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Evaluation of Select Methods of Corrosion Prevention, Corrosion Control, and Repair in Reinforced Concrete Bridges

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FINAL REPORT

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16. Abstract

The objective of this study was to evaluate the effectiveness of selected techniques for corrosion prevention, control, and repair of reinforced concrete bridges. Thirty laboratory specimens were subjected to six months of accelerated corrosion testing that consisted of cyclic wet/dry cycles and an applied regulated voltage. The use of galvanic thermal sprayed zinc, galvanic embedded anodes, sealers, coatings, and epoxy repair mortar was evaluated. The long-term effectiveness of some admixtures and sealers was evaluated on nine different bridge decks across Wisconsin through an extensive analysis of chloride ingress.

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EXECUTIVE SUMMARY

This project aimed to investigate new or promising techniques to improve the repair and maintenance of reinforced concrete bridges in Wisconsin by providing controlled accelerated testing and evaluation on selected techniques and products.

Thirty laboratory specimens were subjected to six months of accelerated corrosion testing that consisted of cyclic wet/dry cycles and an applied regulated voltage. The use of galvanic thermal sprayed zinc, galvanic embedded anodes, sealers, coatings, and epoxy repair mortar was evaluated. Sixteen of the specimens received treatment prior to exposure to accelerated corrosion while the remaining fourteen specimens were cast with mixed-in chlorides and subjected to patch repair treatments after 3 months of accelerated corrosion testing. After repairs, these fourteen specimens were subjected to an additional 3 months of testing. Each treatment in question was applied to two specimens. The specimens were evaluated with respect to corrosion currents, chloride ingress, half-cell potential readings, extent of cracking, rust staining, and condition of the reinforcing steel after the conclusion of testing.

The effectiveness of admixtures and sealers was evaluated on nine different bridge decks across Wisconsin through an extensive analysis of chloride ingress. Two of the bridge decks were cast with admixtures, four of the bridge decks were treated with surface sealers at various times of exposure, and three of the bridge decks were untreated.

In the laboratory, it was found that surface applied sealers and the conjoint use of galvanic thermal sprayed zinc and coatings were much more effective in preventing the onset of corrosion than the galvanic anode cathodic protection systems alone. Specimens

with embedded anodes resulted in a non-uniform chloride distribution along the top bar. When used in a patch repair application, the galvanic thermal sprayed zinc and conjoint use of galvanic thermal sprayed zinc and coatings was shown to be the most effective in controlling corrosion.

In the field, it was discovered that the application of sealer at the time of construction, without any reapplication in later years, was not as effective in reducing chloride ingress. In contrast, periodic reapplication proved to be an effective means of reducing chloride ingress, even when the initial application was not made at the time of construction. The use of admixtures had varied results based on the type of admixture used.

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INTRODUCTION

1.1 General

The expensive and on-going subject of reinforced concrete bridge maintenance and repair is a national concern. In northern deicing states such as Wisconsin, the ingress of chlorides from deicing salts continues to cause considerable deterioration that requires periodic maintenance and repair. While the associated costs are considerable and continue to rise, the inconvenience placed on society when such work is conducted is also significant.

1.2 Background

The cost of bridge maintenance and repair is a well documented issue. The U.S. Department of Transportation reports that an estimated $78 billion to $112 billion is required to address all structural and functional bridge deficiencies nationwide. In order to maintain current bridges through 2011, an estimated $5.2 billion per year is needed. (1)

Even though the percentage of structurally deficient bridges decreased from 18% in 1995 to 15% in 1999, replacement costs had increased 12% during the same period of time. Yunovich et al. report that "…significant maintenance, repair, rehabilitation, and replacement activities for the nation's highway bridge infrastructure are foreseen over the next few decades before current construction practices begin to reverse the trend." (2)

A 2007 report by the American Society of Civil Engineers (ASCE) gave Wisconsin a grade of "C" for the conditions of its bridges. The report also noted that Wisconsin needs $1.75 billion for state and local bridge projects. There is also concern in the engineering community that there is insufficient funding to keep up with the age of infrastructure. (3)

While the cost of bridge maintenance and repair is high, the burden placed on society when a bridge is repaired or replaced is also substantial. As reported by the Federal Highway Administration (FHWA), "…when traffic impact is considered, the importance of bridges…cannot be understated." (4)

The reason bridges are so important is that they are key elements in the transportation system. When a bridge is taken out of service, restrictions on the system cause detours, increased travel times, and increased fuel expenses. (5)

1.3 Problem Statement

While many products and techniques claim to be effective for the maintenance and repair of reinforced/prestressed/precast concrete bridge elements, not all products can perform adequately in severe field conditions over the long-term. By providing controlled accelerated testing and evaluation, this project aimed to investigate new or promising techniques to improve the repair and maintenance of reinforced concrete bridges in Wisconsin.

1.4 Objectives and Scope

After a thorough review of the available literature, a laboratory experimental program was initiated to:

- Evaluate the effectiveness of selected corrosion prevention products in new concrete construction

- Evaluate the effectiveness of selected corrosion control products in concrete members already containing chlorides
- Conduct testing of promising products not yet approved by the Wisconsin Department of Transportation

Accelerated corrosion testing was conducted on 30 small specimens that represent typical bridge deck sections. Two identical specimens were tested for each method in question (except for surface coatings) so that the validity of the tests could be confirmed. Testing included weekly wetting/drying cycles of 6% salt solution and an imposed 9V electrical charge. Corrosion currents, half-cell potential readings, crack-mapping, rust staining, and chloride ingress were analyzed. After testing, all specimens were dissected to inspect and evaluate the condition of the embedded reinforcing steel.

Sixteen (16) specimens were prepared to test various corrosion prevention methods (hereafter referred to as CoP). Testing was performed for six (6) continuous months. The CoP methods tested include:

- Activated thermal sprayed zinc (galvanic)
- Activated thermal sprayed zinc (galvanic) in conjunction with coatings
- Two (2) types of embedded anodes (galvanic)
- Embedded anodes (galvanic) in conjunction with coatings
- Tri-silane penetrating sealer
- An epoxy and polyurethane coating
- An acrylic coating

Fourteen (14) specimens were created to test various corrosion control methods (hereafter referred to as CoC). Chlorides were mixed-in to the concrete prior to exposure. Testing was performed for three (3) months, patch repairs were made, and testing was continued for an additional three (3) months. The CoC methods tested include:

- Activated thermal sprayed zinc (galvanic)
- Activated thermal sprayed zinc (galvanic) in conjunction with coatings
- Two (2) types of embedded anodes (galvanic)
- Embedded anodes (galvanic) in conjunction with coatings
- An epoxy patch repair material

To determine the effectiveness of admixtures and sealers in reducing the ingress of chlorides, field testing of nine (9) bridge decks was performed. By removing and testing concrete powders taken at ¼" increments to a depth of 2", the ingress of chlorides was measured and evaluated at selected locations on each bridge deck.

CHAPTER 2

LITERATURE REVIEW

2.1 Corrosion Induced Deterioration of Reinforced Concrete Structures

Design and construction faults have contributed to the defects found in R/C structures. Design faults include inadequate drainage in horizontal members, insufficient concrete cover that protects the reinforcing steel, and inappropriate concrete mixes. Construction faults include insufficient concrete cover, inadequate consolidation, improper placement techniques, and improper/insufficient joints. (6)

While concrete seems like a solid material, it is not impervious. "Excess water, not required for hydration," according to Chrest et al., "eventually dries, leaving behind an interconnected network of capillary pores." (7) The diameter of these pores range from 15 to 1,000 angstrom (one angstrom equals $1x10^{-10}$m). However, various ions, such as chlorides, are able to penetrate concrete and reach the reinforcing steel as their diameters are less than the capillary pores (Table 1). (7)

Table 1: Radii of penetrating ions (7)

Attacking Substance	Atomic Radius	Ionic Radius
Cl^-	0.99 A	1.18 A
Ca^+	1.97 A	0.99 A
Na^+	1.86 A	0.95 A

To decrease concrete permeability, materials such as pozzolans (microsilica, fly ash, silica-fume, etc.) or polymer-modified concrete can be used. Pozzolans make concrete stronger, denser, less permeable, and more cohesive. Although pozzolans can be used as a replacement for some of the cement in a concrete mix, their dosage must be controlled. When concentrations of pozzolans are too high, the concrete can suffer from plastic shrinkage cracking and reduced alkalinity as the $Ca(OH)_2$ may be used in the pozzolanic reaction. Additionally, curing must be monitored as pozzolans reduce bleed water. [8], [9]

As a repair material, polymer-modified concrete (latex-modified, acrylic, polyvinyl acetate (PVA), etc.) both reduces permeability and increases bond strength with the substrate. Polymer-modified concrete also has a better chemical resistance to alkalis and diluted acids than plain concrete. However, latex additives increase flexural creep in high humidity, reduce the modulus of elasticity of the repair material, and require prompt finishing and curing. [8]

Permeability can also be reduced by specifying concrete with a low water to cementitious material ratio (w/cm). In addition, provisions for adequate concrete cover will further protect the reinforcing steel by increasing the time it takes for ions to reach it. Today, ACI 201.2R recommends a maximum w/cm of 0.40 with a minimum 2 inch clear cover for concrete exposed to deicing salts. It also reports that a design cover of 2.6 inches should be specified because of construction tolerances. [10]

However, high concrete permeability may be an issue with older structures that were built in accordance to earlier design standards. Chrest et al. report that structures built prior to the 1977 ACI Building Code were constructed with concrete containing w/cm of 0.53 or greater, and a cover of 1.5 inches. [7]

Nevertheless, a low w/cm alone does not automatically ensure a low permeability concrete. In addition, the concrete must be properly proportioned, well consolidated, and allowed to cure properly. [10]

High-quality concrete is an ideal environment for reinforcing steel. When water is added to cement, the process of hydration creates a gel that binds the concrete matrix. The cement hydration process also produces calcium hydroxide [$Ca(OH)_2$]. This provides a highly alkaline (basic) environment, pH of 12 to 13, which affords protection to the reinforcing steel. [(7)]

The highly alkaline environment afforded by the concrete leads to the formation of a passive layer on the steel surface. El-Reedy writes that "A passive layer is a dense, impenetrable film that, if fully established and maintained, prevents further corrosion of the steel. The layer formed on steel in concrete is probably part metal oxide/hydroxide and part minerals from the cement. A true passive layer is a very dense, thin layer of oxide that leads to a very slow rate of oxidation (corrosion)." [(11)]

"For steel in concrete," as reported by ACI Committee 222, "the passive corrosion rate is typically 0.1 μm/yr; without the passive film, the steel will corrode at rates at least three orders of magnitude higher than this." [(9)]

If the alkalinity of the concrete is lowered to pH 11.5, the protective oxide film will become unstable and will no longer be able to prevent the initiation of corrosion on the reinforcing steel. [(7)] The two main causes of the reduction in alkalinity and the associated destabilization of the oxide film are chloride attack and carbonation.

Unlike a chemical attack on concrete (sulfate attack for example, where the integrity of the concrete is destroyed), chloride ingress and carbonation do not attack the integrity of the concrete. Instead, they penetrate through the pores of the concrete, without damaging it, and attack the reinforcing steel. The associated corrosion by-products cause distress in the concrete. [(11)]

According to Newman, "Corrosion of reinforcement embedded in concrete is an electrochemical reaction, involving both chemical processes and the flow of electricity between various areas of steel and concrete." [8] The corrosion process is influenced by chloride-ion content, pH levels, concrete permeability, moisture, oxygen, etc. To complete a corrosion cell, an anode, a cathode, a metallic connection between the anode and cathode, an ionic path, moisture, and oxygen are required. [12]

At the anode, corrosion occurs through the process of oxidation, a chemical reaction where an electron is lost. A reduction, chemical reaction where an electron is gained, occurs at the non-corroding cathode (Figure 1). The metallic connection is provided by the reinforcing steel and the ionic path is provided by the concrete matrix (electrolyte). However, there must be sufficient moisture in the concrete matrix so that conductivity can be provided. [12]

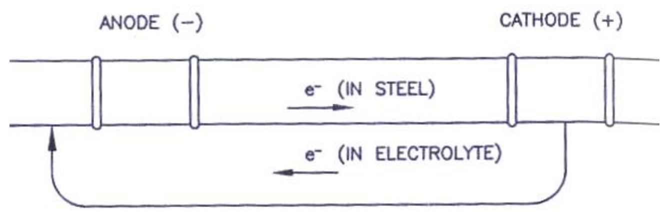

Figure 1: Corrosion cell [8]

The driving force of corrosion is the difference in potential between the anode and the cathode. When this potential occurs on the same element (Figure 2), a corrosion cell termed a "microcell" is created. This potential may be created by [1]:

1. Differences in the surface of the steel bars. Since steel is an alloy created

Figure 2: Corrosion "microcell"

from various elements (most notably iron and carbon), its surface area has sites of differing electrochemical potentials.

2. Differences in electrolytes. These include differences in the concentration of chlorides, oxygen, moisture, hydroxides, etc.

3. Presence of cracks. Cracks allow the more rapid ingress of deteriorating chemicals and moisture.

When the difference in potential occurs between the upper and lower mats of reinforcing steel in a concrete slab, such as a bridge deck, a "macro-cell" can be formed (Figure 3). In this case, the difference in potential occurs because of the difference in chloride ion concentrations along the reinforcement and the amount of chloride ions reaching the upper and lower mats of reinforcing steel. Since the upper mat is more chloride contaminated, it will become anodic in regards to the lower mat when the two layers are electrically connected. The metallic connection can be provided by bent bars or chairs. "Macro-cell" corrosion, which is more widespread than "microcell" corrosion, promotes a more rapid deterioration of the structure. (7)

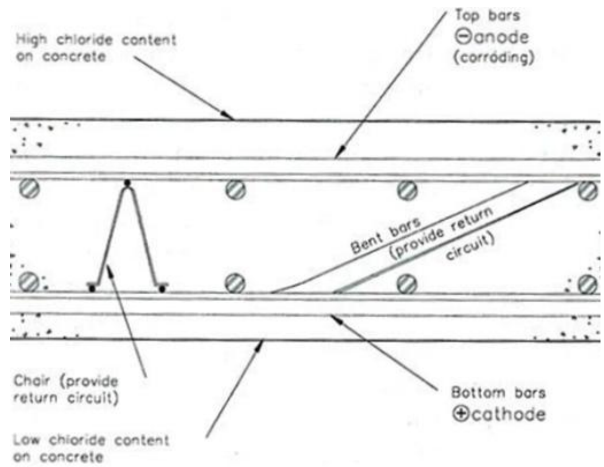

Figure 3: Corrosion "macrocell" (7)

However, the deterioration of most R/C structures can be attributed to instances of both "microcell" and "macro-cell" corrosion. (7)

As corrosion occurs, the cross section of the steel is reduced and the bond between the steel and concrete is damaged. This loss of section and bond loss could reduces the strength of the R/C member. As the cross section of the steel bar is reduced, the corrosion by-products occupy a greater volume than the original steel. [1] This increase can be up to 7 times the original volume of the steel. [9] The expansion causes tensile stresses to be exerted on the surrounding concrete. As concrete is weak in tension, the tensile forces cause local delamination (Figure 4, planes of cracking within the concrete), and eventually, spalling (Figure 5). [1]

Figure 4: Delamination of concrete

Figure 5: Spalling of concrete

At the anode, iron is oxidized to a ferrous state and electrons are released. [1]

$$2Fe \rightarrow 2Fe^{+2} + 4e^{-} \qquad \text{(Eq. 1)}$$

At this time, the iron atom has lost electrons and has become a positively charged ion. [1] These ions are then dissolved in the electrolyte. At the cathode, the lost electrons travel through the steel and combine with oxygen and moisture to form hydroxyl ions. [8]

$$O_2 + 2H_2O + 4e^{-} \rightarrow 4OH^{-} \qquad \text{(Eq. 2)}$$

The ferrous ions from the anode then combine with the hydroxyl ions from the cathode to produce ferrous hydroxide. [1], [8]

$$2Fe^{+} + 4OH^{-} \rightarrow Fe(OH)_2 \qquad \text{(Eq. 3)}$$

Further oxidation, with the presence of oxygen and moisture, produces ferric oxide (i.e. the stable state of iron). [(1)]

$$4Fe(OH)_2 + 2H_2O + O_2 \rightarrow 4Fe(OH)_3 \qquad \text{(Eq. 4)}$$

$$2Fe(OH)_3 \rightarrow Fe_2O_3 + 3H_2O \qquad \text{(Eq. 5)}$$

"The rate of corrosion," according to Newman, "depends on the speed of the ions traveling back from the cathode to the anode, which is a function of the electric potential of the reinforcing bars and the electrical resistance of concrete." A high current can be achieved with a high potential and low resistance. Lower levels of resistance occur when the pores of the concrete contain a lot of electrolyte (moisture and chlorides). [(8)]

2.1.1 Chloride Ingress

The presence of chlorides not only destroys the protective oxide layer, but also fuels the corrosion process. [(13)] Chlorides can be introduced to concrete during mixing or service. Calcium chloride ($CaCl_2$) has been used as an accelerant at the time of mixing. This facilitates the casting of concrete in cold conditions and provides higher early strength concrete. Chlorides may also be found in the aggregates and mixing water. Service chloride contamination occurs because of deicing salts, proximity to sea water, and ground water salts. [(6)]

Bohdanowicz writes that "…iron chloride hydrolysis leads to acidification of the environment and liberation of chloride ions." [(13)] Generally speaking, this means that the pH will be reduced as hydrogen ions, which are acidic, are produced (Eq. 6 and Eq. 7).

$$Fe + 2Cl^{-} \rightarrow FeCl_2 + 2e^{-} \qquad \text{(Eq. 6)}$$

$$FeCl_2 + 2H_2O \rightarrow Fe(OH)_2 + 2H^+ + 2Cl^- \quad \text{(Eq. 7)}$$

The equations above show that pitting corrosion can occur even without the presence of oxygen. [8] They also show that chloride ions are not consumed and are further able to contribute to the corrosion process. In the presence of oxygen and moisture, the ferrous hydroxide produced in Eq. 7 will turn into ferric oxide (see Eq. 4 and Eq. 5).

Although it is accepted that the amount of chloride ions needed to initiate corrosion is relatively small, accepted limits on chloride ion content are not universal. Committees within the American Concrete Institute, ACI 318 and ACI 222, differ on accepted limits of chlorides (Table 2). [9]

Table 2: Chloride limits for new construction [9]

Type of Structure	(Percent Chloride Ions (Cl^-) by mass of cement) **ACI 318-05** water soluble	**ASTM C 1152** acid soluble	**ASTM C 1218** water soluble
Prestressed Concrete	0.06	0.08	0.06
R/C exposed to chloride in service	0.15	0.10	0.08
R/C that will be dry or protected from moisture in service	1.00	0.20	0.15
Other R/C construction	0.30		

ACI 222R-01 recommends the chlorides limits specified in ASTM C1152 and ASTM C 1218. It also emphasizes "…that these are recommended limits for new construction and are not thresholds for electrochemical corrosion." [9]

ACI 222R-01 also writes that it "…has taken a more conservative approach (than ACI 318) because of the serious consequences of corrosion, the conflicting data on corrosion-threshold values, and the difficulty of defining the service environment throughout the life of a structure." [9]

In Table 2 above, the levels of chlorides are presented in terms of water or acid soluble chlorides. Water-soluble chlorides are the "free" chloride ions. That is, they are the chloride ions that are not bound and are extractable in water. Acid-soluble means that all chloride ions, both bound and unbound, are measured. The amount of water-soluble chlorides is approximately 75%-80% of the acid-soluble chlorides. (9)

For electrochemical corrosion, the acid-soluble corrosion threshold for reinforcing steel in concrete, in the United States, is generally considered to be 1.0 to 1.5 lb chloride ions/yd^3 of concrete (0.6 to 0.9 kg/m^3). (9) At 3.0 lb/yd^3, severe rusting of the steel and spalling of the concrete occurs as accelerated corrosion takes place. At 7.0 lb/yd^3, a major loss of steel cross section and significant distress of the concrete occurs. (8)

As with chloride limits, the electrochemical corrosion threshold differs from country to country as well. According to ACI 222R-01, a threshold of 0.4% Cl^- by mass of cement (2.4 lb/yd^3 of concrete or 1.4 kg/m^3) was proposed by the CEB (Comité Euro-International du Béton). (9)

2.1.2 Carbonation

The other process that causes the corrosion of reinforcing steel is carbonation. While carbonation initially increases concrete's compressive strength, modulus of elasticity, surface hardness, and resistance to frost and sulphate attack, it has the detrimental effect of reducing the alkalinity of the concrete. (14) Carbonation occurs when carbon dioxide and other gases from the atmosphere penetrate through the surface pores and capillaries of concrete. When these gases react with water, carbonic acid is formed

(Eq. 8). The carbonic acid then reacts with the calcium hydroxide of the hydrated cement paste to produce calcium carbonate (Eq. 9). [(6)]

$$CO_2 + H_2O \rightarrow H_2CO_3 \qquad \text{(Eq. 8)}$$

$$H_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3 + 2H_2O \qquad \text{(Eq. 9)}$$

A reduction in pH occurs as the calcium carbonate does not have a high alkalinity. Over time, carbonation will drop the pH levels to 8 – 9, and the passive film will start to break down as the lower alkaline concrete is not able to support the protective oxide layer. [(10), (12)]

Carbonation progresses inwards from the outer surface of the concrete. Initially, the outer zone of concrete is affected and over time, the depth of carbonation increases. While the rate of carbonation depends on the permeability of the concrete, it also depends on the relative humidity (RH). According to Hansson et al., "…the penetration of the CO_2 into the concrete is highest at low RH but the reaction with the $Ca(OH)_2$ takes place in solution and is, therefore, highest in saturated concrete." [(15)] Because of this, carbonation is most likely to occur at RH of 50% to 70%. In dry environments, there is not enough moisture to initiate the process. When too much moisture is present, the concrete pores are filled with water and the ingress of carbon dioxide is restricted. [(8)]

A common problem in older structures occurs when the depth of carbonation is greater than the concrete cover provided for the reinforcing steel. When this occurs, the protective layer is destroyed and the reinforcing steel no longer has protection against moisture and oxygen.

Carbonation becomes less of an issue when higher quality (less permeable concrete) concrete with sufficient concrete cover is specified.

2.1.3 Chloride Ingress and Carbonation

In summary, the most common causes of corrosion are "a localized breakdown of the passive film on the steel by the chloride ions and a general breakdown of passivity by neutralization of the concrete from carbon dioxide." (16)

However, chlorides and carbonation can work together. Since carbonation lowers the pH of concrete, even less chloride ions are required to initiate corrosion. (8) The carbonation process can also release bound chlorides, which means that higher concentrations of chlorides will be found in the carbonated zone. (14)

Nevertheless, chloride ingress and carbonation do not alone cause corrosion. "While chlorides are directly responsible for the initiation of corrosion," according to ACI 222R, "they appear to play only an indirect role in determining the rate of corrosion after initiation. The primary rate-controlling factors are the availability of oxygen, the electrical resistivity, the relative humidity, all of which are interrelated, and the pH and the temperature…the chlorides can influence the pH, electrical conductivity, and the porosity. Similarly, carbonation destroys the passive film but does not influence the rate of corrosion." (9)

This is evidenced by the fact that piles immersed in salt water rarely corrode. Although significant levels of water and chlorides are present, there isn't enough oxygen to support the reaction. In contrast, portions of the piles that are located in the "splash-zone" often deteriorate rapidly because of the wet/dry cycles and availability of both water and oxygen. (8)

2.2 Assessment of Deteriorated Reinforced Concrete Structures

To assess the condition of the reinforced concrete, many testing techniques can be utilized. Some of the more common techniques may include: sounding, chloride ion content, depth of carbonation, and half-cell potential testing. Additionally, the impact echo and ultrasonic pulse velocity methods can be used to locate voids in the concrete.

2.2.1 Sounding

Figure 6: Hammer sounding

Figure 7: Chain-drag sounding

Sounding techniques, utilizing a hammer (Figure 6) or a chain-drag (Figure 7), are simple and effective non-destructive techniques used to locate areas of delaminated concrete. While both techniques require a trained ear, hammer sounding requires only a rock hammer and chain-drag sounding requires a chain. The idea behind these techniques is that a change in pitch is heard when an area of delaminated concrete is encountered. By impacting the concrete through the striking of the hammer on a surface or dragging of the chain on a horizontal surface, a pitch that sounds hollow can be heard. The perimeter of the delaminated area is then marked out. It should also be noted that the actual area of corrosion activity may be larger than the discovered area of delamination. [17]

2.2.2 Chloride Ion Content

The chloride ion content of the concrete can be found in a few ways. First, a core can be taken from the concrete in question and subsequently taken back to the laboratory where a portion of the core is ground into a powder. The powder is then mixed with an extraction liquid to determine the amount of chlorides. The second way is to take concrete powders directly. This can be accomplished by drilling into the concrete in question and collecting the powders that are brought up. As before, the powder is mixed with an extraction liquid to determine the chloride content. (17)

As discussed previously, chlorides can be introduced into concrete during mixing or service. If the powders are taken in regular intervals of depth, a profile of chloride content vs. depth can be made (Figure 8). If the chloride content is fairly uniform, it can be concluded that the chlorides were premixed. If the chloride content displays a curve with high levels of chlorides at the surface and levels diminishing with depth, it can be concluded that the chlorides were introduced during service. (6)

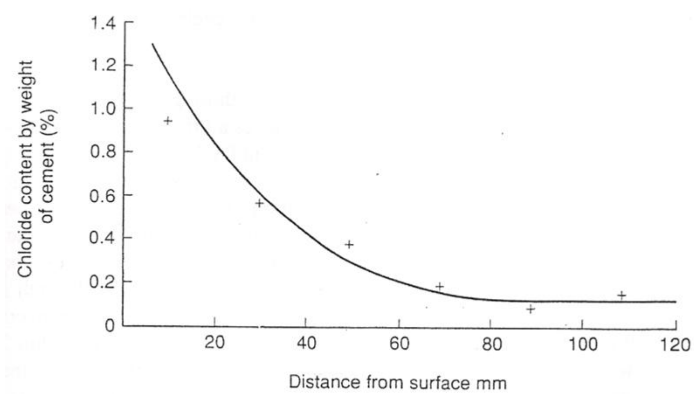

Figure 8: Profile of chloride content vs. depth (6)

2.2.3 Depth of Carbonation

The depth of carbonation can be determined by spraying a phenolphthalein indicator onto a freshly fractured or cut concrete sample. Noncarbonated concrete (pH greater than 10) is found where areas of concrete have changed to a red or purple color while carbonated concrete remains colorless (Figure 9). [17] Although the phenolphthalein solution will not give the exact pH value, other solutions are able to display a gradient of colors so that a range of pH value can be indicated. [18]

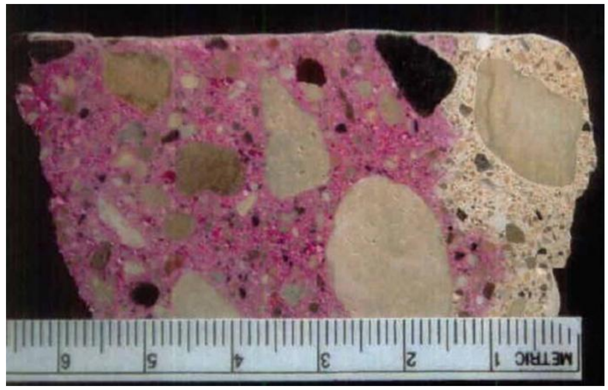

Figure 9: Concrete sample displaying depth of carbonation

2.2.4 Half-Cell Potential Testing

Half-cell potential testing is one method used to estimate the corrosion activity of the reinforcing steel. During the corrosion process, differences in electric potential occur between the anodic half-cells and the cathodic half-cells. By connecting a high-impedance voltmeter between a reference electrode and exposed reinforcing steel, a full electric cell is completed and the potential can be measured (Figure 10). By taking readings in a grid pattern, a potential gradient map is produced and the extents of probable corrosion can be displayed. [17], [19]

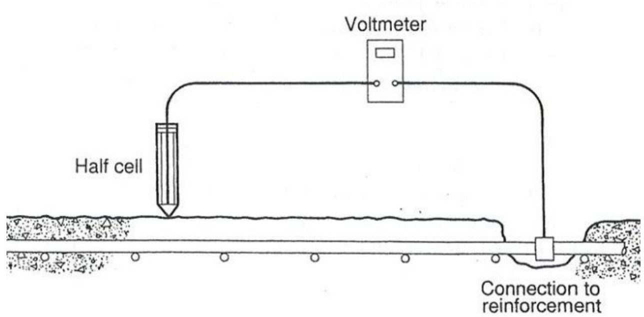

Figure 10: Half-cell potential test [6]

In order to have valid readings, the continuity of the reinforcing steel should be confirmed. If continuity is not achieved, steps should be taken to provide it.

The reference electrode can either be a copper-copper sulfate (Cu-$CuSo_4$) or a silver-silver chloride (Ag-AgCl). The Cu-$CuSo_4$ electrodes have been around longer than the Ag-AgCl electrodes. Although both electrodes work well, the Cu-$CuSo_4$, when compared to the Ag-AgCl, has a slower response time, less stability with respect to time and temperature, and uses a liquid electrolyte. Additionally, the Cu-$CuSo_4$ electrodes have been known to leak. [19], [20]

If using the Cu-$CuSo_4$ electrode, potential readings more negative than -350mV indicate a 90% probability of corrosion activity, readings between -200mV and -350mV indicated an unknown probability of corrosion activity, and readings more positive than -200mV indicate a 90% probability of no corrosion activity. [17] The Ag-AgCl electrode produces readings approximately 100mV less than the Cu-$CuSo_4$ electrode. [20]

2.2.5 Impact Echo and Ultrasonic Pulse Velocity Methods

In order to locate voids, cracks, and honeycombs within the concrete, the impact echo and ultrasonic pulse velocity methods can be used. By impacting the concrete surface and analyzing the pulse that is reflected from defects and boundaries, the impact echo method can predict the probability and depth of defects. By measuring the velocity (distance over time) of ultrasonic pulses between a transmitter and a receiver, the ultrasonic pulse velocity method can compare the uniformity of the concrete. If voids or cracks are present, the velocity of the pulse will be reduced. [17]

2.3 Repair of Deteriorated Reinforced Concrete Structures

As mentioned previously, corrosion of the reinforcing steel can lead to cracking, delamination, and spalling of concrete. When spalling occurs, repairs need to be undertaken. A typical patch repair will include the following:

- saw cutting of the perimeter of the patch area (patch area should be square or rectangular in shape)
- removal of deteriorated concrete to a distance of ¾" to 1" behind the reinforcing steel (essentially, a finger gap)
- cleaning of the reinforcing steel by grit blasting (preferred) or wire brush (not as effective)
- coating the reinforcing steel with a corrosion-inhibiting primer
- proper preparation of the substrate to receive the patch material
- application of a bonding agent to improve bond between patch and existing concrete
- installation of patching materials
    - patch material should have very low shrinkage and have compatible coefficient of thermal expansion with substrate
- application of a protective sealer or membrane to prevent further ingress of harmful chemicals. [(6), (8), (21)]

Even if the aforementioned steps are followed, failure of patches can and do frequently occur. Moulzolf writes that, "…although the design may have addressed all of the critical factors necessary for a successful repair scenario, work and quality control practices associated with the various steps will control the outcome of the repair."

Failures of patches can occur because of a bond failure between the substrate and repair material, poor consolidation of the repair material, damage to the substrate concrete from over-impact during demolition, and/or improper curing which can lead to plastic shrinkage cracking. [21]

Even when installed properly, it is not uncommon for patch repairs to fail, or even increase in size, after only 2-5 years when utilized in chloride-contaminated concrete. This phenomena, known as patch accelerated corrosion, occurs when the once "sound" area that surrounds the initial patch repair now requires repair itself. [12]

Using traditional "chip and patch" procedures, a sudden change is created in the concrete surrounding the reinforcing steel (Figures 11 and 12). This occurs when new concrete, which is chloride-free and has a high pH, is placed adjacent to old concrete, which is chloride-contaminated and has a low pH. The concrete itself creates zones of significantly different corrosion potentials. "This difference in corrosion potential," according to Ball and Whitmore, "is the driving force for new corrosion sites to form in the surrounding chloride-contaminated concrete." [12]

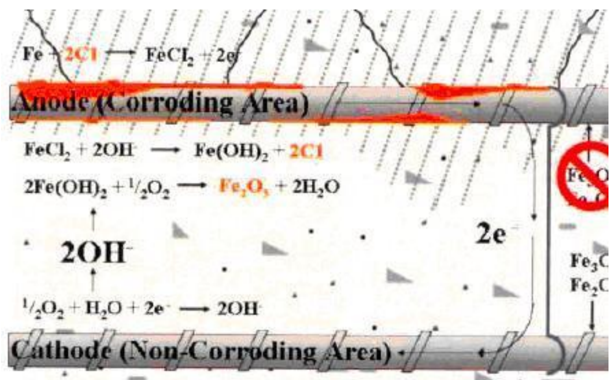

Figure 11: Corrosion cell in concrete [12]

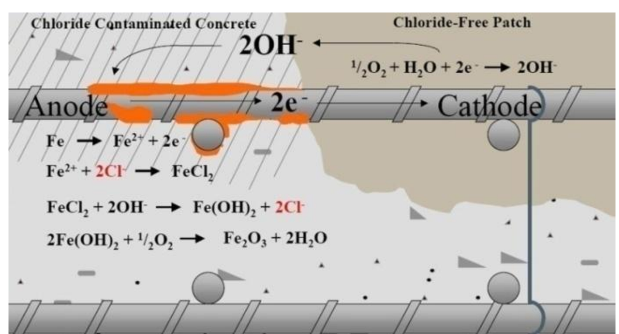

Figure 12: Patch-accelerated corrosion in concrete [12]

The “ring anode” or “halo effect” occurs as the new concrete acts as an accelerant for corrosion. The steel bar within the new concrete acts as a cathode while the bar in the old concrete acts as an anode. Evidence of this can be seen when spalls appear next to previously completed patch repairs. [12]

If significant areas of distressed and chloride-contaminated concrete exist, it may be more effective, in terms of time, cost, and duration of repair, to remove and replace. [8]

One method of repair that should not be used with cracks caused by corrosion is epoxy injection. While this method works effectively on dormant cracks, it is not effective on corrosion induced cracks since it does not address the underlying corrosion issue. [8], [17]

2.4 Corrosion Management Strategies

The management of corrosion can be handled in many ways. According to Vector Corrosion Technologies (VCT), factors including “…the level of chloride contamination and carbonation, amount of concrete damage, location of corrosion activity (localized or widespread), the cost and design life of the corrosion protection system, and the expected service life of the structure” determine which corrosion management strategy to use. [22]

Various corrosion management strategies, such as corrosion prevention, corrosion control, and corrosion passivation, are shown in Table 3.

Table 3: Corrosion management strategies

Corrosion Prevention	Corrosion Control	Corrosion Passivation
Coatings	Coatings	Electrochemical Chloride Extraction
Sealers	Sealers	
Admixed Corrosion Inhibitors	Surface Applied Corrosion Inhibitors	Re-alkalization
Cathodic Protection	Cathodic Protection	

2.4.1 Corrosion Prevention (CoP)

CoP intends that the initiation of corrosion be prevented, even in concrete containing chlorides. Some of these methods include coatings, sealers, admixed corrosion inhibitors, and cathodic protection.

2.4.1.1 Coatings and Sealers

Ball and Whitmore report that the application of protective sealers and coatings helps to prevent the initiation of corrosion. Properly applied sealers and coatings do offer a significant increase in life expectancy when installed before contamination of the concrete. (12)

Sealers work by chemically reacting with the components of concrete to fill the pores; thus, making it difficult for water to penetrate the concrete surface. However, this also inhibits water vapor from exiting the concrete. Today's sealers keep water from penetrating the concrete and are now formulated to allow water vapor to exit. Coatings, meanwhile, provide barrier protection by creating a physical barrier between the concrete and the environment. (23)

Using a sealer or coating depends on the project requirements and service environment. Sealers are, according to Helsel, suggested "…in a moderate climate with limited freeze/thaw cycles, moisture, and salt exposure" while coating/membrane systems are suggested "…in harsher climates with subfreezing temperatures, a good deal of precipitation, and significant salt exposure..." [23]

Tabatabai et al. found that surface treatments (coatings) applied to the end of concrete bridge girders prior to installation in the field and before the onset of corrosion would successfully prevent beam end corrosion. [24]

As part of this project, concrete powders from four candidate bridge decks in Wisconsin that utilized a surface applied tri-siloxane masonry water repellent at various increments of time were taken from the field and analyzed in the lab. Two of the bridges were located in Dodge County and two were located in Pierce County. The bridge decks were chosen because of their frequency in sealer application. Untreated bridge decks (one in Dodge County and two in Pierce County) were also tested for comparison. A detailed discussion can be found in Section 5 of this report.

2.4.1.2 Admixed Corrosion Inhibitors

Admixed corrosion inhibitors, which are added to the concrete at the time of mixing, are used to prevent the onset of corrosion in R/C. While this section gives a brief summary of corrosion inhibitors, in general, its primary focus is on admixed corrosion inhibitors. Section 2.4.2.2 focuses on surface applied corrosion inhibitors.

Corrosion inhibitors, according to Brown, "…function by one or both of two mechanisms: by increasing the threshold concentration for aggressive species necessary for corrosion to occur or by reducing the rate of corrosion once corrosion has begun." [25]

Corrosion inhibitors, whether admixed or surface applied, exist in three basic forms: anodic inhibitors, cathodic inhibitors, and mixed inhibitors. Anodic inhibitors minimize the anodic component of the corrosion process while cathodic inhibitors minimize the cathodic component. Mixed inhibitors prevent both the anodic and cathodic reactions. [26] By forming a film on the steel, coating the surface of the steel, or by reacting with the chloride ions, the interaction between the chloride ions and steel will be prevented. [25]

Anodic inhibitors work by stabilizing the protective film of the concrete. It does so by interfering with the conversion of the ferrous oxide to ferric oxide. The most commonly used anodic inhibitor is calcium nitrate. By reacting with chlorides, higher concentrations of chlorides are necessary for the initiation of corrosion. [11] When using anodic inhibitors, using too low of a concentration in aqueous environments has a possibility of producing pitting corrosion. [26]

Cathodic inhibitors work by reducing the amount of oxygen in the concrete. However, cathodic inhibitors require a large amount of material and are therefore impractical for use in concrete. Furthermore, some cathodic inhibitors slow the setting time of concrete. [11], [26] Mixed inhibitors generally work by coating the entire steel surface with a protective layer. [26]

Corrosion inhibitors can also be distinguished as passivation inhibitors, organic inhibitors, or precipitation inhibitors. [25]

The benefits of admixed corrosion inhibitors are that they slow the ingress of chlorides and may increase the level of chlorides required to initiate the corrosion process. Brown writes that admixtures slow the ingress of chloride ions "…by "clogging" the internal pore structure of the concrete, to deter movement of foreign substances by absorption or diffusion" or by ""scavenging", in which aggressive species or oxygen in pore solution are chemically combined or adsorbed, rendering them inert in the concrete environment." [(25)]

In a 1999 thesis by Brown, a comparison of DCI-S by W.R Grace, Rheogard 222 by Master Builders, Inc., FerroGard 901 by Sika Corp., Catexol 1000 by Axim, MCI 2005 by Cortec, Corporation, and a control was performed. Brown concluded that "…all of the inhibitors extended the average initial time to corrosion, when compared to control concrete…" [(25)]

In December 2002, a report by Balaguru and Nazier compared DCI-S, Xypex C-1000, Rheocrete 222, and Ferrogard 901. The authors "…recommend the use of Xypex in decks with no cracks. The admixture provides a more dense and impermeable concrete that reduces the ingress of chemicals." [(27)]

Several bridges cast with various admixtures were constructed in Dodge County, WI. Specifically, Bridges B-14-0129 and B-14-0133 were used as test bridges for the Wisconsin Department of Transportation (Wis DOT). [(28)]

In 2001, chloride testing was performed by the Wis DOT on cores that were taken from the bridge decks in 2000. [(29)] The testing only examined the chloride ion content at the top steel level. [(30)]

Bridge B-14-0129, constructed in 1994, utilized a complex alkaline earth silicate admixture (referred to as Admix A) on the northern 1/3 of the bridge deck, an untreated control on the center 1/3, and an organic corrosion inhibiting admixture with a water-based combination of amines and esters (referred to as Admix B) on the southern 1/3 of the bridge deck. Chloride ion content for bridge B-14-0129 is shown in Table 4. [(30)]

Table 4: Chloride ion content for Bridge B-14-0129 [30]

Core Label	Pounds of Cl per yd^3 of concrete	Average	Rating	Product Used
P5	1.80	2.52	Good	Admix-A
P6	3.24		Poor	
P3	2.66	2.38	Good	Control
P4	2.09		Good	
P1	1.91	2.75	Good	Admix-B
P2	3.59		Poor	

Bridge B-14-0133, constructed in 1995, utilized a crystalline producing admixture (referred to as Admix C) on the support structure and one-half of the bridge deck. The other half of the bridge deck was used as a control section and did not contain an admixture. Chloride ion content for Bridge B-14-0133 is shown in Table 5. [30]

Table 5: Chloride ion content for Bridge B-14-0133 [30]

Core Label	Pounds of Cl per yd^3 of concrete	Average	Rating	Product Used
G1	3.13	2.84	Fair	Admix-C
G2	2.55		Good	
G3	3.53	6.285	Poor	Control
G4	9.04		Bad	

The age and construction of these bridges ideally lent themselves to additional testing. As such, testing was performed in this study to establish chloride concentration profiles, to calculate a chloride diffusion coefficient for each section in which admixtures were used, and to determine the surface chloride concentration for each bridge. A more detailed discussion on these bridge decks can be found in Section 5.

Another commercially available admixture is Hycrete. The water-based product is reportedly hydrophobic and reacts within the concrete matrix to fill in cracks and capillaries to provide a polar monomolecular barrier that protects the steel. [31]

In a 2000 study at the University of Connecticut, Goodwin et al. reported that adding the DAS (ammonium form of Hycrete) or DSS (Hycrete admixture) prototype chemicals to the concrete "…produced significant improvements in corrosion protection compared with the control concrete and with the two commercial inhibitors. After about 24 months of corrosion monitoring, specimens with the two prototype chemicals showed no sign of corrosion. For specimens with a saw-cut or preformed crack, the chemicals produced greatly reduced amounts of reinforcement corrosion." [(32), (33)]

The two commercial inhibitors in the study were DCI-S and Rheocrete 222. The study also concluded that the DSS prototype chemical performed slightly better than the DAS prototype chemical. [(32), (33)]

A 2007 Virginia Transportation Research Council (VTRC) research report by Sharp and Ozyildirim stated that the conjoint use of fly ash and Hycrete DSS in concrete "considerably restricted" chloride ingress. Furthermore, the report stated that, "If the field performance confirms the laboratory test results of this study, the use of Hycrete DSS is expected to lead to extended service life and to aid in minimizing maintenance costs." [(34)]

2.4.1.3 Cathodic Protection

The basis of corrosion theory is that a measurable difference in potential exists between the anodic and cathodic areas. Cathodic protection (CP) makes use of an externally applied potential, which acts as the anode, to shift all of the reinforcing steel into a cathodic and protected state. [(6)]

When used in new construction or structures in which the initiation of corrosion has not yet occurred, low levels of applied current are needed to prevent the initiation of corrosion. When used in structures where corrosion is on-going, higher levels of current are required. [35]

In order to prevent the initiation of corrosion, current levels significantly less than $0.5 mA/m^2$ of steel surface are required. When chloride levels reached 6 lb/yd^3, current levels of $0.5 mA/m^2$ were able to mitigate the on-going corrosion. Using current levels of 0.5 to $2.0 mA/m^2$ were effective in preventing the initiation of corrosion when chloride concentrations of 10 times the corrosion threshold were used. [35]

A more detailed discussion of CP can be found in Section 2.4.2.3.

2.4.2 **Corrosion Control (CoC)**

CoC strategies, according to VCT, are intended to "…stop on-going corrosion activity or provide a significant reduction in the corrosion rate and an increased service life of the rehabilitated structure." Coating, sealers, surface applied corrosion inhibitors, and cathodic protection systems are examples of corrosion control. [22]

2.4.2.1 **Coatings and Sealers**

Although coatings and sealers work well for corrosion prevention, Tabatabai et al. found that surface applied treatments offered limited effectiveness when applied after the onset of corrosion. [24] Once contamination begins and signs of corrosion distress appear, Whitmore and Ball report that "…barrier systems will generally have a limited impact on the service life of the structure." [12]

2.4.2.2 **Surface Applied Corrosion Inhibitors**

As mentioned previously, surface applied and admixed corrosion inhibitors act much alike. The difference is that surface applied corrosion inhibitors are applied on the concrete surface after the concrete has been placed and cured.

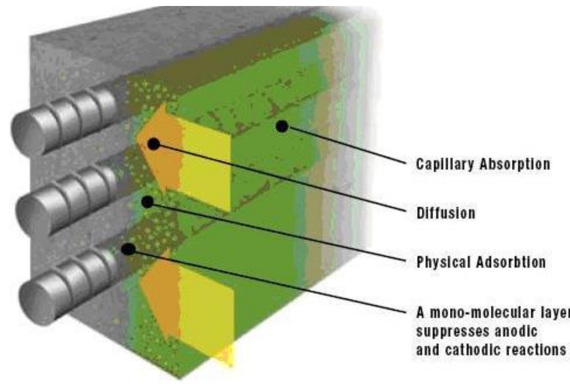

Figure 13: Surface applied corrosion inhibitor (36)

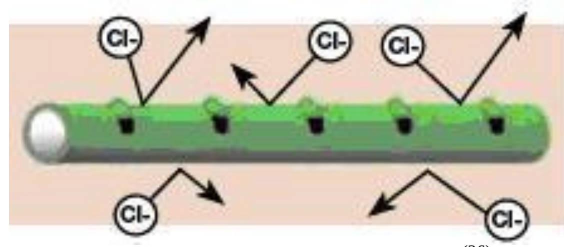

Figure 14: Protection of reinforcing steel (36)

Surface applied corrosion inhibitors work by migrating through the pores of the concrete to seek out and protect the reinforcing bars (Figures 13 and 14) from the ingress of harmful chemicals. (36)

While much research and testing has been performed on surface applied corrosion inhibitors, the results have varied. Newman writes that, "…the only practical method of applying them in concrete repair is to coat the concrete surface and hope that the chemicals migrate deep enough to reach the steel." (8)

A 2004 VTRC report by Sharp investigated the use of FerroGard 903 by Sika, Corp. and TPS-II by Surtreat International. The study by Sharp concluded that "The topical application of inhibitor for corrosion mitigation is ineffective" and that "The vacuum/pressure injection method shows promise, but the methodology requires refinement." (37) It should be noted, however, that the experimental program utilized 15 lb/yd^3 of NaCl around the top layer of reinforcing and none in the bottom layer.

A 2004 thesis by Cook investigated the use of Aquron-7000/CPT 2000 by Aquron, AXIM Post III by Axim, MCI 2020M/MCI 2022 by Cortec, Postrite by Grace, Sonocrete-Corrosion Inhibitor by Master Builders, and FerroGard 903 by Sika. Cook concluded that the products tested "…did initially help delay and slow the corrosion process. As would be expected, none of these products totally stopped or reversed the corrosion process…" It also concluded that "…there is no significant benefit in applying any of the tested corrosion inhibitors to the surface of reinforced concrete when the chloride contamination levels are above 0.5% by weight of cement…" (38)

Projects both in the United States and the United Kingdom by C-Probe Systems Limited have utilized surface applied corrosion inhibitors when half-cell potentials (Cu-$CuSo_4$) were more negative than -200mV and chloride content was less than 1.0% by weight of cement. (39)

Reportedly, the amino-alcohol (Ferrogard 903) and amine carboxylate (MCI 2020) technologies can be used when the chloride content at the reinforcing steel was measured up to 6 lbs/yd^3. (40)

2.4.2.3 Cathodic Protection

"Based on extensive Government and private industry research, the Federal Highway Administration (FHWA) concluded that CP is the only rehabilitation technique that has been proven to stop corrosion is salt-contaminated bridge decks regardless of the chloride content of the concrete." (41)

CP provides a high level of corrosion management by using electrical current to shift the potential of the reinforcing steel in the negative direction. Corrosion can be mitigated if the potential is shifted far enough so that the reinforcement becomes cathodic and is unable to lose electrons. In the absence of the anodic reaction of iron, the electrochemical cell will not exist. [42]

CP is predominantly used when corrosion of the reinforcement is caused by the presence of chlorides. It is not generally used with carbonated concrete, according to Kay, "…because of the increase in electrical resistivity which occurs with carbonation and also because damage is often limited to a small portion of the surface where cover is low. Conventional repair techniques can provide a durable and economical solution in such situations." [6]

As a repair method, Kepler et al. stated that cathodic protection is advantageous as "…only spalls and detached concrete need to be repaired. Chloride contaminated concrete that is still sound can remain in place because the cathodic protection system will prevent further corrosion, and, in fact, reduce the concentration of chloride ions adjacent to protected reinforcing bars…" [42]

In order to inhibit the anodic (corrosive) reactions of corroding steel in normal conditions, the National Association of Corrosion Engineers (NACE) uses a 100 mV polarization criterion. This polarization is measured by estimating "off potential." This "off potential" is measured from the potential decay of the steel that occurs after the protective current is turned off. The initial potential, otherwise known as "instant off" or "IR-free," should be taken 100 to 1,000 msec after the protective current is shut off. The "off potential" is calculated from the difference between the "IR-free" potential and the potential found four hours later. [43]

As displayed in Table 6, the 100 mV polarization criterion may be excessive in low corrosive environments and insufficient in severely corrosive environments. [43]

Table 6: Polarization requirements as a function of chloride concentration at the steel surface [43]

Chloride Concentration (lb/yd^3 concrete)	(kg/m^3 concrete)	**Polarization Needed** (mV)
<1	<0.6	0
1 – 2	0.6 – 1.2	60
2 – 5	1.2 – 3.0	80
5 – 10	3.0 – 6.0	100
10 - 20	6.0 – 12.0	150

CP systems are divided into two categories: impressed current cathodic protection (ICCP) and galvanic cathodic protection (GCP).

2.4.2.3.1 Impressed Current Cathodic Protection

ICCP systems (Figure 15) use an external power source that provides the necessary current, 5 – 20 mA/m^2 (0.5 – 1.9 mA/ft^2), to mitigate corrosion activity. [35] An ICCP system consists of "the reinforcement to be protected, an anode, a power source, concrete surrounding the steel, a monitoring system, and cabling to carry the system power and monitoring signals." [42]

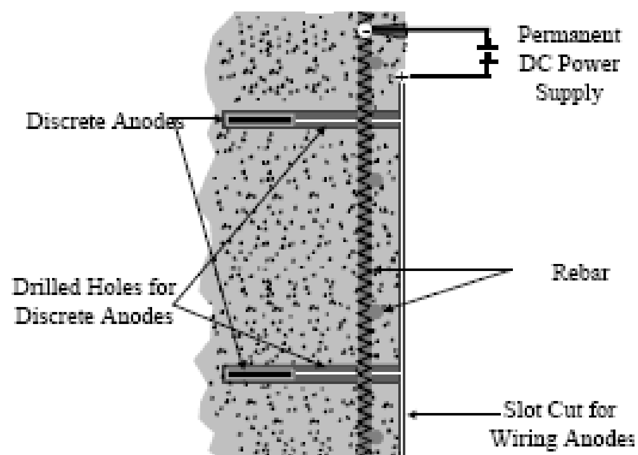

Figure 15: Discrete Anode ICCP [12]

In an ICCP system, anodes are permanently installed and connected to the positive (+) charge from the AC/DC rectifier. The steel is connected to the negative (-) terminal of the rectifier. Thus, the steel is forced into a cathodic and protective condition through this connection to the negative charge. [12] The current flows through the electrolyte that contains alkalis and allows the transfer of current from the anode to the steel reinforcement. [42] Since the driving voltage of an ICCP system is supplied by the DC power source, the anode does not have to be more active than the steel it protects. [44] Therefore, the anode used is non-consumable, and should not corrode. [45]

Because the system is connected to an outside power source, its voltage and current are adjustable. Thus, ICCP can be used on any sized structure or in almost any resistivity environment. [42]

However, one requirement of the ICCP system is that power always needs to be supplied. Since the system is based on DC power to supply the driving voltage, protection will be lost if the system breaks down or loses it power.

Although the upfront material and application cost is high, a low cost per square foot of protection can be achieved by spreading the cost over the life of the project. [12] If properly maintained and monitored, ICCP systems are believed to provide 25+ years of protection. [46]

ICCP is generally not recommended for use with prestressed or post-tensioned concrete because of concerns of hydrogen embrittlement. The impressed current can cause the hydrogen produced by the cathodic reaction to migrate into the steel rather than into the surrounding concrete environment. The formation of hydrogen makes the steel brittle and may cause premature failure. Nevertheless, Kepler reported that it may "…be avoided through careful monitoring and control of the amount of steel polarization." [42]

Today, a few ICCP system installation techniques are used: a discrete anode system, a mesh anode system, a conductive coating system, and a thermal sprayed metal system. The discrete anode system provides local protection, while the mesh anode, conductive coating, and thermal (or arc) sprayed metal systems provide global protection.

2.4.2.3.1.1 **Discrete Anode ICCP**

The discrete anode system utilizes anodes that are permanently embedded in the concrete structure (Figure 16). The individual anodes are connected to one another by titanium feed wire and then connected to the DC power source. [46]

Figure 16: Discrete anode ICCP [46]

2.4.2.3.1.2 **Mesh Anode ICCP**

In the mesh anode system, a metallic mesh with integrated anodes is attached to the exposed concrete surface and connected to a rectifier. A thin layer of concrete (i.e. shotcrete) is applied over the mesh and embeds the anodes into the system. Many state and local transportation agencies have accepted the conjoint use of a titanium mesh anode with a concrete overlay as "…a durable anode for use in impressed current CP of reinforced concrete bridge decks." [1]

2.4.2.3.1.3 **Conductive Coating ICCP**

The conductive coating system utilizes conductive fillers in the coating itself (Figure 17). The conductive coating is applied to the concrete surface and connected to the rectifier by means of

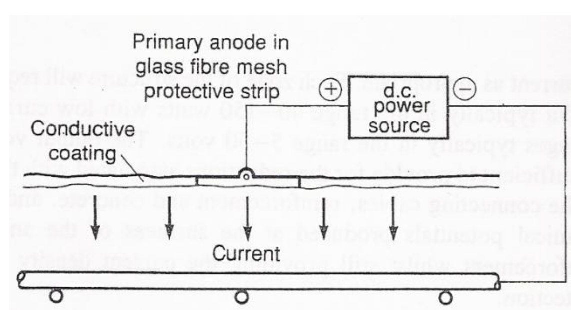

Figure 17: Conductive coating ICCP [6]

feed-wires. The conductive coatings can be over-coated for performance and aesthetic reasons. [6]

2.4.2.3.1.4 Thermal Sprayed ICCP

The thermal or arc sprayed metal application includes the melting of a metal or alloy wire and the spraying of the molten metal to the concrete with compressed air. To provide cathodic protection, a connection is made between the rectifier and the thermal sprayed metal by means of a stainless steel or copper plate that is secured to the concrete surface prior to spraying. The plate is secured with an epoxy. [1] The sprayed metal is either a zinc or catalyzed titanium. [47]

2.4.2.3.2 Galvanic Cathodic Protection

In a GCP system, a connection is made between two dissimilar metals. One of the metals has a higher potential for corrosion (i.e. more electronegative) while the other metal is more noble and has a lower potential for corrosion (i.e. more electropositive). The reinforcing steel, having a lower corrosion potential, is protected as the metal with a higher corrosion potential will sacrifice itself by corroding in preference to the reinforcing steel. As the sacrificial anode now supplies the electrons and thus corrodes, an electrical current is produced. This effectively makes the reinforcing steel a protected cathode. [12], [45]

While the use of GCP is relatively new to reinforced concrete, the idea behind galvanic cathodic protection is not. Its first use is credited to Sir Humphrey Davy in

1824. Davy successfully protected the copper sheeting of navy ship hulls from corrosion in seawater by attaching iron anodes to them. [1]

To understand the performance of sacrificial anodes, a partial galvanic series of metals in seawater is presented in Table 7.

Table 7: Partial galvanic series of metals in seawater [45]

Electropositive (lower corrosion potential)
Platinum
Titanium
Stainless Steel
Monel
Copper
Lead
Iron, Cast Iron, or Steel
Cadmium
Zinc
Aluminum
Magnesium
Electronegative (higher corrosion potential)

While the voltage of galvanic system is fixed, the amount of current supplied is dependent on the surrounding environment. Since the current output changes with the corrosiveness of the environment, a higher current is expected in more corrosive or conductive environments. This means that "…current output will likely exhibit a daily and seasonal variation based on moisture and temperature changes." Because of the fixed voltage, galvanic systems may not reach the accepted 100mV depolarization criteria for cathodic protection. However, "…a significant level of corrosion protection is nevertheless provided to the steel." Additionally, less current is needed as time goes on since "…hydroxyl ions are generated at the steel (thus increasing the pH), chloride ions migrate away from the steel, and passivity develops over time." [12]

The advantages of GCP systems are that they are self-powered and require little to no monitoring and maintenance. Moreover, the low current provided by the sacrificial anodes allows them to be used on prestressed and post-tensioned concrete. The problem with GCP systems is that they have a limited life of 10-20 years because the anode is being sacrificed and consumed. [48]

The use of two types of galvanic cathodic protection systems has been studied: discrete (embedded) anodes and thermal sprayed metals.

2.4.2.3.2.1 Discrete Anode GCP

Discrete (embedded) anode GCP systems provide local protection and have been used in patch repair to stop the "ring anode" or "halo" effect. The discrete sacrificial anodes are intended to function because of the differing electric potentials between the steel and the anode. When attached to the newly cleaned steel at the perimeter of the patched area, the sacrificial anode, being more electronegative, will corrode in preference to the steel in the adjacent, non-patched area (Figure 18). Because of this, the "ring anode" or "halo" effect is supposed to be mitigated. [12]

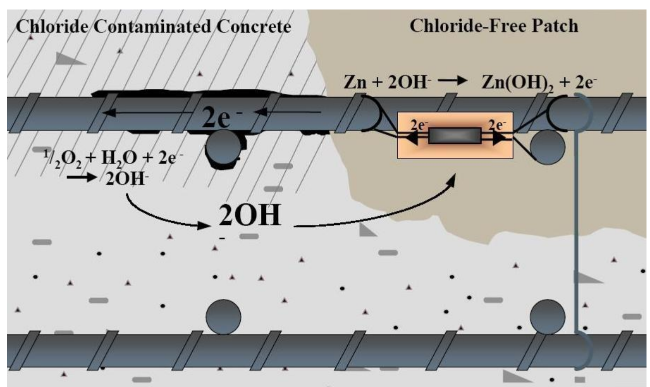

Figure 18: Discrete anode GCP [12]

Since the anodes are an addition to the patch, normal repair techniques can still be used. [49] In 2001, the Concrete Innovations Appraisal Service (CIAS) reported that embedded anodes have "… considerable promise as a strategy to increase the life of concrete repairs" and "…provide an economical method to perhaps eliminate a repair cycle for projects with corrosion related problems." [(50)]

The CIAS also reported that the embedded anodes are "…a viable and cost-effective means of extending the longevity of concrete repairs necessitated by chloride-induced corrosion in reinforced concrete structures…This technology seems to offer the best alternative at a low cost to extend the life of concrete repairs." [(50)]

The use of sacrificial anodes have also been studied by the Vermont Agency of Transportation (VAOT). Between July 2, 2001 and November 15, 2002, "Anodes were installed in all bridges of the Middlesex-Bolton AC IM 089-2(26) project where new concrete was placed next to existing concrete to provide protection against corrosion to the reinforcing steel. No significant difficulties were encountered with the installation of the anodes." In all, 817 anodes and 20 test kits were installed. [(51)]

In early 2005, Jerry McMahan of the VAOT released a report on the results. The report evaluated the test kits, which were monitored for approximately 2 years. McMahan concluded that "There are wide differences in monitored current, and presumably in corrosion rates and the amount of protection provided. Applying the 'weakest link' concept would indicate that the … devices will really only provide significant protection to concrete for 5 to 7 years." [(52)]

In the Midwest, the use of discrete anodes has already been approved by some states. The Michigan Department of Transportation (MDOT) has included several embedded anodes in its "Qualified Products List." [(53)] In addition, the Illinois Department of Transportation (IDOT) has included a commercial embedded anode in its "Products

Evaluation Circular." [54] Field tests installed in June, 2001 were evaluated by IDOT in 2007. Joe Vespa, Development Studies Engineer for the IDOT, responded that, as of the inspections conducted in late 2007, all of the patches, control and with embedded anodes, were in very good condition. [55]

The concrete patch materials should have a resistivity below 15,000 ohm-cm. Additionally, the repair materials should have limited polymer modification and silica fume content. [49] These provisions are made as polymers are electric insulators and silica fume increases the resistivity of the concrete, thereby reducing the available current.

The spacing of the anodes, found in the supplier's guidelines, depends on the chloride content of the concrete and the amount of reinforcement. According to the manufacturers, the service life of sacrificial embedded anodes is estimated to be 10 to 20 years. [48], [56] The cost of each anode ranges from $25-$29. [57], [58]

2.4.2.3.2.2 Thermal Sprayed GCP

Another form of sacrificial cathodic protection is metalizing. Metalizing, or thermal spraying, is a method where a metal is melted and sprayed onto a prepared substrate (Figure 19). The most common method is the wire arc method because of its reported efficiency and low cost. This procedure uses two wires of metal that are energized to an opposing polarity using DC power and are brought together at the gun. A short circuit is created as the wires get close, which causes an arc. The high temperature created at the

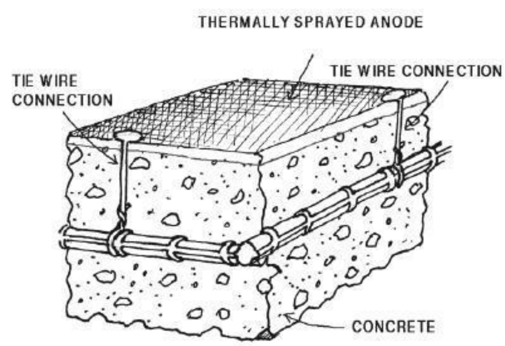

Figure 19: Thermal sprayed GCP [59]

arc melts the wires while high-pressurized air atomizes and applies the melted metal as a coating to the substrate. [47]

Thermally sprayed galvanic coatings can be used for repair in two ways:

1. **Without Reprofiling**: "In this system, concrete excavations in which the reinforcing steel is partially uncovered are not filled with repair mortar and the initial concrete surface is not restored. With this method, the zinc layer is directly sprayed onto the exposed steel and on to the concrete surfaces."
2. **With Reprofiling:** "…the application of zinc coating is possible when either no spalling of the concrete has occurred or spalls have been repaired." A thermal spray coating is applied to the surface of the concrete and an electrical connection is made to the rebar embedded in the concrete. [60]

Table 8 summarizes the different characteristics of thermally sprayed zincs.

Table 8: Comparison of characteristics of thermally sprayed zincs [60]

Characteristics of Thermally Sprayed Zinc	Galvanic Without Reprofiling	Galvanic with Reprofiling	Impressed Current
Reprofiling Required	No	Yes	Yes
Current Measurable	No	Yes	Yes
Protective Capacity Detectable	No	Yes	Yes
Current Adjustable	No	Conditional	Yes
Installation in dry environment	No	No	Yes
Installation in humid environment	Yes	Yes	Possible, but not required

Reportedly, "The entire coating process, blast cleaning, metal spraying, and sealing is completed in one work day. Metalizing can be applied virtually year round and in nearly any shop or field environment." This means that metalized coatings can be applied in both warm and cold temperatures and because it is spray applied, the process can be used on structures of any size or shape. Additionally, the metals used do not contain volatile organic compounds (VOCs). [61]

For reinforced concrete structures, the most commonly used thermal sprayed anodes are pure zinc and an aluminum-zinc-indium alloy (Al-Zn-In). The Al-Zn-In alloy consists of 80% aluminum, 20% zinc, and 0.2% indium. [62] According to a report, a 20-year life can be expected by using a thickness of 300-500 μm (12 mils). [60] Another thermal sprayed metal is the 85/15-alloy (85% zinc and 15% aluminum) [63]

When applied, thermal sprayed zinc has a bright silver gray color. Over time, the color dulls and approaches the color of the concrete. The bond strength between the zinc and the concrete reportedly ranges from 170 to 300 psi. The corrosion product is a white zinc oxide and has "little effect" on the appearance. [64] The Al-Zn-In alloy also has a gray-silver color when applied to the concrete. Its corrosion products are also white. [62]

Some investigators believe that the melted metals also act as a barrier coating and improve aesthetic appearance. [13] When scratched, the metalized coating reportedly continues to give cathodic protection as long as any metal remains in the area. [64]

When comparing zinc and the Al-Zn-In alloy, zinc is more malleable, inexpensive, and can be obtained from several sources. [65] However, the open circuit potential of the Al-Zn-In alloy is higher than zinc. [66]

To have maximum efficiency, the zinc should have the highest purity possible. "For CP," according to Costa, President of Electro Tech CP, "it is important to select the purest alloy available with iron (Fe) content less than 14 ppm. Higher iron contamination could lead to passivation of the anode." [66]

Alloys of zinc and aluminum combine the benefits of both pure zinc and pure aluminum. [61] Although pure zinc is electrochemically active and provides a high level of cathodic protection, its high electrochemical activity also means that the zinc will corrode, thus depleting the coating. Aluminum coatings, on the other hand, are more passive and act as a barrier. [67] Alloys of zinc and aluminum are, according to Butler, "…somewhat more chloride and sulfur dioxide resistant than pure zinc, while still retaining the greater electro-chemical activity of pure zinc." [61]

The problem with thermal sprayed metals is that environmental conditions will affect the levels of cathodic protection and current densities. Moisture content at the anode/concrete interface and temperature are environmental conditions that affect the current output. [62]

In a dry environment, zinc will not work effectively as the resistivity of the concrete will be high. In comparison, the Al-Zn-In alloy will deliver more current than the pure zinc in the same high resistivity environment. [66] This happens because the indium keeps the anode active in the drier conditions. [62]

In extremely cold temperatures, the current output of thermal sprayed metals may be insignificant. When both low temperature and dry concrete are present, the level of protection supplied by the thermal sprayed metals will be greatly reduced. However, the corrosion rate of reinforcing steel in this environment may be negligible. [62]

Although pure zinc may not work effectively in a high resistivity (i.e. low moisture) concrete environment, a chemical treatment can be added to increase the moisture content of the pure zinc. An alkaline humectant is one such chemical that increases the moisture content at the interface, thereby reducing the resistivity of the concrete. The humectant helps to lower the resistivity by forming soluble $Zn(OH)_2$, thus leaving the surface of zinc available for continued reaction and current output by holding moisture in the pores of the metal. [65] Holcomb et al. reported that humectants were effective in "…raising the long-term galvanic current density is GCP (galvanic cathodic protection)" and that "Humectant treatment increased the protection current in GCP. Spot application of humectants would prolong the useful life of GCP zones that were not achieving sufficient galvanic current." [68]

A problem with using humectants on zinc, according to Costa, is the reapplication of the humectant activator. Costa's experience with activated zinc in cold climates is that the humectant loses its effectiveness and needs to be reapplied every two years. [69] When asked about the reapplication of the humectant, Sandron, Business Development Manager of VCT, responded that, "…By monitoring these results (current and polarization) over time, one can decide on reapplication if current throw is insufficient to maintain adequate polarization. We do not recommend a scheduled reapplication of humectant but only suggest that reapplication is required if current drops below acceptable levels." [70]

Testing by Corrpro has reportedly shown that the Al-Zn-In alloy has a higher current density, a higher depolarization (it can actually meet the 100 mV depolarization criterion), and similar adhesion strength to that of pure zinc. [62]

The success of a thermal sprayed system, according to Daily and Green, "…is greatly influences by several factors including adequate concrete surface preparation, electrical continuity of the reinforcing steel, a degree of moisture at the anode/concrete interface to improve overall conductivity, and finally an experienced thermal spray operator who can successfully apply the system to provide adequate bonding in accordance with the project specifications." [62]

Electrical continuity should be checked at 5 locations per every 1000 ft^2 of concrete and among all exposed steel. Continuity can be achieved by welding the reinforcing bars together or by wrapping and tightening uncoated steel wire ties. [62] This check should also be performed for half-cell potential testing and all other forms of cathodic protection.

According to Miltenberger, the problem with the Al-Zn-In alloy is that it is "…available only from one supplier and is patented. The alloy is brittle, causing the wire to break inside the metalizing equipment. This increases wear and tear on the equipment and (gives) less efficient work." [65]

However, Clem Firlotte, Senior Project Manager of North American Concrete Services for Corrpro Companies, Inc., replied:

> "When we first developed this wire (Al-Zn-In alloy), in 1995, some of the early applications had a few problems with the wire jamming up in the lines that feed to the spray gun. This is not because the wire is brittle, but just the opposite, it is a cored (an aluminum sheath wrapped around zinc and indium powder) wire and is soft. The first applications had the equipment set for solid wire such as zinc or aluminum and some problems occurred. We made some adjustments, and with an experienced operator, the wire actually sprays faster and with better efficiency than zinc or aluminum." [71]

In 2003, Whitney et al. released a Project Summary Report on Research Project 7-2945, Performance Evaluation of Cathodic Protection Systems for Queen Isabella

Causeway in Texas. The project studied the use of cathodic protection on substructure elements in the splash zone. The report stated that the non-impressed sprayed zinc and aluminum-zinc alloy systems both performed reasonably well. The report also noted that although the zinc was less expensive, the aluminum-zinc alloy appeared to perform more effectively in dryer conditions and provided more uniform protection. (72)

In an experiment by Bohdanowicz, when a zinc protection layer was applied to reinforced concrete specimens completely immersed in aqueous sodium chloride solutions, a gradual increase of reinforcement cathodic polarization was found. Complete cathodic protection was achieved after two months of polarization. During the experiment, no significant consumption, delamination, or blistering of the zinc layer occurred. A 100% adhesion to the concrete was also found. (13)

Sagues and Powers reported in 1994 that sprayed zinc galvanic systems "…have continued to show physical integrity after up to 4.5 years of service in a harsh marine environment…Field current density measurements over 4.5 years indicate that typically 0.5mA/ft^2 has been maintained on structures containing corroded epoxy-coated rebar. On the order of 1.0 mA/ft^2 was maintained over two years on structures containing corroded ordinary rebar…Rebar probe measurements consistently showed typical steel polarization decay values that exceeded 100mV in as little as one hour." (73)

Laboratory and field investigations of thermal sprayed zincs in deicing salt environments were conducted by the Transport Ministry of Quebec, in cooperation with the Institute for Research in Construction and the Industrial Materials Institute. In 1993, seven reinforced concrete columns of a bridge were flame-sprayed and the zinc continued to protect the columns when tested 20 months later. In another field test, researchers from the National Research Council (NRC) of Canada used zinc to metalize driving surfaces in an Ottawa parking garage. “High levels of protection were provided by the metalizing, although in extremely wet areas the zinc sacrificed itself more rapidly than in the dry areas, indicating that more zinc needs to be applied in areas where water collects.” [74]

The NRC is also studying metalized alloys (zinc in combination with other materials). The researchers believed that these materials would be more effective than pure zinc in dry environments. [74]

Although the life of thermal sprayed metals is limited, Andrews-Phaedonos et al. write that “…The life of the system can be extended by simply whip blasting the surface and spraying additional molten zinc. A longer life system is possible by increasing the coating thickness.” [75]

Although thermal sprayed metals are normally used on bridge substructures or the underside of bridge decks, the Missouri Department of Transportation is currently researching the use of the Al-Zn-In alloy in a bridge deck application. A 0.060” thick alloy 3003 aluminum expanded mesh, with 1” x 2.75” diamond pattern openings, was thermally sprayed. The anode mesh was installed to the existing deck and a 2-¼” thick low slump concrete overlay was then installed. Installed in July 2005, initial depolarization tests performed in September 2005 showed that the anode was working and was producing sufficient current to protect the rebar. [76]

A 2002 report by the Illinois Department of Transportation evaluated thermally sprayed pure zinc, an 85/15% blend of zinc and aluminum, and a zinc/aluminum/indium alloy on prestressed concrete bridge girders. They concluded that “…the systems do not offer any improved amount of protection to the pre-stressing strands when compared to beams not treated. Results from the corrosion potential surveys indicate that the systems are not protecting the steel. It appears that the anodes do not develop enough current necessary to drive the ion exchange to arrest the corrosion process." [77]

However, the results were only based on corrosion potentials. Because the tests were performed in the field, the girders were not dissected to see if the strands were indeed being protected.

When asked to further comment on the report, Gawedzinski replied, "No additional work was performed on the metalized beams after the study was concluded. The cause for the "poor" performance (as described by industry reps) was that the concrete was too "dry," in that it could not conduct enough current to drive the ion transfer between the rebars/strands and sprayed on anodes." [78]

From projects quoted in 2008, the cost of humectant-activated thermal sprayed zinc was approximately $30 per square foot while the cost of the Al-Zn-In alloy was approximately $35 per square foot. [79], [80]

2.4.2.3.3 Galvanic Cathodic Protection with Coatings

To increase the useful life of the sacrificial anodes, the method of using coatings in addition to sacrificial cathodic protection has been researched. Francis writes:

> "The provision of an insulating coating to the structure will greatly reduce the current demand for cathodic protection…The conjoint use of coatings and cathodic protection takes advantage of the most attractive features of each method…the bulk of the protection is provided by the coating and cathodic

protection provides protection to flaws in the coating…A combination of coating and cathodic protection will normally result in the most economic protection system." [45]

2.4.2.3.3.1 Discrete Anode GCP with Coatings

The Interstate Route 480 Viaduct substructure in Omaha, Nebraska utilized discrete (embedded) galvanic anodes in patch repairs of piers with limited chloride contamination and electrochemical chloride extraction on the piers with the highest chloride levels. Fallaha and Whitemore wrote that the anodes "…would address future 'hot spots' which are likely to occur outside of the repair zone." After treatment, the entire substructure was coated with a flexible, breathable acrylic coating to prevent future chloride contamination. [81], [82] As of 2006, Whitmore reported that the treatments seemed to be working well. [83]

However, Costa explained that coatings should not have an effect on the life of the discrete anodes:

> "I don't see any added benefit nor detriment to this type of anode by using an external coating…In my opinion this should not affect the life of the anode. The life of the anode is directly proportional to its current output. Current output is controlled by anode geometry, concrete resistivity and driving voltage between the anode material and the steel. The only variables here are concrete resistivity and driving voltage (which will change as the steel polarizes, if it does). If there is corrosion activity in concrete (enough to warrant the use of discrete anodes), then it follows that the resistivity of the concrete is low. Although chlorides affect the

resistivity, moisture and humidity are the dominant factors, not chlorides. Chlorides primary role in the corrosion process is the removal of the passive film that is created on the steel in alkaline environments. So, coating the exterior of a concrete structure with the objective of preventing further chloride ingress will not affect concrete resistivity, therefore anode current output (and hence anode life) will not be affected by this. Further, exterior coatings will not isolate the concrete matrix from the environment such that no moisture and humidity can penetrate." [66]

2.4.2.3.3.2 Thermal Sprayed GCP with Coatings

To increase the life of melted metals, coatings can be placed on top of the metal to further protect it (Figure 20). Melted metals also give excellent adhesion to top-coatings. [64] Costa commented that, "It is important to use coatings that will allow vapor diffusion (not sealers) to permit moisture to migrate both back and forth from the concrete. This will allow zinc oxides to migrate out and prevent accumulation at the interface of the anode and the concrete, which could lead to debonding of the anode." [66]

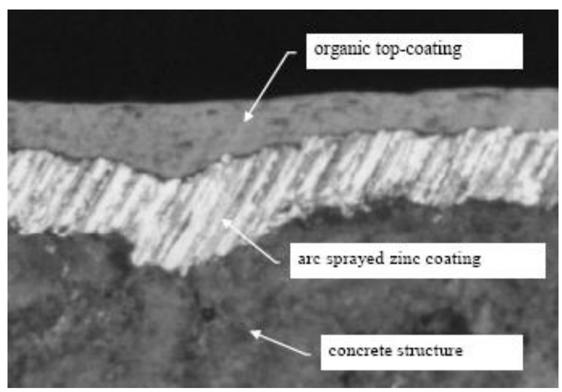

Figure 20: Application of a top-coating to thermal sprayed zinc [60]

David Whitmore, President of VCT, remarked that "The top coat will significantly reduce self corrosion of the galvanic coating especially in conditions where it is exposed to splash and spray." However, top coats should not be used in all situations. He also commented, "I would not recommend it where the concrete is never exposed to moisture or splash and the concrete is not in contact with moisture or humidity (such as the underside of a deck)." (84)

As described by Costa, inorganic zinc primers, such as zinc silicate, have reportedly been used successfully with thermal sprayed zinc in Florida. In other environments, latex coatings have been used with success. (66) According to Firlotte, coatings can be used with the Al-Zn-In alloy provided that the coatings are breathable. (85)

According to Spriestersbach et al., the application of organic top coatings helps to protect and prolong the life of arc-sprayed zinc. Because of the organic top coating, "…the zinc coating is not in direct contact with the atmosphere and thus is not longer subject to self corrosion. Therefore, zinc consumption only takes place at the interface between the zinc coating and the concrete. It is calculated that the zinc consumption can be reduced to 50%..." This calculation is based on Faraday's 2nd law. (60)

After six months of laboratory testing using NaCl contaminated concrete and the salt spray test, the sprayed zinc coated concrete specimens with organic top-coating satisfied the 100mV off-potential (NACE criterion) after only one hour. (60) As discussed previously, sufficient protection is provided when a potential decay greater than 100mV is found after four hours.

The study also examined the use of the arc-sprayed zinc with an organic top-coating as a repair method for severely corroded concrete structures in the Persian Gulf. The repair included the removal of loose concrete, grit blasting of the corroded steel reinforcement, installation of reference cells and electrical contacts, reprofiling of the concrete structure, arc spraying of the zinc anode, and application of the organic top-coating [60]

More than a year-and-a-half after field installation of the arc sprayed zinc and organic top-coating, Spriestersbach et al reported that "…no sign of rebar corrosion could be observed…The obtained values of static potential measurements indicate that there is no sign of corrosion…" [60]

The paper by Spriestersbach et al. concluded as follows:

> "Sprayed zinc coatings do not present any significant limitations with regard to their applicability in comparison with other cathodic protection variants for concrete… Thermally sprayed zinc anodes can be renewed very easily after being consumed... The anode can be easily replaced by spraying a new zinc coating on the concrete surface… By applying organic top-coatings to the sprayed zinc coating, the lifetime can be enhanced considerably." [60]

2.4.2.3.4 Comparison of Cathodic Protection Systems

Table 9 compares and contrasts the characteristics of impressed current and galvanic cathodic protection systems.

Table 9: Characteristics of cathodic protection systems [42]

Impressed Current	Galvanic Anode
External power required	External power not required
Driving voltage can be varied	Driving voltage is fixed
Current can be varied	Current is limited
Can be designed for almost any current requirement	Usually used where current requirements are small
Can be used in any level of resistivity	Usually used in low-resistivity electrolytes
High $/unit cost	Low $/unit cost
Low $/sq. ft. of metal protected	High $/sq. ft. of metal protected

As ICCP systems are more expensive and complex (requires an outside power source, a rectifier, monitoring, and maintenance), their use is not pursued in this project. For this project, the use of galvanic (sacrificial) cathodic protection is pursued because of its simplicity (does not require monitoring or maintenance) and lower initial cost.

According to a 2004 article by the Ontario Ministry of Transportation (MTO), "The implementation of new sacrificial anode systems could dramatically improve and simplify the rehabilitation or some structures suffering from corrosion." The MTO also writes that, "Based on their potential to reduce the costs of long-term monitoring and system maintenance and to enhance the durability of Ontario's bridges, sacrificial anode systems may eventually replace impressed current systems as the standard for cathodic protection." [86]

2.4.3 Corrosion Passivation

Corrosion passivation makes use of electrochemical treatments to address and remove the underlying cause(s) of corrosion. While the electrochemical chloride extraction (ECE) process removes chlorides and the re-alkalization process restores the alkalinity of carbonated concrete, both processes are intended to restore the passivity of all reinforcing steel within the treated area. Operated for a short amount of time, dismantled and then removed, these electrochemical treatments are supposed to provide long-term mitigation benefits without the need for future maintenance and monitoring. (22), (87), (88)

In order to use either technique, the following steps need to be performed: [(87), (88)]

1. All existing surface finishes must be removed
2. All cracks, spalls, and delaminations should be located and repaired using an approved cementitious mortar
3. All metallic features on concrete surface should be located and insulated, or removed
4. Thickness of concrete cover should be determined and built up to a minimum of 3/8" (10mm), if necessary
5. The continuity of the reinforcement should be checked and provided if it does not exist.

2.4.3.1 Electrochemical Chloride Extraction

Used mostly on bridges and parking garages, the ECE process (Figure 21) is supposed to remove chlorides from chloride contaminated concrete and regenerate the passivity of the reinforcing steel. [22] This occurs as the positively charged external anode attracts the negatively charged chloride ions. In turn, all of the rebar becomes a negatively charged cathode and passivity is reinstated as hydroxyl ions are formed at the rebar. [89]

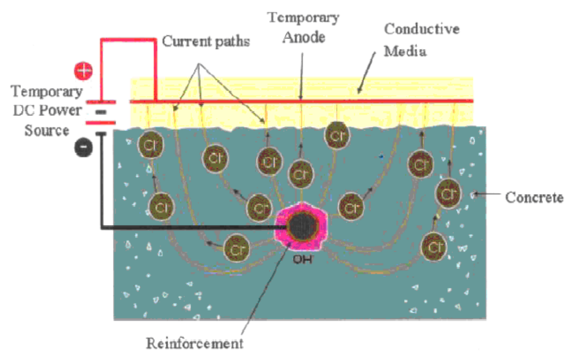

Figure 21: Electrochemical chloride extraction [12]

"…the ECE process," according to Donald Jackson of the Federal Highway Administration (FHWA), "has become nationally recognized as a promising technology that can benefit the owners of thousands of concrete structures." [90] Additionally, James Cheatham writes that "ECE offers benefits over conventional means of bridge rehabilitation or replacement because this technology requires less disruptive and expensive rehabilitation work, can extend the service life of the structure by as much as 12 to 15 years or more, and can save construction time." [90]

The success of the ECE process depends on three facets that will be discussed in the following paragraphs:

1. Site utilities and services
2. Anode, electrolyte, and electrolyte media
3. System operation

The requirements for site utilities and services are a temporary power supply, availability of water for the electrolyte solution, and site access. Although the rectifiers require 240V AC input, the applied voltage ranges from 10 to 40V DC while the current density is normally $1A/m^2$ of concrete surface. [87], [89]

The proper selection of anode, electrolyte, and electrolyte media is paramount to the success of ECE.


Figure 22: Installation of steel mesh [91]

The anode can be either a catalyzed titanium or steel mesh (Figure 22). While the titanium is inert and does not corrode, the catalyzed coating is consumed over time. Whitmore writes that the "Titanium mesh may require the use of a buffered electrolyte or regular electrolyte replacement since chlorides will concentrate in the electrolyte resulting in acidification of the electrolyte over time." In contrast, steel mesh is not inert, will be consumed during the ECE process, and will produce rust stains on the concrete. However, the stains can be taken off with light sandblasting. The cost of the catalyzed titanium mesh is 6 times that of the steel mesh. [89]

The electrolyte can be water, calcium hydroxide (lime) solution, or "lithium borate" solution. The advantages of using water are that it is the most efficient, inexpensive, more readily available, and does not require environmental protection or containment. However, its disadvantage is that water does not have buffering ability. Whitmore writes that, "If water is used as an electrolyte with an inert anode in a closed system, electrolyte acidification will occur if the water is not regularly replaced."

Although calcium hydroxide solutions provide some buffering capability, they are more expensive than water, require time to prepare and maintain, and have somewhat less efficiency than water. "Lithium borate" is a mixture of lithium hydroxide and boric acid. This electrolyte is highly buffered and has been specified for concrete suffering from alkali-silicate reactivity. Whitmore also writes that the "Disadvantages of lithium electrolyte solutions include their relatively high cost and the need for re-circulating systems which are often installed to minimize the quantity of electrolyte required." (89)

The electrolyte media holds the electrolyte solution to the concrete and provides separation between the anode and concrete surface. Sprayed cellulose fibers (Figure 23), used for vertical surfaces, synthetic felt mats, used for horizontal ponding, and surface mounted tanks, used for vertical ponding, are the three types of electrolyte media used. (89)

Figure 23: Application of cellulose fibers (91)

During the treatment (Figure 24), which lasts for six to eight weeks on average, the system must be monitored and maintained. Daily wetting, by a person or by a wetting system, is required for cellulose and synthetic felt installations. The electrolyte of a tank or a ponding

Figure 24: Operational ECE system (91)

system, which is usually buffered, requires periodic circulation, topping, and regular replacement. [89]

A problem with ECE is that when it is used on bridge decks, the traffic must be rerouted so that the system is not disturbed. When the system is used on bridge piers, traffic rerouting is not required. [92]

Additionally, ECE should not be used with structures containing epoxy coated rebar and pre-stressed or post-tensioned steels. The epoxy coating insulates the steel, thus "…preventing electrical continuity, and effective chloride removal." The high applied voltages may cause hydrogen embrittlement of the high strength steel wires used in pre-stressed and post-tensioned concrete. [93]

Although FHWA reported that "Various studies have demonstrated ECE is a promising bridge restoration alternative to CP for chloride-contaminated concrete bridges," it also states that ECE "…data from field and laboratory experiments indicate certain regions in concrete appear to lead to inefficient chloride extraction." [92]

The University of Minnesota conducted a study using ECE on the substructure of reinforced concrete bridges in Minneapolis, Minnesota. The study found that "…the effectiveness of the treatment process varied greatly by location, sample depth, and original chloride content. In general, ECE reduced the average chloride concentrations the most near the concrete surface, and the effectiveness decreased slightly with depth into the structure." However, it was also determined that several locations possessed "…chloride concentrations in excess of the established threshold for corrosion, of 2000 ppm by weight of cement, at multiple sample depths…following ECE treatment."

Therefore, it was concluded that "…corrosion can potentially reoccur once chloride ions migrate back to the reinforcing steel level…" [94]

The Michigan Department of Transportation (MDOT) also evaluated ECE on the substructure of M60 over I-94 in Jackson, MI. The project treated one pier cap and four columns. Kahl concluded that:

> "Passivity of the reinforcing steel was regenerated; eighty-one percent of the readings after the ECE treatment were more positive than -200 mV, the region characteristic of very little corrosion. Chloride levels were reduced at locations above the steel reinforcement, with no adverse effects to the structural integrity of the concrete. At the reinforcement, chloride levels were redistributed, except one location where chlorides were completely removed. However, it was expected that all chloride contamination at the reinforcement depth would be reduced below the corrosion threshold. Despite the incomplete removal of chloride contamination from around the reinforcement, ECE has reduced the ability of the remaining chlorides to initiate corrosion by repassivating the steel. Electrochemical chloride extraction appears to work well, given the resources available at a remote location. Because of the variability in chloride removal at the steel reinforcement, it is recommended that ECE be studied further with additional field trials. More substructure units should be treated with ECE and evaluated before adoption as a standard alternative substructure rehabilitation method in Michigan." [91]

2.4.3.2 Re-alkalization

Used primarily on carbonated building facades, [22] the re-alkalization process (Figure 25) "…restores the alkalinity of carbonated concrete and re-instates the passivity of the steel reinforcement." [88]

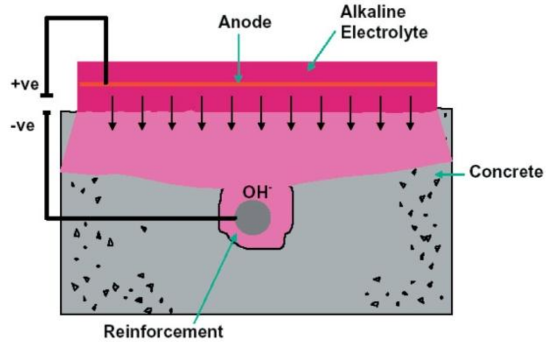

Figure 25: Re-alkalization [88]

During this process, an electric field is applied between the reinforcing steel and an externally mounted anode mesh. A reservoir of electrolytes provides a connection between the concrete and the embedded anode mesh. The electric field produces a high pH environment at the steel surface as electrolysis occurs. Simultaneously, the electrolyte is transported into the concrete and increases the alkalinity of the concrete. [95]

The anode mesh is made of steel or platinized titanium. The alkaline electrolyte, usually a sodium carbonate solution, conducts electricity and provides alkalis to the carbonated concrete. The reservoir may be sprayed-on cellulose fiber, felt cloth, or coffer tanks. [95]

Prior to applying the cellulose fiber, wooden battens are attached to the concrete. The anode mesh is attached to the wooded battens, which provides separation between the concrete surface and the anode mesh. The cellulose fiber is saturated with electrolyte and sprayed onto the concrete surface to a thickness that coats the mesh. Although regular wetting is required, cellulose fiber can be used on most concrete structures. [22], [95]

Felt cloths are used primarily on concrete decks. With this application, the anode mesh is sandwiched between two layers of felt cloth. Constant wetting is required. [95]

Coffer tanks are made of plastic sheets with sealing edge strips and a built-in anode mesh. The coffer tanks are then attached to the concrete and filled with electrolyte. This application is used on smaller, separated areas. (95)

Using an applied voltage between 10 and 40V DC and a current density of 1 A/m^2 of concrete surface, the procedure usually takes a week to complete. To assess the effectiveness of the treatment, cores are taken after a few days and tested to determine the extent of re-alkalization. The treatment continues until sufficient levels of re-alkalization are achieved. When the treatment is stopped, the pH of the concrete is at a value greater than 10.5. At this level, the passivity of the reinforcement can be maintained. The system is dismantled and the concrete surface is washed with water. Finally, all core holes and cavities are repaired. (95)

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CHAPTER 3

EXPERIMENTAL APPROACH

3.1 General

In previous sections of this report, an overview of a few recently developed technologies that could be used for the prevention and repair of corrosion in concrete bridges was presented.

While many products and techniques may appear to be effective for the maintenance and repair of reinforced/prestressed/precast concrete bridge elements, not all effective claims will hold true under field conditions. By providing controlled accelerated testing and evaluation, this project aimed to investigate new or promising techniques to improve the repair and maintenance of reinforced concrete bridges in Wisconsin.

3.2 Products/Techniques Used for Experimental Program

Based on the literature information discussed previously, three galvanic products, one penetrating sealer, two coatings, and two patch repair materials were evaluated experimentally. Additionally, the use of coatings in conjunction with the galvanic anode cathodic protection systems was studied (Table 10). Table 11 details the use of the products for this project.

Table 10: Products used for experimental program

Product	Produced By	Referred to As
Disk-Shaped Embedded Galvanic Anode	Supplier A	EA-A
Box-Shaped Embedded Galvanic Anode	Supplier B	EA-B
Humectant activated Thermal-Sprayed Zinc Galvanic Anode	Zinc was not a proprietary product. Humectant activator from Supplier A	TSZ
Tri-Silane Penetrating Sealer	Supplier C	T-SS
Epoxy/Polyurethane Coating	Supplier D	EP-C
Acrylic Coating	Supplier E	A-C
Epoxy Repair Mortar	Supplier F	EM

Table 11: Table of products used and application to specimens

Specimen Number	Type	General Description	Referred to As	CoP/CoC
01 and 02	Thermal sprayed galvanic anode	Humectant activated zinc	TSZ	CoP
03 and 04	Thermal sprayed galvanic anode with coating	Humectant activated zinc with epoxy/polyurathane coating	TSZ w/EP-C	
05 and 06	Embedded galvanic anode with coating	Disk-shaped anode with acrylic coating	EA-A w/A-C	
07 and 08	Embedded galvanic anode	Disk-shaped anode	EA-A	
09 and 10	Embedded galvanic anode	Box-shaped anode	EA-B	
11 and 12	Penetrating Sealer	Alkylalkoxysilane	T-SS	
13	Coating	Acrylic Coating	A-C	
14	Coating	Epoxy/polyurethane coating	EP-C	
15 and 16	Control	No treatment	Control	
17 and 18	Control	No treatment	Control	CoC
19 and 20	Thermal sprayed galvanic anode with coating	Humectant activated zinc with epoxy/polyurethane coating	TSZ w/EP-C	
21 and 22	Thermal sprayed galvanic anode	Humectant activated zinc	TSZ	
23 and 24	Embedded galvanic anode	Disk-shaped anode	EA-A	
25 and 26	Embedded galvanic anode with coating	Disk-shaped anode with acrylic coating	EA-A w/A-C	
27 and 28	Embedded galvanic anode	Box-shaped anode	EA-B	
29 and 30	Epoxy Repair mortar	Epoxy resins and polyamino amine adducts	EM	

3.2.1 Embedded Galvanic Anodes

As discussed earlier in this report, some previous research reportedly showed that embedded anodes provided an effective means of locally protecting the reinforcing steel in patched concrete. Because the anodes are an addition to the patch, their installation would be relatively quick and easy and would not require special equipment or training.

3.2.1.1 EA-A

EA- A (Figure 26) was chosen because of the reportedly positive results from previous applications of the product. EA-A, used primarily for patch repair and bridge widening, is disk shaped and is comprised of a zinc core encased in an activated cementitious mortar that reportedly provides high capacity, high current output performance. The pH of the mortar is 14 or greater. (48) The number of anodes needed, as reported in the manufacturer's guidelines, depends on the chloride content of the concrete and the amount of reinforcement. The placement and locations of the anodes for this project was confirmed with Supplier A (Figures 27 and 28). (96)

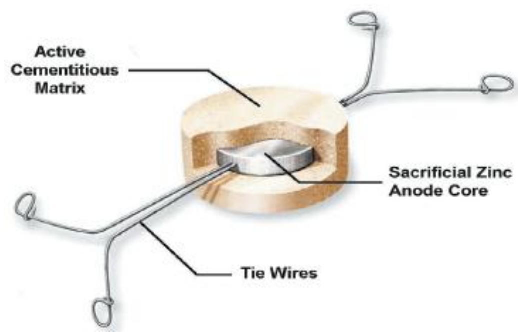

Figure 26: Cut-through of EA-A (48)

Figure 27: Installation of individual EA-A in CoP specimens

Figure 28: Placement of EA-A in CoP specimens

3.2.1.2 EA-A w/A-C

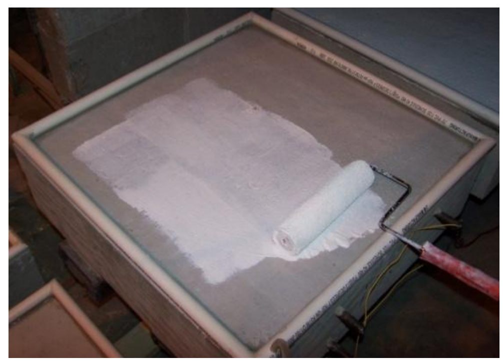

Figure 29: Application of A-C to specimen with EA-A

The use of the A-C, in conjunction with the EA-A, (Figure 29) was pursued to determine the effectiveness of a coating with embedded anodes. The use of this product was endorsed by Supplier A. (82) The acrylic coating was used as it is an "elastomeric, crack-bridging, anti-carbonation, acrylic protective coating." The coating reportedly offers resistance against the ingress of carbon dioxide and other aggressive gases, as well as chlorides and waterborne salts. In addition, it does not act as a vapor barrier. Specified by Supplier E, a coating dry film thickness of 8 mils (16 wet mils applied in two-8 wet mil layers) was applied. (97) The applied thickness of the coatings were measured with a coating thickness gauge.

3.2.1.3 EA-B

EA-B (Figure 30) utilizes a zinc core, two corrosion inhibitors, and a V-notch configuration with insulating barrier and is designed to extend the life of patch repairs in parking decks and bridge structures by preventing the "anode ring effect." The insulating barrier reportedly prevents current "dumping" into the attachment bar. The V-notch configuration is also designed to assist in an "…efficient placement on any sized reinforcing bar." (56), (98) The manufacturer offers guidelines for spacing of the anodes that are similar to that of EA-A. The placement and locations of the anodes for this project was confirmed with Supplier B (Figures 31 and 32). However, they expressed some concerns about the level of voltage, and associated amount of current, that would be used for accelerating corrosion in this project. (99) Nonetheless, the research team evaluated the expressed concerns and decided that the accelerated corrosion setup was not incompatible with the anode, and would represent long-term consumption and depletion of the anode properly.

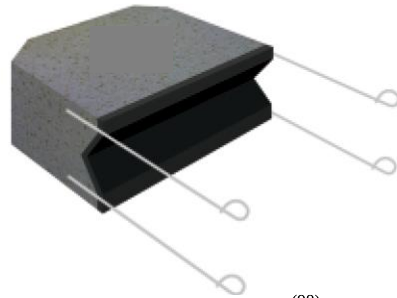

Figure 30: View of EA-B (98)

Figure 31: Installation of individual EA-B in CoP specimens

Figure 32: Placement of EA-B in CoP specimens

3.2.2 Thermal Sprayed Galvanic Metals

As discussed previously, there are a few metals that could have been used for thermal spraying. The use of Supplier A's humectant–activated metalized zinc was pursued because it is more readily available compared to the Al-Zn-In proprietary alternative. At the time we were ready to apply the humectant–activated metalized zinc, circumstances would not allow Supplier A to apply their product to our concrete specimens. With approval from Supplier A, a local metalizing company was able to apply pure zinc to our specimens. The humectant solution, supplied by Supplier A, was then applied to the specimens.

3.2.2.1 TSZ

The use of the thermal sprayed pure zinc with the humectant activator solution, supplied by Supplier A, was tested. Supplier A's humectant–activated metalized zinc application usually utilizes a 3/16" diameter high purity zinc wire at a thickness of 20 mils. [100] The local metalizing company, however, did not have the equipment to use that thickness of wire. Instead, a 1/8" diameter zinc wire was used and sprayed to a thickness of 15 mils as the reduced thickness wire produced smaller droplets and would create less voids. This procedure was confirmed with Supplier A. [101] The application of thermal sprayed zinc was as follows:

1) Grit blast the entire concrete surface (Figure 33)
2) Spray a layer of 6" x 6" area of 6-mil thickness around connection to rebar
3) Apply zinc mesh and secure with galvanized nut
4) Check for electrical continuity between the thermal spray and embedded rebar

5) Apply a uniform thermal spray thickness of 15 mils (Figure 34)

6) Check for electrical continuity between the thermal spray and embedded rebar (Figure 35)

7) Apply humectant activator (Figure 36)

As specified by Supplier A, a second rebar connection was made for redundancy. In the CoP specimens, only one of the connections was used. Because of the small surface area, we did not feel that both connections would be necessary and the second connection was covered. However, the second rebar connection was used in the patch repair for the CoC specimens because of the apparent failure of one of the single connections in the CoP specimens.

Figure 33: Grit blasting of the concrete surface

Figure 34: Application of the thermal spray

Figure 35: Check for electrical continuity

Figure 36: Application of humectant activator

3.2.2.2 TSZ w/EP-C

The conjoint use of a coating with the thermal sprayed zinc was tested as previous research showed this to be a promising means of extending the life of the thermal sprayed zinc. Supplier A specifies the use of a zinc coating by Supplier D with its humectant–activated metalized zinc. [100] However, technical support from Supplier D stated that there is "no advantage of putting zinc on zinc" and suggested using an epoxy/polyurethane topcoat. [102] The United States Army Corps of Engineers (USACE) also specifies the use of an epoxy primer/polyurethane topcoat in conjunction with thermal spray coatings. [103] The use of this coating system was also confirmed with Supplier A. [104]

As such, recommendations of coating thickness by the manufacturer [105] and the USACE [103] were followed (a coating thickness gauge was used):

1) The epoxy coating was applied with a 3/8" woven roller at a dry film thickness of 3 to 4 mils (75 to 100 μm) (Figure 37)
2) The polyurethane coating was applied with a 3/8" woven roller at a dry film thickness of 3 mils (75 μm) (Figure 38)

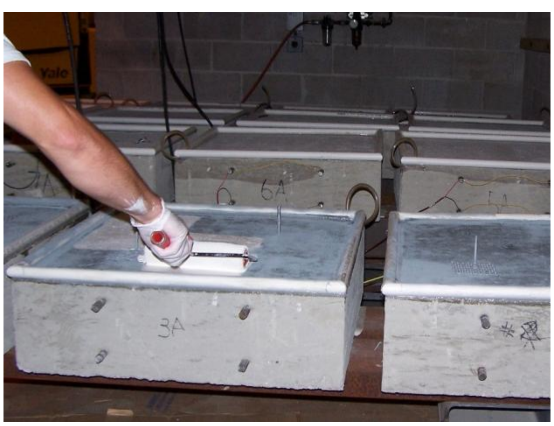

Figure 37: Application of epoxy coating to TSZ

Figure 38: Application of polyurethane coating to epoxy coating

3.2.3 T-SS

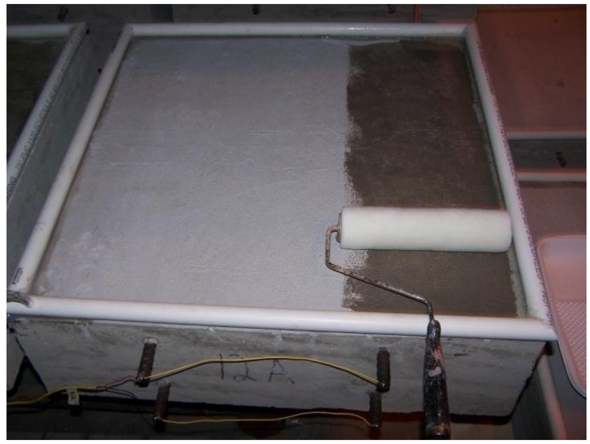

Figure 39: Application of T-SS

The T-SS (Figure 39) was used as a corrosion prevention product based on recommendations from the Wisconsin Highway Research Program (WHRP) Technical Oversight Committee during a proposal meeting for this project. A previous product from Supplier C, a tri-siloxane masonry water repellent, has been widely used by the WisDOT. A newer version of the product (T-SS) from Supplier C has recently (effective April 26, 2007) been listed within WisDOT Approved Lists under Concrete Protective Surface Treatment. [106]

The T-SS is an alkylalkoxysilane and is described as a "…one component, deep penetrating, invisible, non-darkening treatment for concrete." Reportedly, the concrete becomes hydrophobic as the silanol groups chemically bond themselves to the concrete by using the moisture present in the concrete. This reportedly "…eliminates the ever present moisture that had previously engulfed the cementitious material" and prevents the intrusion of water and waterborne salts. [107]

3.2.4 EM

An epoxy repair mortar product identified by WisDOT personnel and the research team appeared to offer some promise for patch repairs. The EM (Figure 40) is a three component, solvent-free, high performance epoxy mortar.

Figure 40: Preparation of EM

According to the manufacturer's data sheet, it is "…based on a blend of solvent free epoxy resins and polyamino amine adducts reinforced with a special blend of silica quartz minerals and lightweight fillers…" The repair system reportedly does not have shrinkage or volume changes. [108]

3.2.5 Conventional Patch Repair Material

When selecting options for a repair material for this project, the WisDOT Approved Products List was first examined. We considered fast-setting materials with a low resistivity and limited silica/polymer modification for compatibility with galvanic anodes. In searching for an acceptable material, we discovered that the resistivity value was not a readily available property. According to Cheney, "…resistivity is not a typical property for evaluation for state DOT's APL's (approved products lists) for road repair materials…" [109] We had initially planned on using commonly-used patch materials, but those products could not be used because of their relatively high resistivity (incompatible with anodes) (Table 12).

Table 12: Evaluation of WisDOT approved rapid setting concrete patch materials

Product	**Composition**	**Resistivity** (ohm-cm)
Five Star Highway Patch	One component, contains cementitious material and crystalline silica [110]	40,386 [109]
Set 45	One-component, magnesium phosphate-based [111]	192,359 (air cured) 22,925 (saturated) [112]

We then contacted Supplier A to inquire about a repair material to use with EA-A. Supplier A provided a long list of approved products and informed us that a repair material with a high resistivity could be used, provided that there was an ionic bridge between the anode and the substrate concrete (Figure 41). This ionic bridge could be provided by using a low-resistivity mortar, <5,000 ohm-cm. [113]

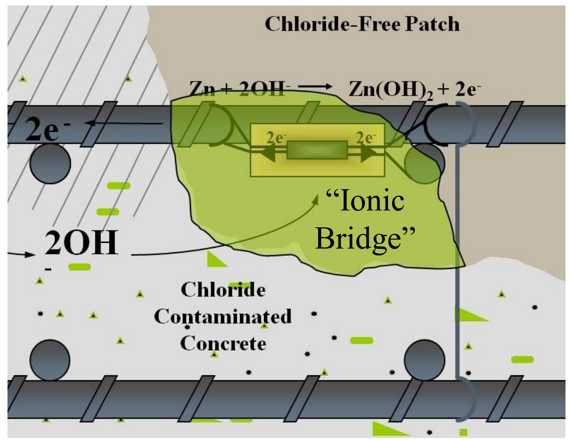

Figure 41: Low resistivity ionic bridge between anode and substrate concrete [113]

Supplier B also provided a list of approved patch materials for use with EA-B. However, they do not recommend the use of an ionic bridge. [114]

As expected, none of the products listed by the two suppliers overlapped. After evaluating available information on the products, we chose a product from Suppler B's approved list. The product is a"…cement based, ready to use, rapid strength gain, patching and repair mortar containing a migratory corrosion inhibitor" and is also "Compatible with galvanic anodes." [115]

3.3 Experimental Plan

To meet the objectives of the project, “salt-ponding” and electrochemical aging were used to accelerate chloride migration and corrosion. While only 14 of the 30 concrete specimens included mixed-in chlorides, all specimens were subjected to wetting/drying cycles of chloride (salt) laden water and an imposed electrical charge.

3.3.1 Setup of Concrete Specimens

To represent typical bridge deck thickness and reinforcing patterns, concrete specimens that measured 28” in width, 28” in length, and 8” in thickness were cast with two layers of #5 reinforcing bars placed at 6” on center (Figure 42). Although the specimen thickness and reinforcement spacing reflect a typical bridge deck, the repair and prevention approaches studied in this project are not limited to bridge decks alone, and can be applied to all parts of concrete bridges.

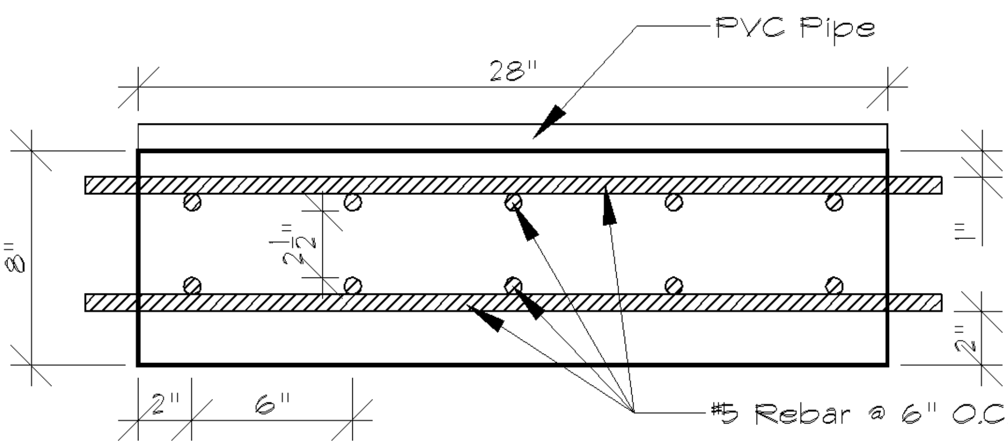

Figure 42: Cross section of concrete specimen

To quicken chloride diffusion and accelerate corrosion, the top layer of reinforcement utilized a 1” clear cover (instead of a more standard 2” clear cover). A standard 2” clear cover was used for the bottom layer of reinforcement. PVC pipe (¾” diameter) was caulked to the perimeter of the top surface of the concrete specimens to create the reservoir or "pond" that periodically held the salt laden water.

The setup of the specimens is depicted in Figures 43 through 45.

Figure 43: Layers of prepared reinforcement

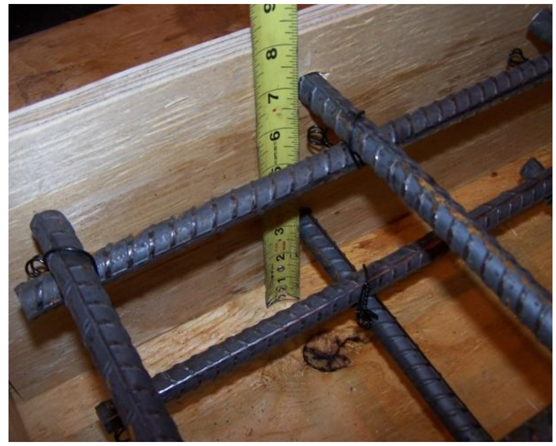

Figure 44: Clear cover to reinforcement

Figure 45: **S**etup of laboratory specimens for concrete pour

3.3.2 Composition of Concrete

The CoP specimens, which represented new construction, did not contain mixed-in chlorides. The CoC specimens, which represented members already containing chlorides, were cast with pre-mixed chlorides.

For all concrete specimens, a conventional 4000 psi concrete mix was used. For the CoC specimens, the bottom 5" of the specimens was cast without chlorides and the upper 3” were cast according to chloride level profiles found in normal bridge conditions. To represent approximately 10 years of chloride exposure, Fick’s 2nd law of diffusion (Eq. 10) was used to determine the appropriate chloride profile.

Fick’s Second Law can be written as:

$$C_{(x,t)} = C_0\left(1 - erf\frac{x}{2\sqrt{D\,t}}\right) \qquad \text{(Eq. 10)}$$

where: $C_{(x,t)}$ = chloride concentration at depth x and time t

C_0 = surface chloride diffusion (lb/yd^3 or kg/m^3)

erf = error function

D = chloride diffusion coefficient (in^2/yr or cm^2/yr)

Weyers et al. released a Strategic Highway Research Program (SHRP) report in 1994 that provided chloride diffusion coefficient (D) and surface chloride concentration (C_0) values for sixteen states. [116] Table 13 presents their findings, based on results from 321 bridges and 2764 samples.

Table 13: State chloride testing results [116]

State	Number Of Bridges	Number of Samples	D (mean, in^2/yr)	C_0 (mean, lb/yd^3)
Arkansas	10	80	0.03	1.81
California	49	252	0.25	3.23
Delaware	3	14	0.05	8.67
Florida	15	52	0.33	5.98
Indiana	6	43	0.09	8.97
Iowa	27	183	0.05	8.09
Kansas	28	275	0.12	3.64
Maryland	59	1069	0.36	4.89
Michigan	13	35	0.15	4.83
Minnesota	59	521	0.05	6.54
Nevada	2	9	0.08	3.01
New York	15	45	0.13	14.63
Pennsylvania	9	6	-	7.26
Virgina	6	57	0.12	6.29
West Virginia	8	48	0.07	8.54
Wisconsin	12	75	0.11	10.10

As mentioned previously, the top 3” of the CoC specimens were profiled according to a 10-year exposure to chlorides. This profile replicates conditions typically seen in bridge decks. To accomplish this, chloride content values at 0.5”, 1.5”, and 2.5” from the concrete surface were used. Based on the results of the SHRP-S-668 study, a chloride diffusion coefficient (*D*) of 0.11 in^2/yr (as suggested by the study) and a surface chloride concentration (C_0) of 5.985 lb/yd^3 (representative of the mean of all of the collected data) were used.

When these values were inserted into Fick’s 2nd Law of diffusion, a chloride content nearly 4.5 times greater than the corrosion threshold was found at a depth of 0.5”, a chloride content 2.0x greater than the corrosion threshold was found a depth of 1.5” (the level of reinforcing steel in this project), and a chloride content approximately 0.5x the corrosion threshold was found a depth of 2.5”. The anticipated chloride profile for a bridge deck with 10 years of exposure can be seen in Figure 46.

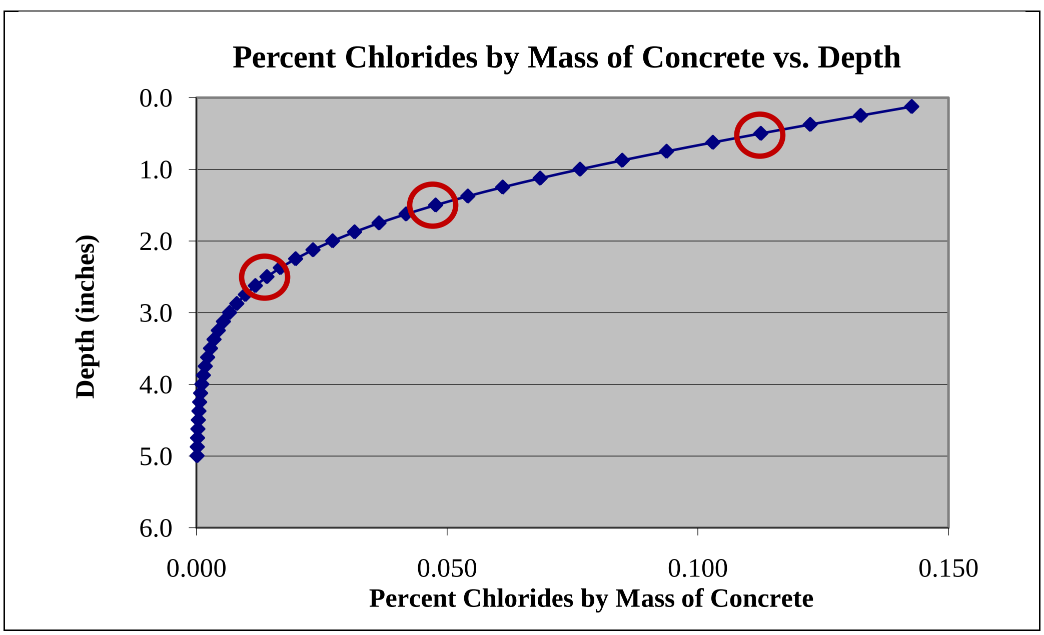

Figure 46: Calculated chloride content profile used for mixed-in chlorides

Table 14 presents the values of the 10 year chloride profile that were used in the CoC specimens for this project. The percentage assumes a concrete unit weight of 145.0 lb/ft^3.

Table 14: Level of chlorides to be mixed into the CoC specimens

Depth	% Chlorides by Mass of Concrete	Chloride Content by Volume of Concrete
0.5”	0.113 %	4.41 lb/yd^3
1.5”	0.048 %	1.87 lb/yd^3
2.5”	0.014 %	0.55 lb/yd^3

3.3.3 Concrete Pour

The slump of the concrete was first measured. After acceptance, the bottom 5” of the CoC specimens was poured (Figure 47). Next, the CoP specimens were completely poured and finished (Figure 48). During this time, the mixed-in chlorides for the CoC specimens were begun.

In order to mix the chlorides into the concrete, a 9-cubic-foot concrete mixer and table salt were used. Levels of chlorides, as presented in Table 14, were mixed into the concrete. Since salt was used, the amount of Cl^- in NaCl was calculated and used in measuring the amount of chlorides to be mixed-in. After the first 5” of the CoC specimens were poured, the bottom profile level was added (Figure 49). After the bottom profile level was completed, the middle profile level was added (Figure 50). Finally, the top profile level was completed.

Since the levels were only 1” thick, the mechanical vibrator was used internally in a horizontal direction to consolidate the concrete. The use of the mechanical vibrator also aided in some blending of the profile levels. When the pour was completed, all of the specimens were covered with a sheet of plastic.

Figure 47: Pouring the bottom 5” of the CoC specimens

Figure 48: Finishing the CoP specimens

Figure 49: Placing the bottom layer of concrete with mixed-in chlorides

Figure 50: Placement of the middle layer of concrete with mixed-in chlorides

3.3.4 Wetting/Drying Cycles and Galvanostatic Electrical Current

To further accelerate the corrosion process, the specimens were subjected to wetting/drying cycles and a galvanostatic electrical current. Cycles of one week wet, using a 6% NaCl solution, and one week dry were performed. A reverse cathodic protection system was created by continuously applying a regulated voltage of 9V from the positive terminal of the regulated power supply to the top layer of reinforcement (the anode). Between the positive terminal and the anode, a 1Ω resistor was used to calculate the difference in current. By connecting the positive terminal to the upper level of reinforcement, a faster than normal rate of chloride diffusion could be found as the negatively charged chloride ions were attracted to the positively charged reinforcing steel. The bottom steel layer (cathode) was attached to the negative terminal. See Figures 51 to 55.

Even though each layer of reinforcement had electrical continuity, the two layers were not electrically connected. This forced the current to travel through the concrete. The accelerated corrosion test regime is similar to the one used for an earlier WHRP Project (No. 0092-01-06). [24]

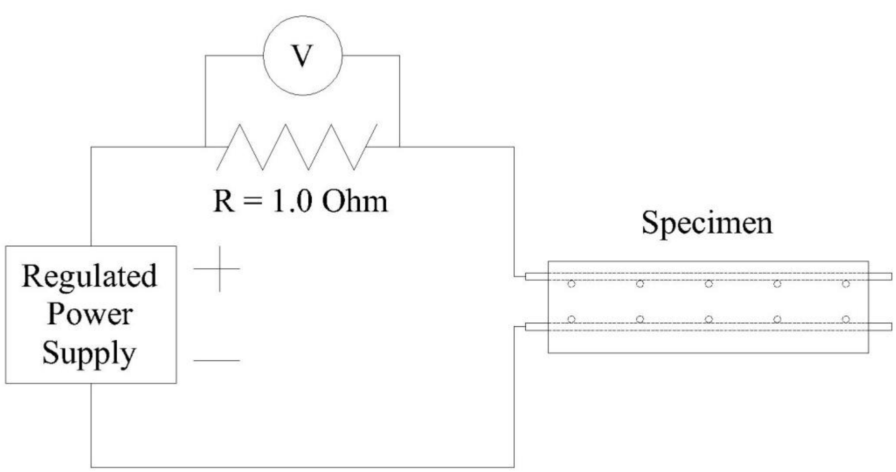

Figure 51: Corrosion cell for laboratory specimens

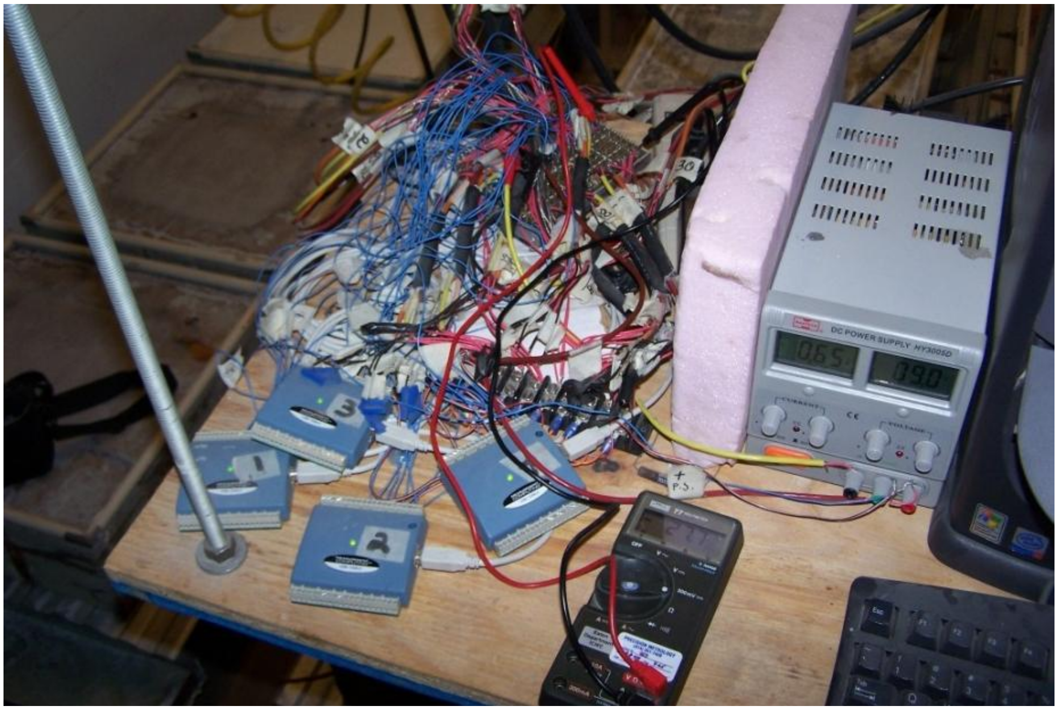

Figure 52: Wiring/data acquisition setup

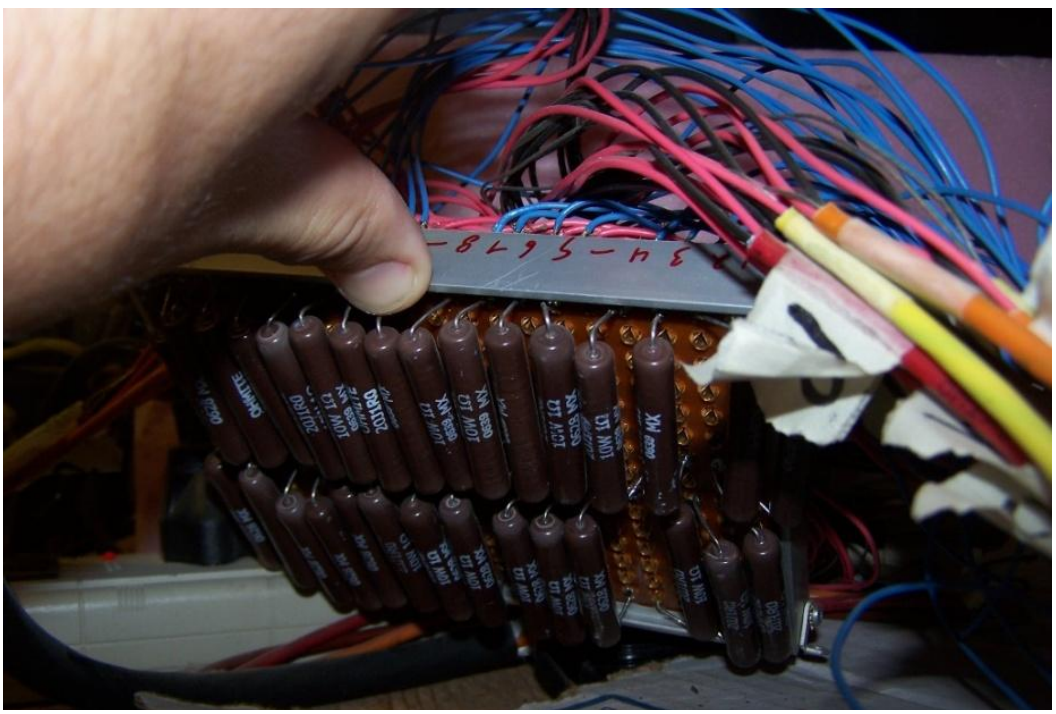

Figure 53: Setup of resistors

Figure 54: Project setup

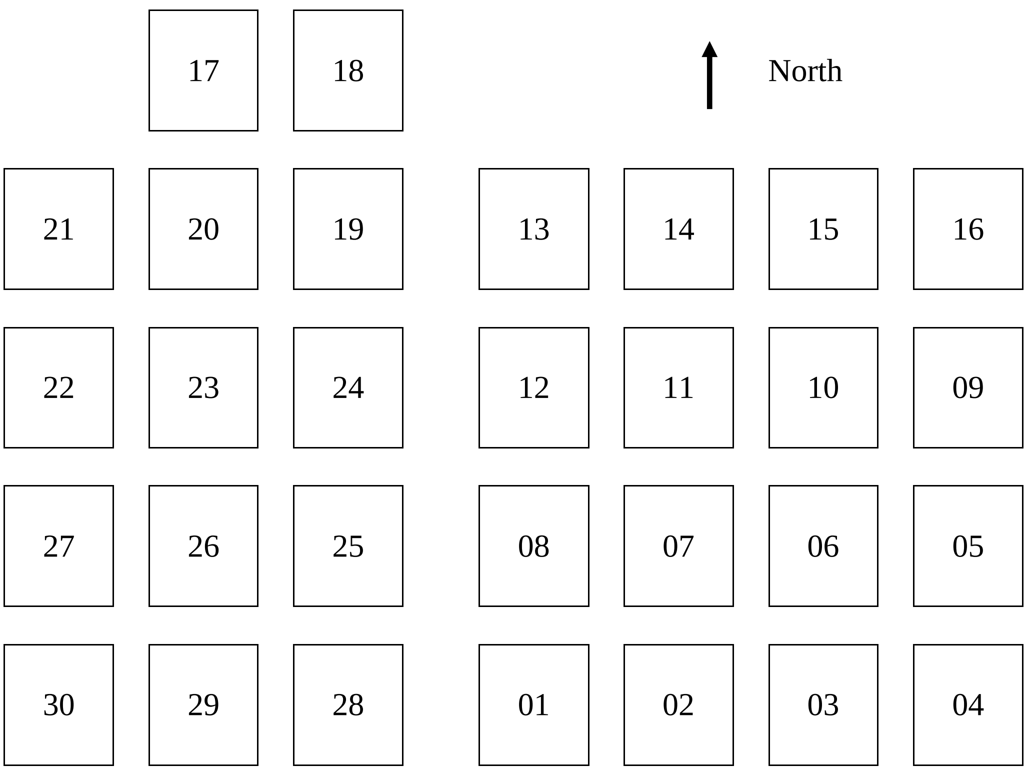

Figure 55: Positioning of specimens per Table 11

3.3.5 Monitoring

The monitoring system was setup so that corrosion current data could be collected and recorded with a data acquisition system. However, due to software issues, manual readings of all of the corrosion currents were taken on a daily basis.

At first, the manual readings were taken across the data acquisition modules. After two-months of testing, however, we realized that the readings were being affected by the resistance of a "jumper" in the circuit. To account for this, the resistance across each "jumper" was determined and used to correct the previously taken readings. Subsequently, all manual readings were taken directly across the resistors, without a need for adjustment.

The chloride content of all specimens was determined by analyzing pulverized concrete samples at various depths. See Figure 56 for the location of the tests. The base-line chlorides for the specimens were initially determined at 6 locations, at depths of ½" and 1", for a total of 12 chloride tests.

The chloride content of each of the 14 CoC specimens (i.e. those containing mixed-in chlorides) were evaluated at depths of ¼", ½", ¾", 1", 1-¼", 1-½", 2", 2-½", and 3" from the concrete surface prior to accelerated corrosion exposure. Three locations were analyzed per specimen (Locations A, B, and C). Therefore, the total number of chloride tests per specimen was 27 for this stage. Each drilled hole was filled with concrete filler after drilling.

After 3-months of accelerated testing, the chloride content of the 14 CoC specimens were re-evaluated at depths of ¼", ½", ¾", 1", 1-¼", 1-½", 1-¾", and 2". Three locations (Locations D, E, and F), for a total of 24 chloride tests per specimen, were analyzed per specimen for this stage. For Specimen #23, location E was re-evaluated at location G.

After 6-months of accelerated testing, the chloride content of the 16 CoP specimens were evaluated at depths of ¼”, ½”, ¾”, 1”, 1-¼”, 1-½”, 1-¾”, and 2”. Three locations (Locations D, E, and F), for a total of 24 chloride tests per specimen, were analyzed per specimen for this stage.

After an additional 3-months of exposure to accelerated corrosion after patch repairs, chloride content of the 14 CoC specimens were evaluated at two locations per specimen at depths of ¼”, ½”, ¾”, 1”, 1-¼”, 1-½”, 1-¾”, and 2”. One location was tested inside the patched area (Location B), and one location was tested outside the patch area (Location H). Because of inconsistencies, additional testing was performed at Locations D, E, G, and I to verify the original results.

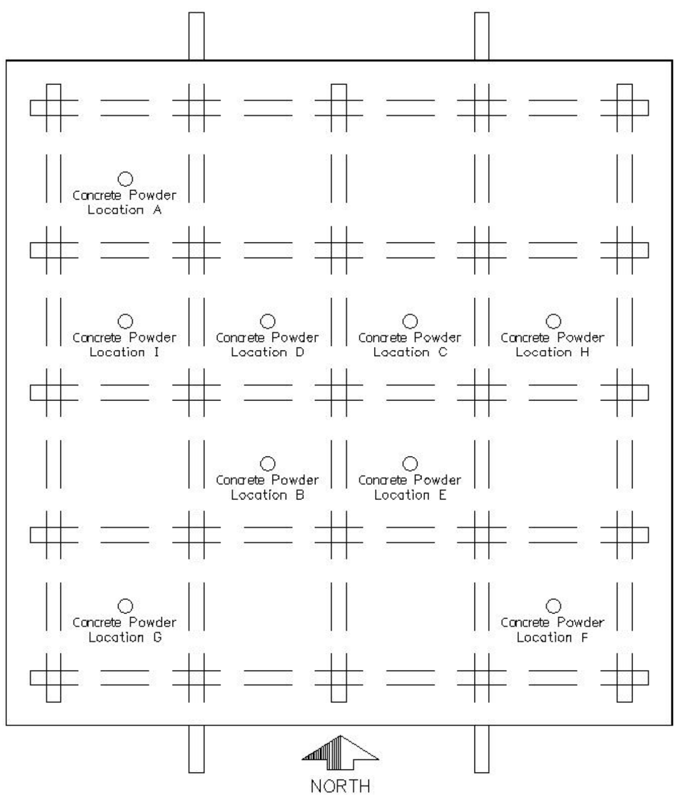

Figure 56: Location of laboratory concrete powders

Periodically, half-cell potential readings were taken. Readings were taken at sixteen locations per specimen. Each recorded location represents a “grid” within the rebar spacing (See Figure 56). The readings were only taken on specimens that did not contain coatings.

In addition, the specimens were monitored for cracking. Detailed crack maps were created at periodic increments. The widths of the cracks were measured using a standard crack width comparator.

3.3.6 Patch Repairs

To test the various corrosion control techniques, patch repairs were completed on the 14 CoC specimens after 3 months of exposure. Repairs were performed in accordance with the International Concrete Repair Institute (ICRI) standards.

3.3.6.1 Patch Repair Process

The patches were sized at 16” by 16”. After sizing, the perimeter of the patches was saw cut and concrete removal commenced (Figure 57). Note the discoloration of the concrete at the rebar locations (Figures 58). The concrete was removed to a depth of ¾” below the top layer of reinforcing steel (Figures 59 and 60). The reinforcing steel was then cleaned with a grinder (Figure 61). Note the loss of ribs (due to corrosion) on the reinforcing steel in Figure 62.

Figure 57: Concrete removal

Figure 58: Discoloration of concrete discovered during concrete removal

Figure 59: Condition after concrete removal

Figure 60: "Finger-gap" below reinforcing steel

Figure 61: Cleaning of the reinforcing steel by wire brush

Figure 62: Loss of ribs on reinforcing steel

Prior to application of patches, the existing cracks on the top of the slab were routed out with a hand-held grinder and diamond blade (Figure 63). After the application of the repair material, the cracks were gravity-fed with an epoxy resin so that further corrosion of the reinforcing steel would not be caused by the presence of existing cracks outside of the patched area (Figure 64).

Figure 63: Presence of cracking exposed through routing

Figure 64: Application of epoxy resin to fill cracks on horizontal face of CoC specimens

In addition, the existing cracks on the sides of the CoC specimens were also addressed (Figure 65). After routing, these cracks were sealed with a silicone sealant (Figure 66).

Figure 65: Existing cracks on the sides of the CoC specimens

Figure 66: **A**pplication of silicone sealant to routed cracks

3.3.6.2 Conventional Patch Material Application

Prior to placement of the repair material, the substrate concrete and reinforcing were prepared. The electrical continuity of the reinforcing bars was also checked. If continuity was not achieved, rebar ties or welding was used to provide it.

As specified by the conventional patch material data sheet (115), a water based and epoxy modified portland cement bonding agent and corrosion resistant coating was used. (117) Once continuity was achieved, the first coat of the corrosion resistant coating was applied to the steel (Figure 67). Care was taken not to coat the points of electrical continuity, the connections of the anodes to the reinforcing steel, or the anodes themselves. After the corrosion resistant coating had cured for the specified amount of time, the epoxy modified portland cement bonding agent was applied to the substrate concrete (Figure 68). However, the bonding agent was not applied directly below the anodes. During this time, the second coat of the corrosion resistant coating was applied to the steel.

Figure 67: Application of anti-corrosion coating to reinforcing steel

Figure 68: Application of bonding agent to substrate (not applied on or directly below anodes)

Although epoxy bonding agents are not generally recommended for use with galvanic anodes (48), (56), epoxy bonding agents can be used if the metallic path and the ionic path are maintained. Since the metallic path had already been confirmed, the ionic path from the anode to the cathode had to be provided as well. This could be accomplished by dry-packing below the anode or not creating a barrier between the anode and the substrate. In the case of using epoxy bonding agents with thermal sprayed metals, the ionic path will still reach the bars in the patch and the areas outside the patch; however, the ionic path may not be able to get to the bars immediately below the patched area because the bonding agent effectively creates a barrier between lower layer of reinforcing steel and the ionic path. [118]

Since the conventional patch material recommended the use of an epoxy bonding agent and the epoxy repair material specified a concrete primer, we chose to use the epoxy bonding agent for consistency. However, an ionic path between the galvanic anodes and the substrate concrete was provided.

After the steel and substrate concrete were prepared, the repair material was placed. As per specifications, the repair material was placed in two, 1½" lifts. Care was taken to ensure that an ionic path was provided by placing the repair material below the embedded anodes (Figure 69). After the first lift was placed and allowed to reach final set (which took approximately 30 minutes), the surface was scored and the second lift was placed (Figure 70). After allowing the 2nd lift to reach final set, the surface was broom finished.

Figure 69: Placing the conventional patch repair material

Figure 70: Scoring of the conventional patch repair material after the first lift had reached final set

3.3.6.3 EM Application

As per recommendations from Supplier F, a liquid epoxy coating was applied to the exposed and cleaned reinforcing steel. After this, the concrete primer was mixed and applied to the substrate concrete (Figure 71). The repair material was then mixed and hand-applied to the still tacky primed area (Figure 72). The repair material was packed under and around the reinforcing steel. It was then finished smooth with the supplied trowel.

Figure 71: Applying the concrete primer for EM

Figure 72: Applying the EM

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CHAPTER 4

EXPERIMENTAL RESULTS AND DISCUSSION

4.1 General

Based on the aforementioned experimental program, the experiments were broken into two categories: "corrosion prevention" and "corrosion control." The CoP specimens were treated prior to exposure to accelerated corrosion testing and evaluated after 6-months of exposure. The CoC specimens were cast with mixed-in chlorides and were first exposed to accelerated corrosion testing for 3-months. Subsequently, they were subjected to concrete patch repairs, treated with various corrosion control products, subjected to an additional 3-months of accelerated corrosion testing, and evaluated at the conclusion of the testing.

The corrosion current was monitored at regular intervals throughout the duration of the accelerated corrosion program. Extensive laboratory testing and analyses of chloride ingress were also performed. In addition, half-cell potential readings were periodically taken. Detailed crack-maps were generated at 0-months, 3-months, and 6-months exposure. At the conclusion of testing, the extent of rust-staining on the concrete surface was evaluated. Finally, the specimens were dissected and the embedded reinforcing steel was evaluated for extent of corrosion.

4.1.1 Concrete Material Data

The slump of the concrete was measured at 4.75". See Table 15 for a mix design (as submitted by the supplier).

Table 15: Concrete Mix Design

Product	Amount
Cement	450 lb
Fly Ash	100 lb
Sand	1370 lb
¾" Aggregate	1830 lb
Water Reducer	4 ounce
Air Entrained	

The average 28-day compressive strength of three, 6"x12" cylinders was measured at 5,839 psi. The concrete delivery sheet and mil certification for the reinforcing steel can be found in Appendix A. The concrete cylinder strength results can be found in Appendix B.

4.1.2 Current Monitoring

A regulated 9V potential was applied between the anode and cathode of the specimens over the duration of the exposure cycles to facilitate accelerated corrosion and to increase the rate of chloride intrusion. Plots of corresponding corrosion current versus time for the CoP specimens are shown in Section 4.1.2.1 and plots for the CoC specimens are shown in Section 4.1.2.2. As expected, the corrosion currents increased during the wet cycles (shaded region) and decreased during the dry cycles.

When examining the corrosion current vs. time graphs, it is important to note that the area under curve is proportional to the amount of steel lost due to corrosion. Accordingly, the specimens that exhibit the least area below the curve experience less steel loss and thereby provide more corrosion protection.

4.1.2.1 Current Monitoring for CoP Specimens

When comparing the “average” (Figure 73) and “individual” (Figure 74) CoP graphs, one can see a reasonable agreement between “identical” specimens. That is, specimens with the same treatment behaved in a reasonably similar fashion.

From the initiation of testing until approximately 60 days, all specimens appeared to exhibit a decrease in monitored current. Tabatabai et al. reported that this phenomenon is common in such experiments as the corrosion products increase electrical resistance around the bar, thereby decreasing current when a fixed voltage is applied. [(24)]

After 60 days, the T-SS, EP-C, TSZ w/EP-C, A-C, TSZ, and EA-A w/A-C specimens continued to display a decrease in corrosion current with respect to time. Meanwhile, the corrosion currents for the EA-A and Control specimens remained relatively constant. However, the EA-B specimens displayed an increase in current. It is believed that a non-uniform chloride ingress caused more severe anodic and cathodic reactions on the rebar, thus increasing the corrosion current. The presence of chloride “hot spots” around the anodes was later verified through chloride testing. The chloride “hot spots” are believed to have contributed to the increased corrosion current.

When comparing the conjoint use of coatings with galvanic anodes (whether they be embedded or thermal sprayed), it was found that the coatings helped reduce corrosion currents. While the corrosion currents for the EP-C and TSZ w/EP-C were similar, the specimens with TSZ alone exhibited higher corrosion currents. In regards to the use of coatings with or without embedded anodes, the A-C alone exhibited a lower corrosion current than the EA-A w/A-C. However, the specimens with the EA-A alone exhibited higher corrosion currents than that of the specimens with EA-A w/A-C

Based on the results of the current monitoring for the laboratory CoP specimens, it can be concluded that the tri-silane sealer (T-SS), epoxy/polyurethane coating (EP-C), and thermal sprayed zinc with epoxy/polyurethane coating (TSZ w/EP-C) were most effective.

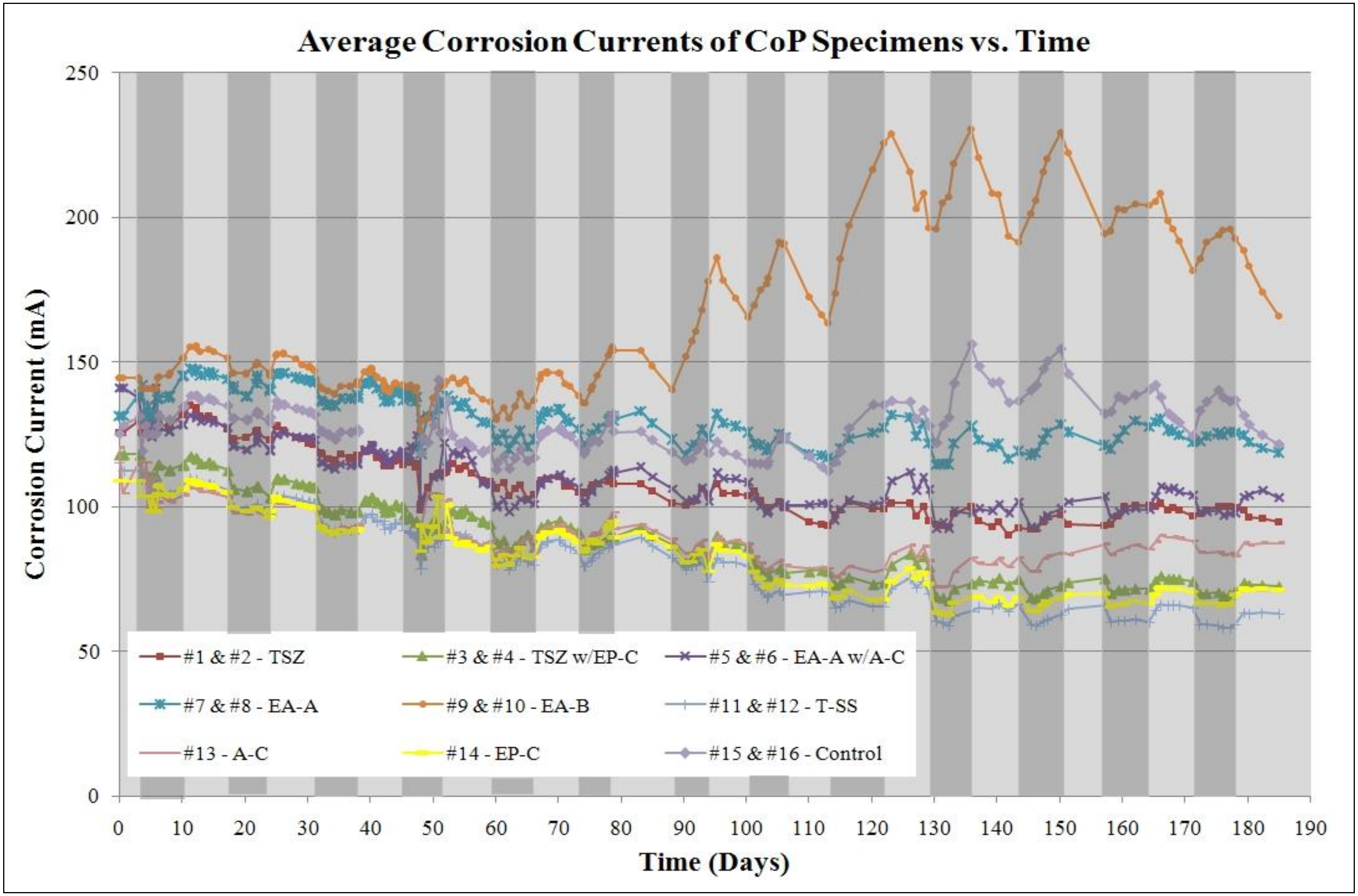

Figure 73: Average corrosion currents of CoP specimens

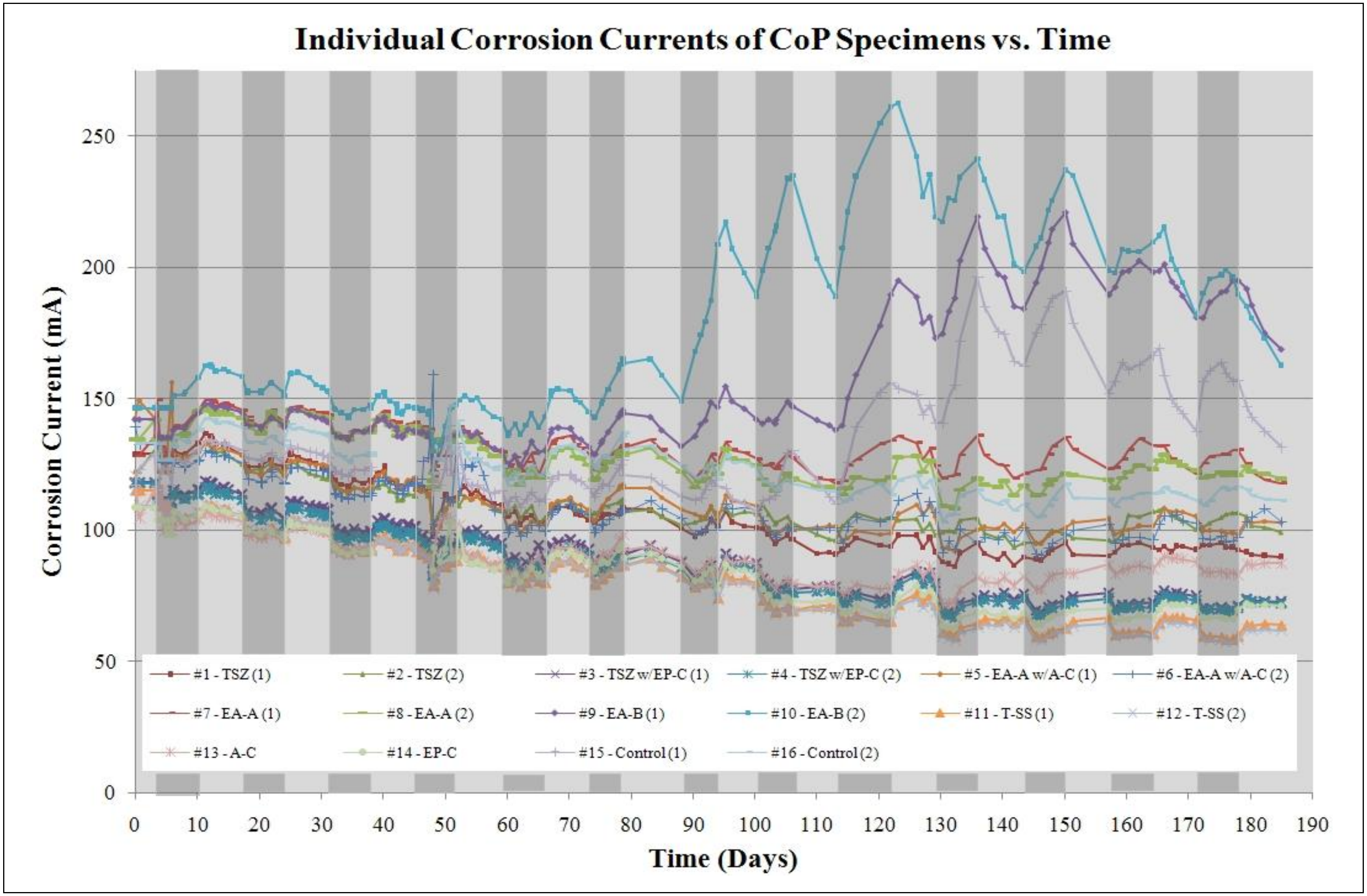

Figure 74: Individual corrosion currents of CoP specimens

4.1.2.2 Current Monitoring for CoC Specimens

When comparing the “average” (Figure 75) and “individual” (Figure 76) CoC graphs from Day 1 to 3-months, there appears to be reasonable agreement among all specimens (as expected). Therefore, it was concluded that the laboratory CoC specimens were in an approximately similar condition after the first 3-months of testing.

When comparing the “average” and “individual” CoC graphs from 3-months to 6-months, reasonable agreement can be seen among individual specimens belonging to TSZ, TSZ w/EP-C, EA-A w/A-C, and EM treatments. However, there were significant discrepancies among specimens belonging to the Control, EA-A, and EA-B treatments. The following discussion is based on the “average” graph.

The TSZ, EA-A w/A-C, and TSZ w/EP-C treatments all displayed a decrease in corrosion current while the Control and EM specimens increased initially, then decreased. It is believed the rapid increase in corrosion current for the EM was due to its widely dissimilar material properties compared with the surrounding concrete. Meanwhile, EA-A and EA-B exhibited an increase in corrosion current over time, after treatment.

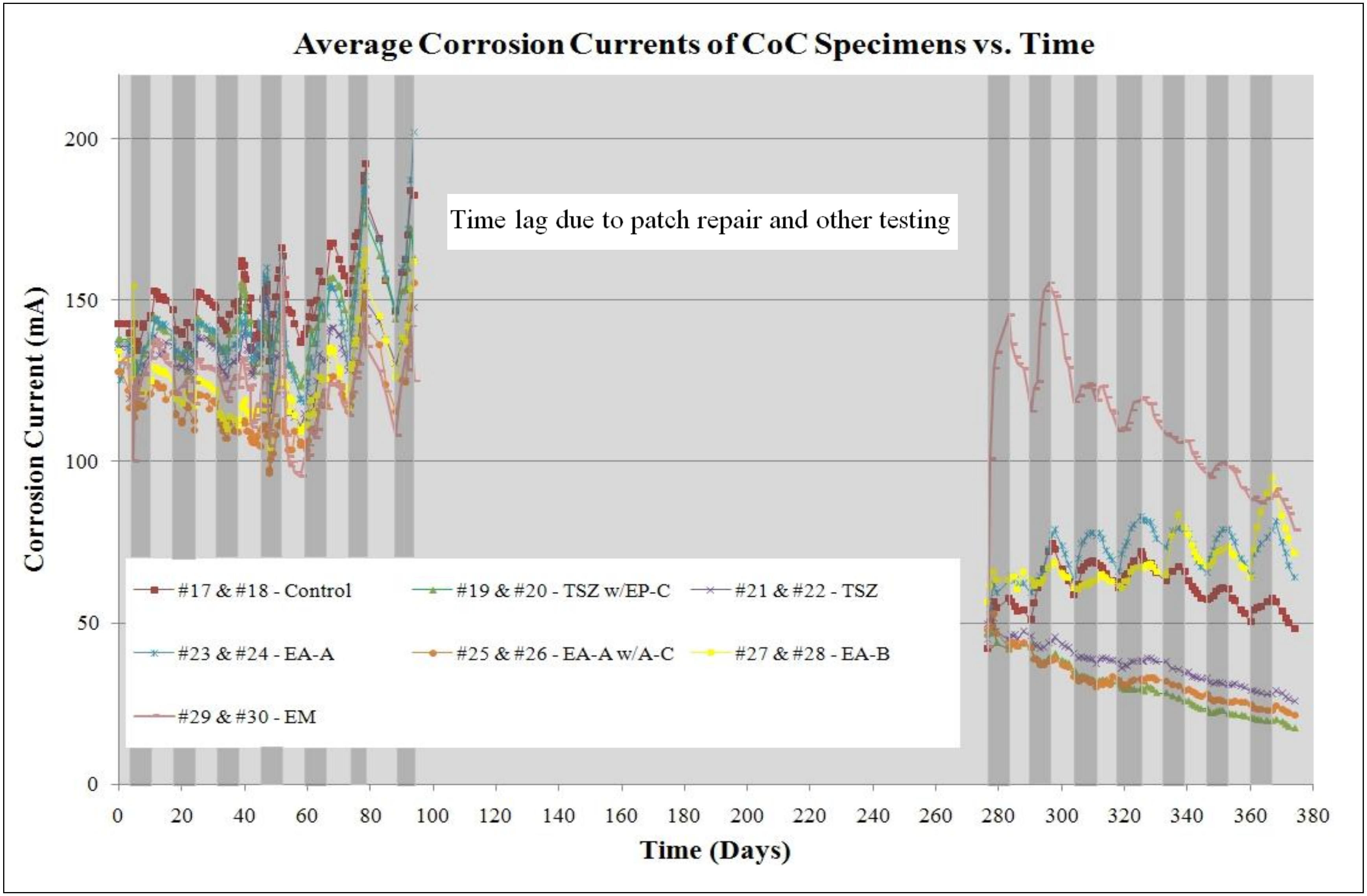

Figure 75: Average corrosion currents of CoC specimens

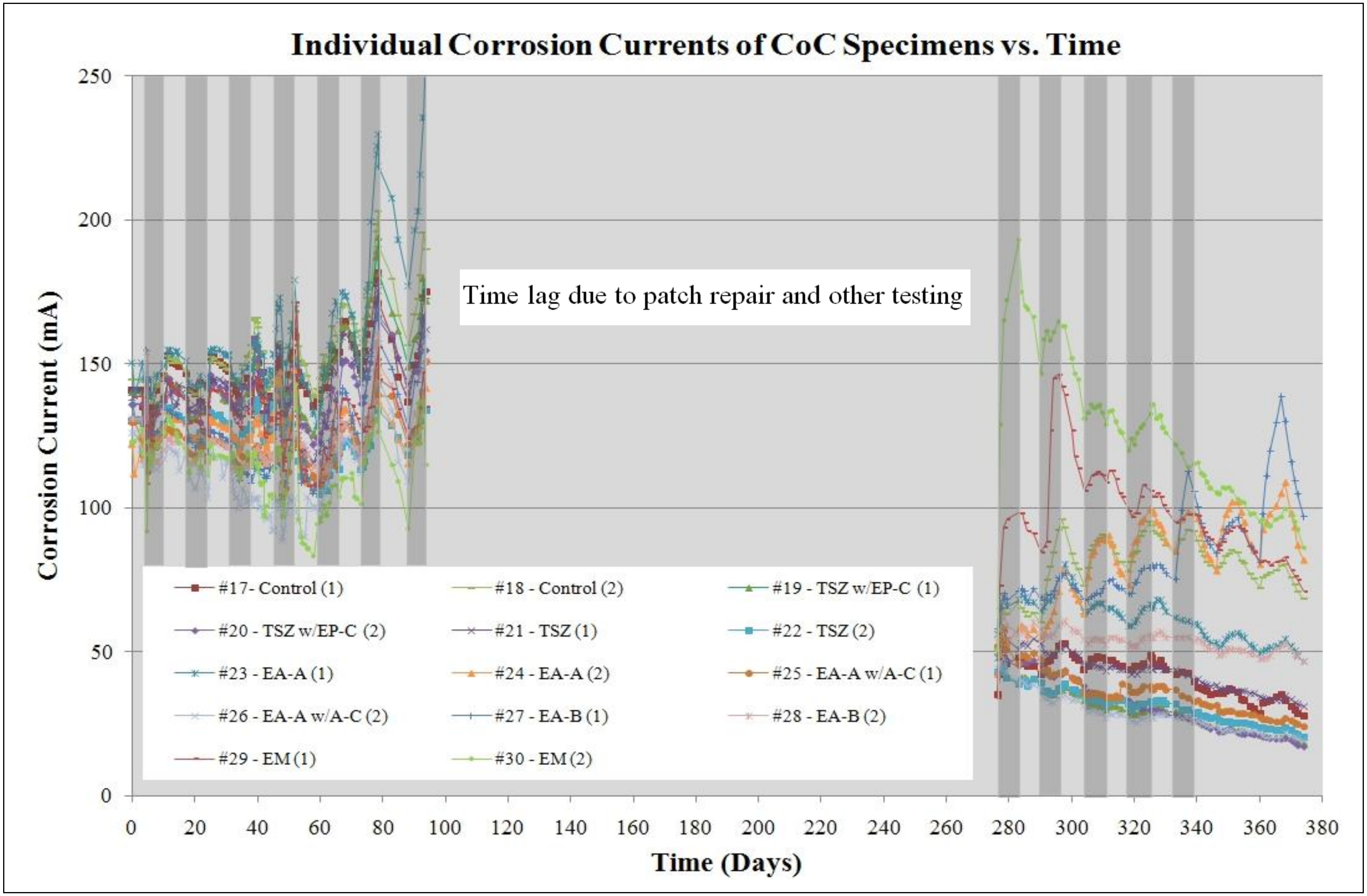

Figure 76: Individual corrosion currents of CoC specimens

4.1.3 Steel Loss

By utilizing the aforementioned corrosion currents, the amount of steel loss could be calculated through the use of Equation 11: (119)

$$m = \frac{A^{tm}C}{Fz} \qquad \text{(Eq. 11)}$$

where m = loss of mass

A^{tm} = atomic mass of the reaction ion (55.85 g/mol for iron)

C = total charge that has passed through the circuit

= $\int I(t)dt$

F = Faraday's constant (96485 C/mol)

z = valence of reaction (assumed to be 2) (24), (119)

Numerical integration was used to calculate the total charge. This was done by summing the products of each current reading by the time increment between readings. For Specimens #13 through #16, there were some sporadic readings during a two-week period. The problem was identified and corrected subsequently.

The results of the steel loss calculations (Tables 16 and 17) were indexed according to a scale of 0 to 4. The indices were determined using Eq. 12:

$$\text{Index} = \left[\frac{\text{(actual value) - (minimum value)}}{\text{(maximum value) – (minimum value)}} \right] \text{x } 4 \qquad \text{(Eq. 12)}$$

Table 16: Steel loss of CoP Specimens after 6-months of exposure

Specimen #	Treatment	Theoretical Steel Loss (g)	Index
1	TSZ	483.8	1.0
2		500.2	1.1
3	TSZ w/EP-C	406.7	0.3
4		397.4	0.3
5	EA-A w/A-C	506.7	1.2
6		500.2	1.1
7	EA-A	605.8	2.0
8		586.2	1.9
9	EA-B	734.4	3.1
10		839.8	4.0
11	T-SS	370.0	0.0
12		365.2	0.0
13	A-C	420.5	0.5
14	EP-C	396.1	0.3
15	Control	610.0	2.1
16		576.6	1.8

For the CoP specimens, the T-SS, EP-C, TSZ w/EP-C and A-C specimens gave the lowest theoretical steel loss index values. In contrast, the EA-B, EA-A, and Control specimens had the highest index values. When comparing these index values to the corrosion currents of Figures 73 and 74, a direct comparison can be seen.

To present the theoretical steel loss values for the CoC specimens over the duration of testing, Table 17 includes the steel loss and associated index values for the following time intervals: 0-3 months, 3-6 months, and 0-6 months. The indices were determined for each data subset using Eq. 11. Specimens #17 through #28 utilized the conventional patch repair material, while Specimens #29 and #30 utilized the EM.

Table 17: Steel loss of CoC specimens after 3-months and 6-months exposure

Specimen #	**Future Treatment**	**0 - 3 Month Steel Loss** (g)	**3 - 6 Month Steel Loss** (g)	**3 - 6 Month Index**	**0 – 6 Month Steel Loss** (g)	**0 – 6 Month Index**
17	Control	348.3	101.4	0.5	449.7	1.9
18		366.0	196.0	2.1	562.0	3.7
19	TSZ w/EP-C	341.9	71.1	0.0	413.0	1.3
20		330.9	76.0	0.1	406.9	1.2
21	TSZ	333.0	105.0	0.6	438.0	1.7
22		293.7	76.2	0.1	369.8	0.5
23	EA-A	381.6	149.7	1.3	531.4	3.2
24		294.6	201.9	2.2	496.5	2.6
25	EA-A w/A-C	288.5	87.7	0.3	376.2	0.7
26		267.9	68.8	0.0	336.7	0.0
27	EA-B	299.6	206.9	2.3	506.5	2.8
28		291.3	131.5	1.0	422.7	1.4
29	EM	310.5	239.5	2.8	550.1	3.5
30		267.5	311.2	4.0	578.7	4.0

For the 0-3 month data, it may at first appear that there is a wide range of index values; however, the average steel loss was calculated to be 315.4g with a standard deviation of 35.4g. Based on the steel loss values, it appears that the CoC specimens were in a reasonably similar condition after the first 3-months of laboratory testing.

For the 3-6 month steel loss data, the Index values can be used to compare the specimens as there is significant variation among the steel loss results. For this period of data, the TSZ w/EP-C, EA-A w/A-C, and TSZ produced the lowest indices.

When looking at the 0-6 month Index, EA-A w/A-C, TSZ, and TSZ w/EP-C had the lowest Index values. Therefore, it can be concluded that these laboratory CoC treatments performed better with regard to theoretical steel loss due to corrosion. It is interesting to note that each of these treatments is essentially a coating.

4.1.4 Chloride Contents

The chloride content of the concrete was determined by analyzing pulverized concrete at various depths using the Rapid Chloride Test method (RCT 1029). This method has been shown to be in excellent agreement with the AASHTO T-260 potentiometric titration. [120] The RCT 1029 method measures the acid soluble chlorides as a percentage of concrete mass. After the concrete powders were extracted from the specimens with a hammer drill (Figure 77), a 1.5g sample was weighed and mixed with a vial that contained 10 mL of an extraction liquid. A potential reading of each sample was taken using the RCT readout device and electrode (Figure 78). Readings were taken 5-minutes after mixing, and then again after 24-hours. The 24-hour test gives higher acid-soluble chloride content. Therefore, it is believed to be closer to the total chloride content in the concrete powder. After testing, the potential results were converted to a chloride content in percent of concrete mass using the supplied calibration chart. Although the calibration chart was initially used to calculate the chloride contents, a spreadsheet equation derived from the calibration chart was later used.

Unless otherwise noted, all values of chloride content presented in the remainder of this work are the 24-hour tests in terms of "percent chlorides by mass of concrete."

Figure 77: Collecting the concrete powders

Figure 78: Mixing concrete powders with the extraction liquid (far) & reading potentials (near)

This same approach was followed for determining the chloride content of virgin concrete, concrete with pre-mixed chlorides in the CoC specimens, concrete after 3-months exposure in CoC specimens, concrete after 6-months exposure in both CoC and CoP specimens, and the bridge decks tested in the field. In all, approximately 2,000 concrete powders were analyzed for this project (Figure 79).

Figure 79: Tested concrete powder samples

4.1.4.1 Base-Line (Virgin Concrete)

The virgin chloride content (taken prior to accelerated corrosion exposure) was taken at two locations in three separate specimens (Table 18). See Appendix B for detailed results. At each location, samples were taken at two different depths from the concrete surface. Powder samples were taken from depths of 0" - ½" and ½" - 1".

Table 18: Base-line chloride content of specimens

Sample Location	Depth of Testing	%Cl by concrete weight	lbs Cl/ yd^3 concrete
11B	0" – ½"	0.037	1.449
11B	½" – 1"	0.034	1.331
11C	0" – ½"	0.046	1.801
11C	½" – 1"	0.040	1.566
13B	0" – ½"	0.035	1.370
13B	½" – 1"	0.033	1.292
13C	0" – ½"	0.048	1.879
13C	½" – 1"	0.046	1.801
15B	0" – ½"	0.050	1.958
15B	½" – 1"	0.048	1.879
15C	0" – ½"	0.049	1.918
15C	½" – 1"	0.039	1.527

The average measured chloride content of the virgin concrete was 0.042% by concrete weight, or approximately 1.648 lb/yd^3 of concrete. This measured chloride content was relatively high. Using a 6:1 cement to concrete ratio, the chloride content equals 0.252 % chlorides by weight of cement. This is approximately 2.5 times greater than the acid-soluble limit recommended by ACI 222 (see Table 2).

An earlier project, WHRP Project 0092-01-06, discovered a similar chloride content in its virgin concrete. (24) The average chloride content of virgin concrete in that study was measured at 0.053% by concrete weight. To find the source of chlorides, they performed a number of tests to determine chloride contents of the mix water, as well as the coarse and fine aggregates. (24)

Based on their findings, it was determined that coarse aggregates (limestone) were the source of the high chloride levels found in the virgin concrete. (24) It was not clear from the tests performed whether the acid-soluble chlorides were bound within the aggregates, or if they could enter the cement paste.

4.1.4.2 CoP Specimens after 6-Months

To determine the effectiveness of the CoP products in reducing the ingress of chlorides into the concrete, chloride analyses were performed after the completion of 6-months of accelerated testing (Table 19). As mentioned previously, three concrete powder locations per specimen, with powders taken at ¼" increments of depth, were used to calculate average chloride contents. Thus, each listed value of chlorides is based on the average of three separate concrete powders. The locations selected for testing were consistent in each specimen tested (See Appendix C for complete results).

Table 19: Average acid-soluble chloride content of CoP specimens after 6-months

	Chloride Content (% Chlorides by Mass of Concrete)							
	TSZ		**TSZ w/EP-C**		**EA-A w/A-C**		**EA-A**	
Depth\Specimen	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**
0" to ¼"	0.197	0.331	0.096	0.197	0.484	0.479	0.416	0.388
¼" to ½"	0.107	0.169	0.040	0.057	0.361	0.290	0.405	0.282
½" to ¾"	0.062	0.055	0.043	0.053	0.163	0.147	0.330	0.165
¾" to 1"	0.035	0.040	0.045	0.035	0.057	0.067	0.268	0.092
1" to 1¼"	0.019	0.032	0.043	0.033	0.052	0.034	0.138	0.050
1¼" to 1½"	0.028	0.028	0.037	0.045	0.048	0.023	0.044	0.031
1½" to 1¾"	0.030	0.022	0.023	0.029	0.028	0.019	0.023	0.019
1¾" to 2"	0.030	0.017	0.033	0.036	0.033	0.025	0.015	0.022
	EA-B		**T-SS**		**A-C**	**EP-C**	**Control**	
Depth\Specimen	**#9**	**#10**	**#11**	**#12**	**#13**	**#14**	**#15**	**#16**
0" to ¼"	0.445	0.555	0.076	0.115	0.415	0.040	0.344	0.372
¼" to ½"	0.418	0.481	0.034	0.034	0.250	0.034	0.292	0.284
½" to ¾"	0.322	0.421	0.027	0.022	0.125	0.028	0.166	0.161
¾" to 1"	0.385	0.380	0.026	0.019	0.062	0.026	0.094	0.079
1" to 1¼"	0.447	0.349	0.020	0.020	0.032	0.022	0.078	0.055
1¼" to 1½"	0.407	0.306	0.020	0.031	0.027	0.023	0.076	0.034
1½" to 1¾"	0.304	0.171	0.025	0.034	0.038	0.019	0.069	0.021
1¾" to 2"	0.160	0.107	0.017	0.028	0.042	0.019	0.045	0.033

To more fully understand the results in Table 19, Figure 80 has been developed to visualize the average chloride content of the CoP specimens at 6-months.

As expected, the chloride content was highest at the concrete surface and decreased with the distance from the surface. The testing also revealed that the epoxy/polyurethane coating (EP-C) was most effective in reducing the ingress of chlorides. This was followed by the tri-silane sealer (T-SS) and thermal sprayed zinc with epoxy/polyurethane coating (TSZ w/EP-C).

One type of specimen shows markedly different chloride profiles. As discussed later, the presence of embedded anodes affected the distribution of chlorides in the horizontal plane.

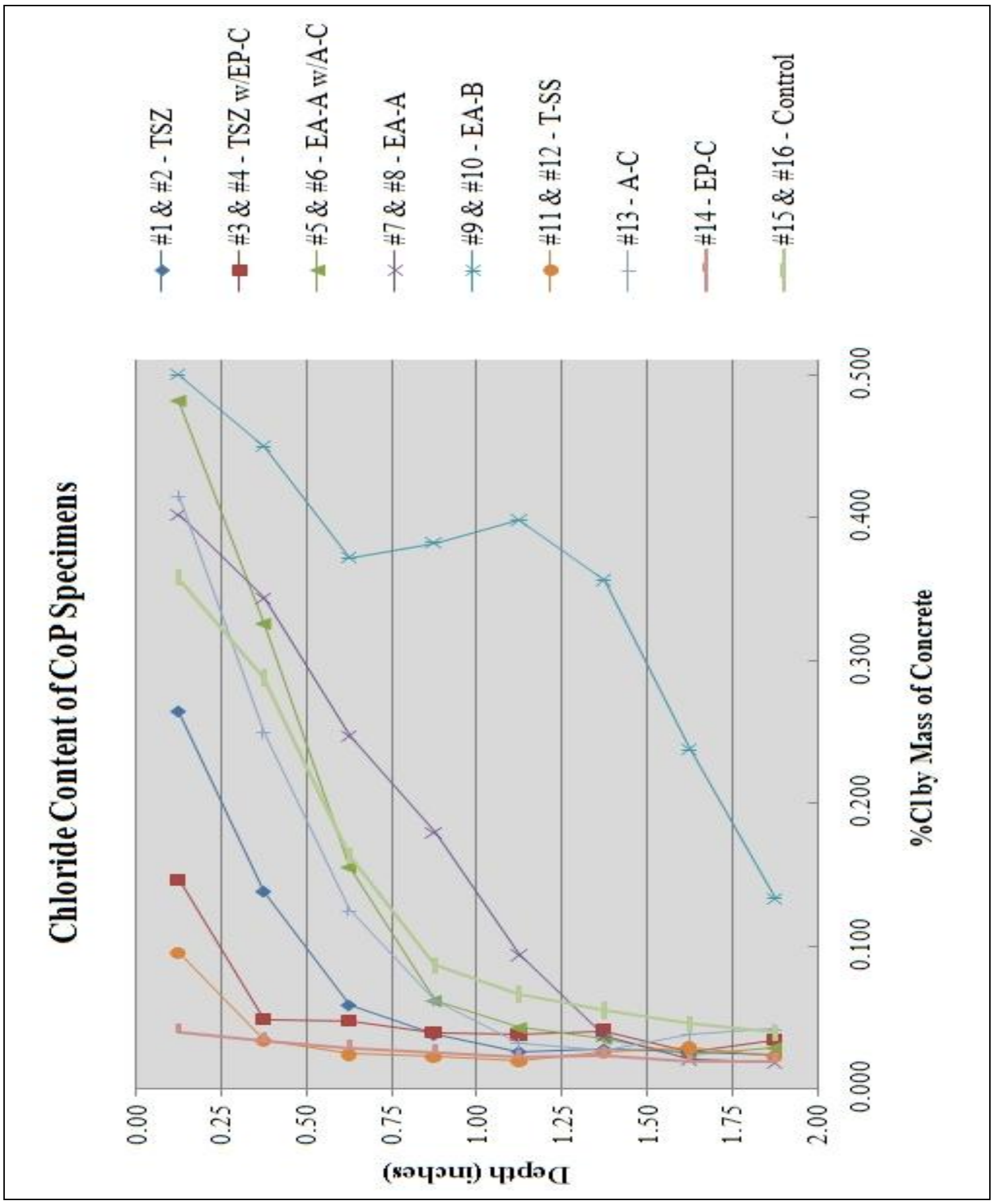

Figure 80: Chloride contents of CoP specimens

To further analyze the chloride content, regression analyses were performed. These analyses involved finding the parameters for Fick's 2nd Law of diffusion (Eq. 10) such that they best-fit the experimental data. The parameters are the diffusion coefficients (*D*) and the surface chloride concentration (C_0). This optimization effort utilized Microsoft Excel's "solver" function and involved minimizing the sum of squares of errors between the experimental data and Fick's Law predictions.

Prior to regression analysis, the virgin chloride content was subtracted from the values shown in Table 19. By doing so, only the chlorides that penetrated the concrete during exposure would be considered. If the actual level of calculated chlorides was less than the base-level chlorides (0.042% by concrete weight), a value of "0" was given.

By utilizing a time of 0.5 years in the regression analysis, a uniform surface chloride concentration of 0.476% chlorides by mass of concrete (18.648 lb/yd^3) was calculated. An example of the agreement between the actual 6-month chlorides and chloride regression plus base-line chlorides is shown in Figure 81. Table 20 presents the calculated diffusion coefficients for each specimen and the average of each treatment.

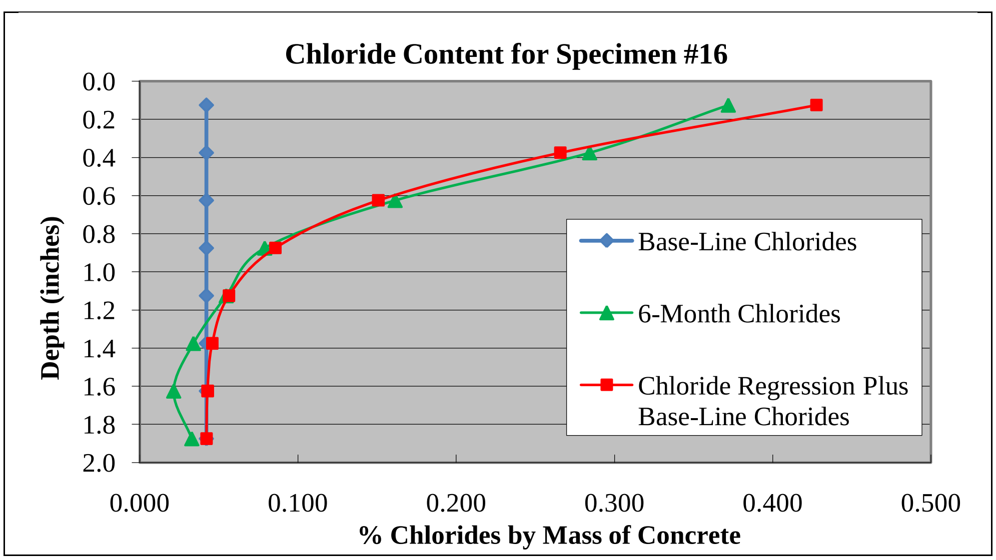

Figure 81: Agreement of actual and theoretical chlorides for Specimen #16

Table 20: Calculated chloride diffusion coefficients for CoP specimens after 6-Months

Specimen #	Treatment	C_0 (% Cl)	$D_{Specimen}$ (in^2/yr)	$D_{Treatment}$ (in^2/yr)
1	TSZ	0.476	0.017	.054
2			0.091	
3	TSZ w/EP-C		0.006	.011
4			0.016	
5	EA-A w/A-C		0.353	.320
6			0.286	
7	EA-A		See Note B	See Note B
8			0.283	
9	EA-B		See Note C	See Note C
10			See Note C	
11	T-SS		0.005	.002
12			0.000	
13	A-C		0.215	.215
14	EP-C		0.000	.000
15	Control		0.295	.282
16			0.269	

NOTE A: For Specimen #2, a failure occurred at the connection between the thermal spray zinc and reinforcing steel.

NOTE B: For Specimen #7, the diffusion coefficient was found to be 0.890 in^2/yr. This high value can be attributed to the level of chlorides found at Location 7E. Using this calculated diffusion coefficient, an average value of 0.586 in^2/yr was calculated for EA-A. Because of the unusually high value of Location 7E, it was removed for the revised analysis (Table 21). Location 7E was adjacent to an anode and points to the presence of chloride "hot spots."

NOTE C: For Specimen #9, there were inconsistencies with the chloride contents of Locations D and E. For Specimen #10, there were also indications of chloride "hot spots" at Location D. The diffusion coefficient for Specimen #9 was calculated to be 6.192 in^2/yr while the value for Specimen #10 was 3.470 in^2/yr. This gave an average of 4.831 in^2/y for EA-B. Because this chloride distribution was not compatible with Fick's 2^{nd} Law, Specimens #9 and #10 were removed in the revised analysis (Table 21).

From Table 20 above, it was found that the EP-C, T-SS, and TSZ w/EP-C were most effective in preventing the ingress of chlorides. To account for the noted inadequacies of Specimens #7, #9, and #10, a revised regression analysis was performed (Table 21).

To create an Index value for Specimens #9 and #10, their diffusion coefficients were assumed to be 0.50 in^2/yr so that they could be compared to the other specimens. As an additional criterion, the chloride content of the top 1" of concrete for all specimens was compared (Table 21). This was then used as the primary rating criteria for the CoP chlorides at 6-months since the regression analysis using Fick's 2nd Law could not be used to directly compare all of the specimens.

Table 21: Revised chloride diffusion coefficients and top 1" chlorides for CoP specimens after 6-Months

Specimen #	**Treatment**	$C_{0\text{-revised}}$ (% Cl)	$D_{\text{Specimen-revised}}$ (in²/yr)	$D_{\text{Treatment-revised}}$ (in²/yr)	**Index for "D"**	**%Cl⁻ in Top 1"**	**Index for %Cl⁻ in Top 1"**
1	TSZ	0.472	0.017	0.055	0.1	0.100	0.6
2			0.092		0.7	0.149	1.1
3	TSZ w/EP-C		0.006	0.011	0.0	0.056	0.2
4			0.016		0.1	0.085	0.5
5	EA-A w/A-C		0.357	0.324	2.9	0.266	2.2
6			0.290		2.3	0.246	2.0
7	EA-A		0.362	0.324	2.9	0.355	3.0
8			0.287		2.3	0.232	1.9
9	EA-B		-	- *	4.0	0.393	3.4
10			-		4.0	0.459	4.0
11	T-SS		0.005	0.002	0.0	0.041	0.1
12			0.000		0.0	0.047	0.1
13	A-C		0.218	0.218	1.7	0.213	1.7
14	EP-C		0.000	0.000	0.0	0.032	0.0
15	Control		0.300	0.287	2.4	0.224	1.8
16			0.273		2.2	0.224	1.8

* - assumed to be 0.50in²/yr to provide a comparison

As seen in Table 21, the surface chloride concentration and diffusion coefficients for the treatments that were not affected by the chloride "hot spots" contents did not change appreciably. However, by removing Location 7E from the regression analysis, the diffusion coefficient for Specimen #7 dropped from 0.890 in^2/yr to 0.362 in^2/yr.

When comparing the Index values for the diffusion coefficients and chloride content of the top 1" of concrete, there is reasonable agreement. Based on these indices, it can be concluded that the EP-C, T-SS, and TSZ w/EP-C were most effective in reducing the ingress of chlorides. In contrast, EA-A and EA-B were least effective in reducing chloride ingress. From the results, it appears that the embedded anodes actually attracted chlorides to their vicinity.

For Specimens #1 - #4, the "before" and "after" calibration numbers varied considerably. To check the validity of chloride testing, the chloride testing equipment were checked against calibration liquids with known chloride contents before and after each set of tests (See Appendix C). In contrast, the "before" and "after" calibration values for the 0-month and 3-month CoC specimens and the bridge decks, all of which will be discussed later, had little variation.

After some experimentation with the 5-minute tests, we discovered that the calibration values changed as soon as a vial containing chloride powders from the TSZ specimens was tested. This experimentation involved the cleaning of the RCT electrode after some tests, replacement of the electrode wetting agent, and retesting of the calibration liquids. When this assessment was completed, the calibration values returned to normal. As soon as a vial with TSZ powder was tested, the calibration values again dropped. After further evaluations and inquiry from the chloride test equipment supplier, we concluded that the zinc from the thermal spray may have an adverse effect on the testing procedure, which is based on potential readings. Therefore, chloride contents for Specimens #1 - #4 were determined from the calibration numbers at the conclusion of testing and not the average of the "before" and "after" calibrations.

In regards to Specimens #7, #9, and #10, Locations 7E, 9D, 9E, and 10D produced chloride profiles that were not consistent with Fick's 2nd Law of Diffusion (Figure 82). Because of these inconsistent values, 2 to 4 additional locations were tested near each area in question (Figures 83 and 84).

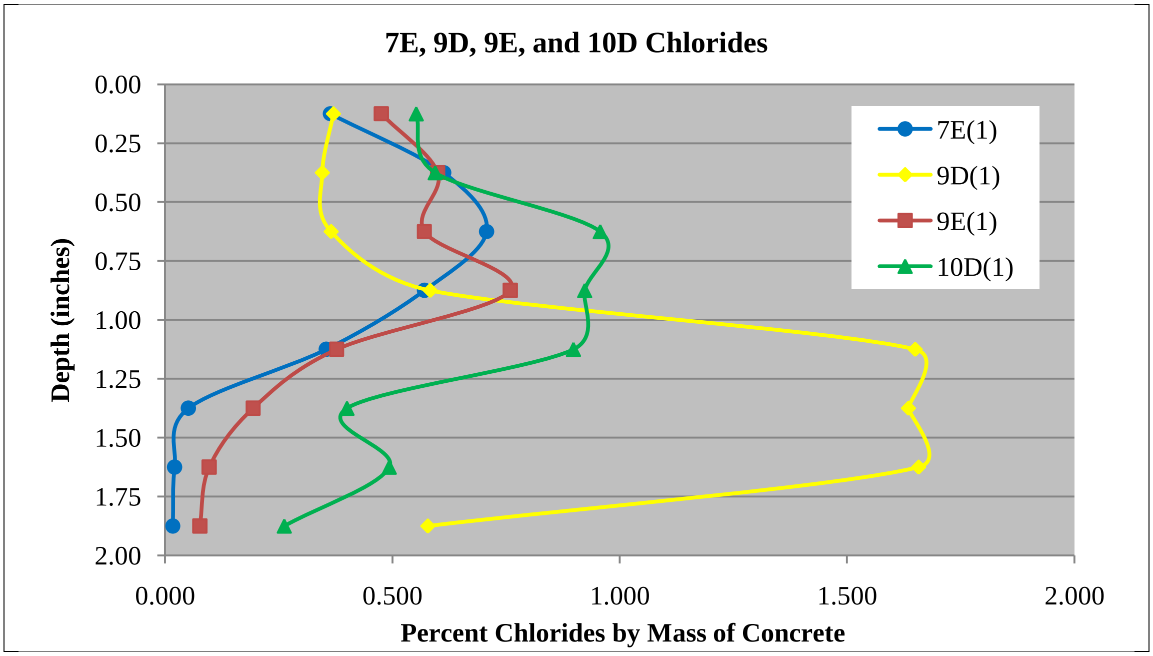

Figure 82: Chloride profiles for Locations 7E(1), 9D(1), 9E(1), and 10D(1)

Figure 83: Location of additional chloride tests for Specimen #9

Figure 84: Location of additional chloride tests for Specimen #10

Similar to the TSZ specimens, the calibration values for Specimens #7, #9, and #10 varied significantly, albeit much more dramatically (See Appendix C). To determine the extent of the change of calibration values, numerous checks were taken during the course of the retests for locations 7E, 9D, 9E, and 10D as the calibration values immediately dropped after the first few tests and continued to drop throughout the testing. To correctly measure the chlorides, the spreadsheet equation was adjusted for each set of calibration checks. As with the TSZ, we feel that the zinc from the embedded anodes may have had an effect on these values.

Because of the variation in chloride contents at similar locations (Figure 85), we concluded that the chloride penetration in these specimens was not one-dimensional and did not conform to Fick's 2nd Law.

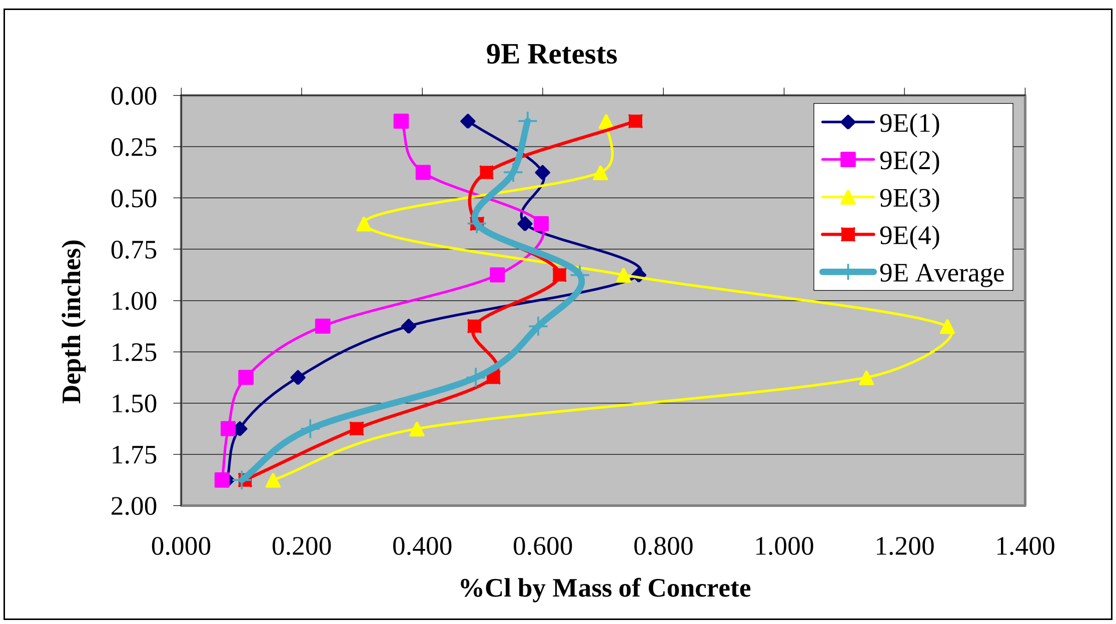

Figure 85: Chloride contents near Location 9E

The most significant variation of chlorides occurred at the level of reinforcing, which was 1” from the concrete surface. As seen in Figure 86, horizontal cracks were present at the level of the reinforcing steel. In addition, significant staining was found on the dissected concrete at the level of the reinforcing steel (Figure 87). Detailed condition observations can be found in Section 4.2.

Figure 86: Presence of cracking on exterior of Specimen #9.

Figure 87: Presence of significant concrete staining on dissected concrete of Specimen #9

To determine where the variation in chlorides occurred, additional testing was performed on the specimens containing EA-B. Two samples were taken near the anode, (i.e. Location A), and two sets of two samples were taken from concrete outside the “anode grid” (i.e. Locations E and W, Figure 88). When referring to the concrete powders locations of Figure 56, tests for Specimen #9 were taken near Location D while tests for Specimen #10 were taken near Location C. The tests revealed that chloride “hot spots” could be found near the anodes (Table 22). Additionally, corrosion staining was more severe in the vicinity of the anodes.

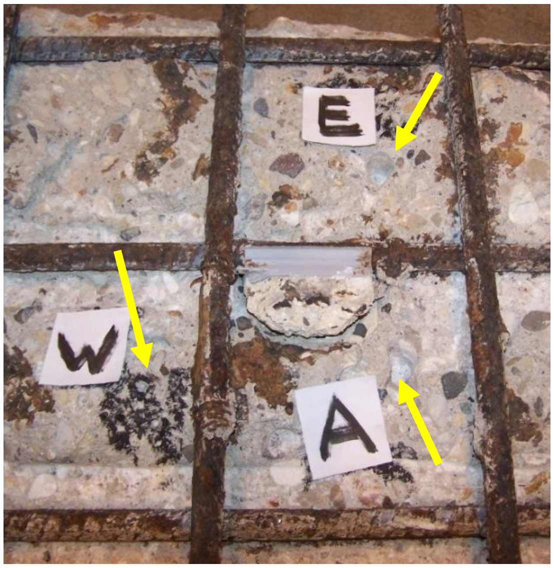

Figure 88: Location of "near anode" chloride tests for EA-B

Table 22: "Near anode" chloride contents for E.A.-B

Location	%Cl by concrete weight	Average %Cl by concrete weight
9W ¼"	0.039	0.026
9W ½"	0.013	
9A ¼"	0.078	0.065
9A ½"	0.053	
9E ¼"	0.035	0.026
9E ½"	0.016	
10W ¼"	0.023	0.022
10W ½"	0.021	
10A ¼"	0.027	0.026
10A ½"	0.025	
10E ¼"	0.026	0.023
10E ½"	0.021	

4.1.4.3 CoC Specimens at 0-Months

The mixed-in chloride content of the CoC specimens was evaluated prior to exposure to accelerated corrosion so that confirmation of the actual chloride contents of the specimens could be made.

Chloride testing (see Appendix D) revealed that the actual chloride content (Table 23) was in reasonable agreement with the initial theoretical chloride content (see Table 13), once the virgin chloride content was added to the theoretical chlorides. For clarification, subsequent treatments for each specimen have been indicated in Table 23.

Table 23: Average acid-soluble chloride contents of CoC specimens at 0-months

Depth\Specimen	Control		TSZ w/EP-C		TSZ		EA-A	
	#17	#18	#19	#20	#21	#22	#23	#24
0” to ¼”	0.177	0.201	0.183	0.183	0.190	0.181	0.194	0.177
¼” to ½”	0.200	0.207	0.169	0.172	0.139	0.173	0.192	0.174
½” to ¾”	0.143	0.159	0.127	0.144	0.129	0.140	0.183	0.163
¾” to 1”	0.139	0.131	0.120	0.103	0.142	0.139	0.143	0.136
1” to 1¼”	0.137	0.128	0.120	0.124	0.111	0.120	0.121	0.119
1¼” to 1½”	0.126	0.110	0.115	0.111	0.099	0.121	0.111	0.094
1½” to 2”	0.097	0.081	0.089	0.080	0.092	0.101	0.094	0.078
2” to 2½”	0.069	0.068	0.067	0.085	0.076	0.076	0.070	0.075
2½” to 3”	0.043	0.072	0.066	0.062	0.073	0.062	0.045	0.050
Depth\Specimen	**EA-A w/A-C**		**EA-B**		**EM**			
	#25	**#26**	**#27**	**#28**	**#29**	**#30**		
0” to ¼”	0.176	0.189	0.162	0.191	0.174	0.179		
¼” to ½”	0.150	0.174	0.161	0.143	0.161	0.178		
½” to ¾”	0.151	0.144	0.131	0.120	0.112	0.141		
¾” to 1”	0.137	0.133	0.132	0.124	0.114	0.106		
1” to 1¼”	0.112	0.124	0.117	0.098	0.111	0.124		
1¼” to 1½”	0.093	0.113	0.099	0.101	0.112	0.115		
1½” to 2”	0.088	0.081	0.078	0.091	0.093	0.106		
2” to 2½”	0.073	0.076	0.066	0.062	0.079	0.087		
2½” to 3”	0.051	0.052	0.059	0.046	0.061	0.052		

To further quantify the effectiveness of the addition of chlorides to the concrete mix, Table 24 displays the average chloride content and standard deviation within the top three inches of concrete.

Table 24: Comparison of initial theoretical and average acid-soluble chloride contents of CoC specimens at 0-months

Depth	Theoretical plus Virgin Chlorides	Average of Actual Chlorides per Increment of Depth	Standard Deviation	Average of Actual Chlorides per Inch
0” to ¼”	.155	0.183	0.010	.156
¼” to ½”		0.171	0.020	
½” to ¾”		0.142	0.018	
¾” to 1”		0.129	0.013	
1” to 1¼”	.090	0.119	0.009	.106
1¼” to 1½”		0.109	0.010	
1½” to 2”		0.089	0.009	
2” to 2½”	.056	0.073	0.007	.065
2½” to 3”		0.057	0.010	

By utilizing the aforementioned regression analysis, the agreement between the intended initial theoretical chloride content (mixed-in chlorides) and experimental data could be further verified. Using a time of 10 years (assumed for calculating the amount of mixed-in chlorides), C_0 was found to equal 0.149% chlorides by concrete weight (5.83 lb/yd^3) and D_{avg} was found to equal 0.150 in^2/yr, with a standard deviation of 0.026 (Table 25). These values are in excellent agreement with the values of C_0 = 0.153% (5.985lb/yd^3) and D = 0.11 in^2/yr that were used initially to determine the mixed-in chlorides. Figure 89 shows the initial theoretical chlorides, initial chlorides, and initial regression plus base-line chlorides. Because the regression analyses did not include the base-line chlorides, the plot includes the addition of the base-line chlorides to the values obtained from the regression analysis. By doing so, one can see a direct comparison of the data.

Because of the excellent agreement of the diffusion coefficients, an Index rating was not used to compare the specimens.

Table 25: Calculated chloride diffusion coefficients for CoC Specimens at 0-months

Specimen #	Subsequent Treatment	C_0 (% by concrete weight)	$D_{Specimen}$ (in^2/yr)	$D_{Treatment}$ (in^2/yr)
17	Control	0.149	0.185	0.181
18			0.177	
19	TSZ w/EP-C		0.143	0.143
20			0.144	
21	TSZ		0.143	0.163
22			0.184	
23	EA-A		0.180	0.160
24			0.140	
25	EA-A w/A-C		0.130	0.142
26			0.154	
27	EA-B		0.121	0.111
28			0.101	
29	EM		0.128	0.148
30			0.168	

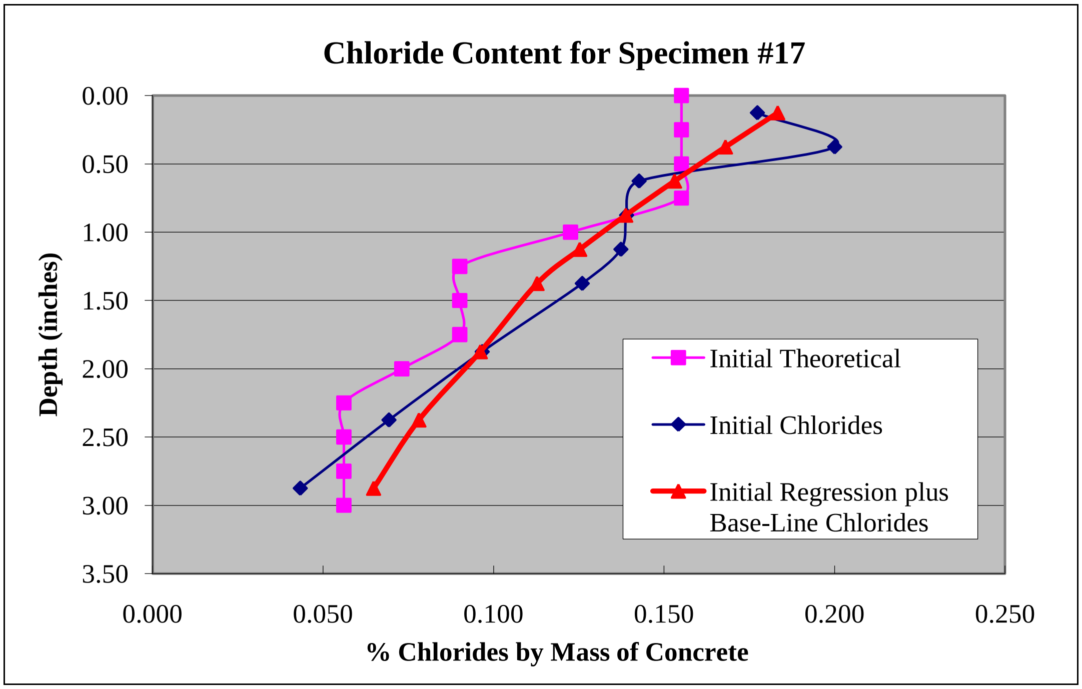

Figure 89: Comparison of initial theoretical, initial, and regression chlorides for Specimen #17

4.1.4.4 CoC Specimens after 3-Months

Prior to removing parts of the CoC specimens for patch repair, the specimens were again evaluated for chlorides after 3-months of accelerated corrosion testing (Table 26). Chloride testing (see Appendix E) revealed that the chlorides were effectively drawn into the concrete. In Table 26, the various treatments shown refer to subsequent treatments since the CoC specimens were not treated within the first 3-months of exposure.

Table 26: Average acid-soluble chloride contents of CoC Specimens after 3-months

Depth\Specimen	Control		TSZ w/EP-C		TSZ		EA-A	
	#17	#18	#19	#20	#21	#22	#23	#24
0” to ¼”	0.492	0.427	0.465	0.468	0.617	0.617	0.467	0.453
¼” to ½”	0.410	0.365	0.398	0.427	0.465	0.422	0.414	0.295
½” to ¾”	0.238	0.255	0.298	0.299	0.365	0.242	0.235	0.187
¾” to 1”	0.158	0.275	0.184	0.220	0.279	0.157	0.171	0.143
1” to 1¼”	0.151	0.183	0.130	0.134	0.215	0.112	0.109	0.096
1¼” to 1½”	0.133	0.157	0.117	0.136	0.156	0.099	0.090	0.084
1½” to 1¾”	0.113	0.129	0.117	0.119	0.104	0.102	0.094	0.087
1¾” to 2”	0.123	0.099	0.093	0.112	0.082	0.079	0.090	0.094

Depth\Specimen	EA-A w/A-C		EA-B		EM	
	#25	#26	#27	#28	#29	#30
0” to ¼”	0.477	0.452	0.603	0.503	0.527	0.460
¼” to ½”	0.330	0.297	0.341	0.321	0.348	0.304
½” to ¾”	0.233	0.211	0.244	0.197	0.204	0.199
¾” to 1”	0.138	0.164	0.148	0.133	0.137	0.136
1” to 1¼”	0.104	0.123	0.111	0.128	0.109	0.128
1¼” to 1½”	0.095	0.103	0.091	0.122	0.086	0.112
1½” to 1¾”	0.093	0.083	0.080	0.089	0.073	0.101
1¾” to 2”	0.072	0.077	0.062	0.080	0.072	0.101

For further assessment, Table 27 compares the chloride content at 0-months and the chloride content and associated standard deviation of chlorides at 3-months.

Table 27: Comparison of average acid-soluble chloride contents of CoC Specimens at 0- and after 3-months

Depth	Average of 0-Month Chlorides	Average of 0-Month Chlorides per Inch	Average of 3-Month Chlorides	Standard Deviation of 3-Month Chlorides	Average of 3-Month Chlorides per Inch
0” to ¼”	0.183	0.156	0.502	0.064	0.322
¼” to ½”	0.171		0.367	0.055	
½” to ¾”	0.142		0.243	0.049	
¾” to 1”	0.129		0.174	0.049	
1” to 1¼”	0.119	0.106	0.131	0.033	0.108
1¼” to 1½”	0.109		0.113	0.025	
1½” to 1¾”	0.089		0.099	0.016	
1¾” to 2”			0.088	0.017	

From Table 27, it is clearly shown that the chlorides were effectively drawn into top 1” of the concrete. More explicitly, the average amount of chlorides in the top 1-inch of concrete more than doubled in the 3-months of accelerated corrosion testing.

A regression analysis using the 3-month chloride content data, minus the initial chloride content, with a time of 0.25 years (3 months) revealed that C_0 = 0.514% by concrete weight (20.12 lb/yd^3) and that D_{avg} = 1.375 in^2/yr, with a standard deviation of 0.565. Table 28 displays the chloride diffusion coefficient values calculated at 3-months.

Table 28: Calculated chloride diffusion coefficients for CoC specimens after 3-months

Specimen #	Subsequent Treatment	C_0 (% by concrete weight)	$D_{Specimen}$ (in^2/yr)	$D_{Fut.-Treat.}$ (in^2/yr)
17	Control	0.514	1.522	1.792
18			2.062	
19	TSZ w/EP-C		1.610	1.757
20			1.905	
21	TSZ		2.793	2.093
22			1.393	
23	EA-A		1.267	1.016
24			0.765	
25	EA-A w/A-C		0.991	0.972
26			0.954	
27	EA-B		1.155	1.059
28			0.964	
29	EM		0.973	0.938
30			0.904	

Figure 90 shows a representative graph comparing the initial theoretical, initial, 3-month, and 3-month regression plus base-line chloride levels.

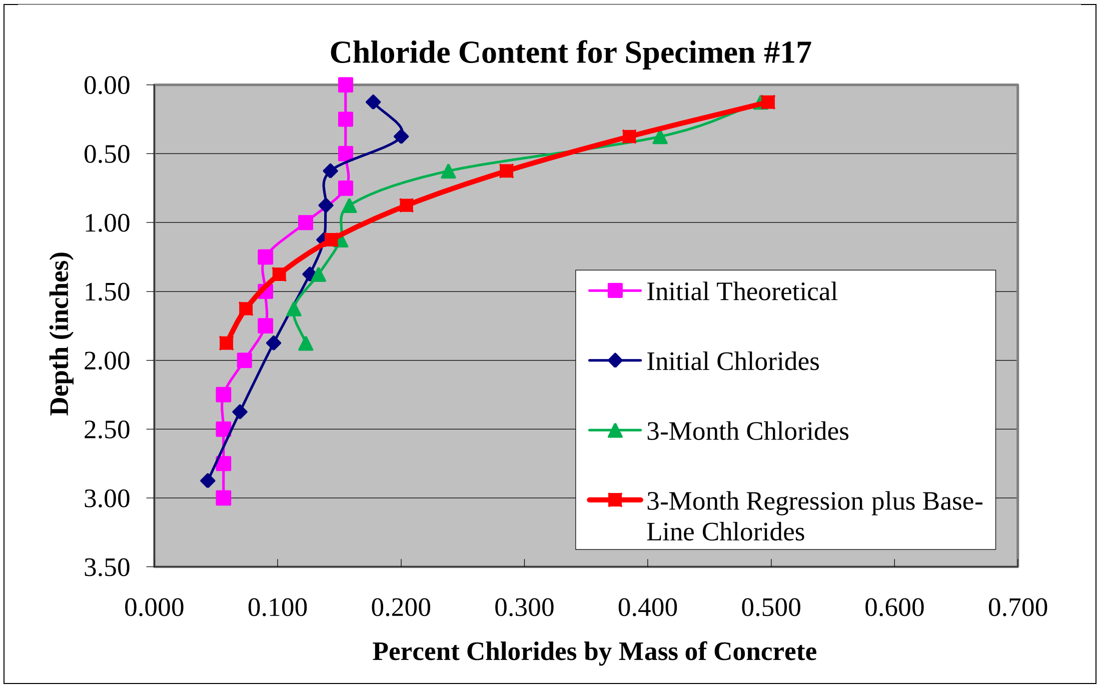

Figure 90: Comparison of initial theoretical, initial, 3-month, and 3-month regression chlorides for Specimen #17

4.1.4.5 Base-Line Chlorides for Patch Repair Materials

To evaluate the virgin chloride content of the conventional patch repair material, concrete powders were taken from a sample of repair material that was made at the time of patch repair (Appendix F). The powders were taken at depths of ½” and 1” in two locations (Table 29).

Table 29: Chloride contents of conventional patch repair material

Location	Depth	Chloride Content (% Cl by concrete weight)	Chloride Content (lb/yd^3)
A	½”	0.010	0.378
	1”	0.007	0.264
B	½”	0.012	0.470
	1”	0.005	0.214

Testing revealed that the average chloride content of the conventional repair mortar was 0.008% by concrete weight (0.331 lb/yd^3). This level of chlorides is well within the accepted limits.

The virgin chloride content of the EM was found to be 0.001% chlorides by weight.

4.1.4.6 CoC Specimens after 6-Months

After exposure to an additional three months of accelerated corrosion testing, the CoC specimens were tested for chloride ingress. As before, testing examined the concrete powders at increments of ¼” to a depth of 2”. Section 4.1.3.6.1 examines the chloride content of the original concrete while Section 4.1.3.6.2 examines the chloride content of the patch repair materials.

4.1.4.6.1 Substrate Concrete

The chloride contents of the substrate concrete for the CoC specimens after 6-months of accelerated corrosion testing can be found in Table 30 (see Appendix F). In order to achieve viable data for the substrate concrete, several locations were tested to confirm results that seemed incompatible with Fick's 2nd Law. Specimens #19 through #22 had non-conforming chloride levels at a depth of ¼" only. The substrate concrete of Specimens #24 had a spike in chloride content at a depth corresponding to the level of reinforcing steel. The substrate concrete of Specimen #30 produced chloride contents that were inconsistent with Fick's 2nd Law (i.e. showing high chloride levels at deeper test locations).

Table 30: Average acid-soluble chloride contents of CoC substrate concrete after 6-months

Depth\Specimen	Control		TSZ w/EP-C		TSZ		EA-A	
	#17	#18	#19	#20	#21	#22	#23	#24
0" to ¼"	0.542	0.576	0.496	1.077	1.270	1.313	0.448	0.607
¼" to ½"	0.438	0.387	0.518	0.515	0.330	0.464	0.409	0.541
½" to ¾"	0.338	0.363	0.236	0.464	0.208	0.458	0.310	0.381
¾" to 1"	0.243	0.247	0.156	0.434	0.145	0.258	0.211	0.321
1" to 1¼"	0.168	0.174	0.148	0.204	0.095	0.192	0.105	0.402
1¼" to 1½"	0.130	0.150	0.100	0.176	0.080	0.110	0.122	0.330
1½" to 1¾"	0.140	0.116	0.074	0.113	0.058	0.067	0.105	0.227
1¾" to 2"	0.128	0.088	0.058	0.083	0.047	0.069	0.132	0.126

Depth\Specimen	EA-A w/A-C		EA-B		EM	
	#25	#26	#27	#28	#29	#30
0" to ¼"	0.521	0.490	0.528	0.493	0.558	0.437
¼" to ½"	0.473	0.414	0.458	0.411	0.526	0.345
½" to ¾"	0.312	0.304	0.402	0.346	0.495	0.347
¾" to 1"	0.173	0.189	0.213	0.250	0.181	0.314
1" to 1¼"	0.119	0.097	0.206	0.222	0.114	0.293
1¼" to 1½"	0.110	0.063	0.154	0.136	0.146	0.286
1½" to 1¾"	0.098	0.087	0.122	0.118	0.120	0.390
1¾" to 2"	0.085	0.059	0.116	0.069	0.112	0.362

As mentioned, Specimens #19 through #22 (i.e. those that were treated with the TSZ) had non-conforming chloride contents at a depth of ¼". To confirm the accuracy of the results, the measurement equipment were calibrated frequently, and steps were made to take out measurement errors due to the presence of zinc ions in the concrete.

It is believed that the TSZ (zinc anode) attracts and retains neagatively-charged chloride ions near the surface, thus causing deviation from Fick's 2nd Law. Figure 91 compares the chloride contents of the control specimens and those treated with thermal sprayed zinc. As can be seen, the chloride contents at a depth of ¼" for Specimens #20 through #22 are much greater than the control specimens.

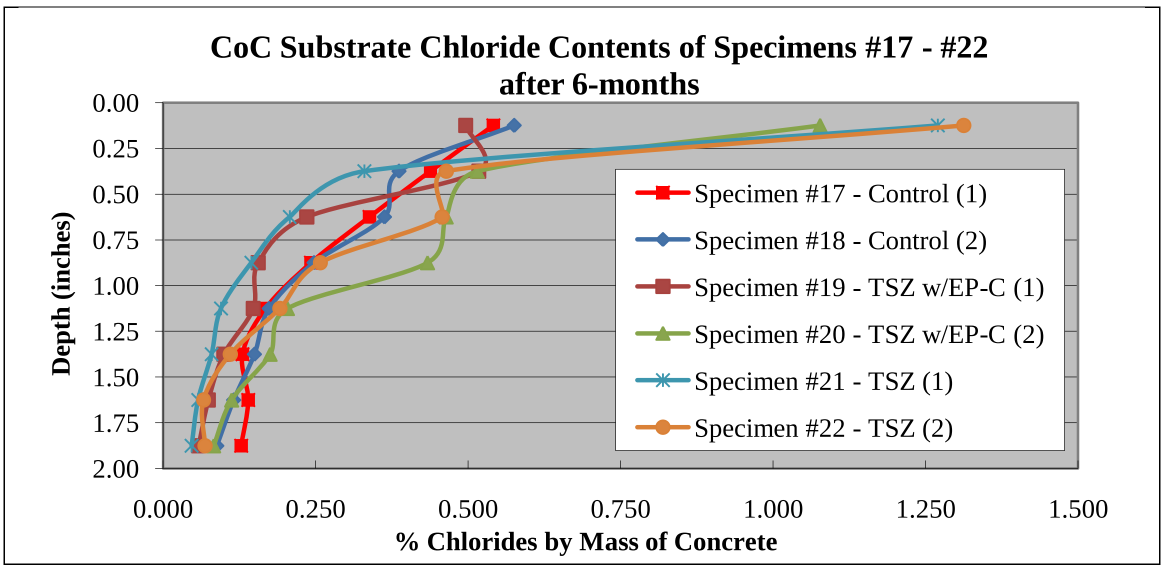

Figure 91: CoC substrate chloride contents of Specimens #17 through #22 after 6-months

For Specimens #24 (EA-A) and #30 (EM), the substrate chloride contents did not entirely agree with Fick's 2nd Law either. To verify the results, additional tests were taken at two locations. After the retests were completed, results from each increment of depth were averaged. Figure 92 displays the non-conformity of Ficks's 2nd Law in regards to the average substrate chloride contents of Specimens #24 and #30. The substrate chloride contents of the Control specimens have also been provided.

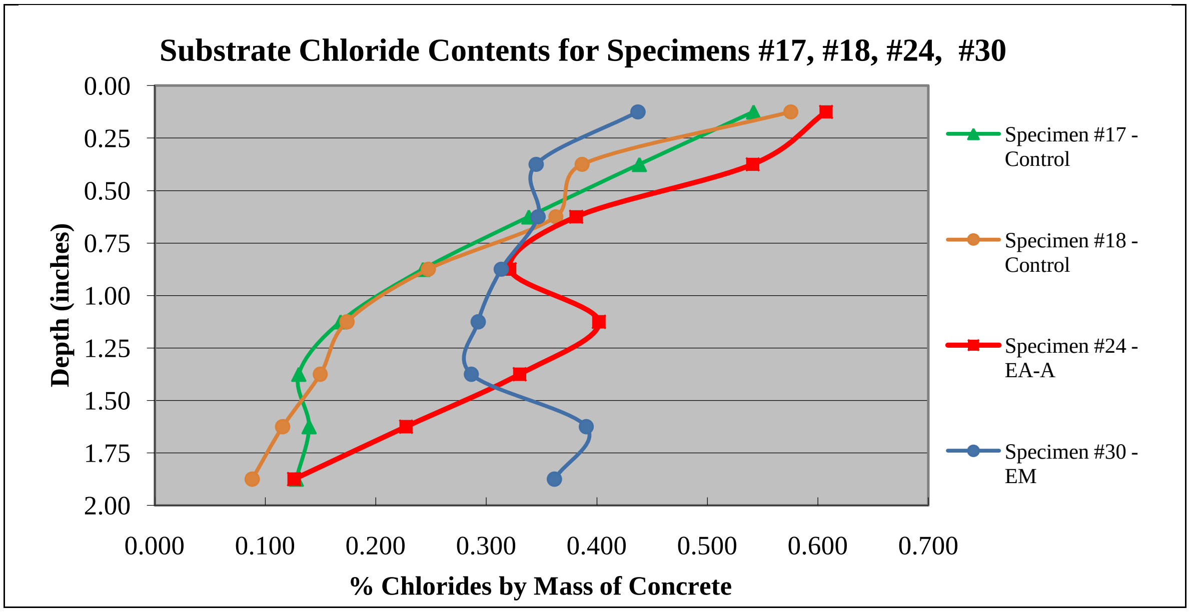

Figure 92: Comparison of substrate chloride contents of Specimens #17, #18, #24, and #30 after 6-months

In assessing the profile of chloride contents for Specimen #24 in Figure 92, it can be seen that a sudden increase in chloride content can be found at the depth of reinforcing steel.

When looking at the sides of Specimens #24 and #30, significant horizontal cracking of the substrate concrete is evidence that corrosion of the embedded reinforcing has occurred (Figures 93 and 94). It seems that the presence of cracks may be cause for the higher level of chlorides found in the substrate concrete of Specimens #24 and #30. The embedded anodes in Specimen #24 may have also caused some of this distress.

Figure 93: Horizontal cracking on exterior of Specimen #24

Figure 94: Horizontal cracking on exterior of Specimen #30

With this information, an additional regression analysis was performed to calculate the surface chloride concentration and diffusion coefficients for the substrate concrete of the CoC specimens after 6-months of exposure (Table 31). The chloride contents at a depth of ¼" for Specimens #19 through #22 were not used in this regression analysis (to take out the localized TSZ effect). In addition, Specimen #30 was not included in the analysis.

Table 31: Calculated chloride diffusion coefficients for substrate concrete of CoC specimens after 6-months

Specimen #	Subsequent Treatment	C_0 (% by concrete weight)	$D_{Specimen}$ (in^2/yr)	$D_{Treatment}$ (in^2/yr)	Index
17	Control	0.570	.993	.982	1.1
18			.971		1.0
19	TSZ w/EP-C		.649	1.147	0.5
20			1.645		2.2
21	TSZ		.379	.727	0.0
22			1.075		1.2
23	EA-A		.701	1.704	0.6
24			2.707		4.0
25	EA-A w/A-C		.714	.652	0.6
26			.590		0.4
27	EA-B		1.117	1.053	1.3
28			.990		1.0
29	EM		1.091	1.091	1.2
30			-		-

It should be noted, however, that the chloride contents of the substrate concrete were not used in evaluating the performance of the treatments within the patch repair materials. The chloride testing of the substrate concrete was performed merely to show that chlorides have continued to penetrate the concrete and that an environment representative of a patch repair in the field was simulated.

Figure 95 shows the ingress of chlorides over the course of the 6 months of testing for the substrate concrete of a Control specimen. Chloride levels increased significantly over the course of testing. Furthermore, the actual chloride content and regression plus base-line chlorides at 6-months have excellent agreement.

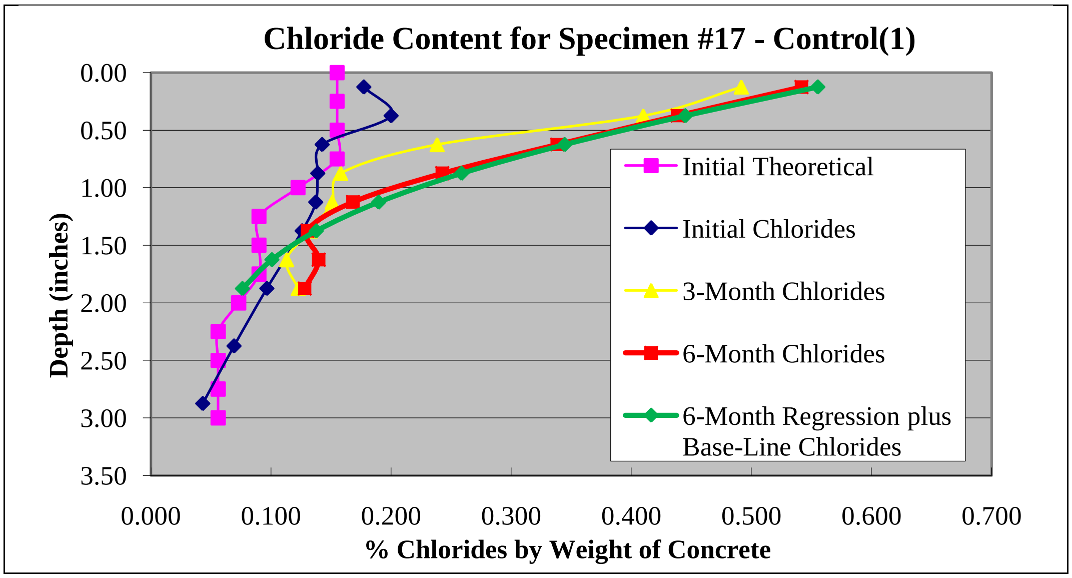

Figure 95: Comparison of initial theoretical, initial, 3-month, 6-month, and 6-month regression chlorides for Specimen #17

4.1.4.6.2 Patch Repair Materials

Analysis of the chloride testing data, Table 32, revealed that chlorides were only drawn into the top ¼" of the patch repair materials, except for Specimens #27 and #30 (See Appendix F). While chlorides were found to have penetrated to a depth of 1" for the conventional patch repair material of Specimen #27, irregular chloride contents were found in the epoxy patch material of Specimen #30. To verify the results, additional testing was performed in the patched areas of Specimens #27 and #30.

Table 32: Average acid-soluble chloride contents of patch materials for CoC specimens after 3-months

Depth\Specimen	Control		TSZ w/EP-C		TSZ		EA-A	
	#17	**#18**	**#19**	**#20**	**#21**	**#22**	**#23**	**#24**
0” to ¼”	0.183	0.085	0.065	0.025	0.008	0.030	0.044	0.041
¼” to ½”	0.009	0.009	0.007	0.005	0.005	0.008	0.010	0.015
½” to ¾”	0.008	0.008	0.006	0.007	0.006	0.005	0.007	0.009
¾” to 1”	0.008	0.007	0.008	0.007	0.005	0.006	0.008	0.007
1” to 1¼”	0.008	0.007	0.006	0.006	0.005	0.005	0.009	0.007
1¼” to 1½”	0.008	0.008	0.006	0.006	0.015	0.005	0.007	0.008
1½” to 1¾”	0.009	0.013	0.007	0.006	0.009	0.006	0.007	0.008
1¾” to 2”	0.010	0.008	0.006	0.007	0.005	0.005	0.008	0.014

Depth\Specimen	EA-A w/A-C		EA-B		EM	
	#25	**#26**	**#27**	**#28**	**#29**	**#30**
0” to ¼”	0.013	0.012	0.136	0.067	0.001	0.003
¼” to ½”	0.005	0.007	0.035	0.007	0.001	0.001
½” to ¾”	0.007	0.006	0.016	0.006	0.001	0.011
¾” to 1”	0.006	0.006	0.010	0.006	0.001	0.043
1” to 1¼”	0.006	0.005	0.007	0.006	0.001	0.055
1¼” to 1½”	0.006	0.006	0.008	0.006	0.001	0.037
1½” to 1¾”	0.006	0.007	0.008	0.006	0.001	0.023
1¾” to 2”	0.005	0.006	0.007	0.007	0.002	0.013

In Specimen #30, the measured chloride values were found to be approximately zero at the concrete surface and increased to a depth of 1¼”, where they then decreased towards a depth of 2.” To locate the discrepancy, further testing was performed. The results of the additional testing (Table 33) revealed that a high level of chlorides was found at Location D and approximately zero chlorides were found at Location E. In addition, a line of discoloration was found approximately ¾” from the surface in Location D (Figure 96), which later was found to be rust staining.

Table 33: Acid-soluble chloride contents of EM for Specimen #30

Depth	Location B/C	Location D	Location E	Average
0.125	0.003	0.004	0.002	0.003
0.375	0.001	0.001	0.001	0.001
0.625	0.004	0.028	0.001	0.011
0.875	0.018	0.110	0.001	0.043
1.125	0.056	0.108	0.001	0.055
1.375	0.046	0.064	0.001	0.037
1.625	0.027	0.041	0.001	0.023
1.875	0.029	0.009	0.001	0.013

Figure 96: Discoloration in EM (Location D) of Specimen #30

A regression analysis was performed on the chloride results (Table 34). Because of the unusual profile of chloride levels for Specimen #30, it was not included in the regression. Using a time of 0.25 years, $C_{0\text{-patch}}$ was found to equal 0.445 % chlorides by concrete weight (17.421 lb/yd^3).

Table 34: Calculated chloride diffusion coefficients for patch materials of CoC specimens after 3-months

Specimen #	Patch Treatment		C_0 (% Cl by concrete weight)	$D_{Specimen}$ (in^2/yr)	$D_{Treatment}$ (in^2/yr)	Index
17	Control	(Conventional patch repair material)	0.445	0.042	0.030	4.0
18				0.017		1.6
19	TSZ w/EP-C			0.013	0.010	1.2
20				0.007		0.6
21	TSZ			0.001	0.004	0.0
22				0.008		0.7
23	EA-A			0.010	0.010	0.9
24				0.010		0.9
25	EA-A w/A-C			0.005	0.005	0.4
26				0.005		0.4
27	EA-B			0.028	0.021	2.6
28				0.014		1.3
29	EM			0.001	0.001	0.0
30				-		

As displayed in Table 34, EM, TSZ and EA-A w/A-C had the lowest effective coefficients of diffusion.

4.1.5 Corrosion of Reinforcing Steel and Concrete Staining

To provide a quantitative measure of the condition of the specimens after exposure to accelerated corrosion testing, a visual examination of the rust staining on the concrete surface and exposed reinforcing steel was performed so that a numerical rating could be assigned to each of the specimens. Based on a rating scale of 0 to 4, with 0 being the best condition and 4 being the worst condition, rust staining on the surface of the specimens and the level of section loss in the reinforcing steel were each evaluated. The two ratings were then added together to determine a combined rating.

The rating scale for staining was based purely on visual examination; the more severe the staining, the higher the grade. The rating scale for the condition of the exposed reinforcing steel was based on the loss of ribs. If no corrosion by-products were present, a grade of 0 was given. If it appeared that all of the ribs were lost, a grade of 4 was given.

4.1.5.1 CoP Specimens after 6-Months

The dissected CoP specimens are displayed in Figure 97 while Table 35 presents the individual and combined ratings for each of the CoP specimens after 6-months of accelerated corrosion testing. In Table 35, Rebar A denotes the top mat reinforcing steel on the west end of the specimens while Rebar E denotes the reinforcing steel on the east end of the specimens. Detailed condition observations of the CoP specimens can be found in Section 4.2.

Figure 97: CoP specimens after dissection

Table 35: Rating of concrete staining and reinforcing steel for CoP Specimens after 6-months

Specimen #	Treatment	Individual Rebar A	B	C	D	E	$Rebar_{Avg.}$	Surface Staining	Combined Rating
1	TSZ	0	1	1	2	0	0.8	0	**0.8**
2		0	4	4	3	1	2.4	4	**6.4**
3	TSZ w/EP-C	0	2	1	1	0	0.8	0	**0.8**
4		1	2	0	1	0	0.8	0	**0.8**
5	EA-A w/A-C	4	3	2	3	3	3.0	4	**7.0**
6		3	3	4	2	2	2.8	3	**5.8**
7	EA-A	3	4	3	4	4	3.6	4	**7.6**
8		4	4	4	4	3	3.8	4	**7.8**
9	EA-B	4	4	4	4	4	4.0	4	**8.0**
10		4	4	4	4	4	4.0	4	**8.0**
11	T-SS	0	1	1	1	1	0.8	0	**0.8**
12		0	0	0	0	0	0.0	0	**0.0**
13	A-C	4	2	2	2	2	2.4	3	**5.4**
14	EP-C	4	1	1	2	1	1.8	2	**3.8**
15	Control	4	4	4	4	4	4.0	4	**8.0**
16		4	4	4	4	4	4.0	4	**8.0**

Based on the above ratings, T-SS (#11 and #12) and TSZ w/EP-C (#3 and #4) provided the best protection against corrosion. The specimens with the embedded anodes (#7 - #10) did not perform better than the control (#15-#16).

4.1.5.2 CoC Specimens after 3-Months

Figure 98 displays the dissected CoC specimens and Table 36 presents the individual grades and final rating for each of the specimens after the initial 3-months of exposure. In Table 36, Rebar B denotes the reinforcing steel on the west end of the patch area while Rebar D denotes the reinforcing steel on the east end of the patch area. Detailed condition observations of the CoC specimens can be found in Section 4.3.

Figure 98: CoC specimens following concrete removal after 3-months

Table 36: Rating of concrete staining and exposed reinforcing steel for CoC specimens after 3-months

Specimen #	Subsequent Treatment	Individual Rebar B	Individual Rebar D	Individual Rebar D	$Rebar_{Avg.}$	Surface Staining	Combined Rating
17	Control	3	2	3	2.7	3	**5.7**
18		3	2	3	2.7	3	**5.7**
19	TSZ w/EP-C	3	2	4	3.0	3	**6.0**
20		4	3	4	3.7	3	**6.7**
21	TSZ	3	2	4	3.0	2	**5.0**
22		3	3	3	3.0	3	**6.0**
23	EA-A	4	2	4	3.3	2	**5.3**
24		3	2	3	2.7	4	**6.7**
25	EA-A w/A-C	4	3	4	3.7	2	**5.7**
26		4	2	4	3.3	4	**7.3**
27	EA-B	4	1	4	3.0	3	**6.0**
28		3	2	4	3.0	4	**7.0**
29	EM	3	2	4	3.0	3	**6.0**
30		3	1	3	2.3	3	**5.3**

The average rating for the exposed reinforcing steel was 3.0 with a standard deviation of 0.4. The average rating for the staining was 3.0 with a standard deviation of

0.7. The average combined rating for the CoP after 3-months of exposure was 6.0 with a standard deviation of 0.7.

4.1.5.3 CoC Specimens after 6-Months

Figure 99 displays the dissected CoC specimens and Table 37 presents the individual grades and combined rating for each of the specimens after 6-months of exposure. In Table 37, Rebar A denotes the reinforcing steel on the west end of the specimens while Rebar E denotes the reinforcing steel on the east end of the specimens. Detailed condition observations of the specimens can be found in Section 4.3.

Figure 99: CoC specimens after dissection after 6-months

In Table 37, all exposed rebar has been rated; however, only the rebars that were exposed, cleaned, and used “in” the patch repairs counted toward the combined rating. The rebar “out” of the patch area did not count toward the combined rating.

Table 37: Rating of concrete staining and reinforcing steel for CoC specimens after 6-months

Specimen #	Individual Rebar								"in" Rebar Average	Surface Staining	Combined Rating
	A	B		C		D		E			
		in	out	in	out	in	out				
17	4	3	4	3	3	3	4	4	3.0	1	**4.0**
18	4	3	4	3	4	3	4	4	3.0	0	**3.0**
19	2	3	4	3	3	4	4	4	3.3	0	**3.3**
20	4	4	4	3	4	4	4	4	3.7	0	**3.7**
21	4	4	4	3	4	4	4	3	3.7	0	**3.7**
22	4	3	4	3	4	4	4	4	3.3	0	**3.3**
23	4	4	4	3	3	4	4	4	3.7	1	**4.7**
24	4	4	4	2	3	4	4	4	3.3	1	**4.3**
25	4	4	4	3	4	4	4	4	3.7	0	**3.7**
26	3	4	4	3	4	4	4	2	3.7	0	**3.7**
27	2	4	4	2	3	4	4	4	3.3	3	**6.3**
28	4	3	4	3	4	4	4	4	3.3	1	**4.3**
29	4	3	4	3	4	4	4	4	3.3	3	**6.3**
30	3	3	4	3	4	3	4	4	3.0	3	**6.0**

4.1.6 Half-Cell Potential Data

Half-cell measurements utilizing a copper-copper sulfate electrode were obtained for each of the concrete specimens that did not contain coatings (Figure 100). Prior to measurement during the dry cycle, the accelerated corrosion system was turned off for a day and the slabs were moistened with tap-water. Readings were made after 3-months (Table 38 and 39) and 6-months (Table 40). Since the readings were generally uniform, contour plots were not made. Additionally, positive values were obtained since the polarity of experimental setup is reversed from the standard method.


Figure 100: Half-cell potential measurement

Table 38: Half-cell potential readings of uncoated CoP specimens after 3-months

Specimen #		Treatment	$Specimen_{Avg}$ (mV)	$Specimen_{StDev}$ (mV)	$Treatment_{Avg}$ (mV)	$Treatment_{StDev}$ (mV)
CoP Specimens	7	EA-A	616.7	22.5	608.9	26.9
	8		601.1	29.3		
	9	EA-B	636.0	24.3	637.5	21.1
	10		639.0	17.9		
	11	T-SS	375.9	5.6	354.6	22.1
	12		333.3	3.7		
	15	Control	639.2	20.5	604.4	36.2
	16		582.7	24.9		

Table 39: Half-cell potential readings of uncoated CoC specimens after 3-months

Specimen #		Future Treatment	$Specimen_{Avg}$ (mV)	$Specimen_{StDev}$ (mV)	$Treatment_{Avg}$ (mV)	$Treatment_{StDev}$ (mV)
CoC Specimens	17	Control	535.2	25.0	546.1	28.4
	18		547.0	30.2		
	19	TSZ w/EP-C	533.0	30.0		
	20		548.1	22.8		
	21	TSZ	550.3	12.5		
	22		515.1	28.5		
	23	EA-A	569.4	20.2		
	24		516.4	18.2		
	25	EA-A w/A-C	564.2	22.0		
	26		544.2	19.1		
	27	EA-B	569.8	24.9		
	28		543.8	34.2		
	29	EM	561.8	19.7		
	30		546.9	13.2		

Based on criteria discussed in Section 2.4.4, the readings from Table 38 indicated that corrosion was occurring in the CoP specimens containing EA-A and EA-B, as well as the Control after 3-months of exposure. However, the specimens with the T-SS were at the threshold of unknown probability after 3-months of exposure. In contrast, all of the readings from Table 39 for the CoC specimens indicated a 90% probability of corrosion after 3-months of exposure.

Table 40: Half-cell potential readings of uncoated CoP specimens after 6-months

Specimen #		Treatment	$\text{Specimen}_{\text{Avg}}$ (mV)	$\text{Specimen}_{\text{StDev}}$ (mV)	$\text{Treatment}_{\text{Avg}}$ (mV)	$\text{Treatment}_{\text{StDev}}$ (mV)
CoP Specimens	7	EA-A	582.9	17.0	579.1	17.9
	8		575.4	18.4		
	9	EA-B	585.3	26.4	582.4	28.1
	10		579.5	30.2		
	11	T-SS	190.4	2.0	186.7	4.1
	12		182.9	1.2		
	15	Control	618.4	21.2	594.5	29.7
	16		570.6	12.4		

The 6-month half-cell readings for the CoP specimens containing EA-A and EA-B, as well as the Control, indicated that corrosion was occurring. However, the readings for the T-SS specimens indicated that no corrosion was occurring.

4.1.7 Summary of Specimen Monitoring

In the previous sections, the rating criteria for the specimens was presented. Section 4.1.7.1 provides a summary of the CoP Specimens while Sections 4.1.7.2 and 4.1.7.3 provide a summary of the CoC Specimens. Since half-cell potential readings were not performed on all of the CoP specimens, they are not included in the final ratings.

4.1.7.1 Summary of CoP Specimen Monitoring

As the previously discussed chloride regression analysis for the CoP specimens would not warrant a direct comparison of all the specimens based on Fick's 2^{nd} Law, the chloride content rating in Table 41 was based on a chloride content index rating of the top 1" of the concrete, and not the regression analysis index rating.

Table 41: Condition summary of CoP specimens after 6-months

Specimen #	Treatment	6-Month Ratings			Total (out of 16)
		Steel Loss	Chloride Content	Rebar Corrosion and Staining	
1	TSZ	1.0	0.6	0.8	2.4
2		1.1	1.1	6.4	8.6
3	TSZ w/EP-C	0.3	0.2	0.8	1.3
4		0.3	0.5	0.8	1.6
5	EA-A w/A-C	1.2	2.2	7.0	10.4
6		1.1	2.0	5.8	8.9
7	EA-A	2.0	3.0	7.6	12.6
8		1.9	1.9	7.8	11.6
9	EA-B	3.1	3.4	8.0	14.5
10		4.0	4.0	8.0	16.0
11	T-SS	0.0	0.1	0.8	0.9
12		0.0	0.1	0.0	0.1
13	A-C	0.5	1.7	5.4	7.6
14	EP-C	0.3	0.0	3.8	4.1
15	Control	2.1	1.8	8.0	11.9
16		1.8	1.8	8.0	11.6

Based on the summary of laboratory results for the CoP Specimens in Table 41, the T-SS and TSZ w/EP-C treatments offered the most effective means of preventing corrosion from initiating. Treatments that coated or sealed the concrete surface prior to exposure offered the most protection. As stated earlier, the connection for Specimen #2 had failed; therefore, it is anticipated that performance similar to Specimen #1 may have been observed if a failure of the connection had not occurred.

The embedded anodes do not appear to offer a benefit in preventing the onset of corrosion in the laboratory specimens. In fact, Specimens #7 thru #10 had less favorable total ratings than the control specimens. The embedded anodes appear to attract more chlorides to their vicinity. This created variable chloride concentrations and non-uniform chloride penetrations in the laboratory specimens containing the embedded anodes.

When comparing the EA-A and EA-A w/A-C, the addition of the acrylic coating improves the performance. However, the A-C alone was more effective in preventing corrosion than the EA-A or EA-A w/A-C laboratory specimens.

4.1.7.2 Summary of CoC Specimen Monitoring after 3-Months

Since the steel loss was similar for each of the CoC specimens prior to patch repairs, it was not included in this evaluation. Additionally, as half-cell potential readings for all of the CoC specimens indicated a high probability of corrosion, a rating of 4.0 was given to each of the specimens (Table 42).

Table 42: Condition summary of CoC specimens after 3-months

Specimen #	Subsequent Treatment	3-Month CoC Ratings			Total (out of 16)
		Chloride Content	Rebar Corrosion and Staining	Half-cell Potential Testing	
17	Control	1.5	5.7	4.0	11.2
18		2.6	5.7	4.0	12.3
19	TSZ w/EP-C	1.7	6.0	4.0	11.7
20		2.2	6.7	4.0	12.9
21	TSZ	4.0	5.0	4.0	13.0
22		1.2	6.0	4.0	11.2
23	EA-A	1.0	5.3	4.0	10.3
24		0.0	6.7	4.0	10.7
25	EA-A w/A-C	0.4	5.7	4.0	10.1
26		0.4	7.3	4.0	11.7
27	EA-B	0.8	6.0	4.0	10.8
28		0.4	7.0	4.0	11.4
29	EM	0.4	6.0	4.0	10.4
30		0.3	5.3	4.0	9.6

With an average value of 11.2 and a standard deviation of 1.01, the CoC specimens appeared to be in a similar condition after the first 3-month of testing. Therefore, it can be concluded that the addition of chlorides to the concrete mix, “ponding” of salt-water, and application of electric current were properly controlled.

4.1.7.3 Summary of CoC Specimen Monitoring after 6-Months

As mentioned previously, the chloride content of the substrate concrete was not used in evaluating the effectiveness of the treatments within the patch repair. In addition, only the "in" patch reinforcing steel was used for the rating (Table 43).

Table 43: Condition summary of CoC specimens after 6-months

Specimen #	Treatment	6-Month CoC Ratings			Total (out of 16)
		Steel Loss	Patch Chloride Content	Rebar Corrosion and Staining	
17	Control	1.9	4.0	4.0	9.9
18		3.7	1.6	3.0	8.3
19	TSZ w/EP-C	1.3	1.2	3.3	5.8
20		1.2	0.6	3.7	5.5
21	TSZ	1.7	0.0	3.7	5.4
22		0.5	0.7	3.3	4.5
23	EA-A	3.2	0.9	4.7	8.8
24		2.6	0.9	4.3	7.8
25	EA-A w/A-C	0.7	0.4	3.7	4.8
26		0.0	0.4	3.7	4.1
27	EA-B	2.8	2.6	6.3	11.7
28		1.4	1.3	4.3	7.0
29	EM	3.5	0.0	6.3	9.8
30		4.0	-*	6.0	10.0*

* Patch chloride content assumed to be zero from data conforming to Fick's 2nd Law

Based on the results of Table 43, EA-A w/A-C, TSZ, and TSZ w/EP-C appeared to be the most effective in controlling corrosion. It is interesting to note that these treatments were effectively coatings. We did not have a specimen with A-C alone to evaluate the relative contributions of EA-A and A-C. However, it should also be noted that the EA-A (without coating) and EA-B specimens did not perform any better than the Control specimens.

In regards to the EM, the high initial corrosion currents and associated steel loss appear to be the result of the dissimilar material properties. As will be seen in Section 4.3, a "ring-anode" effect was visible at the interface of the patch and substrate concrete.

4.2 Condition Observations for CoP Specimens

As seen in Figure 101, visible signs or corrosion, in the form of rust staining on the concrete surface, were present on the CoP specimens that did not contain coatings after only 3-months of exposure. After 6-months of exposure (Figure 102), a majority of the specimens, excluding those with the T-SS and TSZ w/EP-C, displayed signs of rust staining. Sections 4.2.1 through 4.2.16 display the surface condition and associated crack mapping of the CoP specimens at 0-months, 3-months, and 6-months of exposure, as well as the dissected specimens with their rebar ratings. All of the figures in the following sections are oriented with "North" towards the top of the page (Figures 103 to 230). The numbers in parentheses are representative of the specimens for each treatment.

Figure 101: Condition of CoP specimens after 3-months

Figure 102: Condition of CoP specimens after 6-months

4.2.1 Specimen #1 – TSZ (1)

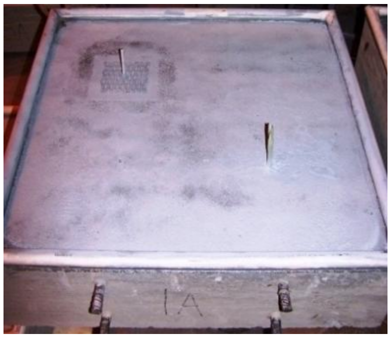

Figure 103: Condition of TSZ(1) at 0-months

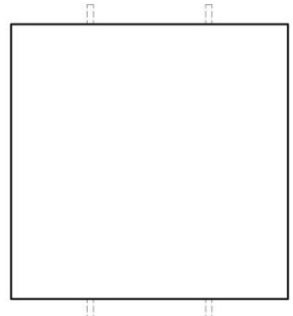

Figure 104: Crack-mapping of TSZ(1) at 0-months

Figure 105: Condition of TSZ(1) after 3-months

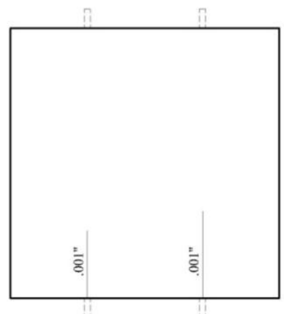

Figure 106: Crack-mapping of TSZ(1) after 3-months

Figure 107: Condition of TSZ(1) after 6-months

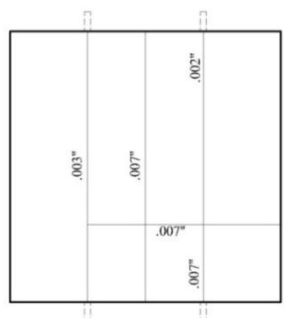

Figure 108: Crack-Mapping of TSZ(1) after 6-months

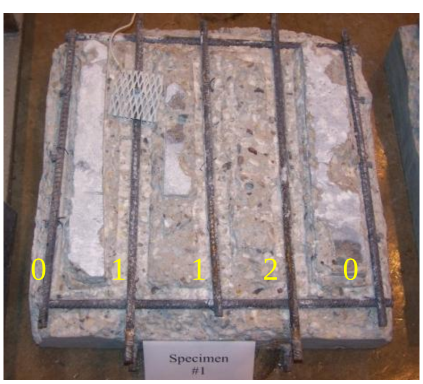

Figure 109: Dissection of TSZ(1) after 6-months

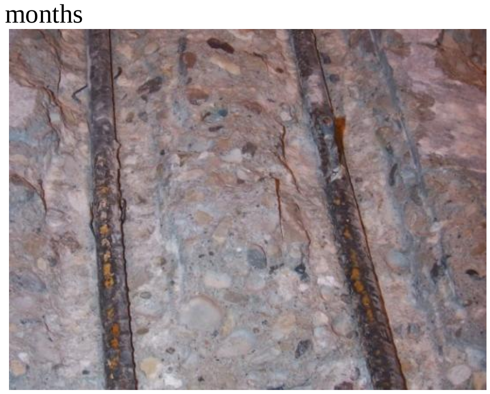

Figure 110: Close-up of TSZ(1) exposed rebar

4.2.2 Specimen #2 – TSZ (2)

Figure 111: Condition of TSZ(2) at 0-months

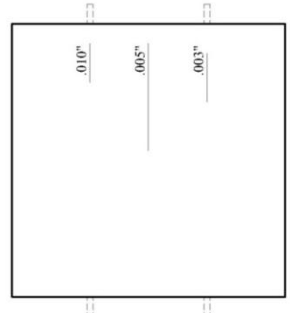

Figure 112: Crack-Mapping of TSZ(2) at 0-months

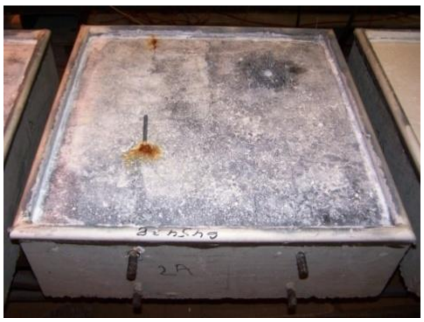

Figure 113: Condition of TSZ(2) after 3-months

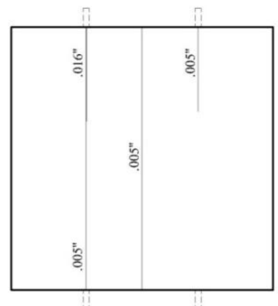

Figure 114: Crack-mapping of TSZ(2) after 3-months

Figure 115: Condition of TSZ(2) after 6-months

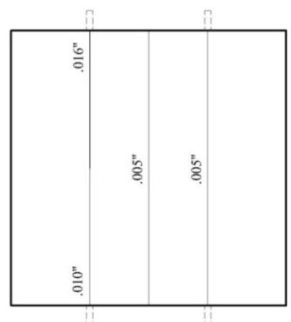

Figure 116: Crack-mapping of TSZ(2) after 6-months

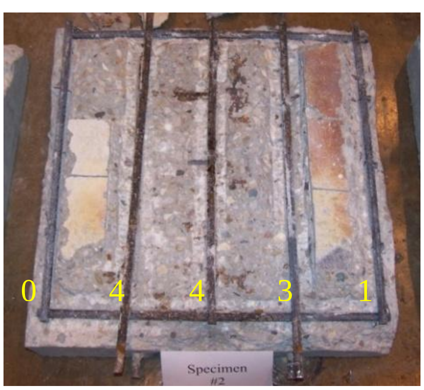

Figure 117: Dissection of TSZ(2) after 6-months

Figure 118: Close-up of TSZ(2) exposed rebar

4.2.3 Specimen #3 – TSZ w/EP-C (1)

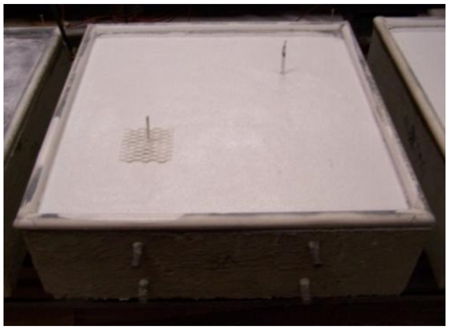

Figure 119: Condition of TSZ w/EP-C(1) at 1.5-months

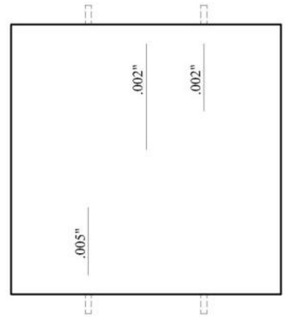

Figure 120: Crack-mapping of TSZ w/EP-C(1) at 0-months

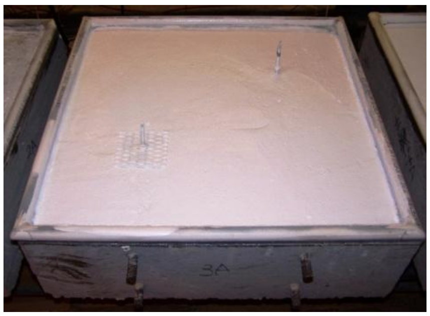

Figure 121: Condition of TSZ w/EP-C(1) after 3-months

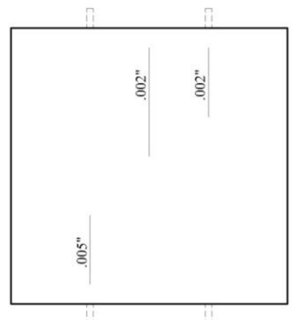

Figure 122: Crack-mapping of TSZ w/EP-C(1) after 3-months

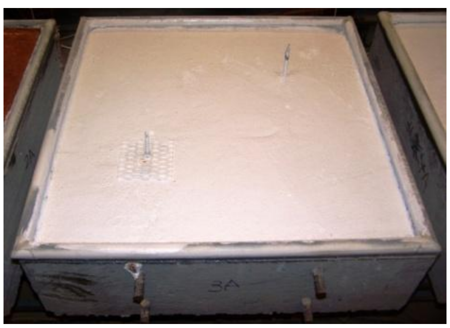

Figure 123: Condition of TSZ w/EP-C(1) after 6-months

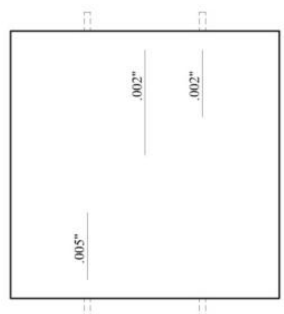

Figure 124: Crack-mapping of TSZ w/EP-C(1) after 6-months

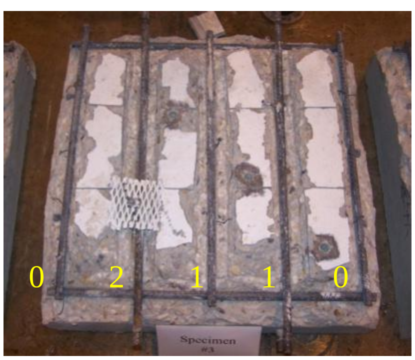

Figure 125: Dissection of TSZ w/EP-C(1) after 6-months

Figure 126: Close-up of TSZ w/EP-C(1) exposed rebar

4.2.4 Specimen #4 – TSZ w/EP-Coating (2)

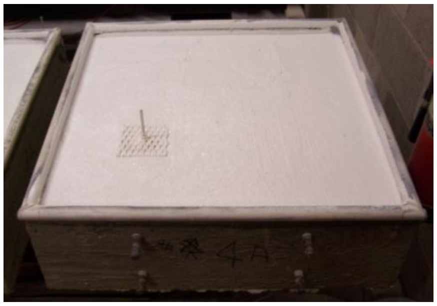

Figure 127: Condition of TSZ w/EP-C(2) at 1.5-months

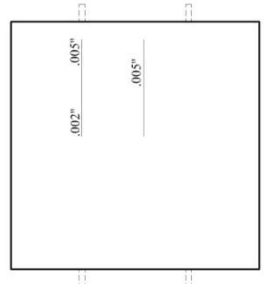

Figure 128: Crack-mapping of TSZ w/EP-C(2) at 0-months

Figure 129: Condition of TSZ w/EP-C(2) after 3-months

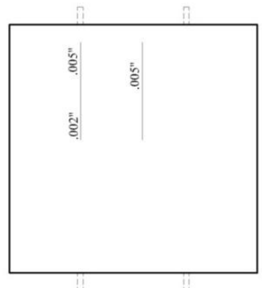

Figure 130: Crack-mapping of TSZ w/EP-C(2) after 3-months

Figure 131: Condition of TSZ w/EP-C(2) after 6-months

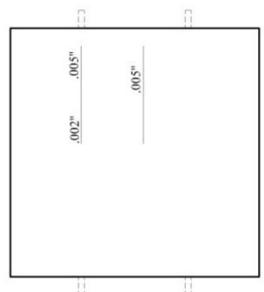

Figure 132: Crack-mapping of TSZ w/EP-C(2) after 6-months

Figure 133: Dissection of TSZ w/EP-C(2) after 6-months

Figure 134: Close-up of TSZ w/EP-C(2) exposed rebar

4.2.5 Specimen #5 – EA-A w/A-C (1)

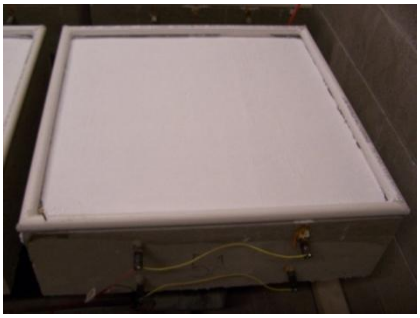

Figure 135: Condition of EA-A w/A-C(1) at 1.5-months

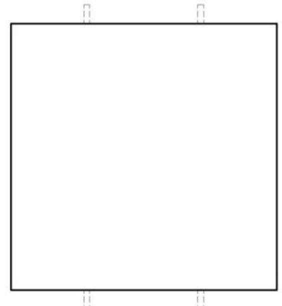

Figure 136: Crack-mapping of EA-A w/A-C(1) at 0-months

Figure 137: Condition of EA-A w/A-C(1) after 3-months

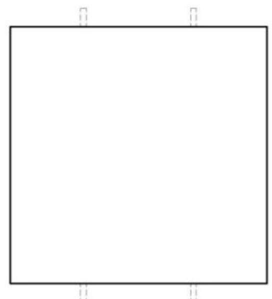

Figure 138: Crack-mapping of EA-A w/A-C(1) after 3-months

Figure 139: Condition of EA-A w/A-C(1) after 6-months

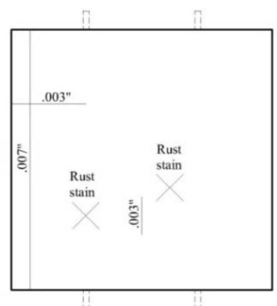

Figure 140: Crack-mapping of EA-A w/A-C(1) after 6-months

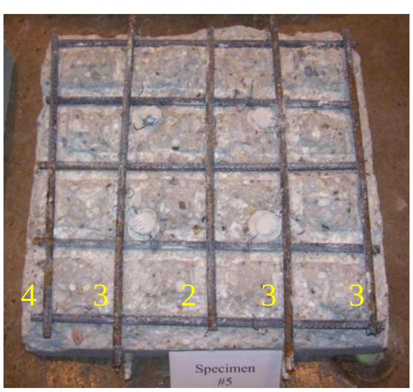

Figure 141: Dissection of EA-A w/A-C(1) after 6-months

Figure 142: Close-up of EA-A w/A-C(1) exposed rebar

4.2.6 Specimen #6 – EA-A w/A-C (2)

Figure 143: Condition of EA-A w/A-C(2) at 1.5-months

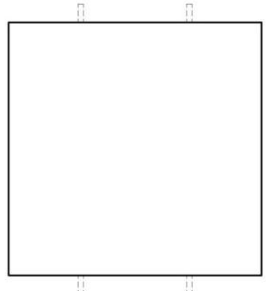

Figure 144: Crack-mapping of EA-A w/A-C(2) at 0-months

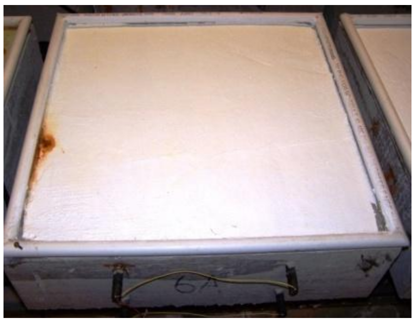

Figure 145: Condition of EA-A w/A-C(2) after 3-months

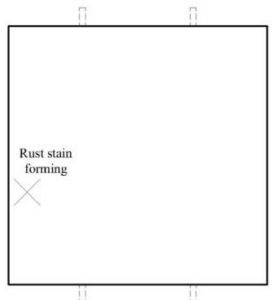

Figure 146: Crack-mapping of EA-A w/A-C(2) after 3-months

Figure 147: Condition of EA-A w/A-C(2) after 6-months

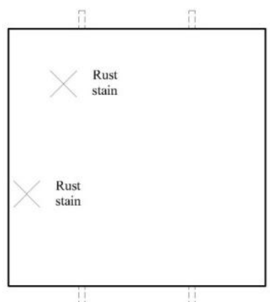

Figure 148: Crack-mapping of EA-A w/A-C(2) after 6-months

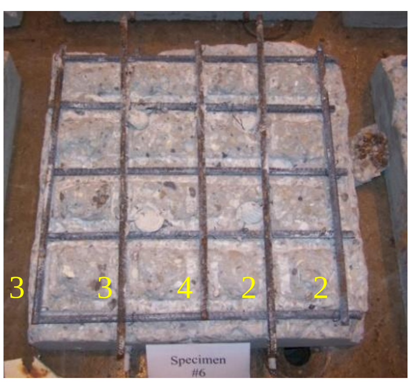

Figure 149: Dissection of EA-A w/A-C(2) after 6-months

Figure 150: Close-up of EA-A w/A-C(2) exposed rebar

4.2.7 Specimen #7 – EA-A (1)

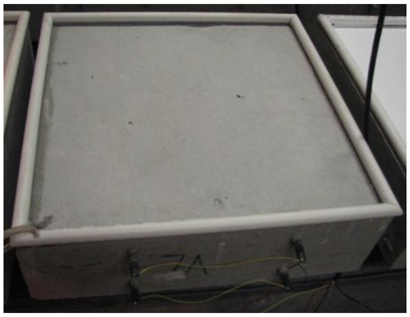

Figure 151: Condition of EA-A(1) at 0-months

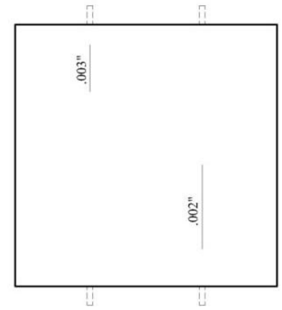

Figure 152: Crack-mapping of EA-A(1) at 0-months

Figure 153: Condition of EA-A(1) after 3-months

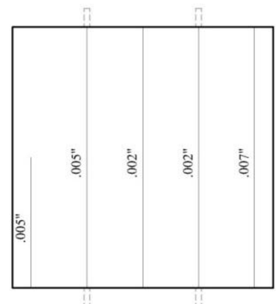

Figure 154: Crack-mapping of EA-A(1) after 3-months

Figure 155: Condition of EA-A(1) after 6-months

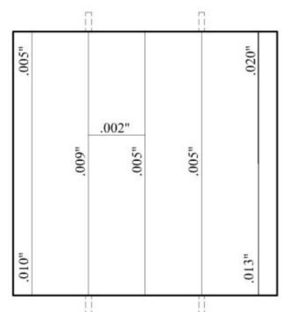

Figure 156: Crack-mapping of EA-A(1) after 6-months

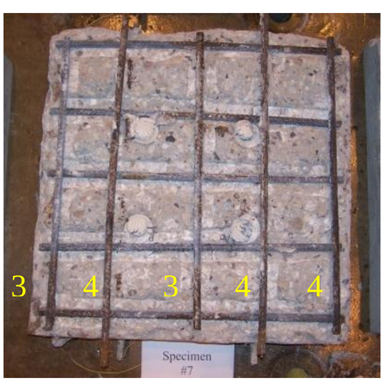

Figure 157: Dissection of EA-A(1) after 6-months

Figure 158: Close-up of EA-A(1) exposed rebar

4.2.8 Specimen #8 – EA-A (2)

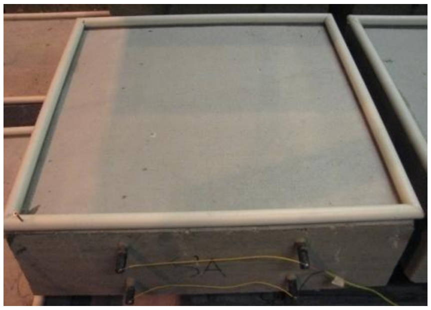

Figure 159: Condition of EA-A(2) at 0-months

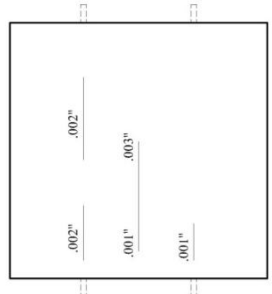

Figure 160: Crack-mapping of EA-A(2) at 0-months

Figure 161: Condition of EA-A(2) after 3-months

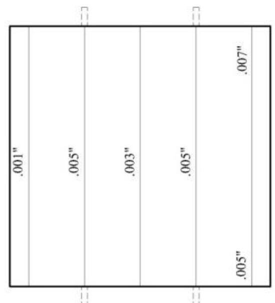

Figure 162: Crack-mapping of EA-A(2) after 3-months

Figure 163: Condition of EA-A(2) after 6-months

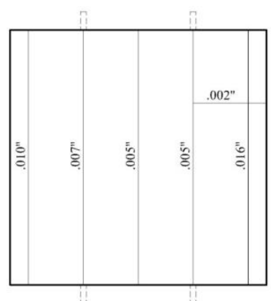

Figure 164: Crack-mapping of EA-A(2) after 6-months

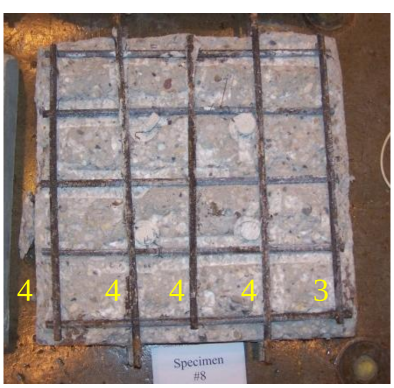

Figure 165: Dissection of EA-A(2) after 6-months

Figure 166: Close-up of EA-A(2) exposed rebar

4.2.9 Specimen #9 – EA-B (1)

Figure 167: Condition of EA-B(1) at 0-months

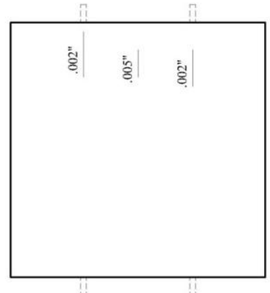

Figure 168: Crack-mapping of EA-B(1) at 0-months

Figure 169: Condition of EA-B(1) after 3-months

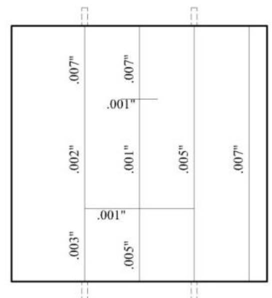

Figure 170: Crack-mapping of EA-B(1) after 3-months

Figure 171: Condition of EA-B(1) after 6-months

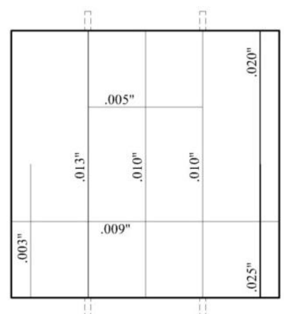

Figure 172: Crack-mapping of EA-B(1) after 6-months

Figure 173: Dissection of EA-B(1) after 6-months

Figure 174: Close-up of EA-B(1) exposed rebar

4.2.10 Specimen #10 – EA-B (2)

Figure 175: Condition of EA-B(2) at 0-months

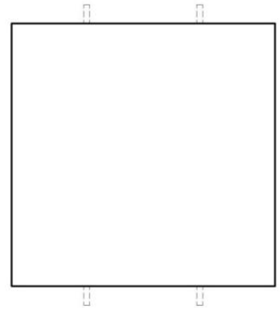

Figure 176: Crack-mapping of EA-B(2) at 0-months

Figure 177: Condition of EA-B(2) after 3-months

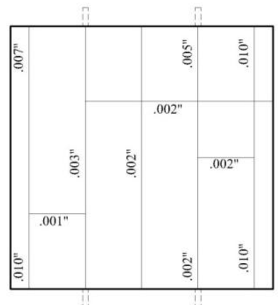

Figure 178: Crack-mapping of EA-B(2) after 3-months

Figure 179: Condition of EA-B(2) after 6-months

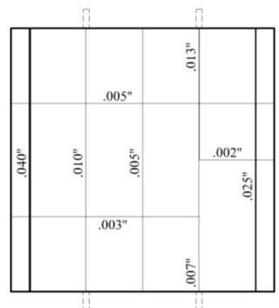

Figure 180: Crack-mapping of EA-B(2) after 6-months

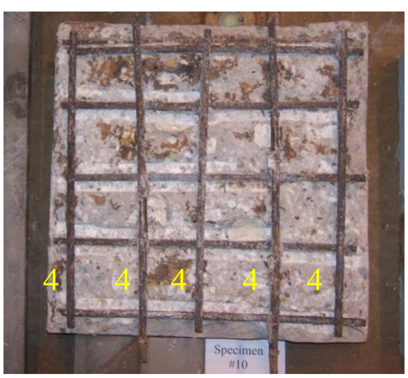

Figure 181: Dissection of EA-B(2) after 6-months

Figure 182: Close-up of EA-B(2) exposed rebar

4.2.11 Specimen #11 – T-SS (1)

Figure 183: Condition of T-SS(1) at 0-months

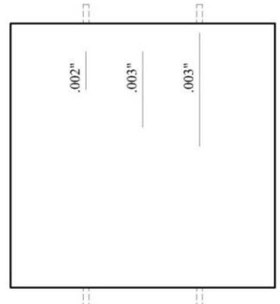

Figure 184: Crack-mapping of T-SS(1) at 0-months

Figure 185: Condition of T-SS(1) after 3-months

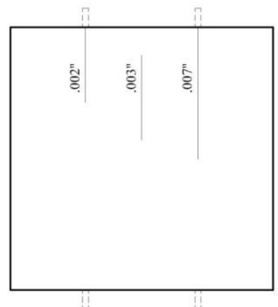

Figure 186: Crack-mapping of T-SS(1) after 3-months

Figure 187: Condition of T-SS(1) after 6-months

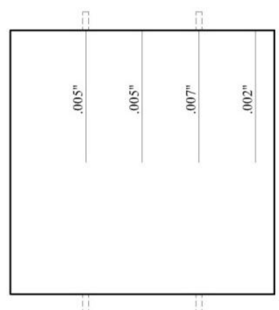

Figure 188: Crack-mapping of T-SS(1) after 6-months

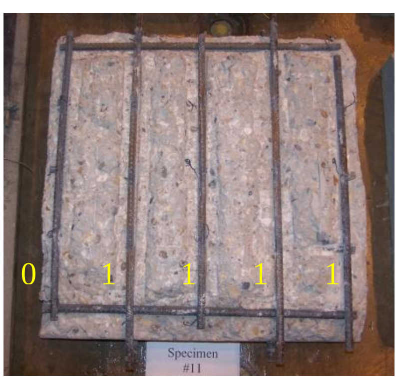

Figure 189: Dissection of T-SS(1) after 6-months

Figure 190: Close-up of T-SS(1) exposed rebar

4.2.12 Specimen #12 – T-SS (2)

Figure 191: Condition of T-SS(2) at 0-months

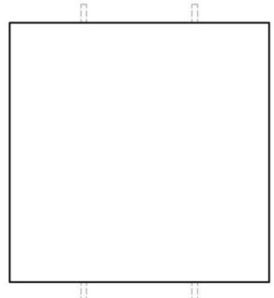

Figure 192: Crack-mapping of T-SS(2) at 0-months

Figure 193: Condition of T-SS(2) after 3-months

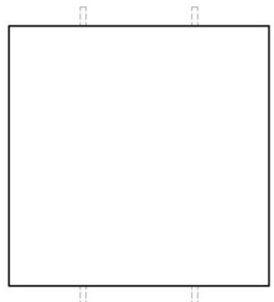

Figure 194: Crack-mapping of T-SS(2) after 3-months

Figure 195: Condition of T-SS(2) after 6-months

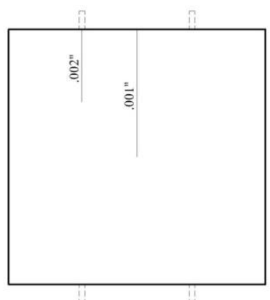

Figure 196: Crack-mapping of T-SS(2) after 6-months

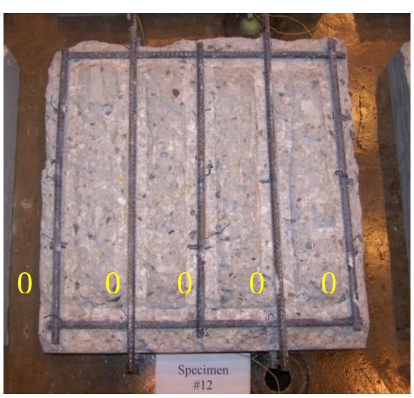

Figure 197: Dissection of T-SS(2) after 6-months

Figure 198: Close-up of T-SS(2) exposed rebar

4.2.13 Specimen #13 – A-C

Figure 199: Condition of A-C at 0-months

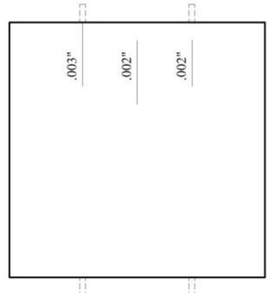

Figure 200: Crack-mapping of A-C at 0-months

Figure 201: Condition of A-C after 3-months

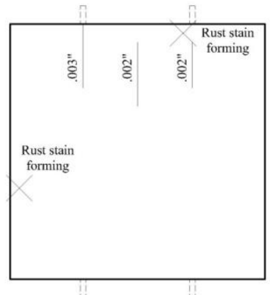

Figure 202: Crack-mapping of A-C after 3-months

Figure 203: Condition of A-C after 6-months

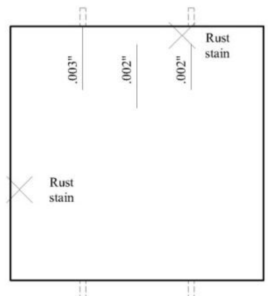

Figure 204: Crack-mapping of A-C after 6-months

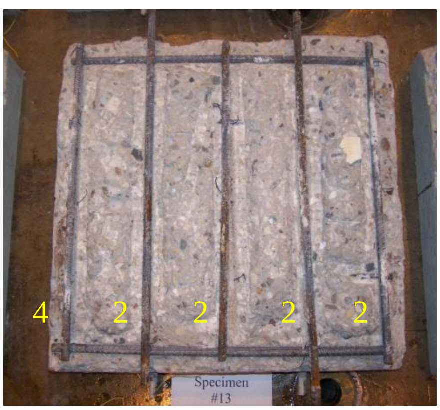

Figure 205: Dissection of A-C after 6-months

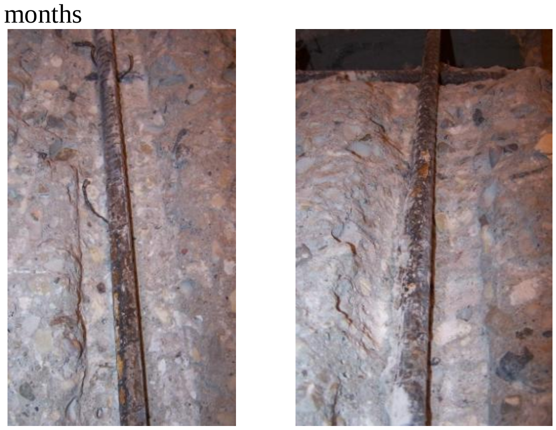

Figure 206: Close-up of A-C exposed rebar

4.2.14 Specimen #14 – EP-C

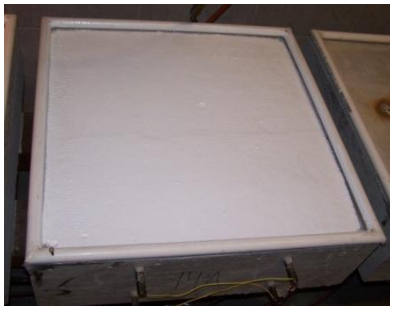

Figure 207: Condition of EP-C at 1.5-months

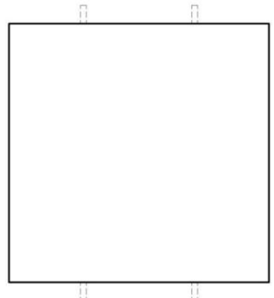

Figure 208: Crack-mapping of EP-C at 0-months

Figure 209: Condition of EP-C after 3-months

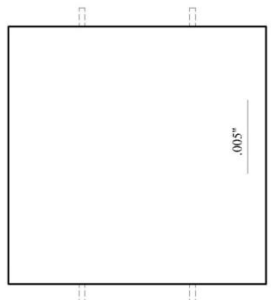

Figure 210: Crack-mapping of EP-C after 3-months

Figure 211: Condition of EP-C after 6-months

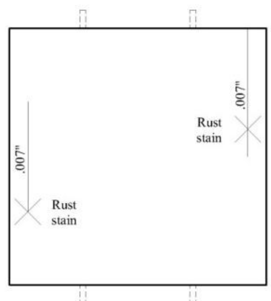

Figure 212: Crack-mapping of EP-C after 6-months

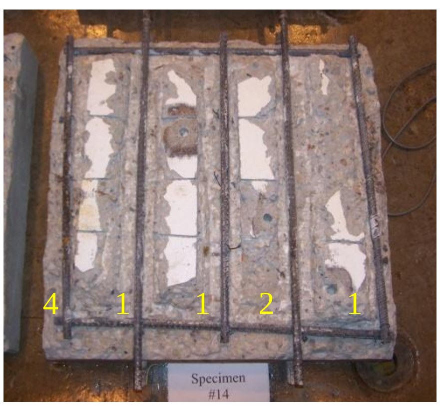

Figure 213: Dissection of EP-C after 6-months

Figure 214: Close-up of EP-C exposed rebar

4.2.15 Specimen #15 – Control (1)

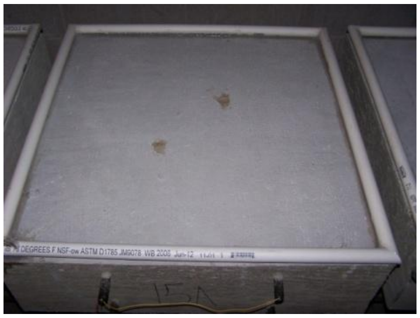
Figure 215: Condition of Control(1) at 0-months

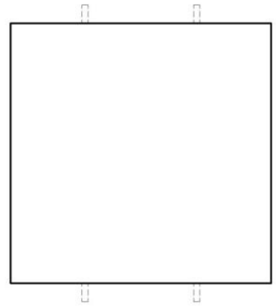
Figure 216: Crack-mapping of Control(1) at 0-months


Figure 217: Condition of Control(1) after 3-months

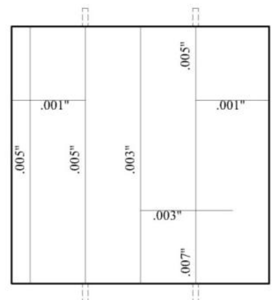

Figure 218: Crack-mapping of Control(1) after 3-months


Figure 219: Condition of Control(1) after 6-months

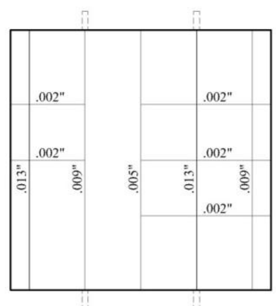

Figure 220: Crack-mapping of Control(1) after 6-months

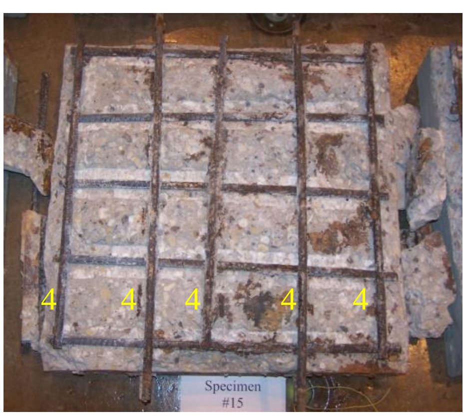

Figure 221: Dissection of Control(1) after 6-months


Figure 222: Close-up of Control(1) exposed rebar

4.2.16 Specimen #16 – Control (2)

Figure 223: Condition of Control(2) at 0-months

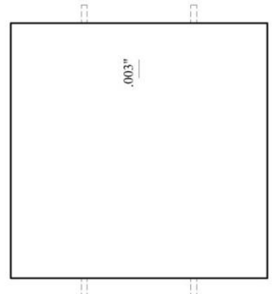

Figure 224: Crack-mapping of Control(2) at0-months

Figure 225: Condition of Control(2) after 3-months

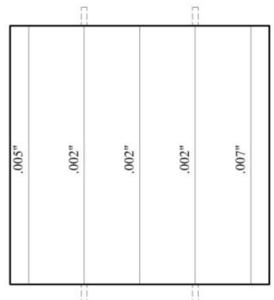

Figure 226: Crack-mapping of Control(2) after 3-months

Figure 227: Condition of Control(2) after 6-months

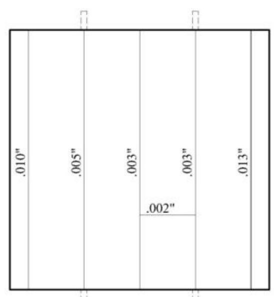

Figure 228: Crack-mapping of Control(2) after 6-months

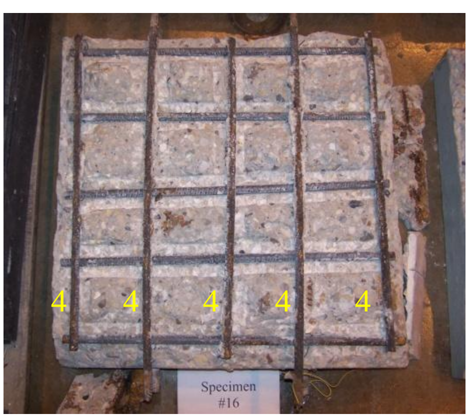

Figure 229: Dissection of Control(2) after 6-months

Figure 230: Close-up of Control(2) exposed rebar

4.2.17 CoP Discussion

The TSZ treatment appeared to offer some protection against the initiation and progression of corrosion. Because of the failed connection of Specimen #2, the condition observations did not accurately portray the effectiveness of the treatment. However, this failure did emphasize the importance of providing redundant connections. In addition, crack-mapping showed that cracks initiated, and increased in width over time. Furthermore, the zinc was indeed "used up" as the color of the zinc turned to a white at the conclusion of accelerated corrosion testing.

In comparison to the TSZ, the TSZ w/EP-C was more effective in preventing the initiation and progression of corrosion. When looking at the crack-map plots, there was no appreciable difference in the cracking over time. When dissected, it is interesting to note that the reinforcing bars with the most corrosion damage were the ones with the connection to the thermal sprayed zinc.

The EA-A w/A-C treatment did not prevent the initiation and progression of corrosion. Although cracking was not prevalent on the concrete surface, rust-staining was.

The EA-A (without coating) treatment was not effective in preventing the initiation and progression of corrosion. Although minor cracking was present at the onset of testing, numerous cracks initiated and grew in size over the duration of accelerated testing. When compared to the Control laboratory specimens, the condition of the exposed EA-A rebar was similar.

Crack initiation, crack growth, and rust-staining were prevalent in the EA-B specimens. The exposed reinforcing steel appeared to be in a visually worse condition than the Control specimens.

The T-SS treatment was effective in preventing the initiation and progression of corrosion. Over the course of testing, only minimal cracks had initiated. When dissected, the condition of the reinforcing steel was in a good state. Only minor surface rust could be found on the exposed reinforcing steel for the T-SS specimens.

The A-C treatment provided some protection against the initiation and progression of corrosion. Although the width of cracks did not appear to increase over time, the presence of rust-staining was evidence that corrosion of reinforcing steel was occurring. When dissected, the rebar was in a better condition compared to the Control specimens. However, the A-C approach was not more effective than the EP-C and T-SS treatments.

The EP-C treatment appeared to be effective in preventing the initiation and progression of corrosion. Although some crack growth and rust-staining occurred, it was limited to a small area on the rebar at the perimeter of the specimens.

As expected, the Control specimens had prevalent crack initiation and growth, as well as extensive rust-staining.

4.3 Condition Observations for CoC Specimens

The initial 3-months of accelerated corrosion testing on the CoC specimens was effective in producing extensive cracking and corrosion of the embedded reinforcing steel. This can be seen with the amount of rust-staining present on the concrete surface (Figure 231).

Figure 231: Rust staining on CoC specimens after 3-months

After the previously discussed patch repairs were completed, the CoC specimens were re-positioned (Figure 232) and the second phase of accelerated corrosion testing for the CoC specimens was commenced (Figures 233 and 234).

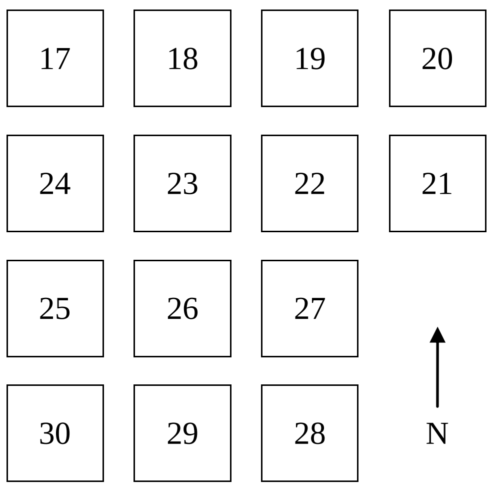

Figure 232: Location of CoC specimens after patch repairs

Figure 233: Condition of CoC specimens after completion of patch repairs

Figure 234: Condition of CoC specimens after 6-months

Sections 4.3.1 through 4.3.14 display the surface condition and associated crack mapping of the CoC specimens at 3-months, the condition of the specimen and exposed reinforcing steel prior to patching, the condition of the specimens after patching, the condition of the specimens after exposure to an additional three months of testing, and the final dissection. Since the initial crack-mapping did not show cracking for any of the CoC specimens, the surface condition and crack-mapping at 0-months were not provided. As before, all of the figures in the following sections are oriented with "North" towards the top of the page (Figures 235 to 346).

4.3.1 Specimen #17 – Control (1)

Figure 235: Condition of Control(1) after 3-months

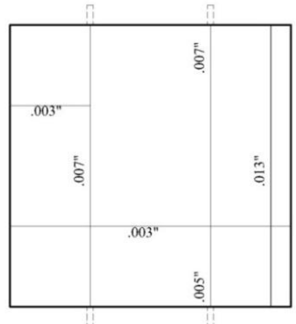

Figure 236: Crack-mapping of Control(1) after 3-months

Figure 237: Condition of Control(1) exposed rebar after 3-months

Figure 238: Close-up of Control(1) exposed rebar after 3-months

Figure 239: Condition of Control(1) after patch repairs

Figure 240: Condition of Control(1) after 6-months

Figure 241: Dissection of Control(1) after 6-months

Figure 242: Close-up of Control(1) exposed rebar after 6-months

4.3.2 Specimen #18 – Control (2)

Figure 243: Condition of Control(2) after 3-months

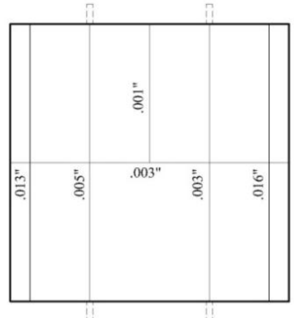

Figure 244: Crack-mapping of Control(2) after 3-months

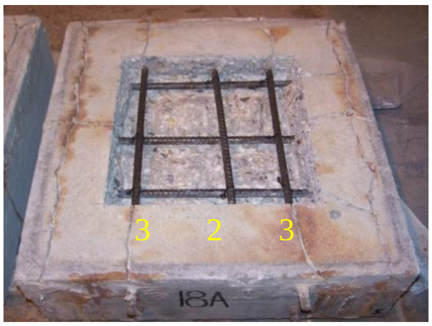

Figure 245: Condition of Control(2) exposed rebar after 3-months

Figure 246: Close-up of Control(2) exposed rebar after 3-months

Figure 247: Condition of Control(2) after patch repairs

Figure 248: Condition of Control(2) after 6-months

Figure 249: Dissection of Control(2) after 6-months

Figure 250: Close-up of Control(2) exposed rebar after 6-months

4.3.3 Specimen #19 – TSZ w/EP-C (1)

Figure 251: Condition of TSZ w/EP-C(1) after 3-months

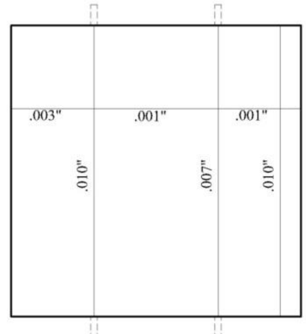

Figure 252: Crack-mapping of TSZ w/EP-C(1) after 3-months

Figure 253: Condition of TSZ w/EP-C(1) exposed rebar after 3-months

Figure 254: Close-up of TSZ w/EP-C(1) exposed rebar after 3-months

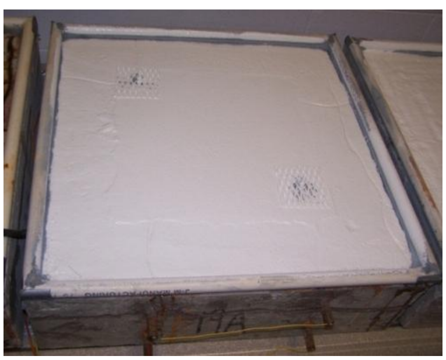

Figure 255: Condition of TSZ w/EP-C(1) after patch repairs

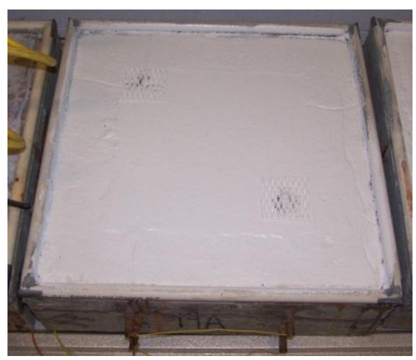

Figure 256: Condition of TSZ w/EP-C(1) after 6-months

Figure 257: Dissection of TSZ w/EP-C(1) after 6-months

Figure 258: Close-up of TSZ w/EP-C(1) exposed rebar after 6-months

4.3.4 Specimen #20 – TSZ w/EP-C (2)

Figure 259: Condition of TSZ w/EP-C(2) after 3-months

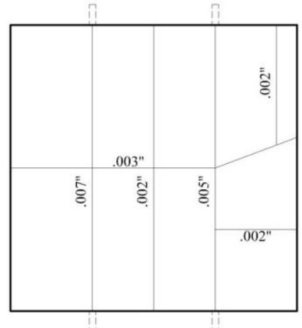

Figure 260: Crack-mapping of TSZ w/EP-C(2) after 3-months

Figure 261: Condition of TSZ w/EP-C(2) exposed rebar after 3-months

Figure 262: Close-up of TSZ w/EP-C(2) exposed rebar after 3-months

Figure 263: Condition of TSZ w/EP-C(2) after patch repairs

Figure 264: Condition of TSZ w/EP-C(2) after 6-months

Figure 265: Dissection of TSZ w/EP-C(2) after 6-months

Figure 266: Close-up of TSZ w/EP-C(2) exposed rebar after 6-months

4.3.5 Specimen #21 – TSZ (1)

Figure 267: Condition of TSZ(1) after 3-months

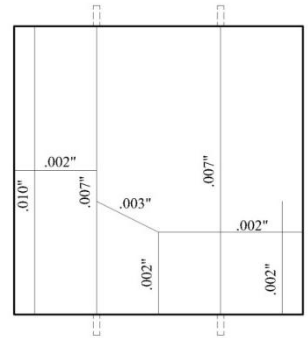

Figure 268: Crack-mapping of TSZ(1) after 3-months

Figure 269: Condition of TSZ(1) exposed rebar after 3-months

Figure 270: Close-up of TSZ(1) exposed rebar after 3-months

Figure 271: Condition of TSZ(1) after patch repairs

Figure 272: Condition of TSZ(1) after 6-months

Figure 273: Dissection of TSZ(1) after 6-months

Figure 274: Close-up of TSZ(1) exposed rebar after 6-months

4.3.6 Specimen #22 – TSZ (2)

Figure 275: Condition of TSZ(2) after 3-months

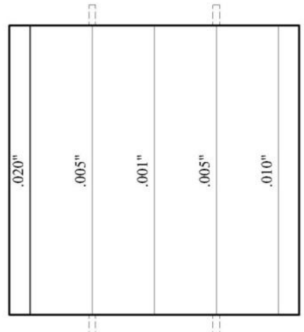

Figure 276: Crack-mapping of TSZ(2) after 3-months

Figure 277: Condition of TSZ (2) exposed rebar after 3-months

Figure 278: Close-up of TSZ(2) exposed rebar after 3-months

Figure 279: Condition of TSZ(2) after patch repairs

Figure 280: Condition of TSZ(2) after 6-months

Figure 281: Dissection of TSZ (2) after 6-months

Figure 282: Close-up of TSZ(2) exposed rebar after 6-months

4.3.7 Specimen #23 – EA-A (1)

Figure 283: Condition of EA-A(1) after 3-months

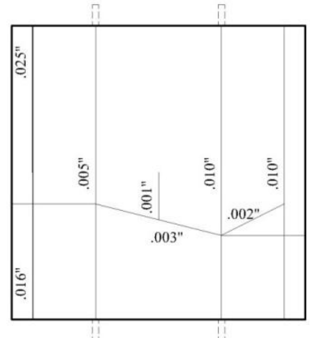

Figure 284: Crack-mapping of EA-A(1) after 3-months

Figure 285: Condition of EA-A(1) exposed rebar after 3-months

Figure 286: Close-up of EA-A(1) exposed rebar after 3-months

Figure 287: Condition of EA-A(1) after patch repairs

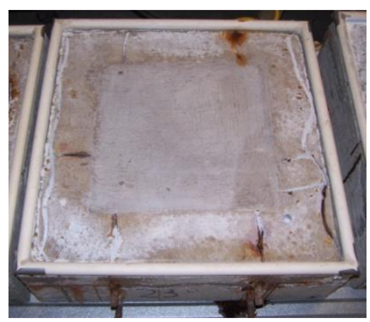

Figure 288: Condition of EA-A(1) after 6-months

Figure 289: Dissection of EA-A(1) after 6-months

Figure 290: Close-up of EA-A(1) exposed rebar after 6-months

4.3.8 Specimen #24 – EA-A (2)

Figure 291: Condition of EA-A(2) after 3-months

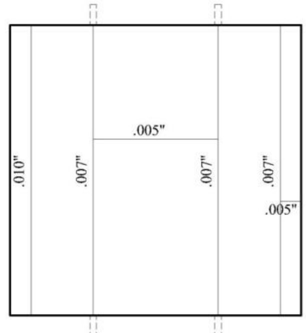

Figure 292: Crack-mapping of EA-A(2) after 3-months

Figure 293: Condition of EA-A(2) exposed rebar after 3-months

Figure 294: Close-up of EA-A(2) exposed rebar after 3-months

Figure 295: Condition of EA-A(2) after patch repairs

Figure 296: Condition of EA-A(2) after 6-months

Figure 297: Dissection of EA-A(2) after 6-months

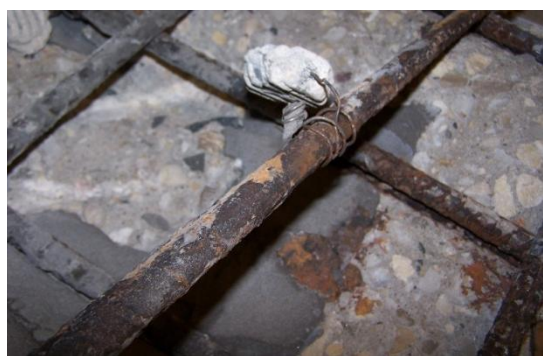

Figure 298: Close-up of EA-A(2) exposed rebar after 6-months

4.3.9 Specimen #25 – EA-A w/A-C (1)

Figure 299: Condition of EA-A w/A-C(1) after 3-months

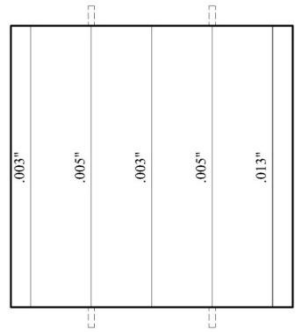

Figure 300: Crack-mapping of EA-A w/A-C(1) after 3-months

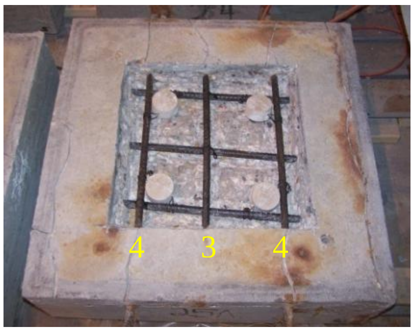

Figure 301: Condition of EA-A w/A-C(1) exposed rebar after 3-months

Figure 302: Close-up of EA-A w/A-C(1) exposed rebar after 3-months

Figure 303: Condition of EA-A w/A-C(1) after patch repairs

Figure 304: Condition of EA-A w/A-C(1) after 6-months

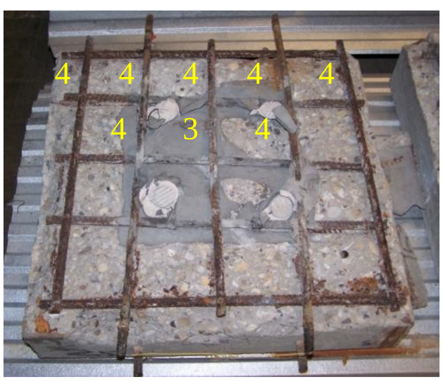

Figure 305: Dissection of EA-A w/A-C(1) after 6-months

Figure 306: Close-up of EA-A w/A-C(1) exposed rebar after 6-months

4.3.10 Specimen #26 – EA-A w/A-C (2)

Figure 307: Condition of EA-A w/A-C(2) after 3-months

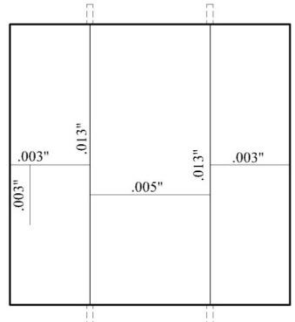

Figure 308: Crack-mapping of EA-A w/A-C(2) after 3-months

Figure 309: Condition of EA-A w/A-C(2) exposed rebar after 3-months

Figure 310: Close-up of EA-A w/A-C(2) exposed rebar after 3-months

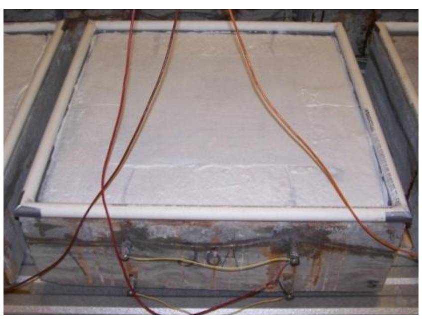

Figure 311: Condition of EA-A w/A-C(2) after patch repairs

Figure 312: Condition of EA-A w/A-C(2) after 6-months

Figure 313: Dissection of EA-A w/A-C(2) after 6-months

Figure 314: Close-up of EA-A w/A-C(2) exposed rebar after 6-months

4.3.11 Specimen #27 – EA-B (1)

Figure 315: Condition of EA-B(1) after 3-months

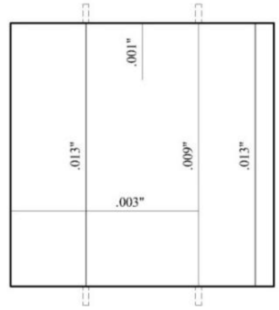

Figure 316: Crack-mapping of EA-B(1) after 3-months

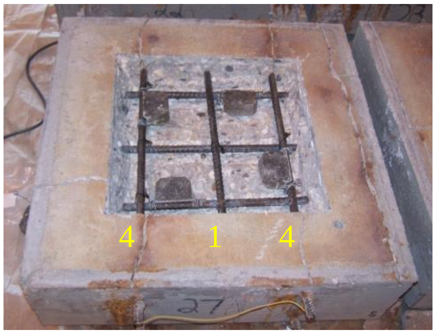

Figure 317: Condition of EA-B(1) exposed rebar after 3-months

Figure 318: Close-up of EA-B(1) exposed rebar after 3-months

Figure 319: Condition of EA-B(1) after patch repairs

Figure 320: Condition of EA-B(1) after 6-months

Figure 321: Dissection of EA-B(1) after 6-months

Figure 322: Close-up of EA-B(1) exposed rebar after 6-months

4.3.12 Specimen #28 – EA-B (2)

Figure 323: Condition of EA-B(2) after 3-months

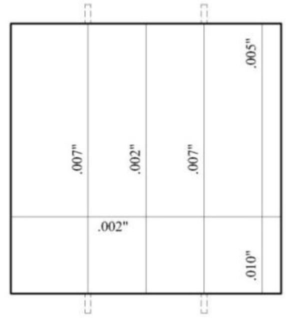

Figure 324: Crack-mapping of EA-B(2) after 3-months

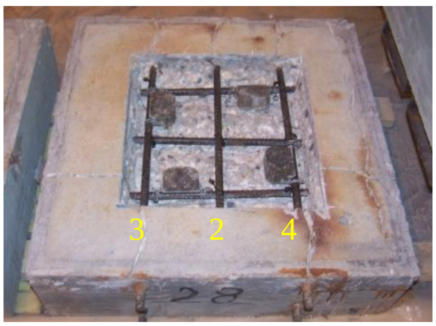

Figure 325: Condition of EA-B(2) exposed rebar after 3-months

Figure 326: Close-up of EA-B(2) exposed rebar after 3-months

Figure 327: Condition of EA-B(2) after patch repairs

Figure 328: Condition of EA-B(2) after 6-months

Figure 329: Dissection of EA-B(2) after 6-months

Figure 330: Close-up of EA-B(2) exposed rebar after 6-months

4.3.13 Specimen #29 – EM (1)

Figure 331: Condition of EM(1) after 3-months

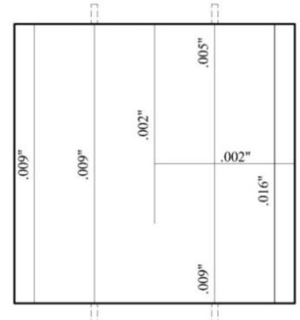

Figure 332: Crack-mapping of EM(1) after 3-months

Figure 333: Condition of EM(1) exposed rebar after 3-months

Figure 334: Close-up of EM(1) exposed rebar after 3-months

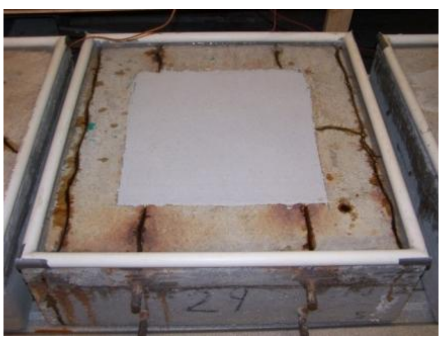

Figure 335: Condition of EM(1) after patch repairs

Figure 336: Condition of EM(1) after 6-months

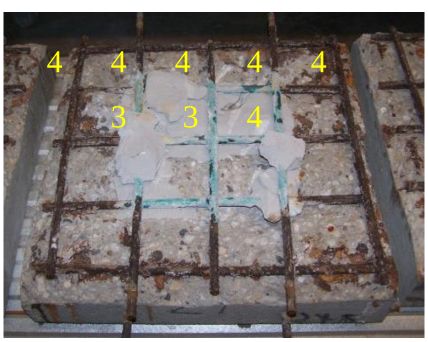

Figure 337: Dissection of EM(1) after 6-months

Figure 338: Close-up of EM(1) exposed rebar after 6-months

4.3.14 Specimen #30 – EM (2)

Figure 339: Condition of EM(2) after 3-months

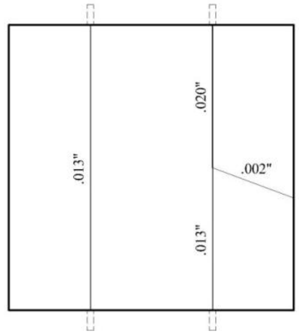

Figure 340: Crack-mapping of EM(2) after 3-months

Figure 341: Condition of EM(2) exposed rebar after 3-months

Figure 342: Close-up of EM(2) exposed rebar after 3-months

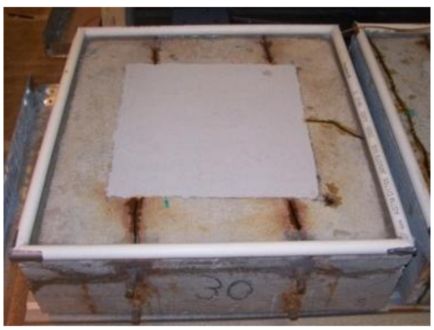

Figure 343: Condition of EM(2) after patch repairs

Figure 344: Condition of EM(2) after 6-months

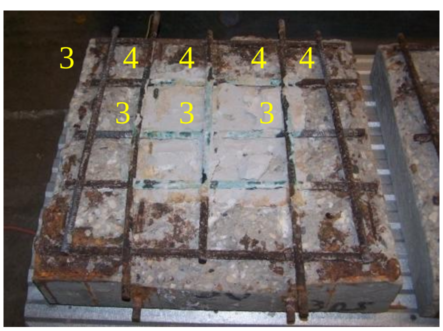

Figure 345: Dissection of EM(2) after 6-months

Figure 346: Close-up of EM(2) exposed rebar after 6-months

4.3.15 CoC Discussion

It appeared that the conventional patch repair material performed well and aided in reducing chloride ingress.

For reinforcing bars that were not exposed and cleaned at 3-months, extensive buildup of corrosion by-products and loss of section on most bars was evident at dissection. This was evidenced by the rating of “4” for the rebar that was “out” of the patch area. Reinforcing bars within the patches did not appear to exhibit major changes from 3-months to 6-months.

When looking at the patched areas of the TSZ and TSZ w/EP-C specimens, it is interesting to note that the rebar directly connected to the thermal sprayed zinc had the most corrosion. Despite this fact, the TSZ treatment was effective in controlling corrosion in the patches.

Specimens with patches containing the EA-A (without coating) and EA-B did not perform better (in controlling corrosion) compared to the Control specimens. The zinc anodes attracted the chloride ions, resulting in increased corrosion on the rebar it was attached to.

Although the EM material did not display signs of cracking, the existence of the “ring-anode” effect at the perimeter of the patch is cause for concern.

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CHAPTER 5

FIELD TESTING OF BRIDGE DECKS

5.1 General

As discussed previously in the report, the project team was informed that numerous bridges in Wisconsin had been constructed with admixtures, sealed with coatings at construction, and sealed with coatings after a few years of exposure. To compare the effectiveness of these treatments, the aforementioned chloride testing procedure was used to determine the surface chloride concentration and diffusion coefficient for each bridge deck in question. By comparing the results to bridge decks that did not receive any treatment, we were able to determine whether or not the treatments were beneficial. The project team would like to thank Mr. Pete Thompson and Mr. Matt Murphy from Dodge County, and Mr. Jerry Hall from Pierce County for providing traffic control for the testing. In addition, Mr. Travis McDaniel from WI DOT was paramount in providing information pertaining to the bridges in question.

5.2 Bridge Decks Tested

The selection of the bridge deck to be tested was based on the year of construction, treatment, average daily traffic (ADT), bridge deck rating (according to the most recent bridge inspection), and the feature under the bridge. The applied sealer, a tri-siloxane masonry water repellent, will be referred to as "Sealer." The bridge decks chosen are presented in Table 44. Chloride testing results and plans with the locations of the chloride testing can be found in Appendix G.

Table 44: Description of bridge decks tested

Bridge	County	Year Built	Treatment	ADT	NBI Deck Rating	Feature Under
B-14-110	Dodge	1994	Sealer at construction (121)	2380	6 (122)	USH 41
B-14-115	Dodge	1994	Sealer at construction (121)	5000	8 (123)	USH 41
B-14-119	Dodge	1995	None	1670	8 (124)	USH 151
B-14-129	Dodge	1994	1/3 Admix A 1/3 None 1/3 Admix B (28)	2800	8 (125)	Rubicon River
B-14-133	Dodge	1995	1/2 None 1/2 Admix C (28)	350	8 (126)	C&NWT Railroad
B-47-110	Pierce	1993	Sealer in 1997, yearly after 1999 (127)	200	7 (128)	Rush River
B-47-118	Pierce	1992	None	2390	6 (129)	Isabelle Creek
B-47-120	Pierce	1992	None	1120	6 (130)	Pine Creek
B-47-141	Pierce	1994	Sealer in 1998, yearly after 2000 (127)	900	7 (131)	Rush Coulee Creek

5.2.1 Bridge B-14-0110

Bridge B-14-0110 (Figure 347) is located on State Highway 28 and crosses over U.S. Highway 41 in Theresa, WI (Dodge County). The bridge, coated with Sealer after construction only, was constructed in 1994 with coated rebar and is supported by steel plate girders. It is 311.1 ft in length (spans of 140 ft and 165 ft), has a deck width of 71 ft, and a roadway width of 52ft. The most recent inspection gave the bridge deck a NBI rating of 6 and noted that are “Numerous transverse cracks. Several diagonal cracks at the deck ends.” (122)

Figure 347: Bridge B-14-0110

5.2.2 Bridge B-14-0115

Figure 348: Bridge B-14-0115

Bridge B-14-0115 (Figure 348) is located at the junction of State Highway 49/County Highway KK and crosses over U.S. Highway 41 in Lomira, WI (Dodge County). The bridge, coated with Sealer after construction only, was constructed in 1994 with coated rebar and is supported by 70" prestressed girders. It is 236.8 ft in length (spans of 115 ft and 115 ft), has a deck width of 71 ft, and a roadway width of 68 ft. The most recent inspection gave the bridge deck a NBI rating of 8 and noted that are "Few light transverse cracks over the pier." [(123)]

5.2.3 Bridge B-14-0119

Figure 349: Bridge B-14-0119

Bridge B-14-0119 (Figure 349) is located on E. Burnett Street and crosses over U.S. Highway 151 in Beaver Dam, WI (Dodge County). The bridge was constructed in 1995 with coated rebar and is supported by 54" prestressed girders. It is 206.5 ft in length (spans of 104ft and 100ft), has a deck width of 45.2 ft, and a roadway width of 37.7 ft. The most recent inspection gave the bridge deck a NBI rating of 8 and noted that are "Several diagonal cracks and short longits at the deck ends. A few transverse cracks over the pier." [(124)]

5.2.4 Bridge B-14-0129

Figure 350: Bridge B-14-0129

Bridge B-14-0129 (Figure 350) is located on County Highway P and spans over the Rubicon River in Rubicon, WI (Dodge County). The bridge was constructed in 1994 with coated rebar and is supported by 70" prestressed girders. It is 133.7 ft in length (span of 130 ft), has a deck width of 38 ft, and a roadway width of 36 ft. The most recent inspection gave the bridge deck a NBI rating of 8 and noted that there is "some light cracking found on both end of the deck." (125)

As mentioned before, Admix-A was admixed into the concrete of the northern 1/3 of the deck, regular concrete was used in the center 1/3, and Admix-B was admixed into the concrete of the southern 1/3 of the deck. Since the bridge was a WisDOT test bridge, compressive strength results were provided (Table 45).

Table 45: Compressive strength results of Bridge B-14-0129 (132)

Deck Section	DOT Breaks		Project Breaks		(tested at site)		
	7-Day (psi)	28-Day (psi)	7-Day (psi)	28-Day (psi)	Slump	Air	Water/ C.Y.
Admix-A	3950	5400	4050	5400	3.5"	5.5%	22 gal.
	4100	5420	-	5400			
	-	-	-	5630			
Control	3160	4490	3260*	4330	3.25"	7.3%	22 gal.
	3360	4440	-	4310			
	-	-	-	4600			
Admix-B	3370	4230	3230	4000	2"	5.1%	22.8 gal.
	3220	4400	-	3780			
	-	-	-	4460			

*Note: Correcting to 5.5% air gives 3800, assuming 300 psi loss in strength for each additional % of air.

5.2.5 Bridge B-14-0133

Bridge B-14-0133 (Figure 351) is located on County Highway G and spans over the Chicago and Northwestern Railroad in Westford, WI (Dodge County). The bridge was constructed with coated rebar and is supported by 28" prestressed girders. It is 160.6 ft in length (spans of 52.1 ft, 52.7 ft, and 52.1 ft), has a deck width of 32 ft, and a roadway width of 30 ft. The most recent inspection gave the bridge deck a NBI rating of 8 and noted "cracking above pier caps." (126)

Figure 351: Bridge B-14-0133

In addition, Admix-C was added to the concrete in the west ½ of the bridge deck, as well as the piers and abutments. Compressive strength results are provided in Table 46.

Table 46: Compressive strength results of Bridge B-14-0133 (132)

Deck Section	DOT Breaks		Independent Lab Tests				(tested at site)	
	7-Day (psi)	28-Day (psi)	7-Day (psi)	14-Day (psi)	28-Day (psi)	56-Day (psi)	Slump	Air
Admix-C	-*	-	5200	5532	5402*	-	2.75"	6.5%
	-*	-	5144	5353	6218*	-		
Control	-*	-	-	-	-	6180	2.25"	5.8%
	-*	-	-	-	-	6149		

*Note: Contained 8% air. No record of any DOT tests.

Because of a color difference between the Admix-C section and control section, a protective surface treatment (TK-26) was placed over the entire bridge deck. (132)

5.2.6 Bridge B-47-0110

Bridge B-47-0110 (Figure 352) is located on County Highway G and spans over the Rush River in El Paso, WI (Pierce County). The bridge was constructed in 1993 with coated rebar and is supported by 36" prestressed girders. It was first coated with Sealer in 1997 and on a yearly basis since 1999. It is 158 ft in length (spans of 51.1 ft, 51.8 ft, and 51.1 ft), has a deck width of 32 ft, and a roadway width of 30 ft. The most recent inspection gave the bridge deck a NBI rating of 7 and noted "Transverse hair line cracking over piers. Some scaling under guard rail W side." (127), (128)

Figure 352: Bridge B-47-0110

5.2.7 Bridge B-47-0118

Bridge B-47-0118 (Figure 353) is located on State Highway 35 and spans over the Isabelle Creek in Bay City, WI (Pierce County). The bridge was constructed in 1992 with coated rebar and is supported by haunched slabs. It is 133.6 ft in length (spans of 40.0 ft, 53.0 ft, and 40 ft), has a deck width of 46 ft, and a roadway width of 44 ft. The most recent inspection gave the bridge deck a NBI rating of 6 and noted a "Couple hairline longitudinal cracks." On the underside of the deck, it

Figure 353: Bridge B-47-0118

noted, "Couple hairline longitudinal leaching cracks. All spans have rust staining. North edge, 2 feet wide full length of deck is spalled with exposed rusty rebar." (129)

5.2.8 Bridge B-47-0120

Bridge B-47-0120 (Figure 354) is located on State Highway 35 and spans over Pine Creek in Maiden Rock, WI (Pierce County). The bridge was constructed in 1992 with coated rebar and is supported by 70" prestressed girders. It is 113.7 ft in length (span of 110 ft), has a deck width of 43 ft, and a roadway width of 40 ft. The most recent inspection gave the bridge deck a NBI rating of 6 and noted "Med. Scaling @ edges" and a "Few hairline diagonal cracks off deck ends." (130)

Figure 354: Bridge B-47-0120

5.2.9 Bridge B-47-0141

Bridge B-47-0141 (Figure 355) is located on County Highway S and spans over the Rush Coulee Creek in Plum City, WI (Pierce County). The bridge was constructed in 1994 with coated rebar and is supported by a flat concrete slab. It was first coated with Sealer in 1998 and on a yearly basis since 2000. It is 47.9 ft in length (span of 46.0 ft), has a deck width of 32 ft, and a roadway width of 30 ft. The most

Figure 355: Bridge B-47-0141

recent inspection gave the bridge deck a NBI rating of 7 and noted that the “concrete deck has minor spalling and small popouts , but there are no cracks at this date.” [(127), (131)]

5.3 Results

To obtain statistically accurate results, a minimum of three locations were tested for each treatment on each bridge deck. At each location, chloride powders were obtained for each ¼” increment of depth to a total depth of 2” (Figure 356). For instance, since the concrete for the bridge deck of Bridge B-14-0129 was placed in thirds, three locations were tested in the Admix-A section, Control section, and Admix-B section of the bridge deck. For the bridge decks with uniform treatments, four locations were tested. See Appendix G for the chloride powder locations and complete chloride testing results.

Figure 356: Obtaining chloride powders from bridge deck

After the chloride powders were obtained, they were brought back to the laboratory at UW-Milwaukee and tested in accordance with the aforementioned RCT-1029 test. Following the calculation of the chloride contents, several SSE regression analyses were performed to determine the surface chloride content and diffusion coefficient for each bridge deck.

To show the levels of chlorides present in each bridge deck, Table 47 has been developed to present the average chloride content of each increment of depth. In addition, the chloride content values obtained from this project at a depth of 2” for bridges B-14-0129 and B-14-0133 were compared against the values provided by the WisDOT (Table 48 and 49).

Table 47: Chloride content of Dodge and Pierce County bridge decks

Depth	B-14-110	B-14-115	B-14-119	B-14-0129		
				Admix-A	Control	Admix-B
0" to ¼"	0.643	0.457	0.574	0.477	0.492	0.543
¼" to ½"	0.511	0.458	0.487	0.365	0.403	0.458
½" to ¾"	0.427	0.368	0.327	0.293	0.348	0.377
¾" to 1"	0.379	0.270	0.293	0.257	0.288	0.251
1" to 1¼"	0.312	0.227	0.205	0.179	0.198	0.202
1¼" to 1½"	0.201	0.202	0.193	0.137	0.136	0.148
1½" to 1¾"	0.188	0.172	0.129	0.083	0.088	0.078
1¾" to 2"	0.115	0.132	0.081	0.046	0.046	0.043
Depth	**B-14-0133**		**B-47-110**	**B-47-118**	**B-47-120**	**B-47-141**
	Control	**Admix-C**				
0" to ¼"	0.627	0.513	0.290	0.406	0.450	0.313
¼" to ½"	0.477	0.380	0.438	0.456	0.615	0.339
½" to ¾"	0.413	0.330	0.342	0.426	0.477	0.285
¾" to 1"	0.342	0.304	0.304	0.321	0.445	0.248
1" to 1¼"	0.246	0.263	0.234	0.283	0.431	0.208
1¼" to 1½"	0.206	0.187	0.192	0.241	0.316	0.147
1½" to 1¾"	0.177	0.168	0.164	0.224	0.317	0.094
1¾" to 2"	0.171	0.124	0.173	0.168	0.290	0.072

At first glance, it is not completely clear from Table 47 as to what treatment was most effective at reducing the ingress of chlorides. If one were to look only at the chloride content at a depth of 2", it would appear that Bridges B-14-0129 and B-47-0141 had the lowest chloride levels. Although the level of chlorides at 2" (assumed to be at the level of reinforcing steel) may be indicative of the performance of the concrete treatment, it does not provide for a thorough comparison.

Table 48: Chloride content comparison of Bridge B-14-0129 at 2" (lb/yd^3) (30)

Treatment	Wis DOT Results		Wis DOT Avg.	WHRP 0092-06-06 Results			WHRP Avg.
Admix-A	1.80	3.24	2.52	1.57	1.88	1.96	1.80
Control	2.66	2.09	2.38	2.31	1.14	1.96	1.80
Admix-B	1.91	3.59	2.75	1.45	1.49	2.08	1.67

Table 49: Chloride content comparison of Bridge B-14-0133 at 2" (lb/yd^3) [30]

Treatment	Wis DOT Results		Wis DOT Avg.	WHRP 0092-06-06 Results			WHRP Avg.
Admix-C	3.13	2.55	2.84	3.76	5.29	5.48	4.84
Control	3.53	9.04	6.29	4.50	8.89	6.66	6.68

When asked about the level chlorides provided by the WisDOT, Peter Kemp replied that, "These structures were cored to look at the chloride ion concentration at the top steel level…Please note that the concrete used does not contain any fly ash or slag. This does not reflect the current state of practice that the department is currently employing." [30] In addition, Kemp stated that the depth was not a measured value, but that 2 inches was typical for a minimum cover. [133] When asked if the chloride content was water or acid-soluble, Kemp looked at the calculations and stated that AgNO3 solution (silver nitrate) was used to calculate the chloride content. Since silver nitrate is very soluble in water, he speculated that the chloride content was water soluble. [134]

In describing the level of salt used in the winter months, Pete Thompson replied, "They (Bridges B-14-0129 and B-14-0133) are typically treated with a 50/50 sand salt mix in the winter. The application rates are about 300-500 lbs of mix per mile. They are both treated with liquid magnesium chloride through a spray bar from a truck-mounted tank. The magnesium chloride is a 30% solution in 70% water. This is used as an anti-icing treatment about every 2-3 days in the frost periods." [135]

In comparing the WisDOT data and this project's data for Bridge B-14-0129 at a depth of 2", the chloride levels provided by the WisDOT were greater than the levels found for this project. Also, it does not appear that the admixtures were effective in reducing the ingress of chlorides into the concrete of the bridge deck. For Bridge B-14-0133, the chloride levels provided by the WisDOT were less than those found for this project. At a depth of 2", it appears that the bridge section admixed with Admix-C has a lower chloride content that the control section. As a thorough comparison, further analyses of these bridge decks, as well as the other seven, follow.

To determine the correlation of the results within each bridge deck, analyses were performed utilizing the chloride content at each "individual location" (Figure 357) and the "average of locations" (Figure 358). The regression analyses revealed that the calculated surface chloride contents and diffusion coefficient for the "individual locations" and "average of locations" had excellent agreement (Table 50).

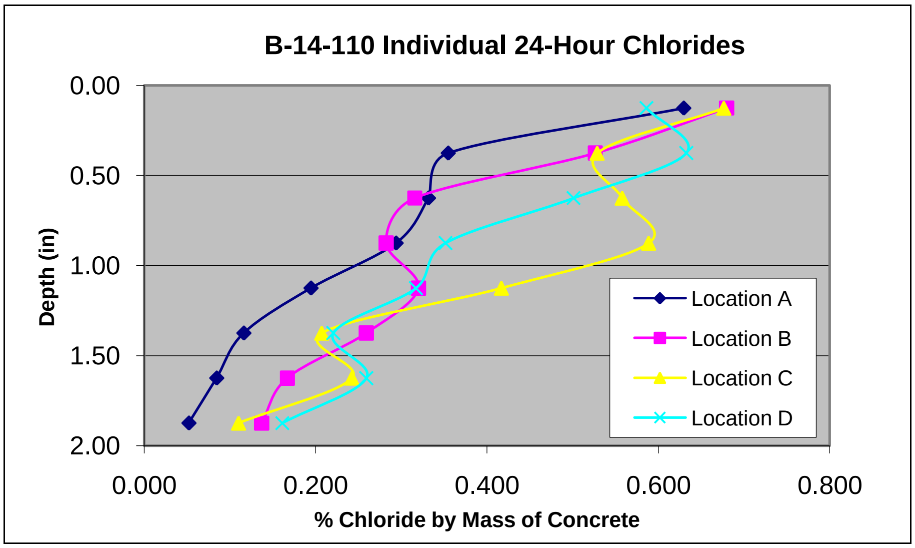

Figure 357: Individual Chloride Content of Locations of Bridge B-14-110

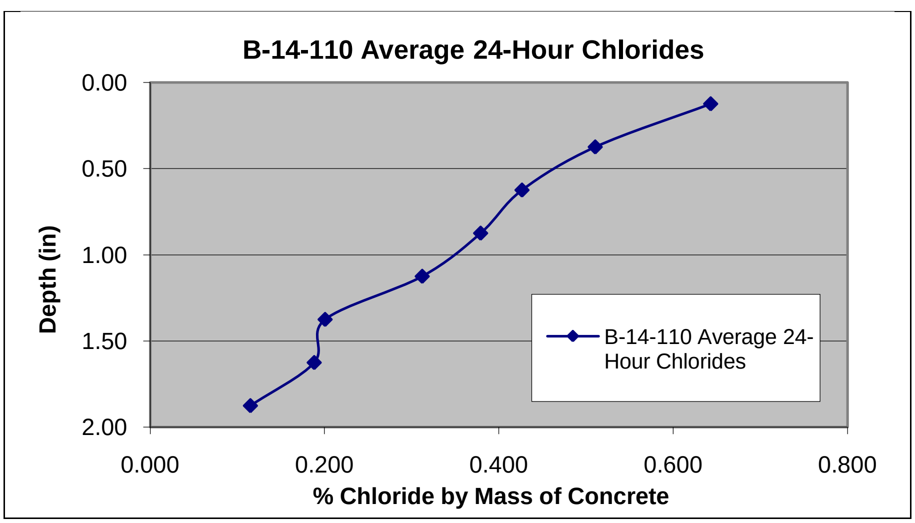

Figure 358: Average Chloride Content of Locations for Bridge B-14-110

Table 50: Diffusion coefficients and surface chloride concentrations for each bridge deck

Bridge	Treatment	Individual Regression						Average Regression	
		$D_{ind.}$ (in²/yr)					$C_{0\text{-}ind}$ (%Cl)	$D_{avg.}$ (in²/yr)	$C_{0\text{-}avg.}$ (%Cl)
		A	B	C	D	Avg.			
14-110	Sealer	.03	.06	.11	.09	.08	.69	.07	.67
14-115	Sealer	.07	.12	.11	.06	.09	.52	.09	.51
14-119	None	.06	.05	.05	.09	.06	.62	.06	.61
14-129	Admix-A	.06	.05	.03	-	.05	.56	.05	.56
	None	.06	.04	.06	-	.06		.06	
	Admix-B	.05	.05	.07	-	.06		.06	
14-133	None	.07	.17	.10	-	.11	.59	.11	.57
	Admix-C	.09	.10	.04	-	.08		.08	
47-110	Sealer	.07	.09	.15	.08	.10	.51	.09	.50
47-118	None	.05	.07	.35	.09	.14	.56	.11	.55
47-120	None	.21	.04	.14	.30	.17	.70	.15	.66
47-141	Sealer	.12	.06	.06	.04	.07	.46	.07	.44

For the bridges in Pierce County, the above analyses did not involve the top ¼” of concrete tested as the chloride content at 0.125” was significantly less than that of the chlorides at 0.375” (Figure 359). A discussion with Jerry Hall, Highway Department Manager for Pierce County, revealed that the bridge decks were flushed with water at the end of April each year, for the last 5 years. [136] It was therefore determined that this would account for the reduction of chlorides in the top ¼” of the concrete.

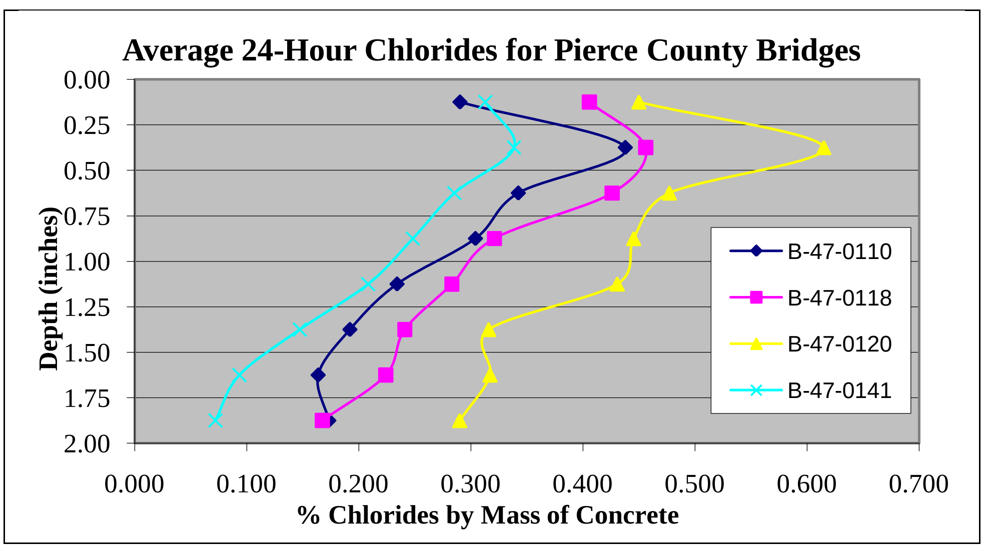

Figure 359: Average chloride content of Pierce County bridge decks

From Table 50 above, it can be seen that the surface chlorides and diffusion coefficients for the “individual locations” and “average of locations” were in close agreement. Therefore, further analyses were performed with the “average of locations.”

Since a “virgin chloride content” was not found and the RCT-1029 method of chloride testing is “acid-soluble”, a theoretical “base-line” chloride level was calculated for each bridge deck. These calculated values were removed from the “raw data” in subsequent analyses so that, theoretically, only the chlorides that entered the bridge decks during exposure would be compared to each another. For Bridges 14-0129 and 14-0133, the control sections were used for calculating the base-line chlorides.

By utilizing Fick’s 2nd Law of diffusion, the data from SHRP S-668 [116], and the data from the control bridges presented above, a determination was made as to what depth chlorides would not be present after 15 years of exposure. This age was used as it was representative of the bridge decks that were tested. Using C_0 = 10.1 lb/yd^3 (0.258% chlorides by concrete weight) and D = 0.11 in^2/yr, as shown in SHRP S-668, chloride levels reached approximately 0% at 5 inches. Using C_0 = 23.1 lb/yd^3 (0.590% chlorides by concrete weight) and D = 0.097 in^2/yr, as found by the control bridge decks in Table 50, chloride levels again reached approximately 0% at 5 inches (Figure 360).

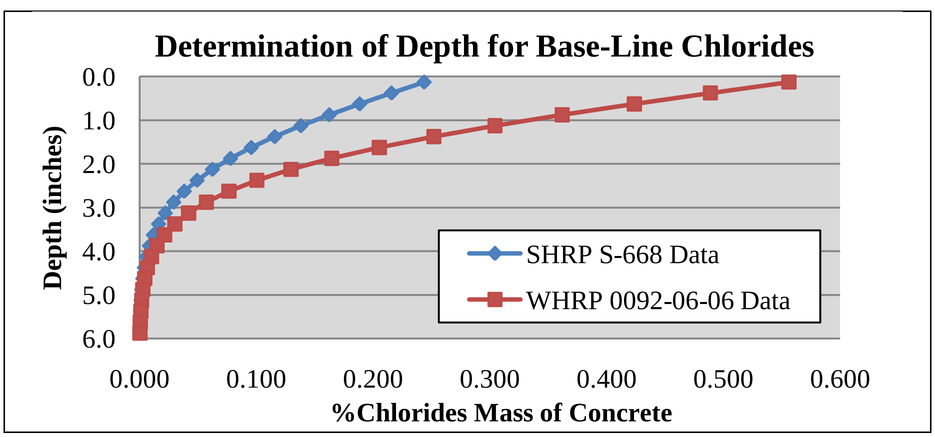

Figure 360: Calculated depth at which chlorides would not be present

Because of these corresponding results, the base-line chlorides were found to be 0% chlorides by mass of concrete at a depth of 5”. By removing this calculated “base-line” level of chlorides from the actual chloride contents, a relative regression analysis could then be performed such that the level of chlorides at 5” was approximately 0% chlorides by mass of concrete. The removal of the “theoretical base-line” chloride content would allow for a plausible comparison among the bridge decks (Table 51).

Table 51: Relative regression analysis for bridge decks

Bridge	Treatment	Average Regression		Relative Regression			
		$D_{avg.}$ (in^2/yr)	$C_{0\text{-avg.}}$ (% Cl^-)	“Base-line” Chlorides	$D_{avg.}$ (in^2/yr)	$C_{0\text{-avg.}}$ (% Cl^-)	% Cl^- at 5”
14-110	Sealer	.073	.672	.000	.073	.672	.000
14-115	Sealer	.092	.511	.010	.087	.502	.001
14-119	None	.059	.612	.000	.059	.612	.000
14-129	Admix-A	.047	.556	.000	.047	.556	.000
	None	.056			.056		.000
	Admix-B	.058			.058		.000
14-133	None	.110	.572	.010	.104	.564	.001
	Admix-C	.082			.077		.000
47-110	Sealer	.095	.503	.020	.083	.488	.001
47-118	None	.105	.547	.030	.089	.521	.002
47-120	None	.155	.664	.050	.126	.619	.009
47-141	Sealer	.072	.439	.000	.072	.439	.000

In Table 51 above, it is shown that the chlorides at a depth of 5” are now approximately 0.0% chlorides by mass of concrete or less, except for Bridge B-47-120. $D_{avg\text{-}rev}$ and $C_{0\text{-}avg\text{-}rev}$ of the control bridges were calculated at 0.087 in^2/yr and 0.574% chlorides by concrete weight, respectively. As a further comparison, the relative regression data was further analyzed to determine the diffusion coefficients for each treatment while also calculating a uniform surface chloride concentration for all of the bridge decks that were tested (Table 52).

Table 52: Comparative regression analysis for bridge decks

Bridge	Treatment	Comparative Regression $D_{avg.-comp}$ (in^2/yr)	C_{0-comp} (%Cl^-)	C_{0-comp} (lb/yd^3)
14-110	Sealer	.106	.565	22.13
14-115	Sealer	.067		
14-119	None	.069		
14-129	Admix-A	.045		
	None	.054		
	Admix-B	.056		
14-133	None	.103		
	Admix-C	.077		
47-110	Sealer	.061		
47-118	None	.074		
47-120	None	.164		
47-141	Sealer	.045		

The final regression revealed that the $D_{avg-comp}$ and C_{0-comp} for the control bridge decks were 0.093 in^2/yr and 0.565% chlorides by concrete weight, respectively. This compared quite favorably to the values obtained in Table 51 above. Because of the consistent surface chloride content, a direct comparison of the bridge decks can be made using the diffusion coefficients of Table 52.

Furthermore, the diffusion coefficient values obtained compare quite favorable to those calculated for Midwestern states found in SHRP S-668 (see Table 13). However, the surface chloride coefficient for Wisconsin was found to be approximately double that of the SHRP S-668 study.

To show how the analyses involving the "comparative chloride regression" and "relative chloride regression" related to the "raw data", Figures 361 and 362 have been provided as a comparison to Figures 358 and 359 above. The "base-line" chlorides have not been added to the regression plots. The plots show an excellent agreement between the raw data and regression curves.

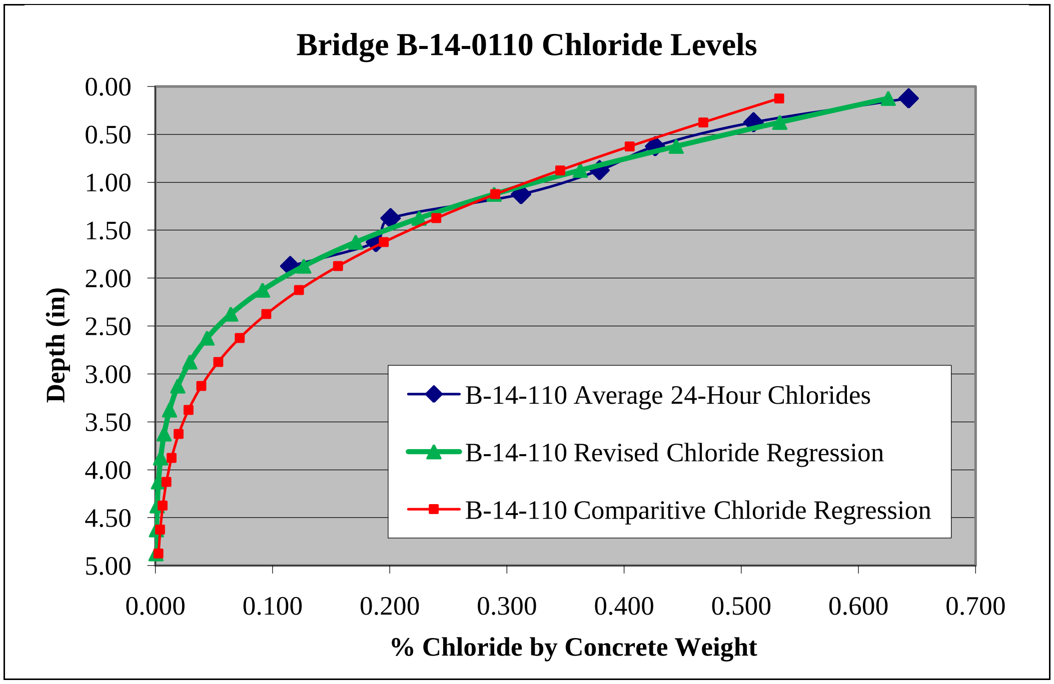

Figure 361: Bridge B-14-0110 Regression Comparison

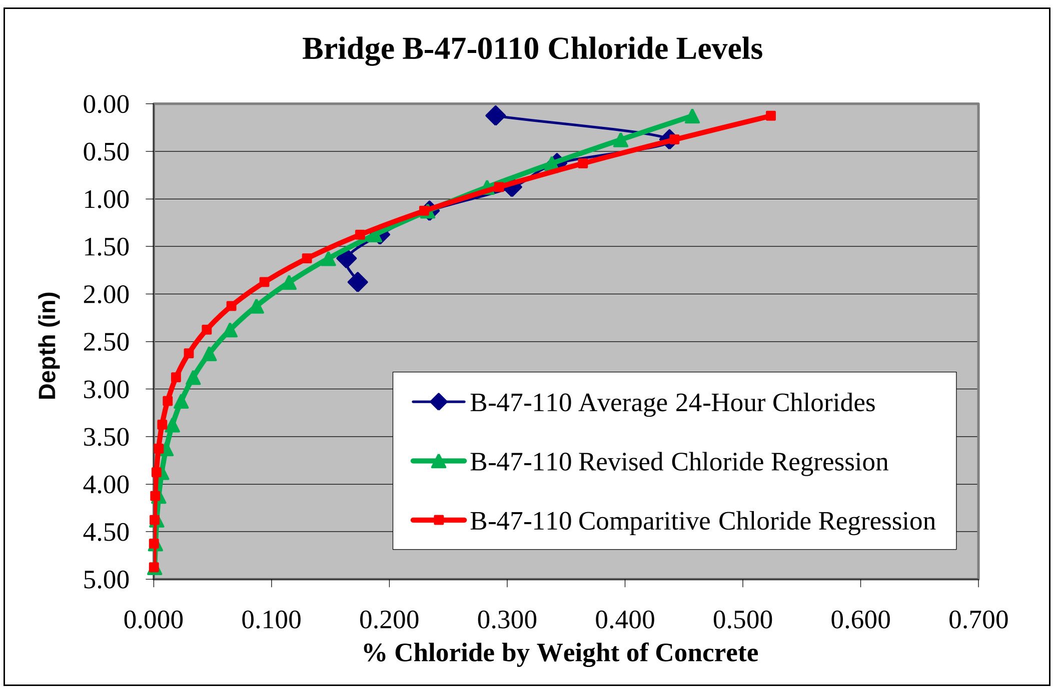

Figure 362: Bridge B-47-0110 Regression Comparison

To compare the effectiveness of the admixtures in reducing chloride ingress, Figures 363 and 364 have been developed. In Figure 364, it appears that Admix-A performs slightly better than Control-AB and Admix-B. However, it is shown in Figure

363 that the chloride content for Admix-A, Control-AB, and Admix-B are the same at a depth of 2”. Thus, the use of Admix-A and Admix-B do not appear to affect the ingress of chlorides. Furthermore, the lower chloride contents of this bridge deck (B-14-0129) in general appear to be due to the material properties of the concrete, and not the admixtures. This is assumed as the control section displays a lower level of chlorides than the other bridge decks. On the other hand, Figures 363 and 364 both show that Admix-C performs better than its control section, Control-C.

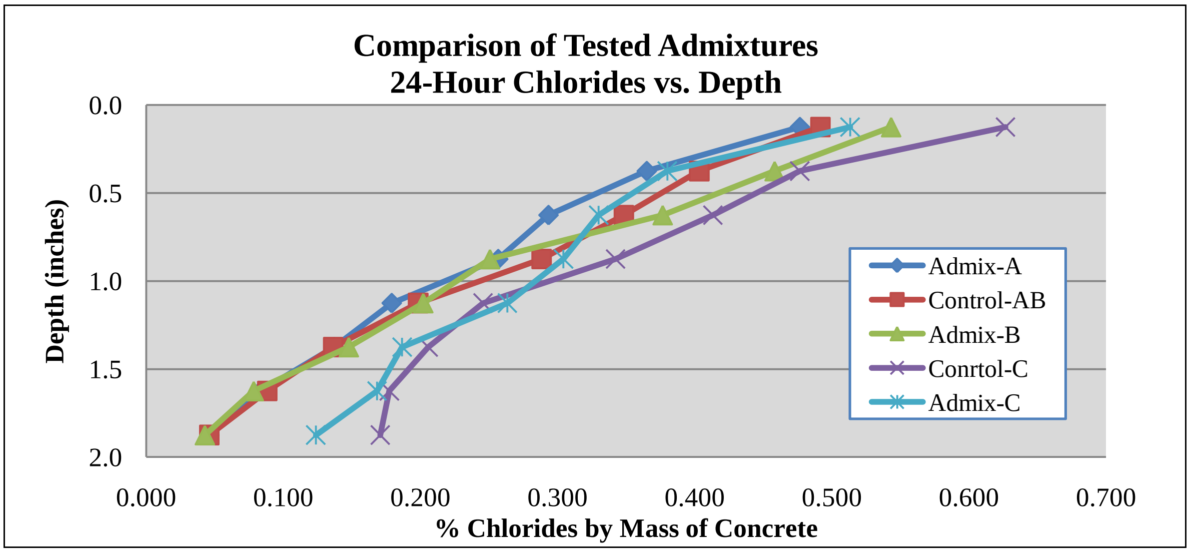

Figure 363: Comparison of chloride contents of tested admixtures

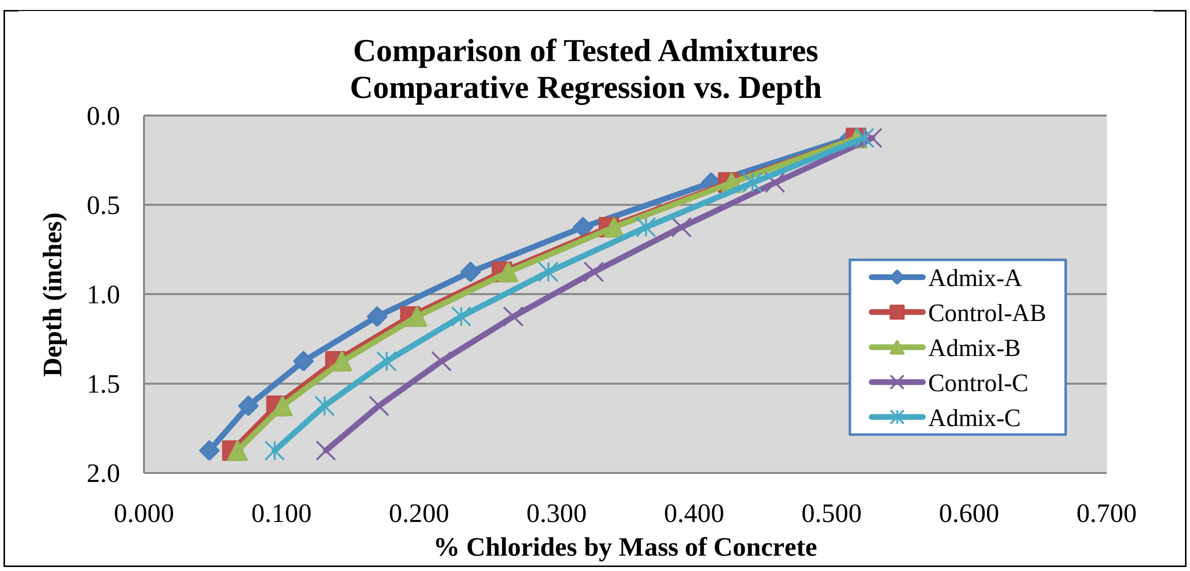

Figure 364: Comparative regression analysis of tested admixtures

5.4 Discussion

From the Dodge County bridge decks, it was discovered that sealers applied at construction only (and without re-application) did not affect the ingress of chlorides. In fact, B-14-0119 performed only slightly worse than B-14-0110 and much better than B-14-0115. Although Admix-A of Bridge B-14-0129 provided a lower diffusion coefficient than Admix-B, it did not perform significantly better than the Control section of that bridge deck. Furthermore, the chloride contents at a depth of 2" were the same for each section of Bridge B-14-0129. In contrast, the diffusion coefficient and level of chlorides at a depth of 2" for Admix-C were less than the Control section of Bridge B-14-0133.

In Pierce County, the bridge decks that have been sealed after a few years of untreated exposure, and with subsequent reapplication, were found to display a lower diffusion coefficient than the bridge decks that had not been sealed at all. This shows that periodic reapplication of sealers, even if not used at construction, aids in reducing chloride ingress. Therefore, it appears that sealers must be periodically re-applied in order to be effective over the long term.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary and Conclusions

Based on an extensive literature review, an experimental program was initiated to investigate new or promising techniques to improve the repair and maintenance of reinforced concrete bridges in Wisconsin.

By subjecting 30 laboratory specimens to 6-months of accelerated corrosion testing that consisted of cyclic wet/dry cycles and an applied regulated voltage, the use of galvanic thermal sprayed zinc, galvanic embedded anodes, sealers, coatings, and epoxy repair mortar was evaluated. Sixteen of the specimens received treatment prior to exposure to accelerated corrosion (CoP) while the remaining fourteen specimens were cast with mixed-in chlorides and subjected to patch repair treatments after 3 months of accelerated corrosion testing (CoC). After repairs, these fourteen specimens were subjected to an additional 3 months of testing. Each treatment in question was applied to two specimens. The specimens were evaluated with respect to corrosion currents, chloride ingress, half-cell potential readings, extent of cracking, rust staining, and inspection of the reinforcing steel after the conclusion of testing.

In addition, the use of admixtures and sealers was evaluated on nine different bridge decks across Wisconsin through an extensive analysis of chloride ingress. Two of the bridge decks were cast with admixtures to reduce chloride ingress, four of the bridge decks were treated with surface sealers at various times of exposure, and three of the bridge decks were untreated.

6.1.1 Laboratory Specimens

Regarding the corrosion prevention specimens (CoP), the tri-silane sealer (T-SS) and thermal sprayed zinc with epoxy/polyurethane coating (TSZ w/EP-C) were found to be the most effective in preventing the initiation of corrosion. Because of the added cost of the TSZ w/EP-C, the T-SS appears to be the most economical choice in preventing the initiation of corrosion. The EP-C alone offered significant protection as well. Although a connection failed in one of the TSZ specimens, the method appeared to be effective when working properly. The embedded anodes (both EA-A and EA-B) were not found to be effective in the laboratory tests. The anodes attracted more chlorides to their vicinity and created variable chloride concentrations and non-uniform chloride penetrations. The use of coatings in conjunction with the embedded anodes was moderately effective; however, the acrylic coating (A-C) alone was more effective than the embedded anode with acrylic coating (EA-A w/A-C).

In regards to the corrosion control specimens (CoC), embedded anode-A with acrylic coating (EA-A w/A-C), thermal spray zinc (TSZ), and thermal sprayed zinc with epoxy/polyurethane coating (TSZ w/EP-C) were most effective in controlling corrosion. Essentially, these repairs utilized a coating. The performance of the embedded anodes (EA-A without coating and EA-B) were similar to that of the Control specimens. For the epoxy repair material (EM), the initial increase in corrosion current and appearance of the "ring-anode" effect at the perimeter of the patch must be considered. Furthermore, the conventional patch repair material itself did not show any signs of distress.

6.1.2 Field Testing of Bridge Decks

Chloride analysis of the bridge decks indicated that sealers applied at construction only (and without subsequent reapplication) did not adequately reduce chloride ingress. It was discovered that sealers should be reapplied on a periodic basis in order to provide long-term protection. In addition, it was discovered that sealing of an untreated bridge, and then providing periodic reapplication, was an effective way to reduce the ingress of chlorides. Furthermore, it was discovered that Admix-A and Admix-B did not perform significantly better than an untreated section of the same bridge deck. In contrast, Admix-C performed better than the untreated section of the same bridge deck.

The surface chloride concentration values calculated in this project were found to be approximately double that of previous findings for Wisconsin while the diffusion coefficient values were found to be similar to earlier reports. This means that measures to prevent the ingress of chlorides are even more important.

6.1.3 Overall Conclusions and Recommendations

For new structures, it is recommended that a surface applied sealer (such as T-SS) be applied prior to exposure to chlorides. A schedule for reapplication of sealers should also be required. Admix-C was found to be the most effective admixture tested when compared to its control section.

For structures with limited exposure and minimal corrosion damage, surface applied sealers should be installed as soon as possible. In addition, a schedule for reapplication of sealers should be required.

For existing structures with significant corrosion damage, the application of thermal sprayed zinc appears to offer benefits. Approved coatings can also be used in conjunction with the thermal sprayed zinc. The embedded anodes did not appear to be beneficial in the laboratory tests. The conventional patch repair material itself performed well.

6.2 Recommendations for Future Research

It is recommended that the testing of sealers and admixtures in the field be expanded. In addition, a long-term study on the use of sealers should be implemented.

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APPENDIX A

Reinforcing Steel and Concrete Data

Ambassador Steel
"REINFORCING AMERICA"

W229 N2520 Duplainville
Waukesha, Wi 53186
Phone: 262-547-6111 Fax:262-547-5679

LOAD SYMBOL	JOB NAME		Barlist/Release Number
Tan T45	UW-M ENGINEERING		0197B
	CUSTOMER: MISC CASH SALES		Job Number: **CASHWAUK**
	DESCRIPTION: **UW-M COLLEGE OF ENGINEERING STOCK SHOP PICKUP**		
MATERIAL TYPE: Rebar-Black 420/60 Grade	CITY, STATE: WAUKESHA, WI 53186	Drawing Number:	Detailed BY: Sue Schilling

Customer Copy

WEIGHT SUMMARY

Total			
Size	Items	Pieces	Lbs
Rebar	Black	420/60	Grade
16/5 Bar	1	800	1891
SizeTot:	1	800	1891

Mill Certification	
Size	Mill Cert. Numbers
Rebar	
16/5 Bar	
SizeTot:	

Straight		Light Bending		Heavy Bending	
Pieces	Lbs	Pieces	Lbs	Pieces	Lbs
800	1891	0	0	0	0
800	1891	0	0	0	0

Total Weight:1891 Lbs. **Longest Length: 2-8** **Widest Width:**

Qty	Size	Length	Mark	Bend	Lbs	A	B	C	D	E	F	G	H	K	R	J	O	EP
Rebar	Black	420/60	Grade															
160	16/5	2-8			445													
640	16/5	2-2			1446													
800		SubTot			1891													

Printed on 12/22/2006 at 12:54:29 PM

#5 60-0 REBAR

NUCOR
BAR MILL GROUP
NUCOR STEEL KANKAKEE, INC.

CERTIFIED MILL TEST REPORT

Page: 1

SOLD TO: AMBASSADOR STEEL CORP
PO BOX 2340
KOKOMO, IN 46904-2340

SHIP TO: AMBASSADOR STEEL CORP
CUST TRUCK
(KC)
KOKOMO, IN 00000-

Ship from:
Nucor Steel Kankakee, Inc.
One Nucor Way
Bourbonnais, IL 60914
815-937-3131

Date: 27-Dec-2006
B.L. Number: 334144
Load Number: 5584940

Material Safety Data Sheets are available at www.nucorbar.com or by contacting your inside sales representative.

HEAT NUM. *	DESCRIPTION	PHYSICAL TESTS					CHEMICAL TESTS						
		YIELD P.S.I.	TENSILE P.S.I.	ELONG % IN 8"	BEND	WT% / DEF	C / Ni	Mn / Cr	P / Mo	S / V	Si / Cb	Cu / Sn	C.E.
PO# =>	NU84940												
KN0810959901	Nucor Steel Kankakee, Inc. 16/#5 Rebar 60' A615M Gr 420 (Gr60) ASTM A615M-06 GR 420	67,324 464MPa	103,630 715MPa	13.8%	OK	-3.4% .036	.38 .19	1.02 .11	.016 .058	.051 .010	.23 .002	.40	.57
PO# =>	NU84940												
KN0610960001	Nucor Steel Kankakee, Inc. 16/#5 Rebar 60' A615M Gr 420 (Gr60) ASTM A615M-06 GR 420	67,051 462MPa	102,499 707MPa	13.8%	OK	-3.4% .036	.38 .16	.96 .13	.016 .065	.049 .009	.21 .002	.44	.57

All steel products produced at Nucor Steel Kankakee are manufactured with over 98% recycled materials.

I HEREBY CERTIFY THAT THE ABOVE FIGURES ARE CORRECT AS CONTAINED IN THE RECORDS OF THE CORPORATION.

ALL MANUFACTURING PROCESSES OF THE STEEL MATERIALS IN THIS PRODUCT, INCLUDING MELTING, HAVE OCCURRED WITHIN THE UNITED STATES. ALL PRODUCTS PRODUCED ARE WELD FREE. MERCURY, IN ANY FORM, HAS NOT BEEN USED IN THE PRODUCTION OR TESTING OF THIS MATERIAL.

QUALITY ASSURANCE: Curtis Glenn

CENTRAL READY MIXED
A Prairie Group Company
E.O.E. / A.A.

TO ORDER CONCRETE CALL:
(414) 258-7000
(800) 258-0010

DATE	TICKET TIME	DUE AT JOB	CUSTOMER NO.	TAX CODE	PLANT ID	POUR TYPE	TICKET NO.
03/13/07	09:11	09:56	1005054		107	<UNKNOWN>	758548

CUSTOMER NAME	JOB NAME/ADDRESS	LOAD NO. / ACCUM. YDS.
JWM ACCOUNTS PAYABLE	JOB 3200 N CRAMER MIL	LOAD NO. 0001 ACCUM. YDS. 5.50

PURCHASE ORDER NO.	DRIVERS NAME	MAP PAGE	MIX SLUMP	FOLLOW VEHICLE	AIR CONTENT
1	TRK# 0095 ROUNDTREE, TERRAN		5.00	0087	

PRODUCT ID	QUANTITY	PRODUCT DESCRIPTION	UNIT/MEASURE	PRICE/UNIT	EXTENDED
3125	5.50	4000 1 AE	CY		
901	5.50	HEAT	CY		
903	1.00	FUEL SURCHARGE	LD		
913	5.50	ENVIRONMENTAL CHARGE	CY		

9:15 Load — Time on Job ______ Min.
9:57 Arrive Job — Overtime ______ Min.
10:15 Start Pour — Rate of X $ ______ Per Min.
11:40 Stop Pour — ______ $ OVERTIME CHARGE

Six (6) minutes per yard free unloading time allowed. Additional unloading time charged at current hourly truck rate.

REASON FOR DELAY TIME:
- ☐ Job Not Ready
- ☐ Job Broke Down
- ☐ Truck Broke Down
- ☐ Adding Water
- ☐ Arrived Job Early
- ☐ Slow Placing Method
- ☐ Other (Explain) ______

TOTAL MINUTES ALLOWED: 33

SUB-TOTAL
SALES TAX
SUB-TOTAL
TAXABLE DELAY TIME

GRAND TOTAL *

CAUTION

May cause eye or skin injury. Contains portland cement. Freshly mixed cement, mortar, concrete, or grout may cause skin injury.

TAKE THESE PRECAUTIONS:
1. Avoid all contact with eyes.
2. Wear rubber boots and gloves, and avoid prolonged contact directly with skin or through porous materials.
3. In case of contact with skin or eyes, FLUSH THOROUGHLY WITH WATER.
4. If irritation persists, get medical attention promptly.
5. Keep children away.

WARNING: ADDING WATER TO CONCRETE MATERIAL REDUCES ITS STRENGTH. SELLER IS NOT RESPONSIBLE FOR STRENGTH OF CONCRETE WHEN WATER OR OTHER MATERIAL IS ADDED BY THE BUYER OR AT HIS REQUEST. NOT RESPONSIBLE FOR REACTIVE AGGREGATE OR COLOR QUALITY.

WATER ADDED	MAX ADD WATER GALS.
0	2

Washout Area: Gravel

PURCHASER assumes all responsibility for all property damage caused by SELLER'S truck within confines of the job site. PURCHASER agrees to provide access clear of fixed objects, underground utilities, and overhanging wire for SELLER'S delivery vehicle to delivery point. SELLER'S vehicle is not permitted to travel inside of, or across curb lines. If so directed, PURCHASER assumes all responsibility for damages that may occur as a result of SELLER'S vehicle inside the curb line.

I have read and understand the above and agree to assume the responsibilities for the above.

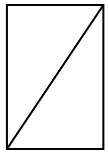
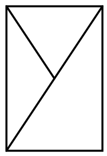
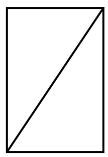
RECEIVED BY: X [signature]
SIGN FULL NAME

CENTRAL READY MIXED
A Prairie Group Company
E.O.E. / A.A.

DELIVERY — Customer agrees to maintain a suitable roadway to point of delivery and customers assume responsibility and shall indemnify seller for truck damage and property damage between curb and point of delivery.
TRUCK WAITING TIME — Customer agrees to pay for excess truck time at current rate per hour for trucks held at place of delivery over the allowable 6 min. per yard.

APPENDIX B

Cylinder Breaks and Baseline Chlorides

Sample #	Break	Compressive Strength (psi)	Average Compressive Strength (psi)
1		5,825	
2		5,994	5,839
3		5,697	

Results of 28-Day Breaks and Compressive Strength

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	99.7	67.8	47.5	-6.2
mV after	99.1	69.8	51.3	-5.3
mV before	103.1	70.7	48.0	-6.0
mV after	100.2	71.0	50.9	-4.6

Baseline Chlorides MDP

	Date:
5 Minute Test	10/18/2007
24 Hour Test	10/19/2007

Assumed weight of concrete = 145.0 lb/yd3

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
11B 1/2"	60.8	0.029	1.135	55.5	0.037	1.449
11B 1"	60.9	0.029	1.135	57.8	0.034	1.331
11C 1/2"	57.8	0.032	1.253	51.0	0.046	1.801
11C 1"	57.3	0.034	1.331	54.2	0.040	1.566
13B 1/2"	59.9	0.030	1.175	56.9	0.035	1.370
13B 1"	64.7	0.024	0.940	59.2	0.033	1.292
13C 1/2"	58.8	0.031	1.214	49.7	0.048	1.879
13C 1"	54.2	0.039	1.527	50.4	0.046	1.801
15B 1/2"	54.6	0.037	1.449	49.3	0.050	1.958
15B 1"	57.6	0.032	1.253	49.8	0.048	1.879
15C 1/2"	54.9	0.037	1.449	49.5	0.049	1.918
15C 1"	58.9	0.031	1.214	54.3	0.039	1.527
	Averages:	**0.032**	**1.256**		**0.042**	**1.648**

Theoretical Chloride Content

Depth	5 Minute Test		24 Hour Test	
	%Cl by mass of concrete	Total %Cl	%Cl by mass of concrete	Total %Cl
0" to 1/4"	0.113	0.145	0.113	0.155
1/4" to 1/2"	0.113	0.145	0.113	0.155
1/2" to 3/4"	0.113	0.145	0.113	0.155
3/4" to 1"	0.113	0.145	0.113	0.155
1" to 1-1/4"	0.049	0.081	0.048	0.090
1-1/4" to 1-1/2"	0.049	0.081	0.048	0.090
1-1/2" to 2"	0.049	0.081	0.048	0.090
2" to 2-1/2"	0.015	0.047	0.014	0.056
2-1/2" to 3"	0.015	0.047	0.014	0.056

Measurement of the acid soluble chloride content of hardened concrete by the RCT method

Report #: ______ **Structure:** ______ **Project:** Baseline Chlorides

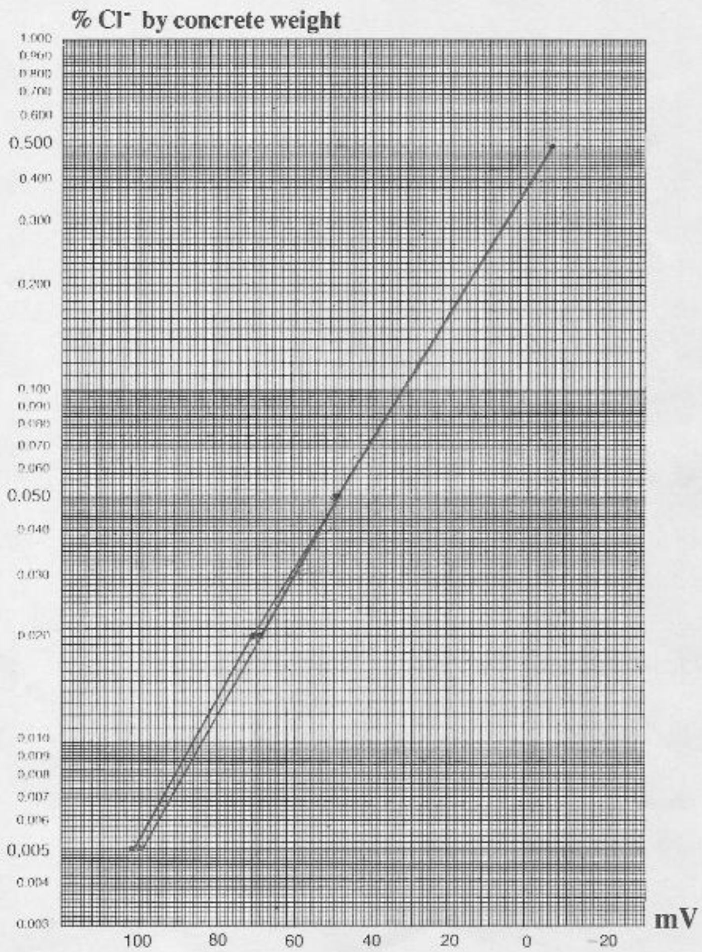
Date of testing: 10/18+19/2007 **Electrode #:** ______ **Person:** MDP

Testing Lab: UWM **Address:** ______ **Phone:** ______

RCT

HARDENED CONCRETE

1.5 gram of concrete dust dissolved in a RCT-1023 vial with 10 milliliter of extraction liquid



CALIBRATION:

Liquid	Clear	Purple	Green	Pink
% Cl	0.005	0.020	0.050	0.500
mV before				
mV after				

SAMPLE #	1		2		Remarks
	mV	% Cl	mV	% Cl	

APPENDIX C

CoP Chlorides

Specimen #1 - 6 Month Exposure

By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	~~106.7~~	~~73.4~~	~~50.3~~	~~-4.7~~
mV after	100.5	67.8	44.5	-11.3
mV after	93.0	62.8	41.8	-13.9
mV after	98.9	68.5	45.2	-11.5

		Date:
	5 Minute Test	6/8/2008
1/4 - 3/4	24 Hour Test	6/23/2008
1 - 2		6/22/2008

Assumed weight of concrete = 145.0 lb/cubic yard

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
1D						
0" to 1/4"	20.3	0.137	5.356	15.6	0.146	5.719
1/4" to 1/2"	54.1	0.034	1.336	40.0	0.051	2.007
1/2" to 3/4"	58.0	0.029	1.138	45.8	0.040	1.565
3/4" to 1"	55.7	0.032	1.251	49.5	0.041	1.608
1" to 1-1/4"	64.9	0.022	0.857	61.9	0.025	0.962
1-1/4" to 1-1/2"	59.3	0.028	1.079	52.0	0.037	1.450
1-1/2" to 1-3/4"	68.8	0.019	0.730	67.6	0.019	0.760
1-3/4" to 2"	79.6	0.012	0.469	69.7	0.018	0.696
1E						
0" to 1/4"	4.9	0.258	10.084	2.5	0.256	10.033
1/4" to 1/2"	30.6	0.090	3.508	19.4	0.124	4.859
1/2" to 3/4"	41.7	0.057	2.224	32.2	0.072	2.805
3/4" to 1"	72.2	0.016	0.635	65.8	0.021	0.818
1" to 1-1/4"	84.8	0.010	0.379	72.7	0.016	0.615
1-1/4" to 1-1/2"	76.9	0.013	0.524	65.2	0.021	0.839
1-1/2" to 1-3/4"	78.7	0.012	0.486	69.4	0.018	0.705
1-3/4" to 2"	75.3	0.014	0.559	60.3	0.026	1.028
1F						
0" to 1/4"	6.6	0.240	9.404	9.6	0.189	7.398
1/4" to 1/2"	24.3	0.116	4.545	15.6	0.146	5.719
1/2" to 3/4"	48.5	0.043	1.682	31.5	0.074	2.891
3/4" to 1"	71.7	0.017	0.648	48.2	0.043	1.697
1" to 1-1/4"	84.8	0.010	0.379	69.4	0.018	0.705
1-1/4" to 1-1/2"	62.0	0.025	0.966	61.6	0.025	0.974
1-1/2" to 1-3/4"	48.3	0.043	1.696	43.6	0.052	2.053
1-3/4" to 2"	49.4	0.041	1.621	46.8	0.046	1.798

Specimen #2 - 6 Month Exposure

By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	~~106.7~~	~~73.4~~	~~50.3~~	~~-4.7~~
mV after	100.5	67.8	44.5	-11.3
mV after	93.0	62.8	41.8	-13.9
mV after	98.9	68.5	45.2	-11.5

		Date:
5 Minute Test		6/8/2008
1/4 - 3/4	24 Hour	6/23/2008
1 - 2	Test	6/22/2008

Assumed weight of concrete = 145.0 lb/cubic yard

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
2D						
0" to 1/4"	-14.3	0.567	22.190	-4.1	0.340	13.318
1/4" to 1/2"	0.8	0.305	11.934	15.6	0.146	5.719
1/2" to 3/4"	26.4	0.106	4.169	29.9	0.079	3.096
3/4" to 1"	42.9	0.054	2.117	42.1	0.056	2.185
1" to 1-1/4"	56.3	0.031	1.221	51.9	0.037	1.456
1-1/4" to 1-1/2"	55.1	0.033	1.282	50.6	0.039	1.536
1-1/2" to 1-3/4"	66.2	0.021	0.813	58.1	0.029	1.126
1-3/4" to 2"	68.4	0.019	0.743	60.7	0.026	1.011
2E						
0" to 1/4"	-15.4	0.593	23.216	-6.6	0.379	14.826
1/4" to 1/2"	9.8	0.211	8.245	10.0	0.186	7.272
1/2" to 3/4"	36.5	0.070	2.753	39.8	0.052	2.025
3/4" to 1"	49.6	0.041	1.607	53.4	0.035	1.368
1" to 1-1/4"	48.9	0.042	1.654	51.7	0.037	1.468
1-1/4" to 1-1/2"	66.5	0.021	0.803	62.8	0.024	0.927
1-1/2" to 1-3/4"	82.8	0.010	0.411	78.7	0.012	0.480
1-3/4" to 2"	86.5	0.009	0.353	77.7	0.013	0.500
2F						
0" to 1/4"	-10.3	0.481	18.828	1.0	0.273	10.700
1/4" to 1/2"	7.3	0.233	9.137	11.5	0.174	6.819
1/2" to 3/4"	42.7	0.055	2.134	49.6	0.034	1.330
3/4" to 1"	60.4	0.026	1.031	57.6	0.029	1.149
1" to 1-1/4"	63.9	0.023	0.893	64.9	0.022	0.849
1-1/4" to 1-1/2"	65.1	0.022	0.850	67.2	0.020	0.772
1-1/2" to 1-3/4"	64.8	0.022	0.861	62.4	0.024	0.942
1-3/4" to 2"	85.2	0.010	0.372	79.2	0.012	0.470

Specimen #3 - 6 Month Exposure By: MDP

Liquid	Clear	Purple	Green	Pink			
%CL	0.005	0.02	0.05	0.5			Date:
mV before	~~106.7~~	~~73.4~~	~~50.3~~	~~-4.7~~	5 Minute Test		6/8/2008
mV after	100.5	67.8	44.5	-11.3			
mV before	93.0	62.8	41.8	-13.9	1/4 - 3/4	24 Hour	6/23/2008
mV after	98.9	68.5	45.2	-11.5	1 - 2	Test	6/22/2008

Assumed weight of concrete = 145.0 lb/cubic yard

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
3D						
0" to 1/4"	15.9	0.164	6.418	13.4	0.161	6.285
1/4" to 1/2"	54.8	0.033	1.298	43.0	0.045	1.765
1/2" to 3/4"	42.3	0.055	2.170	32.7	0.070	2.746
3/4" to 1"	39.5	0.062	2.434	33.5	0.080	3.120
1" to 1-1/4"	65.9	0.021	0.823	52.8	0.036	1.402
1-1/4" to 1-1/2"	66.3	0.021	0.809	55.8	0.032	1.238
1-1/2" to 1-3/4"	76.8	0.013	0.526	63.4	0.023	0.904
1-3/4" to 2"	60.0	0.027	1.049	47.5	0.045	1.747
3E						
0" to 1/4"	33.3	0.080	3.140	27.3	0.088	3.462
1/4" to 1/2"	54.2	0.034	1.331	43.2	0.045	1.750
1/2" to 3/4"	61.1	0.026	1.002	47.1	0.038	1.480
3/4" to 1"	76.3	0.014	0.537	62.0	0.024	0.958
1" to 1-1/4"	46.7	0.046	1.811	39.9	0.061	2.393
1-1/4" to 1-1/2"	52.2	0.037	1.445	45.1	0.049	1.929
1-1/2" to 1-3/4"	78.7	0.012	0.486	63.7	0.023	0.893
1-3/4" to 2"	86.6	0.009	0.352	74.6	0.015	0.568
3F						
0" to 1/4"	49.9	0.041	1.588	46.0	0.040	1.552
1/4" to 1/2"	57.0	0.030	1.186	51.6	0.031	1.220
1/2" to 3/4"	67.1	0.020	0.783	60.3	0.021	0.840
3/4" to 1"	70.2	0.018	0.690	57.0	0.030	1.178
1" to 1-1/4"	63.9	0.023	0.893	54.9	0.033	1.285
1-1/4" to 1-1/2"	67.1	0.020	0.783	57.6	0.029	1.149
1-1/2" to 1-3/4"	76.8	0.013	0.526	62.8	0.024	0.927
1-3/4" to 2"	72.6	0.016	0.625	50.6	0.039	1.536

Specimen #4 - 6 Month Exposure By: MDP

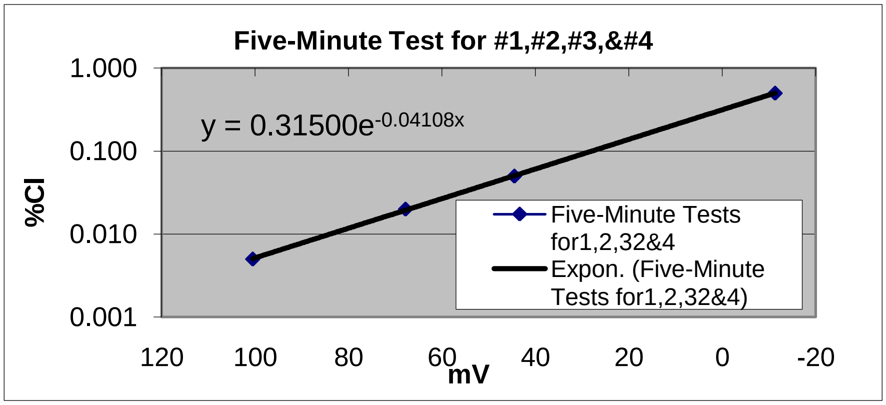
Liquid	Clear	Purple	Green	Pink		
%CL	0.005	0.02	0.05	0.5		Date:
mV before	~~106.7~~	~~73.4~~	~~50.3~~	~~-4.7~~	5 Minute Test	6/8/2008
mV after	100.5	67.8	44.5	-11.3		
mV before	93.0	62.8	41.8	-13.9	1/4 - 3/4 24 Hour	6/23/2008
mV after	98.9	68.5	45.2	-11.5	1 - 2 Test	6/22/2008

Assumed weight of concrete = 145.0 lb/cubic yard

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
4D						
0" to 1/4"	3.5	0.273	10.681	9.3	0.191	7.494
1/4" to 1/2"	46.8	0.046	1.803	30.9	0.076	2.966
1/2" to 3/4"	63.1	0.024	0.923	38.7	0.054	2.122
3/4" to 1"	72.7	0.016	0.622	56.4	0.031	1.208
1" to 1-1/4"	71.7	0.017	0.648	59.9	0.027	1.045
1-1/4" to 1-1/2"	53.6	0.035	1.364	38.0	0.066	2.589
1-1/2" to 1-3/4"	78.4	0.013	0.492	62.1	0.024	0.954
1-3/4" to 2"	71.8	0.016	0.646	62.4	0.024	0.942
4E						
0" to 1/4"	19.9	0.139	5.445	20.5	0.118	4.635
1/4" to 1/2"	69.4	0.018	0.713	61.7	0.020	0.791
1/2" to 3/4"	54.7	0.033	1.304	41.0	0.049	1.923
3/4" to 1"	61.0	0.026	1.006	49.9	0.040	1.581
1" to 1-1/4"	63.9	0.023	0.893	56.5	0.031	1.203
1-1/4" to 1-1/2"	61.4	0.025	0.990	55.8	0.032	1.238
1-1/2" to 1-3/4"	59.7	0.027	1.062	54.9	0.033	1.285
1-3/4" to 2"	77.4	0.013	0.513	63.5	0.023	0.900
4F						
0" to 1/4"	2.5	0.284	11.129	0.4	0.280	10.979
1/4" to 1/2"	35.7	0.073	2.845	31.5	0.074	2.891
1/2" to 3/4"	52.3	0.037	1.439	38.2	0.055	2.168
3/4" to 1"	64.7	0.022	0.864	54.6	0.033	1.302
1" to 1-1/4"	55.4	0.032	1.267	49.2	0.042	1.628
1-1/4" to 1-1/2"	56.8	0.031	1.196	51.5	0.038	1.480
1-1/2" to 1-3/4"	67.8	0.019	0.761	56.3	0.031	1.213
1-3/4" to 2"	47.8	0.044	1.731	40.0	0.061	2.383

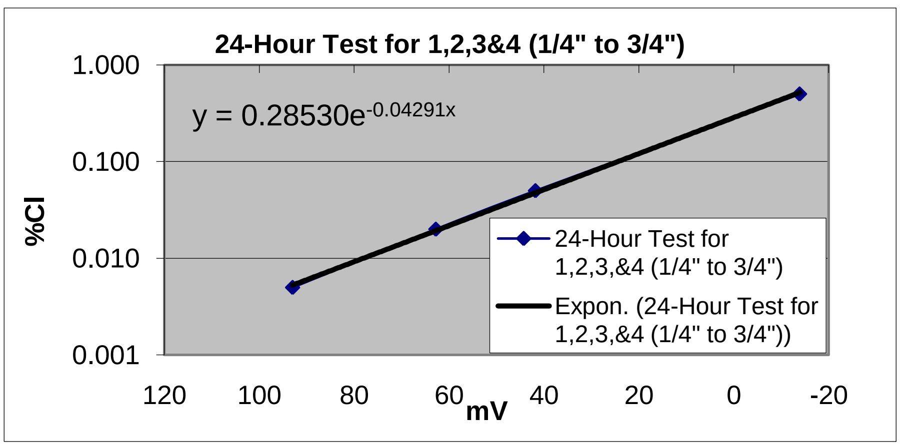
1,2,3,&4 Five-Minutes Chlorides By: MDP

6/8/2008	%Cl	**0.005**	**0.020**	**0.050**	**0.500**
	mV before	~~106.7~~	~~73.4~~	~~50.3~~	~~-4.7~~
	mV after	100.5	67.8	44.5	-11.3



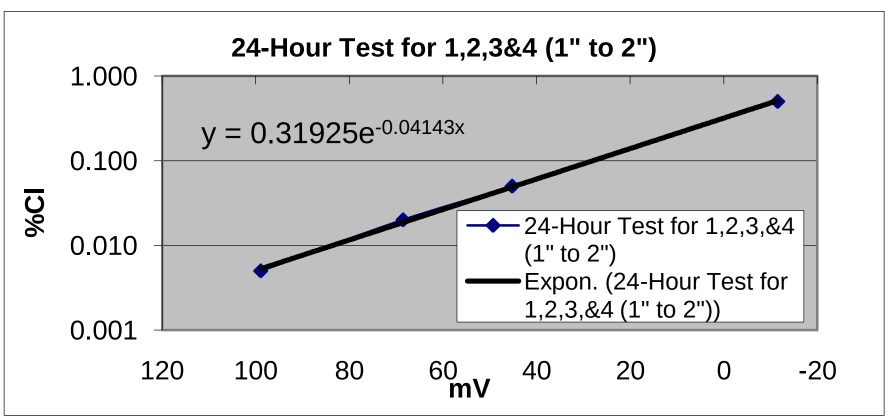
1,2,3,&4 24-Hour Chlorides (1/4" to 3/4")

6/23/2008	%Cl	**0.005**	**0.020**	**0.050**	**0.500**
	mV before	~~99.1~~	~~69.5~~	~~47.4~~	~~-8.1~~
	mV after	93.0	62.8	41.8	-13.9



1,2,3,&4 24-Hour Chlorides (1" to 2")

6/22/2008	%Cl	**0.005**	**0.020**	**0.050**	**0.500**
	mV before	~~105.1~~	~~74.3~~	~~51.0~~	~~-4.9~~
	mV after	98.9	68.5	45.2	-11.5



Specimen #5 - 6 Month Exposure By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	93.6	68.2	45.8	-11.4
mV after	96.8	69.5	46.1	-10.6
mV before	99.4	71.0	47.5	-9.1
mV after	97.4	69.8	46.7	-10.3

	Date:
5 Minute Test	7/23/2008
24 Hour Test	7/24/2008

Assumed weight of concrete = 145.0 lb/cubic yard

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
5D						
0" to 1/4"	-2.3	0.367	14.376	-4.7	0.425	16.628
1/4" to 1/2"	1.1	0.318	12.433	-1.2	0.367	14.350
1/2" to 3/4"	14.7	0.178	6.955	12.1	0.209	8.196
3/4" to 1"	47.4	0.044	1.721	41.8	0.060	2.347
1" to 1-1/4"	53.6	0.034	1.321	51.2	0.040	1.580
1-1/4" to 1-1/2"	50.3	0.039	1.520	48.5	0.045	1.770
1-1/2" to 1-3/4"	63.1	0.022	0.880	59.4	0.029	1.118
1-3/4" to 2"	70.0	0.017	0.655	66.2	0.021	0.840
5E						
0" to 1/4"	-6.2	0.434	16.981	-7.5	0.478	18.709
1/4" to 1/2"	-1.3	0.352	13.775	-3.4	0.402	15.743
1/2" to 3/4"	13.0	0.191	7.479	12.0	0.210	8.231
3/4" to 1"	42.9	0.053	2.086	40.7	0.063	2.458
1" to 1-1/4"	58.6	0.027	1.067	54.5	0.035	1.375
1-1/4" to 1-1/2"	72.0	0.015	0.602	67.7	0.020	0.788
1-1/2" to 1-3/4"	59.7	0.026	1.018	56.5	0.032	1.264
1-3/4" to 2"	42.3	0.055	2.140	40.1	0.064	2.521
5F						
0" to 1/4"	-8.1	0.470	18.417	-10.8	0.549	21.499
1/4" to 1/2"	4.9	0.270	10.570	2.5	0.314	12.279
1/2" to 3/4"	39.7	0.061	2.391	38.6	0.069	2.685
3/4" to 1"	50.2	0.039	1.527	47.6	0.047	1.838
1" to 1-1/4"	35.6	0.073	2.849	35.0	0.080	3.125
1-1/4" to 1-1/2"	37.3	0.068	2.649	35.6	0.078	3.047
1-1/2" to 1-3/4"	68.4	0.018	0.702	64.3	0.023	0.910
1-3/4" to 2"	82.7	0.010	0.381	78.6	0.013	0.498

Specimen #7 - 6 Month Exposure

By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	93.6	68.2	45.8	-11.4
mV after	96.8	69.5	46.1	-10.6
mV before	99.4	71.0	47.5	-9.1
mV after	97.4	69.8	46.7	-10.3

	Date:
5 Minute Test	7/23/2008
24 Hour Test	7/24/2008

Assumed weight of concrete = 145.0 lb/cubic yard

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
7D						
0" to 1/4"	-6.0	0.430	16.837	-5.7	0.443	17.344
1/4" to 1/2"	-4.1	0.397	15.524	-3.5	0.404	15.809
1/2" to 3/4"	13.2	0.189	7.415	11.7	0.213	8.335
3/4" to 1"	18.4	0.152	5.938	17.5	0.167	6.529
1" to 1-1/4"	34.3	0.077	3.011	32.8	0.088	3.428
1-1/4" to 1-1/2"	52.4	0.036	1.390	50.1	0.042	1.654
1-1/2" to 1-3/4"	66.5	0.019	0.761	63.2	0.024	0.953
1-3/4" to 2"	83.8	0.009	0.364	77.8	0.013	0.515

7E Average						
0" to 1/4"		0.481	18.837		0.509	19.912
1/4" to 1/2"		0.545	21.336		0.584	22.868
1/2" to 3/4"		0.558	21.850		0.618	24.191
3/4" to 1"		0.505	19.782		0.558	21.864
1" to 1-1/4"		0.266	10.424		0.292	11.421
1-1/4" to 1-1/2"		0.064	2.508		0.070	2.757
1-1/2" to 1-3/4"		0.027	1.073		0.030	1.173
1-3/4" to 2"		0.017	0.653		0.020	0.774

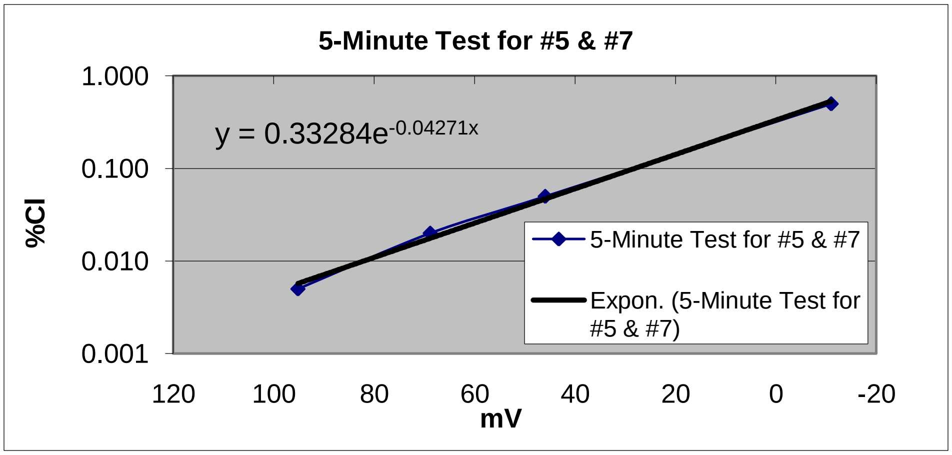
See Average Data after Specimens #9 and #10

7F						
0" to 1/4"	6.1	0.257	10.042	3.8	0.297	11.625
1/4" to 1/2"	13.1	0.190	7.447	10.1	0.228	8.916
1/2" to 3/4"	21.5	0.133	5.202	18.7	0.159	6.207
3/4" to 1"	38.2	0.065	2.549	35.4	0.078	3.073
1" to 1-1/4"	57.9	0.028	1.099	55.3	0.034	1.329
1-1/4" to 1-1/2"	71.6	0.016	0.612	69.1	0.019	0.743
1-1/2" to 1-3/4"	76.9	0.012	0.488	74.3	0.015	0.597
1-3/4" to 2"	81.8	0.010	0.396	77.8	0.013	0.515

5-Minute Test for #5 and #7 By: MDP

7/23/2008

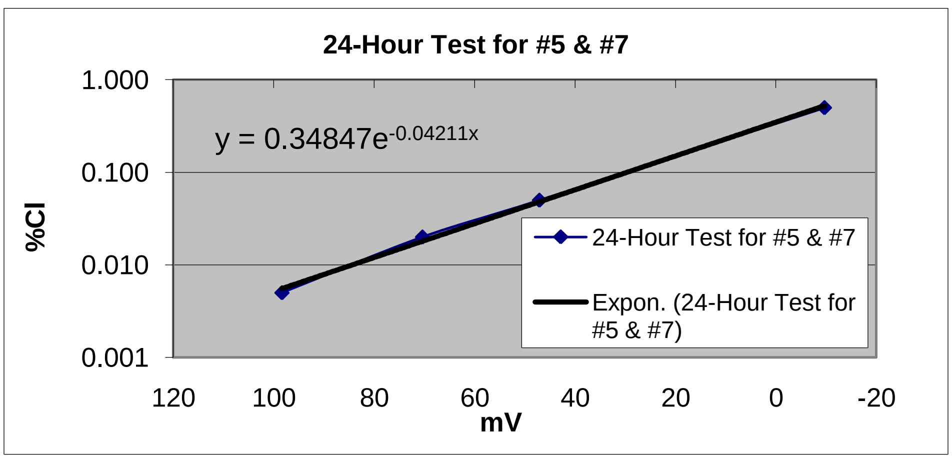
%Cl	0.005	0.020	0.050	0.500
mV before	93.6	68.2	45.8	-11.4
mV after	96.8	69.5	46.1	-10.6
mV average	95.2	68.9	46.0	-11.0



24-Hour Test for #5 and #7

7/24/2008

%Cl	0.005	0.020	0.050	0.500
mV before	99.4	71.0	47.5	-9.1
mV after	97.4	69.8	46.7	-10.3
mV average	98.4	70.4	47.1	-9.7



Specimen #6 - 6 Month Exposure

By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	100.5	73.5	49.4	-7.0
mV after	99.9	72.3	48.3	-7.6
mV before	95.7	70.1	47.5	-7.4
mV after	94.2	68.4	46.3	-8.7

	Date:
5 Minute Test	8/4/2008
24 Hour Test	8/6/2008

Assumed weight of concrete = 145.0 lb/cubic yard

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
6D						
0" to 1/4"	-5.4	0.482	18.881	-6.5	0.495	19.398
1/4" to 1/2"	16.6	0.190	7.453	14.3	0.198	7.760
1/2" to 3/4"	43.8	0.060	2.362	39.6	0.065	2.546
3/4" to 1"	56.4	0.035	1.387	53.9	0.035	1.356
1" to 1-1/4"	60.6	0.030	1.161	52.5	0.037	1.442
1-1/4" to 1-1/2"	74.9	0.016	0.635	60.8	0.026	1.001
1-1/2" to 1-3/4"	82.1	0.012	0.468	66.3	0.020	0.785
1-3/4" to 2"	86.6	0.010	0.387	76.7	0.013	0.497
6E						
0" to 1/4"	-7.2	0.520	20.373	-8.4	0.539	21.092
1/4" to 1/2"	2.1	0.351	13.753	0.3	0.367	14.377
1/2" to 3/4"	9.3	0.259	10.146	8.1	0.260	10.197
3/4" to 1"	29.1	0.112	4.395	24.9	0.124	4.865
1" to 1-1/4"	53.4	0.040	1.574	48.7	0.044	1.705
1-1/4" to 1-1/2"	70.1	0.020	0.777	62.9	0.023	0.912
1-1/2" to 1-3/4"	71.5	0.019	0.733	62.3	0.024	0.937
1-3/4" to 2"	56.0	0.036	1.411	48.2	0.045	1.743
6F						
0" to 1/4"	1.5	0.360	14.106	-1.8	0.403	15.771
1/4" to 1/2"	8.0	0.274	10.719	4.5	0.305	11.949
1/2" to 3/4"	27.5	0.120	4.703	26.3	0.117	4.574
3/4" to 1"	57.6	0.034	1.318	50.0	0.041	1.610
1" to 1-1/4"	73.3	0.017	0.679	65.8	0.021	0.803
1-1/4" to 1-1/2"	77.1	0.015	0.578	67.9	0.019	0.732
1-1/2" to 1-3/4"	86.7	0.010	0.386	74.3	0.014	0.552
1-3/4" to 2"	83.7	0.011	0.438	70.4	0.017	0.656

Specimen #8 - 6 Month Exposure By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	100.5	73.5	49.4	-7.0
mV after	99.9	72.3	48.3	-7.6
mV before	95.7	70.1	47.5	-7.4
mV after	94.2	68.4	46.3	-8.7

Date:

5 Minute Test 8/4/2008

24 Hour Test 8/6/2008

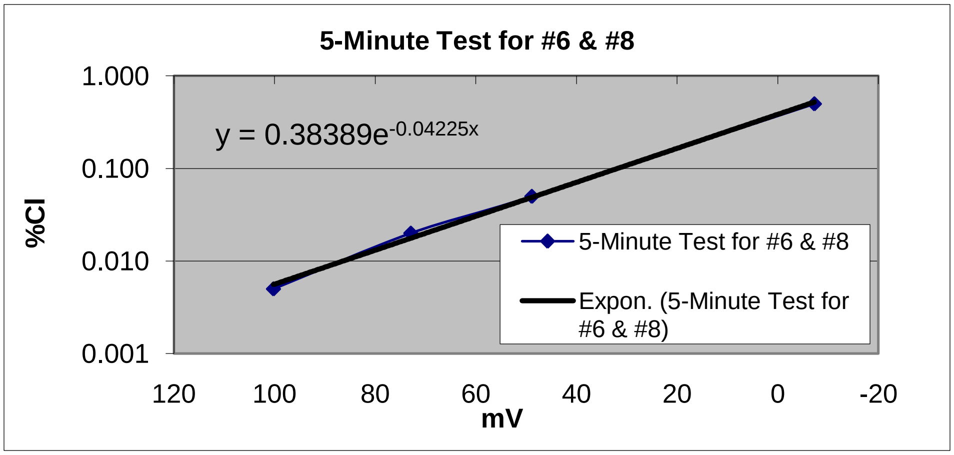
Assumed weight of concrete = 145.0 lb/cubic yard

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
8D						
0" to 1/4"	3.8	0.327	12.800	2.0	0.341	13.340
1/4" to 1/2"	22.7	0.147	5.760	19.1	0.160	6.281
1/2" to 3/4"	33.2	0.094	3.696	29.2	0.103	4.025
3/4" to 1"	39.1	0.074	2.881	35.6	0.078	3.036
1" to 1-1/4"	48.3	0.050	1.953	44.7	0.052	2.034
1-1/4" to 1-1/2"	54.6	0.038	1.497	50.5	0.040	1.575
1-1/2" to 1-3/4"	67.4	0.022	0.871	62.1	0.024	0.945
1-3/4" to 2"	87.8	0.009	0.368	72.9	0.015	0.587
8E						
0" to 1/4"	-3.8	0.451	17.647	-4.9	0.462	18.078
1/4" to 1/2"	-6.0	0.495	19.366	-7.8	0.525	20.542
1/2" to 3/4"	5.9	0.299	11.713	3.7	0.316	12.377
3/4" to 1"	21.8	0.153	5.983	18.0	0.168	6.593
1" to 1-1/4"	42.0	0.065	2.548	35.7	0.077	3.023
1-1/4" to 1-1/2"	63.6	0.026	1.023	55.9	0.032	1.242
1-1/2" to 1-3/4"	84.3	0.011	0.427	75.1	0.014	0.533
1-3/4" to 2"	81.2	0.012	0.486	68.7	0.018	0.707
8F						
0" to 1/4"	3.0	0.338	13.240	0.7	0.361	14.126
1/4" to 1/2"	21.8	0.153	5.983	19.0	0.161	6.309
1/2" to 3/4"	40.2	0.070	2.750	36.3	0.075	2.944
3/4" to 1"	64.4	0.025	0.989	57.6	0.029	1.152
1" to 1-1/4"	72.9	0.018	0.691	63.9	0.022	0.873
1-1/4" to 1-1/2"	80.0	0.013	0.512	66.8	0.020	0.768
1-1/2" to 1-3/4"	79.3	0.013	0.527	66.5	0.020	0.778
1-3/4" to 2"	60.7	0.030	1.157	54.7	0.033	1.309

5-Minute Test for #6 and #8 By: MDP

8/4/2008

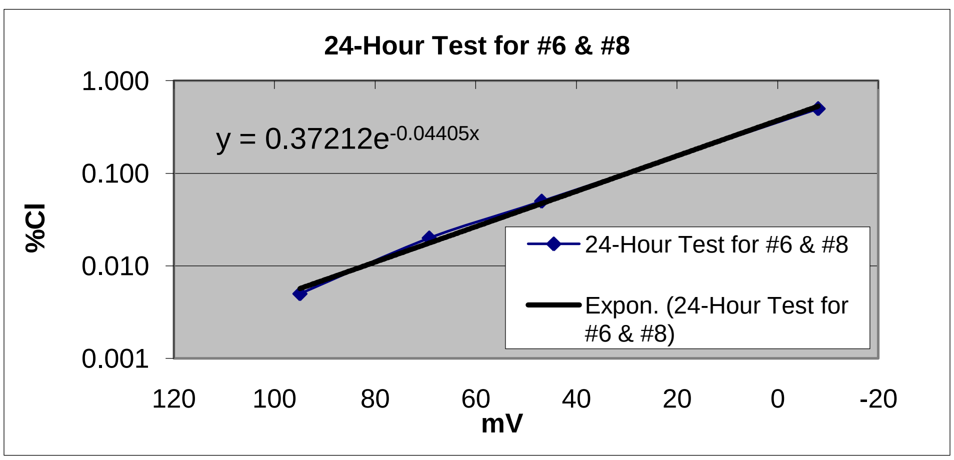
%Cl	**0.005**	**0.020**	**0.050**	**0.500**
mV before	100.5	73.5	49.4	-7.0
mV after	99.9	72.3	48.3	-7.6
mV average	100.2	72.9	48.9	-7.3



24-Hour Test for #6 and #8

8/6/2008

%Cl	**0.005**	**0.020**	**0.050**	**0.500**
mV before	95.7	70.1	47.5	-7.4
mV after	94.2	68.4	46.3	-8.7
mV average	95.0	69.3	46.9	-8.1



Specimen #9 - 6 Month Exposure By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	91.4	68.4	46.2	-9.7
mV after	94.8	67.8	45.7	-10.3
mV before	~~100.8~~	~~72.5~~	~~49.0~~	~~-7.7~~
mV after	93.6	68.2	45.8	-11.4

	Date:
5 Minute Test	5/18/2008 7/21/2008
24 Hour Test	7/23/2008

Assumed weight of concrete = 145.0 lb/cubic yard

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
9D Average						
0" to 1/4"		0.461	18.048		0.454	17.789
1/4" to 1/2"		0.493	19.312		0.407	15.943
1/2" to 3/4"		0.451	17.647		0.348	13.633
3/4" to 1"		0.436	17.051		0.428	16.748
1" to 1-1/4"		0.521	20.387		0.675	26.420
1-1/4" to 1-1/2"		0.663	25.959		0.633	24.792
1-1/2" to 1-3/4"		0.461	18.032		0.623	24.398
1-3/4" to 2"		0.268	10.486		0.314	12.304

See Average Data

9E Average						
0" to 1/4"		0.504	19.726		0.575	22.502
1/4" to 1/2"		0.690	27.014		0.551	21.560
1/2" to 3/4"		0.497	19.467		0.490	19.199
3/4" to 1"		0.601	23.548		0.661	25.889
1" to 1-1/4"		0.716	28.013		0.592	23.192
1-1/4" to 1-1/2"		0.662	25.912		0.489	19.140
1-1/2" to 1-3/4"		0.393	15.390		0.214	8.389
1-3/4" to 2"		0.286	11.203		0.101	3.941

See Average Data

9F						
0" to 1/4"	3.3	0.305	11.943	1.7	0.306	11.984
1/4" to 1/2"	7.0	0.259	10.130	2.4	0.297	11.628
1/2" to 3/4"	23.0	0.127	4.969	21.8	0.129	5.039
3/4" to 1"	41.4	0.056	2.191	37.6	0.065	2.550
1" to 1-1/4"	40.3	0.059	2.301	34.3	0.075	2.940
1-1/4" to 1-1/2"	28.5	0.099	3.890	28.2	0.098	3.824
1-1/2" to 1-3/4"	34.9	0.075	2.926	34.1	0.076	2.966
1-3/4" to 2"	40.4	0.059	2.291	37.9	0.064	2.518

5-Minute Data from 5/18/2008.

Specimen #10 - 6 Month Exposure

By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	91.4	68.4	46.2	-9.7
mV after	94.8	67.8	45.7	-10.3
mV before	~~100.8~~	~~72.5~~	~~49.0~~	~~-7.7~~
mV after	93.6	68.2	45.8	-11.4

	Date:
5 Minute Test	5/18/2008 7/21/2008
24 Hour Test	7/23/2008

Assumed weight of concrete = 145.0 lb/cubic yard

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
10D Average						
0" to 1/4"		0.697	27.272		0.665	26.040
1/4" to 1/2"		0.755	29.573		0.695	27.207
1/2" to 3/4"		0.648	25.378		0.579	22.675
3/4" to 1"		0.621	24.295		0.533	20.871
1" to 1-1/4"		0.571	22.350		0.551	21.583
1-1/4" to 1-1/2"		0.694	27.155		0.586	22.948
1-1/2" to 1-3/4"		0.492	19.279		0.408	15.983
1-3/4" to 2"		0.291	11.383		0.256	10.008

See Average Data

10E(2)						
0" to 1/4"	-15.4	0.660	25.846	-16.2	0.662	25.921
1/4" to 1/2"	-5.1	0.423	16.548	-7.0	0.445	17.436
1/2" to 3/4"	-3.0	0.386	15.110	-3.8	0.388	15.190
3/4" to 1"	1.3	0.320	12.544	0.4	0.324	12.674
1" to 1-1/4"	8.9	0.231	9.027	4.2	0.275	10.760
1-1/4" to 1-1/2"	11.7	0.204	7.997	10.1	0.213	8.344
1-1/2" to 1-3/4"	36.4	0.070	2.745	34.9	0.073	2.865
1-3/4" to 2"	54.0	0.033	1.281	50.8	0.037	1.444

5-Minute Data from 7/21/2008.

10F						
0" to 1/4"	0.4	0.347	13.589	-0.6	0.338	13.233
1/4" to 1/2"	3.4	0.304	11.890	1.9	0.303	11.881
1/2" to 3/4"	4.3	0.292	11.423	2.4	0.297	11.628
3/4" to 1"	6.5	0.265	10.358	3.5	0.283	11.089
1" to 1-1/4"	12.0	0.207	8.109	9.2	0.222	8.674
1-1/4" to 1-1/2"	30.1	0.093	3.623	23.8	0.118	4.623
1-1/2" to 1-3/4"	59.7	0.025	0.970	54.9	0.031	1.210
1-3/4" to 2"	68.6	0.017	0.653	57.9	0.027	1.063

5-Minute Data from 5/18/2008.

Specimen #11 - 6 Month Exposure By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	~~101.7~~	~~76.6~~	~~54.8~~	~~-2.1~~
mV after	91.4	68.4	46.2	-9.7
mV before	101.6	75.9	53.6	-2.8
mV after	98.1	72.1	51.2	-5.2

	Date:
5 Minute Test	5/18/2008
24 Hour Test	5/21/2008

Assumed weight of concrete = 145.0 lb/cubic yard

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
11D						
0" to 1/4"	47.7	0.042	1.655	43.9	0.066	2.591
1/4" to 1/2"	71.4	0.015	0.576	63.5	0.028	1.100
1/2" to 3/4"	68.8	0.017	0.647	63.9	0.028	1.081
3/4" to 1"	68.2	0.017	0.665	62.2	0.030	1.165
1" to 1-1/4"	73.7	0.013	0.520	65.7	0.026	0.999
1-1/4" to 1-1/2"	62.7	0.022	0.849	58.6	0.035	1.363
1-1/2" to 1-3/4"	57.6	0.027	1.065	55.2	0.040	1.581
1-3/4" to 2"	79.8	0.010	0.397	70.9	0.020	0.796
11E						
0" to 1/4"	47.5	0.043	1.670	41.8	0.073	2.840
1/4" to 1/2"	57.4	0.027	1.075	51.9	0.047	1.827
1/2" to 3/4"	66.3	0.018	0.723	59.5	0.033	1.310
3/4" to 1"	69.5	0.016	0.627	61.6	0.031	1.195
1" to 1-1/4"	82.6	0.009	0.350	73.1	0.018	0.723
1-1/4" to 1-1/2"	89.9	0.006	0.253	80.7	0.013	0.519
1-1/2" to 1-3/4"	78.8	0.011	0.415	71.0	0.020	0.793
1-3/4" to 2"	79.7	0.010	0.398	71.8	0.020	0.766
11F(2)						
0" to 1/4"	41.0	0.075	2.941	34.5	0.088	3.442
1/4" to 1/2"	70.7	0.021	0.803	59.9	0.028	1.091
1/2" to 3/4"	78.1	0.015	0.581	67.7	0.020	0.767
3/4" to 1"	78.9	0.014	0.561	69.5	0.018	0.707
1" to 1-1/4"	80.3	0.013	0.528	73.8	0.015	0.582
1-1/4" to 1-1/2"	89.1	0.009	0.359	77.8	0.012	0.486
1-1/2" to 1-3/4"	87.5	0.010	0.385	75.3	0.014	0.544
1-3/4" to 2"	89.7	0.009	0.350	78.9	0.012	0.462

Five minute tests: 5/21/08
24-hour tests: 5/22/08

Specimen #12 - 6 Month Exposure By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	101.7	76.6	54.8	-2.1
mV after	91.4	68.4	46.2	-9.7
mV before	101.6	75.9	53.6	-2.8
mV after	98.1	72.1	51.2	-5.2

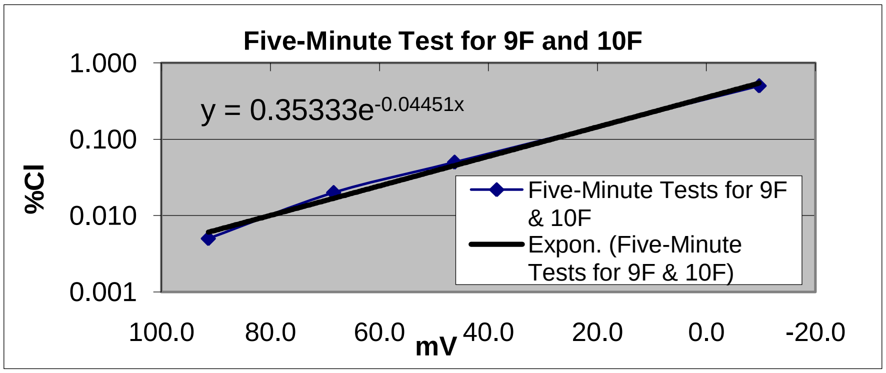
	Date:
5 Minute Test	5/18/2008
24 Hour Test	5/21/2008

Assumed weight of concrete = 145.0 lb/cubic yard

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
12D						
0" to 1/4"	47.1	0.043	1.700	44.1	0.066	2.568
1/4" to 1/2"	79.3	0.010	0.406	70.4	0.021	0.814
1/2" to 3/4"	72.4	0.014	0.551	65.5	0.026	1.008
3/4" to 1"	83.9	0.008	0.330	73.8	0.018	0.701
1" to 1-1/4"	75.0	0.013	0.491	66.8	0.024	0.952
1-1/4" to 1-1/2"	57.8	0.027	1.056	53.6	0.043	1.696
1-1/2" to 1-3/4"	49.2	0.040	1.548	48.3	0.055	2.138
1-3/4" to 2"	61.7	0.023	0.888	58.7	0.035	1.357
12E						
0" to 1/4"	36.8	0.069	2.689	38.4	0.084	3.295
1/4" to 1/2"	68.7	0.017	0.650	62.4	0.029	1.154
1/2" to 3/4"	81.9	0.009	0.361	71.9	0.019	0.762
3/4" to 1"	87.8	0.007	0.278	76.8	0.016	0.615
1" to 1-1/4"	80.4	0.010	0.386	72.3	0.019	0.749
1-1/4" to 1-1/2"	69.2	0.016	0.636	62.4	0.029	1.154
1-1/2" to 1-3/4"	68.8	0.017	0.647	61.8	0.030	1.185
1-3/4" to 2"	65.9	0.019	0.736	61.4	0.031	1.206
12F						
0" to 1/4"	18.4	0.156	6.099	19.1	0.196	7.658
1/4" to 1/2"	59.6	0.025	0.975	50.1	0.050	1.976
1/2" to 3/4"	79.5	0.010	0.402	71.7	0.020	0.769
3/4" to 1"	73.2	0.014	0.532	68.0	0.023	0.904
1" to 1-1/4"	86.9	0.007	0.289	77.1	0.016	0.607
1-1/4" to 1-1/2"	79.0	0.010	0.411	72.4	0.019	0.746
1-1/2" to 1-3/4"	84.3	0.008	0.325	76.1	0.016	0.634
1-3/4" to 2"	78.2	0.011	0.426	71.7	0.020	0.769

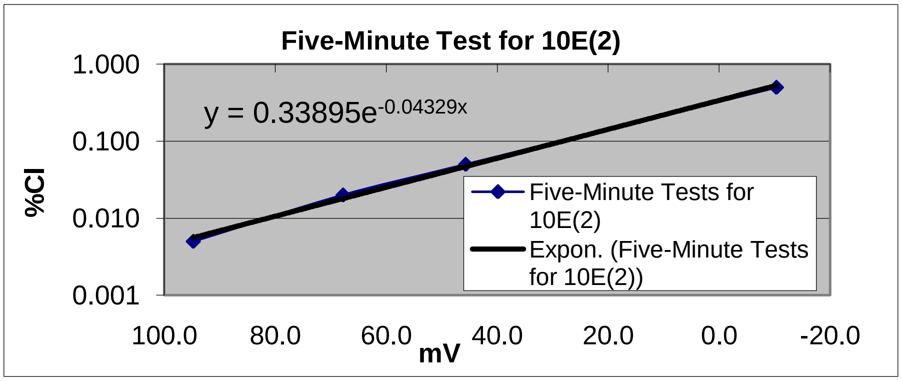
5-Minute Test for 9F and 10F By: MDP

5/18/2008	%Cl	**0.005**	**0.020**	**0.050**	**0.500**
	mV before	~~101.7~~	~~76.6~~	~~54.8~~	~~-2.1~~
	mV after	91.4	68.4	46.2	-9.7



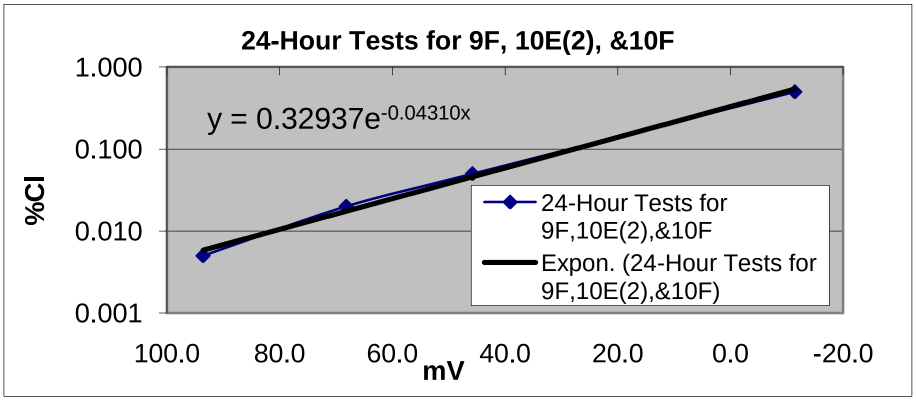
5-Minute Test for 10E(2)

7/21/2008	%Cl	**0.005**	**0.020**	**0.050**	**0.500**
	mV before	~~103.3~~	~~75.6~~	~~53.0~~	~~-2.9~~
	mV after	94.8	67.8	45.7	-10.3



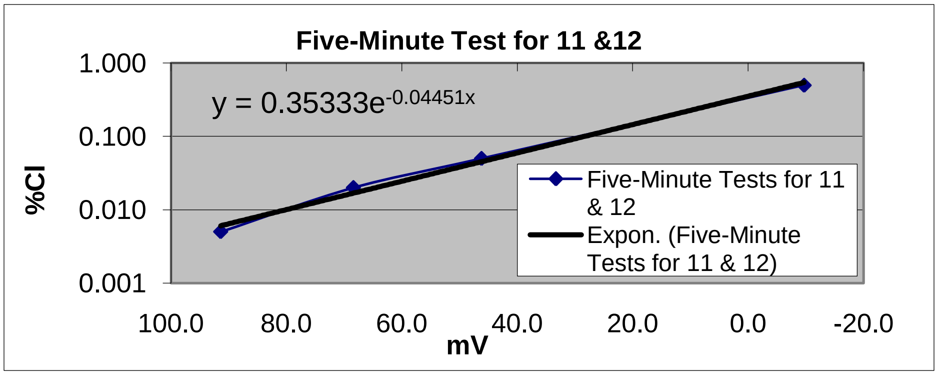
24-Hour Test for 9F, 10E(2), and 10F

7/23/2008	%Cl	**0.005**	**0.020**	**0.050**	**0.500**
	mV before	~~100.8~~	~~72.5~~	~~49.0~~	~~-7.7~~
	mV after	93.6	68.2	45.8	-11.4



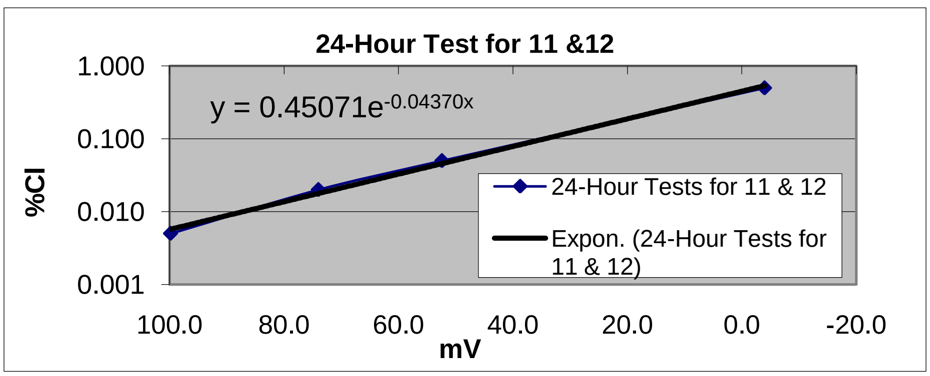
5-Minute Tests for #11 and #12 By: MDP

5/18/2008		0.005	0.020	0.050	0.500
	mV before	~~101.7~~	~~76.6~~	~~54.8~~	~~-2.1~~
	mV after	91.4	68.4	46.2	-9.7



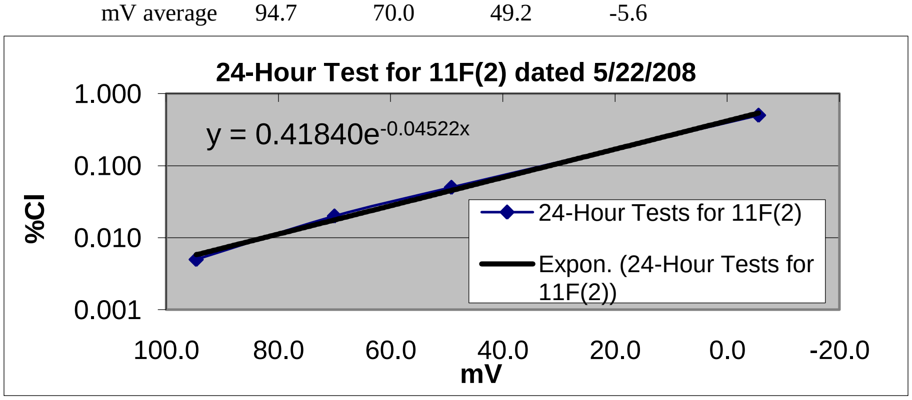
24-Hour Tests for #11 and #12

5/21/2008	%Cl	0.005	0.020	0.050	0.500
	mV before	101.6	75.9	53.6	-2.8
	mv after	98.1	72.1	51.2	-5.2
	mV average	99.9	74.0	52.4	-4.0



24-Hour Test for 11F(2)

5/22/2008	%Cl	0.005	0.020	0.050	0.500
	mV before	95.1	71.1	50.1	-4.6
	mV after	94.2	68.9	48.2	-6.6
	mV average	94.7	70.0	49.2	-5.6



		5-Minute Test		24-Hour Test		By: MDP
		mV	**%Cl**	**mV**	**%Cl**	
7E(1)	1/4"	2.2	0.303	-1.0	0.363	
Tested 7/23/08 and 7/24/08	1/2"	-10.8	0.528	-13.4	0.613	
	3/4"	-13.5	0.592	-16.8	0.707	
	1"	-9.0	0.489	-11.7	0.570	
	1-1/4"	2.1	0.304	-0.4	0.354	
	1-1/2"	48.4	0.042	45.5	0.051	
	1-3/4"	68.6	0.018	66.8	0.021	
	2"	75.9	0.013	71.9	0.017	
7E(2)	1/4"	-12.2	0.643	-13.4	0.671	
Tested 8/4/08 and 8/6/08	1/2"	-7.5	0.527	-9.3	0.561	
	3/4"	-3.0	0.436	-3.9	0.442	
	1"	-2.3	0.423	-4.4	0.452	
	1-1/4"	25.4	0.131	23.0	0.135	
	1-1/2"	71.5	0.019	63.7	0.022	
	1-3/4"	74.8	0.016	67.2	0.019	
	2"	78.0	0.014	69.6	0.017	
7E(3)	1/4"	-11.6	0.498	-11.2	0.491	
Tested 8/25/08/08 and 8/28/08/08	1/2"	-15.0	0.580	-14.9	0.579	
	3/4"	-17.4	0.646	-19.3	0.705	
	1"	-15.9	0.604	-17.6	0.653	
	1-1/4"	-4.6	0.363	-5.8	0.386	
	1-1/2"	18.0	0.131	17.3	0.137	
	1-3/4"	40.3	0.048	40.1	0.050	
	2"	56.9	0.023	55.4	0.025	

7E Average of 5-Minute Tests			**7E Average of 24-Hour Tests**		
	1/4"	0.481		1/4"	0.509
	1/2"	0.545		1/2"	0.584
	3/4"	0.558		3/4"	0.618
	1"	0.505		1"	0.558
	1-1/4"	0.266		1-1/4"	0.292
	1-1/2"	0.064		1-1/2"	0.070
	1-3/4"	0.027		1-3/4"	0.030
	2"	0.017		2"	0.020

By: MDP

		5-Minute Test		24-Hour Test	
		mV	**%Cl**	**mV**	**%Cl**
9D(1)	1/4"	0.3	0.349	-8.1	0.370
Tested 5/18/08 and 8/13/08	1/2"	-13.8	0.653	-6.6	0.346
	3/4"	-16.3	0.730	-7.8	0.365
	1"	-5.4	0.449	-18.1	0.583
	1-1/4"	-17.2	0.760	-41.0	1.650
	1-1/2"	-34.4	1.634	-40.8	1.635
	1-3/4"	-13.3	0.639	-41.1	1.657
	2"	14.1	0.189	-17.9	0.578
9D(2)	1/4"	3.7	0.289	1.2	0.288
Tested 7/21/08 and 8/13/08	1/2"	-7.3	0.465	-9.0	0.447
	3/4"	-0.6	0.348	0.0	0.303
	1"	-9.0	0.500	-9.6	0.459
	1-1/4"	-19.1	0.775	-19.4	0.701
	1-1/2"	-16.4	0.689	-15.3	0.587
	1-3/4"	-22.3	0.890	-20.9	0.748
	2"	-18.2	0.745	-16.2	0.610
9D(3)	1/4"	-5.8	0.415	-6.4	0.396
Tested 8/14/08 and 8/28/08	1/2"	7.4	0.240	8.1	0.207
	3/4"	25.1	0.115	21.9	0.112
	1"	35.2	0.075	32.7	0.069
	1-1/4"	33.6	0.080	30.8	0.075
	1-1/2"	30.0	0.093	26.2	0.092
	1-3/4"	27.9	0.102	24.6	0.099
	2"	35.1	0.076	32.6	0.069
9D(4)	1/4"	-14.5	0.567	-13.6	0.546
Tested 8/25/08 and 8/28/08	1/2"	-11.8	0.502	-9.7	0.459
	3/4"	-6.1	0.389	-3.6	0.350
	1"	18.2	0.130	19.9	0.122
	1-1/4"	36.0	0.058	37.8	0.055
	1-1/2"	48.5	0.033	50.4	0.031
	1-3/4"	49.4	0.032	51.5	0.030
	2"	53.6	0.026	54.4	0.026
9D(5)	1/4"	-18.7	0.685	-18.2	0.671
Tested 8/25/08 and 8/28/08	1/2"	-16.0	0.607	-14.8	0.577
	3/4"	-18.3	0.673	-16.1	0.611
	1"	-27.6	1.022	-24.9	0.905
	1-1/4"	-25.5	0.930	-24.6	0.893
	1-1/2"	-23.9	0.866	-22.7	0.820
	1-3/4"	-17.2	0.640	-15.0	0.582
	2"	-0.6	0.303	0.8	0.287

9D 5-Min Average	
1/4"	0.461
1/2"	0.493
3/4"	0.451
1"	0.436
1-1/4"	0.521
1-1/2"	0.663
1-3/4"	0.461
2"	0.268

9D 24-Hr Average	
1/4"	0.454
1/2"	0.407
3/4"	0.348
1"	0.428
1-1/4"	0.675
1-1/2"	0.633
1-3/4"	0.623
2"	0.314

By: MDP

		5-Minute Test		24-Hour Test	
		mV	**%Cl**	**mV**	**%Cl**
9E(1) Tested 5/18/08 and 8/13/08	1/4"	-10.1	0.554	-13.6	0.476
	1/2"	-28.7	1.268	-18.7	0.599
	3/4"	-22.1	0.945	-17.6	0.570
	1"	-13.1	0.633	-23.9	0.759
	1-1/4"	2.1	0.322	-8.5	0.377
	1-1/2"	6.6	0.263	6.2	0.194
	1-3/4"	38.2	0.065	21.4	0.097
	2"	22.7	0.129	26.7	0.076
9E(2) Tested 7/21/08 and 8/13/08	1/4"	3.7	0.289	-4.3	0.365
	1/2"	-7.3	0.465	-6.5	0.401
	3/4"	-0.6	0.348	-15.7	0.597
	1"	-9.0	0.500	-12.7	0.525
	1-1/4"	-19.1	0.775	5.9	0.235
	1-1/2"	-16.4	0.689	24.0	0.107
	1-3/4"	-22.3	0.890	31.4	0.078
	2"	-18.2	0.745	34.6	0.068
9E(3) Tested 8/14/08 and 8/28/08	1/4"	-16.3	0.577	-19.3	0.705
	1/2"	-15.8	0.564	-19.0	0.695
	3/4"	2.9	0.250	-0.4	0.303
	1"	-19.1	0.652	-20.2	0.734
	1-1/4"	-34.0	1.250	-32.5	1.271
	1-1/2"	-32.1	1.150	-30.0	1.137
	1-3/4"	-2.2	0.312	-6.1	0.391
	2"	13.0	0.161	15.0	0.152
9E(4) Tested 8/25/08 and 8/28/08	1/4"	-15.6	0.596	-20.8	0.754
	1/2"	-10.0	0.463	-11.9	0.506
	3/4"	-9.2	0.447	-11.2	0.491
	1"	-16.5	0.620	-16.7	0.628
	1-1/4"	-12.4	0.516	-11.0	0.487
	1-1/2"	-13.6	0.545	-12.4	0.518
	1-3/4"	-0.8	0.306	0.5	0.291
	2"	21.9	0.110	23.1	0.106

9E 5-Min Average	
1/4"	0.504
1/2"	0.690
3/4"	0.497
1"	0.601
1-1/4"	0.716
1-1/2"	0.662
1-3/4"	0.393
2"	0.286
9E 24-Hr Average	
1/4"	0.575
1/2"	0.551
3/4"	0.490
1"	0.661
1-1/4"	0.592
1-1/2"	0.489
1-3/4"	0.214
2"	0.101

By: MDP

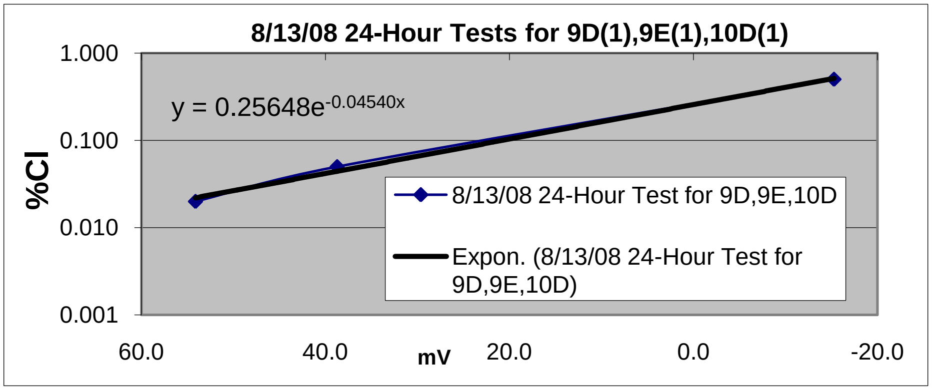
		5-Minute Test		24-Hour Test	
		mV	**%Cl**	**mV**	**%Cl**
10D(1) Tested 5/18/08 and 8/13/08	1/4"	-12.1	0.605	-16.9	0.552
	1/2"	-15.7	0.711	-18.5	0.594
	3/4"	-26.6	1.154	-29.0	0.957
	1"	-23.2	0.992	-28.2	0.923
	1-1/4"	-18.8	0.816	-27.6	0.898
	1-1/2"	-7.0	0.482	-9.8	0.400
	1-3/4"	-12.7	0.622	-14.4	0.493
	2"	6.1	0.269	-0.5	0.262
10D(2) Tested 7/21/08 and 8/13/08	1/4"	-19.8	0.799	-18.6	0.677
	1/2"	-15.5	0.663	-14.0	0.555
	3/4"	-10.5	0.534	-7.5	0.419
	1"	-24.7	0.987	-18.8	0.683
	1-1/4"	-20.7	0.830	-19.6	0.707
	1-1/2"	-31.5	1.325	-26.3	0.944
	1-3/4"	-13.0	0.595	-9.4	0.455
	2"	1.2	0.322	15.6	0.154
10D(3) Tested 8/14/08 and 8/28/08	1/4"	5.3	0.225	4.7	0.241
	1/2"	12.5	0.164	9.5	0.195
	3/4"	23.2	0.103	21.1	0.116
	1"	24.9	0.095	21.0	0.117
	1-1/4"	18.8	0.125	16.1	0.145
	1-1/2"	18.9	0.124	14.9	0.153
	1-3/4"	12.9	0.161	8.4	0.205
	2"	3.1	0.247	1.5	0.278
10D(4) Tested 8/25/08 and 8/28/08	1/4"	-6.1	0.389	-5.2	0.376
	1/2"	-7.4	0.412	-5.8	0.386
	3/4"	-1.5	0.316	0.4	0.292
	1"	-8.3	0.429	-6.3	0.394
	1-1/4"	-25.1	0.914	-23.4	0.846
	1-1/2"	-34.3	1.382	-32.8	1.288
	1-3/4"	-28.0	1.041	-23.5	0.850
	2"	-15.5	0.593	-14.2	0.561
10D(5) Tested 8/25/08 and 8/28/08	1/4"	-35.6	1.466	-35.9	1.479
	1/2"	-40.5	1.827	-39.6	1.745
	3/4"	-29.9	1.134	-29.5	1.112
	1"	-15.7	0.599	-13.7	0.549
	1-1/4"	12.3	0.170	13.9	0.160
	1-1/2"	14.5	0.154	16.1	0.145
	1-3/4"	42.8	0.043	45.9	0.038
	2"	57.6	0.022	58.7	0.022

10D 5-Min Average	
1/4"	0.697
1/2"	0.755
3/4"	0.648
1"	0.621
1-1/4"	0.571
1-1/2"	0.694
1-3/4"	0.492
2"	0.291

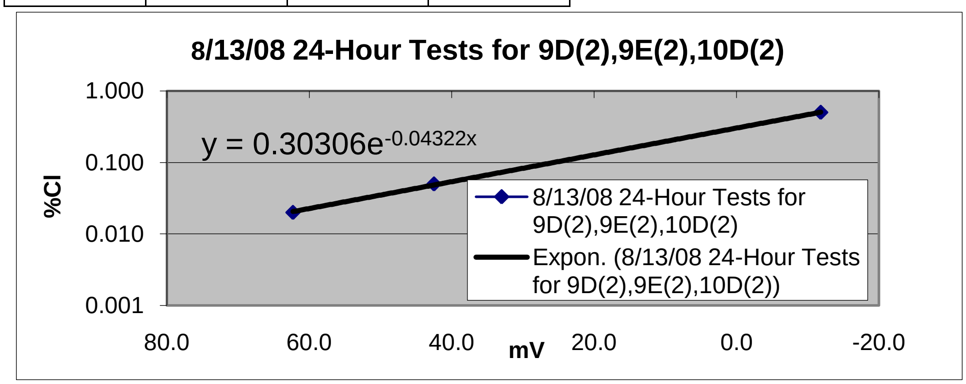
10D 24-Hr Average	
1/4"	0.665
1/2"	0.695
3/4"	0.579
1"	0.533
1-1/4"	0.551
1-1/2"	0.586
1-3/4"	0.408
2"	0.256

By: MDP

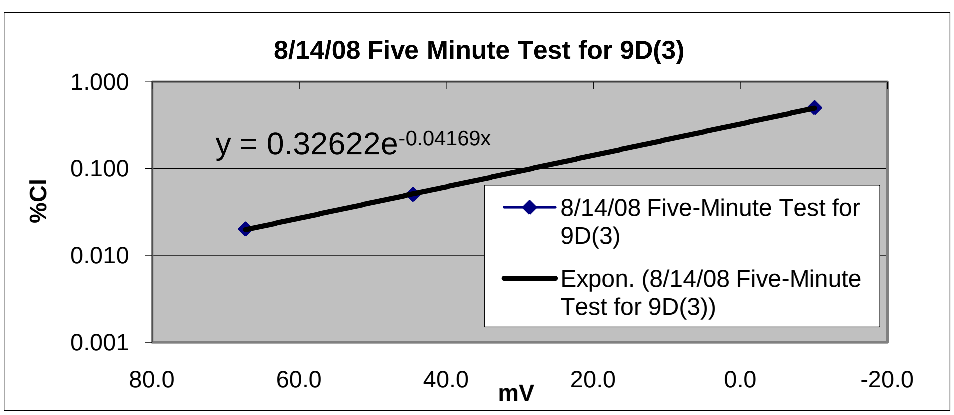
8/13/08 24-Hour Tests for 9D, 9E, 10D			
0.005	*0.020*	*0.050*	*0.500*
-	~~68.9~~	~~49.1~~	~~-5.1~~
-	54.1	38.7	-15.3



8/13/08 24-Hour Tests for 9D(2),9E(2),10D(2)			
0.005	*0.020*	*0.050*	*0.500*
-	~~68.9~~	~~49.1~~	~~-5.1~~
-	62.3	42.5	-11.8

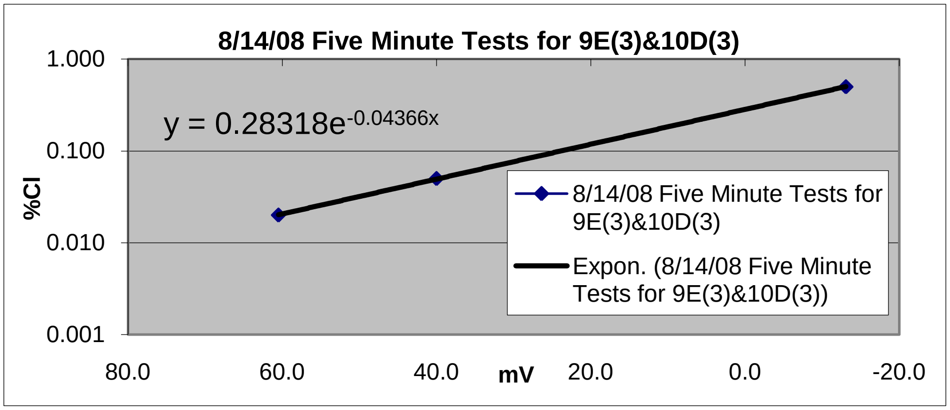


8/14/08 Five Minute Test for 9D(3)			
0.005	*0.020*	*0.050*	*0.500*
-	~~69.6~~	~~46.8~~	~~-7.8~~
-	67.3	44.5	-10.1

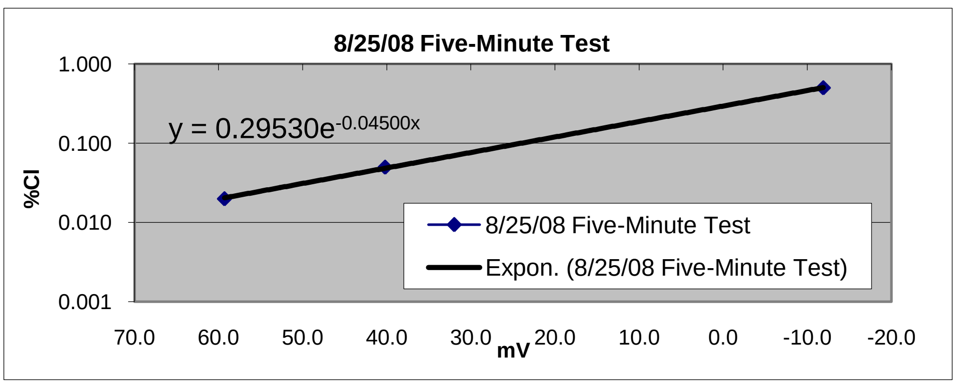


By: MDP

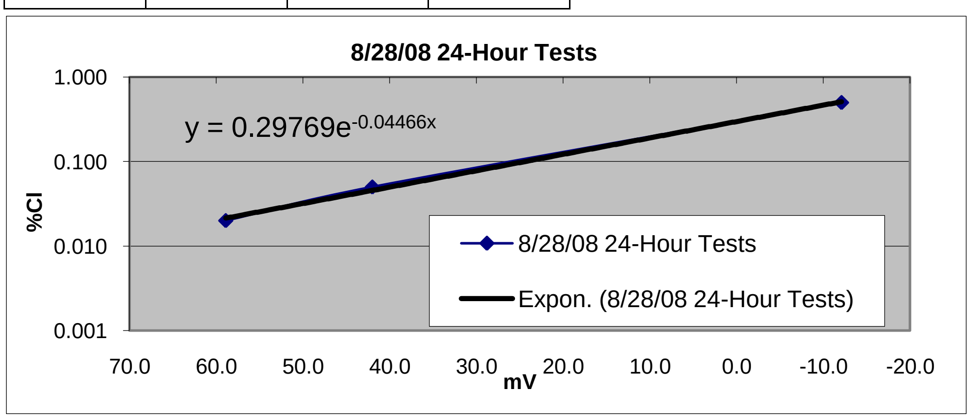
8/14/08 Five Minute Tests for 9E(3)&10D(3)			
0.005	*0.020*	*0.050*	*0.500*
-	~~67.3~~	~~44.5~~	~~-10.1~~
-	60.5	40.0	-13.1



8/25/08 Five-Minute Tests			
0.005	*0.020*	*0.050*	*0.500*
95.4	~~71.2~~	~~51.0~~	~~-5.5~~
-	59.3	40.2	-11.9



8/28/08 24-Hour Tests			
0.005	*0.020*	*0.050*	*0.500*
99.0	~~72.7~~	~~49.8~~	~~-5.8~~
-	58.9	42.0	-12.1



By: MDP

8/13/2008	%Cl Calibration Numbers			
	0.005	**0.020**	**0.050**	**0.500**
Start	-	68.9	49.1	-5.1
After 9D 1-1/4" and 1-3/4"	-	*54.1*	*38.7*	*-15.3*
After remainder of 9D	-	-	*38.9*	-
After 9E and 10D	-	-	*38.4*	-
After 9D(2) 1/4" and 1/2"	-	*62.3*	*42.5*	*-11.8*
After remainder of 9D(2)	-	-	*42.1*	-
After 9E(2) and 10D(2)	-	-	*42.9*	-

8/14/2008	%Cl Calibration Numbers			
	0.005	**0.020**	**0.050**	**0.500**
Start	-	69.6	46.8	-7.8
After 9D(3) 1/4" and 1/2"	-	-	*44.6*	-
After remainder of 9D(3)	-	-	*44.4*	-
After 9E(3)	-	-	*39.8*	-
After 10D(3) 1/4" and 1/2"	-	-	*43.1*	-
After remainder of 10D(3)	-	*60.5*	*40.0*	*-13.1*

8/25/2008	%Cl Calibration Numbers			
	0.005	**0.020**	**0.050**	**0.500**
Start	95.4	71.2	51.0	-5.5
After 9E(4) 1/4" to 1"	-	*65.4*	*45.7*	-
After 9E(4) and 9E(3) at 1-1/4"	-	-	*38.1*	-
After 7E(3)	-	-	*43.3*	-
After 9D(4)	-	-	*40.9*	-
After 9D(5)	-	-	*39.7*	-
After 10D(4)	-	-	*39.3*	-
After 10D(5)	-	*56.6*	*36.3*	*-14.3*
After remainder of 9E(3) and (4)	-	*57.4*	*38.3*	*-13.8*

8/28/2008	%Cl Calibration Numbers			
	0.005	**0.020**	**0.050**	**0.500**
Start	99.0	72.7	49.8	-5.8
After 9D(3)	-	-	*42.2*	-
After 9E(3)	-	-	*39.0*	-
After 10D(3)	-	-	*40.5*	-
After 10D(4)	-	-	*39.8*	-
After 10D(5)	-	*59.0*	*39.5*	*-12.6*
After 9D(5)	-	-	*38.8*	-
After 9E(4)	-	*58.9*	*42.0*	*-12.1*

Specimen #13 - 6 Month Exposure By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	102.1	75.5	54.0	-2.2
mV after	98.7	72.3	53.3	-3.0
mV before	98.0	75.3	53.8	-2.6
mV after	94.5	73.3	52.4	-2.8

	Date:
5 Minute Test	5/16/2008
24 Hour Test	5/17/2008

Assumed weight of concrete = 145.0 lb/cubic yard

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
13D						
0" to 1/4"	15.7	0.240	9.379	12.1	0.282	11.021
1/4" to 1/2"	50.4	0.052	2.024	43.8	0.067	2.616
1/2" to 3/4"	77.3	0.016	0.617	74.9	0.016	0.638
3/4" to 1"	75.8	0.017	0.659	75.0	0.016	0.635
1" to 1-1/4"	74.2	0.018	0.707	69.4	0.021	0.819
1-1/4" to 1-1/2"	82.6	0.012	0.488	75.8	0.016	0.612
1-1/2" to 1-3/4"	76.6	0.016	0.636	69.9	0.020	0.800
1-3/4" to 2"	65.6	0.026	1.034	54.9	0.040	1.581
13E						
0" to 1/4"	6.2	0.365	14.272	2.6	0.433	16.959
1/4" to 1/2"	15.4	0.243	9.504	12.0	0.283	11.071
1/2" to 3/4"	29.7	0.129	5.052	27.4	0.141	5.505
3/4" to 1"	39.1	0.085	3.335	34.6	0.101	3.971
1" to 1-1/4"	60.3	0.033	1.307	53.3	0.043	1.700
1-1/4" to 1-1/2"	62.4	0.030	1.191	56.1	0.038	1.497
1-1/2" to 1-3/4"	57.8	0.037	1.460	50.0	0.050	1.974
1-3/4" to 2"	60.7	0.033	1.284	54.9	0.040	1.581
13F						
0" to 1/4"	0.4	0.471	18.442	-1.9	0.531	20.800
1/4" to 1/2"	7.7	0.341	13.357	4.4	0.399	15.629
1/2" to 3/4"	21.8	0.183	7.163	17.7	0.218	8.548
3/4" to 1"	49.6	0.054	2.097	43.2	0.069	2.688
1" to 1-1/4"	65.0	0.027	1.062	60.7	0.031	1.215
1-1/4" to 1-1/2"	69.7	0.022	0.863	64.2	0.026	1.037
1-1/2" to 1-3/4"	62.8	0.030	1.170	52.7	0.045	1.747
1-3/4" to 2"	60.7	0.033	1.284	52.8	0.044	1.739

Specimen #14 - 6 Month Exposure

By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	102.1	75.5	54.0	-2.2
mV after	98.7	72.3	53.3	-3.0
mV before	98.0	75.3	53.8	-2.6
mV after	94.5	73.3	52.4	-2.8

	Date:
5 Minute Test	5/16/2008
24 Hour Test	5/17/2008

Assumed weight of concrete = 145.0 lb/cubic yard

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
14D						
0" to 1/4"	64.4	0.028	1.090	60.8	0.031	1.210
1/4" to 1/2"	69.8	0.022	0.859	64.0	0.027	1.046
1/2" to 3/4"	76.9	0.016	0.628	68.6	0.022	0.849
3/4" to 1"	72.8	0.019	0.752	67.7	0.023	0.884
1" to 1-1/4"	72.2	0.020	0.772	64.1	0.027	1.041
1-1/4" to 1-1/2"	71.2	0.021	0.807	64.3	0.026	1.032
1-1/2" to 1-3/4"	81.0	0.013	0.524	73.8	0.017	0.671
1-3/4" to 2"	80.6	0.014	0.533	76.3	0.015	0.599
14E						
0" to 1/4"	65.6	0.026	1.034	60.4	0.031	1.232
1/4" to 1/2"	66.8	0.025	0.981	62.0	0.029	1.145
1/2" to 3/4"	65.7	0.026	1.029	63.3	0.028	1.080
3/4" to 1"	67.8	0.024	0.938	65.4	0.025	0.982
1" to 1-1/4"	80.4	0.014	0.538	69.9	0.020	0.800
1-1/4" to 1-1/2"	83.8	0.012	0.463	72.7	0.018	0.705
1-1/2" to 1-3/4"	83.6	0.012	0.467	71.9	0.019	0.731
1-3/4" to 2"	85.9	0.011	0.422	72.2	0.018	0.721
14F						
0" to 1/4"	48.6	0.056	2.192	47.3	0.057	2.232
1/4" to 1/2"	58.2	0.037	1.434	52.6	0.045	1.755
1/2" to 3/4"	62.8	0.030	1.170	57.7	0.036	1.392
3/4" to 1"	66.8	0.025	0.981	62.2	0.029	1.135
1" to 1-1/4"	75.2	0.017	0.677	71.7	0.019	0.738
1-1/4" to 1-1/2"	71.1	0.021	0.811	64.8	0.026	1.009
1-1/2" to 1-3/4"	76.0	0.017	0.653	69.9	0.020	0.800
1-3/4" to 2"	72.7	0.019	0.756	66.8	0.024	0.921

Specimen #15 - 6 Month Exposure

By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	102.1	75.5	54.0	-2.2
mV after	98.7	72.3	53.3	-3.0
mV before	98.0	75.3	53.8	-2.6
mV after	94.5	73.3	52.4	-2.8

	Date:
5 Minute Test	5/16/2008
24 Hour Test	5/17/2008

Assumed weight of concrete = 145.0 lb/cubic yard

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
15D						
0" to 1/4"	13.0	0.270	10.568	11.6	0.288	11.274
1/4" to 1/2"	14.3	0.255	9.978	11.7	0.287	11.223
1/2" to 3/4"	32.7	0.113	4.425	29.3	0.129	5.050
3/4" to 1"	41.3	0.077	3.026	39.7	0.080	3.151
1" to 1-1/4"	36.5	0.096	3.741	33.7	0.106	4.136
1-1/4" to 1-1/2"	35.4	0.100	3.927	34.8	0.101	3.935
1-1/2" to 1-3/4"	42.5	0.073	2.870	40.7	0.077	3.011
1-3/4" to 2"	62.7	0.030	1.175	57.8	0.035	1.386
15E(2)						
0" to 1/4"	4.0	0.379	14.838	0.5	0.417	16.320
1/4" to 1/2"	8.0	0.320	12.536	2.8	0.376	14.738
1/2" to 3/4"	14.4	0.245	9.573	10.6	0.266	10.429
3/4" to 1"	22.1	0.177	6.920	19.7	0.178	6.966
1" to 1-1/4"	33.3	0.110	4.317	31.3	0.106	4.165
1-1/4" to 1-1/2"	34.7	0.104	4.069	30.4	0.111	4.335
1-1/2" to 1-3/4"	42.5	0.075	2.929	36.5	0.084	3.307
1-3/4" to 2"	51.9	0.050	1.971	44.7	0.059	2.299
15F						
0" to 1/4"	10.3	0.304	11.907	8.8	0.327	12.801
1/4" to 1/2"	20.5	0.194	7.587	18.4	0.212	8.281
1/2" to 3/4"	36.8	0.094	3.692	34.6	0.101	3.971
3/4" to 1"	69.4	0.022	0.874	67.0	0.023	0.913
1" to 1-1/4"	75.9	0.017	0.656	69.1	0.021	0.830
1-1/4" to 1-1/2"	77.8	0.015	0.603	74.2	0.017	0.659
1-1/2" to 1-3/4"	54.7	0.043	1.674	52.4	0.045	1.771
1-3/4" to 2"	55.8	0.041	1.594	53.9	0.042	1.654

Tested 7/7/08 and 7/8/08

Specimen #16 - 6 Month Exposure By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	102.1	75.5	54.0	-2.2
mV after	98.7	72.3	53.3	-3.0
mV before	98.0	75.3	53.8	-2.6
mV after	94.5	73.3	52.4	-2.8

	Date:
5 Minute Test	5/16/2008
24 Hour Test	5/17/2008

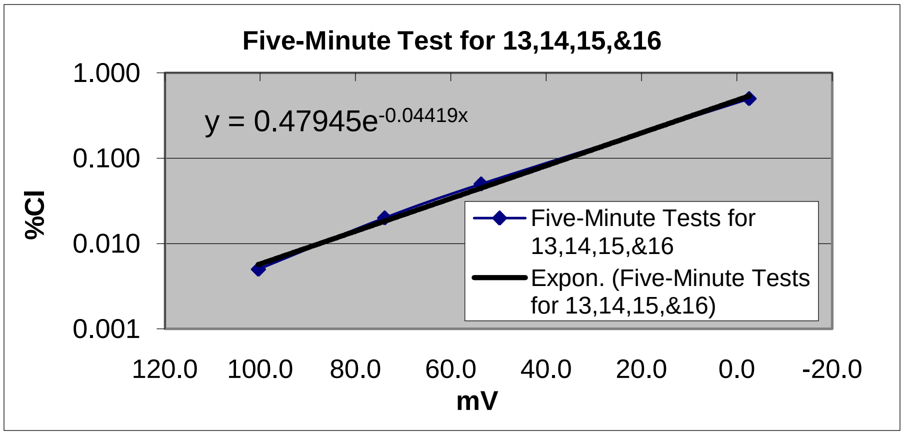
Assumed weight of concrete = 145.0 lb/cubic yard

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
16D						
0" to 1/4"	7.5	0.344	13.475	6.0	0.371	14.535
1/4" to 1/2"	14.6	0.252	9.846	13.2	0.268	10.484
1/2" to 3/4"	32.6	0.114	4.445	30.8	0.121	4.718
3/4" to 1"	57.8	0.037	1.460	53.7	0.043	1.669
1" to 1-1/4"	50.6	0.051	2.006	46.5	0.059	2.314
1-1/4" to 1-1/2"	55.8	0.041	1.594	51.4	0.047	1.853
1-1/2" to 1-3/4"	69.0	0.023	0.890	65.7	0.025	0.968
1-3/4" to 2"	62.2	0.031	1.202	58.5	0.034	1.343
16E						
0" to 1/4"	7.7	0.341	13.357	6.6	0.361	14.145
1/4" to 1/2"	12.4	0.277	10.852	11.2	0.293	11.480
1/2" to 3/4"	24.7	0.161	6.302	22.6	0.175	6.844
3/4" to 1"	37.2	0.093	3.627	35.6	0.097	3.795
1" to 1-1/4"	53.1	0.046	1.796	51.9	0.046	1.811
1-1/4" to 1-1/2"	68.0	0.024	0.930	66.9	0.023	0.917
1-1/2" to 1-3/4"	72.8	0.019	0.752	68.5	0.022	0.853
1-3/4" to 2"	61.7	0.031	1.228	58.4	0.034	1.349
16F						
0" to 1/4"	7.8	0.340	13.298	5.3	0.383	15.004
1/4" to 1/2"	13.0	0.270	10.568	11.3	0.292	11.428
1/2" to 3/4"	23.2	0.172	6.733	20.9	0.189	7.393
3/4" to 1"	36.8	0.094	3.692	35.5	0.097	3.812
1" to 1-1/4"	49.3	0.054	2.125	46.7	0.059	2.293
1-1/4" to 1-1/2"	66.0	0.026	1.016	60.7	0.031	1.215
1-1/2" to 1-3/4"	78.4	0.015	0.587	72.9	0.018	0.699
1-3/4" to 2"	66.3	0.026	1.002	61.5	0.030	1.172

5-Minute Tests for #13 to #16

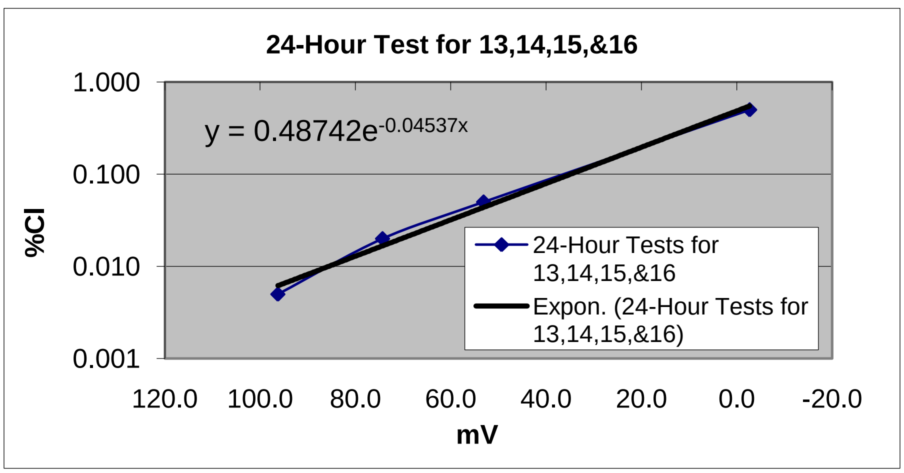
By: MDP

5/16/2008	%Cl	**0.005**	**0.020**	**0.050**	**0.500**
	mV before	102.1	75.5	54.0	-2.2
	mv after	98.7	72.3	53.3	-3.0
	mV average	100.4	73.9	53.7	-2.6



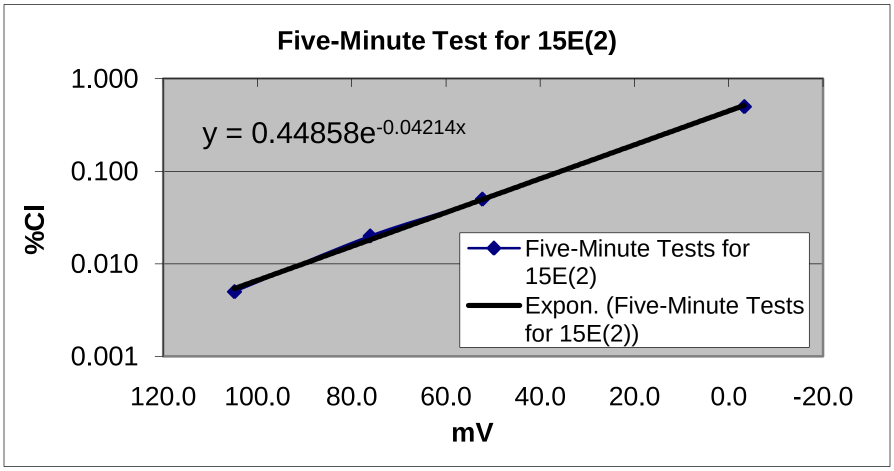
24-Hour Tests for #13 to #16

5/17/2008	%Cl	**0.005**	**0.020**	**0.050**	**0.500**
	mV before	98.0	75.3	53.8	-2.6
	mv after	94.5	73.3	52.4	-2.8
	mV average	96.3	74.3	53.1	-2.7



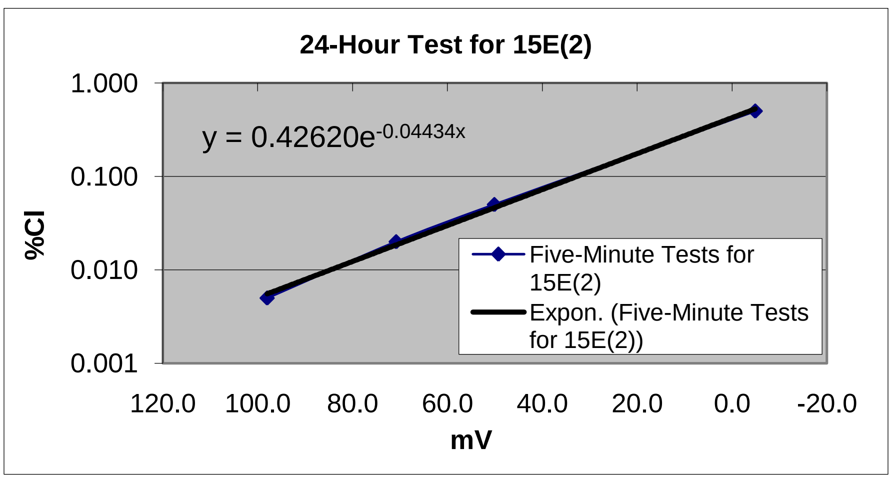
5-Minute Test for 15E(2) By: MDP

7/7/2008	%Cl	**0.005**	**0.020**	**0.050**	**0.500**
	mV after	104.9	76.1	52.3	-3.3



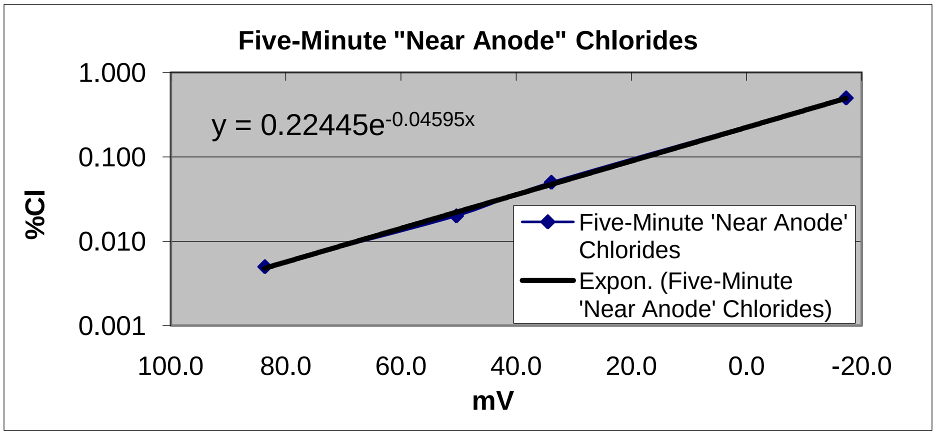
24-Hour Test 15E(2)

7/8/2008	%Cl	**0.005**	**0.020**	**0.050**	**0.500**
	mV after	98.0	70.8	50.1	-4.9



5-Minute Chloride Tests Near Anodes dated 11/14/2008 By: MDP

%Cl	**0.005**	**0.020**	**0.050**	**0.500**
mV after	83.7	50.4	33.9	-17.3



Location	5-Minute mV	5-Minute %Cl	24-Hour %Cl	Average %Cl
9W 1/4"	40.4	0.035	0.039	0.026
9W 1/2"	64.7	0.011	0.013	
9A 1/4"	25.0	0.071	0.078	0.065
9A 1/2"	33.6	0.048	0.053	
9E 1/4"	42.4	0.032	0.035	0.026
9E 1/2"	59.5	0.015	0.016	
10W 1/4"	51.2	0.021	0.023	0.022
10W 1/2"	53.8	0.019	0.021	
10A 1/4"	48.0	0.025	0.027	0.026
10A 1/2"	49.6	0.023	0.025	
10E 1/4"	49.1	0.024	0.026	0.023
10E 1/2"	53.5	0.019	0.021	

24-Hour Test = 5-Minute Tests x 1.1 (assumed per Germann Instruments)

APPENDIX D

CoC Chlorides at 0-Months

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	96.9	71.7	49.8	-4.5
mV after	97.5	72.7	50.7	-4.9
mV before	97.2	71.6	49.7	-4.6
mV after	96.9	70.9	49.1	-4.8

0" to 1/4"

By: MDP

Date:

5 Minute Test 1/2/2008

24 Hour Test 1/3/2008

Assumed weight of concrete = 145.0 lb/yd3

Sample No.	5 Minute Test				24 Hour Test			
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	Average lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	Average lb. Cl/yd^3 concrete
17A	20.5	0.172	6.734	6.695	19.1	0.180	7.047	6.943
17B	27.4	0.129	5.050		26.5	0.132	5.168	
17C	15.5	0.212	8.300		14.6	0.220	8.613	
18A	20.4	0.173	6.773	7.439	18.0	0.190	7.439	7.882
18B	16.9	0.200	7.830		15.1	0.214	8.378	
18C	17.3	0.197	7.713		16.9	0.200	7.830	
19A	20.1	0.175	6.851	6.682	19.0	0.180	7.047	7.151
19B	18.1	0.190	7.439		15.5	0.210	8.222	
19C	24.2	0.147	5.755		22.3	0.158	6.186	
20A	18.2	0.190	7.439	6.695	16.8	0.200	7.830	7.178
20B	23.9	0.150	5.873		22.0	0.160	6.264	
20C	20.4	0.173	6.773		18.1	0.190	7.439	
21A	21.0	0.170	6.656	6.695	17.5	0.193	7.556	7.439
21B	20.4	0.173	6.773		18.4	0.187	7.321	
21C	21.0	0.170	6.656		18.0	0.190	7.439	
22A	21.4	0.167	6.538	6.760	20.0	0.173	6.773	7.073
22B	18.6	0.188	7.360		17.2	0.193	7.556	
22C	21.8	0.163	6.381		19.8	0.176	6.890	
23A	20.2	0.174	6.812	7.191	17.7	0.190	7.439	7.582
23B	17.1	0.200	7.830		15.4	0.210	8.222	
23C	19.8	0.177	6.930		18.9	0.181	7.086	
24A	22.2	0.160	6.264	6.577	21.0	0.168	6.577	6.930
24B	21.1	0.168	6.577		19.4	0.178	6.969	
24C	20.0	0.176	6.890		18.4	0.185	7.243	
25A	24.1	0.148	5.794	6.512	22.2	0.158	6.186	6.890
25B	21.8	0.163	6.381		20.6	0.170	6.656	
25C	18.4	0.188	7.360		16.9	0.200	7.830	
26A	19.3	0.180	7.047	7.204	17.8	0.190	7.439	7.399
26B	17.8	0.192	7.517		17.1	0.195	7.634	
26C	19.4	0.180	7.047		18.7	0.182	7.125	
27A	23.8	0.150	5.873	6.003	21.7	0.160	6.264	6.355
27B	20.1	0.175	6.851		18.0	0.189	7.399	
27C	26.2	0.135	5.285		25.5	0.138	5.403	
28A	18.2	0.190	7.439	6.656	16.0	0.205	8.026	7.478
28B	25.2	0.140	5.481		23.3	0.150	5.873	
28C	19.6	0.180	7.047		14.8	0.218	8.535	
29A	21.2	0.168	6.577	6.381	19.7	0.177	6.930	6.812
29B	24.0	0.148	5.794		22.0	0.160	6.264	
29C	20.3	0.173	6.773		18.5	0.185	7.243	
30A	23.1	0.153	5.990	6.290	20.0	0.175	6.851	7.008
30B	21.9	0.162	6.342		18.6	0.185	7.243	
30C	21.2	0.167	6.538		19.7	0.177	6.930	

Measurement of the acid soluble chloride content of hardened concrete by the RCT method

Report #: ________ **Structure:** ________ **Project:** 1/4" 5-minute Test

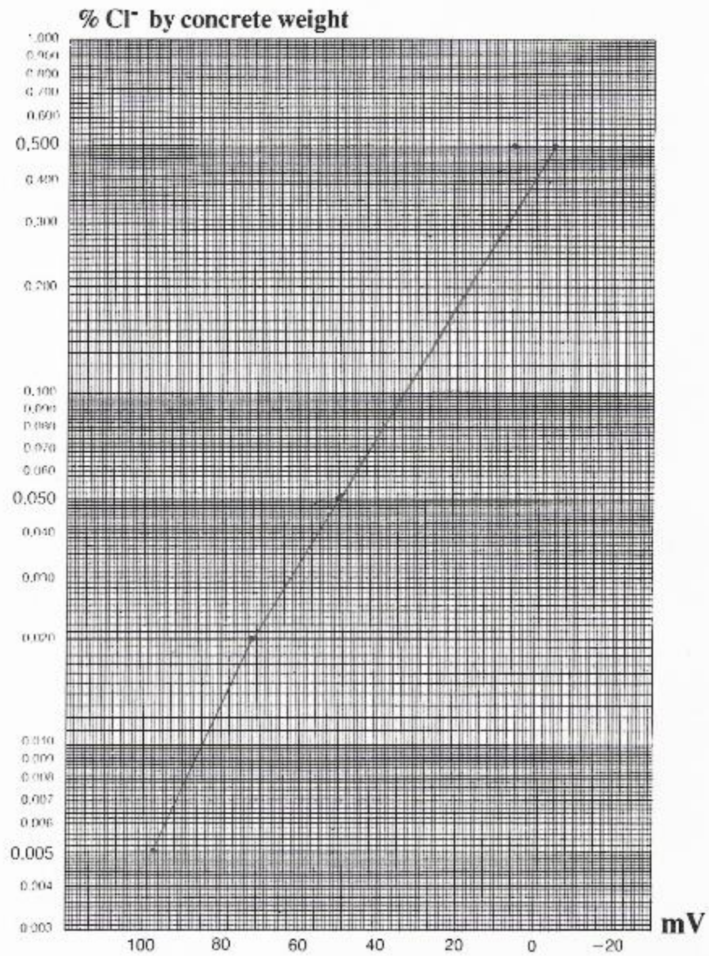
Date of testing: 1/2/08 **Electrode #:** ________ **Person:** MDP

Testing Lab: UWM **Address:** ________ **Phone:** ________

RCT

HARDENED CONCRETE

1.5 gram of concrete dust dissolved in a RCT-1023 vial with 10 milliliter of extraction liquid



CALIBRATION:

Liquid	Clear		Purple		Green		Pink	
% Cl	0.005		0.020		0.050		0.500	
mV before	96.9	97.2	71.7	72.2	49.8	50.3	-4.5	-4.7
mV after	97.5		72.7		50.7		-4.9	

SAMPLE #	1		2		Remarks
	mV	% Cl	mV	% Cl	

Measurement of the acid soluble chloride content of hardened concrete by the RCT method

Report #: ______ **Structure:** ______ **Project:** 1/4" 24-Hour Test

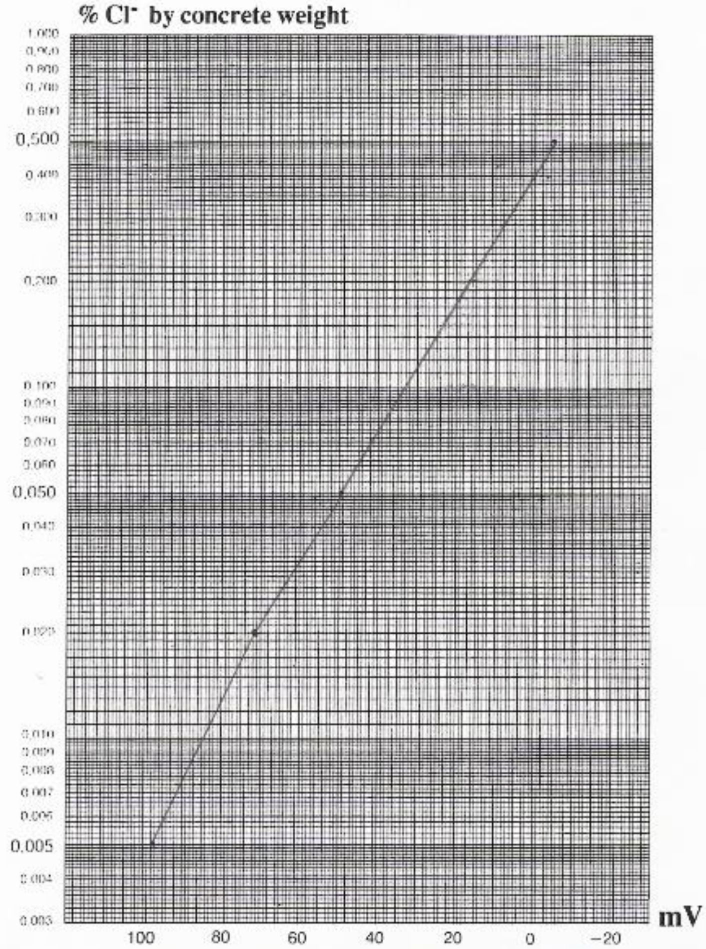
Date of testing: 1/3/08 **Electrode #:** ______ **Person:** MDP

Testing Lab: UWM **Address:** ______ **Phone:** ______

RCT

HARDENED CONCRETE

1.5 gram of concrete dust dissolved in a RCT-1023 vial with 10 milliliter of extraction liquid



CALIBRATION:

Liquid	Clear	Purple	Green	Pink
% Cl	0.005	0.020	0.050	0.500
mV before	97.2	71.6	49.7	-4.6
mV after	96.9	70.9	49.1	-4.8
(average)	97.1	71.3	49.4	-4.7

SAMPLE #	1		2		Remarks
	mV	% Cl	mV	% Cl	

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	96.2	72.4	50.9	-4.1
mV after	96.8	74.2	52.8	-3.7
mV before	93.9	72.2	51.4	-3.2
mV after	96.6	73.2	52.0	-4.0

1/4" to 1/2"

By: MDP

Date:

5 Minute Test 12/14/2007

24 Hour Test 12/15/2007

Assumed weight of concrete = 145.0 lb/yd3

Sample No.	5 Minute Test				24 Hour Test			
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	Average lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	Average lb. Cl/yd^3 concrete
17A	22.0	0.170	6.656	6.825	18.7	0.200	7.830	7.830
17B	25.4	0.148	5.794		22.2	0.170	6.656	
17C	18.0	0.205	8.026		15.3	0.230	9.005	
18A	20.7	0.180	7.047	6.825	17.4	0.210	8.222	8.091
18B	21.0	0.178	6.969		16.8	0.215	8.417	
18C	23.0	0.165	6.460		19.2	0.195	7.634	
19A	23.0	0.165	6.460	5.677	19.1	0.197	7.713	6.616
19B	29.2	0.128	5.011		25.7	0.150	5.873	
19C	26.3	0.142	5.559		24.0	0.160	6.264	
20A	22.2	0.170	6.656	6.081	19.4	0.194	7.595	6.747
20B	25.4	0.148	5.794		24.4	0.158	6.186	
20C	25.3	0.148	5.794		23.2	0.165	6.460	
21A	30.3	0.120	4.698	4.868	27.5	0.138	5.403	5.455
21B	25.4	0.148	5.794		23.8	0.162	6.342	
21C	33.2	0.105	4.111		31.6	0.118	4.620	
22A	24.4	0.155	6.068	5.964	21.6	0.178	6.969	6.760
22B	24.2	0.155	6.068		22.1	0.172	6.734	
22C	25.6	0.147	5.755		23.0	0.168	6.577	
23A	25.3	0.148	5.794	6.825	23.8	0.162	6.342	7.530
23B	21.5	0.175	6.851		20.1	0.190	7.439	
23C	18.2	0.200	7.830		15.7	0.225	8.809	
24A	25.7	0.147	5.755	6.264	23.8	0.162	6.342	6.793
24B	-	-	-		-	-	-	
24C	21.7	0.173	6.773		20.4	0.185	7.243	
25A	28.2	0.130	5.090	5.155	27.0	0.142	5.559	5.859
25B	28.8	0.128	5.011		25.7	0.150	5.873	
25C	27.4	0.137	5.364		24.6	0.157	6.147	
26A	21.9	0.172	6.734	6.107	19.3	0.195	7.634	6.825
26B	24.1	0.155	6.068		22.0	0.173	6.773	
26C	26.6	0.141	5.520		24.8	0.155	6.068	
27A	26.1	0.145	5.677	5.390	22.5	0.170	6.656	6.290
27B	26.8	0.140	5.481		22.9	0.167	6.538	
27C	28.9	0.128	5.011		26.5	0.145	5.677	
28A	22.2	0.170	6.656	4.920	20.2	0.188	7.360	5.598
28B	38.3	0.086	3.367		36.6	0.096	3.758	
28C	30.1	0.121	4.737		26.8	0.145	5.677	
29A	28.2	0.131	5.129	5.598	24.5	0.155	6.068	6.303
29B	23.4	0.160	6.264		21.6	0.178	6.969	
29C	27.0	0.138	5.403		25.7	0.150	5.873	
30A	21.6	0.175	6.851	6.042	16.2	0.222	8.691	6.969
30B	26.7	0.140	5.481		25.8	0.148	5.794	
30C	25.4	0.148	5.794		23.5	0.164	6.421	

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	96.2	72.4	50.9	-4.1
mV after	96.8	74.2	52.8	-3.7
mV before	93.9	72.2	51.4	-3.2
mV after	96.6	73.2	52.0	-4.0

1/2" to 3/4" By: MDP

Date:

5 Minute Test 12/14/2007

24 Hour Test 12/15/2007

Assumed weight of concrete = 145.0 lb/yd3

Sample No.	5 Minute Test				24 Hour Test			
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	Average lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	Average lb. Cl/yd^3 concrete
17A	25.3	0.150	5.873	5.233	24.0	0.160	6.264	5.585
17B	28.3	0.130	5.090		27.5	0.138	5.403	
17C	30.2	0.121	4.737		28.6	0.130	5.090	
18A	24.8	0.150	5.873	5.546	24.4	0.158	6.186	6.238
18B	29.4	0.125	4.894		27.3	0.140	5.481	
18C	25.1	0.150	5.873		21.5	0.180	7.047	
19A	29.3	0.125	4.894	4.502	27.1	0.142	5.559	4.959
19B	34.8	0.100	3.915		33.9	0.107	4.189	
19C	30.7	0.120	4.698		28.7	0.131	5.129	
20A	27.7	0.135	5.285	5.090	25.1	0.152	5.951	5.638
20B	27.0	0.138	5.403		25.8	0.150	5.873	
20C	31.0	0.117	4.581		28.9	0.130	5.090	
21A	29.5	0.125	4.894	4.698	28.1	0.135	5.285	5.050
21B	28.6	0.130	5.090		27.3	0.140	5.481	
21C	33.8	0.105	4.111		32.5	0.112	4.385	
22A	29.2	0.127	4.972	5.050	27.6	0.138	5.403	5.481
22B	27.1	0.138	5.403		25.6	0.150	5.873	
22C	29.9	0.122	4.776		28.7	0.132	5.168	
23A	24.4	0.155	6.068	6.355	20.4	0.185	7.243	7.164
23B	26.4	0.142	5.559		23.3	0.164	6.421	
23C	19.6	0.190	7.439		18.5	0.200	7.830	
24A	24.0	0.155	6.068	5.768	22.5	0.170	6.656	6.381
24B	28.1	0.132	5.168		26.8	0.144	5.638	
24C	24.0	0.155	6.068		22.0	0.175	6.851	
25A	29.5	0.125	4.894	5.220	28.4	0.134	5.246	5.899
25B	25.0	0.150	5.873		22.6	0.170	6.656	
25C	29.4	0.125	4.894		26.0	0.148	5.794	
26A	25.6	0.147	5.755	5.285	24.8	0.155	6.068	5.651
26B	27.1	0.138	5.403		26.0	0.148	5.794	
26C	30.3	0.120	4.698		29.0	0.130	5.090	
27A	31.0	0.118	4.620	4.594	30.2	0.123	4.815	5.142
27B	34.0	0.103	4.032		31.2	0.119	4.659	
27C	28.3	0.131	5.129		25.3	0.152	5.951	
28A	24.2	0.155	6.068	4.463	23.0	0.165	6.460	4.711
28B	36.6	0.093	3.641		36.2	0.096	3.758	
28C	36.3	0.094	3.680		35.3	0.100	3.915	
29A	29.2	0.127	4.972	4.150	28.1	0.135	5.285	4.398
29B	30.0	0.121	4.737		29.7	0.128	5.011	
29C	43.3	0.070	2.741		42.8	0.074	2.897	
30A	18.4	0.200	7.830	4.972	16.0	0.222	8.691	5.520
30B	49.0	0.054	2.114		49.3	0.056	2.192	
30C	29.0	0.127	4.972		26.8	0.145	5.677	

Measurement of the acid soluble chloride content of hardened concrete by the RCT method

Report #: ______ **Structure:** ______ **Project:** 1/2" + 3/4" 5-minute Test

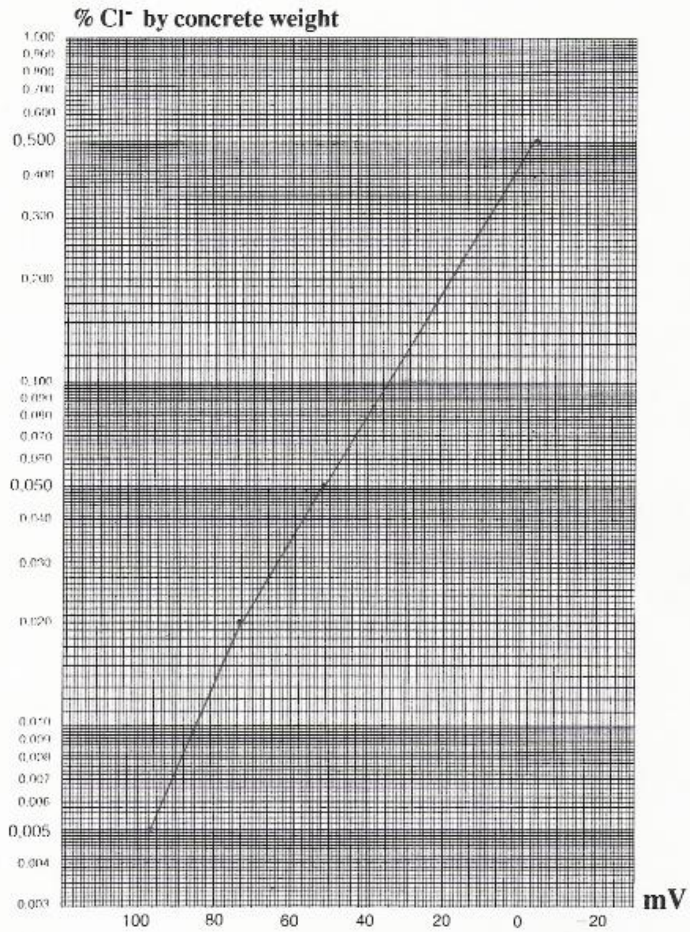
Date of testing: 12/14/07 **Electrode #:** ______ **Person:** MDP

Testing Lab: UWM **Address:** ______ **Phone:** ______

RCT

HARDENED CONCRETE

1.5 gram of concrete dust dissolved in a RCT-1023 vial with 10 milliliter of extraction liquid



CALIBRATION:

Liquid	Clear		Purple		Green		Pink	
% Cl	0.005		0.020		0.050		0.500	
mV before	96.2	96.5	72.4	73.3	50.9	51.9	-4.1	-3.9
mV after	96.8		74.2		52.8		-3.7	

SAMPLE #	1		2		Remarks
	mV	% Cl	mV	% Cl	

Measurement of the acid soluble chloride content of hardened concrete by the RCT method

Report #: ________ **Structure:** ________ **Project:** 1/2" + 3/4" 24-Hour Test

Date of testing: 12/15/07 **Electrode #:** ________ **Person:** MDP

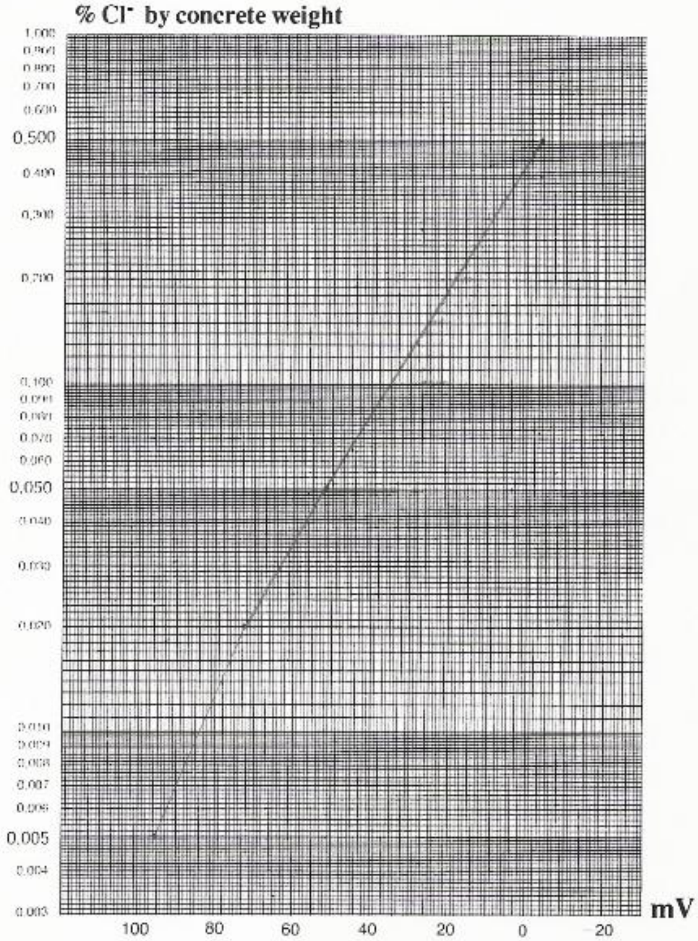
Testing Lab: UWM **Address:** ________ **Phone:** ________

RCT

HARDENED CONCRETE

1.5 gram of concrete dust dissolved in a RCT-1023 vial with 10 milliliter of extraction liquid

% Cl⁻ by concrete weight



CALIBRATION:

Liquid	Clear	Purple	Green	Pink
% Cl	0.005	0.020	0.050	0.500
mV before	93.9 95.3	72.2 72.7	51.4 51.7	-3.2 -3.6
mV after	96.6	73.2	52.0	-4.0

SAMPLE #	1		2		Remarks
	mV	% Cl	mV	% Cl	

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	97.2	72.8	50.5	-4.2
mV after	99.9	73.4	51.5	-3.8
mV before	98.4	72.9	51.4	-4.5
mV after	97.4	72.6	50.3	-3.9

3/4" to 1" By: MDP

Date:

5 Minute Test 11/24/2007

24 Hour Test 11/25/2007

Assumed weight of concrete = 145.0 lb/yd3

Sample No.	5 Minute Test				24 Hour Test			
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	Average lb. Cl/yd^3	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	Average lb. Cl/yd^3 concrete
17A	23.7	0.155	6.068		23.1	0.159	6.225	
17B	28.0	0.130	5.090	5.311	27.8	0.130	5.090	5.442
17C	29.3	0.122	4.776		28.0	0.128	5.011	
18A	31.2	0.112	4.385		30.5	0.115	4.502	
18B	26.2	0.141	5.520	4.920	24.6	0.148	5.794	5.129
18C	29.0	0.124	4.855		27.8	0.130	5.090	
19A	28.8	0.125	4.894		27.7	0.130	5.090	
19B	27.3	0.132	5.168	4.450	24.4	0.145	5.677	4.711
19C	38.3	0.084	3.289		37.1	0.086	3.367	
20A	33.0	0.105	4.111		31.7	0.110	4.307	
20B	31.2	0.112	4.385	3.758	28.4	0.125	4.894	4.032
20C	42.5	0.071	2.780		40.9	0.074	2.897	
21A	27.1	0.135	5.285		26.1	0.138	5.403	
21B	29.2	0.122	4.776	5.220	27.5	0.130	5.090	5.559
21C	25.7	0.143	5.598		23.0	0.158	6.186	
22A	26.2	0.141	5.520		24.6	0.145	5.677	
22B	28.3	0.127	4.972	5.298	27.1	0.132	5.168	5.455
22C	26.5	0.138	5.403		25.8	0.141	5.520	
23A	27.0	0.135	5.285		22.5	0.160	6.264	
23B	32.3	0.108	4.228	5.063	29.9	0.118	4.620	5.612
23C	25.2	0.145	5.677		23.9	0.152	5.951	
24A	28.3	0.128	5.011		27.0	0.132	5.168	
24B	27.9	0.130	5.090	5.207	27.3	0.132	5.168	5.337
24C	26.2	0.141	5.520		25.3	0.145	5.677	
25A	31.7	0.111	4.346		29.5	0.120	4.698	
25B	26.2	0.141	5.520	4.881	22.3	0.160	6.264	5.351
25C	29.2	0.122	4.776		27.2	0.130	5.090	
26A	28.3	0.127	4.972		27.1	0.130	5.090	
26B	26.9	0.135	5.285	5.011	26.5	0.138	5.403	5.194
26C	29.1	0.122	4.776		27.5	0.130	5.090	
27A	36.0	0.093	3.641		34.9	0.094	3.680	
27B	30.1	0.120	4.698	5.063	28.3	0.125	4.894	5.181
27C	21.1	0.175	6.851		20.3	0.178	6.969	
28A	30.3	0.118	4.620		28.8	0.124	4.855	
28B	28.0	0.130	5.090	4.594	26.3	0.135	5.285	4.855
28C	33.1	0.104	4.072		30.8	0.113	4.424	
29A	27.3	0.133	5.207		24.2	0.150	5.873	
29B	38.5	0.084	3.289	4.137	36.9	0.087	3.406	4.463
29C	33.9	0.100	3.915		33.1	0.105	4.111	
30A	21.9	0.168	6.577		20.7	0.175	6.851	
30B	58.6	0.036	1.409	3.889	54.6	0.046	1.801	4.137
30C	35.7	0.094	3.680		35.0	0.096	3.758	

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	97.2	72.8	50.5	-4.2
mV after	99.9	73.4	51.5	-3.8
mV before	98.4	72.9	51.4	-4.5
mV after	97.4	72.6	50.3	-3.9

1" to 1-1/4" By: MDP

Date:

5 Minute Test 11/24/2007

24 Hour Test 11/25/207

Assumed weight of concrete = 145.0 lb/yd3

Sample No.	5 Minute Test				24 Hour Test			
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	Average lb. Cl/yd^3	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	Average lb. Cl/yd^3 concrete
17A	28.7	0.125	4.894	4.972	26.0	0.140	5.481	5.377
17B	27.2	0.133	5.207		25.2	0.142	5.559	
17C	28.9	0.123	4.815		27.5	0.130	5.090	
18A	25.4	0.145	5.677	4.789	24.1	0.150	5.873	4.998
18B	31.8	0.111	4.346		29.8	0.119	4.659	
18C	31.7	0.111	4.346		30.4	0.114	4.463	
19A	29.2	0.122	4.776	4.254	26.0	0.140	5.481	4.711
19B	34.1	0.100	3.915		31.6	0.110	4.307	
19C	33.2	0.104	4.072		31.2	0.111	4.346	
20A	26.0	0.140	5.481	4.424	24.2	0.150	5.873	4.842
20B	39.1	0.082	3.210		38.5	0.086	3.367	
20C	30.7	0.117	4.581		26.8	0.135	5.285	
21A	30.8	0.117	4.581	4.189	28.9	0.122	4.776	4.333
21B	33.1	0.104	4.072		32.8	0.105	4.111	
21C	34.2	0.100	3.915		32.6	0.105	4.111	
22A	26.3	0.140	5.481	4.568	24.6	0.145	5.677	4.711
22B	35.4	0.095	3.719		34.8	0.098	3.837	
22C	30.9	0.115	4.502		30.1	0.118	4.620	
23A	28.1	0.128	5.011	4.424	25.8	0.140	5.481	4.750
23B	36.0	0.093	3.641		35.2	0.094	3.680	
23C	30.4	0.118	4.620		27.2	0.130	5.090	
24A	32.0	0.110	4.307	4.111	29.2	0.120	4.698	4.646
24B	33.2	0.103	4.032		27.7	0.130	5.090	
24C	33.7	0.102	3.993		32.8	0.106	4.150	
25A	33.1	0.105	4.111	3.876	31.6	0.110	4.307	4.385
25B	33.7	0.102	3.993		27.7	0.130	5.090	
25C	36.8	0.090	3.524		34.8	0.096	3.758	
26A	41.4	0.074	2.897	4.098	39.1	0.080	3.132	4.855
26B	30.0	0.120	4.698		25.2	0.142	5.559	
26C	30.2	0.120	4.698		24.2	0.150	5.873	
27A	36.2	0.092	3.602	3.993	34.9	0.096	3.758	4.581
27B	35.0	0.096	3.758		29.5	0.120	4.698	
27C	30.4	0.118	4.620		26.5	0.135	5.285	
28A	33.1	0.104	4.072	3.563	31.1	0.112	4.385	3.824
28B	36.8	0.090	3.524		35.1	0.095	3.719	
28C	40.0	0.079	3.093		37.2	0.086	3.367	
29A	35.1	0.096	3.758	4.046	33.2	0.102	3.993	4.333
29B	41.4	0.074	2.897		39.4	0.080	3.132	
29C	26.2	0.140	5.481		24.1	0.150	5.873	
30A	34.4	0.100	3.915	4.437	33.8	0.100	3.915	4.868
30B	30.2	0.120	4.698		25.1	0.140	5.481	
30C	30.1	0.120	4.698		27.0	0.133	5.207	

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	97.2	72.8	50.5	-4.2
mV after	99.9	73.4	51.5	-3.8
mV before	99.6	73.1	50.7	-3.9
mV after	96.4	69.4	47.2	-5.5

1-1/4" to 1-1/2" By: MDP

Date:

5 Minute Test 11/24/207

24 Hour Test 11/25/2007

Assumed weight of concrete = 145.0 lb/yd3

Sample No.	5 Minute Test				24 Hour Test			
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	Average lb. Cl/yd^3	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	Average lb. Cl/yd^3 concrete
17A	36.7	0.091	3.563	4.254	32.6	0.100	3.915	4.933
17B	28.8	0.127	4.972		23.6	0.150	5.873	
17C	32.8	0.108	4.228		27.0	0.128	5.011	
18A	32.1	0.110	4.307	3.876	27.7	0.125	4.894	4.293
18B	34.2	0.100	3.915		30.8	0.110	4.307	
18C	37.5	0.087	3.406		34.4	0.094	3.680	
19A	32.0	0.110	4.307	3.967	28.2	0.120	4.698	4.502
19B	35.2	0.096	3.758		39.7	0.115	4.502	
19C	34.4	0.098	3.837		30.3	0.110	4.307	
20A	34.9	0.099	3.876	3.941	31.3	0.107	4.189	4.346
20B	32.8	0.108	4.228		29.0	0.118	4.620	
20C	35.4	0.095	3.719		31.0	0.108	4.228	
21A	39.3	0.081	3.171	3.458	35.4	0.090	3.524	3.889
21B	32.6	0.108	4.228		28.2	0.120	4.698	
21C	41.0	0.076	2.975		35.9	0.088	3.445	
22A	31.8	0.111	4.346	4.176	28.0	0.122	4.776	4.737
22B	34.5	0.099	3.876		27.4	0.126	4.933	
22C	32.0	0.110	4.307		29.4	0.115	4.502	
23A	29.1	0.125	4.894	3.863	24.0	0.144	5.638	4.333
23B	40.0	0.079	3.093		37.6	0.082	3.210	
23C	36.1	0.092	3.602		31.1	0.106	4.150	
24A	42.5	0.071	2.780	3.210	38.3	0.078	3.054	3.667
24B	36.7	0.091	3.563		31.2	0.105	4.111	
24C	38.4	0.084	3.289		33.1	0.098	3.837	
25A	33.4	0.103	4.032	3.132	28.4	0.120	4.698	3.641
25B	34.4	0.100	3.915		29.1	0.117	4.581	
25C	58.5	0.037	1.449		53.8	0.042	1.644	
26A	34.6	0.098	3.837	3.758	29.3	0.115	4.502	4.437
26B	38.1	0.085	3.328		32.4	0.100	3.915	
26C	33.0	0.105	4.111		27.8	0.125	4.894	
27A	40.2	0.079	3.093	3.380	35.7	0.090	3.524	3.863
27B	38.9	0.082	3.210		34.4	0.094	3.680	
27C	34.8	0.098	3.837		30.0	0.112	4.385	
28A	33.3	0.104	4.072	3.537	28.9	0.119	4.659	3.967
28B	34.7	0.099	3.876		30.9	0.109	4.267	
28C	43.8	0.068	2.662		39.2	0.076	2.975	
29A	31.8	0.112	4.385	3.837	29.0	0.118	4.620	4.385
29B	40.5	0.077	3.015		34.5	0.093	3.641	
29C	33.2	0.105	4.111		27.8	0.125	4.894	
30A	34.9	0.097	3.798	3.980	30.6	0.110	4.307	4.502
30B	34.2	0.100	3.915		31.7	0.105	4.111	
30C	32.6	0.108	4.228		26.3	0.130	5.090	

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	97.2	72.8	50.5	-4.2
mV after	99.9	73.4	51.5	-3.8
mV before	99.6	73.1	50.7	-3.9
mV after	96.4	69.4	47.2	-5.5

1-1/2" to 2" By: MDP

Date:

5 Minute Test 11/24/2007

24 Hour Test 11/25/2007

Assumed weight of concrete = 145.0 lb/yd3

Sample No.	5 Minute Test				24 Hour Test			
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	Average lb. Cl/yd^3	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	Average lb. Cl/yd^3 concrete
17A	40.2	0.079	3.093		34.0	0.095	3.719	
17B	34.5	0.099	3.876	3.445	31.8	0.105	4.111	3.785
17C	37.9	0.086	3.367		35.4	0.090	3.524	
18A	42.7	0.071	2.780		36.1	0.086	3.367	
18B	40.6	0.077	3.015	2.767	35.2	0.090	3.524	3.158
18C	45.0	0.064	2.506		42.9	0.066	2.584	
19A	35.1	0.096	3.758		31.2	0.106	4.150	
19B	48.1	0.056	2.192	3.002	42.3	0.067	2.623	3.484
19C	40.4	0.078	3.054		34.1	0.094	3.680	
20A	46.1	0.061	2.388		42.0	0.068	2.662	
20B	38.3	0.084	3.289	2.819	35.2	0.090	3.524	3.132
20C	42.8	0.071	2.780		37.1	0.082	3.210	
21A	41.4	0.074	2.897		35.7	0.089	3.484	
21B	35.5	0.095	3.719	3.028	29.3	0.115	4.502	3.615
21C	45.6	0.063	2.466		40.3	0.073	2.858	
22A	36.1	0.092	3.602		31.1	0.108	4.228	
22B	40.8	0.077	3.015	3.615	36.5	0.086	3.367	3.967
22C	32.2	0.108	4.228		30.6	0.110	4.307	
23A	35.5	0.095	3.719		29.4	0.115	4.502	
23B	49.4	0.053	2.075	3.028	44.4	0.061	2.388	3.680
23C	38.3	0.084	3.289		32.4	0.106	4.150	
24A	44.3	0.066	2.584		39.0	0.076	2.975	
24B	42.2	0.071	2.780	2.545	35.5	0.090	3.524	3.054
24C	47.2	0.058	2.271		42.0	0.068	2.662	
25A	36.0	0.093	3.641		30.3	0.110	4.307	
25B	39.2	0.081	3.171	3.028	35.2	0.090	3.524	3.458
25C	47.6	0.058	2.271		43.1	0.065	2.545	
26A	40.8	0.076	2.975		34.9	0.092	3.602	
26B	48.3	0.056	2.192	2.727	43.0	0.066	2.584	3.184
26C	40.5	0.077	3.015		36.6	0.086	3.367	
27A	46.4	0.060	2.349		39.7	0.074	2.897	
27B	47.4	0.058	2.271	2.701	41.7	0.068	2.662	3.067
27C	36.8	0.089	3.484		34.6	0.093	3.641	
28A	37.6	0.088	3.445		31.1	0.108	4.228	
28B	38.4	0.084	3.289	3.080	34.0	0.095	3.719	3.563
28C	45.1	0.064	2.506		41.5	0.070	2.741	
29A	39.8	0.080	3.132		34.0	0.095	3.719	
29B	41.3	0.075	2.936	3.119	35.6	0.090	3.524	3.654
29C	38.4	0.084	3.289		34.3	0.095	3.719	
30A	35.3	0.096	3.758		30.9	0.110	4.307	
30B	38.8	0.084	3.289	3.706	34.4	0.094	3.680	4.163
30C	33.4	0.104	4.072		29.4	0.115	4.502	

Measurement of the acid soluble chloride content of hardened concrete by the RCT method

Report #: ______ **Structure:** ______ **Project:** 1", 1-1/4", 1-1/2", 2" 5-minute test

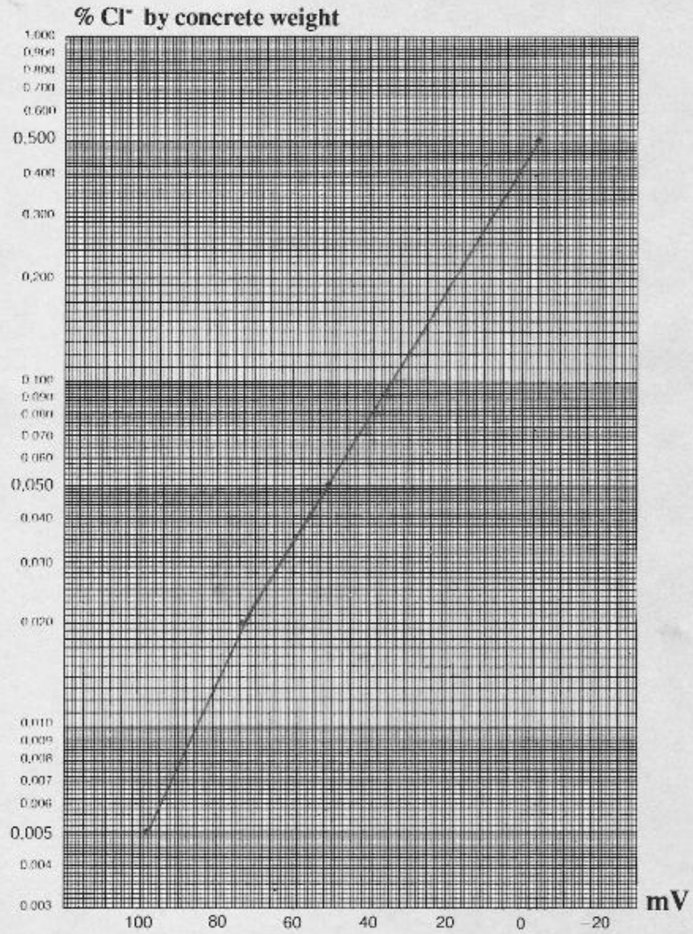
Date of testing: 11/24/07 **Electrode #:** ______ **Person:** MDP

Testing Lab: UWM **Address:** ______ **Phone:** ______

RCT

HARDENED CONCRETE

1.5 gram of concrete dust dissolved in a RCT-1023 vial with 10 milliliter of extraction liquid



CALIBRATION:

Liquid	Clear		Purple		Green		Pink	
% Cl	0.005		0.020		0.050		0.500	
mV before	97.2	98.6	72.8	73.1	50.5	51.0	-4.2	-4.0
mV after	99.9		73.4		51.5		-3.8	

SAMPLE #	1		2		Remarks
	mV	% Cl	mV	% Cl	

Measurement of the acid soluble chloride content of hardened concrete by the RCT method

Report #: ______ Structure: ______ Project: 1" and 1-1/4" 24-Hour Test

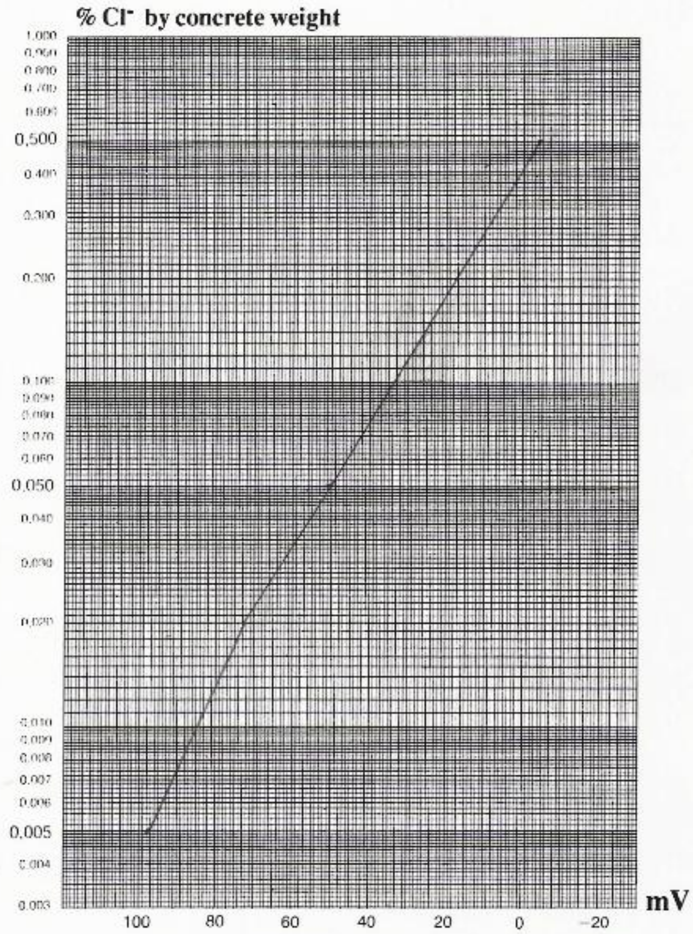
Date of testing: 11/25/07 Electrode #: ______ Person: MDP

Testing Lab: UWM Address: ______ Phone: ______

RCT

HARDENED CONCRETE

1.5 gram of concrete dust dissolved in a RCT-1023 vial with 10 milliliter of extraction liquid



CALIBRATION:

Liquid	Clear	Purple	Green	Pink
% Cl	0.005	0.020	0.050	0.500
mV before	98.4 97.9	72.9 72.8	51.4 50.9	-4.5 -4.2
mV after	97.4	72.6	50.3	-3.9

SAMPLE #	1		2		Remarks
	mV	% Cl	mV	% Cl	

Measurement of the acid soluble chloride content of hardened concrete by the RCT method

Report #: ______ **Structure:** ______ **Project:** 1-1/2" and 2" 24-Hour Test

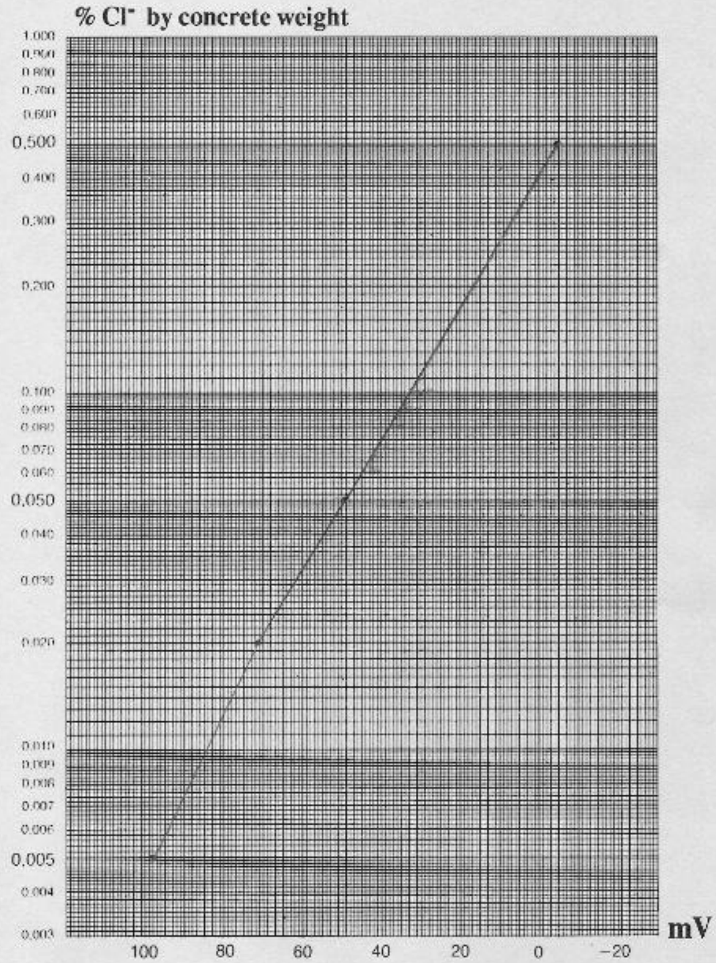
Date of testing: 11/25/07 **Electrode #:** ______ **Person:** MDP

Testing Lab: UWM **Address:** ______ **Phone:** ______

RCT

HARDENED CONCRETE

1.5 gram of concrete dust dissolved in a RCT-1023 vial with 10 milliliter of extraction liquid



CALIBRATION:

Liquid	Clear	Purple	Green	Pink
% Cl	0.005	0.020	0.050	0.500
mV before	99.6	73.1	50.7	-3.9
mV after	96.4	69.4	47.2	-5.5
(average)	98.0	71.3	49.0	-4.7

SAMPLE #	1		2		Remarks
	mV	% Cl	mV	% Cl	

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	99.4	71.3	47.3	-5.3
mV after	98.6	71.4	49.0	-4.7
mV before	100.5	71.1	47.2	-5.2
mV after	99.3	71.4	48.4	-5.3

2" to 2-1/2" By: MDP

	Date:
5 Minute Test	11/3/2007
24 Hour Test	11/4/207

Assumed weight of concrete = 145.0 lb/yd3

Sample No.	5 Minute Test				24 Hour Test			
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	Average lb. Cl/yd^3	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	Average lb. Cl/yd^3 concrete
17A	44.3	0.058	2.271		38.3	0.076	2.975	
17B	40.2	0.070	2.741	2.349	37.3	0.078	3.054	2.714
17C	47.2	0.052	2.036		46.3	0.054	2.114	
18A	40.3	0.070	2.741		35.9	0.084	3.289	
18B	43.2	0.061	2.388	2.336	42.0	0.064	2.506	2.662
18C	48.9	0.048	1.879		45.3	0.056	2.192	
19A	45.1	0.056	2.192		43.8	0.058	2.271	
19B	42.2	0.064	2.506	2.323	40.2	0.070	2.741	2.636
19C	44.3	0.058	2.271		38.6	0.074	2.897	
20A	42.4	0.064	2.506		36.0	0.084	3.289	
20B	34.9	0.086	3.367	2.793	33.2	0.094	3.680	3.315
20C	42.2	0.064	2.506		37.7	0.076	2.975	
21A	43.9	0.058	2.271		38.2	0.076	2.975	
21B	41.8	0.064	2.506	2.453	38.1	0.076	2.975	2.975
21C	41.2	0.066	2.584		38.0	0.076	2.975	
22A	38.8	0.072	2.819		35.9	0.084	3.289	
22B	47.5	0.050	1.958	2.506	44.0	0.058	2.271	2.975
22C	39.4	0.070	2.741		35.1	0.086	3.367	
23A	47.5	0.050	1.958		43.9	0.058	2.271	
23B	48.4	0.049	1.918	2.284	43.7	0.058	2.271	2.741
23C	38.4	0.076	2.975		33.4	0.094	3.680	
24A	38.4	0.076	2.975		34.3	0.090	3.524	
24B	41.9	0.064	2.506	2.427	36.6	0.080	3.132	2.949
24C	49.9	0.046	1.801		45.3	0.056	2.192	
25A	46.6	0.052	2.036		42.2	0.064	2.506	
25B	42.0	0.064	2.506	2.414	37.1	0.080	3.132	2.845
25C	40.1	0.069	2.701		38.9	0.074	2.897	
26A	42.7	0.060	2.349		39.0	0.072	2.819	
26B	45.2	0.056	2.192	2.375	39.9	0.070	2.741	2.975
26C	41.1	0.066	2.584		35.4	0.086	3.367	
27A	46.5	0.051	1.997		40.7	0.068	2.662	
27B	53.9	0.039	1.527	2.036	49.9	0.045	1.762	2.597
27C	41.4	0.066	2.584		35.1	0.086	3.367	
28A	44.1	0.058	2.271		37.1	0.078	3.054	
28B	53.0	0.041	1.605	1.958	47.9	0.049	1.918	2.414
28C	46.6	0.051	1.997		43.8	0.058	2.271	
29A	44.0	0.058	2.271		39.1	0.074	2.897	
29B	43.8	0.058	2.271	2.453	37.9	0.076	2.975	3.080
29C	38.8	0.072	2.819		35.1	0.086	3.367	
30A	35.6	0.082	3.210		31.3	0.104	4.072	
30B	39.7	0.070	2.741	2.767	36.0	0.084	3.289	3.393
30C	43.4	0.060	2.349		39.4	0.072	2.819	

Measurement of the acid soluble chloride content of hardened concrete by the RCT method

Report #: ______ **Structure:** Specimen Depth 2-2½ **Project:** 5 minute test

Date of testing: 11/3/07 **Electrode #:** ______ **Person:** MDP

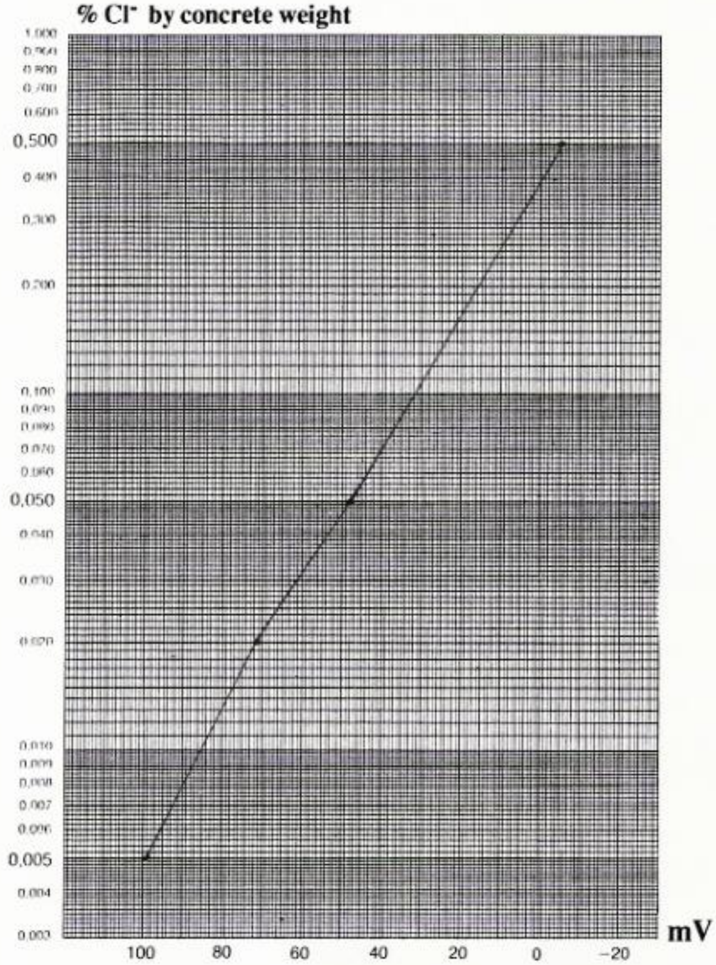
Testing Lab: UWM **Address:** ______ **Phone:** ______

RCT

HARDENED CONCRETE

1.5 gram of concrete dust dissolved in a RCT-1023 vial with 10 milliliter of extraction liquid

% Cl⁻ by concrete weight



CALIBRATION:

Liquid	Clear	Purple	Green	Pink
% Cl	0.005	0.020	0.050	0.500
mV before	99.4	71.3	47.3	-5.3
mV after	98.6	71.4	49.0	-4.7

SAMPLE #	1		2		Remarks
	mV	% Cl	mV	% Cl	

Measurement of the acid soluble chloride content of hardened concrete by the RCT method

Report #: ______ **Structure:** Specimen Depth 2-2½ **Project:** 24 Hour Test

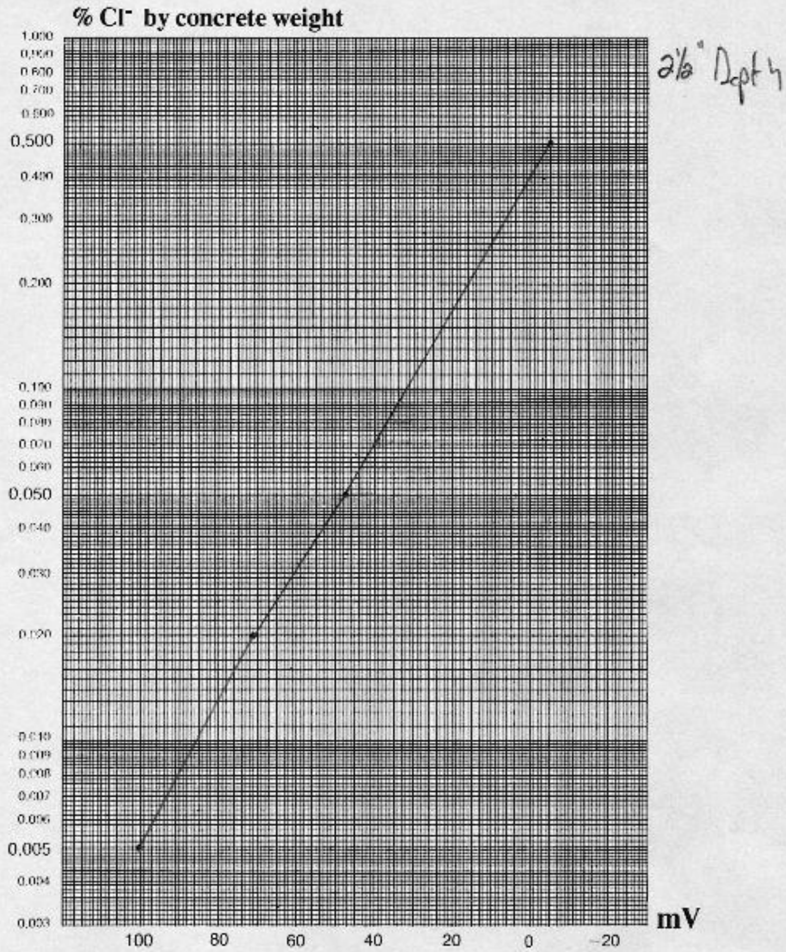
Date of testing: 11/4/07 **Electrode #:** ______ **Person:** MDP

Testing Lab: UWM **Address:** ______ **Phone:** ______

RCT

HARDENED CONCRETE

1.5 gram of concrete dust dissolved in a RCT-1023 vial with 10 milliliter of extraction liquid



CALIBRATION:

Liquid	Clear	Purple	Green	Pink
% Cl	0.005	0.020	0.050	0.500
mV before				
mV after				

SAMPLE #	1		2		Remarks
	mV	% Cl	mV	% Cl	

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	100.8	71.5	49.4	-4.8
mV after	100.2	72.5	49.8	-4.2
mV before	100.5	71.1	47.2	-5.2
mV after	99.3	71.4	48.4	-5.3

2-1/2" to 3" By: MDP

	Date:
5 Minute Test	11/3/2007
24 Hour Test	11/4/207

Assumed weight of concrete = 145.0 lb/yd3

Sample No.	5 Minute Test				24 Hour Test			
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	Average lb. Cl/yd^3	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	Average lb. Cl/yd^3 concrete
17A	57.4	0.037	1.449		52.9	0.040	1.566	
17B	50.5	0.047	1.840	1.592	47.8	0.048	1.879	1.697
17C	56.8	0.038	1.488		51.9	0.042	1.644	
18A	40.0	0.082	3.210		34.0	0.090	3.524	
18B	50.1	0.048	1.879	2.558	47.2	0.050	1.958	2.832
18C	44.3	0.066	2.584		37.5	0.077	3.015	
19A	51.1	0.047	1.840		45.5	0.054	2.114	
19B	43.3	0.069	2.701	2.297	37.0	0.079	3.093	2.597
19C	45.6	0.060	2.349		40.9	0.066	2.584	
20A	42.1	0.073	2.858		36.1	0.082	3.210	
20B	55.8	0.038	1.488	2.153	52.6	0.040	1.566	2.427
20C	48.4	0.054	2.114		41.8	0.064	2.506	
21A	37.6	0.088	3.445		34.5	0.088	3.445	
21B	46.1	0.060	2.349	2.558	39.8	0.070	2.741	2.845
21C	49.8	0.048	1.879		42.9	0.060	2.349	
22A	41.1	0.076	2.975		35.8	0.082	3.210	
22B	50.4	0.048	1.879	2.179	44.1	0.058	2.271	2.414
22C	53.1	0.043	1.683		50.0	0.045	1.762	
23A	52.8	0.043	1.683		49.7	0.045	1.762	
23B	59.4	0.034	1.331	1.592	55.1	0.037	1.449	1.749
23C	52.1	0.045	1.762		45.9	0.052	2.036	
24A	48.1	0.053	2.075		45.1	0.056	2.192	
24B	49.2	0.050	1.958	1.801	44.4	0.058	2.271	1.971
24C	58.1	0.035	1.370		55.2	0.037	1.449	
25A	46.6	0.056	2.192		41.1	0.064	2.506	
25B	54.2	0.041	1.605	1.788	50.4	0.045	1.762	1.984
25C	55.1	0.040	1.566		50.9	0.043	1.683	
26A	50.3	0.048	1.879		45.9	0.052	2.036	
26B	53.9	0.041	1.605	1.853	49.2	0.046	1.801	2.036
26C	47.9	0.053	2.075		44.2	0.058	2.271	
27A	46.8	0.056	2.192		40.6	0.066	2.584	
27B	60.1	0.033	1.292	1.971	54.4	0.038	1.488	2.297
27C	44.8	0.062	2.427		38.8	0.072	2.819	
28A	52.9	0.043	1.683		49.2	0.046	1.801	
28B	50.7	0.048	1.879	1.670	48.3	0.049	1.918	1.801
28C	57.2	0.037	1.449		50.8	0.043	1.683	
29A	50.5	0.047	1.840		43.3	0.060	2.349	
29B	42.7	0.070	2.741	2.101	39.3	0.072	2.819	2.375
29C	51.9	0.044	1.723		47.0	0.050	1.958	
30A	45.7	0.060	2.349		41.0	0.066	2.584	
30B	57.3	0.037	1.449	1.801	50.7	0.043	1.683	2.036
30C	54.0	0.041	1.605		49.1	0.047	1.840	

Measurement of the acid soluble chloride content of hardened concrete by the RCT method

Report #: ________ **Structure:** Specimen Depth 2½-3" **Project:** 5 minute test

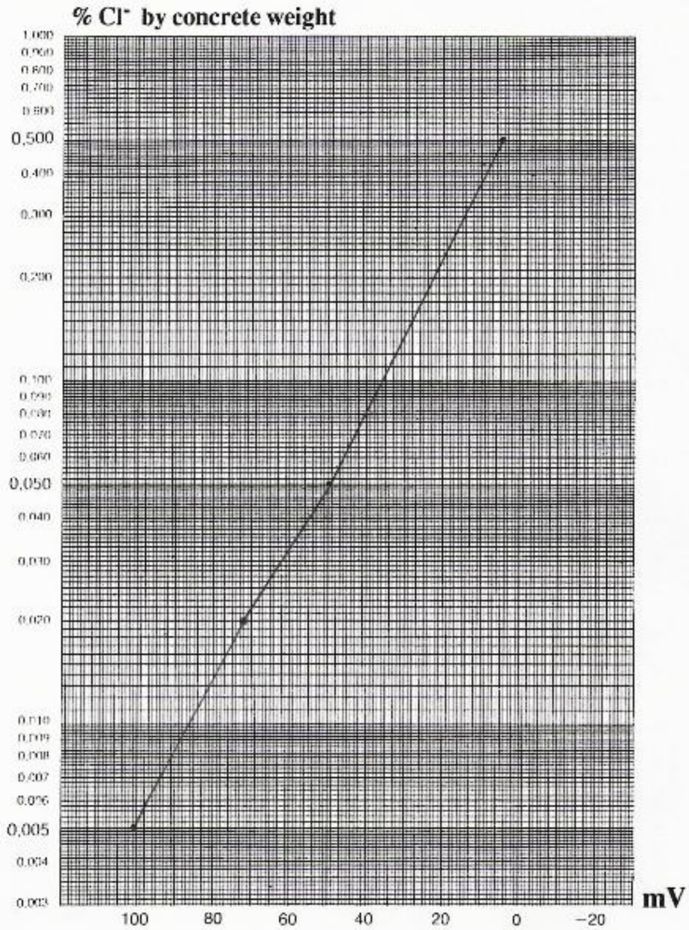
Date of testing: 11/3/07 **Electrode #:** ________ **Person:** MDP

Testing Lab: UWM **Address:** ________ **Phone:** ________

RCT

HARDENED CONCRETE

1.5 gram of concrete dust dissolved in a RCT-1023 vial with 10 milliliter of extraction liquid



CALIBRATION:

Liquid	Clear	Purple	Green	Pink
% Cl	0.005	0.020	0.050	0.500
mV before	100.8	71.5	49.4	-4.8
mV after	100.2	72.5	49.8	-4.2

SAMPLE #	1		2		Remarks
	mV	% Cl	mV	% Cl	

Measurement of the acid soluble chloride content of hardened concrete by the RCT method

Report #: ______ **Structure:** Specimen Depth 2½-3" **Project:** 24 hour test

Date of testing: 11/4/07 **Electrode #:** ______ **Person:** MDP

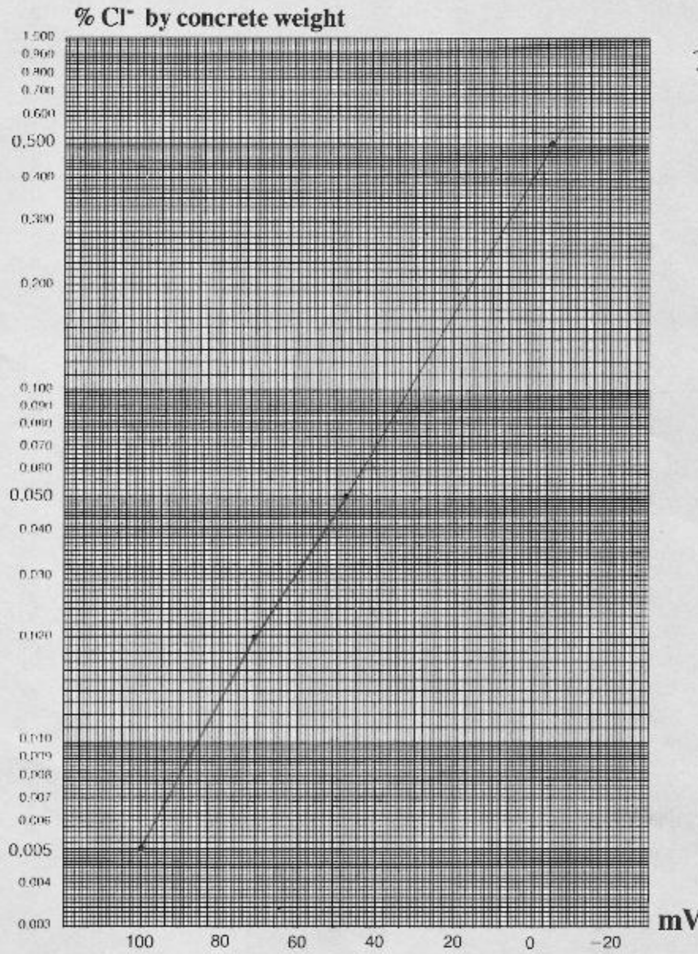
Testing Lab: UWM **Address:** ______ **Phone:** ______

3" Depth

RCT

HARDENED CONCRETE

1.5 gram of concrete dust dissolved in a RCT-1023 vial with 10 milliliter of extraction liquid



CALIBRATION:

Liquid	Clear	Purple	Green	Pink
% Cl	0.005	0.020	0.050	0.500
mV before	100.5	71.1	47.2	-5.2
mV after	99.3	71.4	48.4	-5.3

SAMPLE #	1		2		Remarks
	mV	% Cl	mV	% Cl	

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APPENDIX E

CoC Chlorides at 3-Months

Specimen #17 - 3 Month Exposure

By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	103.4	74.2	53.2	-2.9
mV after	100.2	75.4	53.6	-3.3
mV before	97.8	74.0	53.0	-3.0
mV after	93.4	72.4	50.6	-4.4

	Date:
5 Minute Test	3/16/2008
24 Hour Test	3/17/2008

Assumed weight of concrete = 145.0 lb/yd3

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
17D						
0" to 1/4"	5.7	0.349	13.663	1.6	0.405	15.856
1/4" to 1/2"	4.5	0.365	14.290	0.2	0.425	16.639
1/2" to 3/4"	17.4	0.215	8.417	12.3	0.258	10.101
3/4" to 1"	36.8	0.100	3.915	33.1	0.108	4.228
1" to 1-1/4"	38.0	0.094	3.680	34.8	0.102	3.993
1-1/4" to 1-1/2"	39.2	0.089	3.484	35.0	0.101	3.954
1-1/2" to 1-3/4"	39.0	0.090	3.524	33.8	0.106	4.150
1-3/4" to 2"	26.2	0.151	5.912	21.4	0.177	6.930
17E						
0" to 1/4"	2.2	0.402	15.738	-1.8	0.460	18.009
1/4" to 1/2"	6.2	0.340	13.311	2.0	0.400	15.660
1/2" to 3/4"	20.8	0.189	7.399	17.0	0.212	8.300
3/4" to 1"	22.6	0.177	6.930	17.8	0.208	8.143
1" to 1-1/4"	25.2	0.158	6.186	20.5	0.182	7.125
1-1/4" to 1-1/2"	26.0	0.153	5.990	20.7	0.181	7.086
1-1/2" to 1-3/4"	38.9	0.091	3.563	32.6	0.112	4.385
1-3/4" to 2"	46.8	0.066	2.584	39.5	0.084	3.289
17F						
0" to 1/4"	-4.0	0.510	19.967	-8.8	0.610	23.882
1/4" to 1/2"	7.8	0.320	12.528	1.6	0.405	15.856
1/2" to 3/4"	18.3	0.208	8.143	13.6	0.245	9.592
3/4" to 1"	29.2	0.133	5.207	24.4	0.158	6.186
1" to 1-1/4"	28.8	0.138	5.403	22.8	0.169	6.616
1-1/4" to 1-1/2"	37.3	0.097	3.798	31.6	0.117	4.581
1-1/2" to 1-3/4"	36.2	0.100	3.915	30.5	0.121	4.737
1-3/4" to 2"	40.0	0.087	3.406	33.7	0.107	4.189

Specimen #18 - 3 Month Exposure

By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	103.4	74.2	53.2	-2.9
mV after	100.2	75.4	53.6	-3.3
mV before	97.8	74.0	53.0	-3.0
mV after	93.4	72.4	50.6	-4.4

	Date:
5 Minute Test	3/16/2008
24 Hour Test	3/17/2008

Assumed weight of concrete = 145.0 lb/yd3

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
18D						
0" to 1/4"	2.8	0.392	15.347	-1.6	0.460	18.009
1/4" to 1/2"	12.4	0.261	10.218	4.8	0.355	13.898
1/2" to 3/4"	17.3	0.213	8.339	12.0	0.261	10.218
3/4" to 1"	6.1	0.342	13.389	3.0	0.380	14.877
1" to 1-1/4"	22.0	0.180	7.047	17.4	0.210	8.222
1-1/4" to 1-1/2"	36.2	0.101	3.954	30.1	0.122	4.776
1-1/2" to 1-3/4"	41.4	0.081	3.171	32.2	0.113	4.424
1-3/4" to 2"	52.6	0.052	2.036	46.5	0.063	2.466

18G						
0" to 1/4"	9.8	0.295	11.549	8.4	0.320	12.528
1/4" to 1/2"	5.3	0.355	13.898	3.2	0.395	15.464
1/2" to 3/4"	15.2	0.234	9.161	14.7	0.243	9.513
3/4" to 1"	17.3	0.217	8.496	15.6	0.233	9.122
1" to 1-1/4"	26.1	0.159	6.225	23.8	0.170	6.656
1-1/4" to 1-1/2"	19.0	0.204	7.987	16.4	0.227	8.887
1-1/2" to 1-3/4"	25.5	0.158	6.186	24.0	0.170	6.656
1-3/4" to 2"	29.6	0.132	5.168	27.8	0.146	5.716

Tested 5/16/08 and 5/17/08

18F						
0" to 1/4"	0.7	0.430	16.835	-3.9	0.500	19.575
1/4" to 1/2"	11.2	0.277	10.845	5.5	0.345	13.507
1/2" to 3/4"	17.8	0.212	8.300	12.0	0.261	10.218
3/4" to 1"	25.1	0.158	6.186	17.0	0.212	8.300
1" to 1-1/4"	30.6	0.127	4.972	22.5	0.170	6.656
1-1/4" to 1-1/2"	36.3	0.100	3.915	30.1	0.122	4.776
1-1/2" to 1-3/4"	39.2	0.089	3.484	34.0	0.105	4.111
1-3/4" to 2"	43.6	0.075	2.936	38.2	0.088	3.445

Specimen #19 - 3 Month Exposure

By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	103.4	74.2	53.2	-2.9
mV after	100.2	75.4	53.6	-3.3
mV before	97.8	74.0	53.0	-3.0
mV after	93.4	72.4	50.6	-4.4

	Date:
5 Minute Test	3/16/2008
24 Hour Test	3/17/2008

Assumed weight of concrete = 145.0 lb/yd3

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
19D						
0" to 1/4"	1.1	0.420	16.443	-2.5	0.480	18.792
1/4" to 1/2"	3.5	0.380	14.877	-1.3	0.452	17.696
1/2" to 3/4"	8.9	0.308	12.058	4.6	0.358	14.016
3/4" to 1"	23.8	0.168	6.577	19.2	0.192	7.517
1" to 1-1/4"	33.7	0.112	4.385	27.8	0.138	5.403
1-1/4" to 1-1/2"	38.5	0.092	3.602	32.0	0.115	4.502
1-1/2" to 1-3/4"	44.0	0.074	2.897	36.7	0.094	3.680
1-3/4" to 2"	43.8	0.074	2.897	37.2	0.092	3.602
19E						
0" to 1/4"	3.3	0.380	14.877	-0.2	0.435	17.030
1/4" to 1/2"	4.7	0.362	14.172	-1.2	0.450	17.618
1/2" to 3/4"	16.9	0.221	8.652	12.0	0.262	10.257
3/4" to 1"	29.0	0.136	5.324	24.3	0.158	6.186
1" to 1-1/4"	41.6	0.081	3.171	36.5	0.095	3.719
1-1/4" to 1-1/2"	39.3	0.088	3.445	34.0	0.105	4.111
1-1/2" to 1-3/4"	33.4	0.102	3.993	28.9	0.131	5.129
1-3/4" to 2"	41.2	0.082	3.210	35.8	0.098	3.837
19F						
0" to 1/4"	1.3	0.412	16.130	-2.8	0.480	18.792
1/4" to 1/2"	12.1	0.262	10.257	9.1	0.293	11.471
1/2" to 3/4"	15.0	0.238	9.318	11.0	0.273	10.688
3/4" to 1"	21.0	0.188	7.360	18.3	0.201	7.869
1" to 1-1/4"	29.8	0.132	5.168	24.4	0.158	6.186
1-1/4" to 1-1/2"	35.3	0.105	4.111	29.0	0.130	5.090
1-1/2" to 1-3/4"	38.5	0.092	3.602	29.8	0.127	4.972
1-3/4" to 2"	42.3	0.079	3.093	38.3	0.088	3.445

Specimen #20 - 3 Month Exposure

By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	103.4	74.2	53.2	-2.9
mV after	100.2	75.4	53.6	-3.3
mV before	97.8	74.0	53.0	-3.0
mV after	93.4	72.4	50.6	-4.4

	Date:
5 Minute Test	3/16/2008
24 Hour Test	3/17/2008

Assumed weight of concrete = 145.0 lb/yd3

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
20D						
0" to 1/4"	-2.2	0.485	18.988	-5.1	0.538	21.063
1/4" to 1/2"	1.4	0.415	16.247	-2.7	0.480	18.792
1/2" to 3/4"	6.2	0.340	13.311	3.0	0.380	14.877
3/4" to 1"	11.7	0.270	10.571	6.8	0.327	12.802
1" to 1-1/4"	33.5	0.112	4.385	29.7	0.126	4.933
1-1/4" to 1-1/2"	31.5	0.122	4.776	27.5	0.138	5.403
1-1/2" to 1-3/4"	33.3	0.112	4.385	29.4	0.127	4.972
1-3/4" to 2"	40.6	0.085	3.328	35.3	0.100	3.915
20E						
0" to 1/4"	1.0	0.420	16.443	-1.3	0.455	17.813
1/4" to 1/2"	2.8	0.395	15.464	-0.3	0.435	17.030
1/2" to 3/4"	16.7	0.222	8.691	12.6	0.255	9.983
3/4" to 1"	25.4	0.158	6.186	21.8	0.175	6.851
1" to 1-1/4"	32.6	0.117	4.581	28.3	0.132	5.168
1-1/4" to 1-1/2"	33.8	0.112	4.385	29.7	0.127	4.972
1-1/2" to 1-3/4"	38.8	0.092	3.602	34.3	0.104	4.072
1-3/4" to 2"	42.8	0.077	3.015	38.6	0.087	3.406
20F						
0" to 1/4"	2.8	0.395	15.464	1.2	0.410	16.052
1/4" to 1/2"	6.1	0.341	13.350	4.0	0.365	14.290
1/2" to 3/4"	15.5	0.231	9.044	11.9	0.262	10.257
3/4" to 1"	29.7	0.132	5.168	24.4	0.158	6.186
1" to 1-1/4"	32.0	0.120	4.698	26.3	0.143	5.598
1-1/4" to 1-1/2"	30.0	0.130	5.090	26.4	0.142	5.559
1-1/2" to 1-3/4"	33.9	0.111	4.346	29.7	0.127	4.972
1-3/4" to 2"	31.2	0.123	4.815	25.8	0.149	5.833

Measurement of the acid soluble chloride content of hardened concrete by the RCT method

Report #: ______ **Structure:** ______ **Project:** 17D,6F - 20D,6F 5-Minute

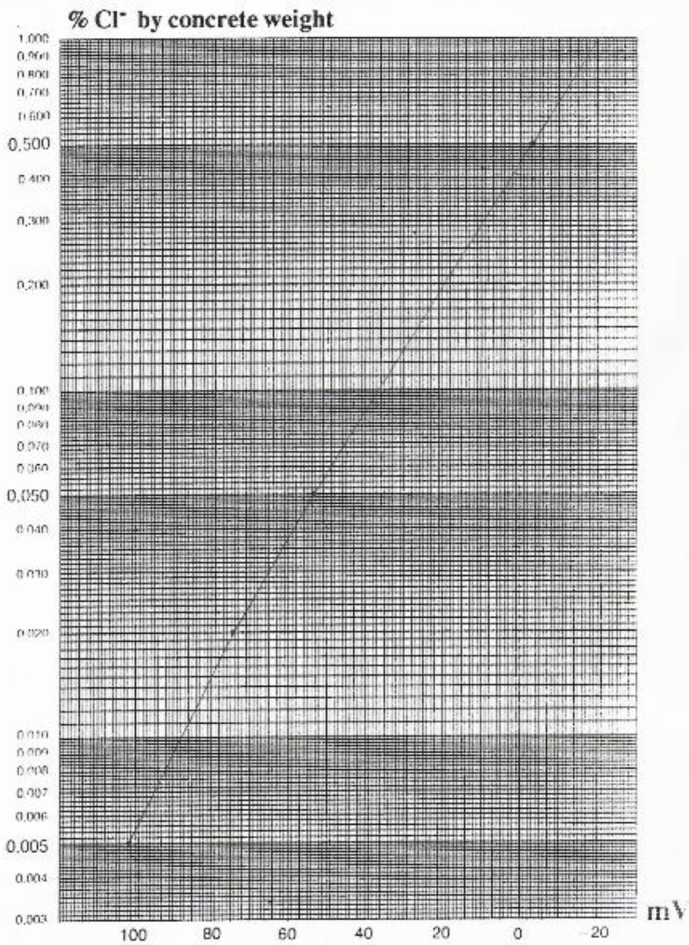
Date of testing: 3/16/08 **Electrode #:** ______ **Person:** MDP

Testing Lab: UWM **Address:** ______ **Phone:** ______

RCT

HARDENED CONCRETE

1.5 gram of concrete dust dissolved in a RCT-1023 vial with 10 milliliter of extraction liquid



CALIBRATION:

Liquid	Clear	Purple	Green	Pink
% Cl	0.005	0.020	0.050	0.500
mV before	103.4	74.2	53.2	-2.9
mV after	100.2	75.4	53.6	-3.3
(average)	101.8	74.8	53.4	-3.1

SAMPLE #	1		2		Remarks
	mV	% Cl	mV	% Cl	

Measurement of the acid soluble chloride content of hardened concrete by the RCT method

Report #: ______ **Structure:** ______ **Project:** 17D,E,F - 20 D,E,F 24-Hour

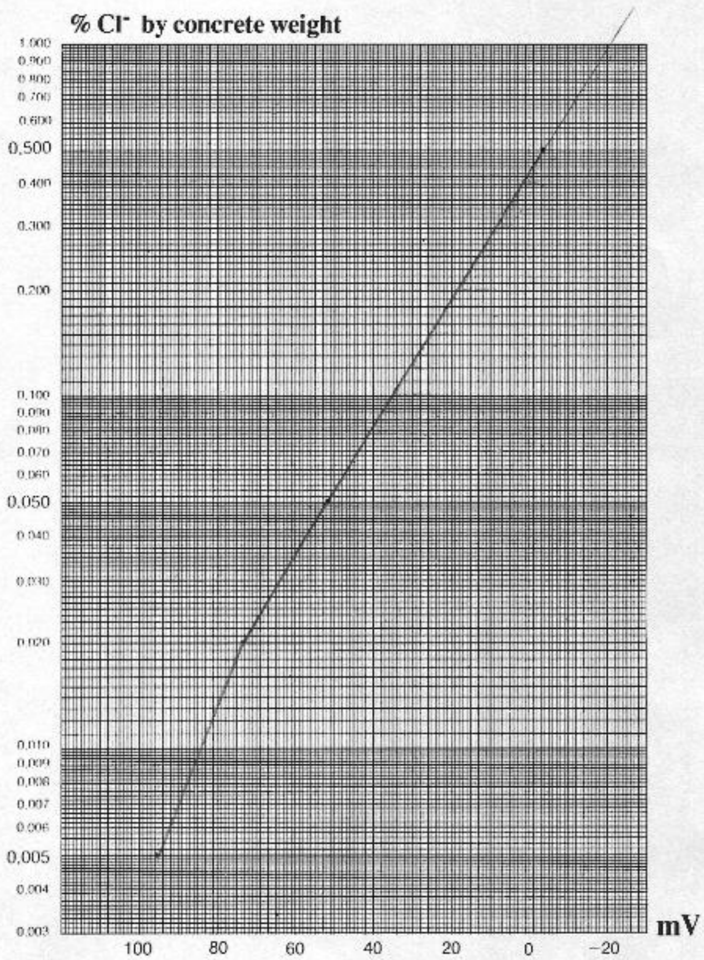
Date of testing: 3/17/08 **Electrode #:** ______ **Person:** MDP

Testing Lab: UWM **Address:** ______ **Phone:** ______

RCT

HARDENED CONCRETE

1.5 gram of concrete dust dissolved in a RCT-1023 vial with 10 milliliter of extraction liquid



CALIBRATION:

Liquid	Clear		Purple		Green		Pink	
% Cl	0.005		0.020		0.050		0.500	
mV before	97.8	95.6	74.0	73.2	53.0	51.8	-3.0	-3.7
mV after	93.4		72.4		50.6		-4.4	

SAMPLE #	1		2		Remarks
	mV	% Cl	mV	% Cl	

Specimen #21 - 3 Month Exposure By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	95.1	74.7	52.8	-2.1
mV after	102.8	76.9	55.0	-1.9
mV before	100.3	75.9	53.8	-2.6
mV after	96.9	73.5	52.0	-4.6

	Date:
5 Minute Test	2/9/2008
24 Hour Test	2/10/2008

Assumed weight of concrete = 145.0 lb/yd3

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
21D						
0" to 1/4"	-2.4	0.505	19.771	-4.2	0.515	20.162
1/4" to 1/2"	-1.1	0.475	18.596	-2.9	0.500	19.575
1/2" to 3/4"	0.3	0.445	17.422	-1.2	0.455	17.813
3/4" to 1"	0.8	0.430	16.835	-0.3	0.440	17.226
1" to 1-1/4"	7.1	0.328	12.841	5.2	0.350	13.703
1-1/4" to 1-1/2"	20.9	0.190	7.439	17.5	0.210	8.222
1-1/2" to 1-3/4"	37.7	0.095	3.719	32.9	0.110	4.307
1-3/4" to 2"	45.8	0.068	2.662	37.4	0.092	3.602
21E						
0" to 1/4"	-4.6	0.545	21.337	-7.4	0.595	23.294
1/4" to 1/2"	8.3	0.315	12.332	4.9	0.355	13.898
1/2" to 3/4"	17.1	0.220	8.613	11.3	0.270	10.571
3/4" to 1"	28.7	0.138	5.403	23.1	0.165	6.460
1" to 1-1/4"	33.5	0.112	4.385	28.0	0.135	5.285
1-1/4" to 1-1/2"	34.0	0.110	4.307	29.0	0.130	5.090
1-1/2" to 1-3/4"	34.2	0.109	4.267	30.7	0.122	4.776
1-3/4" to 2"	41.4	0.082	3.210	35.2	0.102	3.993
21F						
0" to 1/4"	-10.6	0.700	27.405	-12.9	0.740	28.971
1/4" to 1/2"	-1.1	0.460	18.009	-4.9	0.540	21.141
1/2" to 3/4"	8.6	0.310	12.137	3.8	0.370	14.486
3/4" to 1"	21.0	0.190	7.439	15.0	0.232	9.083
1" to 1-1/4"	29.4	0.134	5.246	24.0	0.160	6.264
1-1/4" to 1-1/2"	34.9	0.106	4.150	29.6	0.128	5.011
1-1/2" to 1-3/4"	44.9	0.070	2.741	41.1	0.079	3.093
1-3/4" to 2"	56.0	0.045	1.762	52.0	0.051	1.997

Specimen #22 - 3 Month Exposure By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	95.1	74.7	52.8	-2.1
mV after	102.8	76.9	55.0	-1.9
mV before	100.3	75.9	53.8	-2.6
mV after	96.9	73.5	52.0	-4.6

	Date:
5 Minute Test	2/9/2008
24 Hour Test	2/10/2008

Assumed weight of concrete = 145.0 lb/yd3

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
22D						
0" to 1/4"	-5.8	0.570	22.316	-8.9	0.630	24.665
1/4" to 1/2"	2.4	0.400	15.660	-0.9	0.445	17.422
1/2" to 3/4"	17.9	0.213	8.339	14.0	0.240	9.396
3/4" to 1"	26.3	0.152	5.951	21.2	0.180	7.047
1" to 1-1/4"	37.0	0.098	3.837	32.5	0.112	4.385
1-1/4" to 1-1/2"	39.4	0.089	3.484	34.3	0.104	4.072
1-1/2" to 1-3/4"	44.3	0.072	2.819	37.0	0.093	3.641
1-3/4" to 2"	51.0	0.055	2.153	43.7	0.071	2.780

22E						
0" to 1/4"	-4.8	0.550	21.533	-7.7	0.600	23.490
1/4" to 1/2"	6.3	0.340	13.311	2.8	0.385	15.073
1/2" to 3/4"	16.4	0.228	8.926	12.2	0.260	10.179
3/4" to 1"	35.1	0.105	4.111	29.8	0.126	4.933
1" to 1-1/4"	43.5	0.074	2.897	39.3	0.085	3.328
1-1/4" to 1-1/2"	42.6	0.078	3.054	37.0	0.093	3.641
1-1/2" to 1-3/4"	36.3	0.100	3.915	29.8	0.126	4.933
1-3/4" to 2"	41.8	0.080	3.132	36.5	0.095	3.719

22F						
0" to 1/4"	-4.1	0.540	21.141	-8.3	0.620	24.273
1/4" to 1/2"	3.1	0.390	15.269	-0.3	0.435	17.030
1/2" to 3/4"	19.0	0.205	8.026	15.6	0.227	8.887
3/4" to 1"	28.9	0.136	5.324	23.2	0.164	6.421
1" to 1-1/4"	33.7	0.112	4.385	27.6	0.138	5.403
1-1/4" to 1-1/2"	41.0	0.082	3.210	35.2	0.100	3.915
1-1/2" to 1-3/4"	44.9	0.070	2.741	38.5	0.088	3.445
1-3/4" to 2"	50.6	0.056	2.192	43.6	0.071	2.780

Specimen #23 - 3 Month Exposure By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	95.1	74.7	52.8	-2.1
mV after	102.8	76.9	55.0	-1.9
mV before	100.3	75.9	53.8	-2.6
mV after	96.9	73.5	52.0	-4.6

	Date:
5 Minute Test	2/9/2008
24 Hour Test	2/10/2008

Assumed weight of concrete = 145.0 lb/yd3

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
23D						
0" to 1/4"	-3.1	0.520	20.358	-5.6	0.550	21.533
1/4" to 1/2"	-0.2	0.445	17.422	-3.3	0.500	19.575
1/2" to 3/4"	17.3	0.220	8.613	13.6	0.247	9.670
3/4" to 1"	23.8	0.170	6.656	19.0	0.195	7.634
1" to 1-1/4"	32.9	0.115	4.502	28.5	0.132	5.168
1-1/4" to 1-1/2"	40.6	0.084	3.289	34.9	0.103	4.032
1-1/2" to 1-3/4"	41.4	0.081	3.171	33.0	0.110	4.307
1-3/4" to 2"	51.0	0.053	2.075	42.2	0.075	2.936
23G						
0" to 1/4"	4.2	0.370	14.486	3.6	0.385	15.073
1/4" to 1/2"	6.8	0.338	13.233	4.9	0.368	14.407
1/2" to 3/4"	14.1	0.245	9.592	11.8	0.278	10.884
3/4" to 1"	27.9	0.213	8.339	25.8	0.158	6.186
1" to 1-1/4"	43.4	0.075	2.936	41.1	0.084	3.289
1-1/4" to 1-1/2"	43.4	0.075	2.936	41.5	0.082	3.210
1-1/2" to 1-3/4"	42.0	0.080	3.132	39.3	0.090	3.524
1-3/4" to 2"	32.8	0.117	4.581	29.4	0.135	5.285
23F						
0" to 1/4"	1.8	0.410	16.052	-1.9	0.465	18.205
1/4" to 1/2"	8.3	0.315	12.332	3.4	0.375	14.681
1/2" to 3/4"	27.4	0.145	5.677	21.0	0.180	7.047
3/4" to 1"	30.7	0.127	4.972	24.0	0.160	6.264
1" to 1-1/4"	38.3	0.092	3.602	32.7	0.112	4.385
1-1/4" to 1-1/2"	45.0	0.070	2.741	39.0	0.086	3.367
1-1/2" to 1-3/4"	46.4	0.066	2.584	40.5	0.081	3.171
1-3/4" to 2"	51.2	0.054	2.114	47.3	0.061	2.388

Tested 5/16/08 and 5/17/08

Specimen #24 - 3 Month Exposure

By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	95.1	74.7	52.8	-2.1
mV after	102.8	76.9	55.0	-1.9
mV before	100.3	75.9	53.8	-2.6
mV after	96.9	73.5	52.0	-4.6

	Date:
5 Minute Test	2/9/2008
24 Hour Test	2/10/2008

Assumed weight of concrete = 145.0 lb/yd3

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
24D						
0" to 1/4"	4.8	0.365	14.290	2.4	0.390	15.269
1/4" to 1/2"	11.4	0.280	10.962	7.2	0.320	12.528
1/2" to 3/4"	18.1	0.210	8.222	15.8	0.227	8.887
3/4" to 1"	25.3	0.158	6.186	22.7	0.170	6.656
1" to 1-1/4"	36.2	0.100	3.915	32.6	0.112	4.385
1-1/4" to 1-1/2"	42.1	0.079	3.093	37.2	0.092	3.602
1-1/2" to 1-3/4"	45.0	0.070	2.741	40.0	0.082	3.210
1-3/4" to 2"	47.3	0.064	2.506	44.5	0.069	2.701
24E						
0" to 1/4"	4.6	0.365	14.290	2.0	0.400	15.660
1/4" to 1/2"	15.5	0.235	9.200	12.3	0.260	10.179
1/2" to 3/4"	24.0	0.165	6.460	20.7	0.183	7.164
3/4" to 1"	31.6	0.120	4.698	27.0	0.140	5.481
1" to 1-1/4"	38.4	0.092	3.602	34.2	0.105	4.111
1-1/4" to 1-1/2"	44.5	0.072	2.819	39.2	0.085	3.328
1-1/2" to 1-3/4"	44.8	0.071	2.780	41.1	0.080	3.132
1-3/4" to 2"	37.6	0.096	3.758	35.8	0.100	3.915
24F						
0" to 1/4"	-2.1	0.500	19.575	-6.4	0.570	22.316
1/4" to 1/2"	13.6	0.255	9.983	8.3	0.305	11.941
1/2" to 3/4"	29.8	0.131	5.129	25.8	0.150	5.873
3/4" to 1"	36.6	0.099	3.876	31.5	0.118	4.620
1" to 1-1/4"	48.6	0.061	2.388	43.2	0.072	2.819
1-1/4" to 1-1/2"	45.0	0.070	2.741	42.6	0.074	2.897
1-1/2" to 1-3/4"	39.1	0.089	3.484	35.8	0.099	3.876
1-3/4" to 2"	37.0	0.097	3.798	32.7	0.112	4.385

Specimen #25 - 3 Month Exposure By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	95.1	74.7	52.8	-2.1
mV after	102.8	76.9	55.0	-1.9
mV before	100.3	75.9	53.8	-2.6
mV after	96.9	73.5	52.0	-4.6

	Date:
5 Minute Test	2/9/2008
24 Hour Test	2/10/2008

Assumed weight of concrete = 145.0 lb/yd3

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
25D						
0" to 1/4"	-0.1	0.440	17.226	-2.2	0.470	18.401
1/4" to 1/2"	12.5	0.265	10.375	9.6	0.290	11.354
1/2" to 3/4"	20.4	0.192	7.517	17.0	0.213	8.339
3/4" to 1"	30.8	0.125	4.894	25.8	0.150	5.873
1" to 1-1/4"	34.9	0.107	4.189	31.9	0.118	4.620
1-1/4" to 1-1/2"	35.0	0.105	4.111	31.7	0.118	4.620
1-1/2" to 1-3/4"	36.2	0.100	3.915	30.6	0.122	4.776
1-3/4" to 2"	44.0	0.073	2.858	38.5	0.088	3.445

25E						
0" to 1/4"	0.4	0.435	17.030	-1.8	0.460	18.009
1/4" to 1/2"	14.3	0.248	9.709	9.8	0.290	11.354
1/2" to 3/4"	22.9	0.173	6.773	18.0	0.205	8.026
3/4" to 1"	36.2	0.100	3.915	31.7	0.118	4.620
1" to 1-1/4"	43.7	0.074	2.897	41.0	0.080	3.132
1-1/4" to 1-1/2"	45.8	0.068	2.662	42.4	0.075	2.936
1-1/2" to 1-3/4"	41.3	0.081	3.171	37.5	0.092	3.602
1-3/4" to 2"	47.5	0.064	2.506	44.0	0.070	2.741

25F						
0" to 1/4"	-0.9	0.455	17.813	-3.6	0.500	19.575
1/4" to 1/2"	4.0	0.375	14.681	1.5	0.410	16.052
1/2" to 3/4"	13.2	0.258	10.101	10.7	0.280	10.962
3/4" to 1"	29.8	0.131	5.129	26.1	0.145	5.677
1" to 1-1/4"	34.4	0.108	4.228	32.2	0.113	4.424
1-1/4" to 1-1/2"	41.2	0.082	3.210	37.1	0.093	3.641
1-1/2" to 1-3/4"	49.7	0.058	2.271	45.5	0.066	2.584
1-3/4" to 2"	52.1	0.052	2.036	49.0	0.057	2.232

Measurement of the acid soluble chloride content of hardened concrete by the RCT method

Report #: ______ **Structure:** ______ **Project:** 21-25 D-F 5-Minute Test

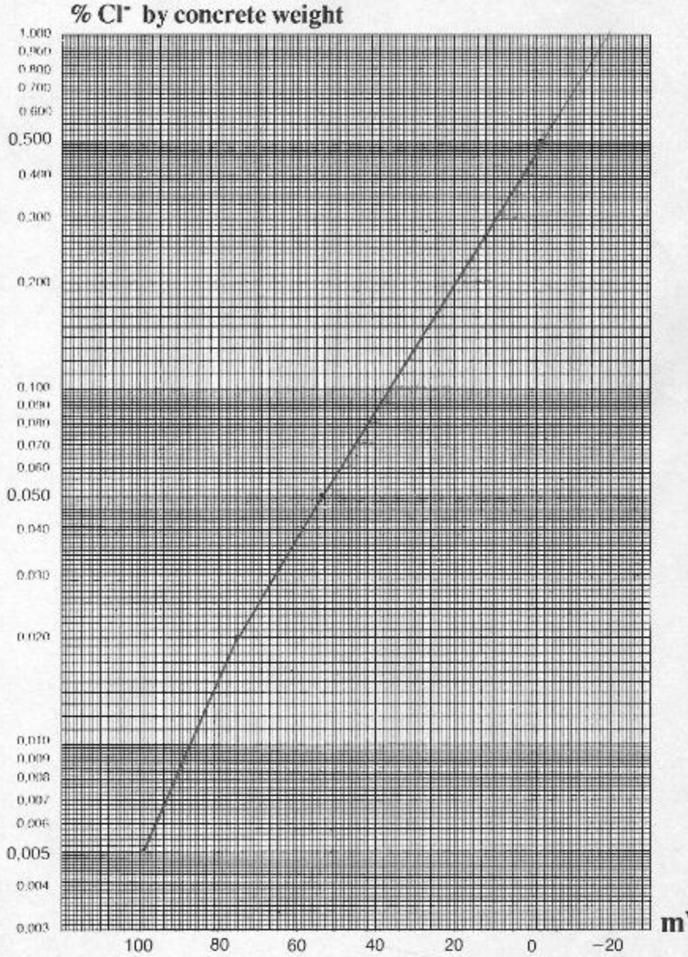
Date of testing: 2/9/08 **Electrode #:** ______ **Person:** MDP

Testing Lab: UWM **Address:** ______ **Phone:** ______

RCT

HARDENED CONCRETE

1.5 gram of concrete dust dissolved in a RCT-1023 vial with 10 milliliter of extraction liquid



CALIBRATION:

Liquid	Clear		Purple		Green		Pink	
% Cl	0.005		0.020		0.050		0.500	
mV before	95.1	99.0	74.7	75.8	52.8	53.9	-2.1	-2.0
mV after	100.8		76.9		55.0		-1.9	

SAMPLE #	1		2		Remarks
	mV	% Cl	mV	% Cl	

Measurement of the acid soluble chloride content of hardened concrete by the RCT method

Report #: ________ **Structure:** ________ **Project:** 21E-25F 24-Hour

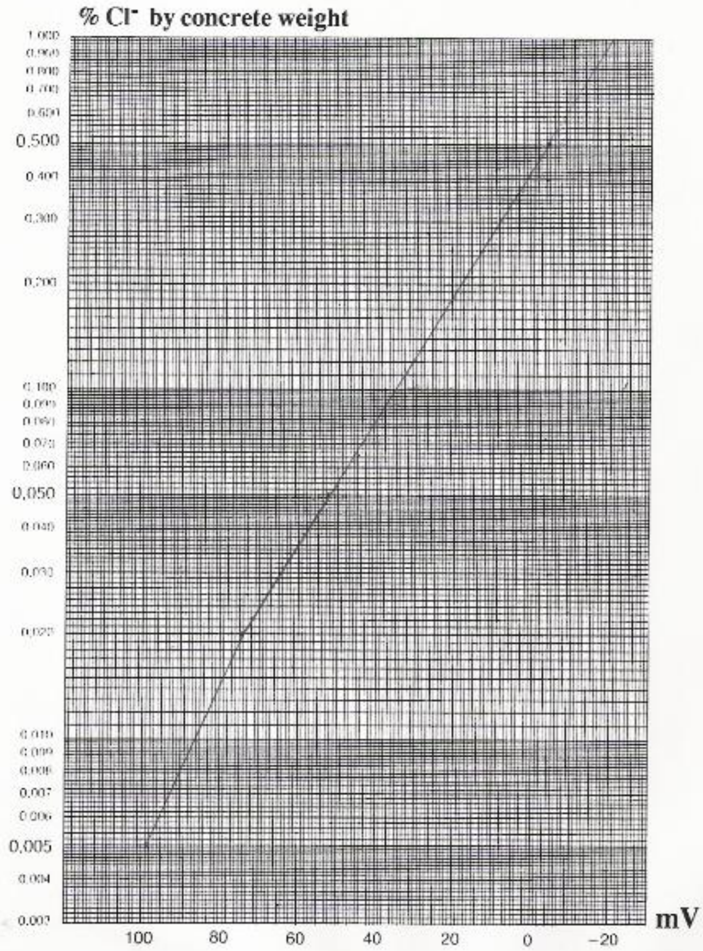
Date of testing: 2/10/08 **Electrode #:** ________ **Person:** MDP

Testing Lab: UWM **Address:** ________ **Phone:** ________

RCT

HARDENED CONCRETE

1.5 gram of concrete dust dissolved in a RCT-1023 vial with 10 milliliter of extraction liquid



CALIBRATION:

Liquid	Clear	Purple	Green	Pink
% Cl	0.005	0.020	0.050	0.500
mV before	100.3 98.6	75.9 74.7	53.8 52.9	-2.6 -3.6
mV after	96.9	73.5	52.0	-4.6

SAMPLE #	1		2		Remarks
	mV	% Cl	mV	% Cl	

Specimen #26 - 3 Month Exposure

By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	99.2	73.6	51.5	-3.0
mV after	101.2	74.6	52.5	-3.2
mV before	99.4	73.1	51.2	-3.1
mV after	97.8	72.7	51.0	-4.1

	Date:
5 Minute Test	2/2/2008
24 Hour Test	2/3/2008

Assumed weight of concrete = 145.0 lb/yd3

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
26D						
0" to 1/4"	0.4	0.425	16.639	-2.9	0.470	18.401
1/4" to 1/2"	16.6	0.218	8.535	13.7	0.235	9.200
1/2" to 3/4"	19.3	0.190	7.439	15.2	0.222	8.691
3/4" to 1"	28.4	0.132	5.168	24.6	0.150	5.873
1" to 1-1/4"	36.3	0.094	3.680	32.2	0.109	4.267
1-1/4" to 1-1/2"	38.7	0.086	3.367	32.3	0.108	4.228
1-1/2" to 1-3/4"	42.1	0.074	2.897	37.9	0.086	3.367
1-3/4" to 2"	46.7	0.062	2.427	40.0	0.079	3.093
26E						
0" to 1/4"	-0.4	0.440	17.226	-3.1	0.475	18.596
1/4" to 1/2"	7.2	0.320	12.528	4.3	0.350	13.703
1/2" to 3/4"	22.2	0.170	6.656	18.9	0.192	7.517
3/4" to 1"	23.6	0.160	6.264	19.2	0.188	7.360
1" to 1-1/4"	28.2	0.132	5.168	23.6	0.157	6.147
1-1/4" to 1-1/2"	36.4	0.094	3.680	29.3	0.123	4.815
1-1/2" to 1-3/4"	46.2	0.062	2.427	41.4	0.074	2.897
1-3/4" to 2"	52.8	0.048	1.879	47.7	0.057	2.232
26F						
0" to 1/4"	2.4	0.390	15.269	0.8	0.410	16.052
1/4" to 1/2"	10.2	0.280	10.962	7.7	0.307	12.019
1/2" to 3/4"	19.3	0.190	7.439	15.5	0.220	8.613
3/4" to 1"	28.0	0.133	5.207	24.1	0.153	5.990
1" to 1-1/4"	38.8	0.086	3.367	33.1	0.104	4.072
1-1/4" to 1-1/2"	43.8	0.069	2.701	40.6	0.077	3.015
1-1/2" to 1-3/4"	42.6	0.073	2.858	36.8	0.090	3.524
1-3/4" to 2"	41.4	0.076	2.975	35.2	0.096	3.758

Specimen #27 - 3 Month Exposure

By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	99.2	73.6	51.5	-3.0
mV after	101.2	74.6	52.5	-3.2
mV before	99.4	73.1	51.2	-3.1
mV after	97.8	72.7	51.0	-4.1

	Date:
5 Minute Test	2/2/2008
24 Hour Test	2/3/2008

Assumed weight of concrete = 145.0 lb/yd3

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
27D						
0" to 1/4"	-9.0	0.630	24.665	-14.2	0.750	29.363
1/4" to 1/2"	5.2	0.342	13.389	0.5	0.410	16.052
1/2" to 3/4"	18.2	0.200	7.830	14.0	0.235	9.200
3/4" to 1"	26.4	0.142	5.559	21.2	0.171	6.695
1" to 1-1/4"	28.2	0.132	5.168	24.0	0.154	6.029
1-1/4" to 1-1/2"	36.1	0.095	3.719	32.4	0.108	4.228
1-1/2" to 1-3/4"	35.8	0.096	3.758	32.3	0.109	4.267
1-3/4" to 2"	44.6	0.067	2.623	40.3	0.078	3.054
27E						
0" to 1/4"	-1.9	0.470	18.401	-5.4	0.530	20.750
1/4" to 1/2"	10.4	0.280	10.962	6.5	0.320	12.528
1/2" to 3/4"	18.0	0.200	7.830	12.8	0.248	9.709
3/4" to 1"	29.2	0.128	5.011	25.8	0.143	5.598
1" to 1-1/4"	40.8	0.079	3.093	37.9	0.086	3.367
1-1/4" to 1-1/2"	43.9	0.070	2.741	39.3	0.081	3.171
1-1/2" to 1-3/4"	47.3	0.060	2.349	42.7	0.071	2.780
1-3/4" to 2"	54.9	0.044	1.723	52.1	0.048	1.879
27F						
0" to 1/4"	-1.5	0.460	18.009	-5.4	0.530	20.750
1/4" to 1/2"	12.7	0.255	9.983	8.6	0.292	11.432
1/2" to 3/4"	16.9	0.212	8.300	12.5	0.250	9.788
3/4" to 1"	33.0	0.105	4.111	28.2	0.129	5.050
1" to 1-1/4"	40.9	0.078	3.054	36.2	0.092	3.602
1-1/4" to 1-1/2"	42.6	0.073	2.858	38.5	0.084	3.289
1-1/2" to 1-3/4"	49.2	0.055	2.153	46.4	0.060	2.349
1-3/4" to 2"	50.6	0.051	1.997	46.9	0.059	2.310

Specimen #28 - 3 Month Exposure

By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	99.2	73.6	51.5	-3.0
mV after	101.2	74.6	52.5	-3.2
mV before	99.4	73.1	51.2	-3.1
mV after	97.8	72.7	51.0	-4.1

	Date:
5 Minute Test	2/2/2008
24 Hour Test	2/3/2008

Assumed weight of concrete = 145.0 lb/yd3

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
28D						
0" to 1/4"	-2.6	0.480	18.792	-4.9	0.508	19.888
1/4" to 1/2"	8.0	0.310	12.137	3.1	0.367	14.368
1/2" to 3/4"	24.6	0.154	6.029	21.9	0.168	6.577
3/4" to 1"	38.7	0.086	3.367	35.7	0.094	3.680
1" to 1-1/4"	41.5	0.076	2.975	37.5	0.087	3.406
1-1/4" to 1-1/2"	41.2	0.077	3.015	35.0	0.097	3.798
1-1/2" to 1-3/4"	43.1	0.072	2.819	38.8	0.084	3.289
1-3/4" to 2"	44.9	0.066	2.584	42.0	0.072	2.819

28E						
0" to 1/4"	-1.3	0.046	1.801	-4.2	0.500	19.575
1/4" to 1/2"	12.0	0.026	1.018	8.5	0.295	11.549
1/2" to 3/4"	20.8	0.181	7.086	16.2	0.212	8.300
3/4" to 1"	31.2	0.118	4.620	25.6	0.142	5.559
1" to 1-1/4"	35.4	0.099	3.876	30.2	0.119	4.659
1-1/4" to 1-1/2"	39.7	0.082	3.210	35.1	0.097	3.798
1-1/2" to 1-3/4"	38.7	0.086	3.367	34.8	0.099	3.876
1-3/4" to 2"	43.2	0.071	2.780	37.7	0.087	3.406

28F						
0" to 1/4"	-1.7	0.460	18.009	-4.3	0.500	19.575
1/4" to 1/2"	11.2	0.270	10.571	8.0	0.300	11.745
1/2" to 3/4"	19.9	0.189	7.399	16.7	0.210	8.222
3/4" to 1"	26.8	0.142	5.559	22.6	0.163	6.381
1" to 1-1/4"	25.0	0.152	5.951	20.6	0.178	6.969
1-1/4" to 1-1/2"	26.8	0.142	5.559	21.1	0.171	6.695
1-1/2" to 1-3/4"	41.7	0.076	2.975	38.6	0.084	3.289
1-3/4" to 2"	45.3	0.065	2.545	39.2	0.081	3.171

Specimen #29 - 3 Month Exposure By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	99.2	73.6	51.5	-3.0
mV after	101.2	74.6	52.5	-3.2
mV before	99.4	73.1	51.2	-3.1
mV after	97.8	72.7	51.0	-4.1

	Date:
5 Minute Test	2/2/2008
24 Hour Test	2/3/2008

Assumed weight of concrete = 145.0 lb/yd3

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
29D						
0" to 1/4"	-1.2	0.455	17.813	-4.3	0.500	19.575
1/4" to 1/2"	13.0	0.250	9.788	8.2	0.298	11.667
1/2" to 3/4"	22.0	0.172	6.734	19.0	0.190	7.439
3/4" to 1"	32.0	0.113	4.424	28.4	0.128	5.011
1" to 1-1/4"	44.1	0.068	2.662	40.4	0.077	3.015
1-1/4" to 1-1/2"	47.2	0.060	2.349	42.0	0.073	2.858
1-1/2" to 1-3/4"	52.2	0.050	1.958	44.2	0.066	2.584
1-3/4" to 2"	46.3	0.062	2.427	38.4	0.084	3.289
29E						
0" to 1/4"	-4.8	0.522	20.436	-7.9	0.580	22.707
1/4" to 1/2"	7.3	0.320	12.528	2.0	0.385	15.073
1/2" to 3/4"	18.2	0.200	7.830	14.2	0.231	9.044
3/4" to 1"	32.8	0.110	4.307	29.3	0.124	4.855
1" to 1-1/4"	37.0	0.092	3.602	30.6	0.117	4.581
1-1/4" to 1-1/2"	39.6	0.083	3.249	33.7	0.104	4.072
1-1/2" to 1-3/4"	43.4	0.070	2.741	35.9	0.094	3.680
1-3/4" to 2"	47.7	0.059	2.310	41.7	0.073	2.858
29F						
0" to 1/4"	-1.0	0.450	17.618	-4.1	0.500	19.575
1/4" to 1/2"	7.1	0.320	12.528	3.8	0.360	14.094
1/2" to 3/4"	23.7	0.160	6.264	19.0	0.190	7.439
3/4" to 1"	28.8	0.130	5.090	23.5	0.158	6.186
1" to 1-1/4"	32.0	0.112	4.385	27.3	0.134	5.246
1-1/4" to 1-1/2"	41.7	0.076	2.975	39.0	0.082	3.210
1-1/2" to 1-3/4"	47.0	0.061	2.388	46.2	0.060	2.349
1-3/4" to 2"	49.5	0.055	2.153	46.8	0.059	2.310

Specimen #30 - 3 Month Exposure

By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.02	0.05	0.5
mV before	99.2	73.6	51.5	-3.0
mV after	101.2	74.6	52.5	-3.2
mV before	99.4	73.1	51.2	-3.1
mV after	97.8	72.7	51.0	-4.1

	Date:
5 Minute Test	2/2/2008
24 Hour Test	2/3/2008

Assumed weight of concrete = 145.0 lb/yd3

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
30D						
0" to 1/4"	-3.3	0.500	19.575	-5.4	0.520	20.358
1/4" to 1/2"	5.6	0.340	13.311	2.0	0.385	15.073
1/2" to 3/4"	16.4	0.218	8.535	11.8	0.258	10.101
3/4" to 1"	23.3	0.161	6.303	22.1	0.165	6.460
1" to 1-1/4"	26.2	0.145	5.677	23.4	0.157	6.147
1-1/4" to 1-1/2"	28.3	0.131	5.129	24.0	0.154	6.029
1-1/2" to 1-3/4"	40.5	0.080	3.132	35.6	0.095	3.719
1-3/4" to 2"	40.1	0.081	3.171	34.7	0.099	3.876
30E						
0" to 1/4"	3.8	0.370	14.486	1.4	0.395	15.464
1/4" to 1/2"	13.4	0.248	9.709	9.9	0.275	10.766
1/2" to 3/4"	24.1	0.156	6.107	21.4	0.170	6.656
3/4" to 1"	36.8	0.093	3.641	32.0	0.108	4.228
1" to 1-1/4"	38.8	0.086	3.367	32.5	0.107	4.189
1-1/4" to 1-1/2"	34.4	0.102	3.993	30.0	0.120	4.698
1-1/2" to 1-3/4"	26.0	0.147	5.755	22.6	0.165	6.460
1-3/4" to 2"	29.4	0.127	4.972	27.1	0.134	5.246
30F						
0" to 1/4"	0.1	0.430	16.835	-2.4	0.465	18.205
1/4" to 1/2"	16.9	0.213	8.339	12.1	0.252	9.866
1/2" to 3/4"	24.2	0.155	6.068	21.5	0.170	6.656
3/4" to 1"	30.2	0.122	4.776	27.2	0.135	5.285
1" to 1-1/4"	35.3	0.099	3.876	29.9	0.120	4.698
1-1/4" to 1-1/2"	47.8	0.059	2.310	46.2	0.061	2.388
1-1/2" to 1-3/4"	58.4	0.038	1.488	54.8	0.043	1.683
1-3/4" to 2"	46.8	0.062	2.427	43.2	0.069	2.701

Measurement of the acid soluble chloride content of hardened concrete by the RCT method

Report #: ________ **Structure:** ________ **Project:** 26DEF - 30DEF 5-minute

Date of testing: 2/2/08 **Electrode #:** ________ **Person:** MDP

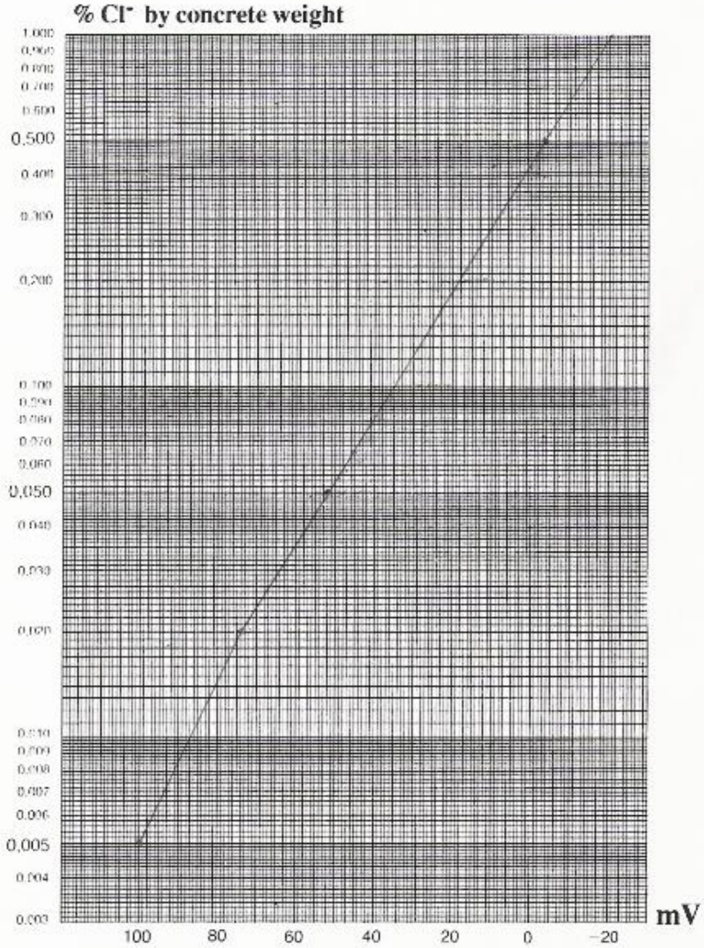
Testing Lab: UWM **Address:** ________ **Phone:** ________

RCT

HARDENED CONCRETE

1.5 gram of concrete dust dissolved in a RCT-1023 vial with 10 milliliter of extraction liquid

% Cl^- by concrete weight



CALIBRATION:

Liquid	Clear	Purple	Green	Pink
% Cl	0.005	0.020	0.050	0.500
mV before	99.2	73.6	51.5	-3.0
mV after	101.2	74.6	52.5	-3.2
(average)	100.2	74.1	52.0	-3.1

SAMPLE #	1		2		Remarks
	mV	% Cl	mV	% Cl	

Measurement of the acid soluble chloride content of hardened concrete by the RCT method

Report #: ________ **Structure:** ________ **Project:** 26DEF - 30DEF 24-Hour

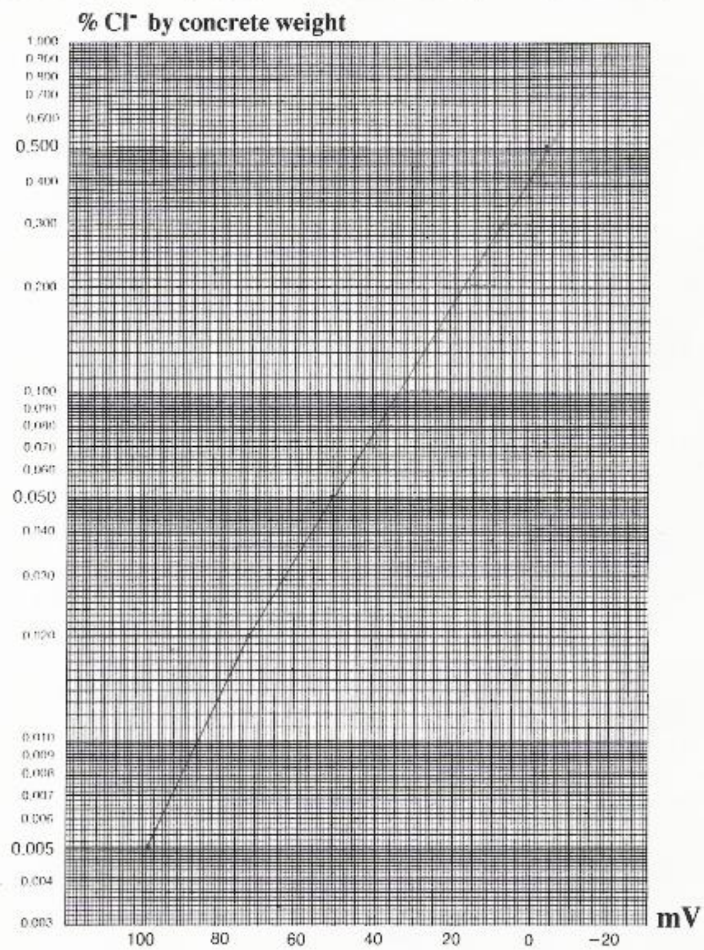
Date of testing: 2/3/08 **Electrode #:** ________ **Person:** MDP

Testing Lab: UWM **Address:** ________ **Phone:** ________

RCT

HARDENED CONCRETE

1.5 gram of concrete dust dissolved in a RCT-1023 vial with 10 milliliter of extraction liquid



CALIBRATION:

Liquid	Clear		Purple		Green		Pink	
% Cl	0.005		0.020		0.050		0.500	
mV before	99.4	98.6	73.1	72.9	51.2	51.1	-3.1	-3.6
mV after	97.8		72.7		51.0		-4.1	

SAMPLE #	1		2		Remarks
	mV	% Cl	mV	% Cl	

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APPENDIX F

CoC Chlorides at 6-Months

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.020	0.050	0.500
mV before	95.4	71.2	51.0	-5.5
mV after	-	-	-	-
mV before	99.0	72.7	49.8	-5.8
mV after	-	-	-	-

By: MDP

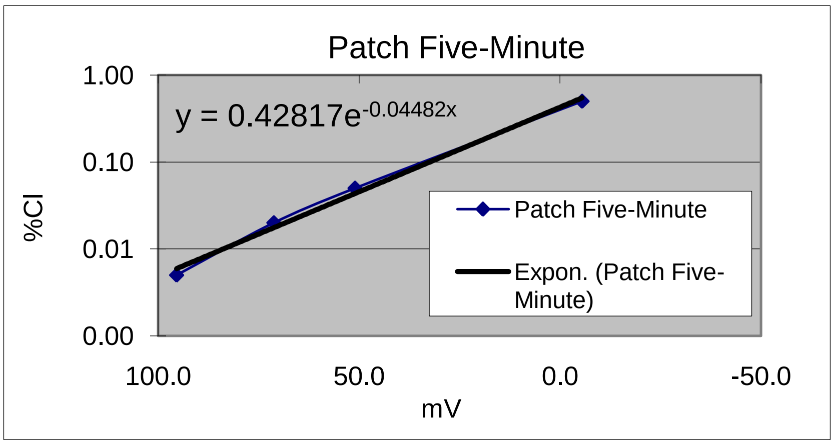
Patch Material Date:

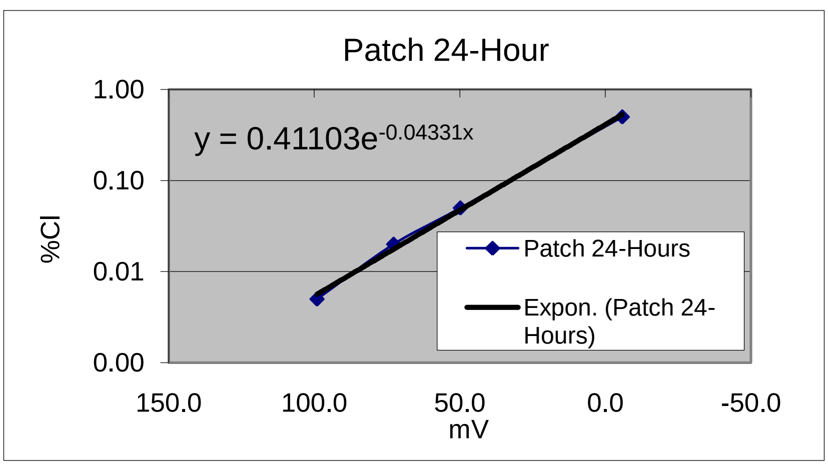
5 Minute Test 8/25/2008

24 Hour Test 8/28/2008

Assumed weight of concrete = 145.0 lb/yd^3

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
A 1/2"	90.5	0.007	0.290	86.6	0.010	0.378
A 1"	101.0	0.005	0.181	94.9	0.007	0.264
B 1/2"	85.7	0.009	0.360	81.6	0.012	0.470
B 1"	101.6	0.005	0.176	99.8	0.005	0.214
	Averages:	**0.006**	**0.252**		**0.008**	**0.331**





Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.020	0.050	0.500
mV before	101.6	73.9	51.2	-4.3
mV after	97.2	68.3	47.4	-8.1
mV after	101.1	73.6	50.4	-4.7
mV after	99.1	70.7	49.1	-6.4

By: MDP

Date:

5 Minute Test 10/28/2008

24-Hour Test 11/4/2008

Assumed weight of concrete = 145.0 lb/cubic yard

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
17B						
0" to 1/4"	23.7	0.144	5.623	18.8	0.183	7.148
1/4" to 1/2"	98.8	0.006	0.219	89.3	0.009	0.341
1/2" to 3/4"	101.8	0.005	0.192	89.9	0.008	0.332
3/4" to 1"	95.9	0.006	0.248	90.1	0.008	0.329
1" to 1-1/4"	100.7	0.005	0.201	89.9	0.008	0.332
1-1/4" to 1-1/2"	101.6	0.005	0.194	91.5	0.008	0.310
1-1/2" to 1-3/4"	97.1	0.006	0.235	89.1	0.009	0.344
1-3/4" to 2"	93.5	0.007	0.275	85.7	0.010	0.398
17H						
0" to 1/4"	-2.7	0.450	17.609	-6.4	0.542	21.209
1/4" to 1/2"	0.1	0.398	15.601	-1.5	0.438	17.166
1/2" to 3/4"	6.8	0.298	11.677	4.5	0.338	13.250
3/4" to 1"	13.3	0.225	8.816	12.2	0.243	9.503
1" to 1-1/4"	24.2	0.141	5.503	20.7	0.168	6.585
1-1/4" to 1-1/2"	27.4	0.122	4.792	26.6	0.130	5.105
1-1/2" to 1-3/4"	29.0	0.114	4.471	25.0	0.140	5.470
1-3/4" to 2"	30.4	0.108	4.209	27.0	0.128	5.017
18B						
0" to 1/4"	43.2	0.062	2.420	36.4	0.085	3.344
1/4" to 1/2"	99.4	0.005	0.213	88.2	0.009	0.358
1/2" to 3/4"	104.8	0.004	0.169	91.9	0.008	0.305
3/4" to 1"	105.5	0.004	0.164	94.7	0.007	0.270
1" to 1-1/4"	106.8	0.004	0.155	94.9	0.007	0.268
1-1/4" to 1-1/2"	104.3	0.004	0.172	91.4	0.008	0.311
1-1/2" to 1-3/4"	90.8	0.008	0.309	80.6	0.013	0.496
1-3/4" to 2"	103.7	0.005	0.177	91.8	0.008	0.306
18H						
0" to 1/4"	-6.5	0.530	20.754	-8.1	0.583	22.823
1/4" to 1/2"	1.1	0.382	14.941	0.1	0.409	16.021
1/2" to 3/4"	2.9	0.353	13.822	1.2	0.390	15.278
3/4" to 1"	9.8	0.262	10.256	9.8	0.269	10.540
1" to 1-1/4"	13.5	0.223	8.740	13.8	0.227	8.869
1-1/4" to 1-1/2"	18.5	0.180	7.041	17.4	0.194	7.593
1-1/2" to 1-3/4"	22.4	0.152	5.948	21.7	0.161	6.307
1-3/4" to 2"	30.8	0.106	4.137	29.0	0.118	4.602

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.020	0.050	0.500
mV before	95.8	67.1	45.7	-9.4
mV after	97.2	67.7	47.5	-7.6
mV after	101.1	73.6	50.4	-4.7
mV after	99.1	70.7	49.1	-6.4

By: MDP

Date:

5 Minute Test 10/29/2008

24-Hour Test 11/4/2008

Assumed weight of concrete = 145.0 lb/cubic yard

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
23B						
0" to 1/4"	53.7	0.035	1.354	51.8	0.044	1.720
1/4" to 1/2"	92.4	0.006	0.250	87.1	0.010	0.375
1/2" to 3/4"	102.7	0.004	0.160	93.9	0.007	0.280
3/4" to 1"	103.2	0.004	0.156	90.2	0.008	0.328
1" to 1-1/4"	93.5	0.006	0.239	89.8	0.009	0.334
1-1/4" to 1-1/2"	99.9	0.005	0.180	93.0	0.007	0.291
1-1/2" to 1-3/4"	102.9	0.004	0.158	94.8	0.007	0.269
1-3/4" to 2"	97.8	0.005	0.198	91.5	0.008	0.310
23H						
0" to 1/4"	-1.1	0.378	14.781	-2.0	0.448	17.540
1/4" to 1/2"	0.2	0.357	13.966	0.1	0.409	16.021
1/2" to 3/4"	7.0	0.265	10.381	6.5	0.310	12.154
3/4" to 1"	14.8	0.189	7.387	15.4	0.211	8.277
1" to 1-1/4"	31.1	0.093	3.628	31.6	0.105	4.114
1-1/4" to 1-1/2"	27.5	0.108	4.245	28.2	0.122	4.764
1-1/2" to 1-3/4"	31.4	0.091	3.581	31.7	0.105	4.096
1-3/4" to 2"	27.3	0.109	4.282	26.4	0.132	5.149
24B						
0" to 1/4"	57.2	0.030	1.162	53.6	0.041	1.592
1/4" to 1/2"	84.6	0.009	0.352	76.4	0.015	0.595
1/2" to 3/4"	99.8	0.005	0.181	89.8	0.009	0.334
3/4" to 1"	104.9	0.004	0.145	94.1	0.007	0.277
1" to 1-1/4"	100.7	0.004	0.174	93.4	0.007	0.286
1-1/4" to 1-1/2"	96.4	0.005	0.210	92.0	0.008	0.303
1-1/2" to 1-3/4"	101.5	0.004	0.168	91.7	0.008	0.307
1-3/4" to 2"	81.3	0.010	0.406	78.8	0.014	0.536
24H						
0" to 1/4"	-12.6	0.623	24.409	-12.2	0.696	27.242
1/4" to 1/2"	-4.9	0.446	17.446	-4.4	0.497	19.455
1/2" to 3/4"	-0.5	0.368	14.399	-0.2	0.415	16.229
3/4" to 1"	-1.9	0.391	15.306	-1.7	0.442	17.315
1" to 1-1/4"	-12.8	0.629	24.623	-12.5	0.705	27.597
1-1/4" to 1-1/2"	-1.7	0.388	15.173	-0.8	0.425	16.655
1-1/2" to 1-3/4"	14.3	0.193	7.550	14.0	0.225	8.793
1-3/4" to 2"	26.6	0.113	4.415	25.3	0.138	5.399

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.020	0.050	0.500
mV before	95.8	67.1	45.7	-9.4
mV after	97.2	67.7	47.5	-7.6
mV after	95.0	65.0	45.5	-9.4
mV after	94.4	64.1	44.3	-9.2

By: MDP

Date:

5 Minute Test 10/29/2008

24-Hour Test 11/5/2008

Assumed weight of concrete = 145.0 lb/cubic yard

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
25B						
0" to 1/4"	82.2	0.010	0.391	74.6	0.013	0.496
1/4" to 1/2"	102.4	0.004	0.162	94.9	0.005	0.202
1/2" to 3/4"	99.7	0.005	0.182	88.5	0.007	0.268
3/4" to 1"	98.9	0.005	0.188	89.7	0.006	0.254
1" to 1-1/4"	103.8	0.004	0.152	91.8	0.006	0.232
1-1/4" to 1-1/2"	104.3	0.004	0.149	93.2	0.006	0.218
1-1/2" to 1-3/4"	98.8	0.005	0.189	90.1	0.006	0.250
1-3/4" to 2"	104.5	0.004	0.148	95.9	0.005	0.193
25H						
0" to 1/4"	-7.8	0.506	19.798	-9.5	0.521	20.403
1/4" to 1/2"	-6.5	0.478	18.707	-7.3	0.473	18.512
1/2" to 3/4"	2.7	0.320	12.523	2.1	0.312	12.218
3/4" to 1"	17.0	0.171	6.711	15.5	0.173	6.758
1" to 1-1/4"	27.6	0.108	4.227	24.0	0.119	4.641
1-1/4" to 1-1/2"	29.2	0.101	3.942	25.7	0.110	4.305
1-1/2" to 1-3/4"	34.0	0.082	3.197	28.3	0.098	3.838
1-3/4" to 2"	39.4	0.065	2.526	31.4	0.085	3.346
26B						
0" to 1/4"	84.9	0.009	0.347	74.9	0.012	0.489
1/4" to 1/2"	95.4	0.006	0.220	88.7	0.007	0.266
1/2" to 3/4"	101.7	0.004	0.167	91.2	0.006	0.238
3/4" to 1"	103.8	0.004	0.152	91.9	0.006	0.231
1" to 1-1/4"	106.3	0.003	0.136	93.5	0.005	0.215
1-1/4" to 1-1/2"	103.5	0.004	0.154	90.8	0.006	0.242
1-1/2" to 1-3/4"	100.6	0.004	0.175	89.6	0.007	0.255
1-3/4" to 2"	102.7	0.004	0.160	90.5	0.006	0.246
26H						
0" to 1/4"	-5.1	0.450	17.599	-8.1	0.490	19.179
1/4" to 1/2"	-2.4	0.400	15.643	-4.3	0.414	16.213
1/2" to 3/4"	4.8	0.292	11.427	2.7	0.304	11.899
3/4" to 1"	15.7	0.181	7.103	13.5	0.189	7.382
1" to 1-1/4"	31.4	0.091	3.581	28.6	0.097	3.787
1-1/4" to 1-1/2"	43.9	0.053	2.076	38.4	0.063	2.456
1-1/2" to 1-3/4"	36.4	0.074	2.879	30.9	0.087	3.421
1-3/4" to 2"	44.1	0.053	2.058	39.7	0.059	2.319

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.020	0.050	0.500
mV before	101.6	73.9	51.2	-4.3
mV after	97.2	68.3	47.4	-8.1
mV after	101.1	73.6	50.4	-4.7
mV after	99.1	70.7	49.1	-6.4

By: MDP

Date:

5 Minute Test 10/28/2008

24-Hour Test 11/4/2008

Assumed weight of concrete = 145.0 lb/cubic yard

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
27B						
0" to 1/4"	27.4	0.122	4.792	25.6	0.136	5.330
1/4" to 1/2"	58.9	0.031	1.227	57.1	0.035	1.369
1/2" to 3/4"	78.7	0.013	0.521	75.0	0.016	0.632
3/4" to 1"	92.3	0.007	0.290	87.2	0.010	0.373
1" to 1-1/4"	100.8	0.005	0.201	93.5	0.007	0.284
1-1/4" to 1-1/2"	99.1	0.006	0.216	91.7	0.008	0.307
1-1/2" to 1-3/4"	96.6	0.006	0.240	90.4	0.008	0.325
1-3/4" to 2"	100.5	0.005	0.203	92.8	0.007	0.293
27H						
0" to 1/4"	-3.7	0.470	18.387	-5.8	0.528	20.667
1/4" to 1/2"	-2.8	0.452	17.685	-2.5	0.458	17.923
1/2" to 3/4"	0.0	0.400	15.669	0.5	0.402	15.746
3/4" to 1"	14.9	0.210	8.227	15.2	0.213	8.349
1" to 1-1/4"	15.6	0.204	7.981	16.0	0.206	8.066
1-1/4" to 1-1/2"	23.3	0.146	5.721	22.8	0.154	6.014
1-1/2" to 1-3/4"	28.9	0.115	4.491	28.1	0.122	4.785
1-3/4" to 2"	30.5	0.107	4.191	29.3	0.116	4.543
28B						
0" to 1/4"	45.5	0.056	2.191	42.1	0.067	2.615
1/4" to 1/2"	99.9	0.005	0.208	92.8	0.007	0.293
1/2" to 3/4"	104.5	0.004	0.171	99.3	0.006	0.221
3/4" to 1"	105.7	0.004	0.162	97.5	0.006	0.239
1" to 1-1/4"	107.6	0.004	0.149	99.0	0.006	0.224
1-1/4" to 1-1/2"	102.1	0.005	0.190	96.8	0.006	0.247
1-1/2" to 1-3/4"	100.8	0.005	0.201	96.4	0.006	0.251
1-3/4" to 2"	100.3	0.005	0.205	94.3	0.007	0.275
28H						
0" to 1/4"	-1.4	0.425	16.646	-4.2	0.493	19.288
1/4" to 1/2"	3.7	0.341	13.352	0.0	0.411	16.090
1/2" to 3/4"	4.8	0.325	12.732	4.0	0.346	13.539
3/4" to 1"	12.5	0.233	9.126	11.5	0.250	9.795
1" to 1-1/4"	15.4	0.206	8.051	14.3	0.222	8.680
1-1/4" to 1-1/2"	27.0	0.125	4.875	25.7	0.136	5.307
1-1/2" to 1-3/4"	33.2	0.095	3.729	28.9	0.118	4.622
1-3/4" to 2"	42.9	0.063	2.451	41.4	0.069	2.695

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.020	0.050	0.500
mV before	96.0	66.8	46.0	-8.9
mV after	97.0	66.4	47.4	-6.7
mV after	101.1	73.6	50.4	-4.7
mV after	99.1	70.7	49.1	-6.4

By: MDP

Date:

5 Minute Test 10/2/2008

24-Hour Test 11/4/2008

Concrete weight = 145.0 lb/cubic yard

Epoxy mortar weight = 50.0 lb/yd^3

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
29B/C						
0" to 1/4"	129.7	0.001	0.048	130.8	0.001	0.020
1/4" to 1/2"	143.3	0.001	0.026	140.7	0.001	0.013
1/2" to 3/4"	149.4	0.001	0.020	146.2	0.001	0.010
3/4" to 1"	137.3	0.001	0.034	138.4	0.001	0.014
1" to 1-1/4"	141.8	0.001	0.028	138.0	0.001	0.014
1-1/4" to 1-1/2"	142.1	0.001	0.028	138.9	0.001	0.014
1-1/2" to 1-3/4"	134.9	0.001	0.038	139.3	0.001	0.014
1-3/4" to 2"	120.7	0.002	0.071	123.8	0.002	0.027
29H						
0" to 1/4"	-7.4	0.509	19.933	-7.1	0.558	21.859
1/4" to 1/2"	-6.2	0.483	18.907	-5.7	0.526	20.578
1/2" to 3/4"	-3.9	0.436	17.086	-4.3	0.495	19.371
3/4" to 1"	17.1	0.173	6.776	19.0	0.181	7.086
1" to 1-1/4"	28.3	0.106	4.138	29.8	0.114	4.446
1-1/4" to 1-1/2"	25.1	0.122	4.764	24.0	0.146	5.711
1-1/2" to 1-3/4"	30.0	0.098	3.839	28.5	0.120	4.703
1-3/4" to 2"	29.7	0.099	3.890	30.2	0.112	4.370
30B/C						
0" to 1/4"	109.6	0.003	0.115	112.4	0.003	0.043
1/4" to 1/2"	134.5	0.001	0.039	139.7	0.001	0.013
1/2" to 3/4"	108.8	0.003	0.119	108.9	0.004	0.050
3/4" to 1"	68.8	0.018	0.695	72.8	0.018	0.240
1" to 1-1/4"	45.0	0.051	1.983	46.3	0.056	0.752
1-1/4" to 1-1/2"	50.9	0.039	1.529	50.7	0.046	0.622
1-1/2" to 1-3/4"	62.7	0.023	0.910	62.9	0.027	0.367
1-3/4" to 2"	59.6	0.027	1.043	61.4	0.029	0.392
30H						
0" to 1/4"	-4.1	0.440	17.237	-3.4	0.476	18.633
1/4" to 1/2"	6.8	0.272	10.665	7.7	0.295	11.540
1/2" to 3/4"	4.0	0.308	12.065	4.6	0.337	13.193
3/4" to 1"	-0.8	0.381	14.905	-1.2	0.433	16.945
1" to 1-1/4"	3.3	0.318	12.443	3.2	0.358	14.014
1-1/4" to 1-1/2"	8.2	0.256	10.028	8.5	0.285	11.149
1-1/2" to 1-3/4"	2.6	0.328	12.832	2.9	0.363	14.197
1-3/4" to 2"	2.5	0.329	12.889	3.2	0.358	14.014

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.020	0.050	0.500
mV before	96.0	66.8	46.0	-8.9
mV after	97.0	66.4	47.4	-6.7
mV after	101.1	73.6	50.4	-4.7
mV after	99.1	70.7	49.1	-6.4

By: MDP

Date:

5 Minute Test 11/2/2008

24-Hour Test 11/4/2008

Assumed weight of concrete = 145.0 lb/cubic yard

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
18i						
0" to 1/4"	-7.1	0.502	19.671	-7.5	0.568	22.240
1/4" to 1/2"	3.3	0.318	12.443	2.8	0.364	14.258
1/2" to 3/4"	5.4	0.290	11.344	4.7	0.336	13.136
3/4" to 1"	14.6	0.193	7.565	13.9	0.226	8.831
1" to 1-1/4"	29.7	0.099	3.890	28.3	0.121	4.743
1-1/4" to 1-1/2"	33.8	0.083	3.248	31.5	0.106	4.132
1-1/2" to 1-3/4"	41.6	0.059	2.303	40.9	0.070	2.754
1-3/4" to 2"	44.5	0.052	2.027	45.1	0.059	2.297
24i						
0" to 1/4"	-8.8	0.542	21.201	-8.8	0.601	23.523
1/4" to 1/2"	-8.9	0.544	21.294	-9.3	0.614	24.037
1/2" to 3/4"	-0.7	0.379	14.840	-1.5	0.438	17.166
3/4" to 1"	8.1	0.257	10.072	7.1	0.303	11.843
1" to 1-1/4"	9.6	0.241	9.428	9.4	0.274	10.724
1-1/4" to 1-1/2"	4.3	0.304	11.907	3.6	0.352	13.774
1-1/2" to 1-3/4"	13.0	0.207	8.117	12.5	0.240	9.381
1-3/4" to 2"	31.4	0.092	3.610	30.7	0.109	4.277
24G						
0" to 1/4"	-5.9	0.477	18.659	-5.7	0.526	20.578
1/4" to 1/2"	-5.3	0.464	18.172	-5.1	0.512	20.052
1/2" to 3/4"	8.6	0.252	9.853	8.0	0.291	11.392
3/4" to 1"	15.0	0.190	7.433	14.6	0.219	8.568
1" to 1-1/4"	14.3	0.196	7.665	13.8	0.227	8.869
1-1/4" to 1-1/2"	17.1	0.173	6.776	15.2	0.213	8.349
1-1/2" to 1-3/4"	15.4	0.187	7.303	14.7	0.218	8.531
1-3/4" to 2"	27.3	0.110	4.324	26.5	0.131	5.127

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.020	0.050	0.500
mV before	96.0	66.8	46.0	-8.9
mV after	97.0	66.4	47.4	-6.7
mV after	101.1	73.6	50.4	-4.7
mV after	99.1	70.7	49.1	-6.4

By: MDP

Date:

5 Minute Test 10/2/2008

24-Hour Test 11/4/2008

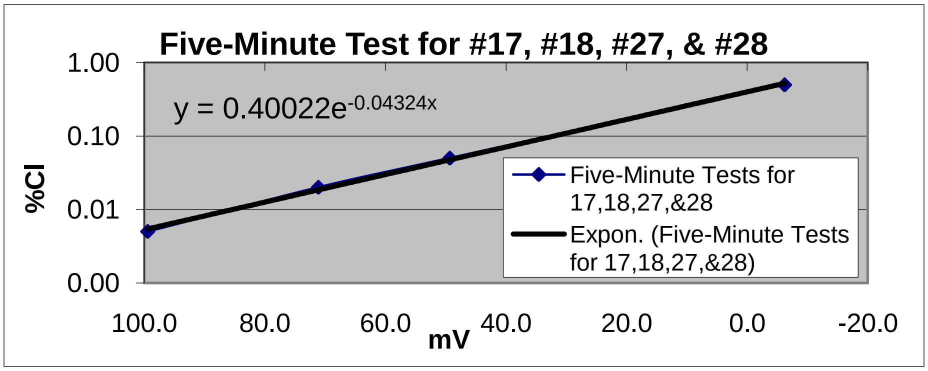
Concrete weight = 145.0 lb/cubic yard

Epoxy mortar weight = 50.0 lb/yd^3

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
30D						
0" to 1/4"	115.0	0.002	0.091	109.6	0.004	0.049
1/4" to 1/2"	139.0	0.001	0.032	138.7	0.001	0.014
1/2" to 3/4"	62.5	0.023	0.918	61.9	0.028	0.384
3/4" to 1"	27.8	0.108	4.230	30.6	0.110	1.481
1" to 1-1/4"	29.1	0.102	3.994	31.0	0.108	1.456
1-1/4" to 1-1/2"	44.2	0.052	2.054	43.0	0.064	0.867
1-1/2" to 1-3/4"	54.7	0.033	1.294	53.2	0.041	0.558
1-3/4" to 2"	90.9	0.007	0.263	87.5	0.009	0.127
30E						
0" to 1/4"	123.8	0.002	0.062	122.3	0.002	0.028
1/4" to 1/2"	142.5	0.001	0.027	140.7	0.001	0.013
1/2" to 3/4"	150.3	0.000	0.019	141.6	0.001	0.012
3/4" to 1"	140.7	0.001	0.029	137.3	0.001	0.015
1" to 1-1/4"	139.4	0.001	0.031	139.5	0.001	0.013
1-1/4" to 1-1/2"	153.9	0.000	0.016	142.9	0.001	0.012
1-1/2" to 1-3/4"	149.6	0.001	0.020	145.8	0.001	0.010
1-3/4" to 2"	153.3	0.000	0.017	148.2	0.001	0.009
30i						
0" to 1/4"	2.4	0.331	12.946	3.1	0.360	14.075
1/4" to 1/2"	4.3	0.304	11.907	4.5	0.338	13.250
1/2" to 3/4"	1.0	0.352	13.769	0.8	0.397	15.544
3/4" to 1"	10.1	0.236	9.223	9.7	0.270	10.586
1" to 1-1/4"	7.3	0.266	10.433	7.0	0.304	11.894
1-1/4" to 1-1/2"	0.6	0.358	14.014	0.1	0.409	16.021
1-1/2" to 1-3/4"	-6.8	0.496	19.413	-6.4	0.542	21.209
1-3/4" to 2"	-2.5	0.410	16.064	-2.2	0.452	17.693
30G						
0" to 1/4"	-4.6	0.450	17.620	-3.4	0.476	18.633
1/4" to 1/2"	2.0	0.337	13.176	0.5	0.402	15.746
1/2" to 3/4"	7.6	0.263	10.296	6.8	0.306	11.998
3/4" to 1"	13.5	0.203	7.940	12.7	0.238	9.300
1" to 1-1/4"	17.2	0.172	6.746	14.9	0.216	8.458
1-1/4" to 1-1/2"	23.1	0.133	5.203	21.1	0.165	6.472
1-1/2" to 1-3/4"	11.0	0.226	8.864	10.0	0.267	10.450
1-3/4" to 2"	10.5	0.231	9.062	9.3	0.275	10.770

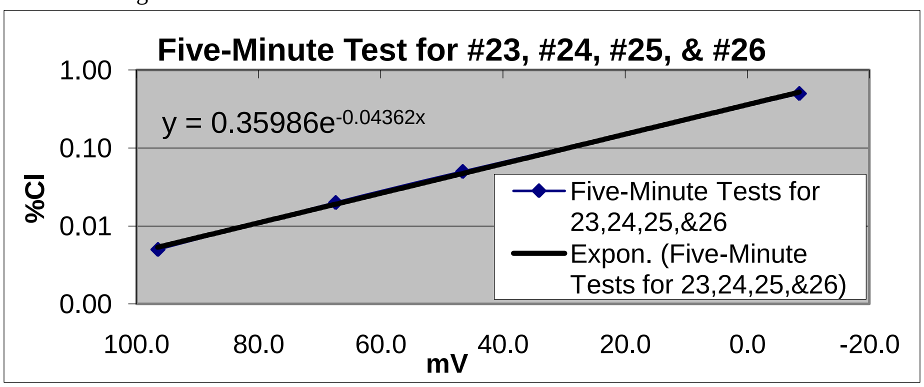
5 Minute Test for #17, #18, #27, and #30 By: MDP

10/25/2008	**0.005**	**0.020**	**0.050**	**0.500**
mV before	101.6	73.9	51.2	-4.3
mV after	97.2	68.3	47.4	-8.1
mV average	99.4	71.1	49.3	-6.2



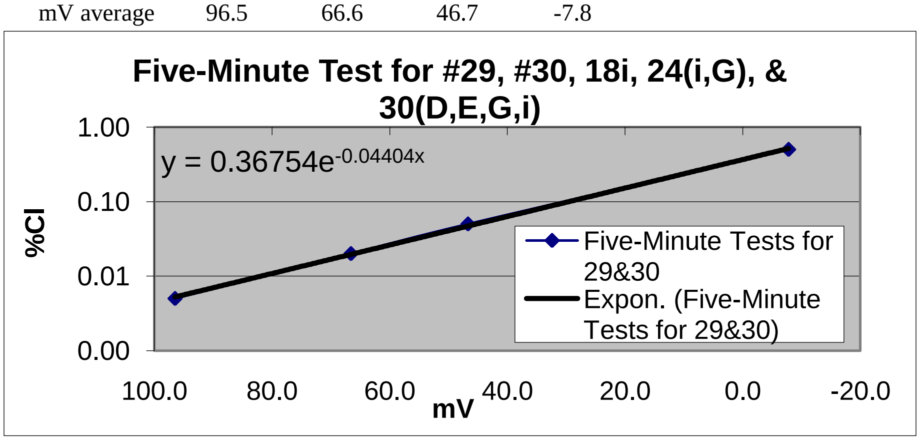
5 Minute Test for #23, #24, #25, and #26

10/29/2008	**0.005**	**0.020**	**0.050**	**0.500**
mV before	95.8	67.1	45.7	-9.4
mV after	97.2	67.7	47.5	-7.6
mV average	96.5	67.4	46.6	-8.5



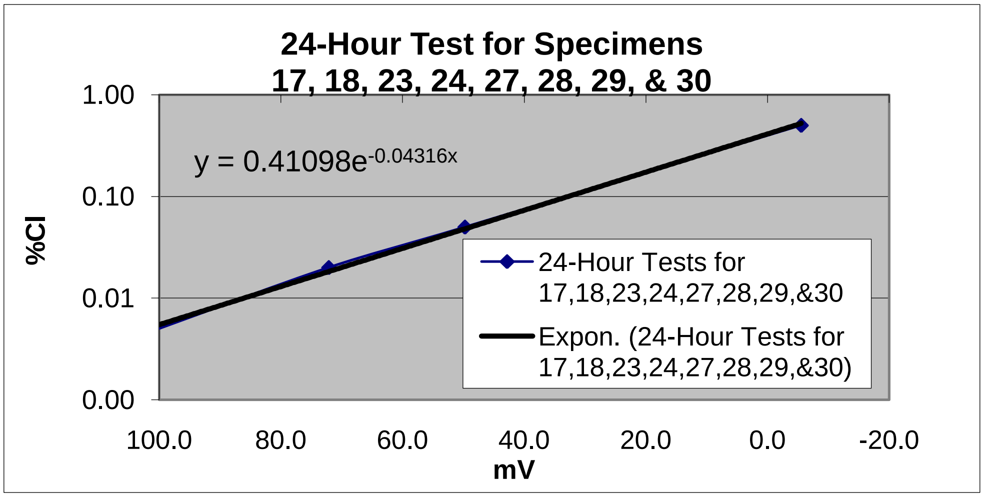
5 Minute Test for #29, #30, #18i, #24(I,G), and #30(D,E,G,i)

11/2/2008	**0.005**	**0.020**	**0.050**	**0.500**
mV before	96.0	66.8	46.0	-8.9
mV after	97.0	66.4	47.4	-6.7
mV average	96.5	66.6	46.7	-7.8



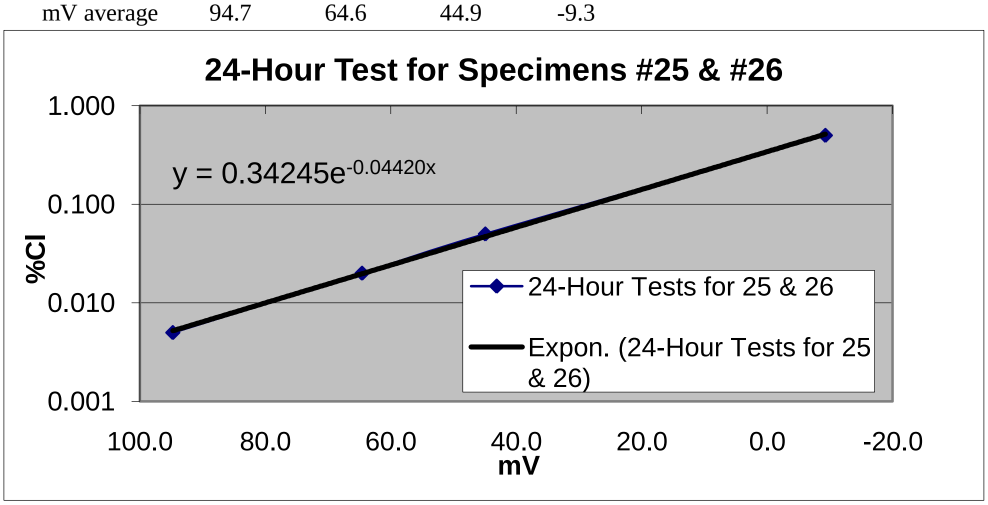
24-Hour Test for #17, #18, #23, #24, #27, #28, #29, and #30 By: MDP

11/4/2008	**0.005**	**0.020**	**0.050**	**0.500**
mV before	101.1	73.6	50.4	-4.7
mV after	99.1	70.7	49.1	-6.4
mV average	100.1	72.2	49.8	-5.6



24-Hour Test for #25 and #26

11/5/2008	**0.005**	**0.020**	**0.050**	**0.500**
mV before	95.0	65.0	45.5	-9.4
mV after	94.4	64.1	44.3	-9.2
mV average	94.7	64.6	44.9	-9.3



Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.020	0.050	0.500
mV before	102.3	73.6	53.1	-3.8
mV after	Varies - see attached			
mV befre	94.4	64.1	44.3	-9.2
mV after	Varies - see attached			

By: MDP

Date:

5 Minute Test 10/31/2008

24-Hour Test 11/5/2008

Assumed weight of concrete = 145.0 lb/cubic yard

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
19B						
0" to 1/4"	40.2	0.031	1.222	20.4	0.065	2.526
1/4" to 1/2"	88.1	0.004	0.165	78.3	0.007	0.286
1/2" to 3/4"	97.4	0.004	0.144	90.7	0.006	0.238
3/4" to 1"	90.9	0.005	0.192	85.8	0.008	0.296
1" to 1-1/4"	95.0	0.004	0.160	91.3	0.006	0.232
1-1/4" to 1-1/2"	95.3	0.004	0.158	92.9	0.006	0.216
1-1/2" to 1-3/4"	92.8	0.005	0.176	87.6	0.007	0.273
1-3/4" to 2"	97.1	0.004	0.146	92.5	0.006	0.220
19H						
0" to 1/4"	-17.1	0.305	11.944	-23.0	0.496	19.424
1/4" to 1/2"	-6.8	0.274	10.724	-15.5	0.518	20.272
1/2" to 3/4"	8.0	0.215	8.421	8.3	0.236	9.234
3/4" to 1"	16.7	0.147	5.745	17.6	0.156	6.110
1" to 1-1/4"	18.1	0.138	5.402	18.8	0.148	5.793
1-1/4" to 1-1/2"	29.3	0.084	3.302	27.7	0.100	3.902
1-1/2" to 1-3/4"	36.6	0.061	2.395	34.3	0.074	2.911
1-3/4" to 2"	41.4	0.050	1.940	39.8	0.058	2.280
20B						
0" to 1/4"	58.8	0.014	0.540	40.7	0.025	0.973
1/4" to 1/2"	98.7	0.003	0.104	85.9	0.005	0.202
1/2" to 3/4"	92.3	0.005	0.180	86.8	0.007	0.283
3/4" to 1"	89.4	0.005	0.205	86.5	0.007	0.287
1" to 1-1/4"	89.1	0.005	0.208	92.1	0.006	0.224
1-1/4" to 1-1/2"	91.9	0.005	0.183	89.4	0.006	0.252
1-1/2" to 1-3/4"	88.7	0.005	0.211	89.7	0.006	0.249
1-3/4" to 2"	88.6	0.005	0.212	88.9	0.007	0.258
20H						
0" to 1/4"	-40.4	0.850	33.264	-39.5	1.077	42.183
1/4" to 1/2"	-12.0	0.344	13.479	-15.4	0.515	20.181
1/2" to 3/4"	-12.4	0.459	17.984	-13.1	0.464	18.178
3/4" to 1"	-9.8	0.410	16.042	-11.6	0.434	16.981
1" to 1-1/4"	6.1	0.204	7.974	5.0	0.204	7.988
1-1/4" to 1-1/2"	10.7	0.166	6.514	8.3	0.176	6.876
1-1/2" to 1-3/4"	19.6	0.113	4.405	18.1	0.113	4.405
1-3/4" to 2"	28.4	0.076	8.421	24.8	0.083	3.249

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.020	0.050	0.500
mV before	102.3	73.6	53.1	-3.8
mV after	Varies - see attached			
mV before	94.4	64.1	44.3	-9.2
mV after	Varies - see attached			

By: MDP

	Date:
5 Minute Test	10/31/2008
24-Hour Test	11/5/2008

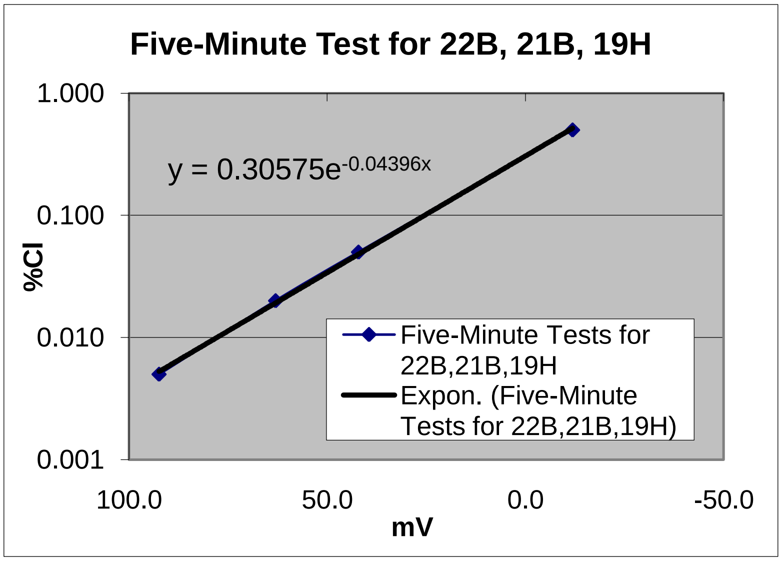
Assumed weight of concrete = 145.0 lb/cubic yard

Sample No.	5 Minute Test			24 Hour Test		
	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete	mV	%Cl by mass of concrete	lb. Cl/yd^3 concrete
21B						
0" to 1/4"	68.3	0.009	0.355	64.5	0.008	0.318
1/4" to 1/2"	95.4	0.003	0.120	84.6	0.005	0.215
1/2" to 3/4"	92.8	0.005	0.202	84.9	0.006	0.251
3/4" to 1"	100.9	0.004	0.142	90.5	0.005	0.195
1" to 1-1/4"	102.7	0.003	0.131	91.8	0.005	0.183
1-1/4" to 1-1/2"	74.0	0.012	0.463	66.3	0.015	0.580
1-1/2" to 1-3/4"	85.2	0.007	0.283	76.7	0.009	0.363
1-3/4" to 2"	98.3	0.004	0.159	88.3	0.005	0.215
21H						
0" to 1/4"	-35.6	0.688	26.936	-43.0	1.270	49.725
1/4" to 1/2"	6.1	0.155	6.083	-5.6	0.330	12.929
1/2" to 3/4"	8.8	0.181	7.082	7.8	0.208	8.134
3/4" to 1"	15.7	0.134	5.229	15.8	0.145	5.669
1" to 1-1/4"	24.0	0.093	3.630	25.1	0.095	3.725
1-1/4" to 1-1/2"	31.4	0.067	2.622	29.0	0.080	3.124
1-1/2" to 1-3/4"	41.9	0.042	1.653	36.2	0.058	2.257
1-3/4" to 2"	41.4	0.043	1.690	40.7	0.047	1.842
22B						
0" to 1/4"	41.2	0.030	1.170	37.0	0.030	1.158
1/4" to 1/2"	85.3	0.005	0.187	77.5	0.008	0.296
1/2" to 3/4"	95.9	0.005	0.177	88.5	0.005	0.213
3/4" to 1"	94.5	0.005	0.188	87.3	0.006	0.225
1" to 1-1/4"	94.6	0.005	0.187	89.3	0.005	0.205
1-1/4" to 1-1/2"	96.4	0.004	0.173	88.9	0.005	0.209
1-1/2" to 1-3/4"	93.9	0.005	0.193	86.2	0.006	0.236
1-3/4" to 2"	99.7	0.004	0.150	92.6	0.005	0.177
22H						
0" to 1/4"	-37.7	0.755	29.541	-43.7	1.313	51.388
1/4" to 1/2"	-11.3	0.334	13.070	-13.1	0.464	18.178
1/2" to 3/4"	-10.4	0.421	16.470	-9.7	0.458	17.922
3/4" to 1"	3.2	0.231	9.059	3.0	0.258	10.102
1" to 1-1/4"	9.4	0.176	6.897	9.6	0.192	7.499
1-1/4" to 1-1/2"	22.0	0.101	3.964	21.8	0.110	4.324
1-1/2" to 1-3/4"	30.5	0.070	2.728	33.0	0.067	2.608
1-3/4" to 2"	30.3	0.070	2.752	32.2	0.069	2.704

By: MDP

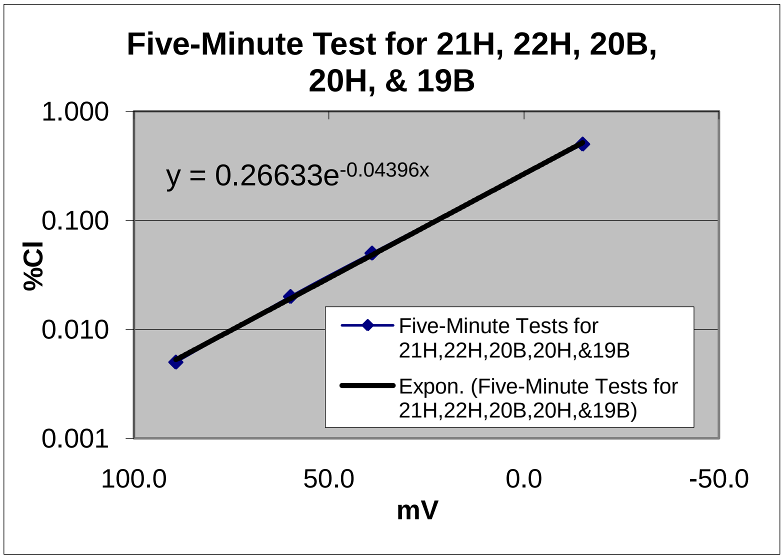
5 Minute Test

10/31/2008	**0.005**	**0.020**	**0.050**	**0.500**
	92.4	63.0	42.1	-11.9



Calibration values based on difference of 0.050% Cl checks.

21H, 22H, 20B, 20H, 19B avg. =			39.0	
		Avg. change =	3.1	
0.005	**0.020**	**0.050**	**0.500**	
89.3	59.9	39.0	-15.0	



After 22H (all tests):
.050% = 30.1

Significant change, calibrations redone:

.005% = 92.4
.020% = 63.0
.050% = 42.1
.500% = -11.9

All 1/4" & 1/2" samples to be tested at end.

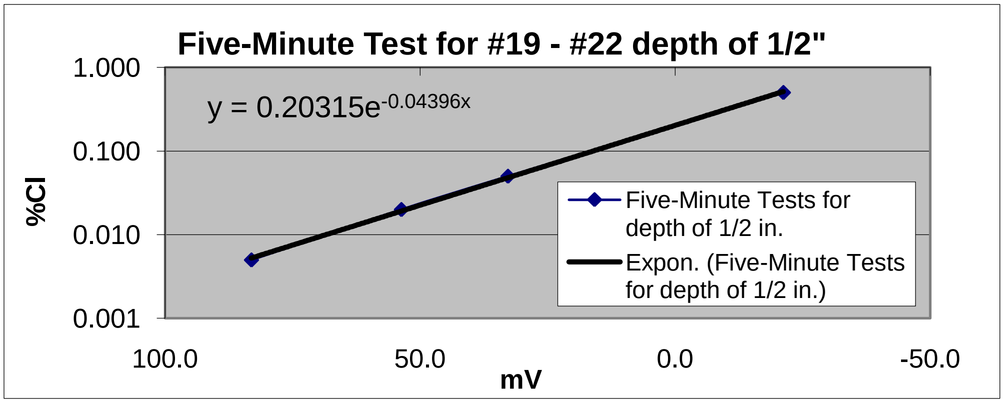
After 22B Tests:
.005% = 41.8
After 21B Tests:
.005% = 42.5
After 21H Tests:
.005% = 38.9
After 22H Tests:
.005% = 39.1
After 20B Tests:
.005% = 37.0
After 20H Tests:
.005% = 39.6
After 19B Tests:
.005% = 40.2
After 19H Tests:
.005% = 41.5
After 1/2" Tests:

.005% = 32.8
After 1/4" Tests (B):
.005% = 30.4
After 1/4" Tests (H):
.020% = 46.5
.050% = 24.3

5 Minute Test: Tests at depth of 1/2" By: MDP

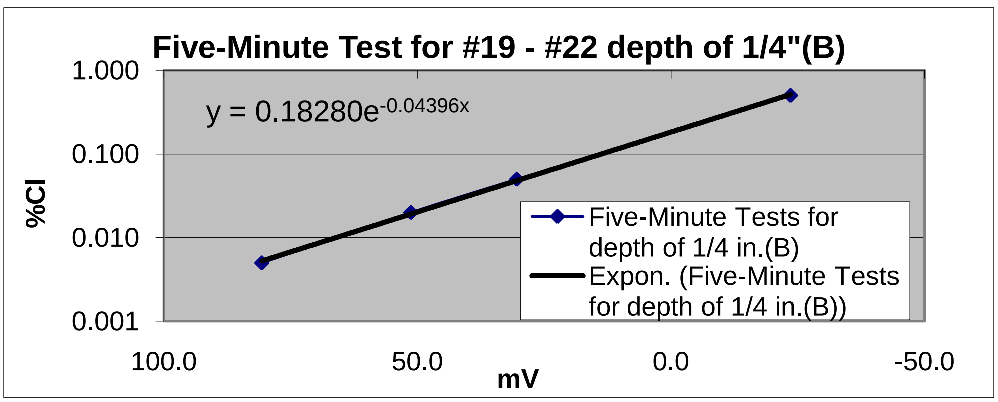
10/31/2008

Change at .050% Cl =		9.3	
0.005	**0.020**	**0.050**	**0.500**
83.1	53.7	32.8	-21.2



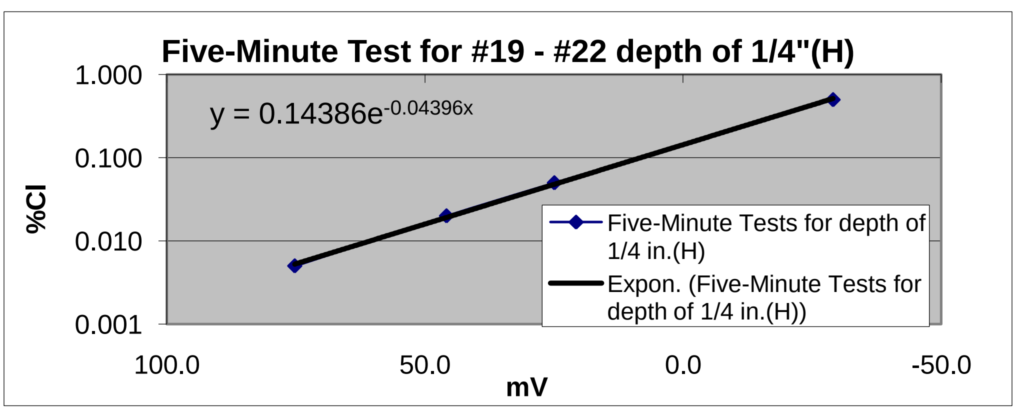
5 Minute Test: Tests at depth of 1/4"(B)

Change at .050% Cl =		11.7	
0.005	**0.020**	**0.050**	**0.500**
80.7	51.3	30.4	-23.6



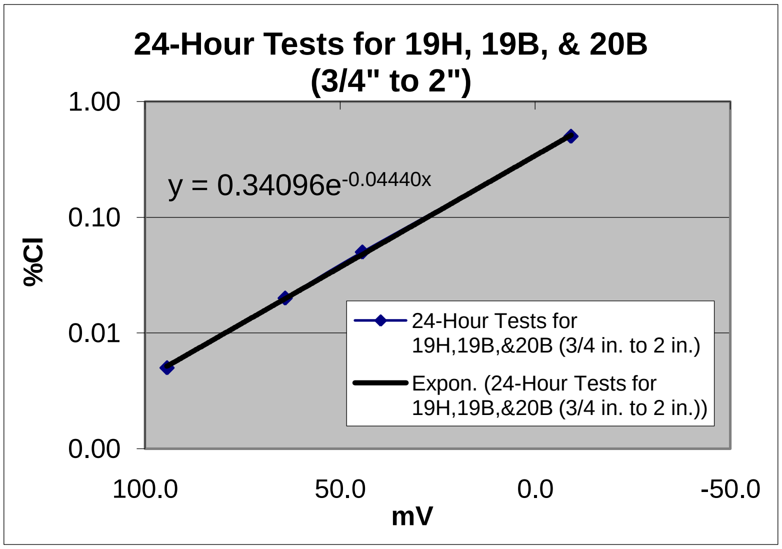
5 Minute Test: Tests at depth of 1/4"(H)

Change at .020% Cl =		16.5		Change at .050% Cl =	17.8
0.005	**0.020**	**0.050**	**0.500**	Avg. Change =	17.2
75.3	45.9	25.0	-29.1		

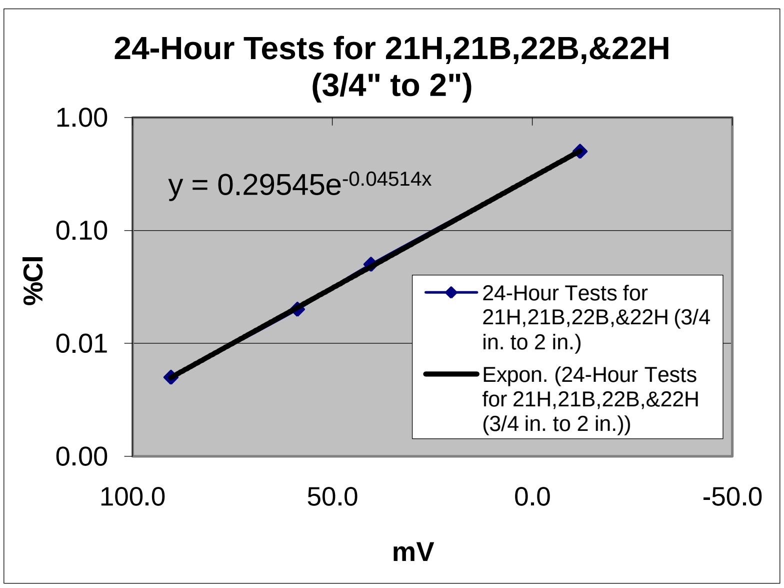


By: MDP

24-Hour Tests	0.005	0.020	0.050	0.500
11/5/2008	94.4	64.1	44.3	-9.2



0.005	0.020	0.050	0.500
90.4	58.8	40.4	-11.9

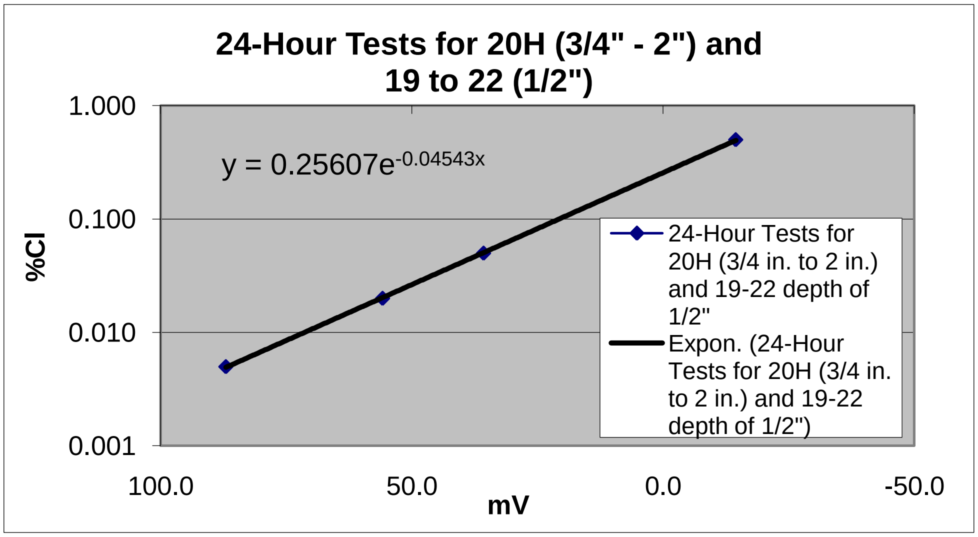


1/4" and 1/2" tests performed at end.

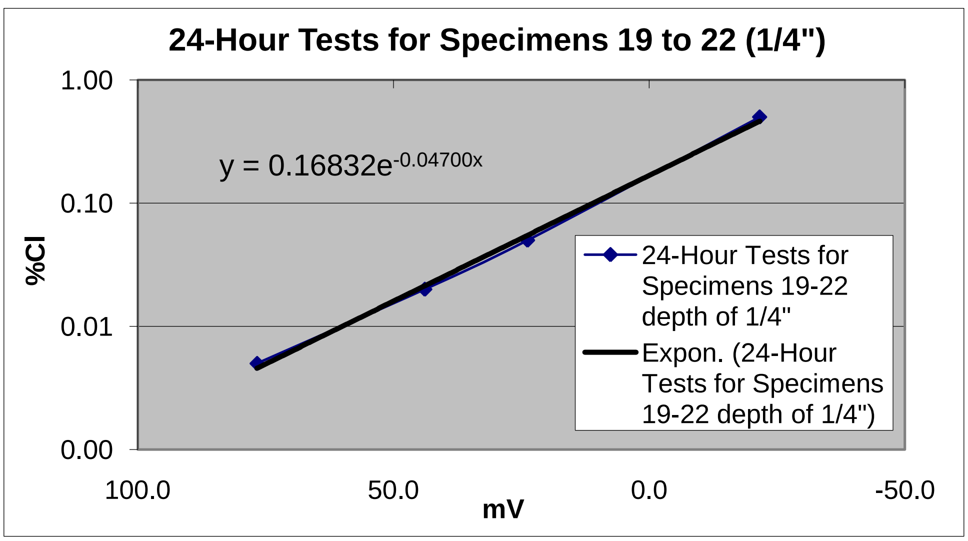
After 19H Tests:
.05 = 43.5
After 19B Tests:
.05 = 43.0
After 20B Tests:
.05 = 43.3
After 21H Tests:
.05 = 39.7
After 21B Tests:
0.005= 90.4
.02 = 58.8
.05 = 40.4
.50 = -11.9
After 22B Tests:
.05 = 40.4
After 22H Tests:
.05 = 39.3
After 20H Tests:
.005= 87.0
.02 = 55.8
.05 = 35.7

.50 = -14.5
After 1/2"(B) Tests:
.05 = 35.4
After 1/2"(H) Tests:
.05 = 35.0
After 1/4"(B) Tests:
.05 = 24.1
After 1/4"(H) Tests:
.005= 76.7
.02 = 43.9
.05 = 23.8
.50 = -21.6

24-Hour Tests	**0.005**	**0.020**	**0.050**	**0.500**	By: MDP
11/5/2008	87.0	55.8	35.7	-14.5	



0.005	**0.020**	**0.050**	**0.500**
76.7	43.9	23.8	-21.6



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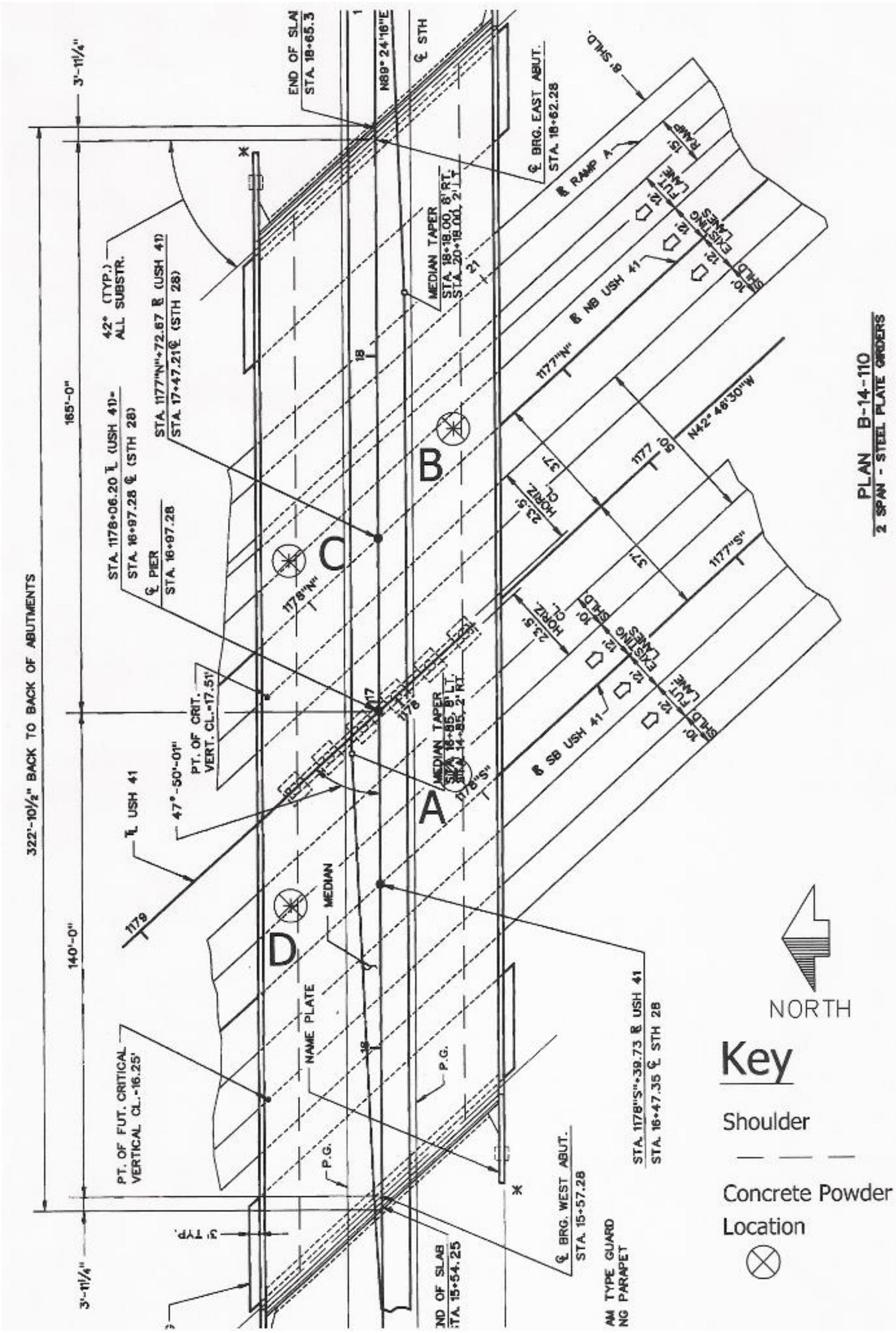
APPENDIX G

Bridge Deck Chlorides


PLAN B-14-110
2 SPAN - STEEL PLATE GIRDERS
322'-10½" BACK TO BACK OF ABUTMENTS
165'-0"
140'-0"
3'-11¼"
42° (TYP.) ALL SUBSTR.
47°-50'-01"
STA. 1178+06.20 ℄ (USH 41)=
STA. 16+97.28 ℄ (STH 28)
℄ PIER
STA. 16+97.28
STA. 1177"N"+72.67 ℄ (USH 41)
STA. 17+47.21℄ (STH 28)
STA. 1178"S"+39.73 ℄ USH 41
STA. 16+47.35 ℄ STH 28
℄ BRG. EAST ABUT.
STA. 18+62.28
℄ BRG. WEST ABUT.
STA. 15+57.28
END OF SLAB
STA. 18+65.3
N89° 24'16"E
N42° 46'30"W
MEDIAN TAPER
PT. OF CRIT. VERT. CL.=17.51'
PT. OF FUT. CRITICAL VERTICAL CL.=16.25'
℄ USH 41
℄ NB USH 41
℄ SB USH 41
℄ RAMP A
NAME PLATE
MEDIAN
P.G.
A
B
C
D
NORTH
Key
Shoulder
Concrete Powder Location

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.020	0.050	0.500
mV before	95.8	69.2	46.9	-8.7
mV after	95.5	71.0	48.5	-7.1
mV before	94.6	69.4	48.0	-5.9
mV after	95.7	70.2	49.1	-6.4

Bridge B-14-0110

Date:

5 Minute Test 8/5/2008

24 Hour Test 8/8/2008

Assumed weight of concrete = 145.0 lb/cubic yard

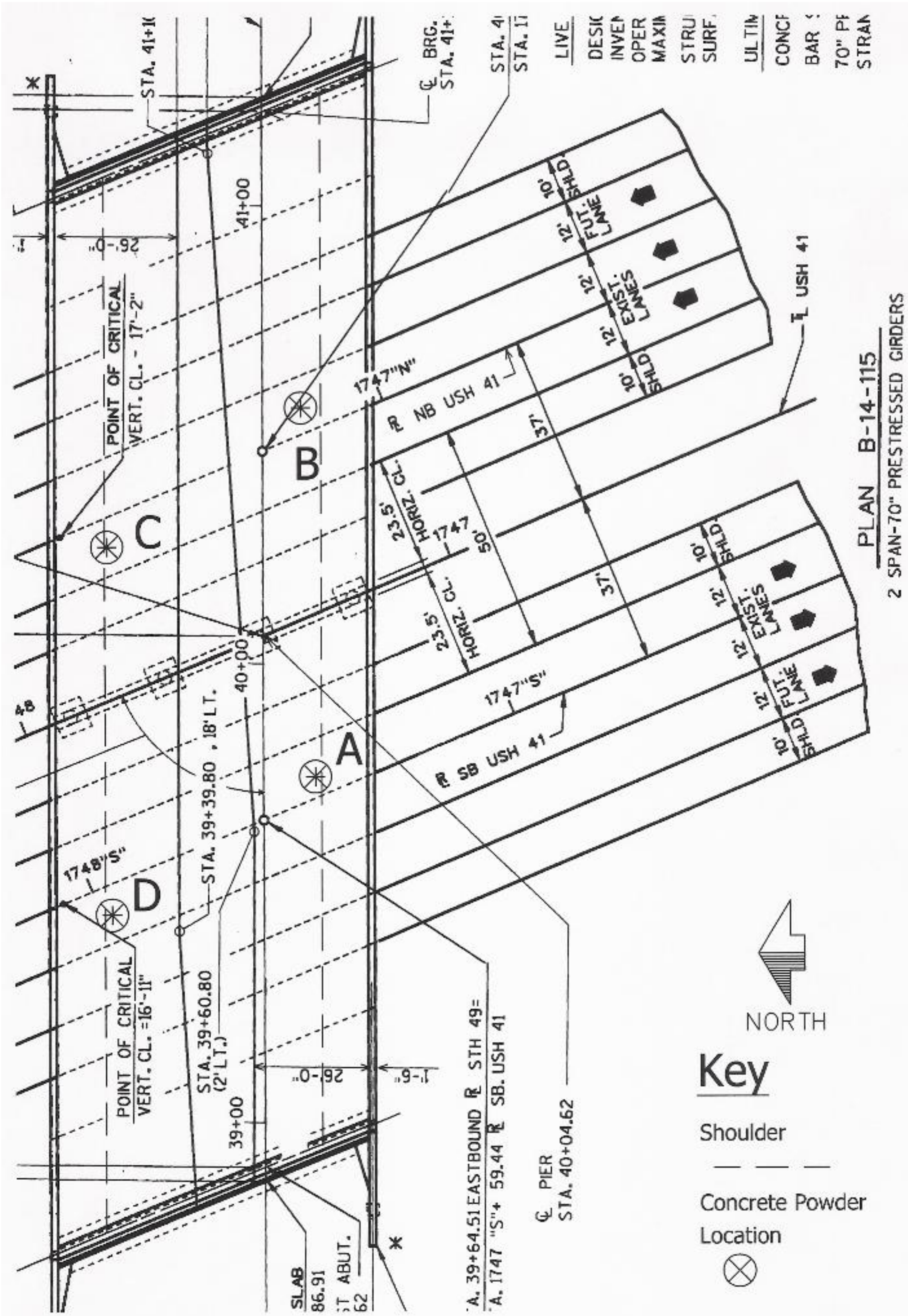
By: MDP

Sample No.	5 Minute Test			24 Hour Test		
A	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	-9.1	0.562	21.992	-9.8	0.630	24.655
1/4" to 1/2"	2.7	0.335	13.119	3.0	0.355	13.891
1/2" to 3/4"	3.4	0.325	12.723	4.5	0.332	12.988
3/4" to 1"	6.6	0.283	11.060	7.2	0.294	11.508
1" to 1-1/4"	15.3	0.193	7.557	16.4	0.195	7.619
1-1/4" to 1-1/2"	27.6	0.113	4.410	27.9	0.116	4.551
1-1/2" to 1-3/4"	35.9	0.078	3.067	35.0	0.085	3.310
1-3/4" to 2"	47.4	0.047	1.854	45.8	0.052	2.040

Sample No.	5 Minute Test			24 Hour Test		
B	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	-10.8	0.605	23.691	-11.5	0.680	26.607
1/4" to 1/2"	-6.5	0.501	19.626	-5.8	0.526	20.608
1/2" to 3/4"	4.9	0.304	11.915	5.6	0.316	12.363
3/4" to 1"	8.6	0.259	10.133	8.1	0.282	11.053
1" to 1-1/4"	5.1	0.302	11.811	5.3	0.320	12.531
1-1/4" to 1-1/2"	9.4	0.250	9.784	10.0	0.259	10.151
1-1/2" to 1-3/4"	19.5	0.161	6.288	19.8	0.167	6.542
1-3/4" to 2"	25.0	0.126	4.942	24.2	0.137	5.371

Sample No.	5 Minute Test			24 Hour Test		
C	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	-12.1	0.641	25.079	-11.4	0.677	26.488
1/4" to 1/2"	-6.2	0.495	19.370	-5.9	0.529	20.701
1/2" to 3/4"	-8.3	0.542	21.235	-7.1	0.558	21.845
3/4" to 1"	-7.5	0.524	20.504	-8.3	0.589	23.052
1" to 1-1/4"	-1.7	0.406	15.906	-0.6	0.417	16.324
1-1/4" to 1-1/2"	14.1	0.203	7.964	15.0	0.207	8.113
1-1/2" to 1-3/4"	10.8	0.235	9.202	11.5	0.242	9.491
1-3/4" to 2"	28.3	0.109	4.277	29.1	0.110	4.312

Sample No.	5 Minute Test			24 Hour Test		
D	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	-7.9	0.533	20.867	-8.2	0.586	22.948
1/4" to 1/2"	-9.8	0.579	22.677	-9.9	0.633	24.765
1/2" to 3/4"	-4.5	0.459	17.981	-4.7	0.501	19.617
3/4" to 1"	2.0	0.346	13.528	3.2	0.352	13.767
1" to 1-1/4"	5.0	0.303	11.863	5.5	0.317	12.419
1-1/4" to 1-1/2"	13.1	0.213	8.321	13.6	0.221	8.638
1-1/2" to 1-3/4"	11.2	0.231	9.043	10.0	0.259	10.151
1-3/4" to 2"	20.0	0.157	6.151	20.6	0.161	6.312



PLAN B-14-115
2 SPAN-70" PRESTRESSED GIRDERS
A
B
C
D
NORTH
Key
Shoulder
Concrete Powder
Location

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.020	0.050	0.500
mV before	95.8	69.2	46.9	-8.7
mV after	95.5	71.0	48.5	-7.1
mV before	94.6	69.4	48.0	-5.9
mV after	95.7	70.2	49.1	-6.4

Bridge B-14-0115

Date:

5 Minute Test 8/5/2008

24 Hour Test 8/8/2008

Assumed weight of concrete = 145.0 lb/cubic yard

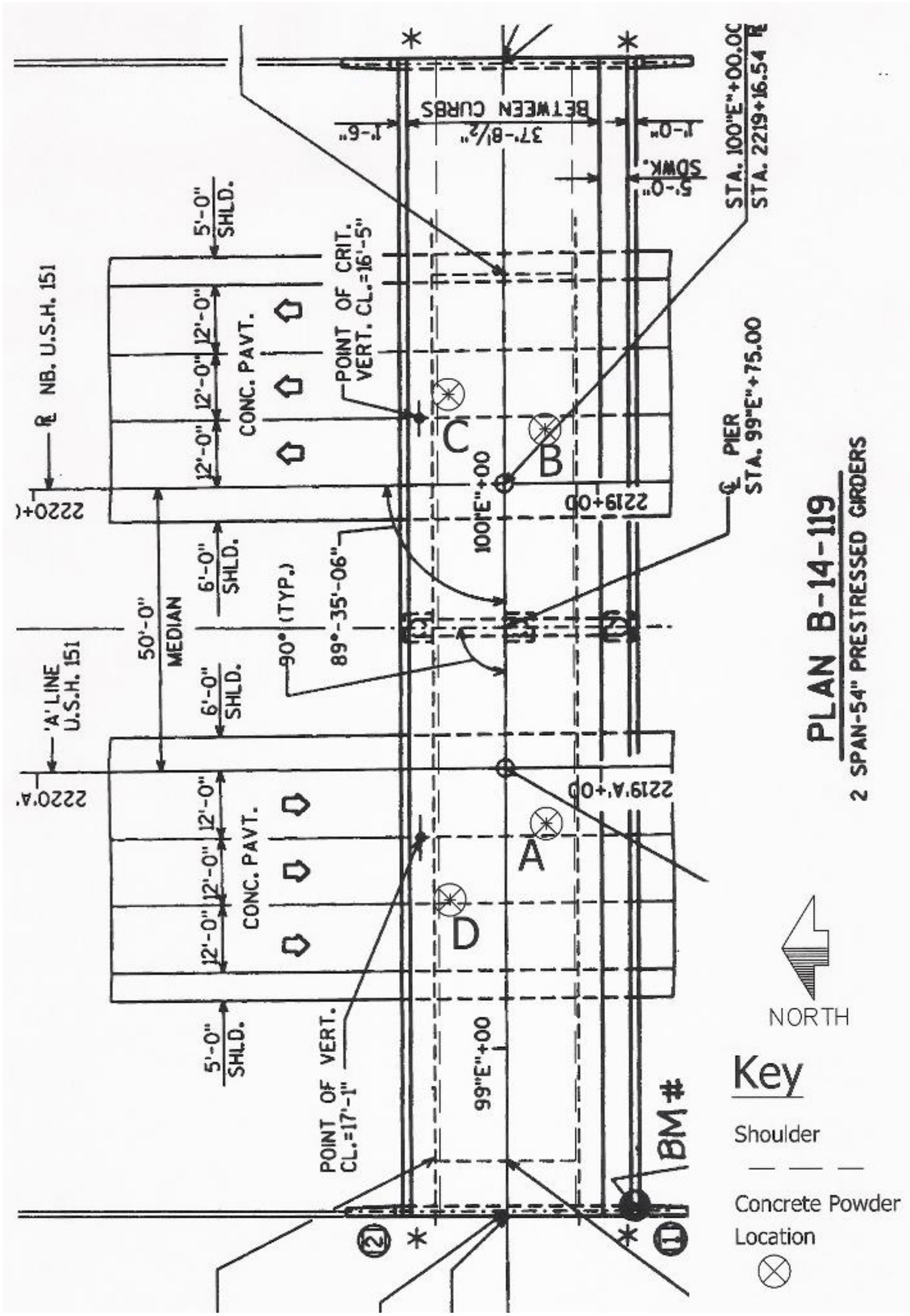
By: MDP

Sample No.	5 Minute Test			24 Hour Test		
A	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	2.5	0.338	13.235	1.9	0.373	14.593
1/4" to 1/2"	5.2	0.300	11.759	6.1	0.309	12.089
1/2" to 3/4"	3.3	0.326	12.779	2.5	0.363	14.206
3/4" to 1"	13.4	0.210	8.212	15.4	0.204	7.969
1" to 1-1/4"	12.8	0.215	8.431	12.5	0.232	9.075
1-1/4" to 1-1/2"	24.1	0.131	5.141	24.3	0.137	5.347
1-1/2" to 1-3/4"	19.6	0.160	6.260	19.8	0.167	6.542
1-3/4" to 2"	17.9	0.172	6.744	17.0	0.189	7.417

Sample No.	5 Minute Test			24 Hour Test		
B	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	-1.3	0.399	15.630	-1.9	0.442	17.303
1/4" to 1/2"	-4.2	0.453	17.746	-3.7	0.479	18.757
1/2" to 3/4"	-5.5	0.480	18.785	-5.9	0.529	20.701
3/4" to 1"	0.0	0.377	14.765	-0.8	0.421	16.471
1" to 1-1/4"	12.5	0.218	8.542	11.4	0.244	9.533
1-1/4" to 1-1/2"	19.3	0.162	6.343	18.0	0.181	7.092
1-1/2" to 1-3/4"	20.1	0.156	6.125	19.7	0.168	6.572
1-3/4" to 2"	27.4	0.114	4.449	26.2	0.125	4.911

Sample No.	5 Minute Test			24 Hour Test		
C	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	1.4	0.355	13.888	0.7	0.393	15.400
1/4" to 1/2"	-6.1	0.493	19.285	-6.6	0.546	21.360
1/2" to 3/4"	5.8	0.293	11.454	6.1	0.309	12.089
3/4" to 1"	7.1	0.276	10.821	7.5	0.290	11.354
1" to 1-1/4"	8.2	0.263	10.312	9.0	0.271	10.616
1-1/4" to 1-1/2"	10.4	0.239	9.365	10.3	0.256	10.015
1-1/2" to 1-3/4"	14.9	0.196	7.690	15.5	0.203	7.933
1-3/4" to 2"	24.7	0.128	5.007	25.1	0.132	5.159

Sample No.	5 Minute Test			24 Hour Test		
D	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	-7.7	0.528	20.685	-9.4	0.619	24.217
1/4" to 1/2"	-2.9	0.428	16.764	-4.5	0.497	19.442
1/2" to 3/4"	8.7	0.258	10.089	9.0	0.271	10.616
3/4" to 1"	20.5	0.154	6.018	19.8	0.167	6.542
1" to 1-1/4"	20.1	0.156	6.125	20.6	0.161	6.312
1-1/4" to 1-1/2"	13.5	0.209	8.176	12.2	0.235	9.197
1-1/2" to 1-3/4"	23.2	0.137	5.347	22.0	0.151	5.928
1-3/4" to 2"	36.0	0.078	3.053	35.7	0.082	3.208


PLAN B-14-119
2 SPAN-54" PRESTRESSED GIRDERS
NORTH
Key
Shoulder
Concrete Powder Location
A
B
C
D
BM #
STA. 100"E"+00.00
STA. 2219+16.54
℄ PIER
STA. 99"E"+75.00
℄ NB. U.S.H. 151
'A' LINE U.S.H. 151
50'-0" MEDIAN
CONC. PAVT.
POINT OF CRIT. VERT. CL.=16'-5"
POINT OF VERT. CL.=17'-1"
37'-8½" BETWEEN CURBS
90° (TYP.)
89°-35'-06"

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.020	0.050	0.500
mV before	95.8	69.2	46.9	-8.7
mV after	95.5	71.0	48.5	-7.1
mV before	94.6	69.4	48.0	-5.9
mV after	95.7	70.2	49.1	-6.4

Bridge B-14-0119

Date:

5 Minute Test 8/5/2008

24 Hour Test 8/8/2008

Assumed weight of concrete = 145.0 lb/cubic yard

By: MDP

Sample No.	5 Minute Test			24 Hour Test		
A	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	-10.5	0.597	23.382	-11.9	0.692	27.088
1/4" to 1/2"	1.8	0.349	13.647	2.0	0.371	14.528
1/2" to 3/4"	12.7	0.216	8.468	13.3	0.224	8.755
3/4" to 1"	8.1	0.265	10.357	8.8	0.274	10.711
1" to 1-1/4"	14.6	0.199	7.792	13.9	0.218	8.523
1-1/4" to 1-1/2"	11.0	0.233	9.122	9.3	0.268	10.474
1-1/2" to 1-3/4"	25.6	0.123	4.814	24.2	0.137	5.371
1-3/4" to 2"	34.8	0.082	3.218	34.4	0.087	3.400

Sample No.	5 Minute Test			24 Hour Test		
B	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	-1.6	0.405	15.837	-1.5	0.434	16.996
1/4" to 1/2"	-3.5	0.440	17.210	-4.1	0.488	19.096
1/2" to 3/4"	8.9	0.255	10.001	9.0	0.271	10.616
3/4" to 1"	11.3	0.230	9.003	11.2	0.246	9.619
1" to 1-1/4"	17.7	0.174	6.803	16.6	0.193	7.551
1-1/4" to 1-1/2"	18.5	0.168	6.569	17.2	0.188	7.351
1-1/2" to 1-3/4"	29.4	0.104	4.076	27.6	0.118	4.612
1-3/4" to 2"	44.1	0.055	2.142	41.5	0.063	2.474

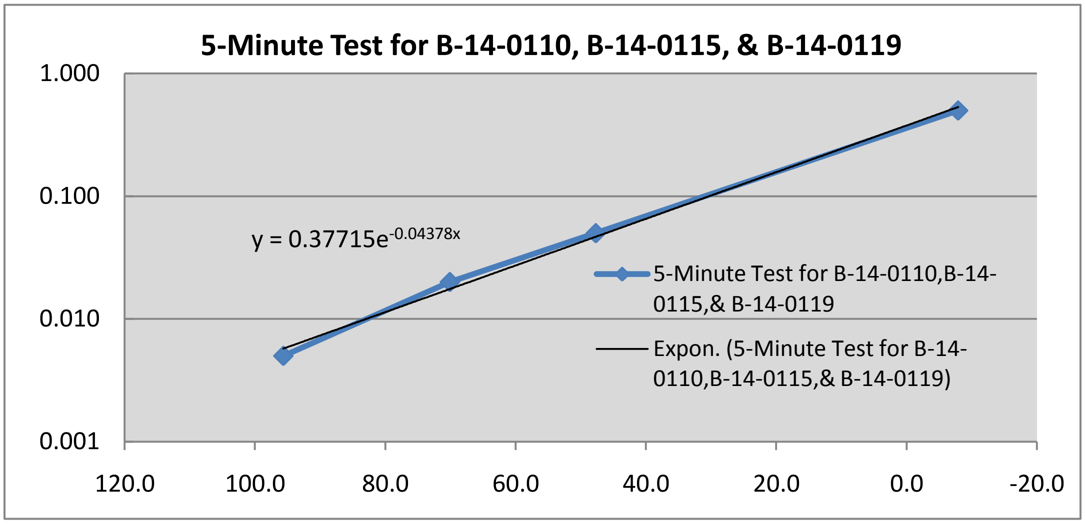
Sample No.	5 Minute Test			24 Hour Test		
C	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	3.8	0.319	12.502	3.5	0.347	13.584
1/4" to 1/2"	-9.4	0.569	22.283	-10.6	0.653	25.555
1/2" to 3/4"	6.7	0.281	11.012	6.1	0.309	12.089
3/4" to 1"	11.0	0.233	9.122	9.9	0.260	10.196
1" to 1-1/4"	17.4	0.176	6.893	15.0	0.207	8.113
1-1/4" to 1-1/2"	29.3	0.105	4.094	27.5	0.118	4.633
1-1/2" to 1-3/4"	39.5	0.067	2.619	36.6	0.079	3.081
1-3/4" to 2"	52.1	0.039	1.509	48.0	0.047	1.848

Sample No.	5 Minute Test			24 Hour Test		
D	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	-15.4	0.740	28.977	-15.8	0.824	32.262
1/4" to 1/2"	-1.7	0.406	15.906	-1.6	0.436	17.072
1/2" to 3/4"	-4.5	0.459	17.981	-4.9	0.506	19.793
3/4" to 1"	1.3	0.356	13.949	0.7	0.393	15.400
1" to 1-1/4"	16.1	0.186	7.297	15.5	0.203	7.933
1-1/4" to 1-1/2"	16.9	0.180	7.046	16.1	0.197	7.722
1-1/2" to 1-3/4"	18.8	0.166	6.483	17.9	0.182	7.124
1-3/4" to 2"	27.6	0.113	4.410	26.0	0.127	4.955

By: MDP

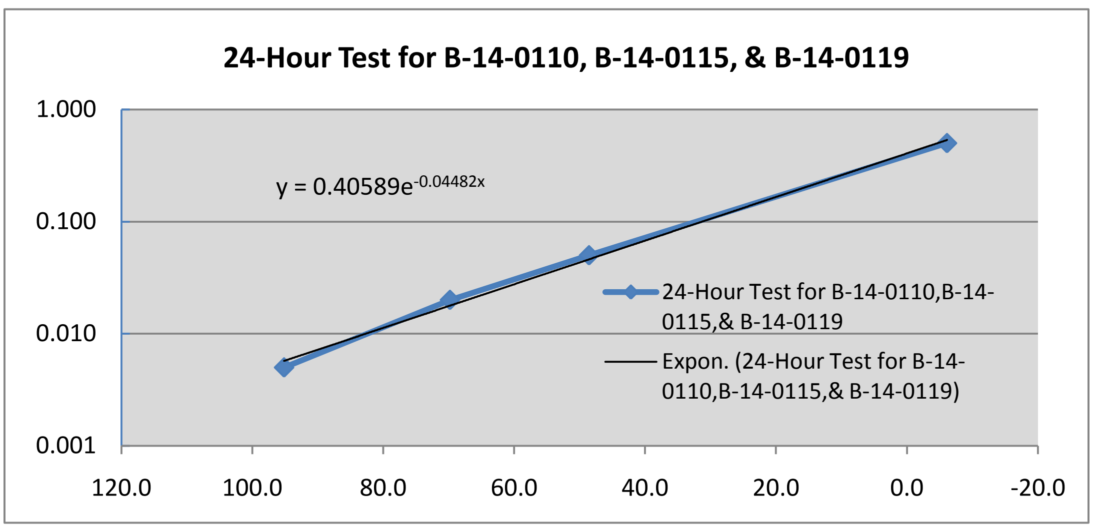
5-Minute Test for B-14-0110, B-14-0115, & B-14-0119

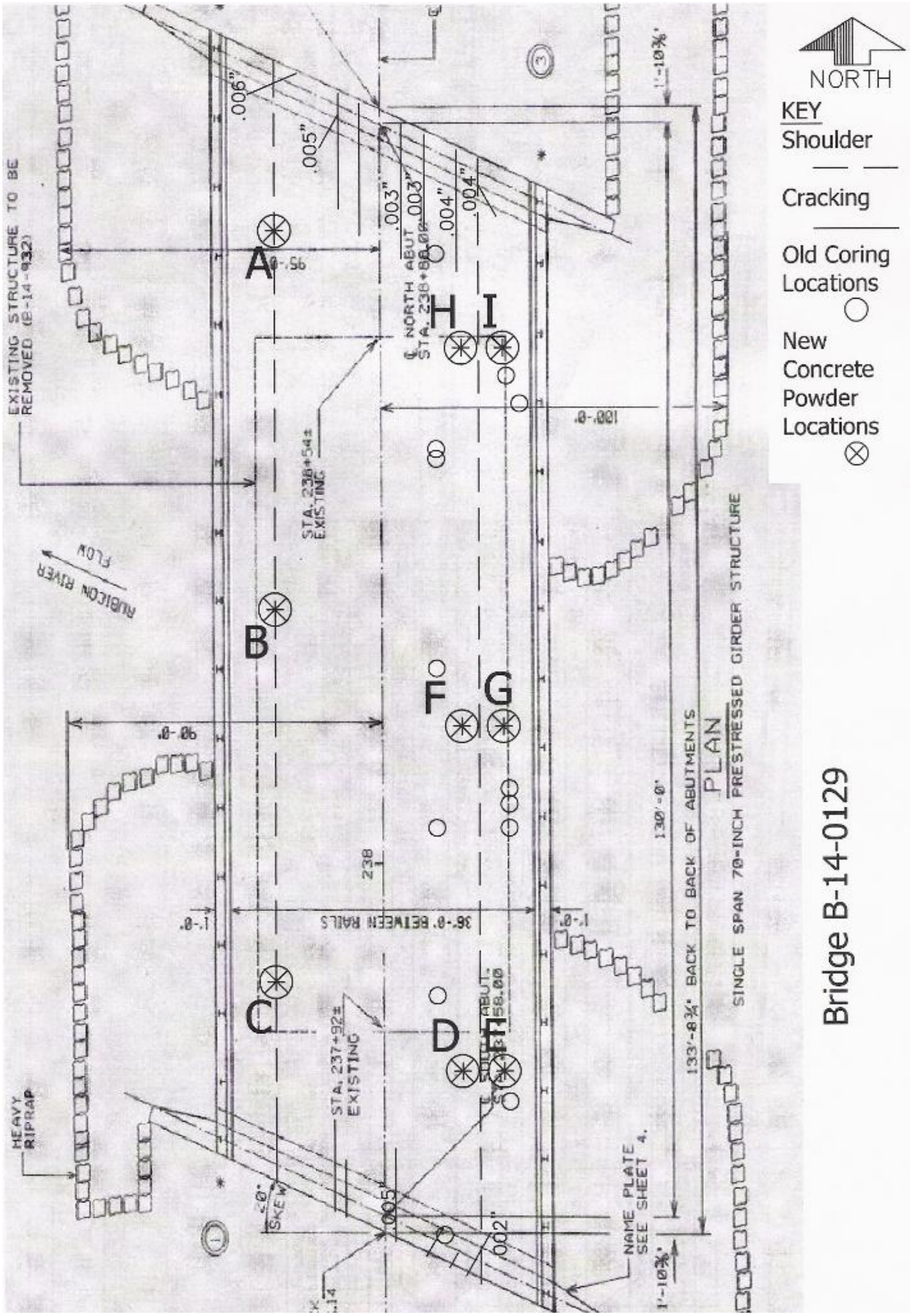
%Cl	0.005	0.020	0.050	0.500
mV before	95.8	69.2	46.9	-8.7
mV after	95.5	71.0	48.5	-7.1
mV average	95.7	70.1	47.7	-7.9



24-Hour Test for B-14-0110, B-14-0115, & B-14-0119

%Cl	0.005	0.020	0.050	0.500
mV before	94.6	69.4	48.0	-5.9
mV after	95.7	70.2	49.1	-6.4
mV average	95.2	69.8	48.6	-6.2




Bridge B-14-0129
NORTH
KEY
Shoulder
Cracking
Old Coring Locations
New Concrete Powder Locations
A
B
C
D
E
F
G
H
I
PLAN
SINGLE SPAN 70-INCH PRESTRESSED GIRDER STRUCTURE
133'-8¾" BACK TO BACK OF ABUTMENTS
130'-0"
36'-0" BETWEEN RAILS
EXISTING STRUCTURE TO BE REMOVED (B-14-932)
RUBICON RIVER FLOW
HEAVY RIPRAP
NAME PLATE SEE SHEET 4.
STA. 238+54± EXISTING
STA. 237+92± EXISTING
NORTH ABUT. STA. 238+80.00
20° SKEW
.006"
.005"
.003"
.004"
.002"

Liquid	Clear	Purple	Green	Pink
%CL	0.0	0.02	0.05	0.5
mV before	98.8	74.4	51.8	-3.9
mV after	99.8	73.2	51.7	-4.0
mV before	100.3	74.6	52.2	-3.8
mV after	98.1	71.6	49.6	-4.8

Bridge B-14-0129

Date:

5 Minute Test 11/17/2007

24 Hour Test 11/18/2007

Assumed weight of concrete = 145.0 lb/cubic yard

By: MDP

Sample No.	5 Minute Test			24 Hour Test		
A	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	-4.7	0.520	20.358	-6.8	0.560	21.924 [a]
1/4" to 1/2"	-3.9	0.500	19.575	-4.8	0.520	20.358
1/2" to 3/4"	5.3	0.340	13.311	2.8	0.365	14.290
3/4" to 1"	11.1	0.270	10.571	8.9	0.285	11.158
1" to 1-1/4"	19.9	0.185	7.243	17.3	0.200	7.830
1-1/4" to 1-1/2"	30.8	0.118	4.620	27.2	0.135	5.285
1-1/2" to 1-3/4"	50.5	0.053	2.075	46.7	0.060	2.349
1-3/4" to 2"	60.7	0.034	1.331	56.2	0.040	1.566

[a] 0.10g short

Sample No.	5 Minute Test			24 Hour Test		
B	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	6.5	0.325	12.724	4.4	0.340	13.311
1/4" to 1/2"	-0.6	0.435	17.030	-1.5	0.440	17.226
1/2" to 3/4"	4.0	0.360	14.094	0.8	0.395	15.464
3/4" to 1"	7.4	0.310	12.137	5.6	0.325	12.724
1" to 1-1/4"	15.3	0.225	8.809	14.0	0.230	9.005
1-1/4" to 1-1/2"	28.0	0.133	5.207	26.5	0.137	5.364
1-1/2" to 1-3/4"	37.4	0.090	3.524	33.9	0.100	3.915
1-3/4" to 2"	51.4	0.052	2.036	47.0	0.059	2.310

Sample No.	5 Minute Test			24 Hour Test		
C	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	-5.6	0.550	21.533	-7.9	0.580	22.707
1/4" to 1/2"	0.2	0.420	16.443	-1.7	0.440	17.226
1/2" to 3/4"	7.1	0.320	12.528	5.4	0.330	12.920
3/4" to 1"	16.1	0.220	8.613	12.3	0.247	9.670
1" to 1-1/4"	19.9	0.185	7.243	17.1	0.200	7.830
1-1/4" to 1-1/2"	26.1	0.145	5.677	22.2	0.162	6.342
1-1/2" to 1-3/4"	44.0	0.069	2.701	40.6	0.078	3.054
1-3/4" to 2"	61.3	0.034	1.331	58.2	0.037	1.449

Sample No.	5 Minute Test			24 Hour Test		
D	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	-0.2	0.420	16.443	-3.7	0.480	18.792
1/4" to 1/2"	1.9	0.390	15.269	-1.4	0.435	17.030
1/2" to 3/4"	8.6	0.300	11.745	3.9	0.350	13.703
3/4" to 1"	14.8	0.230	9.005	13.3	0.235	9.200
1" to 1-1/4"	22.3	0.170	6.656	19.2	0.185	7.243
1-1/4" to 1-1/2"	27.0	0.140	5.481	23.7	0.155	6.068
1-1/2" to 1-3/4"	44.3	0.069	2.701	42.7	0.071	2.780
1-3/4" to 2"	59.8	0.035	1.370	57.8	0.038	1.488

Bridge B-14-0129

By: MDP

Sample No.	5 Minute Test			24 Hour Test		
E	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	-5.8	0.540	21.141	-7.7	0.570	22.316
1/4" to 1/2"	-3.0	0.480	18.792	-4.2	0.500	19.575
1/2" to 3/4"	0.2	0.420	16.443	-1.9	0.450	17.618
3/4" to 1"	11.0	0.265	10.375	9.9	0.270	10.571
1" to 1-1/4"	18.4	0.200	7.830	15.1	0.221	8.652
1-1/4" to 1-1/2"	33.9	0.105	4.111	28.5	0.126	4.933
1-1/2" to 1-3/4"	39.4	0.084	3.289	37.9	0.086	3.367
1-3/4" to 2"	54.6	0.044	1.723	49.4	0.053	2.075

Sample No.	5 Minute Test			24 Hour Test		
F	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	4.6	0.345	13.507	3.8	0.355	13.898
1/4" to 1/2"	2.8	0.370	14.486	2.0	0.380	14.877
1/2" to 3/4"	12.2	0.255	9.983	11.1	0.260	10.179
3/4" to 1"	15.0	0.230	9.005	12.4	0.250	9.788
1" to 1-1/4"	17.8	0.205	8.026	16.1	0.210	8.222
1-1/4" to 1-1/2"	31.3	0.118	4.620	29.2	0.122	4.776
1-1/2" to 1-3/4"	43.6	0.070	2.741	41.1	0.075	2.936
1-3/4" to 2"	67.1	0.026	1.018	63.9	0.029	1.135

Sample No.	5 Minute Test			24 Hour Test		
G	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	-12.9	0.720	28.188	-14.9	0.780	30.537
1/4" to 1/2"	2.3	0.385	15.073	1.1	0.390	15.269
1/2" to 3/4"	2.4	0.380	14.877	1.0	0.390	15.269
3/4" to 1"	11.1	0.265	10.375	8.4	0.290	11.354
1" to 1-1/4"	26.0	0.145	5.677	23.6	0.155	6.068
1-1/4" to 1-1/2"	27.6	0.135	5.285	24.3	0.150	5.873
1-1/2" to 1-3/4"	40.5	0.080	3.132	36.7	0.090	3.524
1-3/4" to 2"	54.1	0.046	1.801	50.9	0.050	1.958

Sample No.	5 Minute Test			24 Hour Test		
H	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	-5.8	0.540	21.141	-7.6	0.570	22.316
1/4" to 1/2"	7.3	0.315	12.332	5.6	0.325	12.724
1/2" to 3/4"	8.8	0.295	11.549	6.4	0.315	12.332
3/4" to 1"	13.2	0.245	9.592	11.0	0.260	10.179
1" to 1-1/4"	26.2	0.145	5.677	22.0	0.167	6.538
1-1/4" to 1-1/2"	28.0	0.135	5.285	23.2	0.158	6.186
1-1/2" to 1-3/4"	38.0	0.088	3.445	34.0	0.100	3.915
1-3/4" to 2"	55.7	0.042	1.644	51.8	0.048	1.879

Sample No.	5 Minute Test			24 Hour Test			
I	mV	%CL	lb. Cl	mV	%CL	lb. Cl	
0" to 1/4"	9.1	0.290	11.354	7.2	0.300	11.745	[b] 0.22g short
1/4" to 1/2"	-	-	-	-	-	-	
1/2" to 3/4"	18.1	0.200	7.830	17.7	0.200	7.830	
3/4" to 1"	15.9	0.220	8.613	14.7	0.225	8.809	
1" to 1-1/4"	22.1	0.170	6.656	21.6	0.170	6.656	
1-1/4" to 1-1/2"	31.5	0.115	4.502	30.1	0.118	4.620	
1-1/2" to 1-3/4"	39.9	0.080	3.132	37.0	0.090	3.524	
1-3/4" to 2"	54.1	0.046	1.801	50.7	0.050	1.958	

Measurement of the acid soluble chloride content of hardened concrete by the RCT method

Report #: ______ **Structure:** Bridge B-14-0129 **Project:** 5 min-le test

Date of testing: 11/17/07 **Electrode #:** ______ **Person:** MDP

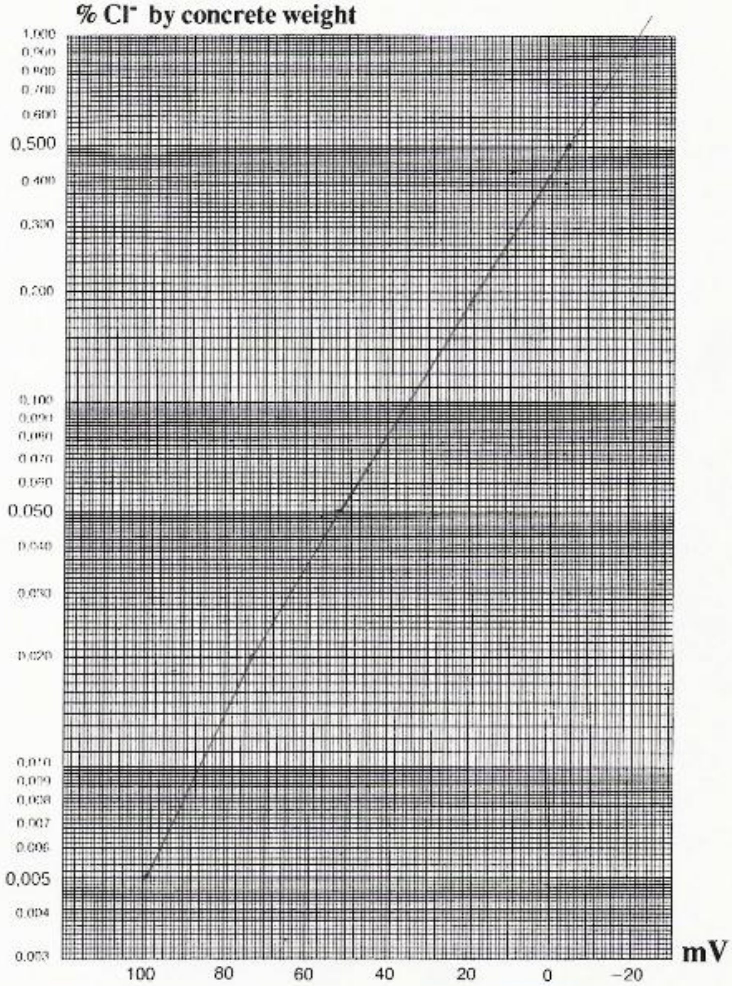
Testing Lab: UW/M **Address:** ______ **Phone:** ______

RCT

HARDENED CONCRETE

1.5 gram of concrete dust dissolved in a RCT-1023 vial with 10 milliliter of extraction liquid

% Cl⁻ by concrete weight



CALIBRATION:

Liquid	Clear	Purple	Green	Pink
% Cl	0.005	0.020	0.050	0.500
mV before	98.8 99.3	74.4 73.6	51.8 51.8	-3.9 -4.0
mV after	99.8	73.2	51.7	-4.0

SAMPLE #	1		2		Remarks
	mV	% Cl	mV	% Cl	

Measurement of the acid soluble chloride content of hardened concrete by the RCT method

Report #: ________ **Structure:** Bridge B-14-0129 **Project:** 24 hour test

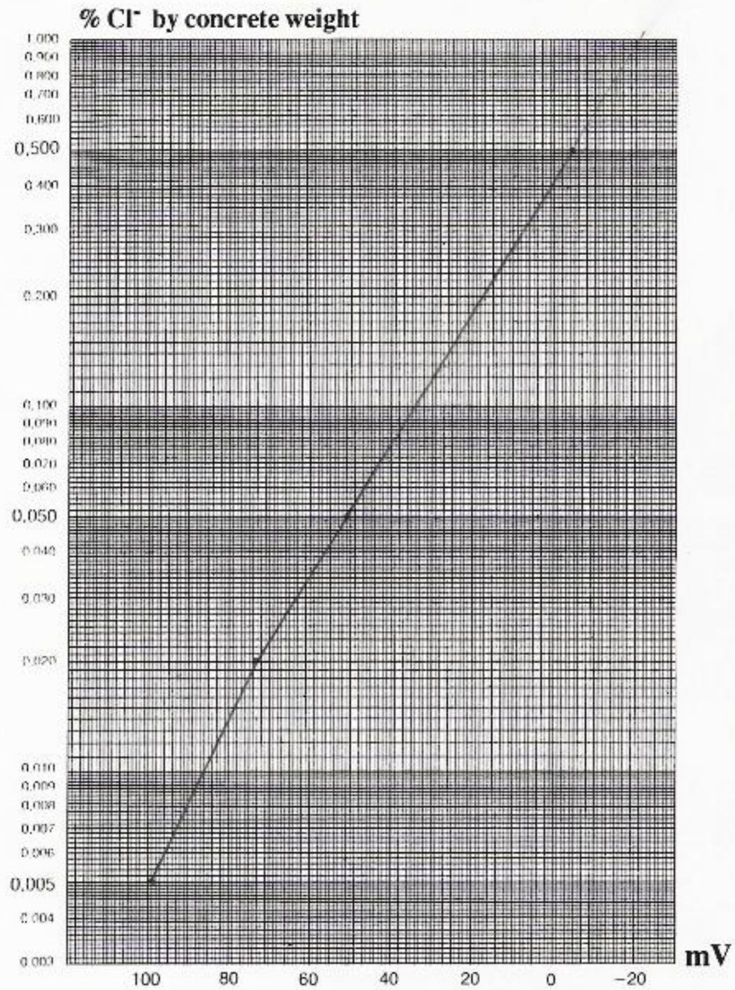
Date of testing: 11/18/07 **Electrode #:** ________ **Person:** MDP

Testing Lab: UWM **Address:** ________ **Phone:** ________

RCT

HARDENED CONCRETE

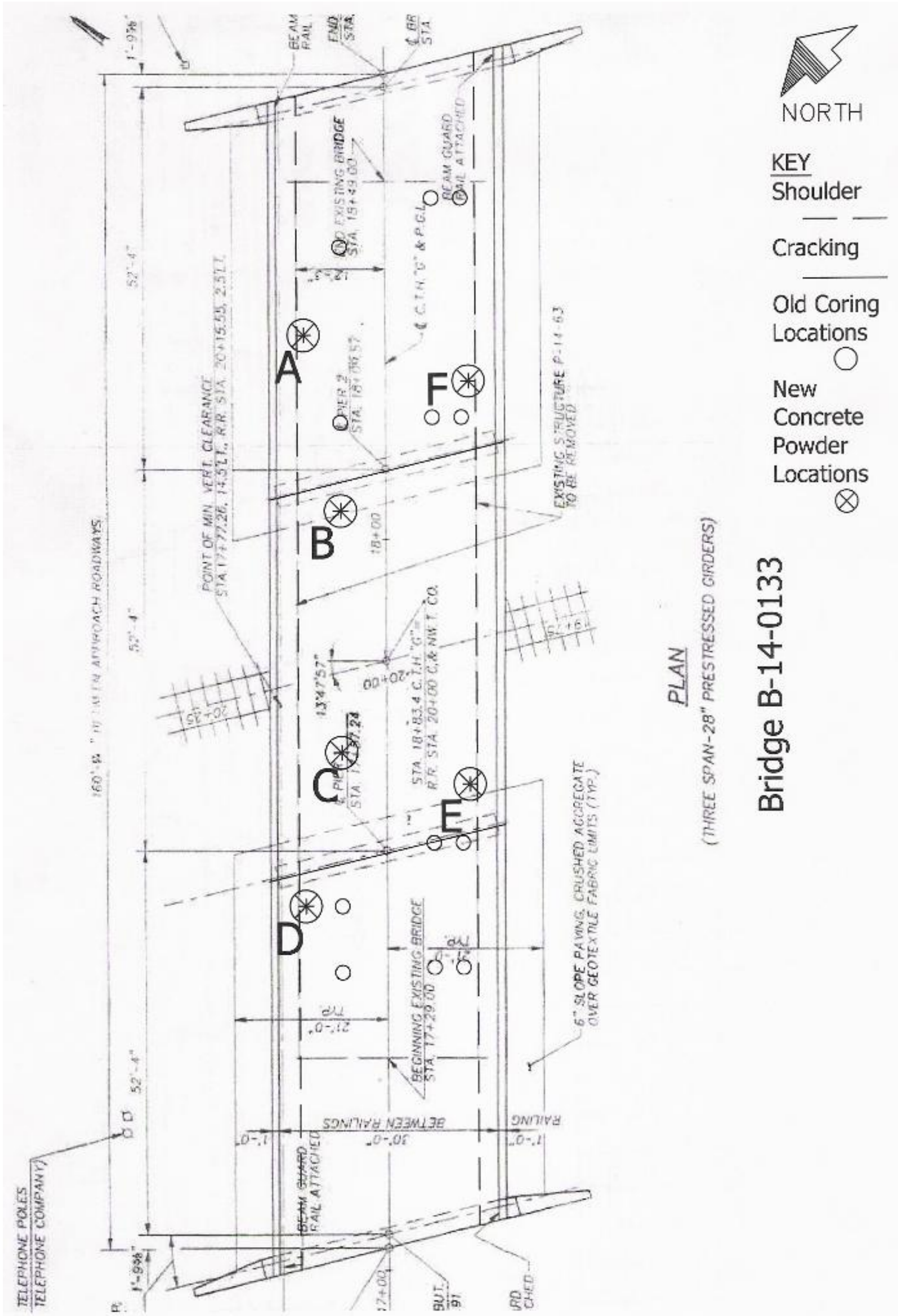
1.5 gram of concrete dust dissolved in a RCT-1023 vial with 10 milliliter of extraction liquid



CALIBRATION:

Liquid	Clear	Purple	Green	Pink
% Cl	0.005	0.020	0.050	0.500
mV before	100.3 99.2	74.6 73.1	52.2 50.9	-3.8 -4.3
mV after	98.1	71.6	49.6	-4.8

SAMPLE #	1		2		Remarks
	mV	% Cl	mV	% Cl	


NORTH
KEY
Shoulder
Cracking
Old Coring Locations
New Concrete Powder Locations
Bridge B-14-0133
PLAN
(THREE SPAN-28" PRESTRESSED GIRDERS)
A
B
C
D
E
F

Liquid	Clear	Purple	Green	Pink		
%CL	0.005	0.02	0.05	0.5		**Bridge B-14-0133**
mV before	95.6	70.9	49.0	-4.3		Date:
mV after	105.5	75.8	53.4	-3.7	5 Minute Test	11/6/2007
mV before	101.9	72.9	51.1	-4.3		
mV after	102.0	74.1	51.4	-4.1	24 Hour Test	11/7/2007

Assumed weight of concrete = 145.0 lb/cubic yard

By: MDP

Sample No.	5 Minute Test			24 Hour Test			
A	mV	%CL	lb. Cl	mV	%CL	lb. Cl	
0" to 1/4"	-14.5	0.780	30.537	-15.7	0.800	31.320	
1/4" to 1/2"	2.3	0.390	15.269	0.6	0.415	16.247	
1/2" to 3/4"	5.2	0.340	13.311	3.8	0.360	14.094	
3/4" to 1"	11.2	0.265	10.375	10.4	0.277	10.845	
1" to 1-1/4"	17.5	0.205	8.026	16.8	0.210	8.222	
1-1/4" to 1-1/2"	22.1	0.170	6.656	21.5	0.172	6.734	[a] 0.10g short
1-1/2" to 1-3/4"	30.5	0.120	4.698	29.0	0.125	4.894	
1-3/4" to 2"	31.8	0.110	4.307	31.1	0.115	4.502	

Sample No.	5 Minute Test			24 Hour Test		
B	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	-5.1	0.520	20.358	-6.0	0.540	21.141
1/4" to 1/2"	-6.9	0.560	21.924	-8.2	0.595	23.294
1/2" to 3/4"	0.4	0.420	16.443	-1.2	0.440	17.226
3/4" to 1"	4.1	0.360	14.094	1.1	0.400	15.660
1" to 1-1/4"	10.9	0.270	10.571	9.5	0.282	11.040
1-1/4" to 1-1/2"	9.1	0.290	11.354	8.1	0.295	11.549
1-1/2" to 1-3/4"	17.3	0.210	8.222	14.5	0.232	9.083
1-3/4" to 2"	16.9	0.210	8.222	15.0	0.227	8.887

Sample No.	5 Minute Test			24 Hour Test		
C	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	-10.9	0.660	25.839	-12.4	0.700	27.405
1/4" to 1/2"	4.1	0.360	14.094	1.2	0.390	15.269
1/2" to 3/4"	7.5	0.310	12.137	6.0	0.330	12.920
3/4" to 1"	5.9	0.330	12.920	4.5	0.350	13.703
1" to 1-1/4"	10.0	0.280	10.962	6.6	0.320	12.528
1-1/4" to 1-1/2"	19.9	0.190	7.439	18.4	0.195	7.634
1-1/2" to 1-3/4"	25.7	0.145	5.677	21.4	0.175	6.851
1-3/4" to 2"	35.9	0.094	3.680	35.5	0.096	3.758

Sample No.	5 Minute Test			24 Hour Test		
D	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	-3.8	0.500	19.575	-5.2	0.510	19.967
1/4" to 1/2"	2.4	0.390	15.269	1.8	0.450	17.618
1/2" to 3/4"	1.5	0.400	15.660	0.5	0.420	16.443
3/4" to 1"	6.0	0.330	12.920	3.8	0.360	14.094
1" to 1-1/4"	11.8	0.260	10.179	10.6	0.270	10.571
1-1/4" to 1-1/2"	17.5	0.205	8.026	16.9	0.210	8.222
1-1/2" to 1-3/4"	22.8	0.165	6.460	22.4	0.170	6.656
1-3/4" to 2"	28.3	0.130	5.090	27.1	0.135	5.285

Bridge B-14-0133

By: MDP

Sample No.	5 Minute Test			24 Hour Test		
E	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	7.6	0.300	11.745	5.8	0.330	12.920
1/4" to 1/2"	9.5	0.285	11.158	8.1	0.300	11.745
1/2" to 3/4"	14.4	0.235	9.200	13.3	0.240	9.396
3/4" to 1"	19.1	0.190	7.439	17.9	0.203	7.947
1" to 1-1/4"	19.3	0.190	7.439	18.0	0.200	7.830
1-1/4" to 1-1/2"	25.2	0.150	5.873	24.4	0.155	6.068
1-1/2" to 1-3/4"	25.6	0.140	5.481	23.2	0.160	6.264
1-3/4" to 2"	27.5	0.135	5.285	26.3	0.140	5.481

Sample No.	5 Minute Test			24 Hour Test		
F	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	-5.4	0.530	20.750	-6.0	0.540	21.141
1/4" to 1/2"	1.5	0.400	15.660	-0.1	0.420	16.443
1/2" to 3/4"	-0.2	0.430	16.835	-0.9	0.440	17.226
3/4" to 1"	5.4	0.340	13.311	4.4	0.350	13.703
1" to 1-1/4"	14.8	0.230	9.005	12.9	0.245	9.592
1-1/4" to 1-1/2"	24.8	0.150	5.873	25.2	0.150	5.873
1-1/2" to 1-3/4"	21.5	0.170	6.656	21.3	0.175	6.851
1-3/4" to 2"	22.2	0.170	6.656	21.9	0.170	6.656

Measurement of the acid soluble chloride content of hardened concrete by the RCT method

Report #: WHRP **Structure:** Bridge B-14-0133 **Project:** 5 minute test

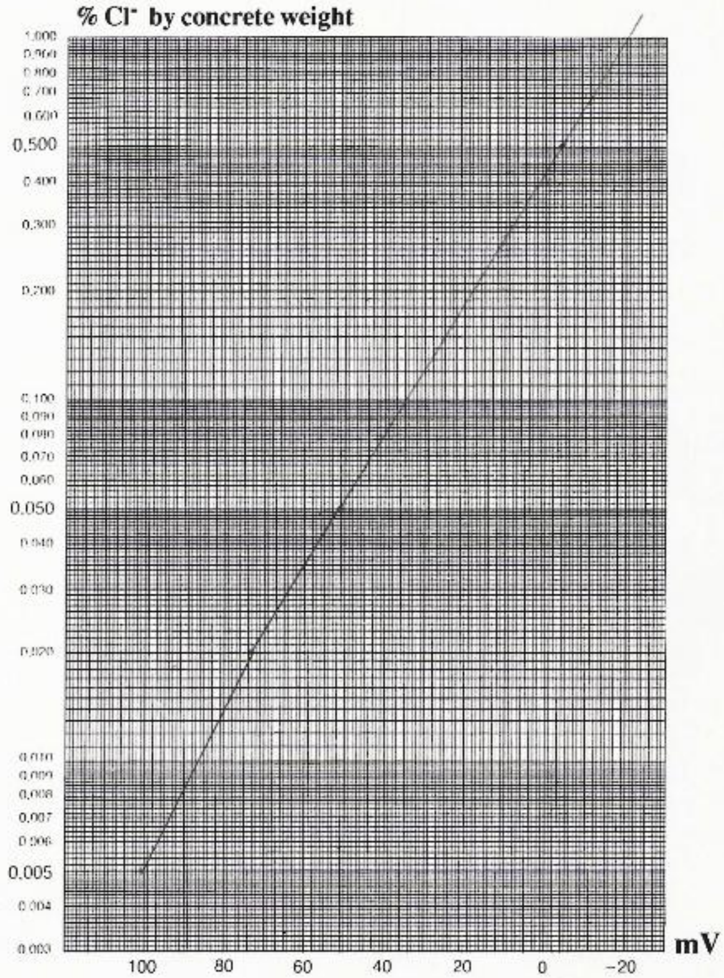
Date of testing: 11/6/07 **Electrode #:** ______ **Person:** MDP

Testing Lab: UWM **Address:** ______ **Phone:** ______

RCT

HARDENED CONCRETE

1.5 gram of concrete dust dissolved in a RCT-1023 vial with 10 milliliter of extraction liquid



CALIBRATION:

Liquid	Clear	Purple	Green	Pink
% Cl	0.005	0.020	0.050	0.500
mV before	95.6	70.9	49.0	-4.3
	100.6	73.4	51.2	-4.0
mV after	105.5	75.8	53.4	-3.7

SAMPLE #	1		2		Remarks
	mV	% Cl	mV	% Cl	

Measurement of the acid soluble chloride content of hardened concrete by the RCT method

Report #: WHRP **Structure:** Bridge B-14-0133 **Project:** 24 Hour Test

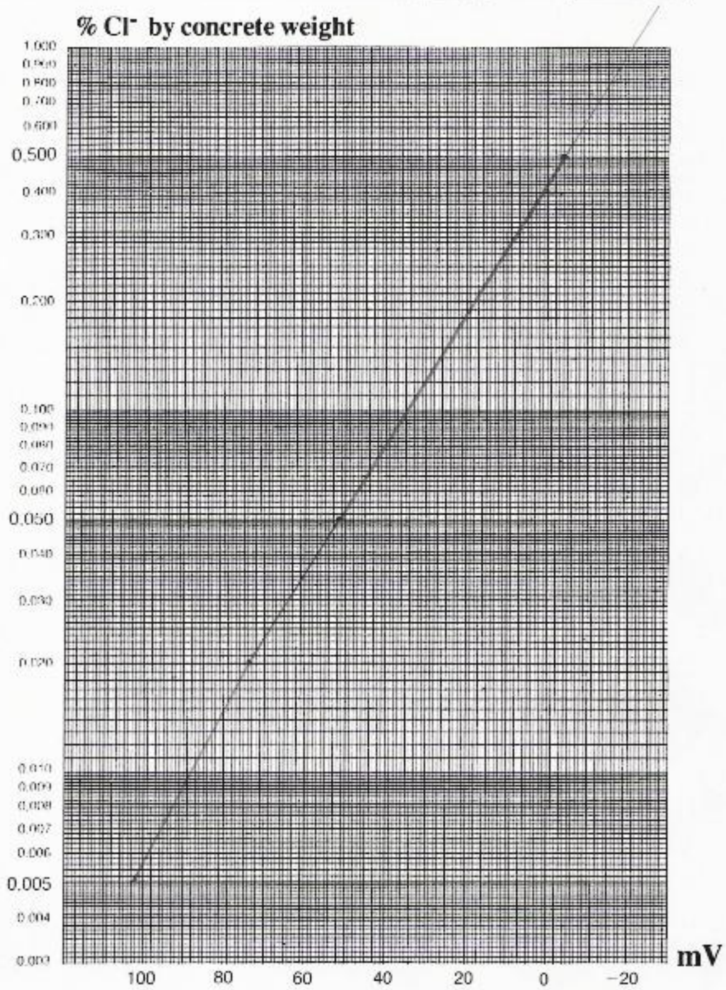
Date of testing: 11/7/07 **Electrode #:** ______ **Person:** MDP

Testing Lab: UW/M **Address:** ______ **Phone:** ______

RCT

HARDENED CONCRETE

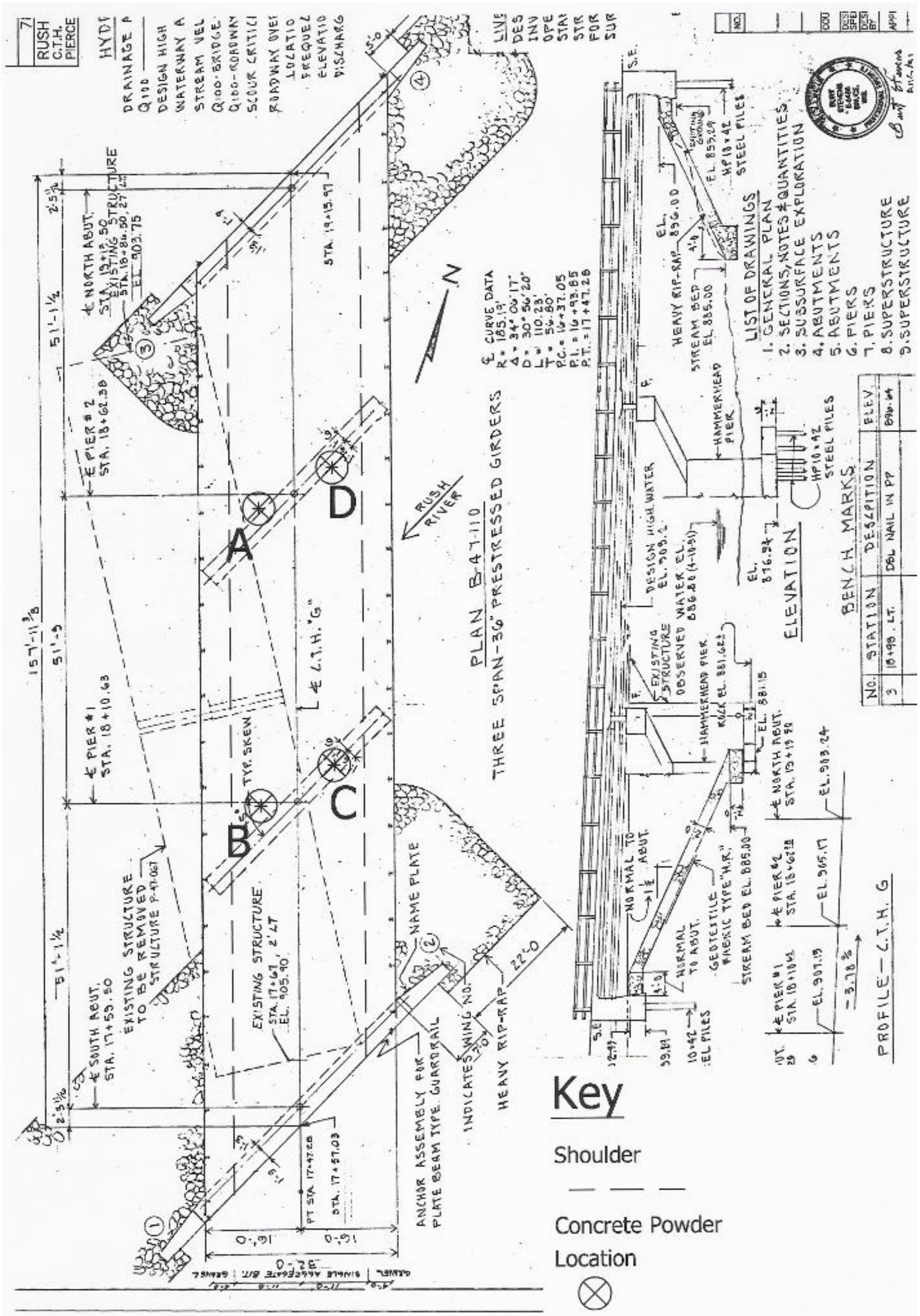
1.5 gram of concrete dust dissolved in a RCT-1023 vial with 10 milliliter of extraction liquid



CALIBRATION:

Liquid	Clear	Purple	Green	Pink
% Cl	0.005	0.020	0.050	0.500
mV before	101.9	72.9	51.1	−4.3
mV after	102.0	74.1	51.4	−4.1

SAMPLE #	1		2		Remarks
	mV	% Cl	mV	% Cl	


A
B
C
D
PLAN B-47-110
THREE SPAN-36" PRESTRESSED GIRDERS
RUSH RIVER
ELEVATION
PROFILE – C.T.H. G
Key
Shoulder
Concrete Powder
Location

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.020	0.050	0.500
mV before	99.9	72.3	48.3	-7.6
mV after	96.7	71.3	48.7	-7.4
mV before	93.4	71.8	49.0	-5.6
mV after	94.6	71.6	50.8	-4.2

Bridge B-47-0110

Date:

5 Minute Test 8/4/2008

24 Hour Test 8/7/2008

Assumed weight of concrete = 145.0 lb/cubic yard

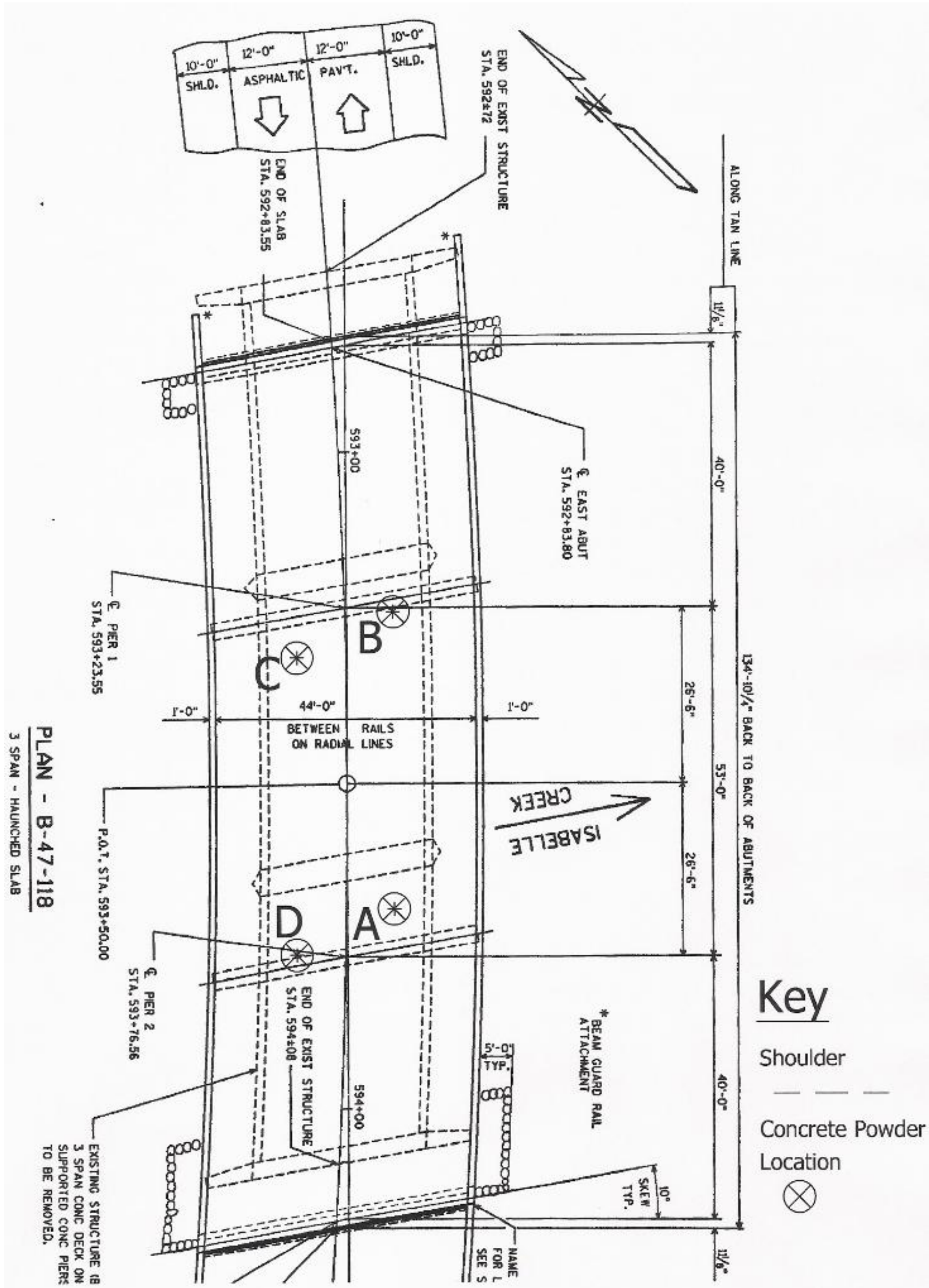
By: MDP

Sample No.	5 Minute Test			24 Hour Test		
A	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	7.4	0.278	10.902	9.1	0.288	11.288
1/4" to 1/2"	2.3	0.347	13.567	3.8	0.367	14.364
1/2" to 3/4"	8.5	0.266	10.399	9.2	0.287	11.237
3/4" to 1"	6.0	0.296	11.577	6.7	0.322	12.590
1" to 1-1/4"	17.9	0.177	6.949	18.3	0.190	7.430
1-1/4" to 1-1/2"	24.5	0.134	5.236	25.9	0.134	5.259
1-1/2" to 1-3/4"	23.3	0.141	5.512	22.6	0.156	6.111
1-3/4" to 2"	23.0	0.143	5.584	22.1	0.160	6.251

Sample No.	5 Minute Test			24 Hour Test		
B	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	21.7	0.151	5.904	22.5	0.157	6.139
1/4" to 1/2"	1.4	0.360	14.101	2.3	0.393	15.377
1/2" to 3/4"	3.5	0.329	12.887	4.1	0.362	14.169
3/4" to 1"	8.1	0.270	10.579	8.6	0.295	11.548
1" to 1-1/4"	15.7	0.195	7.637	16.2	0.209	8.174
1-1/4" to 1-1/2"	16.0	0.193	7.539	15.8	0.213	8.324
1-1/2" to 1-3/4"	20.8	0.157	6.136	20.9	0.169	6.602
1-3/4" to 2"	23.2	0.141	5.536	23.8	0.148	5.786

Sample No.	5 Minute Test			24 Hour Test		
C	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	2.6	0.342	13.394	1.8	0.402	15.731
1/4" to 1/2"	-6.1	0.497	19.452	-5.4	0.557	21.822
1/2" to 3/4"	-3.8	0.450	17.625	-2.6	0.491	19.214
3/4" to 1"	2.5	0.344	13.452	3.0	0.380	14.896
1" to 1-1/4"	9.1	0.259	10.135	9.4	0.284	11.135
1-1/4" to 1-1/2"	16.4	0.189	7.411	16.8	0.203	7.954
1-1/2" to 1-3/4"	23.5	0.140	5.465	23.1	0.153	5.973
1-3/4" to 2"	16.0	0.193	7.539	15.4	0.217	8.477

Sample No.	5 Minute Test			24 Hour Test		
D	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	5.5	0.302	11.827	7.2	0.314	12.307
1/4" to 1/2"	-1.2	0.403	15.765	0.1	0.434	16.995
1/2" to 3/4"	12.1	0.228	8.912	14.1	0.230	8.993
3/4" to 1"	14.5	0.205	8.040	15.1	0.220	8.593
1" to 1-1/4"	12.0	0.229	8.950	11.9	0.254	9.939
1-1/4" to 1-1/2"	14.7	0.204	7.971	15.2	0.219	8.554
1-1/2" to 1-3/4"	20.3	0.160	6.269	19.7	0.178	6.972
1-3/4" to 2"	21.5	0.152	5.955	20.8	0.169	6.632


PLAN - B-47-118
3 SPAN - HAUNCHED SLAB
ALONG TAN LINE
134'-10¼" BACK TO BACK OF ABUTMENTS
END OF EXIST STRUCTURE
STA. 592±72
END OF SLAB
STA. 592+83.55
℄ EAST ABUT
STA. 592+83.80
℄ PIER 1
STA. 593+23.55
P.O.T. STA. 593+50.00
℄ PIER 2
STA. 593+76.56
END OF EXIST STRUCTURE
STA. 594±08
44'-0"
BETWEEN RAILS
ON RADIAL LINES
ISABELLE CREEK
BEAM GUARD RAIL ATTACHMENT
EXISTING STRUCTURE
3 SPAN CONC DECK ON
SUPPORTED CONC PIERS
TO BE REMOVED.
SHLD.
ASPHALTIC
PAV'T.
A
B
C
D
Key
Shoulder
Concrete Powder
Location

Bridge B-47-0118

Date:

5 Minute Test 8/4/2008

24 Hour Test 8/7/2008

By: MDP

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.020	0.050	0.500
mV before	99.9	72.3	48.3	-7.6
mV after	96.7	71.3	48.7	-7.4
mV before	93.4	71.8	49.0	-5.6
mV after	94.6	71.6	50.8	-4.2

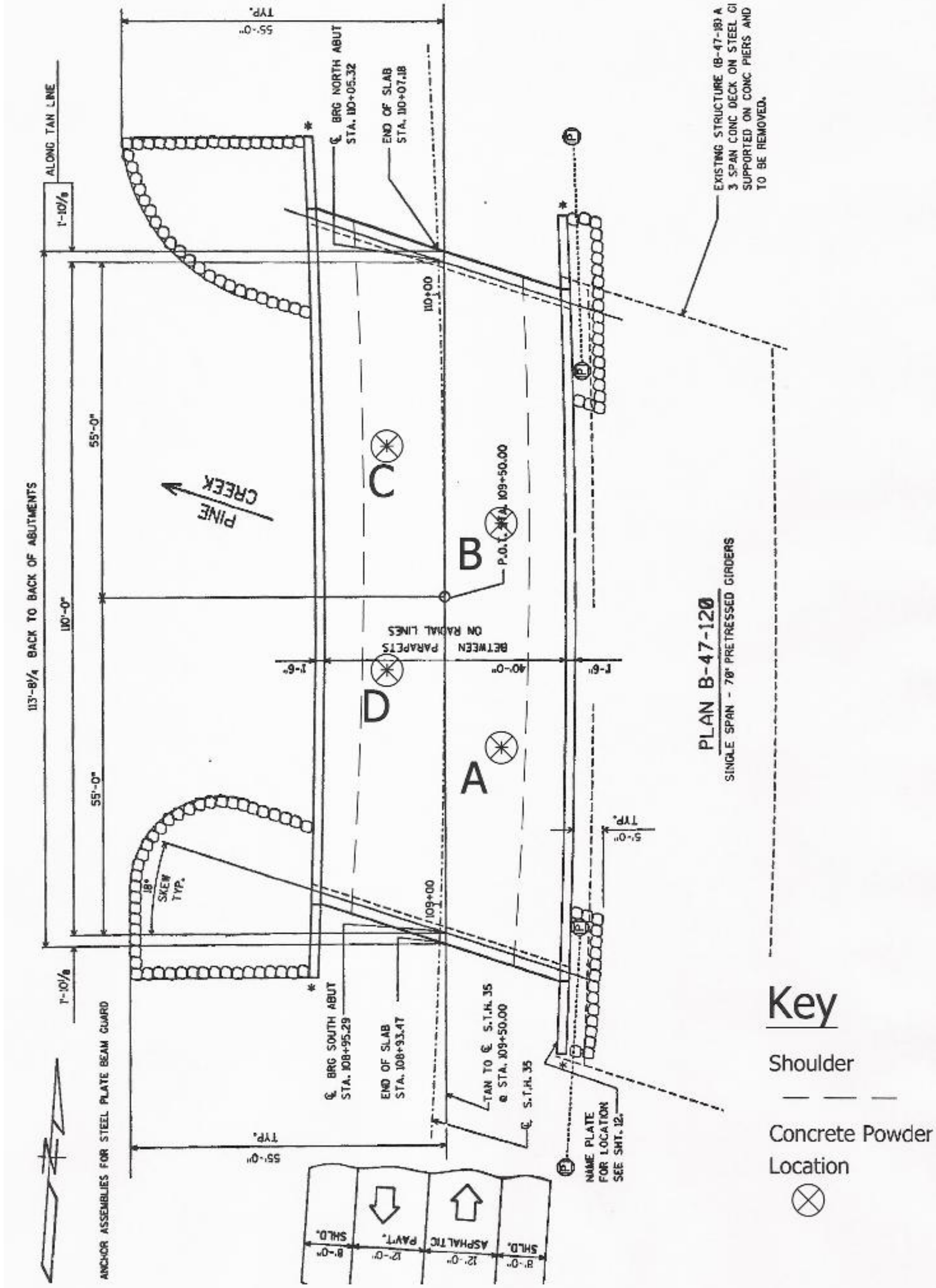
Assumed weight of concrete = 145.0 lb/cubic yard

Sample No.	5 Minute Test			24 Hour Test		
A	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	5.3	0.305	11.929	6.2	0.329	12.879
1/4" to 1/2"	8.0	0.271	10.625	9.6	0.282	11.035
1/2" to 3/4"	2.2	0.348	13.626	2.7	0.386	15.100
3/4" to 1"	7.5	0.277	10.855	7.6	0.309	12.085
1" to 1-1/4"	13.7	0.213	8.321	13.0	0.241	9.454
1-1/4" to 1-1/2"	21.2	0.154	6.032	21.4	0.165	6.453
1-1/2" to 1-3/4"	37.6	0.076	2.985	38.8	0.075	2.926
1-3/4" to 2"	26.0	0.125	4.910	24.9	0.141	5.504

Sample No.	5 Minute Test			24 Hour Test		
B	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	8.5	0.266	10.399	9.4	0.284	11.135
1/4" to 1/2"	-2.0	0.417	16.315	-1.7	0.471	18.444
1/2" to 3/4"	2.0	0.351	13.743	2.9	0.382	14.964
3/4" to 1"	11.6	0.233	9.105	12.8	0.244	9.541
1" to 1-1/4"	9.7	0.252	9.878	10.2	0.274	10.738
1-1/4" to 1-1/2"	16.3	0.190	7.443	16.0	0.211	8.249
1-1/2" to 1-3/4"	20.9	0.156	6.110	21.3	0.166	6.483
1-3/4" to 2"	36.5	0.080	3.129	36.1	0.084	3.308

Sample No.	5 Minute Test			24 Hour Test		
C	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	-4.4	0.462	18.084	-4.2	0.528	20.664
1/4" to 1/2"	-6.9	0.514	20.131	-6.3	0.581	22.734
1/2" to 3/4"	-5.1	0.476	18.635	-3.8	0.518	20.291
3/4" to 1"	-2.9	0.433	16.957	-1.6	0.469	18.360
1" to 1-1/4"	3.9	0.324	12.668	4.1	0.362	14.169
1-1/4" to 1-1/2"	4.7	0.313	12.240	5.0	0.347	13.601
1-1/2" to 1-3/4"	0.0	0.382	14.974	0.7	0.422	16.537
1-3/4" to 2"	10.2	0.247	9.668	10.4	0.272	10.640

Sample No.	5 Minute Test			24 Hour Test		
D	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	-3.5	0.444	17.399	-2.2	0.482	18.868
1/4" to 1/2"	-3.4	0.443	17.325	-2.6	0.491	19.214
1/2" to 3/4"	0.2	0.379	14.846	0.9	0.419	16.388
3/4" to 1"	10.1	0.248	9.710	11.1	0.263	10.307
1" to 1-1/4"	11.4	0.235	9.183	11.8	0.255	9.984
1-1/4" to 1-1/2"	12.5	0.224	8.760	13.0	0.241	9.454
1-1/2" to 1-3/4"	13.1	0.218	8.537	13.7	0.234	9.158
1-3/4" to 2"	21.0	0.155	6.084	20.3	0.173	6.784



PLAN B-47-120
SINGLE SPAN - 70" PRETRESSED GIRDERS
PINE CREEK
A
B
C
D
Key
Shoulder
Concrete Powder Location

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.020	0.050	0.500
mV before	99.9	72.3	48.3	-7.6
mV after	96.7	71.3	48.7	-7.4
mV before	93.4	71.8	49.0	-5.6
mV after	94.6	71.6	50.8	-4.2

Bridge B-47-0120

Date:

5 Minute Test 8/4/2008

24 Hour Test 8/7/2008

Assumed weight of concrete = 145.0 lb/cubic yard

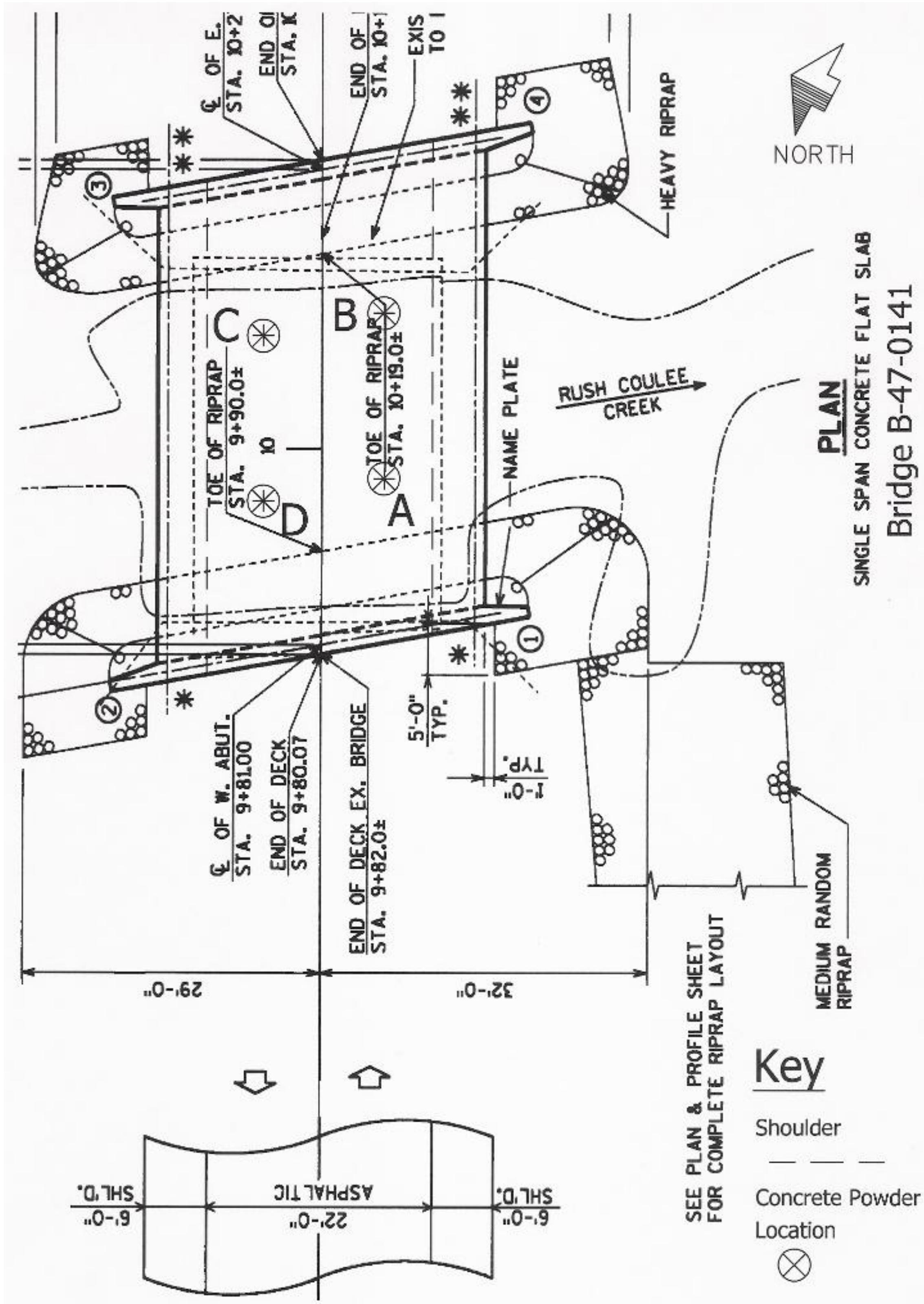
By: MDP

Sample No.	5 Minute Test			24 Hour Test		
A	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	3.7	0.326	12.777	5.2	0.344	13.478
1/4" to 1/2"	-5.4	0.482	18.877	-4.9	0.545	21.332
1/2" to 3/4"	-3.5	0.444	17.399	-1.7	0.471	18.444
3/4" to 1"	0.1	0.381	14.910	1.8	0.402	15.731
1" to 1-1/4"	-7.9	0.537	21.013	-7.4	0.610	23.899
1-1/4" to 1-1/2"	3.4	0.331	12.942	5.1	0.346	13.539
1-1/2" to 1-3/4"	2.8	0.339	13.280	2.5	0.389	15.238
1-3/4" to 2"	2.4	0.345	13.509	3.1	0.379	14.828

Sample No.	5 Minute Test			24 Hour Test		
B	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	-0.7	0.394	15.430	-0.4	0.444	17.385
1/4" to 1/2"	1.0	0.366	14.345	2.1	0.396	15.518
1/2" to 3/4"	10.1	0.248	9.710	10.8	0.267	10.449
3/4" to 1"	7.5	0.277	10.855	8.0	0.303	11.867
1" to 1-1/4"	11.9	0.230	8.988	14.3	0.228	8.912
1-1/4" to 1-1/2"	19.9	0.163	6.378	20.6	0.171	6.692
1-1/2" to 1-3/4"	21.1	0.155	6.058	21.5	0.164	6.424
1-3/4" to 2"	20.7	0.157	6.163	20.8	0.169	6.632

Sample No.	5 Minute Test			24 Hour Test		
C	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	0.9	0.368	14.407	2.3	0.393	15.377
1/4" to 1/2"	-11.1	0.616	24.105	-10.7	0.709	27.768
1/2" to 3/4"	-5.7	0.488	19.121	-5.4	0.557	21.822
3/4" to 1"	-3.4	0.443	17.325	-3.5	0.511	20.017
1" to 1-1/4"	1.5	0.359	14.041	2.0	0.398	15.588
1-1/4" to 1-1/2"	2.7	0.341	13.337	3.3	0.375	14.694
1-1/2" to 1-3/4"	11.0	0.239	9.342	11.8	0.255	9.984
1-3/4" to 2"	10.3	0.246	9.627	11.1	0.263	10.307

Sample No.	5 Minute Test			24 Hour Test		
D	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	-9.1	0.565	22.123	-7.7	0.619	24.228
1/4" to 1/2"	-14.2	0.703	27.532	-13.6	0.809	31.681
1/2" to 3/4"	-8.2	0.544	21.285	-7.5	0.613	24.008
3/4" to 1"	-6.6	0.508	19.874	-5.7	0.565	22.122
1" to 1-1/4"	-2.7	0.429	16.813	-2.4	0.486	19.040
1-1/4" to 1-1/2"	2.4	0.345	13.509	3.5	0.372	14.561
1-1/2" to 1-3/4"	-1.7	0.411	16.107	-1.2	0.461	18.029
1-3/4" to 2"	4.1	0.321	12.559	4.9	0.349	13.663


PLAN
SINGLE SPAN CONCRETE FLAT SLAB
Bridge B-47-0141
NORTH
HEAVY RIPRAP
MEDIUM RANDOM RIPRAP
RUSH COULEE CREEK
NAME PLATE
TOE OF RIPRAP STA. 9+90.0±
TOE OF RIPRAP STA. 10+19.0±
A
B
C
D
℄ OF W. ABUT. STA. 9+81.00
END OF DECK STA. 9+80.07
END OF DECK EX. BRIDGE STA. 9+82.0±
5'-0" TYP.
1'-0" TYP.
29'-0"
32'-0"
6'-0" SHL'D.
22'-0" ASPHALTIC
6'-0" SHL'D.
SEE PLAN & PROFILE SHEET FOR COMPLETE RIPRAP LAYOUT
Key
Shoulder
Concrete Powder Location

Liquid	Clear	Purple	Green	Pink
%CL	0.005	0.020	0.050	0.500
mV before	99.9	72.3	48.3	-7.6
mV after	96.7	71.3	48.7	-7.4
mV before	93.4	71.8	49.0	-5.6
mV after	94.6	71.6	50.8	-4.2

Bridge B-47-0141

Date:

5 Minute Test 8/4/2008

24 Hour Test 8/7/2008

Assumed weight of concrete = 145.0 lb/cubic yard

By: MDP

Sample No.	5 Minute Test			24 Hour Test		
A	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	-3.8	0.450	17.625	-3.5	0.511	20.017
1/4" to 1/2"	0.2	0.379	14.846	0.7	0.422	16.537
1/2" to 3/4"	-0.9	0.398	15.563	-1.2	0.461	18.029
3/4" to 1"	2.6	0.342	13.394	2.8	0.384	15.032
1" to 1-1/4"	8.3	0.268	10.489	7.7	0.307	12.030
1-1/4" to 1-1/2"	18.0	0.177	6.919	18.3	0.190	7.430
1-1/2" to 1-3/4"	35.8	0.082	3.225	36.6	0.083	3.234
1-3/4" to 2"	39.6	0.070	2.740	40.0	0.071	2.771

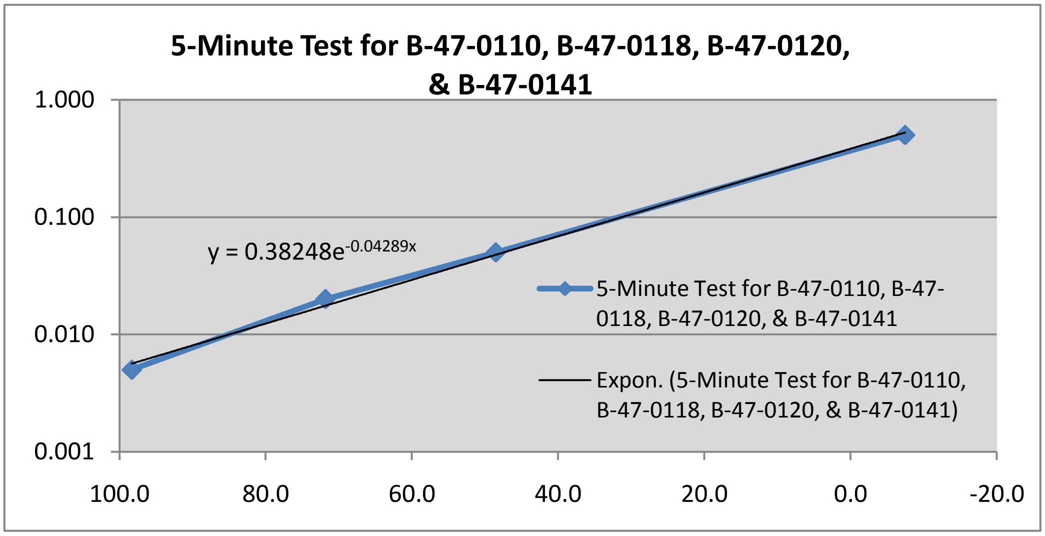
Sample No.	5 Minute Test			24 Hour Test		
B	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	19.7	0.164	6.433	20.5	0.172	6.723
1/4" to 1/2"	4.1	0.321	12.559	4.2	0.360	14.105
1/2" to 3/4"	18.0	0.177	6.919	18.7	0.186	7.296
3/4" to 1"	17.3	0.182	7.130	18.2	0.191	7.464
1" to 1-1/4"	17.3	0.182	7.130	17.6	0.196	7.670
1-1/4" to 1-1/2"	22.7	0.144	5.656	23.3	0.151	5.919
1-1/2" to 1-3/4"	29.9	0.106	4.153	29.2	0.116	4.527
1-3/4" to 2"	33.5	0.091	3.559	32.5	0.100	3.896

Sample No.	5 Minute Test			24 Hour Test		
C	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	2.9	0.338	13.223	3.4	0.374	14.627
1/4" to 1/2"	5.0	0.309	12.084	5.7	0.337	13.175
1/2" to 3/4"	10.3	0.246	9.627	10.8	0.267	10.449
3/4" to 1"	16.9	0.185	7.253	17.6	0.196	7.670
1" to 1-1/4"	16.5	0.188	7.379	16.1	0.210	8.212
1-1/4" to 1-1/2"	22.7	0.144	5.656	22.3	0.158	6.195
1-1/2" to 1-3/4"	32.5	0.095	3.715	33.2	0.096	3.774
1-3/4" to 2"	38.8	0.072	2.835	37.0	0.081	3.175

Sample No.	5 Minute Test			24 Hour Test		
D	mV	%CL	lb. Cl	mV	%CL	lb. Cl
0" to 1/4"	17.5	0.181	7.069	17.7	0.195	7.635
1/4" to 1/2"	13.4	0.215	8.428	13.6	0.235	9.200
1/2" to 3/4"	14.1	0.209	8.179	14.3	0.228	8.912
3/4" to 1"	15.0	0.201	7.869	14.8	0.223	8.711
1" to 1-1/4"	27.9	0.116	4.525	28.2	0.121	4.737
1-1/4" to 1-1/2"	33.8	0.090	3.514	34.6	0.090	3.541
1-1/2" to 1-3/4"	39.1	0.071	2.799	37.4	0.080	3.118
1-3/4" to 2"	55.2	0.036	1.403	54.1	0.037	1.459

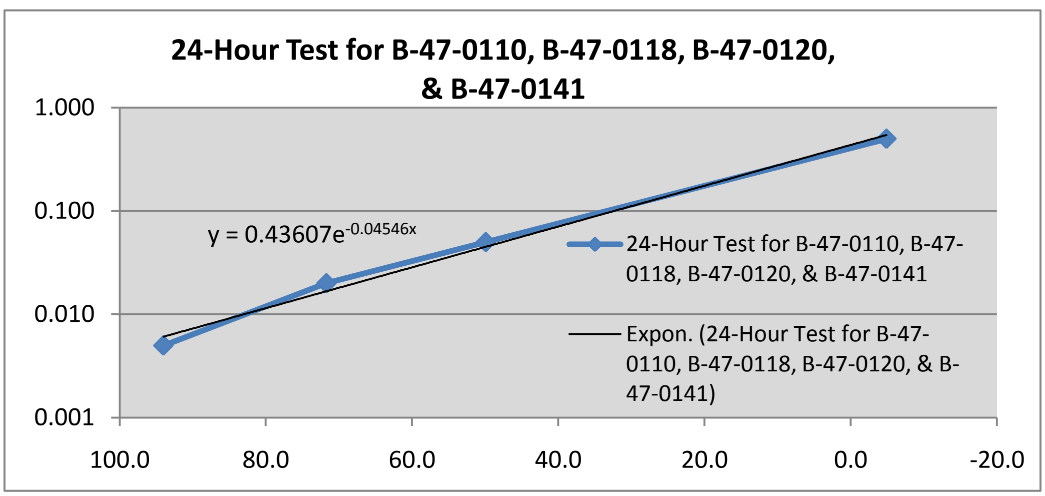
5-Minute Test for B-47-0110, B-47-0118, B-47-0120, & B-47-0141

%Cl	0.005	0.020	0.050	0.500
mV before	99.9	72.3	48.3	-7.6
mV after	96.7	71.3	48.7	-7.4
mV average	98.3	71.8	48.5	-7.5



24-Hour Test for B-47-0110, B-47-0118, B-47-0120, & B-47-0141

%Cl	0.005	0.020	0.050	0.500
mV before	93.4	71.8	49.0	-5.6
mV after	94.6	71.6	50.8	-4.2
mV average	94.0	71.7	49.9	-4.9



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IMPLEMENTATION PLAN

WisDOT Research	**Wisconsin Department of Transportation**	**Nina McLawhorn, Research Administrator**
	4802 Sheboygan Ave., Rm. 451	**Ann Pahnke, Program Analyst**
	P.O. Box 7965	**Linda Keegan, Program Analyst**
	Madison, WI 53707-7965	**Louis Bearden, Program Analyst**
	www.dot.state.wi.us/dtid/research	**Pat Casey, Communications Consultant**

Implementation of Research Results

Project Information	
Project Title:	**Project ID:** **Today's Date:**
Technical Oversight Committee (WHRP or COR):	**TOC Chair and Phone number:**
Project Start Date:	**Approved Contract Amount:**
Project End Date:	**Final Project Expenditures:**
Reference Final Report Draft Dated:	
Principal Investigator: **Organization:**	**Phone:** **E-Mail:**

Technical Oversight Committee Recommendations	
1. Check one of the two choices below: ☐ **Yes. We recommend changes to current practice based on <u>some or all</u> of the results of this report. The research was sound, and the report's conclusions appear to offer an advance over current practice.** ☐ **No. We do not recommend changes to current practice at this time. This approach does not appear fruitful OR future study is needed OR our objectives have changed, etc.**	
2. If implementation <u>is not recommended</u>, we suggest the following actions instead:	
3. If implementation <u>is recommended,</u> we suggest the following <u>specific</u> changes to current practice, detailed on the <u>attached work plan and timeline</u> (check applicable items): ☐ **Standard Specifications** ☐ **Quality Management Program (QMP) Specifications** ☐ **Facilities Development Manual (FDM)** ☐ **Highway Maintenance Manual** ☐ **Training, outreach** ☐ **Other (describe):**	
4. Approval of this implementation plan by the Technical Oversight Committee (chair on behalf of entire committee):	**Signature:** **Date:**
5. Approval of this implementation plan by the Council on Research (for COR approved projects):	**Signature(s):** **Date:**

6. Referral for development of detailed work plan and timeline to (check one):	☐ **WisDOT/Industry Technical Committee on:** ____ ☐ **Other WisDOT policy body:** ____
7. Approval of work plan and timeline by the WisDOT Bureau Director(s) responsible for the policies described in item #3 above:	**Signature(s):** **Date**
8. Acceptance by a project manager of the responsibility for completing these implementation efforts according to the attached work plan and timeline:	**Signature:** **Date:**

Rev. 4/8/01

Implementation Work Plan	
1. Project Title:	**2. Prepared by:**
1. Scope and objectives of implementation, including specific changes to WisDOT procedures.	
2. Estimated cost (if any) to implement.	
4. Expected benefits and how they will be measured (dollar savings, time savings, other).	
5. Possible pitfalls and how they will be avoided.	

Implementation Timeline (Gantt Chart)												
Tasks/Person Responsible												

Rev. 5/8/01

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608/262-2013
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