Evaluation of Alternatives for
Extending the Service Life of
Interstate Route 480 Viaduct Substructure
Omaha, Nebraska

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Abstract

Constructed in the early 1970's, the I-480 viaduct through downtown Omaha, Nebraska consists of 1.5 miles of concrete deck and steel box girders, supported by 66 large conventionally reinforced concrete hammerhead piers. By the mid-1990s the viaduct was showing evidence of significant chloride-induced corrosion and deterioration of the concrete deck and concrete substructure.

The corrosion damage on the concrete deck was severe enough to require a complete deck replacement. However, the concrete piers required an evaluation of options to determine the most economical method to meet the 40+ year design service life for the rehabilitated viaduct structure.

In order to determine the current status of the concrete piers, a condition evaluation was completed. The evaluation consisted of core testing, petrographic analysis, delamination survey, chloride profile, carbonation testing and a half-cell corrosion potential survey. The evaluation indicated that the existing conditions varied through the structure.

With this information in hand, various rehabilitation options could be considered to extend the service life of the concrete piers including: protective coatings, removal and replacement of the chloride-contaminated concrete, impressed current cathodic protection, and electrochemical chloride extraction. Each option had its advantages and disadvantages in cost, service life performance, and disruption to the public.

After consideration of these options, it was determined that a combination of strategies would be utilized to rehabilitated the depending upon the conditions. The level of protection could be tailored to suite the varying needs of the structure and achieve the service life objectives.

Introduction

Among the many problems facing North America's infrastructure, one of the most significant is the continued deterioration of reinforced concrete bridges. The extensive use of sodium chloride as a de-icing agent in cooler climates is causing serious corrosion problems. Chloride ions penetrate through the concrete and trigger corrosion of the reinforcing steel. When steel corrodes, the corrosion products (rust) can expand to as much as eight hundred percent of its original volume, thus creating large stresses that crack and delaminate the concrete. Once chloride induced corrosion begins maintenance costs tend to increase exponentially as the structure ages.

Repair and Rehabilitation of Reinforced Steel Concrete

In recent years, attention has been shifting towards repair and rehabilitation of deficient concrete infrastructure rather than replacement. While rehabilitation is often the most cost-effective strategy, the durability of repairs plays a significant role in determining which alternative will be the most economical. Deterioration caused by reinforcing steel corrosion in concrete structures has been recognized as one of the greatest maintenance challenges facing many government agencies and owners today. Technological advances have created a wide array of new products and systems to meet the demand for long-lasting protection and serviceability for these structures however, in order to effectively address the problem it is essential to first understand the cause of the corrosion. If the root cause of the corrosion is not addressed, there is no way to guarantee that additional deterioration will be prevented, and in many cases the life of the repair will be jeopardized.

Corrosion of Steel in Reinforced Concrete

Corrosion within concrete structures is commonly caused by the presence of sufficient concentrations of chloride ions. Chloride ions, in sufficient quantities, can break down and destroy the passive oxide layer that protects the reinforcing steel, leaving it vulnerable to corrosion. (See Figure 1: Typical Corrosion Cell in a Concrete Deck)

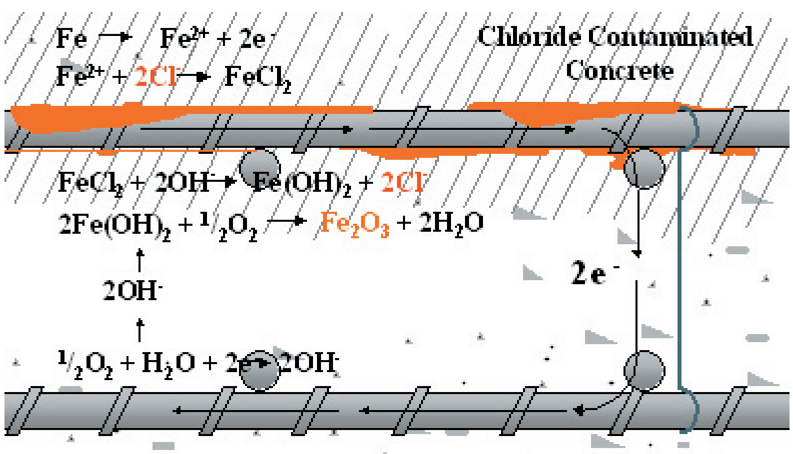

Figure 1: Typical Corrosion Cell in a Concrete Deck

Ring Anode Corrosion

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 will in many situations actually accentuate corrosion in the reinforcing steel adjacent to the repair area. This phenomenon is often referred to as “Ring Anode”, or “Patch Accelerated” corrosion. (See Figure 2: Ring Anode Corrosion Adjacent to Repair Patch)

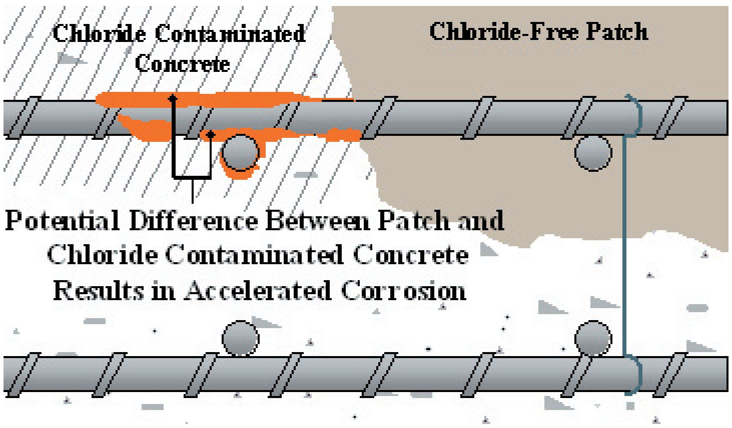

Figure 2: Ring Anode Corrosion Adjacent to Repair Patch

Ring anode corrosion results from electrochemical differences between the repair and the substrate concrete. Differences between the base concrete and the repair can create differing electrical potentials, which drive new corrosion cells across the interface between the patch and the substrate. These factors may lead to accelerated corrosion in the repair itself, but more often result in deterioration of the concrete adjacent to the repair. The rate of deterioration due to ring anode corrosion is dependent upon the same factors, which control the overall rate of corrosion. These include the amount and difference in chloride content, moisture availability, temperature, and permeability of the concrete.

Corrosion Protection Techniques Available

“Chip And Patch” Repair Technique

As previously mentioned, 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 nothing to address the microcells, or localized pockets of electrochemical imbalances that remain. Rebar corrosion will therefore continue in the concrete surrounding the newly patched areas. Replacement of visibly damaged concrete is therefore a treatment of symptoms only.

Embedded Galvanic Anodes

Embedded Galvanic Anodes are galvanic devices designed to extend the service life of the repair by neutralizing or slowing down new corrosion cells, which would otherwise develop around a patch.

The core of the sacrificial anode is composed of zinc, which is cast around a pair of steel tie wires. The zinc core is encased within a shell of specially formulated mortar that is designed to keep the anode active over time. The device is shaped like a short cylinder, about 2.5 inches in diameter, and 1 inch thick. The tie wires extend out opposing sides of the anode to enable it to be tied to the reinforcing steel. (See Figure 3: Cut-Away Diagram of Embedded Galvanic Anode) As the zinc corrodes, it releases a supply of electrons. This electrical current travels through the tie wires, into the surrounding reinforcing steel to reduce new corrosion activity on the steel.

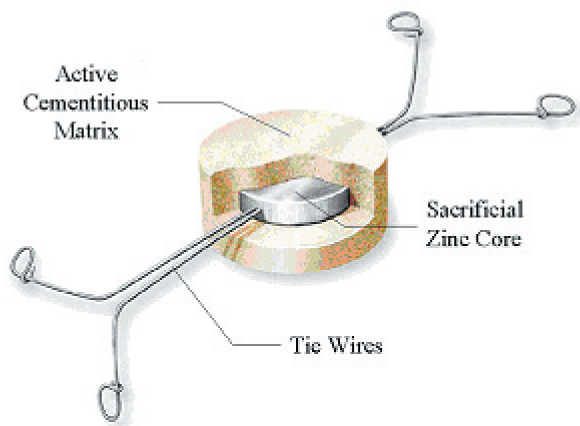

Figure 3: Cut-Away Diagram of Embedded Galvanic Anode

Embedded galvanic anodes provide localized corrosion prevention where it is required most, at the interface between the repair and remaining contaminated concrete. (See Figure 4: Installed Embedded Galvanic Anode in Patch Repair) They are a low cost method of providing galvanic corrosion prevention to extend the service life of concrete patch repairs. Their size and shape allow them to be utilized in many applications such as patch repairs, slab repair, expansion joint repairs, bridge deck widening and in pre-stressed concrete. Their installation into a structure is quick and easy and requires no special equipment. This form of corrosion protection requires no external power source or system monitoring and reduces the need for future repairs.

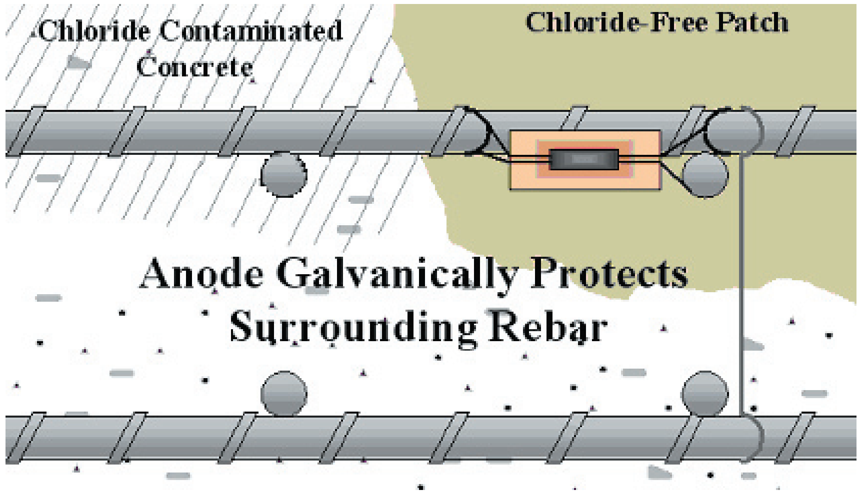

Figure 4: Installed Embedded Galvanic Anode in Patch Repair

Discrete Impressed Current Cathodic Protection (ICCP)

A Discrete Impressed Current Cathodic Protection (ICCP) system can provide long-term durability to both new and existing structures under highly aggressive conditions.

Discrete Impressed Current Cathodic Protection (ICCP) systems mitigate corrosion activity by supplying sufficient electrical current from an external source to overcome the on-going corrosion current in the structure. The discrete anodes are permanently installed into the structure. An external DC power source provides the source of electrical current that overpowers corrosion activity. The anodes are connected to the positive (+) terminal. According to industry standards, an ICCP system is considered to be effective when the system polarizes the reinforcing steel sufficiently to result in a 100mV depolarization after the system is turned off.

Discrete anodes are available in a range of sizes and diameters to provide excellent design flexibility. Their unique design flexibility allows them to be applied to a variety of structures that include: bridges, parking garages, steel frame buildings, and marine structures.

For installations into reinforced concrete structures, the discrete anodes are installed in pre-drilled holes, which are 4 to 8 mm larger than the nominal anode diameter and typically no more than 600 mm apart. The holes and discrete anodes should be located to minimize their proximity to the steel reinforcement in order to provide an even current distribution to the steel within the local vicinity to provide the highest level of protection to stop on-going corrosion activity. Saw cuts of minimum 10 mm depth and 8 mm width into the concrete or mortar joints between the holes allow for the titanium feeder wire interconnecting the anodes.

Prior to the installation of discrete anodes, all holes and saw cuts should be blown or vacuum cleaned of all debris and pre-soaked with water.

A sufficient amount of grout should be placed in the rear of a drilled anode hole; this will avoid any air entrapment. The grout will also ensure coverage to the entire length of the active discrete anode once it is installed. The thixotropic nature of the grout will prevent significant flow from vertical and overhead holes. Prior to installing the discrete anodes, each anode should be wetted with clean water before being gently inserted into the pre-drilled hole. Correct installation will ensure that a sufficient length of tail wire will remain exposed to enable connection with the feed wire before the anode is sealed into the structure with additional grout.

When the grout has set for a minimum of 24 hours without any physical disturbance, strings of discrete anodes are connected together as recommended by a cathodic protection design engineer using titanium feeder wire. All wire jointing requires the use of titanium metal crimps, secured using an appropriate crimping tool or a titanium welder.

After connections have been made, the continuity is to be tested with a resistance meter. Any connections found to have a resistance greater than 1 ohm will require re-crimping. When the integrity of the connection is established the tail of each discrete anode can be gently bent, thus setting the wire into the saw cut groove. The saw cuts are then filled with grout or a cementitious mortar, and left undisturbed for a minimum of 4 days before connecting to the power system.

It should be noted that in chloride contaminated structures, particular attention should be paid to the control of applied voltage, Potentials greater than 7 volts should not be applied to the titanium connecting wires. The performance of a discrete anode is dependent upon the correct design, installation and maintenance of the cathodic protection system.

Electrochemical Chloride Extraction (ECE)

Electrochemical Chloride Extraction (ECE) is an electrochemical process used to stop and prevent reinforcement corrosion in salt contaminated concrete structures. The objective of chloride extraction is to return the structure to a passive state by changing the environment around the reinforcing steel. The method is a simple process in which chloride ions are transported out of the concrete by ion migration under the influence of an electric field. Simultaneously, the pH level of the concrete surrounding the reinforcement is increased sufficiently to re-passivate the reinforcement. (See Figure 5: Electrochemical Chloride Extraction (ECE) System)

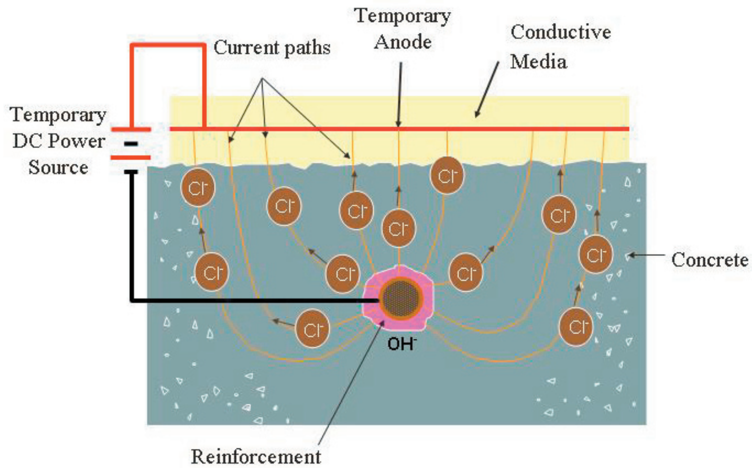

Figure 5: Electrochemical Chloride Extraction (ECE) System

ECE is accomplished by applying an electric field between the reinforcing steel in the concrete and an externally mounted electrode mesh. The electrode mesh is embedded in a sprayed-on mixture of potable water and cellulose fiber.

While the system is energized, the concrete is kept saturated with water allowing negatively charged chloride ions to be pushed away from the reinforcing steel and out of the concrete toward the positively charged external electrode mesh by means of ion migration. Chlorides that leave the concrete are trapped in the fibrous electrolyte mixture. Once the chloride content has been reduced to acceptable levels and the pH of the concrete has been raised, the temporary anode and electrolyte media that contain the chlorides is removed from the structure.

Tests conducted have proven that an additional 20 to 25 years service life of a structure can be expected after performing the ECE process. Even longer service lives may be achieved if a coating or sealer applied is maintained and/or re-applied following the treatment.

The chloride extraction treatment is nondestructive in the sense that only already spalled and cracked concrete needs to be repaired with only nominal cleaning of the exposed reinforcing bars. In situations where damage due to chloride contamination is at the pre-spall stage of development, little or no concrete removal is necessary. The noise and dust problems are almost eliminated, and the process uses environmentally safe materials.

Unlike a Discrete Impressed Current Cathodic Protection (ICCP) system, the ECE system is a treatment process, which removes the cause of the corrosion from the concrete. No permanent system is left in place, to be operated, maintained, and monitored for years into the future. Electrochemical Chloride Extraction does not require any equipment or wiring to be left on the structure that can be vandalized or otherwise damaged.

History Of I-480 Viaduct Substructure

Constructed in the early 1970's, the mainline structure of the I-480 viaduct through downtown Omaha, Nebraska to the Missouri River consists of 1.5 miles of elevated concrete deck and steel box girders supported by 66 large conventionally reinforced concrete hammerhead piers.

During the summers of 1998 and 1999, the Nebraska Department of Roads performed a large rehabilitation project on Interstate Route 480 in downtown Omaha. The project consisted of re-decking approximately 0.6 miles or 1 kilometer of the eastbound and westbound elevated expressway, along with rehabilitation of the substructure.

Condition of I-480 Viaduct Substructure

By the mid-1990s the 30 year-old structure was experiencing deterioration of the concrete deck and concrete substructure. This deterioration was due to chloride-induced corrosion of the reinforcing steel.

The corrosion damage to the concrete deck had progressed to the point that complete deck replacement was the most cost effective long-term strategy. The concrete piers had also become chloride contaminated through failed expansion joints and plugged deck drains. The Nebraska Department of Roads was interested in developing a rehabilitation strategy for the piers instead of replacing them. One of the requirements of the rehabilitation strategy for the concrete piers was that it would allow them to achieve a similar service life from the rehabilitated piers as was expected from the newly replaced deck.

Assessment of Corrosion Activity

In order to determine the corrosion activity status of the I-480 viaduct's concrete piers, Vector Corrosion Technologies conducted a detailed condition evaluation in the summer of 1997.
The evaluation consisted of:

- core testing
- petrographic analysis
- delamination survey
- chloride profile
- carbonation testing
- half cell corrosion potential survey

All evaluations and laboratory tests were carried out in accordance with the appropriate ASTM and AASTHO procedures and standards.
The evaluation indicated that the existing conditions varied through the structure. This information served as the basis for selecting the appropriate corrosion mitigation options to address the various levels of corrosion activity.

Options of Repair and Rehabilitation

Upon completion of the condition evaluation and assessing the information obtained a number of rehabilitation options were considered by the Nebraska Department of Roads that could be employed to extend the service life of I-480 viaduct's concrete piers. The rehabilitation options considered included:

- removal and replacement of the chloride-contaminated concrete
- impressed current cathodic protection
- electrochemical chloride extraction
- protective coatings

Each option had its advantages and disadvantages in cost, service life performance, and disruption to the public.

Solutions Chosen by Nebraska Department of Roads

After consideration of the rehabilitation options available, the Nebraska Department of Roads determined that a combination of strategies would be utilized to rehabilitate the I-480 viaduct's concrete piers depending upon the conditions. Each level of protection could be tailored to suite the varying needs of the structure and achieve the overall service life objectives.

Electrochemical chloride extraction (ECE) was chosen to meet the design objectives for twenty-six of the piers with the highest chloride contamination levels. Embedded galvanic anodes were installed in the patch repairs on the remaining fifty-five piers with limited chloride contamination. This practice would address future “hot spots” which are likely to occur outside of the repair zone. The entire substructure would then be coated with an aesthetically pleasing pigmented coating to prevent future chloride contamination.

By employing the ECE treatment to the piers, the repair cost would be minimized as only the spalled and delaminated concrete needed to be repaired with nominal cleaning of the exposed reinforcing bars. This would provide an added benefit by eliminating many noise and dust problems. Also the electrochemical chloride extraction treatment process employs only environmentally safe materials. This targeted approach would effectively extended the service life of the existing piers thus avoiding significant future maintenance or replacement cost.

Process of Repair and Rehabilitation

After selecting the most effective and efficient rehabilitation options for the I-480 viaduct substructure, the project was completed in two scheduled phases.

Each phase began with performing conventional chip and patch repairs on the delaminated areas of the hammerhead piers. All damaged concrete was removed from around and behind the reinforcing steel.

For the piers with limited concrete damage and low chloride concentrations, embedded galvanic anodes were installed below or next to the reinforcing steel and as close as practical to the edge of the repair area to provide the greatest protection to the surrounding concrete. This practice prevented the initiation of new corrosion activity around the concrete patches. (See Figure 6: Embedded Galvanic Anodes Installed in I-480 Pier)

Figure 6: Embedded Galvanic Anodes Installed in I-480 Pier

The Electrochemical Chloride Extraction (ECE) system was applied to piers with the highest chloride contamination levels. Approximately 9 weeks was required to install the ECE system. The ECE treatment involved installing a temporary steel mesh anode to the surface of the piers. (See Figure 7: Electrode Mesh Installed on Surface of Piers)

Figure 7: Electrode Mesh Installed on Surface of Piers

The mesh was then encapsulated in a cellulose fiber that acted as a conductive media, which distributed the current supplied by a rectifier uniformly over the concrete surface. (See Figure 8: Cellulose Fiber Mixture Sprayed onto Surface of Concrete).

Figure 8: Cellulose Fiber Mixture Sprayed onto Surface of Concrete

During phase 1, the ECE treatment was specified for a minimum of 60 days. Upon completion and review of the phase 1 report, Nebraska Department of Roads chose to reduce the Phase 2 ECE treatment duration to 45 days. This decision was made due to the success in removing the majority of the chloride ions during the first few weeks of treatment. In total, the Electrochemical Chloride Extraction system treated over 29,000 ft^2 of concrete surface area.

The substructure rehabilitation concluded with concrete coatings applied to the sixty-six large hammerhead piers. The coating provided valuable protection against re-contamination by future chlorides. (See Figure 9: Completed Repair And Rehabilitation of I-480 Viaduct Substructure)

Figure 9: Completed Repair And Rehabilitation of I-480 Viaduct Substructure

Test Results

Upon completion of the substructure rehabilitation, additional condition evaluation testing was conducted with the focus being on the Electrochemical Chloride Extraction (ECE) process to determine its effectiveness. Testing included drilling and collection of concrete dust samples for water-soluble chloride ion testing. All samples were extracted from locations immediately adjacent to the pre-treated locations so that a comparison of the before and after concentrations was possible. Chloride ion concentration was reduced to be less than the corrosion threshold.

A summary of the Chloride Concentration Analysis is presented in Table 1: Average Chloride Concentrations Before and After Treatment and in Figure 10: Average Chloride Concentration.

Location	Sample Depth (in)	Initial % Cl-ions	Initial Lbs Cl-/yd^3	Final % Cl-ions	Final Lbs Cl-/ yd^3	Percent Reduction
Average For All Samples	0”-1”	0.0633	2.4796	0.0218	0.8534	66%
	1”-2”	0.0451	1.7659	0.0110	0.4324	76%
	2”-3”	0.0306	1.1993	0.0290	0.2361	80%

Table 1: Average Chloride Concentrations Before and After Treatment

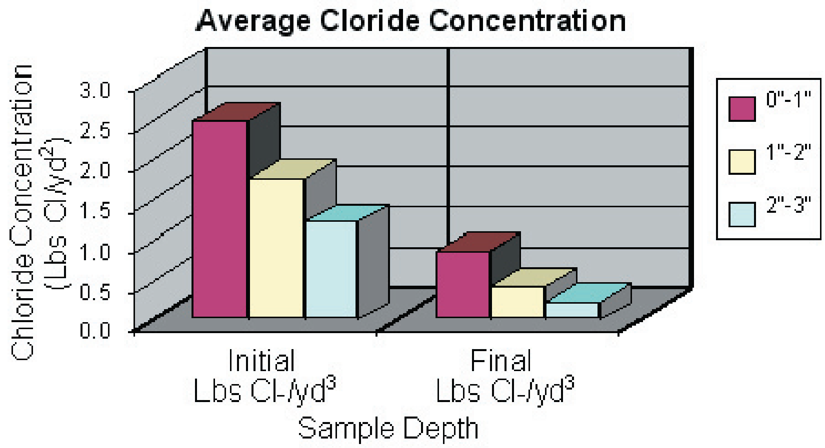

Figure 10: Average Chloride Concentration

In addition to chloride ion analysis, corrosion potential readings were also taken to provide a corrosion related measurement. This information was very helpful in determining the effectiveness of the treatment.

Corrosion potentials taken after Electrochemical Chloride Extraction (ECE) process showed a significant shift in the corrosion potential readings into the passive range.

Conclusion

Electrochemical Chloride Extraction (ECE) is a beneficial technique for the rehabilitation of concrete structures suffering from chloride-induced corrosion. The term “chloride extraction” is not fully descriptive of the process since the beneficial effect is also largely due to the increase in the alkalinity at the steel/concrete interface. Electrochemical Chloride Extraction (ECE) is best applied to structures which are chloride contaminated and undergoing active corrosion, but which have not undergone significant deterioration.

Based on the corrosion potential testing and chloride ion data collected before and after the treatment of the I-480 Viaduct Substructure, it can be concluded that the Electrochemical Chloride Extraction treatment was successful. There was a significant shift in the corrosion potentials towards the passive range, as well as a definite reduction in the chloride ion concentration. The reduction amount was the greatest at the surface where the concentrations were the highest, and decreased with depth.

Recommendations

In order for the full benefits of an Electrochemical Chloride Extraction ECE system to be achieved, it is desirable to treat structures that require little conventional repairs. If a structure were treated before spalling then there would be little cost associated with the repairs. This makes the Electrochemical Chloride Extraction ECE system very favorable when performing a cost/benefit analysis to compare different rehabilitation options.