Electrochemical Treatment

Extending the Life of a Historic Viaduct Structure

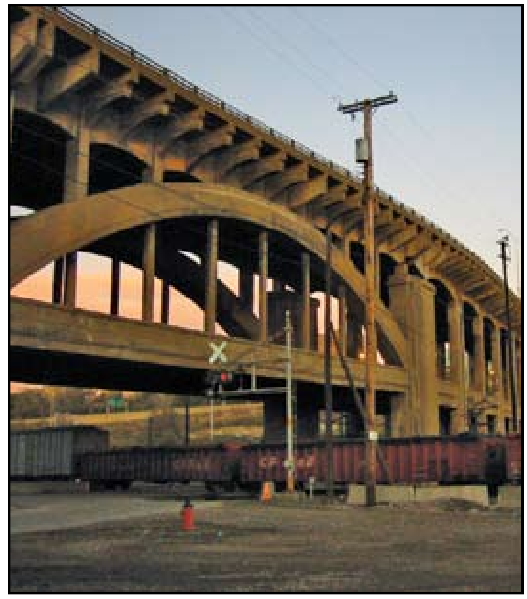
By J. Christopher Ball

To keep up our national infrastructure, continued investment will be required particularly in the areas of maintenance and repair of structures. According to the 2005 American Society of Civil Engineers (ASCE), the total investment needs for America's infrastructure is estimated at $1.6 trillion over a five year period. In their annual Report Card, ASCE gives America's infrastructure an overall grade of D corresponding to "Poor". The same report estimates an annual investment of $9.4 billion would be required over the next 20 years to eliminate all bridge deficiencies. Similarly, in 2002, the National Association of Corrosion Engineers (NACE) reported the annual direct cost of corrosion at $276 billion, or 3.1% of the United States gross domestic product. It has been recently estimated that the overall cost of repair, rehabilitation, protection and strengthening of concrete structures to be $18 to $21 billion per year (*Concrete Repair Bulletin*).

12th Street Viaduct Under Construction, completed in 1915. Courtesy of HNTB Corporation and Architectural & Historical Research Consultants.

One of the most important causes of deterioration of concrete structures is due to corrosion of the reinforcing steel. Corrosion activity is caused by the elimination of the passive oxide layer on the reinforcing steel. This is typically due to exposure to chlorides in the environment (typically de-icing salts or saltwater along the coastline), or due to carbonation of the concrete. Once corrosion is initiated, the structure is destined for a cycle of on-going maintenance repairs which accelerate over time. For many structures, additional steps to mitigate corrosion to extend there service life is worthy of serious consideration.

Over the last 15 to 20 years, there has been a significant increase in technologies available to mitigate corrosion in reinforced concrete structures. Electrochemical treatments such as Electrochemical Chloride Extraction (ECE) are non-destructive technologies that directly address the root cause of corrosion problems by altering the environment around the steel to passivate active corrosion. The ECE treatment generates increased alkalinity and significantly reduces the amount of aggressive chloride ions around the reinforcing steel.



12th Street Viaduct, 2005. Courtesy of Vector Corrosion Technologies.

The 12th Street Trafficway Viaduct

Completed in 1915, the historic 12th Street Trafficway Viaduct is a 2,300-foot long reinforced concrete structure that was constructed to link the industrial district in the bottom land along the confluence of the Missouri and Kansas rivers to the commercial district along the bluffs 200 feet above. The Viaduct is undergoing a major restoration program to extend the service life of the 90-year old structure. In 2005, ECE was used to treat the large concrete columns as part of an overall rehabilitation.

Designed by J. A. L. Waddell and John Lyle Harrington, the structure utilizes a prominent bowstring arch span and 45 girder spans masked as arches at the upper deck. The upper deck, with a grade of 5.5%, provided a 30-foot roadway for vehicular traffic, a double-track electric railway on a 21½-foot independent right-of-way, and a single 5-foot sidewalk. The lower deck, with a grade of 3%, provided a 30-foot roadway for slower team traffic carrying heavy commercial loads.

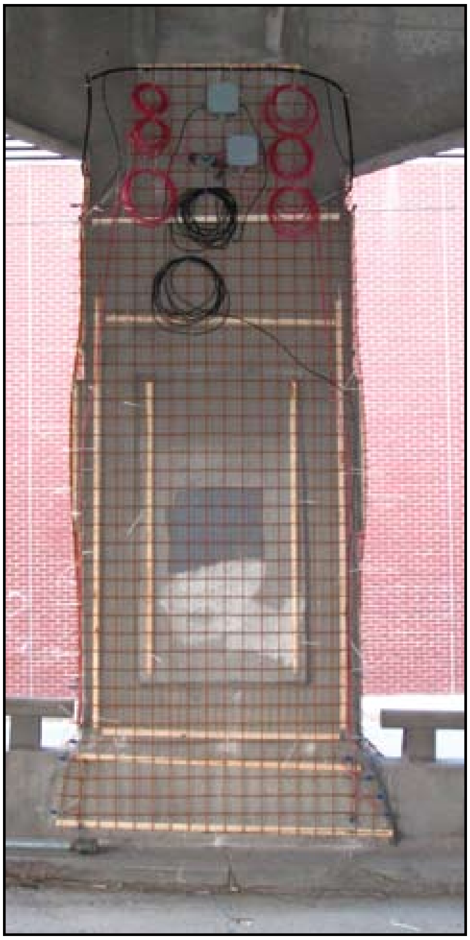
Originally constructed by the Graff Construction Co. for $625,000, the viaduct was completed in 15 months and was officially opened for traffic on March 18, 1915. As one of the earliest concrete double-tiered bridges constructed in the United States, the structure is recognized for its engineering and construction accomplishment. According to the 1994 Missouri Historic Bridge Inventory, the viaduct is eligible for listing in the National Register of Historic Places.

In 1965, Howard Needles Tammen and Bergendoff (HNTB) determined that the bridge was showing signs of deterioration, including cracked concrete and deterioration of the expansion joints. HNTB recommended that the structure be rehabilitated, eliminate the lane originally utilized by streetcar rails on the upper deck and that the deck be widened to four lanes. The project was completed in 8½ months and the structure was open for traffic in October 1965.

Deterioration

The structure is currently undergoing another round of repair and rehabilitation. Surveys completed in 2004 found that the structure was experiencing concrete deterioration. The deterioration is primarily due to corrosion of the reinforcing steel from exposure to chloride salts present in de-icing chemicals. Once chloride ions from deicing salts penetrate through the concrete cover down to the level of the steel reinforcement, it is only a matter of time before corrosion of the reinforcing steel begins. The corrosion of steel causes an increase in volume that, when embedded in concrete, produces a tensile stress that eventually causes cracking, leading to delaminations and spalling.

The most commonly used repair technique is mechanical removal and replacement of all spalled and delaminated concrete. This "chip and patch" technique is effective in repairing the visual deterioration, but does not address the overall corrosion problem. The rebar corrosion will therefore continue in the remaining chloride contaminated concrete, especially the sections of concrete surrounding the newly patched areas.



Concrete pier with ECE wiring installed. Courtesy of TranSystems.

Installation of temporary anode mesh onto concrete surface. Courtesy of Vector Corrosion Technologies.

The progressive deterioration that is commonly found adjacent to concrete patch repairs is referred to as patch accelerated corrosion or the "halo effect".

While replacement of damaged concrete and reinforcing steel treats the symptoms, a process known as electrochemical chloride extraction (ECE) is known to be an effective method of treating the root cause of corrosion. Simply put, the objective of the ECE treatment is to passivate active corrosion and thus extend the service life of otherwise sound concrete structures. The process is accomplished by electrochemically altering the corrosive environment around the reinforcing.

The first structure in North America to be treated with the ECE was the Burlington Skyway in Ontario in 1989. This project was subsequently evaluated as part of the Strategic Highway Research Program which released the SHRP-C-620 report in 1993. In summary, the report concluded that the ECE treatment process is effective at returning reinforcing steel to a non-corrosive state. The Ontario Ministry of Transportation (MTO) continues to monitor the site, and after 17 years the treated area is still passive.

The ECE treatment process works by applying a direct current to the structure. Under influence of the DC field, chloride ions are moved away from the reinforcing steel and transported out of the concrete by ion migration. Simultaneously, hydroxyl ions are generated at the steel/concrete interface, thereby causing the pH level of the concrete surrounding the reinforcement to increase. The net result is the mitigation of active corrosion and future corrosion of the reinforcement with no negative mechanical or chemical effects on the concrete or reinforcing steel.

Concrete repairs completed prior to installation of ECE treatment. Courtesy of Vector Corrosion Technologies.

ECE Treatment Process

The chloride extraction treatment is a non-destructive method of corrosion mitigation. In areas where the chloride contamination has not yet caused concrete damage, little or no concrete removal is required. In areas with corrosion-induced damage, cracked, spalled, and delaminated concrete is repaired prior to the treatment. Overall, much of the noise and dust problems associated with conventional repair are reduced.

The temporary DC electric field is created by an external electrode mesh mounted on the surface of the concrete. To make the mesh electrically conductive with the concrete, it is embedded in a sprayed-on mixture of potable water and cellulose fiber. The electrode mesh is connected to the positive terminal of a transformer rectifier and the reinforcing steel is connected to the negative terminal. During the treatment, negatively charged chloride ions are pushed away from the reinforcing and drawn toward the positively charged external electrode mesh, where they are trapped in the fibrous electrolyte mixture.

Once the chloride content has been reduced to acceptable levels, and the pH of the concrete surrounding the reinforcing steel has been raised, the temporary anode and electrolyte media is removed. After the treatment is complete, barrier protection is provided by the application of a clear concrete sealer to prevent future chloride contamination.

Application of cellulose fiber for conductive media around temporary anode. Courtesy of TransSystems.

ECE on the 12th Avenue Viaduct

In the summer of 2005, the Kansas City Department of Public Works undertook a large rehabilitation project on the 12th Street Viaduct in downtown Kansas City. The substructure rehabilitation consisted of conventional chip and patch repairs on 46 reinforced concrete piers. Of these piers, 25 received ECE treatment. These piers typically had elevated chloride levels due to leaking expansion joints in the deck. Installation of the ECE system on the Viaduct began in May of 2005. Installation was completed 5 months later, in September of 2005.

A baseline chloride profile analysis was conducted before the treatment process. Two locations in each pier were sampled at the following depths from the concrete surface: 0-1 inches, 1-2 inches, and 2-3 inches. Chloride concentrations are generally found to be high at the surface of the concrete, and decrease with depth of concrete. This is due to the migration process of chloride ions from the surface, and was seen to be true of the piers of the 12th Street Viaduct.

Prior to the installation of the electrode mesh, a cover survey was completed over the entire surface of the concrete piers to be protected. The minimum depth of cover of the reinforcing steel in the treatment areas should be 10 millimetres to ensure that the rebar does not short out to the electrode mesh. Any areas with less than 10 millimetres of cover were addressed by cutting back the reinforcing steel to a depth greater than 10 millimetres and patching with a cement-based mortar. All metals that were on the surface of the concrete were removed.

After the removal of near surface metals, a survey was performed to verify the electrical continuity of the reinforcing steel. All measurements showed an electrical potential difference of less than 1mV, indicating that the steel was electrically continuous and the structure was suitable for the ECE process.

To prepare the structure for ECE installation, all existing concrete delaminations and spalls were repaired with a cement based repair mortar. All cracks in the concrete were repaired or sealed to prevented direct contact between the electrolyte (water) and the rebar, hence reducing the possibility of an electrical short.

A minimum of one cathode or rebar connection is required for every 500 square feet, with a minimum of two for each pier. The electrical connections were made by locating and drilling a ¾-inch diameter hole down to a reinforcing steel bar. A 6-guage wire was stripped back approximately 1¼ inches and then wrapped with a small strip of lead and pounded into the hole with a punch. The connection was than sealed with silicone to prevent contact with any water. These connections were checked for electrical continuity to ensure that all reinforcing steel within each member of the structure was continuous. The electrical potential difference between two connections should be less than 1mV.

Wood spacers, approximately 1-inch thick, were anchored to the surface of the concrete using plastic spikes so that there was no chance of electrical shorts. The wood spacers serve two purposes: they act as a spacer to keep the mesh off the surface of the concrete, as well as provide a support to hang the steel mesh anode. The steel welded wire mesh anode was then attached to the wood battens. The mesh was secured around each pier by running plastic cable ties underneath the wood batten spacers and over the mesh.

The layout of the steel mesh anode is designed such as to allow on-going monitoring of small zones of 100 to 150 square feet of concrete surface area. This also allows adjustments and repair to smaller sections if problems arise, such as a lost rebar connection or electrical short occurs.

A low voltage DC rectifier was hooked up to the system such that the reinforcing steel was negatively charged, and the steel anode mesh was positively charged. This was accomplished by running a power cable from each terminal on the rectifier into a junction box located at the top of the pier. The negatively charged cable was connected to the cathode wires in the junction box, and therefore the reinforcing steel carried a negative charge. The positively charged cable was connected to the anode wires.

The steel mesh was then encapsulated in a wet spray-applied cellulose fiber/hydrated lime mixture. Hydrated lime powder was added to the cellulose fiber at a rate of 10% by weight. The lime and cellulose fiber were thoroughly mixed in the hopper of the fiber blower and then dry-blown through the hose. Water was injected at the nozzle to create a saturated mixture that sticks to the concrete and mesh. The fiber acts as a conductive media that distributes the current uniformly over the surface of the concrete.

To ensure an effective treatment, it is important to keep the concrete and cellulose fiber mix surrounding the steel mesh anode saturated during the treatment. This procedure reduces the resistivity of the concrete and allows the chloride ions to migrate more efficiently through the concrete. An irrigation system was installed using drip hoses at the top of each pier. The system was to allow ½ gallon of water to pass through each dripper in one hour, which was sufficient to keep the structure wet while minimizing the amount of water collecting at the base of the pier. To minimize evaporation of the water, electrolyte the piers were wrapped with 6 mil plastic sheets. Plastic banding and shrink-wrap were also used to hold the plastic sheets tight.

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 40 V and/or 0.2 A/square foot of concrete surface area. As each rectifier was turned on, the cables running into the junction boxes were tested to ensure correct polarity. During the time the system was running, electrical measurements and system inspections and adjustments were conducted on an on-going basis.

Acceptance Criteria

The following criteria was specified to determine if the ECE treatment was successful:

1) The treatment had run for 60 days, or
2) A total of 600 A-hrs/m2 of current had been passed, or
3) The chloride concentration in the vicinity of the reinforcing steel had decreased to 0.03% by weight of concrete.

ECE Treatment Results:

1) Average number of treatment days = 60.9.
2) Average total current passed = 623.6 $A\text{-}Hrs/m^2$.
3) Chloride concentration at the level of steel below 0.03%, 64.4% average reduction.

The overall performance of the system was very effective in removing the majority of the chloride ions. The main area of concern is the region surrounding the rebar. If contaminated with chlorides, this area will contribute to the corrosion of the reinforcement. In fact, at the depth of the reinforcing steel, the chloride levels are below the corrosion threshold.

It has been well documented that the ECE process generates hydroxyl ions at the level of the reinforcing steel. The increase in hydroxyl ions and decrease in chloride ions effectively lower the Cl^-/OH^- ratio. The effects of decreasing this ratio are considered very beneficial from a corrosion protection standpoint. Decreasing this ratio is likely to be more important than solely removing chlorides.

Several piers undergoing ECE treatment process. Courtesy of Vector Corrosion Technologies.

Summary

Rebar corrosion can be successfully mitigated with the use of Electrochemical Chloride Extraction (ECE) treatment process. Applying a temporary electric field between the concrete surface and the reinforcing steel can expel or remove chloride ions from salt-contaminated reinforced concrete structures. This effect, along with the generation of hydroxyl ions at the steel/concrete interface, has proven to be effective in the mitigation of reinforcement corrosion, thus prolonging the life of a structure.

In 2005, the ECE treatment was used on the first phase of a major rehabilitation project in Kansas City, Missouri where 25 reinforced concrete bridge piers were electrochemically treated. The treatment process exceeded all three acceptance criteria including days of treatment, average total current passed, and reduction in chloride content. Additionally, through the generation of hydroxyl ions, the alkalinity at the surface of the steel was significantly increased. The net result is a passivation of active corrosion and a significant increase in service life of the concrete structure. ECE is currently being utilized in the second phase of the project as part of the overall rehabilitation of the historic 12th Street Viaduct.▪

Application of concrete sealer to prevent future chloride contamination after ECE treatment is completed. Courtesy of TranSystems.

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