient to provide electrically conductive media. The water runoff was collected and recycled. The pH of the water was constantly monitored and maintained in a safe range (Fig. 11).
2. The rectifier was then switched on and operated in the constant voltage mode. The DC output was set as high as possible, but not to exceed 45 V. By monitoring the electrical measurements over time, the development of certain trends can be observed. Notably, the system current will gradually decrease over time as the reduced chloride content increases the concrete resistivity.
3. The contract specification required that the treatment continue for 60 days or until a total of 200 A-hr/ft^2 was achieved. Based on data gathered during the treatment, the system was shut down once the contract requirements had been achieved.

Embedded Galvanic Anodes

Embedded galvanic anodes are galvanic devices designed to neutralize or slow down new corrosion cells, which would otherwise develop patch-accelerated corrosion or the ring anode effect. Therefore, galvanic anodes are placed around the perimeter of a patch to extend the service life of the repair (Fig. 12).

Fig. 9: Installation of reinforcing steel (cathode) connections

Fig. 10: Cellulose fiber installed over anode mesh

The heart of the device is a metallic anode composed of zinc, which is cast around a pair of steel tie wires. This unit is encased within an activated cementitious shell. The device is shaped like a short cylinder, approximately 2.5 in. (64 mm) in diameter, and 1 in. (25 mm) thick. The tie wires

Fig. 11: ECE treatment in progress

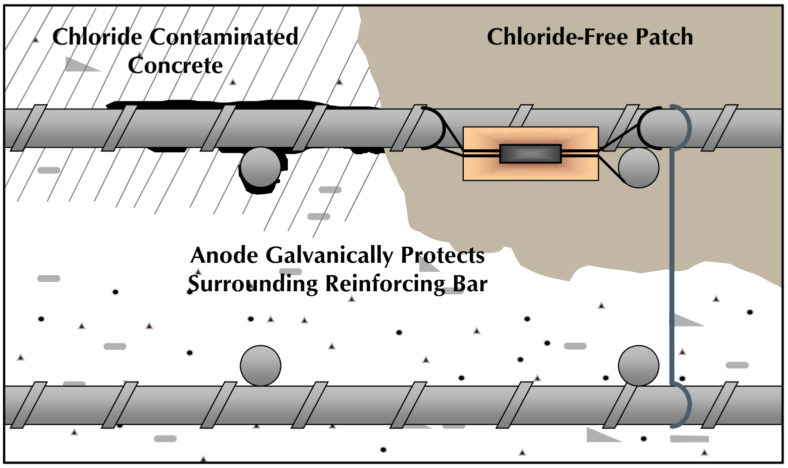

Fig. 12: Illustration of galvanic anode in patch repairs

extend out opposing sides of the anode to enable it to be tied to the reinforcing steel.

As the zinc corrodes, it provides a small electrical current to the surrounding reinforcing steel to prevent the initiation of new corrosion adjacent to the repair.

Installation of Embedded Galvanic Anodes

Installation of the embedded anodes began with the removal of all damaged concrete, including removal of concrete from around and behind the reinforcing steel. The reinforcing steel was cleaned and the anodes installed below or next to the reinforcing steel, ensuring that sufficient concrete cover was maintained over the anodes. The anodes were attached by wrapping the integral tie wires around the reinforcing steel, ensuring that a secure connection was made. The connection of the anode was verified by continuity testing. Once the anodes were in place, the repair was completed with a cement-based repair mortar.

System Benefits

ECE was performed only on the main span arches and base piers, while galvanic anodes were installed in the patch repairs to provide localized corrosion protection.

Listed as follows are the many benefits that ECE and embedded galvanic anodes brought to the project.

Electrochemical Chloride Extraction:

- Addressed the source of the problem by reducing chloride and increasing pH around the steel (corrosion passivation);
- Minimized the impact on the aesthetics of the historic structure;
- Allowed the structure to be restored versus replaced;
- Allowed shorter construction time and minimal traffic interruption compared with replacement; and
- Addressed corrosion issues without leaving a system in place that requires monitoring or replacement over time.

Embedded Galvanic Anodes:

- Addressed localized patch corrosion;
- Allows cost saving—fewer repairs will be required in the future; and
- Provided easy installation—no special skills or tools were required for installing anodes.

Upon completion of the project, the corrosion of the substructure and the concrete arches had been mitigated. Not only were important structural issues addressed, but aesthetics maintained as well. By including advanced corrosion mitigation technologies such as ECE and embedded galvanic anodes, the owner had taken a major step in reducing future maintenance concerns.

Rainbow Bridge

Owner
Idaho Department of Transportation
Boise, Idaho

Project Engineer/Designer
CH2M Hill
Boise, Idaho

Repair Contractor
Vector Corrosion Technologies
Wesley Chapel, Florida

General Contractor
Mowat Construction
Desert Hills, Arizona

Material Supplier/Manufacturer
Vector Corrosion Technologies
Wesley Chapel, Florida