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Evaluation of Corrosion Inhibitors

FINAL REPORT

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16. Abstract

Corrosion of reinforcement is a global problem that has been studied extensively. The use of good quality concrete and corrosion inhibitors seems to be an economical, effective, and logical solution, especially for new structures. A number of laboratory studies are available on the performance of various corrosion inhibiting admixtures. But studies on concrete used in the field are rare. A new bypass constructed by the New Jersey Department of Transportation provided a unique opportunity to evaluate the admixtures in the field. Five new bridge decks were used to evaluate four corrosion-inhibiting admixtures.

The primary objective of the study was to evaluate the effectiveness of four commercially available corrosion reduction admixtures. The four admixtures were: DCI-S, XYPEX C-1000, Rheocrete 222+, and Ferrogard 901. The fifth deck was used as a control. All the decks with admixtures had black steel where as the control deck had epoxy coated bars. Extra black steel bars were placed on the control deck.

Both laboratory and field tests methods were used to evaluate the admixtures. The uniqueness of the study stems from the use of field concrete, obtained as the concrete for the individual bridge deck were placed. In addition to cylinder strength tests, minidecks were prepared for accelerated corrosion testing. The bridge was instrumented for long term corrosion monitoring. Tests to measure corrosion rate, corrosion potential, air permeability, and electrical resistance were used to determine the performance of the individual admixtures.

Unfortunately the length of the study o about 4 years was not sufficient to induce corrosion, even in the accelerated tests. It was expected that the field study will not result in any corrosion measurements because the steel in the decks can no be expected to corrode in 4 years. But the accelerated tests also did not provide measurable corrosion because of the good quality of concrete. The corrosion just initiated in accelerated test specimens and only for the control concrete that had no admixtures. In other samples there is a trend but not statically significant.

In terms of scientific observations, xypex provides a denser concrete. If the concrete can be kept free of cracks this product will minimize the ingress of liquids reducing corrosion. The other three provides a protection to reinforcement by providing a barrier, reducing the effect of chlorides or both. In order to distinguish the differences the study should continue or a different test method should be adopted.

Based on the results, the authors can recommend the use of xypex if there are no cracks in the slab. The admixture will reduce the ingress of chemicals. It is also recommended to continue the field measurements and develop a more effective accelerated test.

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Executive Summary

Corrosion of reinforcement is a global problem that has been studied extensively. The use of good quality concrete and corrosion inhibitors seems to be an economical, effective, and logical solution, especially for new structures. A number of laboratory studies are available on the performance of various corrosion inhibiting admixtures. But studies on concrete used in the field are rare. A new bypass constructed by the New Jersey Department of Transportation provided a unique opportunity to evaluate the admixtures in the field. Five new bridge decks were used to evaluate four corrosion-inhibiting admixtures.

The primary objective of the study was to evaluate the effectiveness of four commercially available corrosion reduction admixtures. The four admixtures were: DCI-S, XYPEX C-1000, Rheocrete 222+, and Ferrogard 901. The fifth deck was used as a control. All the decks with admixtures had black steel where as the control deck had epoxy coated bars. Extra black steel bars were placed on the control deck.

Both laboratory and field tests methods were used to evaluate the admixtures. The uniqueness of the study stems from the use of field concrete, obtained as the concrete for the individual bridge deck were placed. In addition to cylinder strength tests, minidecks were prepared for accelerated corrosion testing. The bridge was instrumented for long term corrosion monitoring. Tests to measure corrosion rate, corrosion potential, air permeability, and electrical resistance were used to determine the performance of the individual admixtures.

Unfortunately the length of the study of about 4 years was not sufficient to induce corrosion, even in the accelerated tests. It was expected that the field study will not result in any corrosion measurements because the steel in the decks can not be expected to corrode in 4 years. But the accelerated tests also did not provide measurable corrosion because of the good quality of concrete. The corrosion just initiated in accelerated test specimens and only for the control concrete that had no admixtures. In other samples there is a trend but not statically significant.

In terms of scientific observations, xypex provides a denser concrete. If the concrete can be kept free of cracks this product will minimize the ingress of liquids, thus reducing corrosion. The other three provides a protection to reinforcement by providing a barrier, reducing the effect of chlorides or both. In order to distinguish the differences the study should continue or a different test method should be adopted.

Based on the results, the authors can recommend the use of xypex if there are no cracks in the slab. The admixture will reduce the ingress of chemicals. It is also recommended to continue the field measurements and develop a more effective accelerated test.

Recommendations

Based on the scientific principles and comparative behavior of mini decks, 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.

For field study, the authors strongly recommend to continue the measurements of corrosion potential and corrosion rate. The instrumentation is in place and the results will be very valuable for the entire world. It is recommended that the readings should be taken every 6 months. Since the bridges are in use, NJDOT should provide traffic control during measurements. Since the instrumentation is in place, the cost for the measurement and yearly report could be in the range of $7,000. If the contract is extended to 10 years, 15 years data could be obtained for an additional cost of $70,000. The authors believe that the uniqueness of this database, which does not exit anywhere, makes this expenditure worthwhile.

For the laboratory study, improvements are needed for the current procedure. The major problem was the permeability of concrete. The concrete should not be allowed to dry-out and the corrosion should be induced after 24 hours. The authors recommend that NJDOT initiate another study to develop the test procedure. The main factors that contribute to corrosion are permeability of concrete and cracks through which the chemicals permeate. The accelerated test method should be designed to incorporate these two factors. The study should utilize 2 or 3 NJDOT standard mixes with no admixture. However, for both sets of specimens, a higher water cement ratio should be used to increase the permeability of concrete; in addition, the samples should not be cured, resulting further increase in permeability.

The mini decks can be prepared using the same procedure used for the current Minidecks. However, for one set of samples, very thin plastic plates should be placed on both top and bottom covers to simulate cracking.

The objective of the new study is to develop an accelerated test method that will provide corrosion within 18 months. The test method should be able to evaluate the effectiveness of corrosion inhibitors. The envisioned variables are as follows:

- Minimum water-cement ratio that can provide corrosion in 18 months for the NJDOT mixes.
- Maximum thickness of plates used for crack simulation.

The researchers can chose a range for both water-cement ratio and plate thickness to formulate their experimental program.

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1. Introduction

Corrosion of reinforcement is a global problem that has been studied extensively. Though the high alkali nature of concrete normally protects reinforcing steel with the formation of a tightly adhering film which passivates the steel and protects it from corrosion, the harsh environment in the Northeastern United States and similar locations around the world accelerate the corrosion process. The major techniques used for reducing corrosion and preventing it to some extent are: (i) Use of concrete with least permeability, (ii) Use corrosion inhibitors, (iii) Use of epoxy coated bars, (iv) Surface protection of concrete, and (v) Cathodic protection of reinforcement. Use the nonmetallic reinforcement is one more technique to reduce corrosion, which is still in development stage.

The use of inhibitors to control the corrosion of concrete is a well-established technology. Inhibitors are in effect any materials that are able to reduce the corrosion rates present at relatively small concentrations at or near the steel surface. When correctly specified and applied by experienced professionals, inhibitors can be effective for use in both the repair of deteriorating concrete structures and enhancing the durability of new structures.

The use of good quality concrete and corrosion inhibitors seems to be an economical, effective, and logical solution, especially for new structures. The objective of this study is to determine the effectiveness of four different corrosion inhibitors to reduce corrosion of the structural steel reinforcement in a structure. The data is compared with the data from structural steel reinforcement not protected by a corrosion inhibitor.

1.1 Objective

The primary objective of the research program is to evaluate the effectiveness of the latest corrosion inhibiting admixtures for steel reinforced concrete using laboratory and field study. It was envisioned that the laboratory accelerated test will provide effectiveness of the commercially available corrosion inhibitors, and these results can be used to predict the behavior of bridge decks. The bridge decks were instrumented to measure corrosion levels and the results from these decks were to be correlated with laboratory results.

2. Background Information

Steel reinforced concrete is one of the most durable and cost effective construction materials. The alkaline environment of the concrete passivates the steel resulting in reduction of corrosion activity in steel. However, concrete is often utilized in extreme environments in which it is subjected to exposure to chloride ions, which disrupt the passivity (Berke, 1995). Though corrosion inhibitors are one of the most practical and effective means to arrest the corrosion process in old and new reinforced concrete, the use of good quality concrete is also very significant in inhibiting corrosion. Concrete with low water to cement ratios can lower the amount of chloride ingress. Pozzolans such as silica-fume increases concrete resistively and permeably to chloride (Berke, 1995).

The principle of most inhibitors is to develop a thin chemical layer usually one or two molecules thick on the steel surface that inhibits the corrosion attack. Inhibitors can prevent the cathodic reaction, the anodic reaction, or both. They are consumed and will only work up to a given level of attack. The chloride content of the concrete determines the level of attack (Broomfield, 1997).

There are a number of inhibitors available in the market. They have different effects on the steel or the concrete to enhance the alkalinity, block the chloride intrusion and reduce the corrosion rate. Some are true corrosion inhibitors; some are hybrid inhibitors, pore blockers and alkali generators (Broomfield, 1997).

There are a number of ways inhibitors can be applied. Corrosion inhibiting admixtures are added to fresh concrete during the batching process. Other inhibitors can be applied to the surface of hardened concrete. These migrating inhibitors are called vapor phase inhibitors. These are volatile compounds that can be incorporated into a number of carries such as waxes, gels, and oils. In principle their ability to diffuse as a vapor gives them an advantage over liquid inhibitors. However, they could also diffuse out of the concrete unless trapped in place (Broomfield, 1997).

DCI – S developed by W.R. Grace & Co., XYPEX C-1000 developed by Quick-Wright Associates, Inc., Rheocrete 222+ developed by Masters Builders, Inc., and

Ferrogard 901 developed by Sika Corporation are all corrosion inhibiting admixtures for concrete and represent the state of the art in technology. These admixtures were evaluated for their performance as a means to reduce corrosion in new structures.

DCI – S corrosion inhibitor is a calcium nitrite-based solution. It is added to concrete during the batching process and effectively inhibits the corrosion of reinforcing steel and prestressed strands. According to W.R. Grace & Co., the admixture chemically reacts with the embedded metal to form a "passivating" oxide layer, which inhibits chloride attack of the fortified reinforcing steel. The addition of DCI – S to concrete delays the onset of corrosion, and reduces the corrosion rate once it has begun. DCI – S is a neutral set (DCI – S Corrosion Inhibitor, 1997)

XYPEX C-1000 is a corrosion inhibitor, which is specially formulated as an additive for concrete at the time of batching. According to the manufacture, the concrete itself becomes sealed against the penetration of water or liquid. The active chemicals in XYPEX C-1000 cause a catalytic reaction, which generates a non-soluble crystalline formation within the pores and capillary tracts of concrete preventing the penetration of water and liquids necessary to the corrosion process. XYPEX C-1000 may delay the initial set time of the fresh concrete (XYPEX Concrete Waterproofing by Crystallization).

Rheocrete 222+ is a corrosion inhibitor admixture formulated to prevent the corrosion of steel reinforced concrete. According the manufacturer, Rheocrete 222+ can extend the service life of reinforced concrete in two ways. The admixture slows the ingress of chlorides and moisture, two elements involved in the corrosion process, by lining the pores of the concrete matrix. The admixture also slows the rate of corrosion by forming a protective film on the reinforcing steel depriving the corrosion process of oxygen and moisture. Rheocrete 222+ is added to the concrete batch water during the mixing process and does not require changes to the normal batching procedures (Rheocrete 222+: Organic Corrosion Inhibiting Admixture, 1995).

The Ferrogard 901 corrosion inhibitor admixture for fresh concrete, developed by the Sika Corporation, is based on an organic film forming amino compound that can diffuse through the pores of the concrete. The protective film that forms around the reinforcing steel is a protective layer that can protect the steel in both anodic and cathodic areas. According to the manufacturer, this Ferrogard 901 suppresses the electrochemical corrosion reaction and shows no detrimental effects to the concrete (MacDonald, 1996).

DCI-S, Rheocrete 222+, and Ferrogard 911 are primarily made of organic products. The organic substances form a coating around the steel and provide protection. XYPEX C-2000 consists of Portland cement, very fine treated silica and various active proprietary chemicals. These active chemicals react with the moisture in concrete forming non soluble crystalline formation in the concrete pores.

3. Experimental Program

The primary objective of the research program is to evaluate the effectiveness of the latest corrosion inhibiting admixtures for steel reinforced concrete using laboratory and field study. It was envisioned that the laboratory accelerated test will provide effectiveness of the commercially available corrosion inhibitors, and these results can be used to predict the behavior of bridge decks. The bridge decks were instrumented to measure corrosion levels and the results from these decks were to be correlated with laboratory results.

The test variables are the four corrosion-inhibiting admixtures mentioned in chapter 2. These were incorporated in bridge decks during the construction of the bridge decks on the route 133 Hightstown Bypass. One deck was constructed with no corrosion-inhibiting admixture, which served as control.

The field evaluation consists of three tests: GECOR 6 Corrosion Rate Meter, Surface Air Flow Permeability Indicator, and Electrical Resistance Test for Penetrating Sealers. The results of these tests can be used to determine the physical characters as well as the corrosion protection provided by a particular admixture. The bridges were instrumented for corrosion testing and are periodically monitored for corrosion activity. The laboratory samples were tested using ASTM G 109. This accelerated process will give an early indication of the effectiveness of the admixtures. All the concrete samples were taken from the field as the concrete for the individual bridge decks was placed.

Fresh concrete was tested for workability and air content. Compressive strength was obtained at 28 days. The parameters studied were corrosion rate, corrosion potential, air permeability, and electrical resistance.

3.1 Test Variables

During the course of this research program, four types of corrosion inhibiting admixtures as well as control specimens, with no corrosion inhibiting admixtures, were evaluated in laboratory and field tests. Table 3.1 lists the bridge locations on Route 133 Hightstown Bypass and the corresponding admixtures used on each bridge deck.

Table 3.1: Bridge Locations with Corresponding Corrosion Inhibiting Admixtures and Reinforcing Steel Type

Bridge Location	**Corrosion Inhibiting Admixture**	**Type of Reinforcing Steel**
North Main Street - Westbound	W.R. Grace: DCI-S	Black
North Main Street - Eastbound	Quick Wright Associates, Inc.: XYPEX C-1000	Black
Wyckoff Road – Westbound	Master Builders, Inc.: Rheocrete 222+	Black
Wyckoff Road – Eastbound	Sika Corporation: Ferrogard 901	Black
Route 130 – Westbound	Control: none	Epoxy Coated

The control concrete did not contain any corrosion-inhibiting admixture. Epoxy coated steel was used in the reinforcement of the concrete deck unlike the other bridges tested which used uncoated black reinforcing steel.

The mix proportions for the five types of concrete used are presented in Tables 3.2, 3.3, 3.4, 3.5, and 3.6. The proportions were developed by the New Jersey Department of Transportation in accordance with ASTM C 94. From the tables 3.2 to 3.6, it can be seen that the cement and aggregate contents remained the same for all the mixes. The water content was adjusted to account for water present in the admixtures.

Table 3.2: Mix Design of North Main Street – Westbound (Corrosion Inhibitor: DCI-S)

Bridge Deck over North Main Street – Westbound **Date of Deck Pour: May 6, 1998**	
Cements (lbs)	700
Sand (lbs)	1346
¾ in. Aggregate (lbs)	1750
Water (gal)	29.3
W/C Ratio	0.38
Sika Corporation AER Air-Entraining Admixture ASTM C-150 (oz)	6.3
Sika Corporation Plastocrete 161 Water reducing Admixture Type "A" ASTM C 494 (oz)	21
W.R. Grace: DCI-S (gal)	3
Slump (inches)	3±1
Air (%)	6±1.5

Table 3.3: Mix Design of North Main Street – Eastbound (Corrosion Inhibitor: XYPEX C-1000)

Bridge Deck over North Main Street – Eastbound **Date of Deck Pour: May 14, 1998**	
Cements (lbs)	700
Sand (lbs)	1346
¾ in. Aggregate (lbs)	1750
Water (gal)	31.8
W/C Ratio	0.38
Sika Corporation AER Air-Entraining Admixture ASTM C-150 (oz)	4.2
Sika Corporation Plastocrete 161 Water reducing Admixture Type "A" ASTM C 494 (oz)	21
Quick Wright Associates, Inc.: XYPEX C-1000 (lbs)	12
Slump (inches)	3±1
Air (%)	6±1.5

Table 3.4: Mix Design of Wyckoff Road - Westbound

Bridge Deck over Wyckoff Road – Westbound **Date of Deck Pour: May 21, 1998**	
Cements (lbs)	700
Sand (lbs)	1346
¾ in. Aggregate (lbs)	1750
Water (gal)	31.8
W/C Ratio	38
Sika Corporation AER Air-Entraining Admixture ASTM C-150 (oz)	8.4
Sika Corporation Plastocrete 161 Water reducing Admixture Type "A" ASTM C 494 (oz)	21
Master Builders, Inc.: Rheocrete 222+ (gal)	1
Slump (inches)	3±1
Air (%)	6±1.5

Table 3.5: Mix Design of Wyckoff Road - Eastbound

Bridge Deck over Wyckoff Road – Westbound **Date of Deck Pour: May 21, 1998**	
Cements (lbs)	700
Sand (lbs)	1346
¾ in. Aggregate (lbs)	1750
Water (gal)	29.1
W/C Ratio	0.38
Sika Corporation AER Air-Entraining Admixture ASTM C-150 (oz)	4.2
Sika Corporation Plastocrete 161 Water reducing Admixture Type "A" ASTM C 494 (oz)	21
Sika Corporation: Ferrogard 901 (gal)	2
Slump (inches)	3±1
Air (%)	6±1.5

Table 3.6: Mix design of Route 130-Westbound (Corrosion Inhibitor: none)

Bridge Deck over Route 130 – Westbound **Date of Deck Pour: May 29, 1998**	
Cements (lbs)	700
Sand (lbs)	1346
¾ in. Aggregate (lbs)	1750
Water (gal)	31.8
W/C Ratio	0.38
Sika Corporation AER Air-Entraining Admixture ASTM C-150 (oz)	4.2
Sika Corporation Plastocrete 161 Water reducing Admixture Type "A" ASTM C 494 (oz)	21
Slump (inches)	3±1
Air (%)	6±1.5

3.2 Test Methods

The test procedures used are described in the following sections. The first three tests were conducted in the field where as the fourth one was conducted in the laboratory.

The laboratory test provides the information on corrosion potential which can be used to estimate the effectiveness of corrosion inhibitors. The air permeability and the electrical resistance test conducted in the field were used to determine possible variations in permeability and uniformity of concrete in the five bridge decks chosen for the study. Corrosion rate measured in the field can be used to correlate the laboratory test results that were obtained using accelerated corrosion.

3.2.1 GECOR Corrosion Rate Meter

The GECOR 6 Corrosion rate Meter provides valuable insight into the kinematics of the corrosion process. Based on a steady state linear polarization technique it provides information on the rate of the deterioration process. The meter monitors the electrochemical process of corrosion to determine the rate of deterioration. This nondestructive technique works by applying a small current to the reinforcing bar and measuring the change in the half-cell potential. The corrosion rate, corrosion potential and electrical resistance are provided by the corrosion rate meter.

Description of the equipment and test procedure is presented in Appendix A.

3.2.2 Surface Air Flow Field Permeability Indicator

The Concrete Surface Air Flow (SAF) Permeability Indicator is a nondestructive technique designed to give an indication of the relative permeability of flat concrete surfaces. The SAF can be utilized to determine the permeability of concrete slabs, support members, bridge decks, and pavement (Manual for the Operation of a Surface Air Flow Field Permeability Indicator, 1994). The concrete permeability is based on airflow out of the concrete surface under an applied vacuum. The depth of measurement was determined to be approximately 0.5in. below the concrete surface. A study between the relationships between SAF readings and air and water permeability determined that there is a good correlation in the results. As stated in the Participant's Workbook: FHWA-SHRP Showcase, (Scannell, 1996) the SAF should not be used as a substitute for actual laboratory permeability testing. Cores tested under more standardized techniques will provide a more accurate value for permeability due the fact that the effects of surface texture and micro cracks have not been fully studied for the SAF.

The SAF can determine permeability of both horizontal surfaces, by use of an integral suction foot, and vertical surfaces, by use of external remote head. The remote head was not used for this project. A description of the equipment and the test procedure are presented in Appendix C.

3.2.3 Electrical Resistance Test for Penetrating Sealers

Although the main use of this testing method is to determine the effectiveness of concrete penetrating sealers, it can also indicate the resistance of unsealed concrete surfaces. The resistance measurement is tested on two strips of conductive paint sprayed onto the concrete surface to be tested by using a, Nilsson 400, soil resistance meter. The spray pattern can be seen in Fig. 3.1.

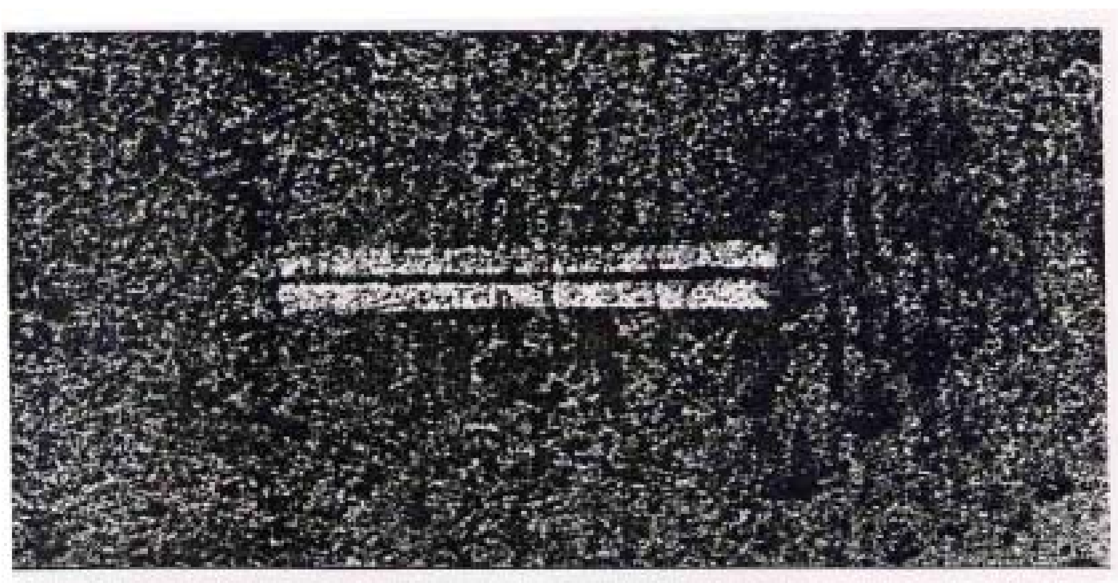

Fig. 3.1: Strips of Silver Conductive Paint

The materials needed for this test and test procedure are presented in Appendix D

The higher the resistance the less potential for corrosion in the embedded steel due to the higher density of the concrete and improved insulation against the electrochemical process of corrosion. The collected data and a discussion on the resistance indicated are presented and discussed in the Test Results and Discussions chapter.

3.2.4 Minideck Test

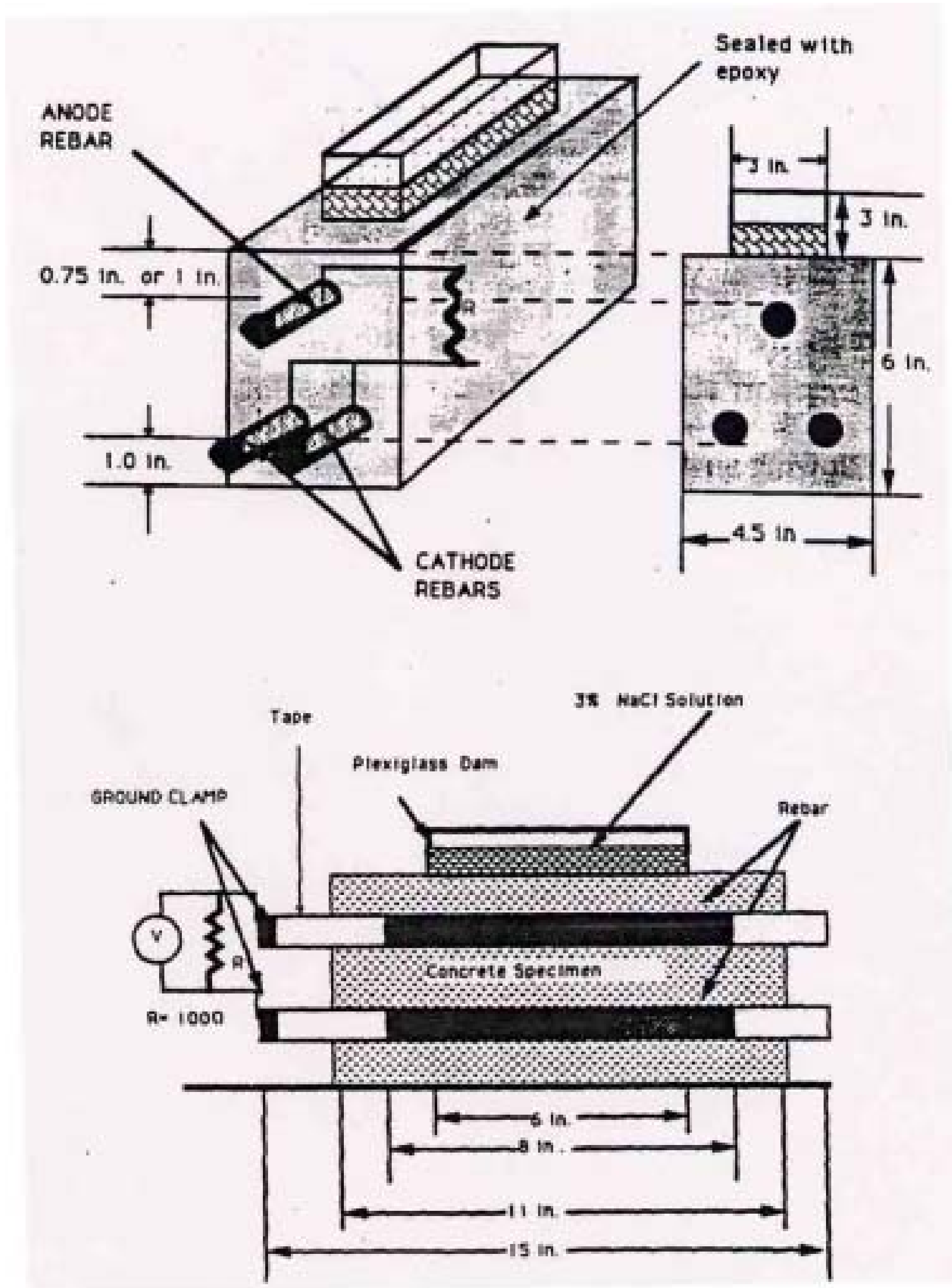

Fig. 3.2: View of Concrete Minideck (ASTM G 109)

The corrosion rate is tested using minidecks presented in Fig.3.2 and a high impedance voltmeter accurate up to 0.01 mV. The top bar is used as the anode while the bottom bars are used as the cathode. Voltage is measured across a 100Ω resistor. The current flowing, I_j, from the electrochemical process is calculated from the measured voltage across the 100Ω resistor, Vj as:

$$I_j = V_j/100$$

The corrosion potential of the bars is measured against a reference electrode half-cell. The electrode is placed in the dam containing the NaCl solution. The voltmeter is connected between the electrodes and bars.

The current is monitored as a function of time until the average current of the control specimens is 10 μA or Greater, and at least half the samples show currents equal to or greater than 10 μA. The test is continued for a further three complete cycles to ensure the presence of sufficient corrosion for a visual evaluation. At the conclusion of the test, the minidecks are broken and the bars removed to assess the extent of corrosion and to record the percentage of corroded area.

The results are interpreted with Table B.1 and Table B.2 in the Appendix. The results of this test are presented in the results and Discussion Chapter.

3.3 Instrumentation for Field Tests

Electrical connections were made to the top-reinforcing mat of each bridge deck before the placement of the concrete. Five connections were made to Route 130 Westbound and four each on the remaining four bridges. A total of 105 readings were taken per cycle using the GECOR 6 Corrosion Rate Meter. Twenty-five readings were taken at the bridge deck over RT130 West Bound. Twenty readings each were taken at the other four bridge decks tested. The locations of the tests are presented on Fig.3.3, 3.4, 3.5, 3.6, and 3.7. Due to the use of epoxy coated reinforcing bars on the bridge deck over RT130 West Bound, it was necessary to place uncoated reinforcing bars into the top mat. The locations of these bars are presented in Fig. 3.8. Short lengths of uncoated reinforcing bars were welded to the existing reinforcement. The ends were tapped to accept stainless steel nuts and bolts to attach underground copper feeder cables seen in Fig. 3.9 that were used to connect the meter to the reinforcement in the bridge deck. To ensure accurate readings, the connecting lengths of reinforcing bars were wire brushed to remove the existing corrosion. They were then coated with epoxy and spray painted to seal out moisture.

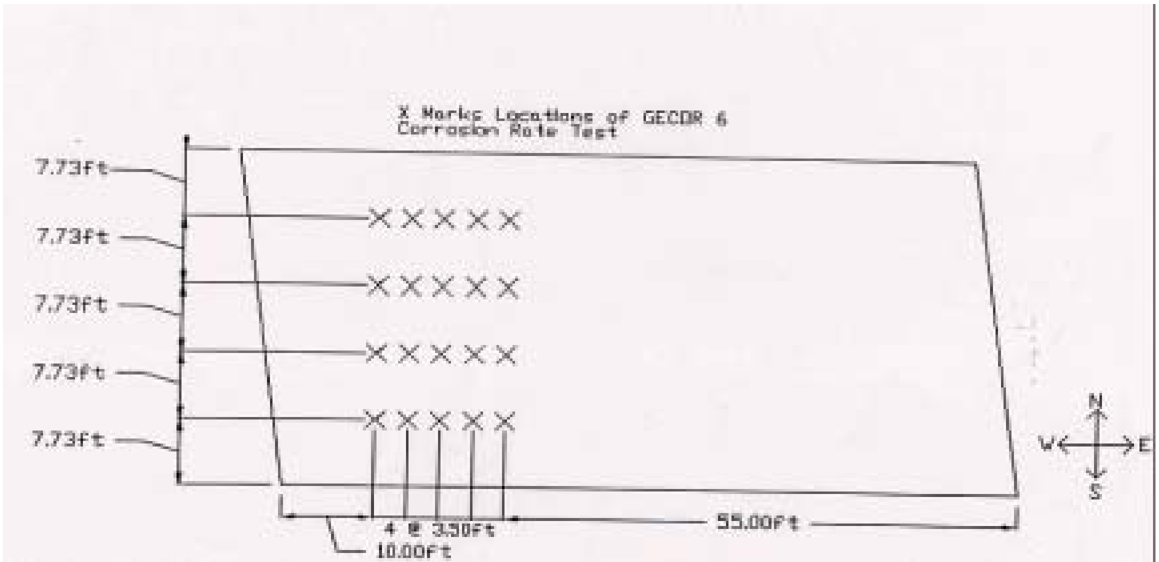

Fig. 3.3: Locations of GECOR 6 Corrosion Rate Meter Tests
North Main Street Westbound (x: location at which reading was taken)

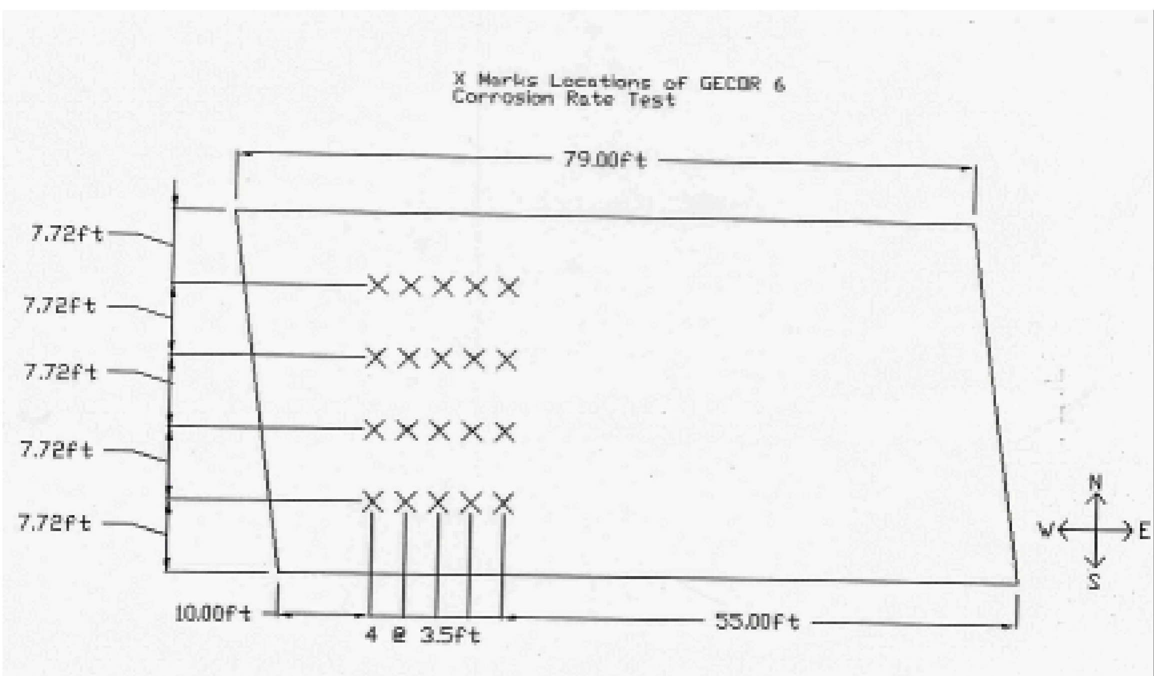

Fig. 3.4: Locations of GECOR 6 Corrosion Rate Meter Tests
North Main Street Eastbound (x: location at which reading was taken)

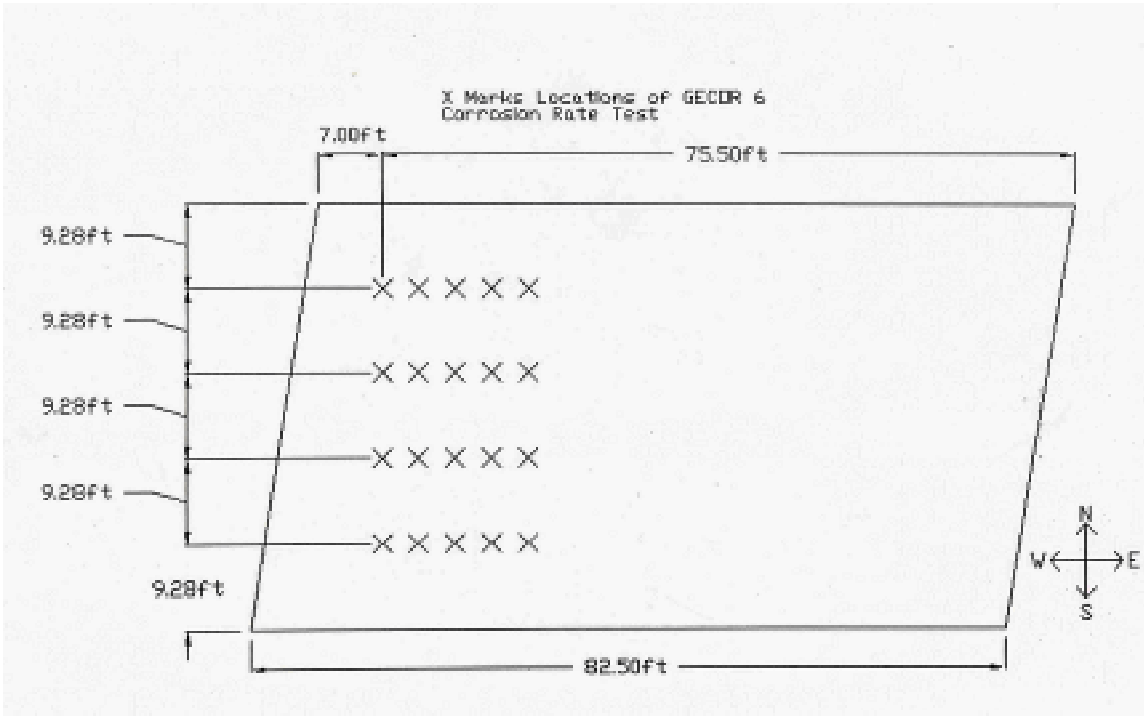

Fig. 3.5: Locations of GECOR 6 Corrosion Rate Meter Tests

Wyckoff Road Westbound (x: location at which reading was taken)

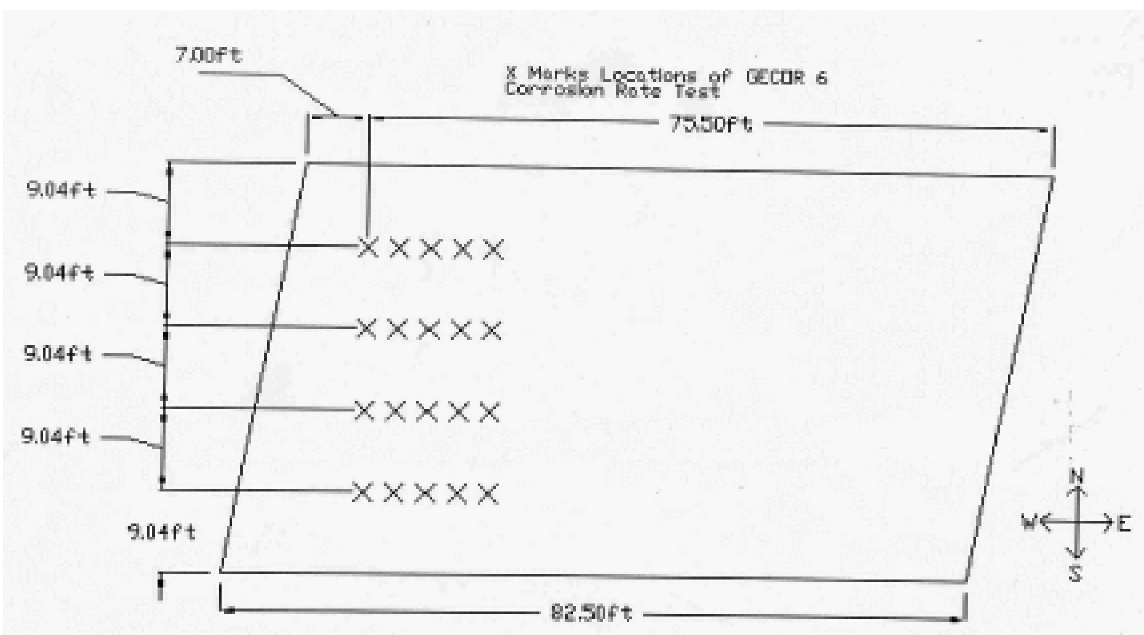

Fig. 3.6: Locations of GECOR 6 Corrosion Rate Meter Tests

Wyckoff Road Eastbound (x: location at which reading was taken)

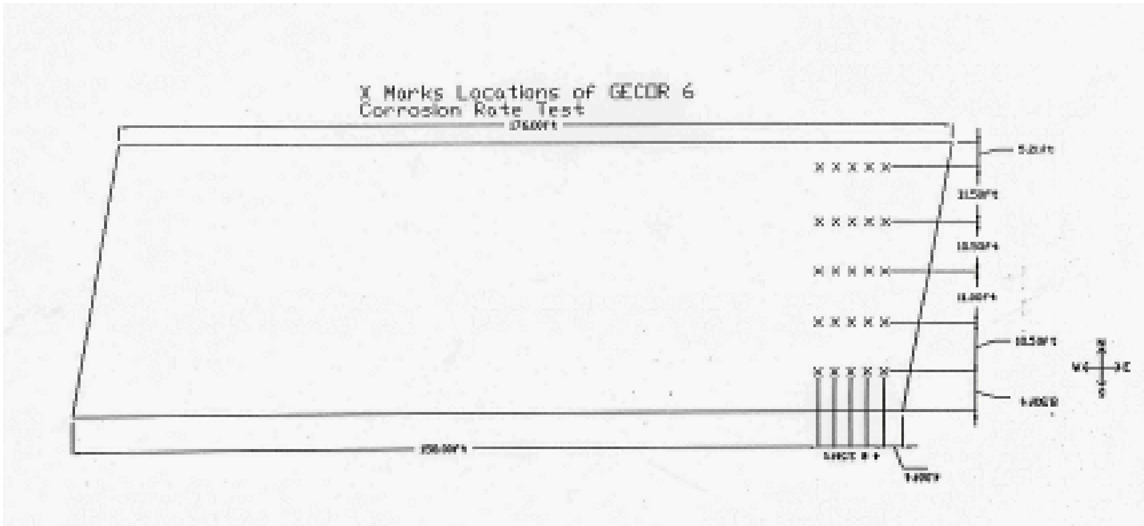

Fig. 3.7: Locations of GECOR 6 Corrosion Rate Meter Tests
Route 130 Westbound (x: location at which reading was taken)

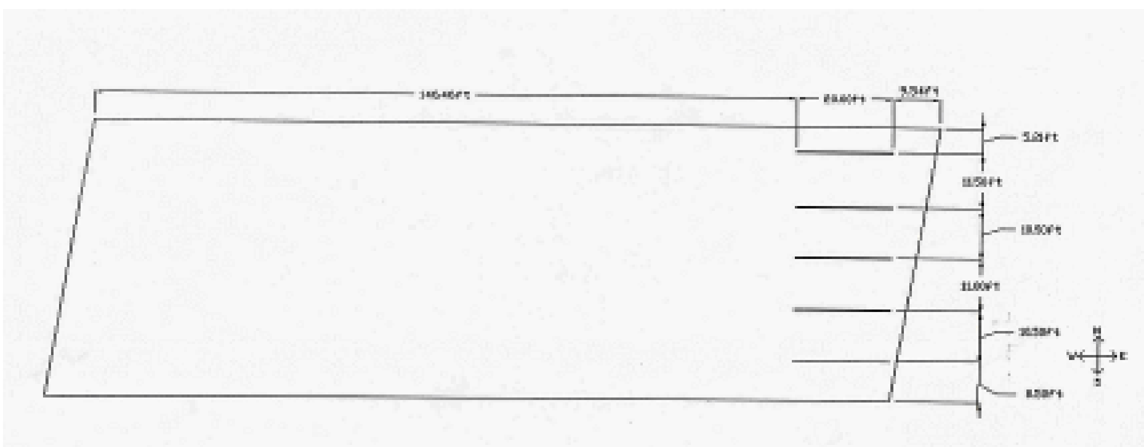

Fig. 3.8: Locations of Uncoated Steel Reinforcement Bars on Route 130 Westbound
(X: location at which reading was taken)

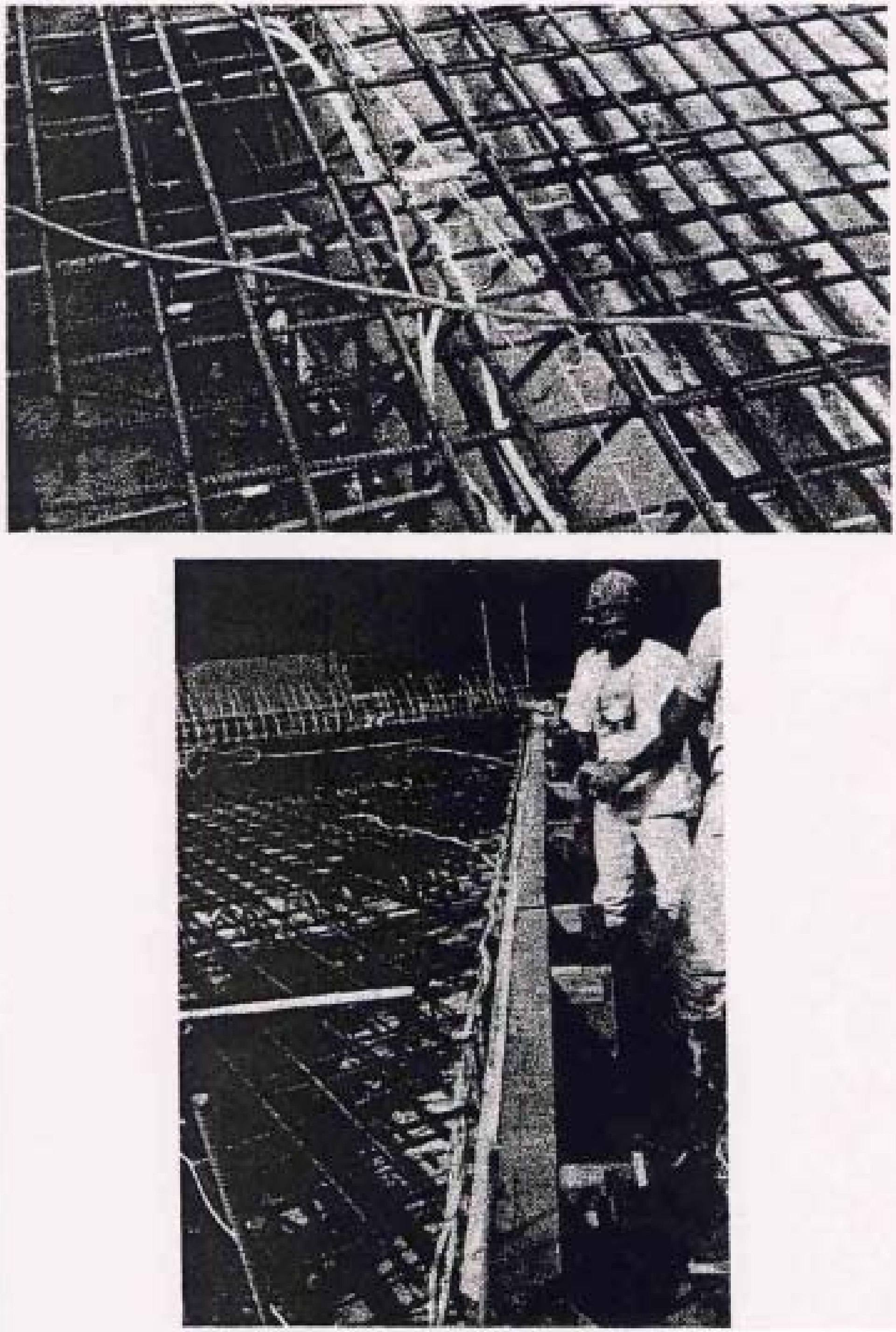

Fig. 3.9: Insulated Copper Underground Feeder Cables

A total of fifteen readings were recorded per cycle using the Surface Air Flow Field Permeability Indicator. Three readings were taken transversely across the concrete deck at either end and at midspan. The locations of the readings can be seen on Fig. 3.10, 3.11, 3.12, 3.13, and 3.14. The readings provide an indication of effect of a particular corrosion-inhibiting admixture on permeability.

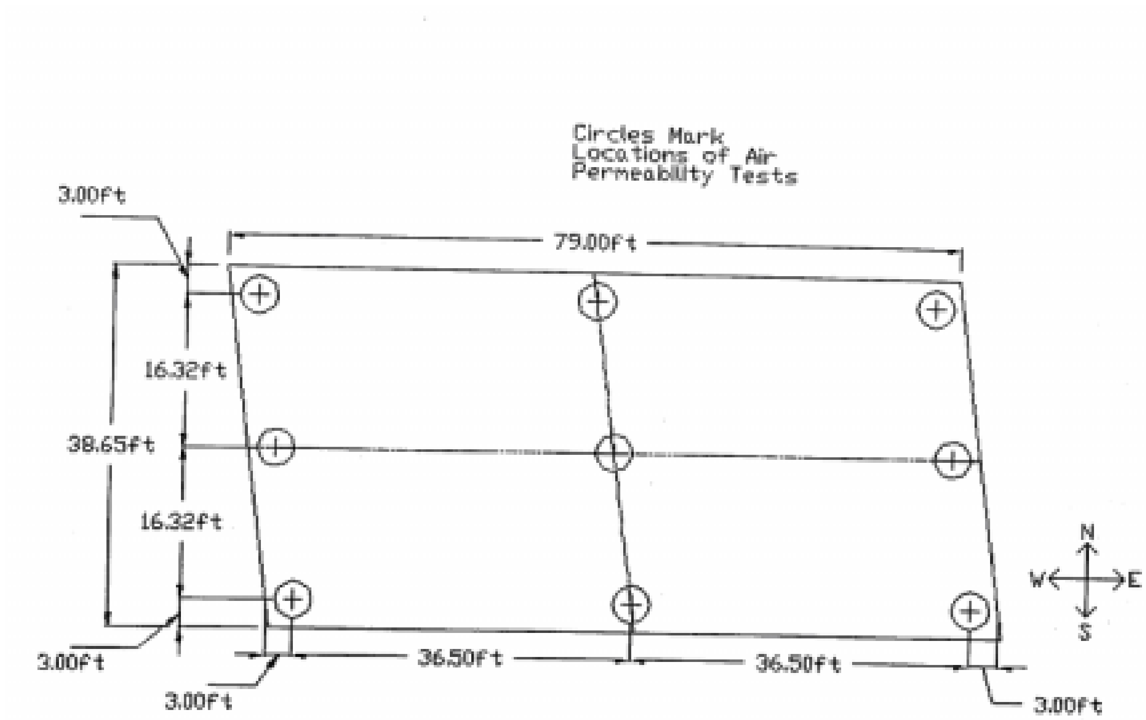

Fig. 3.10: Locations of Surface Air Flow Field Permeability Indicator Readings North Main Street Westbound (x: location at which reading was taken)

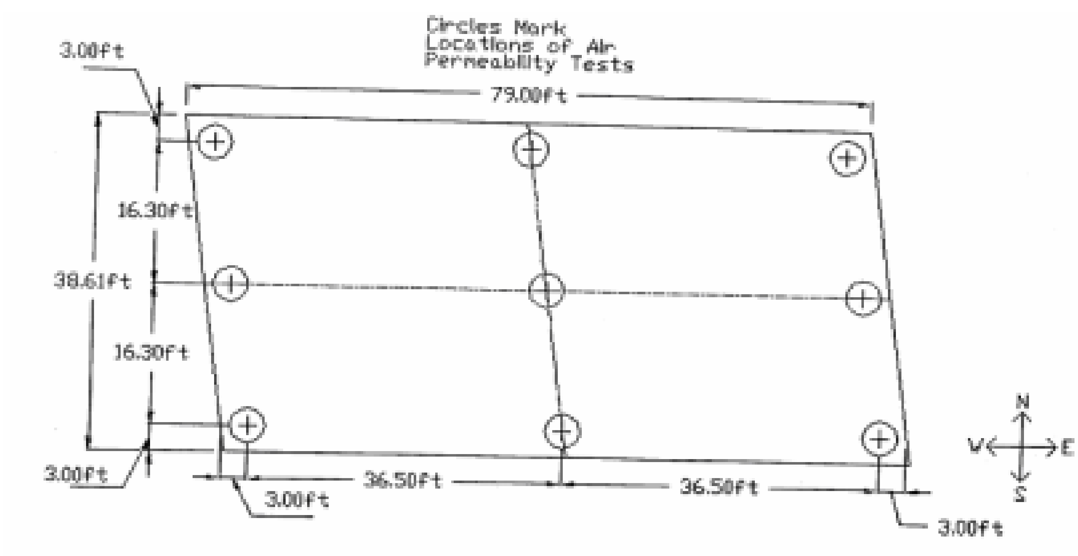

Fig. 3.11: Locations of Surface Air Flow Field Permeability Indicator Readings North Main Street Eastbound (x: location at which reading was taken)

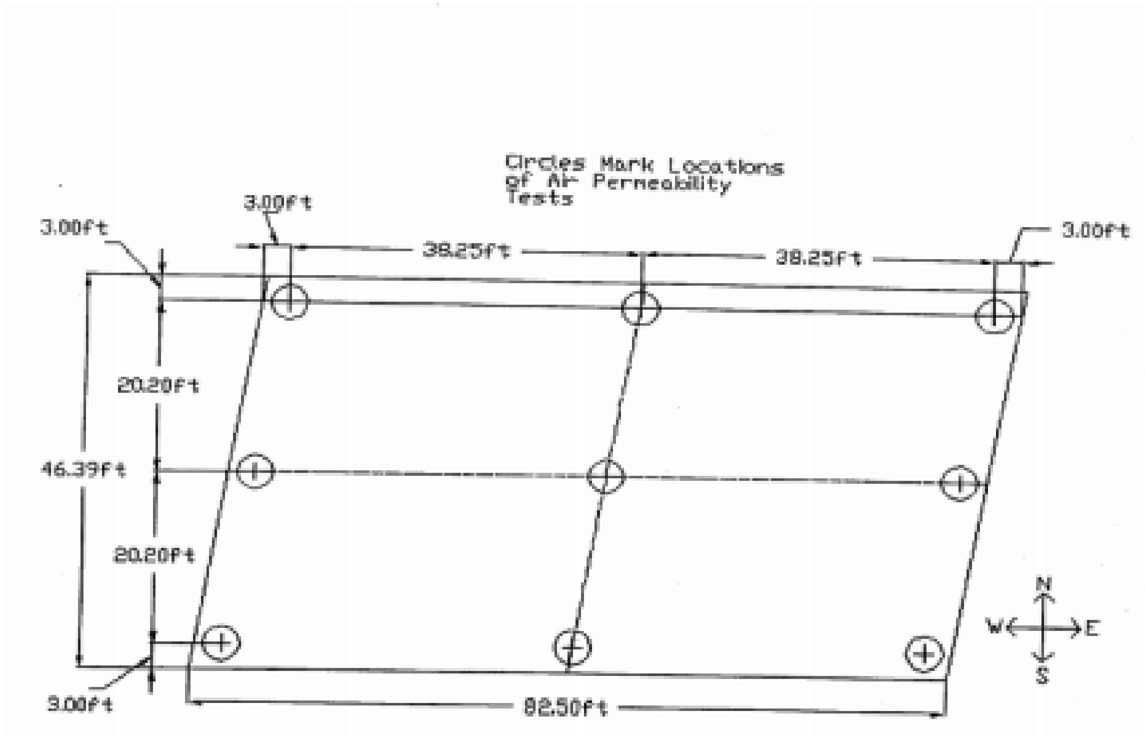

Fig. 3.12: Locations of Surface Air Flow Field Permeability Indicator Readings Wyckoff Road Westbound (x: location at which reading was taken)

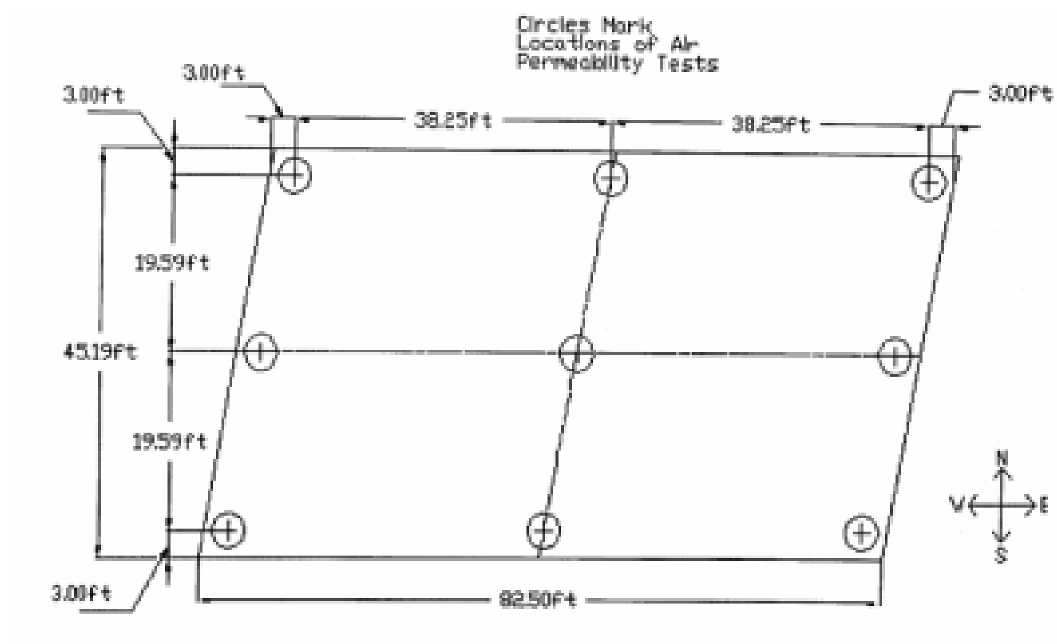

Fig. 3.13: Locations of Surface Air Flow Field Permeability Indicator Readings Wyckoff Road Eastbound (x: location at which reading was taken)

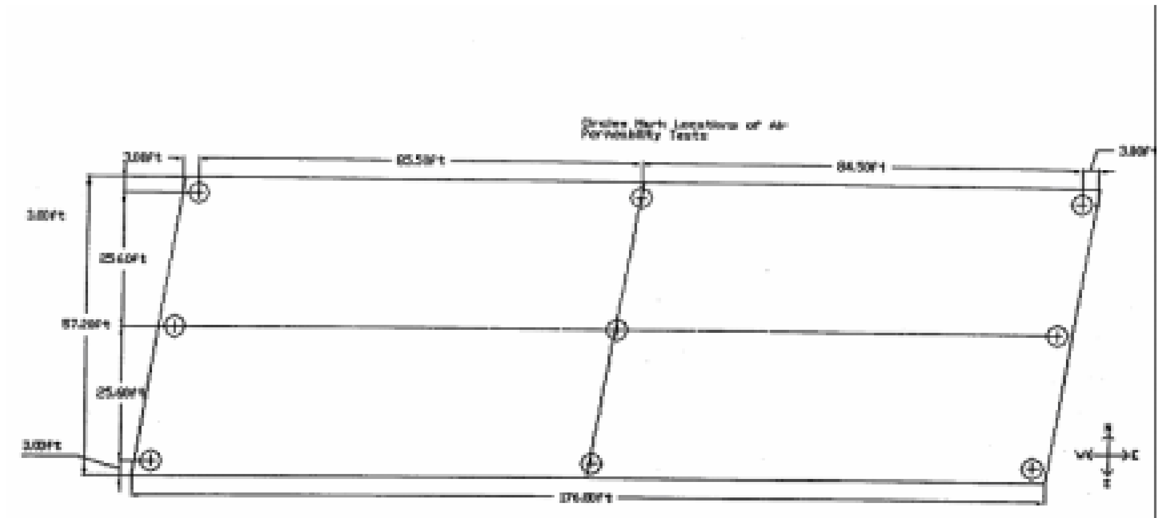

Fig. 3.14: Locations of Surface Air Flow Field Permeability Indicator Readings Route 130 Westbound (x: location at which reading was taken)

A total of fifteen readings were taken per cycle using the Electrical Resistance Test for Penetrating Sealers. Three resistance readings were taken on each bridge deck at midspan. The locations of the readings can be seen on Fig. 3.15, 3.16, 3.17, 3.18, and 3.19. Due to the difficulty in creating an adequate gage using the fine line tape and the metal mask, an aluminum mask with a rubber gasket was fabricated. The stiff aluminum mask fabricated with the correct dimensions eliminated the need for the fine line tape and mask as well as producing a better gage according to the acceptance criteria. Though a formal determination has not been made for categorizing unsealed concrete effectiveness against corrosive effects using the testing method, a comparison of the various bridge decks admixtures in relation to each other can determine which is most effective.

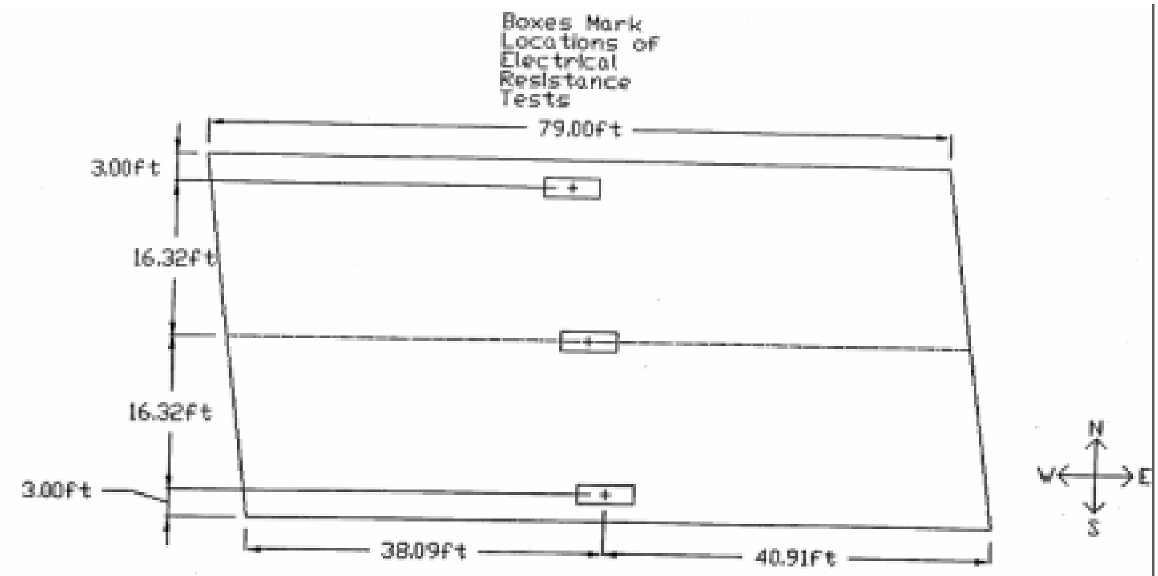

Fig. 3.15: Locations of Electrical Resistance Tests

North Main Street Westbound (x: location at which reading was taken)

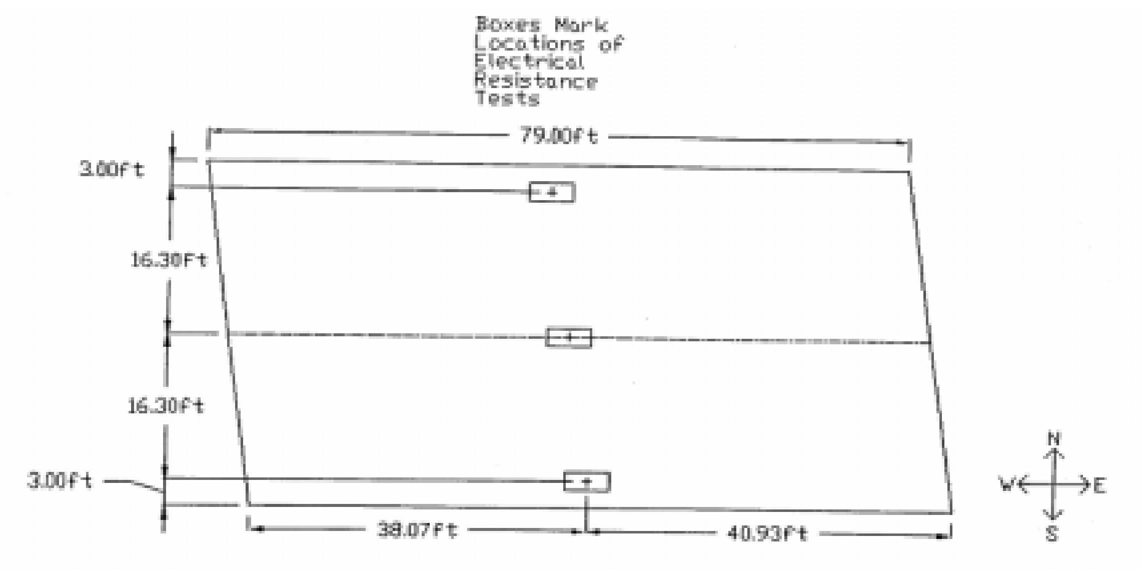

Fig. 3.16: Locations of Electrical Resistance Tests

North Main Street Eastbound (x: location at which reading was taken)

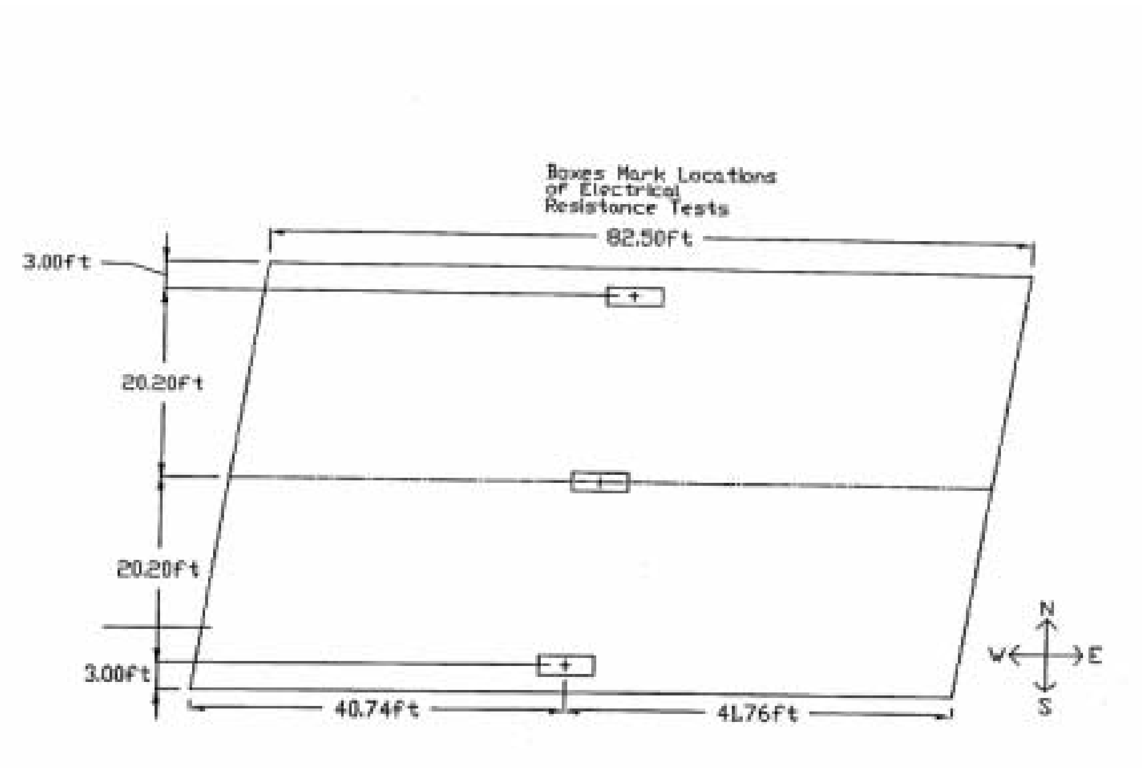

Fig. 3.17: Locations of Electrical Resistance Tests
Wyckoff Road Westbound (x: location at which reading was taken)

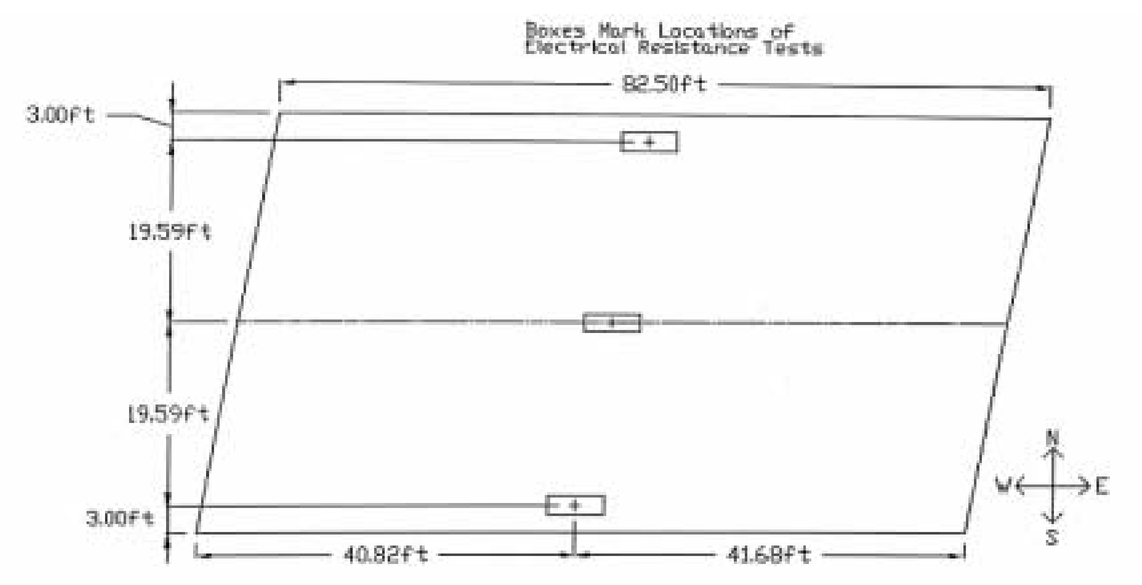

Fig. 3.18: Locations of Electrical Resistance Tests
Wyckoff Road Eastbound (x: location at which reading was taken)

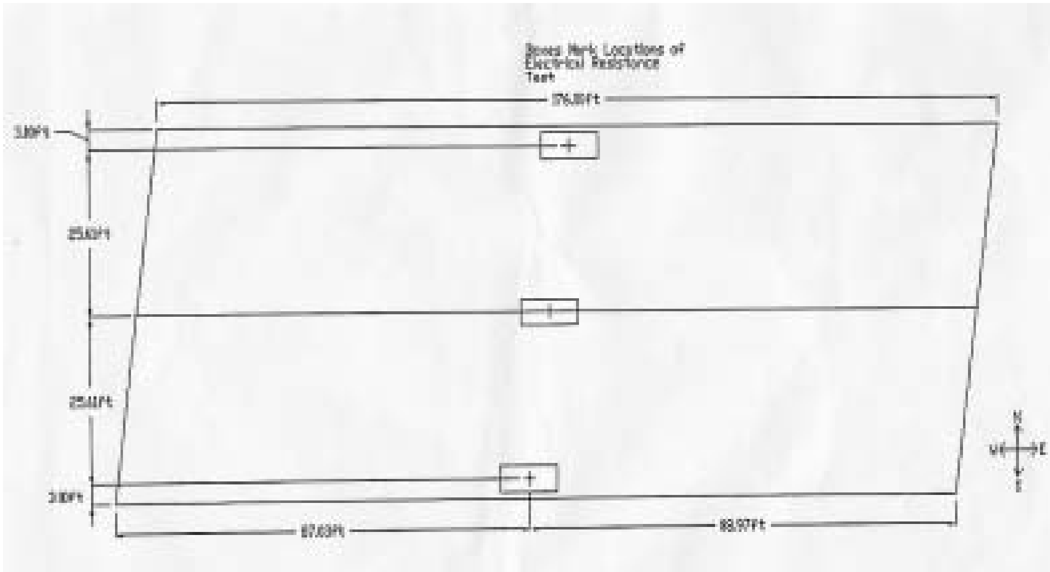

Fig. 3.19: Locations of Electrical Resistance Tests

Route 130 Westbound (x: location at which reading was taken)

3.4 Specimen Preparation for Laboratory Tests

Molds for the ASTM G 109 Test were fabricated from ½ in. Plexiglas because of its impermeability and durability. No 5 reinforcing bars were used for the test instead of the No 4 bars specified in the ASTM to better correlate the laboratory test results with data gathered from the field. The connections made to the five bridge decks on Route 133 Hightstown Bypass for the GECOR 6 Corrosion Rate Test were specially placed on the No. 5 bars that make up the top mat of the reinforcement. Holes were drilled and tapped in one end of each of the pieces of reinforcing bar that were to be placed in the molds to receive stainless threaded rods and nuts. This provided a better connection for the corrosion rate and corrosion potential tests. The wire brushed and wrapped bars were placed into the molds and caulked into place as shown in Fig. 3.20.

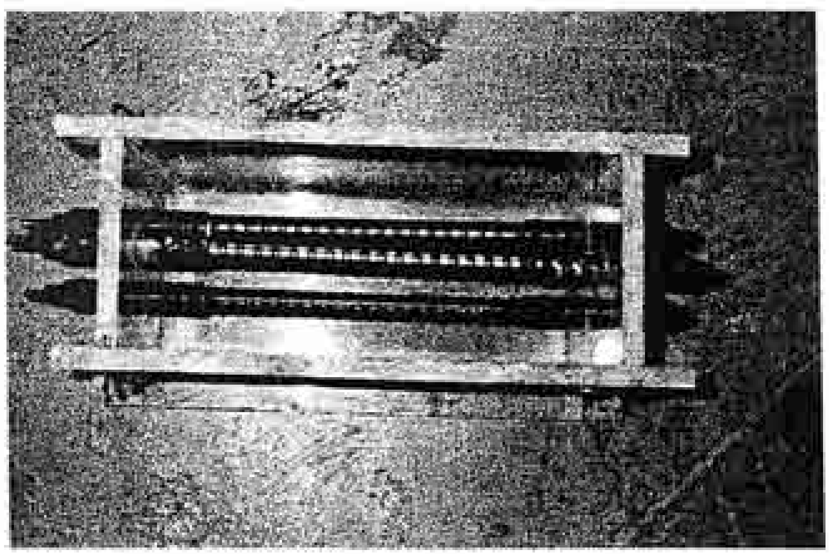

Fig. 3.20: Prepared Minideck Mold

A total of thirty minidecks were cast for the ASTM G 109 Test. All the concrete samples used for the research program were taken from the mixing trucks as the concrete for the individual decks were placed. Six minidecks were cast for each of the five bridges. The concrete taken were from two separate trucks per bridge deck to better correlate the Minideck samples to the actual concrete being placed in the new bridge deck. Fresh and hardened concrete properties were taken by the NJDOT Quality Control

Team and are provided on Table 4.1 and 4.2 in the Results and Discussion Chapter. The samples were consolidated through rodding and placed under plastic sheets to cure for the first 24 hours. The samples were removed from the molds after the 24 hours and placed in a 100% humidity room to cure for 90 days. Fig. 3.21 shows a Minideck after removal from mold.

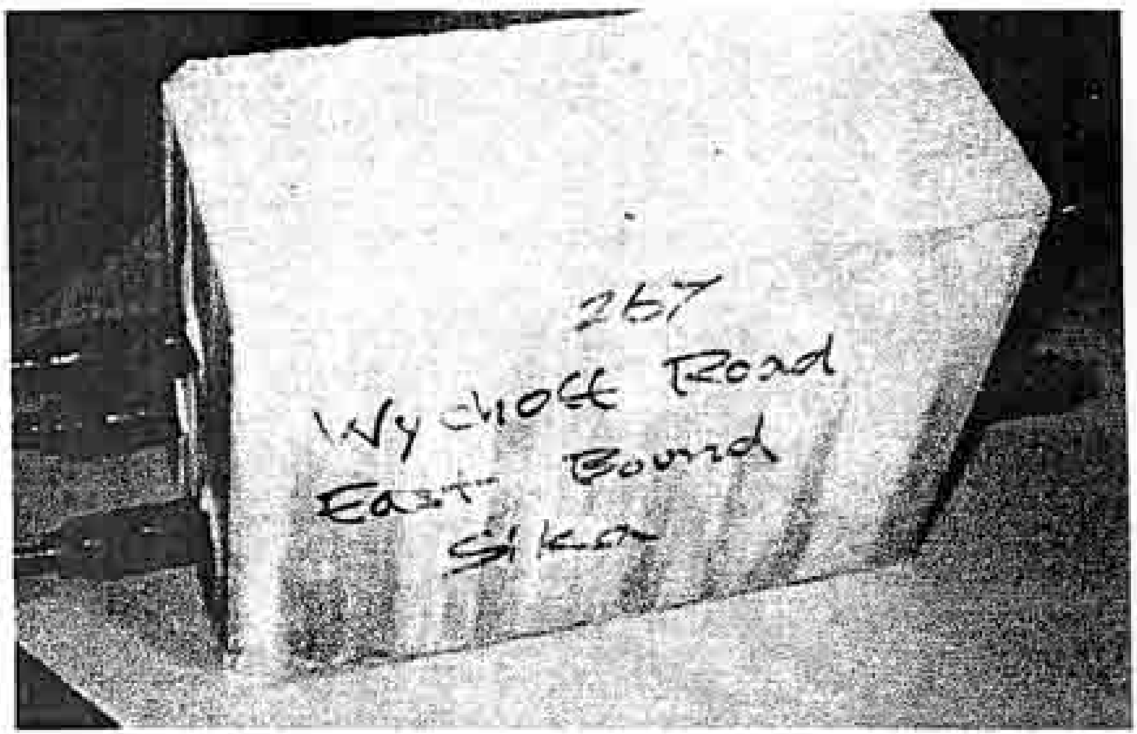

Fig. 3.21: Minideck after Removal from Mold

The minidecks were prepared for accelerated corrosion tests after 90 days. Silicon caulk was then used to fix ¼ in. thick Plexiglas dams to the top of each sample in the center. The Plexiglas dam can be seen in Fig.3.22. Concrete sealing epoxy was used to seal all four sides and the top of the sample except for the area enclosed by the dam. The samples were placed on sturdy racks supported on ½ in. strips of wood. The Minideck designation is listed on Table 3.7.

The samples were ponded with 3% NaCl solution and tested for corrosion rate and corrosion potential as per ASTM G 109 and ASTM C 876, respectively. The ponded specimens can be seen in Fig. 3.23. The corrosion data is provided in the Results and Discussion Chapter.

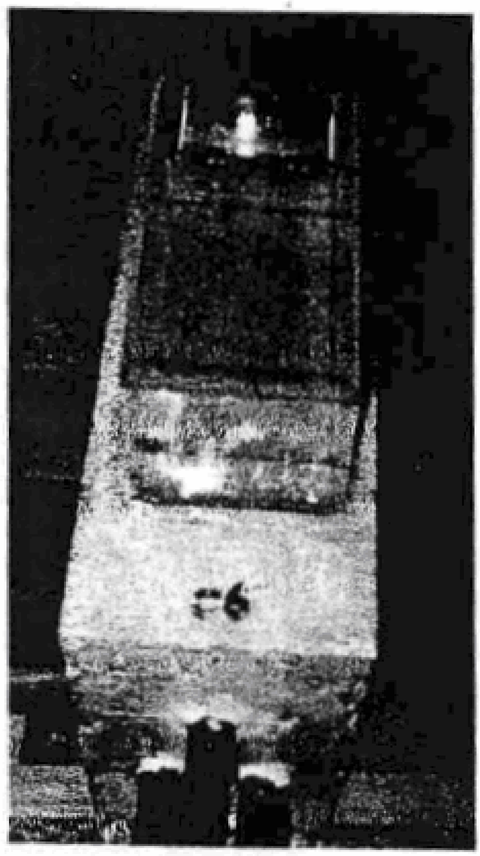

Fig. 3.22: View of Plexiglas Dam

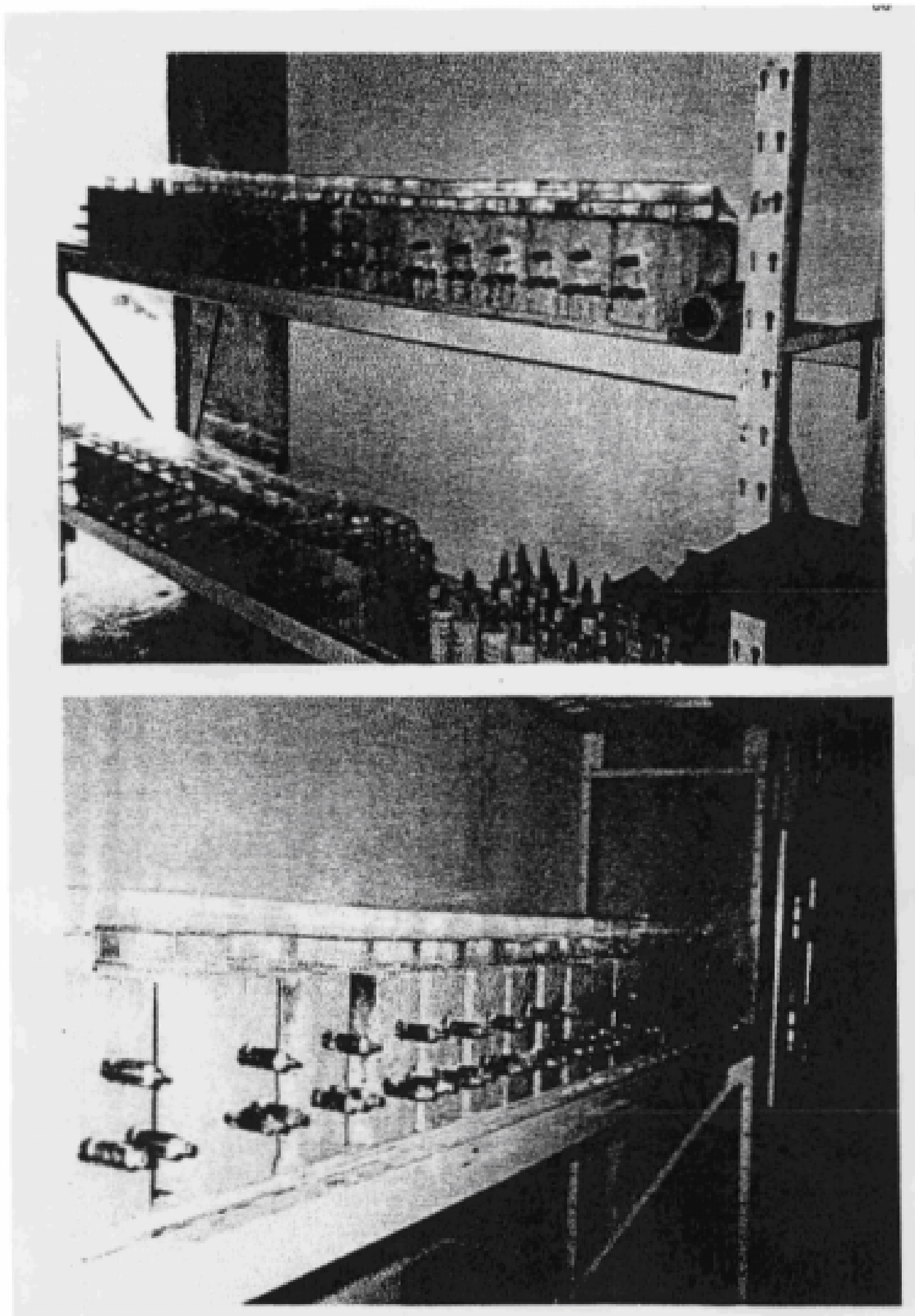

Fig.3.23: Ponded Minideck Samples

Table 3.7: Minideck Sample Location, Admixture Type, and Designation

Bridge Location	Corrosion Inhibiting Admixture	ASTM G 109 Minideck Designations
North Main Street – West Bound	W.R. Grace: DCI – S	**A**
North Main Street – East Bound	Quick Wright Associates, Inc.: XYPEX C-2000	**B**
Wyckoff Road – West Bound	Master Builders, Inc.: Rheocrete 222+	**C**
Wyckoff Road – East Bound	Sika Corporation: Ferrogard 901	**D**
Route 130 – West Bound	Control: none	**E**

4. Results and Discussion

The results presented consist of fresh and hardened concrete properties, accelerated laboratory tests, and field measurement. Fresh concrete properties are presented in table 4.1. Hardened concrete properties are presented in table 4.2.

Table 4.1: Fresh Concrete Properties

Minideck	Concrete Temp. (°F)	Slump (inches)	Entrained Air Content (%)
A	65	3.38	6.00
B	64	3.00	5.85
C	82	3.38	5.70
D	78	3.88	5.05
E	84	4.00	5.28

Table 4.2: Hardened Concrete Properties

Minideck	28Day Average Compressive Strength (PSI)
A	5825
B	5305
C	4425
D	6123
E	4935

From Tables 4.1 and 4.2, it can be seen that the slump and air contents are not significantly different for the various admixtures. The slump varied from 3 to 4 in., where as the air content varied from 5 to 6%.

Compressive strength varied from 4425 to 6125 psi. The variation could be considered a little high. However, this variation may not influence corrosion studies because the corrosion is primarily influenced by permeability. Rapid air permeability tests indicate that the variation in permeability among the five bridge decks is not significant.

Corrosion rate and corrosion potential for minidecks subjected to accelerated corrosion and actual bridge decks are presented in the following sections. Since the corrosion process did not start in either set of samples, a correlation could not be developed. However the data will be very useful if future readings taken in the field indicate corrosion activity. Once corrosion activity is evident in the laboratory or field tests, a correlation can be attempted.

4.1 Electrical Resistance and Air Permeability

Variations of electrical resistance for the five decks are presented in Fig. 4.1 to 4.5 and the variations of air permeability are presented in Fig. 4.6 to 4.10. The actual numbers are presented in Appendix F.

Overall, the variation in both air permeability and electrical resistance is negligible among the five bridge decks. Therefore the permeability of uncracked decks can be assumed to be the same for all fiver decks.

4.1.1 Electrical Resistance

Review of Fig. 4.1 to 4.5 leads to the following observations:

- The resistance varies from 20 to 100 KΩ. Since the resistance is very sensitive to a number of factors, this variation is not significant.
- Except for North Main Street - East bound (XYPEX C – 1000), the average resistance was higher than 50 KΩ. For North Main Street – West bound, the resistance was about 30 KΩ.
- The variations across and among the decks were not significant. Therefore, the uniformity of concrete and quality of concrete for all the decks can be assumed to be

same for all the five bridge decks. It should be noted that this observation is based on the measurements taken on uncracked decks.

4.1.2 Air Permeability

Review of Fig 4.6 to 4.10 leads to the following observations:

- The air flow rate varied from 25 to 45 ml/min.
- The magnitude of variation in air flow across and among (the five) the decks were smaller for air flow as compared to electrical resistance. This should be expected because air flow is primarily influenced by density. Other factors such as degree of saturation have much less effect on permeability as compared to electrical resistance.
- Careful review of all the readings leads to the conclusion that the variation of air permeability across and among the five decks is negligible. Here again, the results were obtained on uncracked decks.

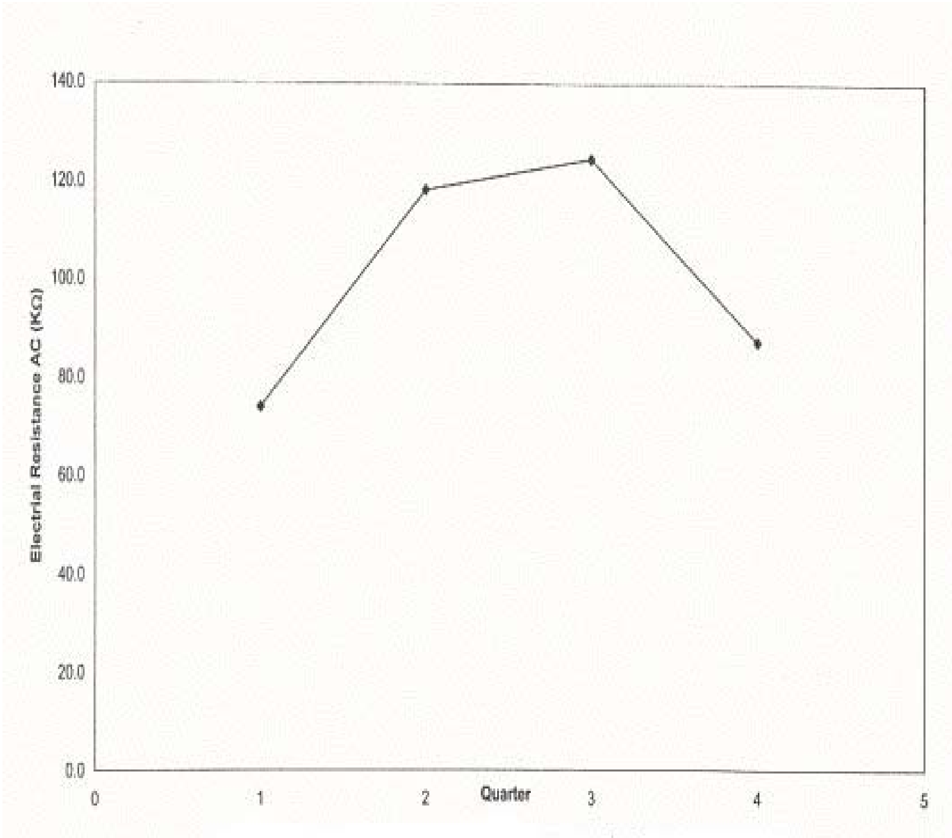

Fig. 4.1: North Main Street Westbound Average Electrical Resistance AC (KΩ)

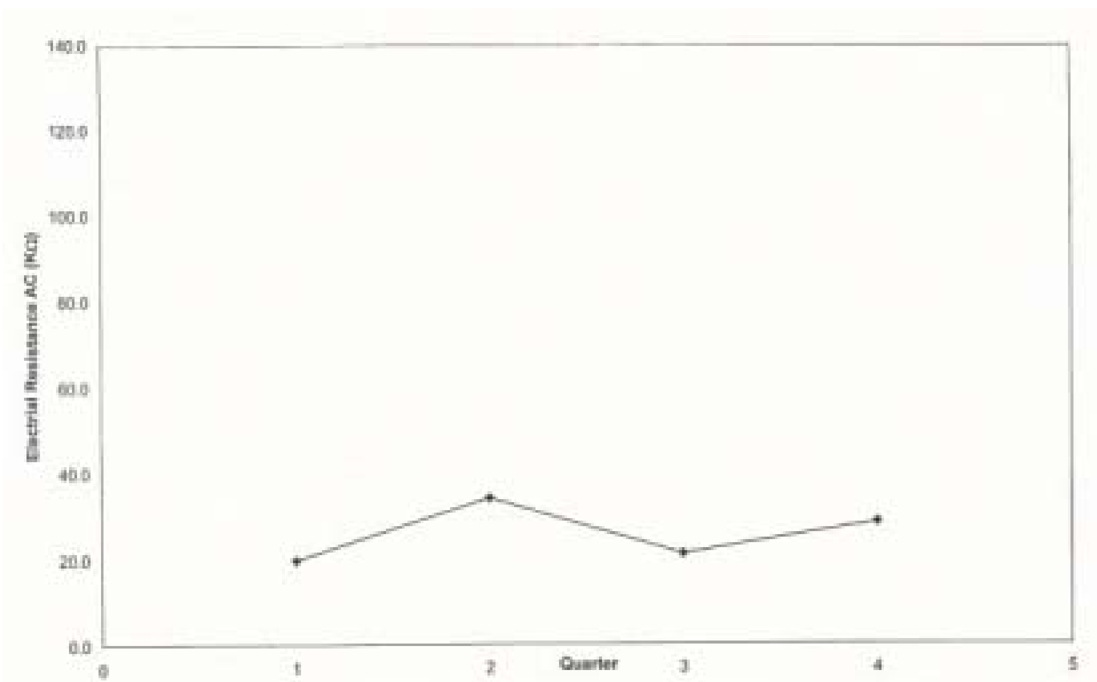

Fig. 4.2: North Main Street Eastbound Average Electrical Resistance AC (KΩ)

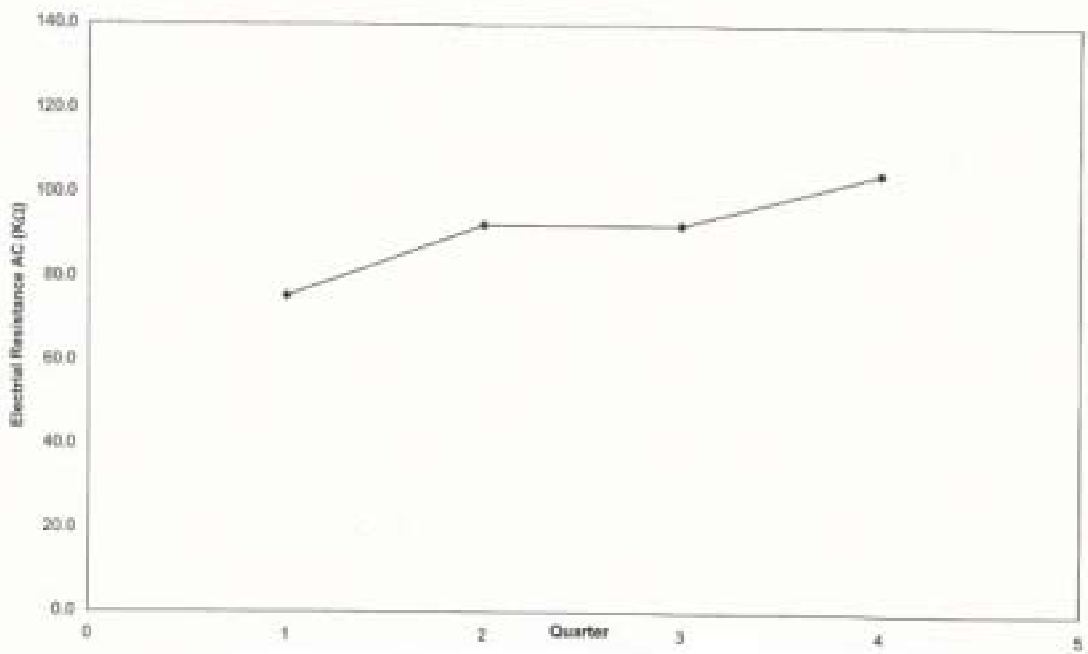

Fig. 4.3: Wyckoff Road Westbound Average Electrical Resistance AC (KΩ)

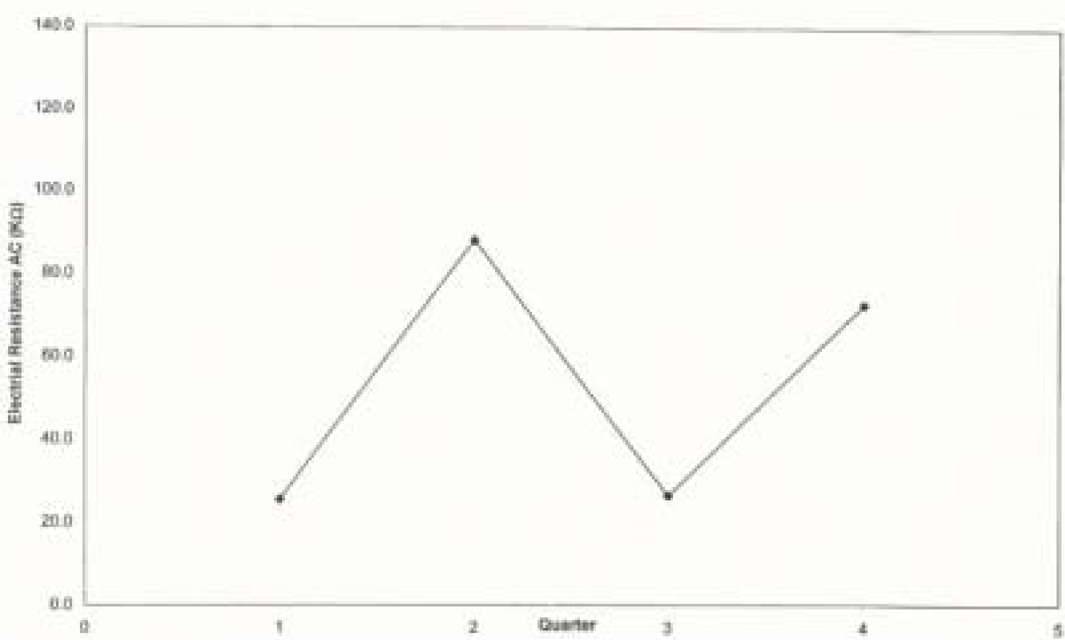

Fig. 4.4: Wyckoff Road Eastbound Average Electrical Resistance AC (KΩ)

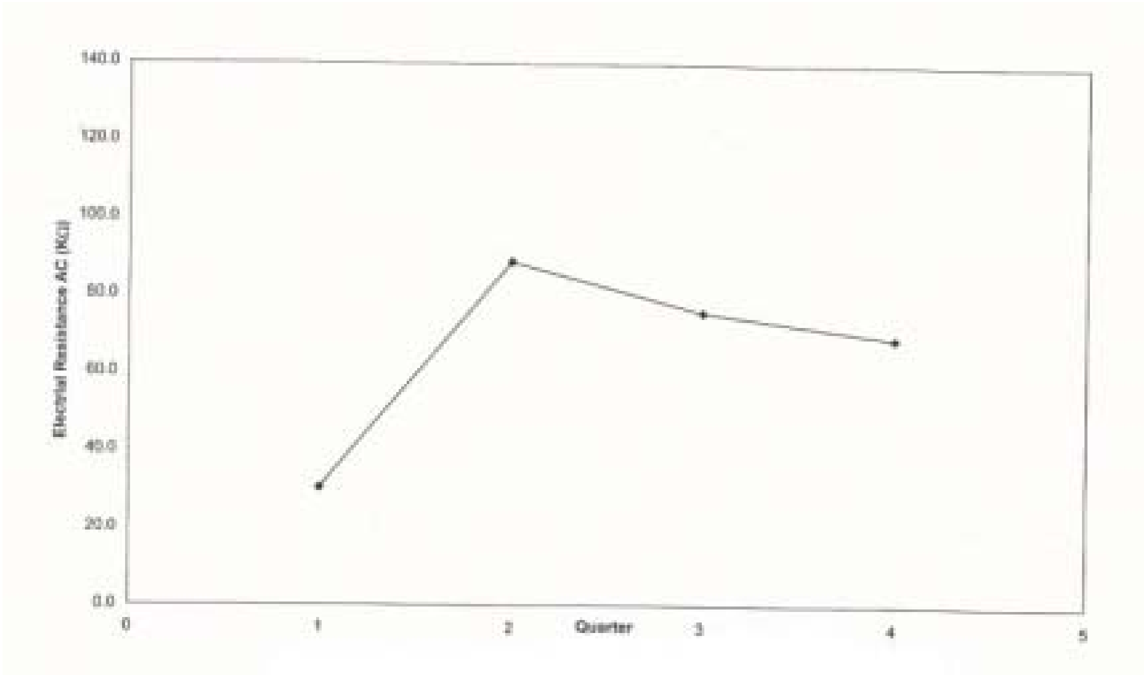

Fig. 4.5: Route 130 Westbound Average Electrical Resistance AC (KΩ)

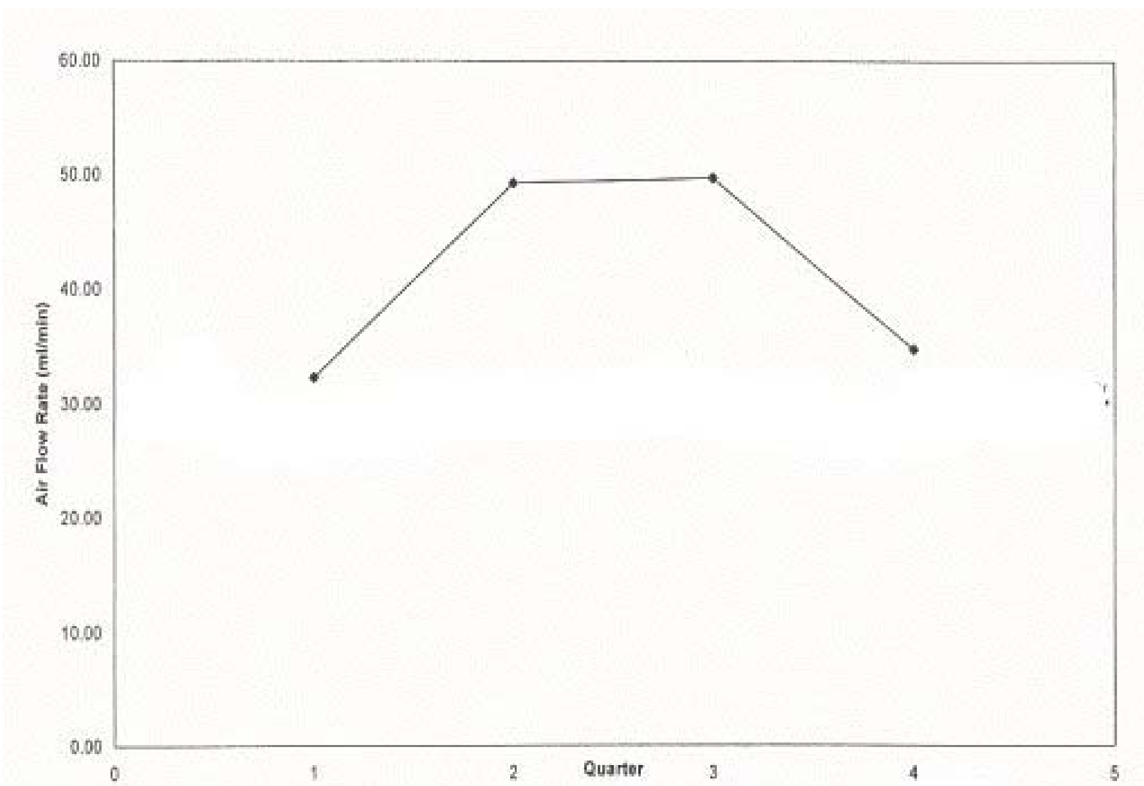

Fig. 4.6: North Main Street Westbound Average Air Flow Rate (ml/min)

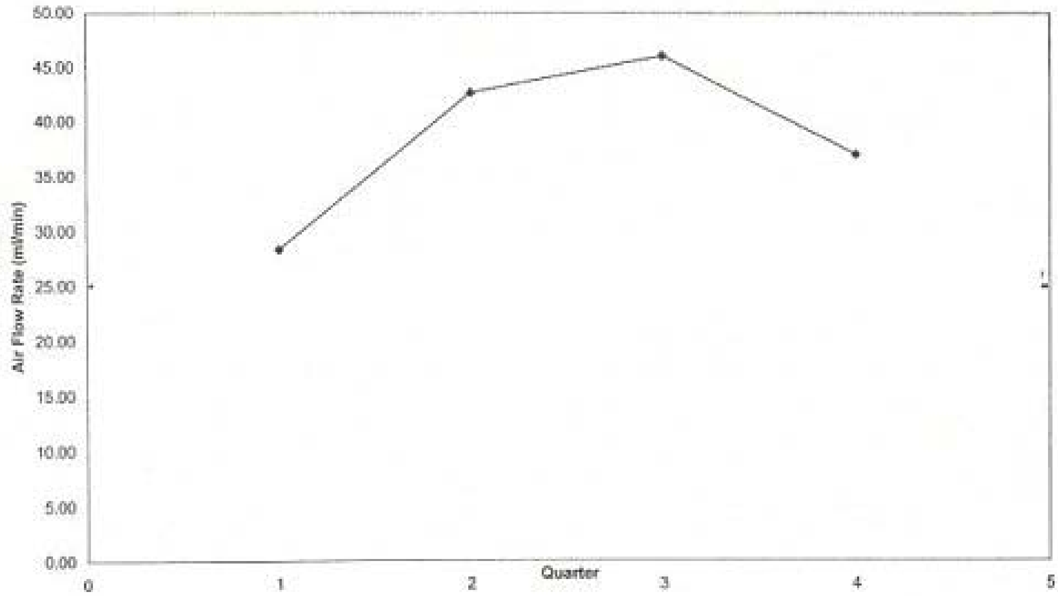

Fig. 4.7: North Main Street Eastbound Average Air Flow Rate (ml/min)

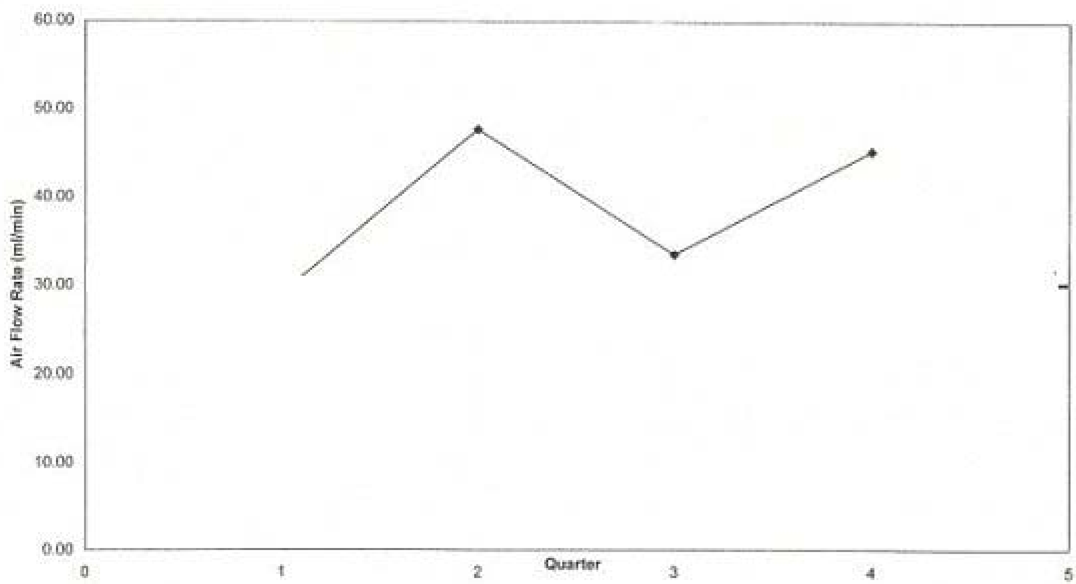

Fig. 4.8: Wyckoff Road Westbound Average Air Flow Rate (ml/min)

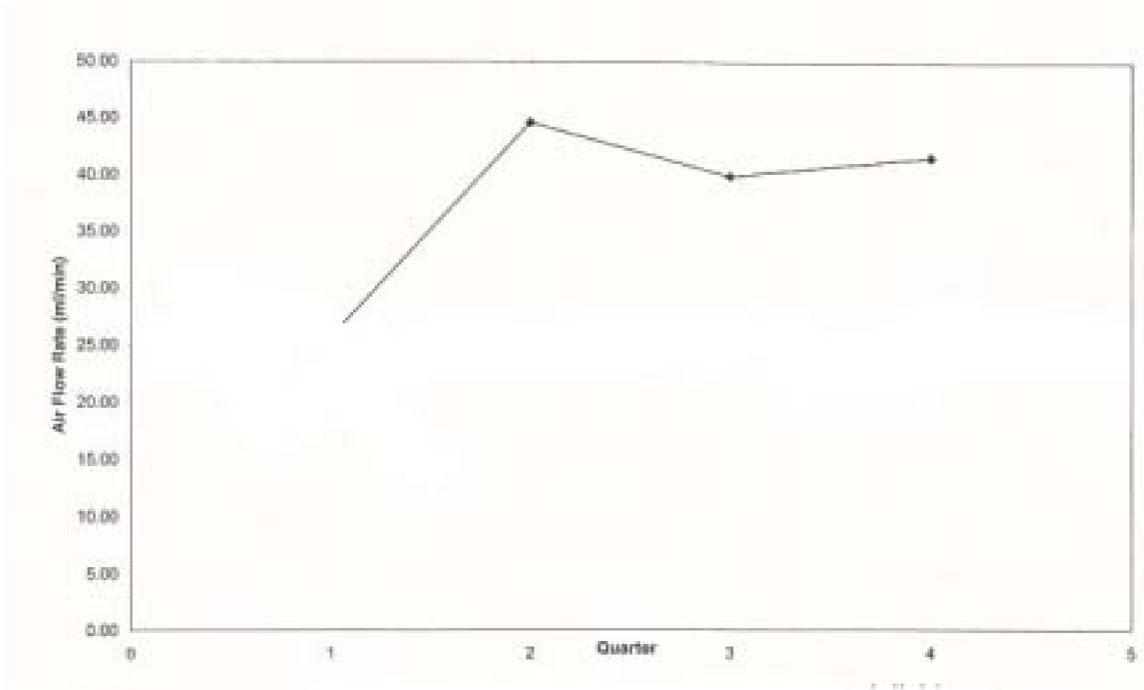

Fig. 4.9: Wyckoff Road Westbound Average Air Flow Rate (ml/min)

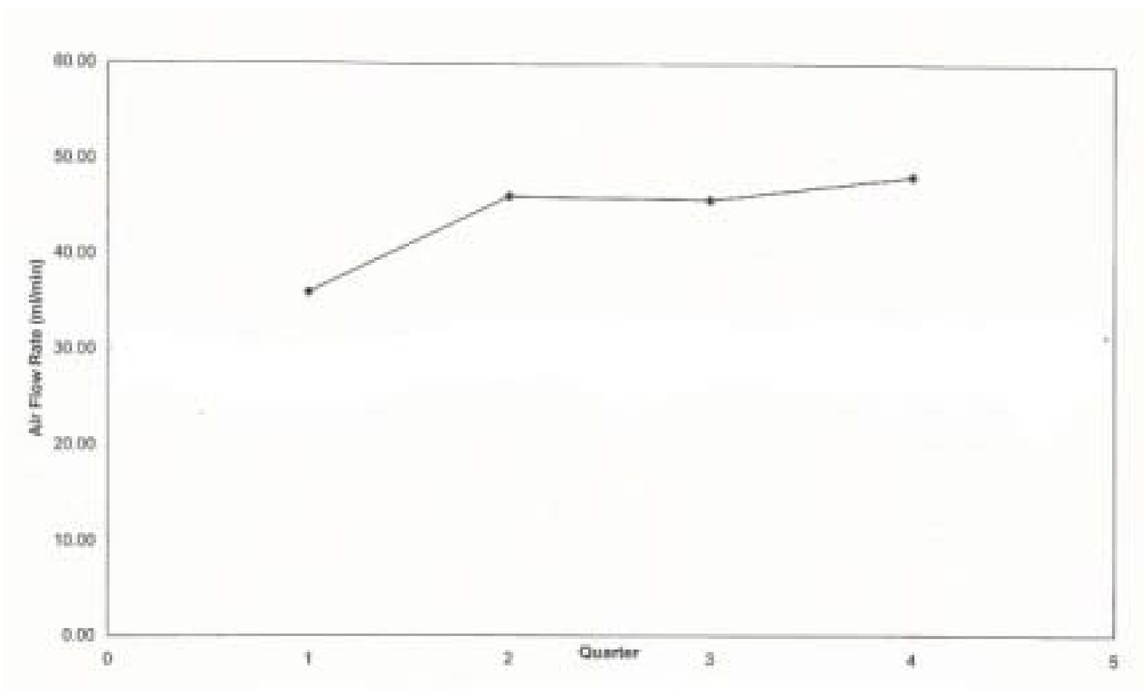

Fig. 4.10: Route 130 Westbound Average Air Flow Rate (ml/min)

4.2 Corrosion Measurements

Corrosion potential and corrosion rate (ASTM G109) were made on both minidecks and the five bridge decks. For minidecks, each cycle consists of two weeks of ponding with salt water and two weeks of drying. For the bridge decks, measurements were taken at approximately 6 months intervals. Since the corrosion rates were more consistent, the changes in corrosion rate with number of cycles are presented in a graphical form. The actual corrosion rates, corrosion potentials and variation of corrosion potentials are presented in Appendix G.

The variations of corrosion rate for minidecks are presented in Fig. 4.11 to 4.15. The results for decks with W.R. Grace (DCI – S), Quick Wright Associates Inc. (XYPEX C-2000), Master Builders, INC (Rheocrete 222+) and Sika Corporation (Ferrogard 901) are presented is Fig. 4.11, 4.12, 4.13 and 4.14 respectively. The results for the control deck with no inhibitors are presented in Fig. 4.15.

The variation of corrosion rate measured on actual decks is presented in Fig. 4.16 to 4.10. The results The results for decks with W.R. Grace (DCI – S), Quick Wright Associates Inc. (XYPEX C-2000), Master Builders, INC (Rheocrete 222+) and Sika Corporation (Ferrogard 901) are presented is Fig. 4.16, 4.17, 4.18 and 4.19 respectively. The results for the control deck with no inhibitors are presented in Fig. 4.20.

A careful review of Fig. 4.11 to 4.20 and results presented in Appendix G lead to the following observations:

- As expected, the variation of corrosion potential and corrosion rate is smaller in bridge decks as compared to minidecks. This should be expected because the corrosion potential on actual decks is non existent and minidecks were ponded with salt solution.
- Corrosion activity is much lower in actual decks as compared to mini decks. For example, the corrosion rate for actual decks is well bellow 1 μA where as for

minidecks the values are as high as 6 μA. Here again, the presence of salt solution on minidecks plays an important role.

- There should not be any corrosion activity in the well constructed bridge decks for at least 15 years, and the very low readings confirm the early trend.
- For minidecks, the corrosion rate has to be more than 10 μA in order to ascertain the presence of corrosion. Unfortunately, none of the minidecks had average readings more than 7 μA. Most readings were less than 2 μA and hence conclusions could not be drawn on the actual or comparative performance of the four corrosion inhibitors. Some of the decks are beginning to show some corrosion activity. However, it was decided to terminate the rest program because the decks were evaluated for more than 2 years.
- Further analysis of corrosion activities are presented in section 4.3.

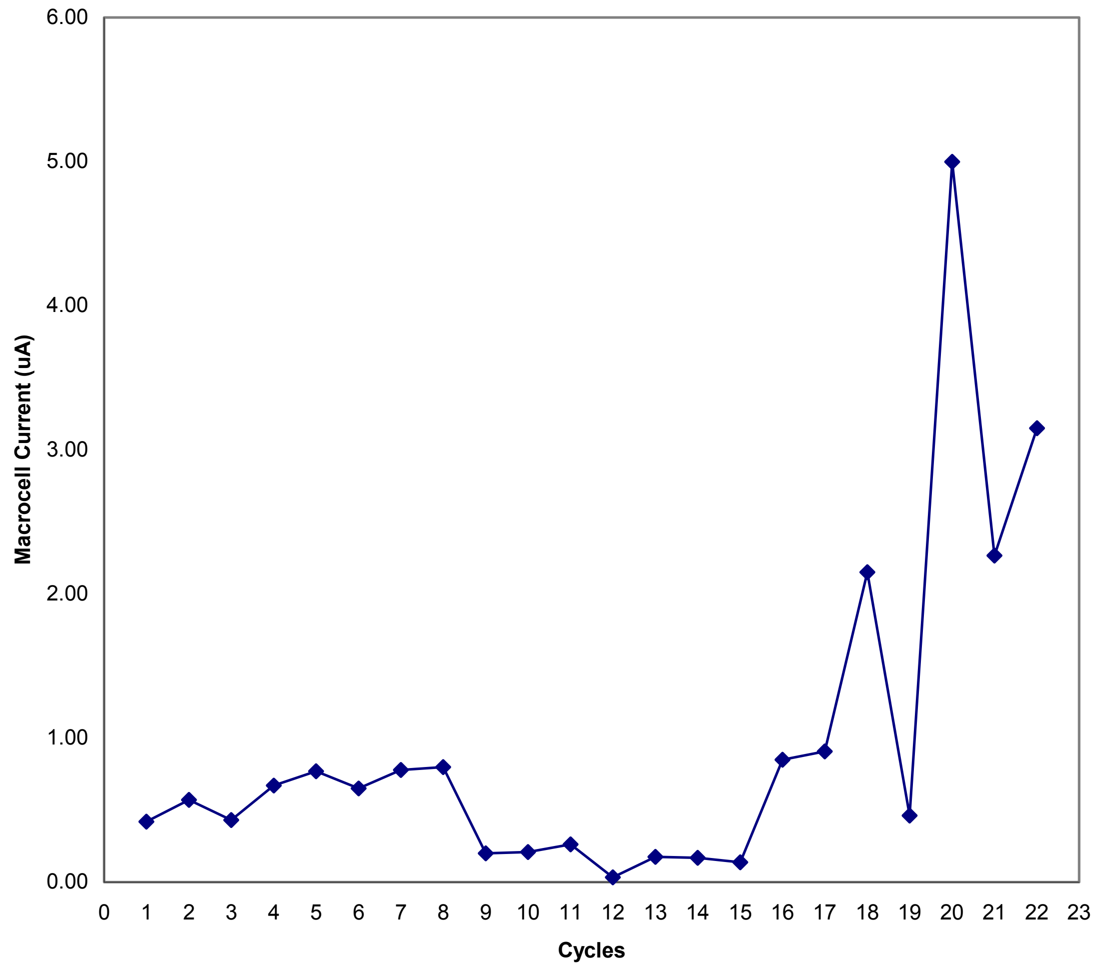

Fig 4.11: Minideck A – Average Corrosion Rate Macrocell Current (μA)

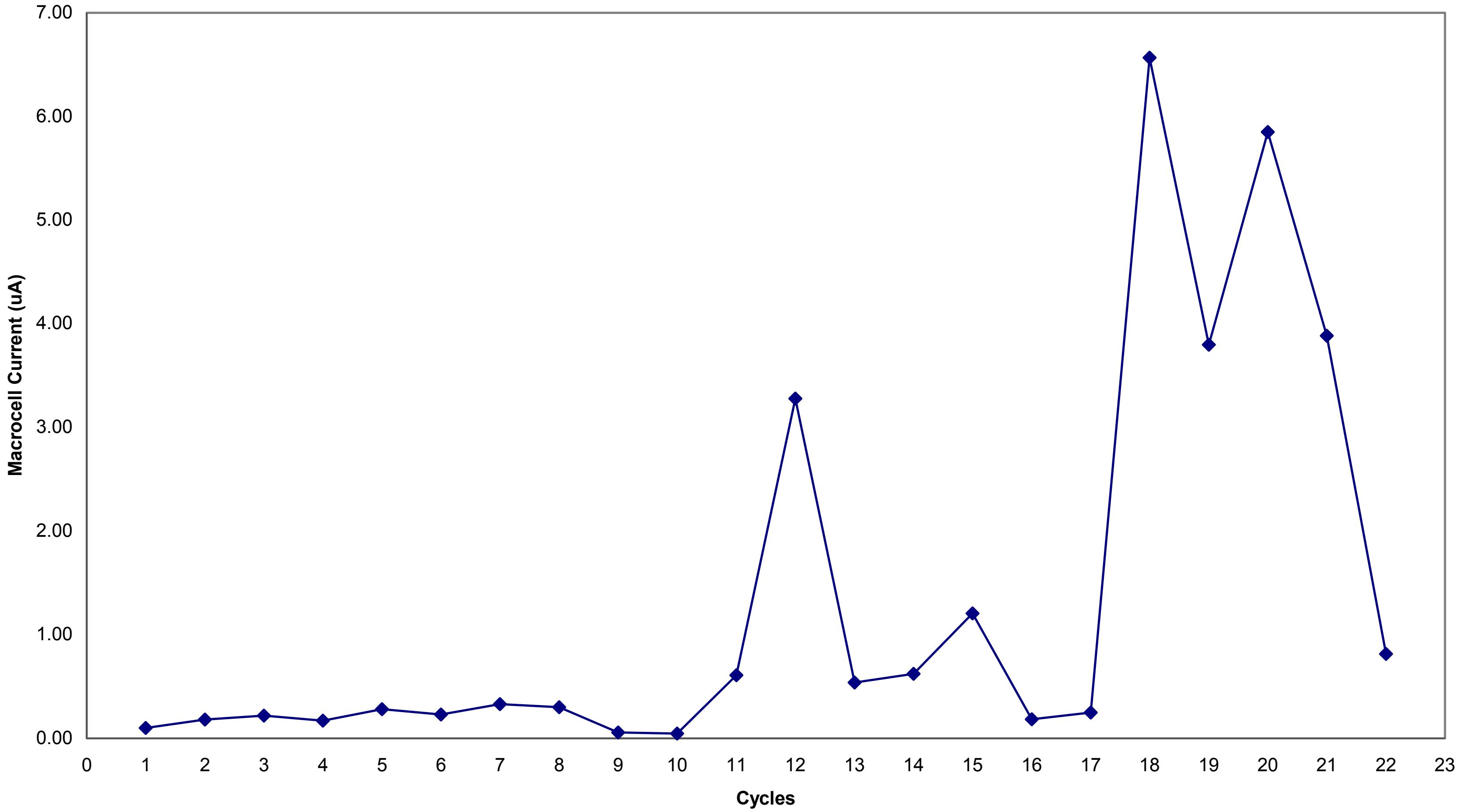

Fig 4.12: Minideck B – Average Corrosion Rate Macrocell Current (μA)

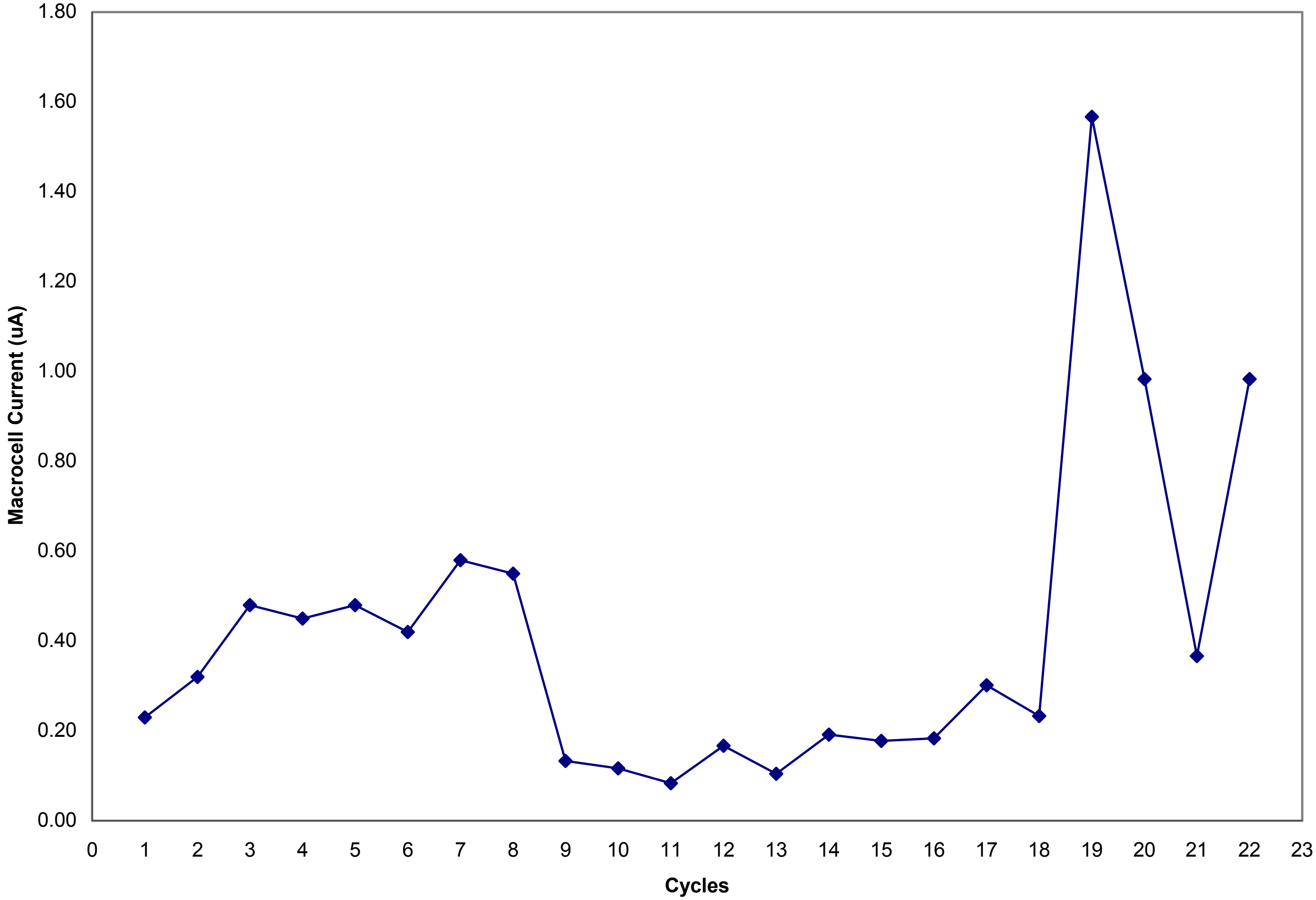

Fig. 4.13: Minideck C – Average Corrosion Rate Macrocell Current (μA)

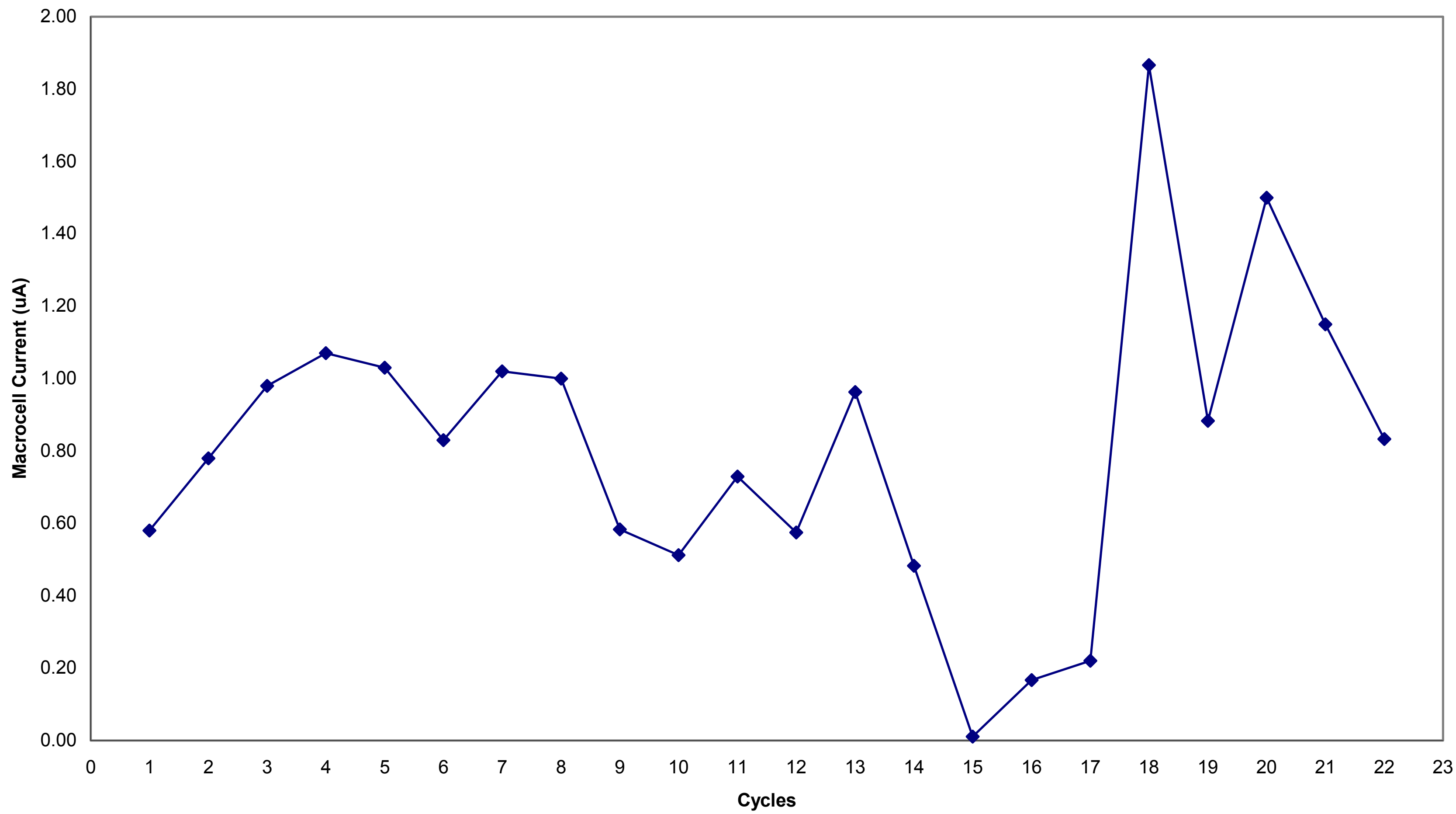

Fig 4.14: Minideck D – Average Corrosion Rate Macrocell Current (µA)

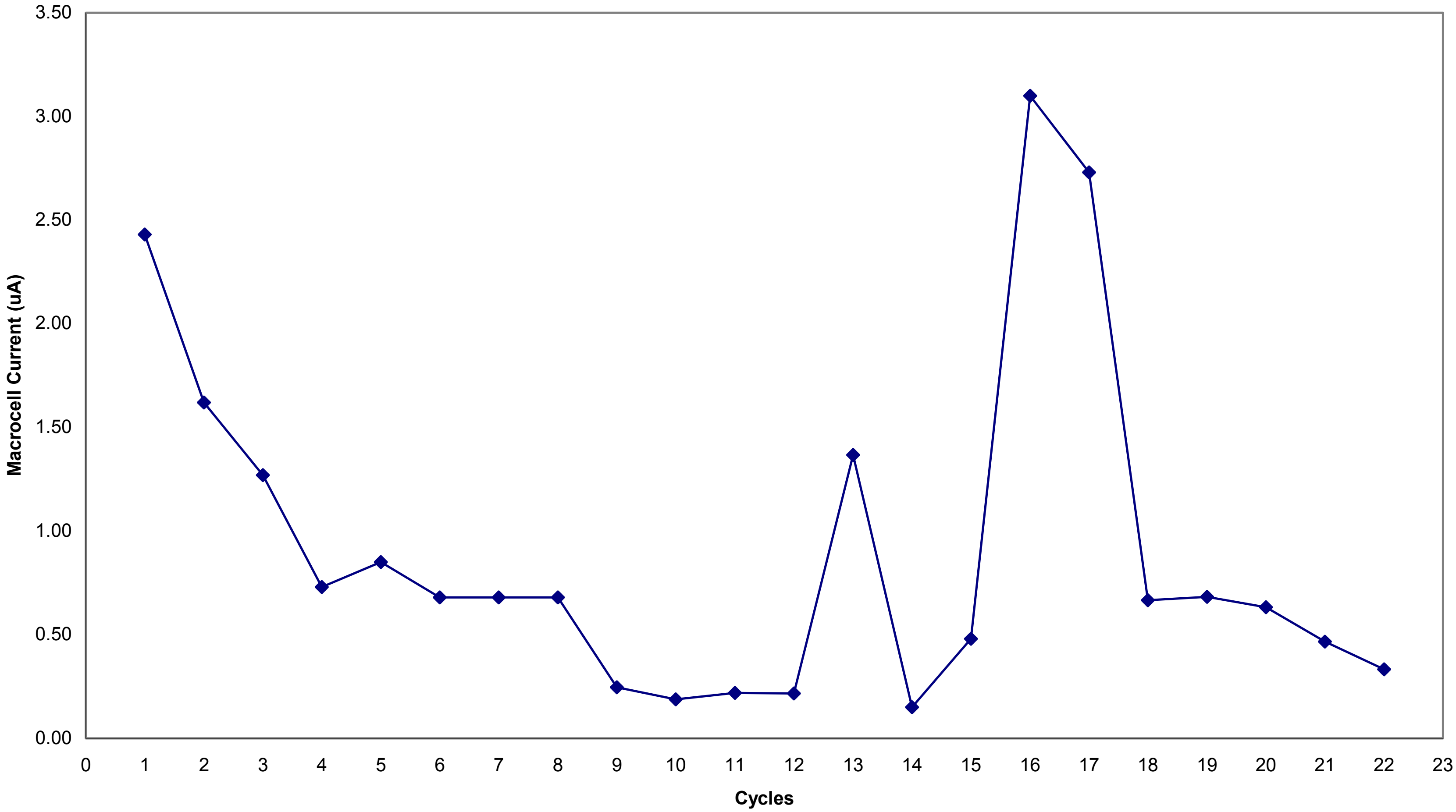

Fig. 4.15: Minideck E – Average Corrosion Rate Macrocell Current (μA)

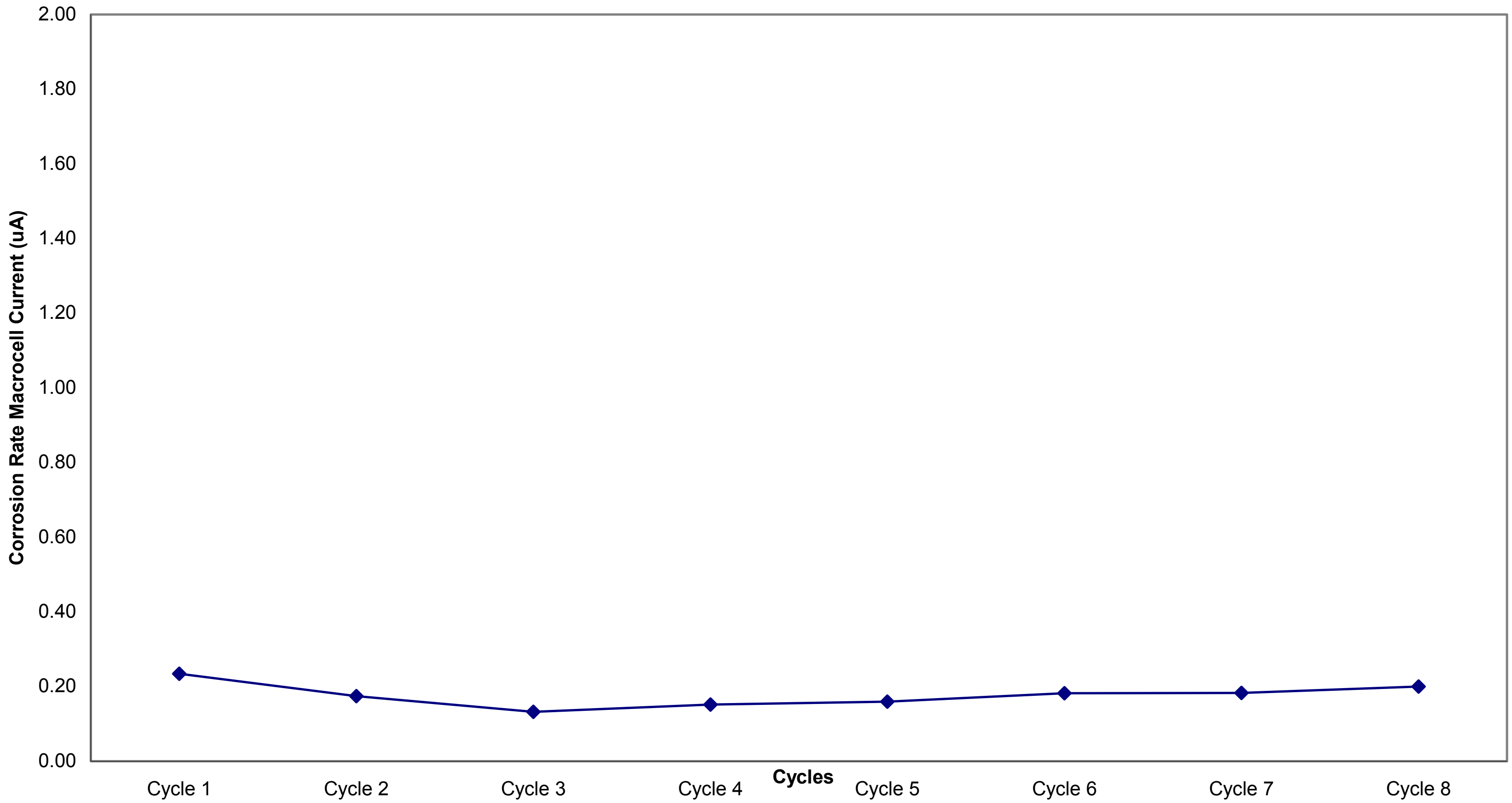

Fig 4.16: North Main Street Westbound GECOR 6 Average Corrosion Rate Macrocell Current (μA)

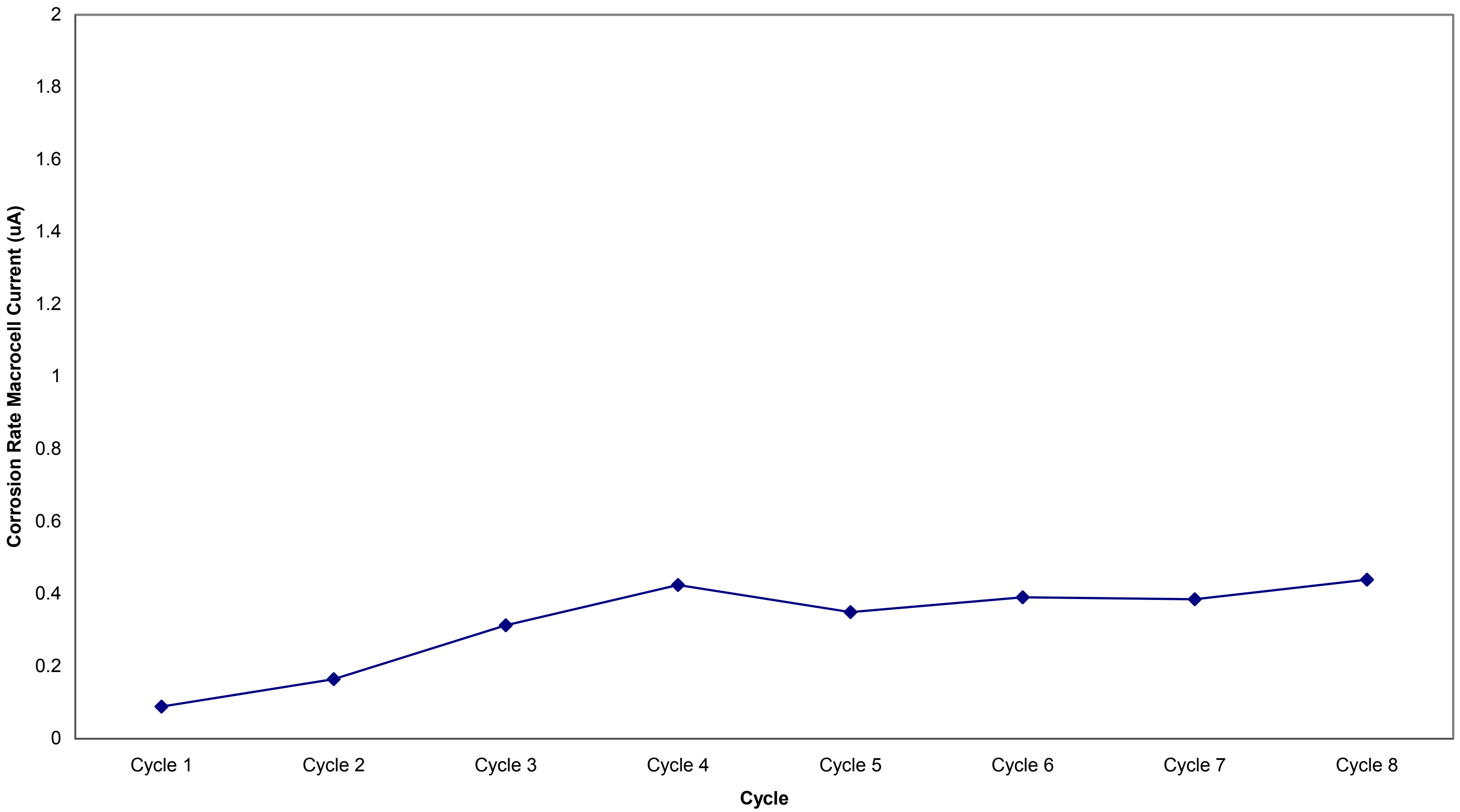

Fig. 4.17: North Main Street Eastbound Average Corrosion Rate Macrocell Current (μA)

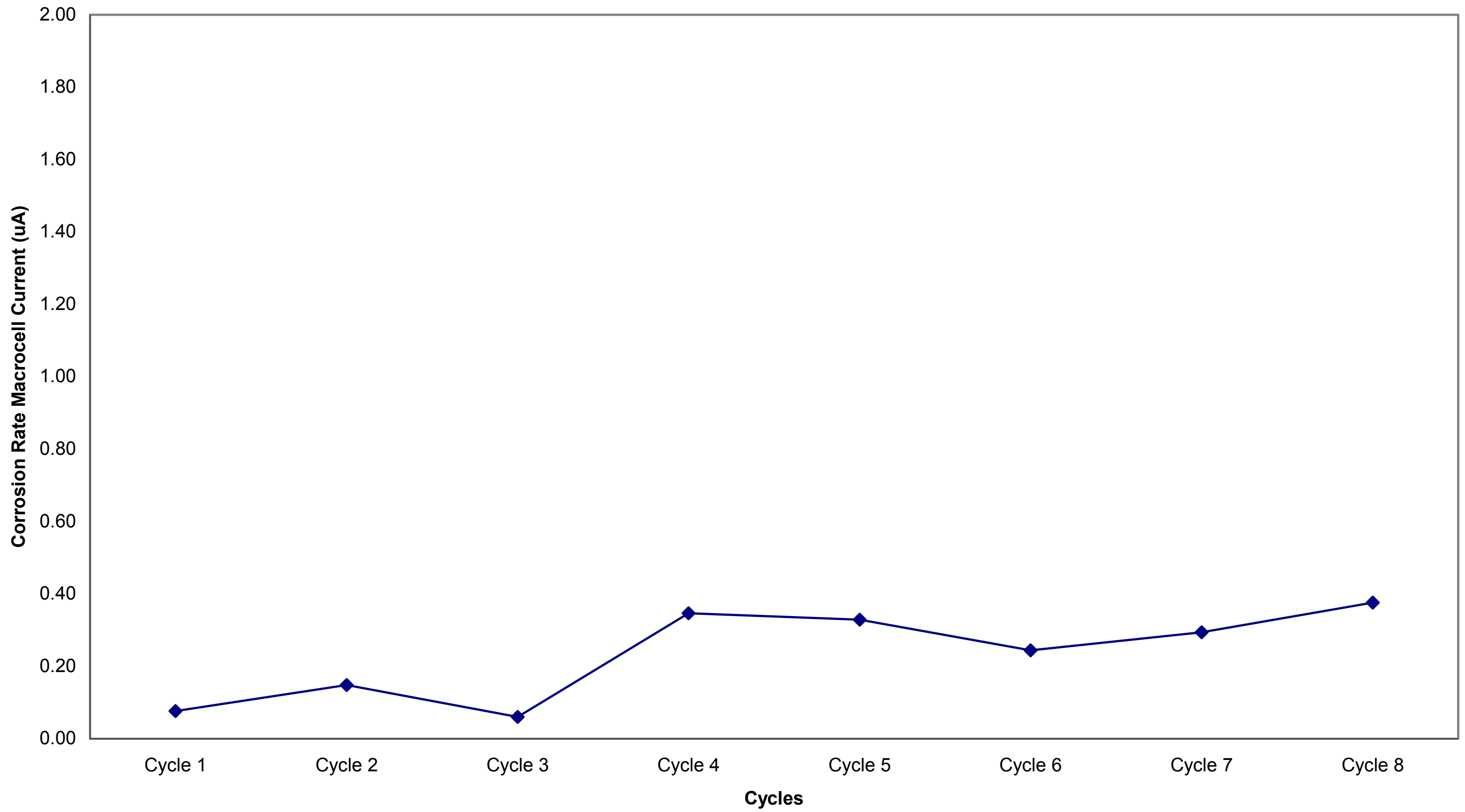

Fig 4.18: Wyckoff Road Westbound GECOR 6 Average Corrosion Rate Macrocell Current (μA)

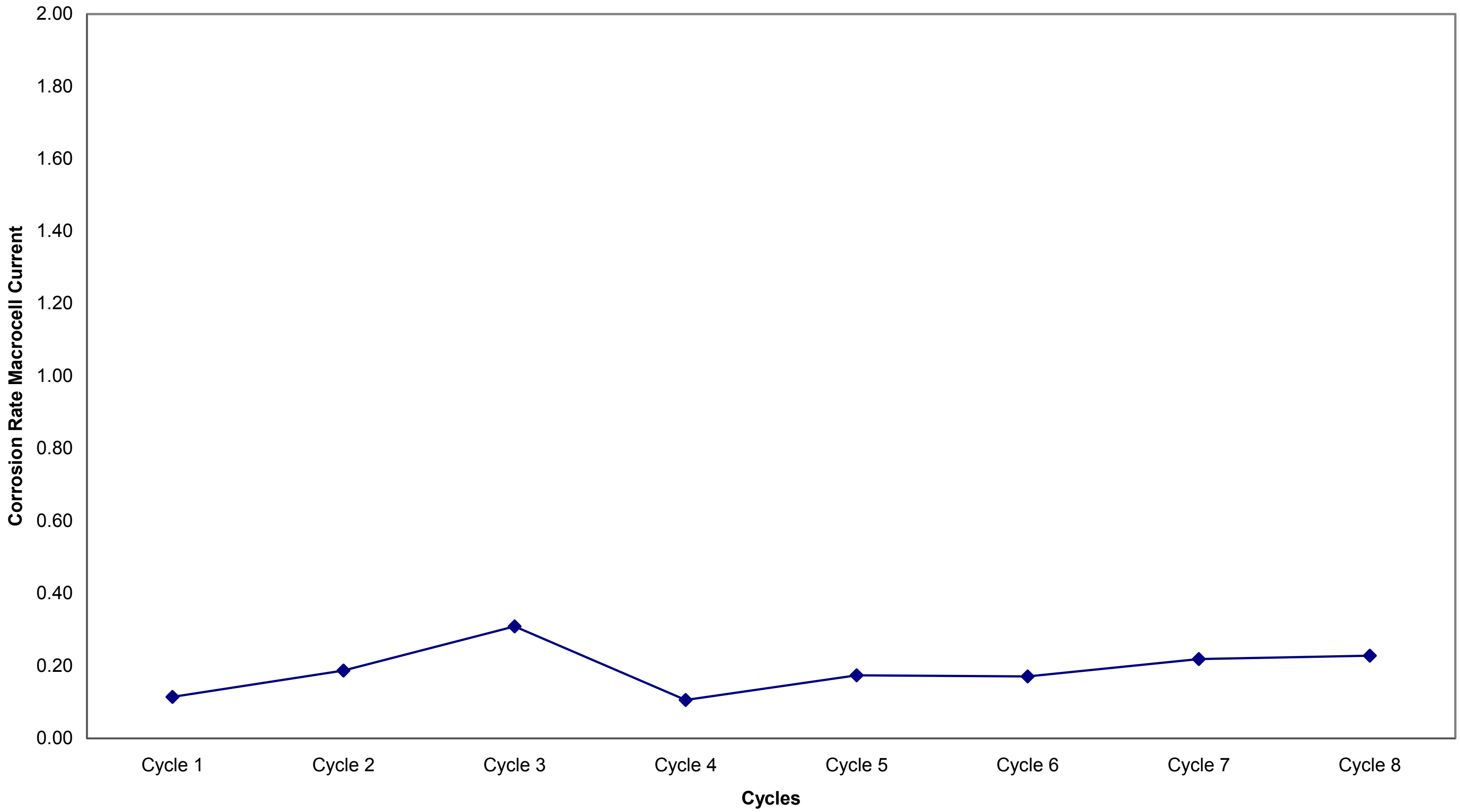

Fig 4.19: Wyckoff Road Eastbound GECOR 6 Average Corrosion Rate Macrocell Current (μA)

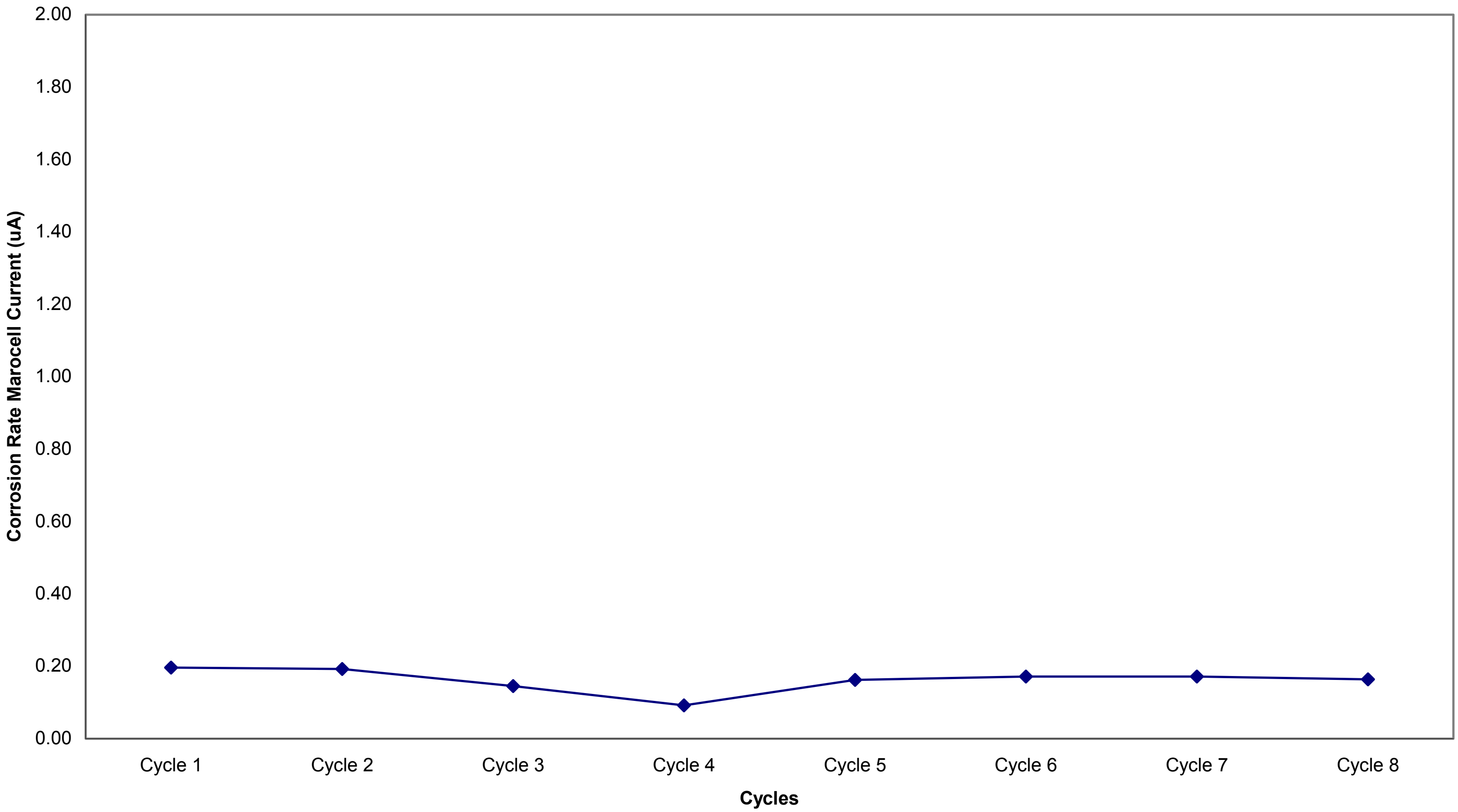

Fig 4.20: Route 130 Westbound GECOR 6 Average Corrosion Rate Macrocell Current (μA)

4.3 Performance of Corrosion Inhibiting Admixtures: Further Analysis

Field data for all five decks including control concrete indicate that there is no corrosion activity. This should be expected because the bridges are less than 4 years old. The instrumentation is in place and the authors recommend that readings be taken after 5 years.

Data taken using minidecks start to show some corrosion activity. Here again, the data does not show much difference except for control concrete. The control concrete seems to show the starting of corrosion activity.

To confirm the observations of graphs and tables, a regression analysis was carried out. For each set of data, a linear regression relationship was developed between corrosion rate and corrosion potential versus the age in days. The correlation coefficients, expressed in terms of R Square, are presented in Table 4.3. The high correlation of 0.926 between corrosion potential for control (Minideck E) shows that the potential is starting to increase. This is an indication of the initiation of corrosion. The equation developed using corrosion potential and logarithm of time further confirms the aforementioned observation. The R square for regressions using Logarithm of time is presented in Table 4.4.

Table 4.3: R Square Values for Corrosion Rate and Corrosion Potential

(a) Corrosion Rate

Minideck	R Square
A	0.169406322
B	0.245391494
C	0.047466507
D	0.001754974
E	0.097588551

(b) Corrosion Potential

Minideck	R Square
A	0.157884832
B	0.248121115
C	0.458786955
D	0.512547608
E	0.926168975

Table 4.4: R Square Values for the Correlation between the Logarithm of time and the Corrosion Rate and Corrosion Potential

(a) Corrosion Rate

Minideck	R Square
A	0.082462327
B	0.220550345
C	0.019432379
D	0.063782587
E	0.017419943

(b) Corrosion Potential

Minideck	R Square
A	0.200227812
B	0.257215627
C	0.463155286
D	0.489597971
E	0.881117966

- Continuation of the experiments is needed to fully evaluate the performance of the admixtures.

5. Conclusions and Recommendations

5.1 Conclusions

Based on the experimental results and observations made during the fabrication and testing, the following conclusions can be drawn:

- There are no significant differences in the plastic and hardened concrete properties for the four admixtures evaluated.
- The authors suggest that though the results of the Surface Air Flow Field Permeability Indicator can be used for a rough evaluation and comparison of admixtures, it should not be used as an accurate means to determine air permeability.
- In authors' opinion, the GECOR 6 Corrosion Rate Meter provides better electrical resistance reading than the Electrical Resistance Test of Penetrating Sealers.
- Time of exposure is not sufficient to cause any corrosion activity in the field. This is reflected in the corrosion potential and corrosion rate readings taken in the field. If the instrumentation is protected readings could be taken after 15 or 20 years of exposure.
- As expected, the laboratory samples had more corrosion activity. However, here again, the corrosion was not sufficient to evaluate the difference in behavior among various admixtures. Since the samples are not cracked, admixtures that decrease the permeability show less corrosion activity. However, the difference is not statistically different. The control mix is starting to show some corrosion activity. This lack of corrosion activity denied the achievement of the objective of "evaluation of the effectiveness of the admixtures."

5.2 Recommendations

Based on the scientific principles and comparative behavior of mini decks, 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.

The aforementioned statement is not intended to indicate that only XYPEX is recommended for use. The remaining three admixtures are being used in the field. Since we could not initiate the corrosion in any of the minidecks, we are not able to provide any recommendations on the contribution of inhibitors. Since the quality of concrete and quality control were good, the control concrete itself provided very good performance. Even though this is good and logical, the primary objective of the research could not be fulfilled. Since the experiments were run for more than 2 years, the NJDOT decided to terminate the project.

For field study, the authors strongly recommend to continue the measurements of corrosion potential and corrosion rate. The instrumentation is in place and the results will be very valuable for the entire world. It is recommended that the readings should be taken every 6 months. Since the bridges are in use, NJDOT should provide traffic control during measurements. Since the instrumentation is in place, the cost for the measurement and yearly report could be in the range of $7,000. If the contract is extended to 10 years, 15 years data could be obtained for an additional cost of $70,000. The authors believe that the uniqueness of this database, which does not exit anywhere, makes this expenditure worthwhile.

For the laboratory study, improvements are needed for the current procedure. The major problem was the permeability of concrete. The concrete should not be allowed to dry-out and the corrosion should be induced after 24 hours. The authors recommend that NJDOT initiate another study to develop the test procedure. The main factors that contribute to corrosion are permeability of concrete and cracks through which the chemicals permeate. The accelerated test method should be designed to incorporate these two factors. The study should utilize 2 or 3 NJDOT standard mixes with no admixture. However, for both sets of specimens, a higher water cement ratio should be used to increase the permeability of concrete; In addition, the samples should not be cured, resulting further increase in permeability.

The mini decks can be prepared using the same procedure used for the current Minidecks. However, for one set of samples, very thin plastic plates should be placed on both top and bottom covers to simulate cracking.

The objective of the new study is to develop an accelerated test method that will provide corrosion within 18 months. The test method should be able to evaluate the effectiveness of corrosion inhibitors. The envisioned variables are as follows:

- Minimum water-cement ratio that can provide corrosion in 18 months for the NJDOT mixes.
- Maximum thickness of plates used for crack simulation.

The researchers can chose a range for both water-cement ratio and plate thickness to formulate their experimental program.

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Appendix A

Description of Equipment and Test Procedure for GECOR 6

The GECOR 6 Corrosion Rate Meter has three major components, the rate meter and two separate sensors. Only the larger sensor was used during this project. The sensor is filled with a saturated $Cu/CuSO_4$ solution for the test for half-cell potential. The main components of this device can be seen in Fig.A.1. A wet sponge is used between the probe and the concrete surface as seen in Fig. A.2. Long Lengths of wire are also provided to connect the sensor to the rate meter and to connect the rate meter to the reinforcing bar mat of the bridge deck, a necessary step for the operation of the meter.

The procedure for the operation of the GECOR 6 Corrosion Rate Meter is as follows (Scannel, 1996):

1. The device should not be operated at temperatures below 0°C (32°°F) or above 50 C (122°F). The relative humidity within the unit should not exceed 80%.

2. Use a reinforcing steel locator to define the layout at the test location. Mark the bar pattern on the concrete surface at the test location.

3. Place a wet sponge and the sensor over a single bar or over the point where the bars intersect perpendicularly if the diameter of both bars is known.

4. Connect the appropriate lead to an exposed bar. The leads from the sensor and exposed reinforcing steel are then connected to the GECOR device.

5. Turn on the unit. The program version appears on the display screen.

    "LG-ECM-06 V2.0
    © GEOCISA 1993"

6. A help message appears on the screen momentarily. This message advises the operator to use the arrows for selecting an option and C.R. to activate an option. The various options are:
   - "CORROSION RATE MEASUREMENT"
   - "REL.HUMIDITY AND TEMPERATURE"
   - "RESISTIVITY MEASUREMENT PARAMETERS"
   - "EDIT MEASUREMENT PARAMETERS"
   - "DATAFILE SYSTEM EDITING"
   - "DATAAND TIME CONTROL"
7. Select the option CORROSION RATE MEASUREMENT and press the C.R. key.
8. The screen prompts the user to input the area of steel. Calculate the area of steel using the relationship, Area = 3.142 x D x 10.5 cm. D is the diameter of the bar in centimeters and 10.5 cm. (4 in.) is the length of the bar confined by the guard ring. Key ii the area to one decimal space. In case of an error, use the B key to delete the previous character. Press the C.R. key to enter the area.
9. The next screen displays;

   "ADJUSTING
   OFFSET, WAIT"

No operator input is required at this stage. The meter measures the half-cell potential and then nulls it out to measure the potential shift created by the current applied from the sensor.

10. The next screen displays:

    "Er mV OK"
    "Vs mV OK"

    Er (E_{CORR}) is the static half-cell potential versus CSE and Vs is the difference in potential between the reference electrodes, which control the current confinement. Once the Er and the Vs values are displayed, no input is required from the operator.

11. The meter now calculates the optimum applied current I_{CE}. This current is applied through the counter electrode at the final stage of the measurement. The optimum I_{CE} value is displayed. No input is required from the operator.
12. The next screen displays the polarized potential values. No input is required from the operator.
13. The meter now calculates the "balance constant" in order to apply the correct current to the guard ring. It is displayed on the next screen. No input is required from the operator.
14. The meter now calculated the corrosion rate using the data collected from the sensor and input from the operator. The corrosion rate is displayed in $\mu A/cm^2$. Associated parameters including corrosion potential, mV and electrical resistance KΩ can be viewed using the cursor keys.
15. Record the corrosion rate, corrosion potential, electrical resistance.
16. Press the B key to reset the meter for the next reading. The screen will return to CORROSION RATE MEASUREMENT. Repeat the procedure for the next test location.

The corrosion rate and corrosion potential data can be interpreted using Table A.1 and A.2 and Tables B.1 and B.2 in Appendix B, respectively. Higher resistance is an indication for less potential for corrosion in the embedded steel due to higher density of the concrete. Higher resistance is also an indication of improved insulation against the electrochemical process of corrosion.

Unlike The Electrical Resistance Test for Penetrating Sealers, the GECOR 6 penetrates the concrete surface for a greater area of measurement.

Table A.1: Interpretation of Corrosion Rate Data (Scannell, 1997)

I_{CORR} μA/cm^2	**Corrosion Condition**
Less than 0.1	Passive Condition
0.1 to 0.5	Low to Moderate Corrosion
0.5 to 1.0	Moderate to High Corrosion
Greater than 1.0	High Corrosion

Table A.2: Interpretation of Half Cell (Corrosion) Potential Readings (ASTM C 876)

Half cell Potential (mV)	**Corrosion Activity**
-200>	90% Probability of No Corrosion Occurring
-200 to –350	Corrosion Activity Uncertain
<-350	90% Probability of Corrosion Occurring

Fig.A.1: Components of the GECOR 6 Corrosion Rate Meter

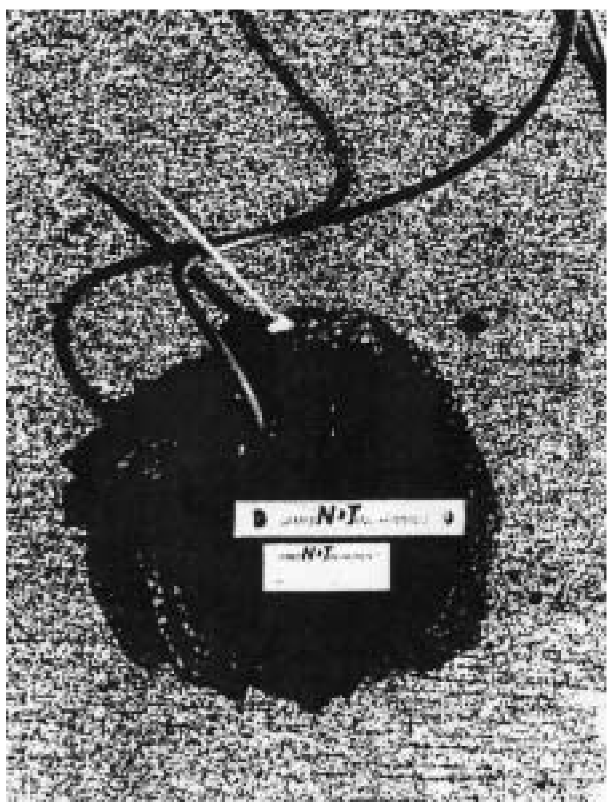

Fig.A.2: GECOR 6 Corrosion Rate Meter Sensor with Sponge

Appendix B

Table B.1: Interpretation of Corrosion rate data (Scannell, 1997)

Icorr (μA/cm^2)	**Corrosion Condition**
Less than 0.1	Passive Condition
0.1 to 0.5	Low to Moderate Corrosion
0.5 to 1	Moderate to High Corrosion
Greater than 1.0	High Corrosion

Table B.2: Interpretation of Half Cell (Corrosion) Potential Readings (ASTM C 876)

Half Cell Potential (mV)	**Corrosion Activity**
-200	90% Probability of No Corrosion Occurring
-200 to -350	Corrosion Activity Uncertain
<350	90% Probability of Corrosion Occurring

Table B.3: Relative Concrete Permeability by Surface Air Flow (Manual for the Operation of a Surface Air Flow Field Permeability Indicator, 1994).

Air Flow Rate (ml/minute)	**Relative Permeability Indicated**
0 to 30	Low
30 to 80	Moderate
80>	High

Appendix C

Description of the Equipment and the Test Procedure for the Surface Air Flow Field Permeability Indicator

A picture of the device and its accessories can be seen in Fig.C.1 and Fig.C.2. For transportability the device uses a rechargeable NI-Cad battery. The suction foot is mounted using three centering springs to allow it to rotate and swivel in relation to the main body. A closed cell foam gasket is used between the foot and the testing surface to create an airtight seal. Two-foot pads are threaded into the suction foot so the operator can apply pressure to compress the gasket. The switches to open the solenoid and hold the current reading are located within easy reach at the base of the handles. Digital displays for the permeability readings and the time are located at the top of the device Fig.C.3. Outline drawings of the device and its schematics can be seen on Fig.C.4 and Fig.C.5, respectively (Manual for the Operation of a Surface Air Flow Field Permeability Indicator, 1994).

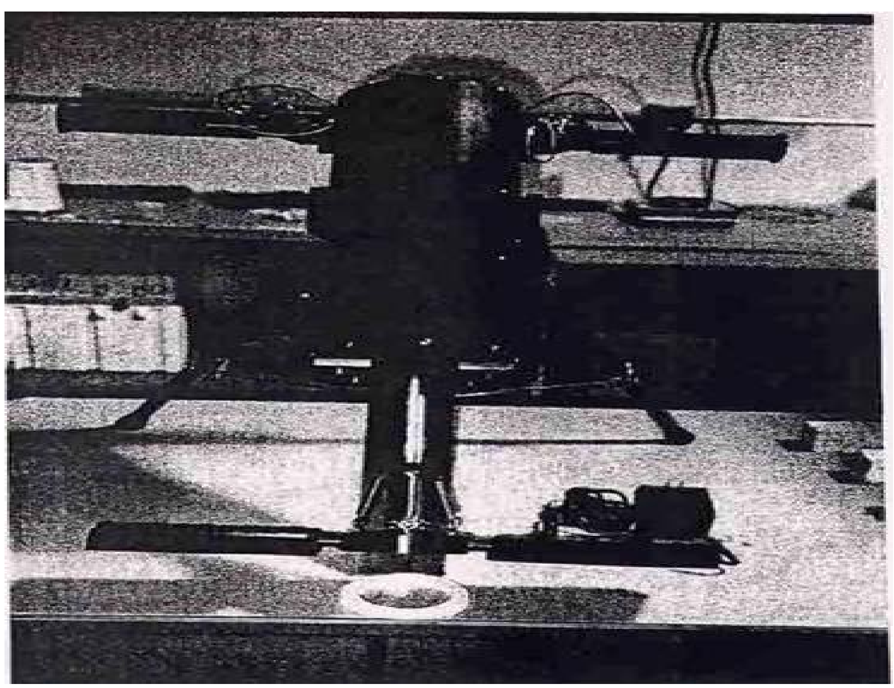

Fig.C.1: Surface Air Flow Field Permeability Indicator (Front View)

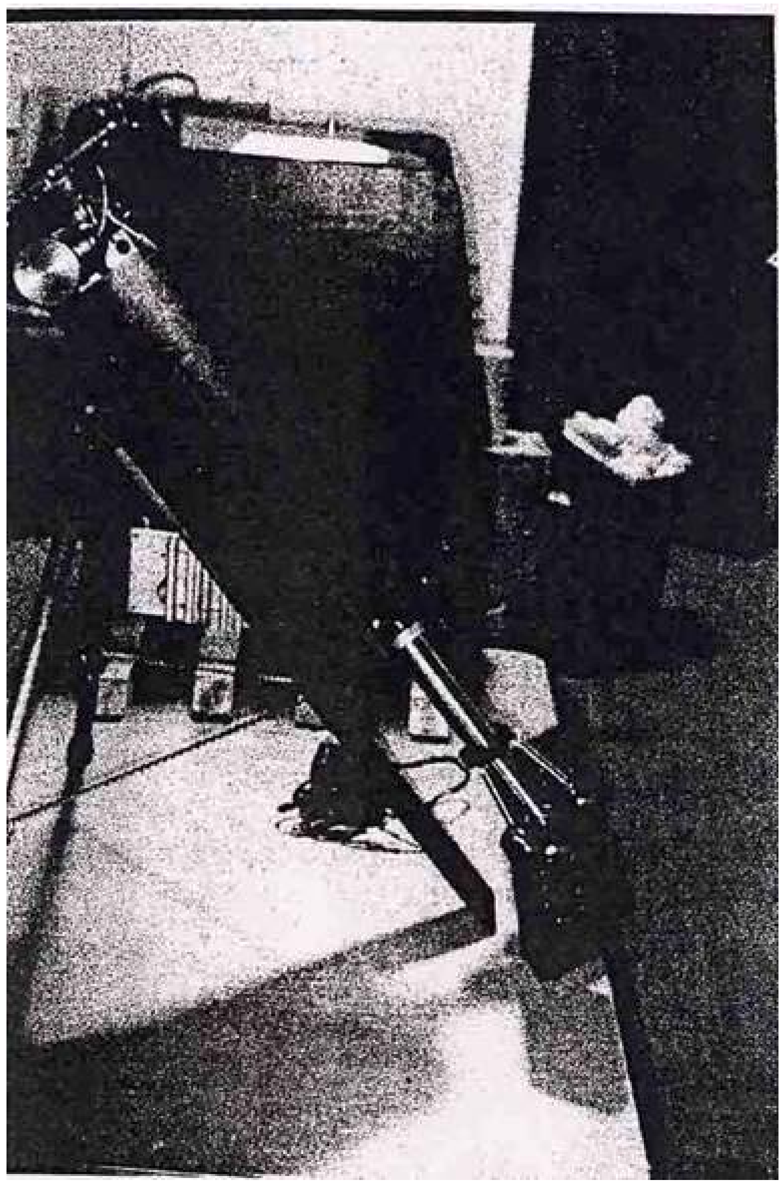

Fig.C.2: Surface Air Flow Field Permeability Indicator (Front View)

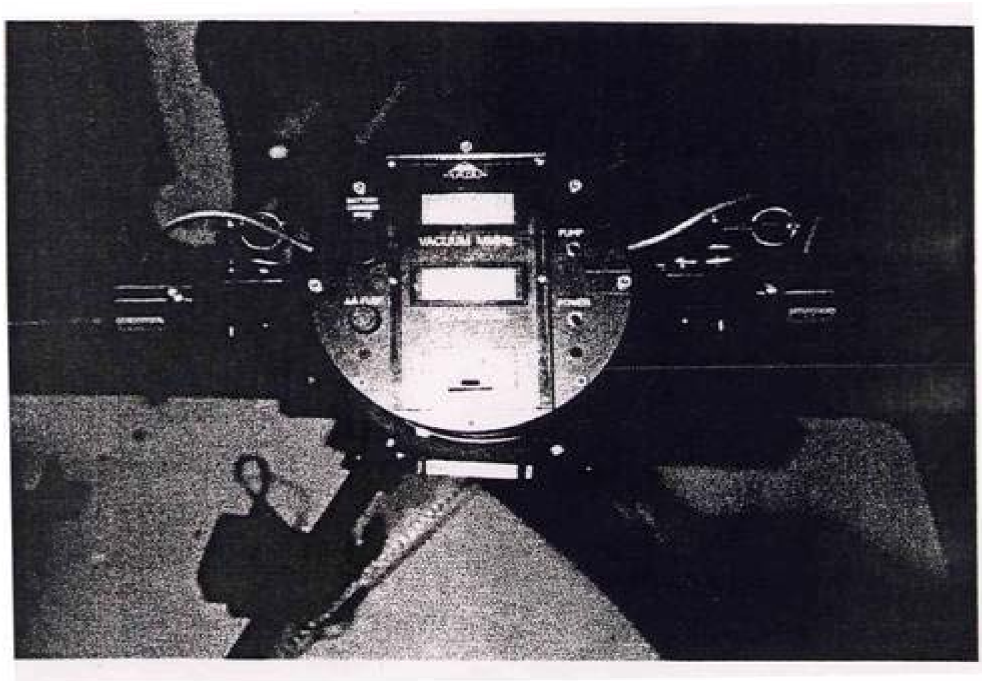

Fig.C.3: Surface Air Flow Field Permeability Indicator
(Top View of Digital Displays)

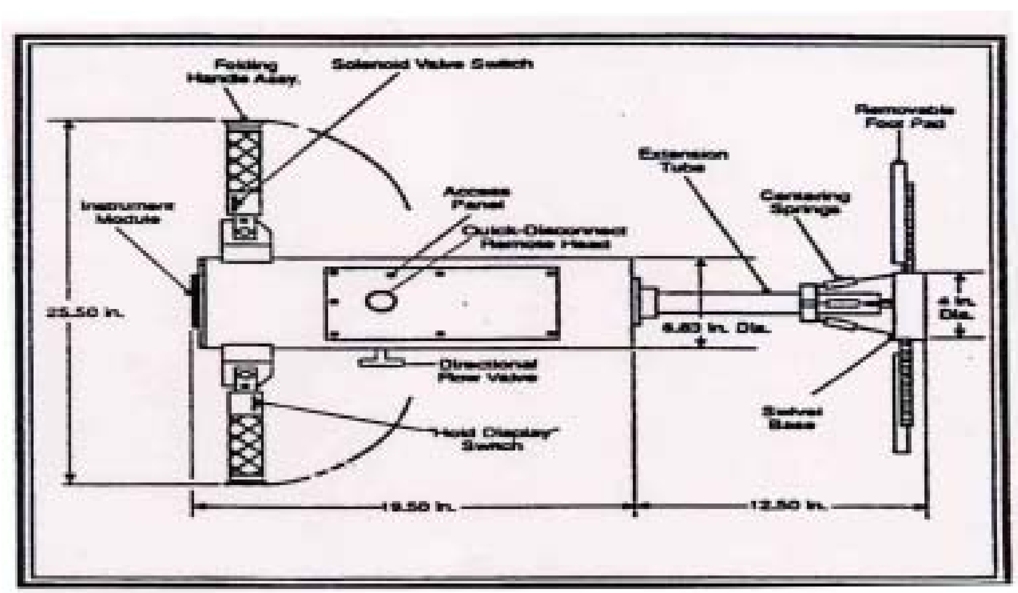

Fig.C.4: Drawing of Concrete Surface Air Flow Permeability Indicator

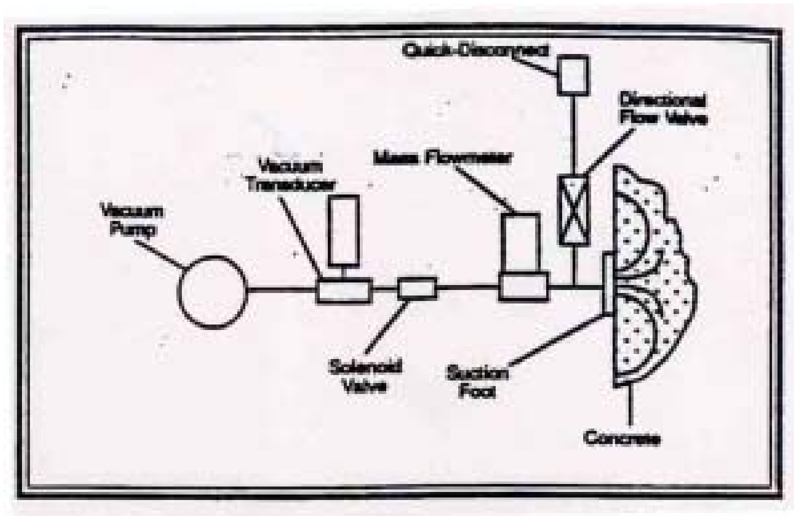

Fig.C.5: Schematic of Concrete Surface Air Flow Permeability Indicator

The procedure for the operation of the SAF on horizontal surfaces is as follows (<u>Manual for the Operation of a Surface Air Flow Field Permeability Indicator</u>, 1994).

1. Remove the instrument from its case and install the two-foot pads. The footpads should be screwed all the way into the tapped holes on the suction foot base and then backed out until the aluminum-checkered plates are pointed to the top of the machine.

2. Unfold the two handles by pushing the buttons on either end of the "T" handle lock pins, and removing them. When the handles are horizontal, the lock pins are needed to be reinserted the other holes in the handle brackets to lock the handles in the extended positions.

3. Make sure all the switches are in the off position and the left handle switch in the release position. Set the elapsed time indicator to zero by pushing the RESET switch. Ensure that the directional valve switch is in the down position.

4. Charge the battery for at least eighteen hours before testing.

5. Unplug the charger and turn on the power switch, and observe that the digital displays are activated. Turn on the power switch. Wait ten minute for the device to warm up. The device should be tested before any field activities to make sure that it is operating correctly. To test the vacuum in a closed system, turn the PUMP in ON position. Wait thirty seconds. The readings should stabilize between 750 to 765 mm Hg. To test the device as an open system, leave the PUMP ON and turn ON the solenoid switch. Wait thirty seconds. The readings should stabilize at a value of 29 to 31 SCCM.

6. To check the device on a reference plate, place the closed cell gasket on an impermeable metallic plate. Center the suction foot over the gasket.

7. Stand on the footpads with the balls of your feet. About half of the body weight should be placed on the footpads and the other half on the heels. This will compress the gasket and form an airtight seal.

8. Turn ON the PUMP. At this time both the flow and vacuum gages will display values and the elapsed time indicator will start. The vacuum should stabilize greater than 650 mm Hg. vacuum. The flow will have a high initial value due to air in the lines, but will stabilize after about fifteen to twenty seconds.

9. Turn On the solenoid

10. When the elapsed time indicator reads 45 seconds, push the left handle to the hold position to freeze the reading. Record the reading at this point. The vacuum should read greater than 650 mm Hg, and the flow should be less than 1 SCCM (1ml/min).

11. Turn off the vacuum PUMP, and the solenoid valve. Turn the switch on the left handle to the release position and push the reset button on the elapsed time indicator. The device is now ready to be moved to the next test spot.

12. Tests on actual concrete surfaces are performed in a manner identical to the initial check test. In some cases, however it may take longer than 45 seconds for the readings to stabilize. Surfaces should be dry, free of dirt or debris, and not cracked grooved or textured.

The permeability of concrete greatly contributes to the corrosion potential of the embedded steel bars due to water and chloride penetration. The lower the permeability the more resistant the concrete is to chloride penetration. The relative concrete permeability readings provided by SAF can be categorized into low, moderate, and high according to the airflow rate (ml/min) illustrated on table 3.9 and Table 6.3 in the Appendix. The collected data and a discussion on the permeability indicated are presented and discussed in the Results and Discussions chapter.

Table C.1: Relative Concrete Permeability by Surface Air Flow (Manual for the Operation of a Surface Air Flow Field Permeability Indicator, 1994)

Air Flow Rate (ml/minute)	**Relative Permeability Indicated**
0 to 30	Low
30 to 80	Moderate
80>	High

Appendix D

Description and Test Procedure for Resistance Measurement

The materials needed for this test are shown in Fig.D.1 and are as follows:

Fine line tape (1/8in. wide)

Metal mask (with 5/8in. wide and 4 in. long cutout)

Conductive silver spray paint

Duct tape

Nilsson 400, soil resistance meter

Multimeter

Thermometer

Infrared propane heater

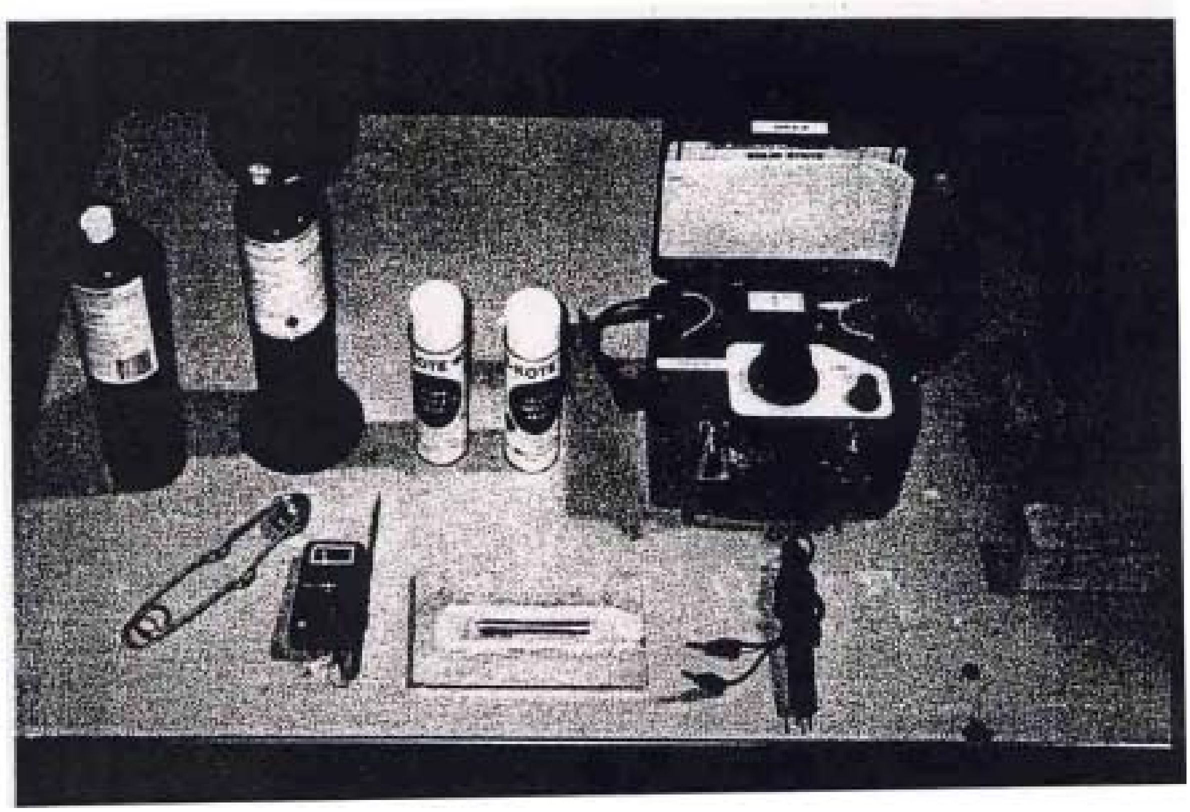

Fig.D.1: Equipment Required for Electrical Resistance Test for Penetrating Sealers

The procedure for the performing the Electrical Resistance Test for Penetrating Sealers is as follows (Scannell, 1996):

1. Surface must be clean and dry with no grooves or cracks.
2. Apply the fine line tape t the test area.
3. Center metal mask over fine line tape.
4. Duct tape mask in place.
5. Spray paint lengthwise over slit six times.
6. Heat surface with infrared heater for five minutes keeping the temperature at 120 F.
7. Repeat steps 5 and 6 two additional times.
8. Remove the mask and the fine line tape.
9. Measure DC end-to-end resistance of both sides of the gage using the multimeter and records the readings.
10. Measure the DC resistance between the two sides of the gage using the multimeter and record the reading.
11. Compare the DC readings for the end-to-end resistance as well and the one taken between the two sides to the acceptance criteria in Table 3.10.
12. Lay wet sponge on gage and keep wet for five minutes.
13. Remove the sponge and press a folder paper towel against the gage for five seconds.
14. Gently wipe the gage with a crumpled paper towel in a lengthwise direction.
15. Place the probes on the soil resistance meter against the gage and record the AC resistance reading.

Table D.1: Preliminary DC Testing of Gauge (Scannell, 1996)

Test	**Acceptance Criteria**
End-to-End Resistance	5 to 15 Ω – Very Good up to 125 Ω - Acceptable
Insulation Resistance (Side-to-Side)	>20MΩ – Normal > 5 MΩ – Acceptable

Appendix E
Details of Connections on Bridge Decks

The details of the connections are presented in Fig.E.1, E.2, E.3, E.4 and E.5. The cables were passed through flexible steel conduits and into rain tight steel enclosure to protect then from the elements and from possible tampering Fig.E.6, E.7, E.8, E.9 and E.10. A reinforcing steel locator was not needed because locations of reinforcement and connections were recorded before the placement of the concrete

Connections were observed during the placement of concrete and were tested after the concrete had hardened to check for broken connections. Pictures of the connections during concrete placement can be seen in Fig.E.11, E.12, and E.13. All connections survived and remained intact.

Photographs of the five bride decks tested on the new Route 133 Hightstown Bypass can be seen in Fig.E.14, E.15, E.16, E.17, and E.18.

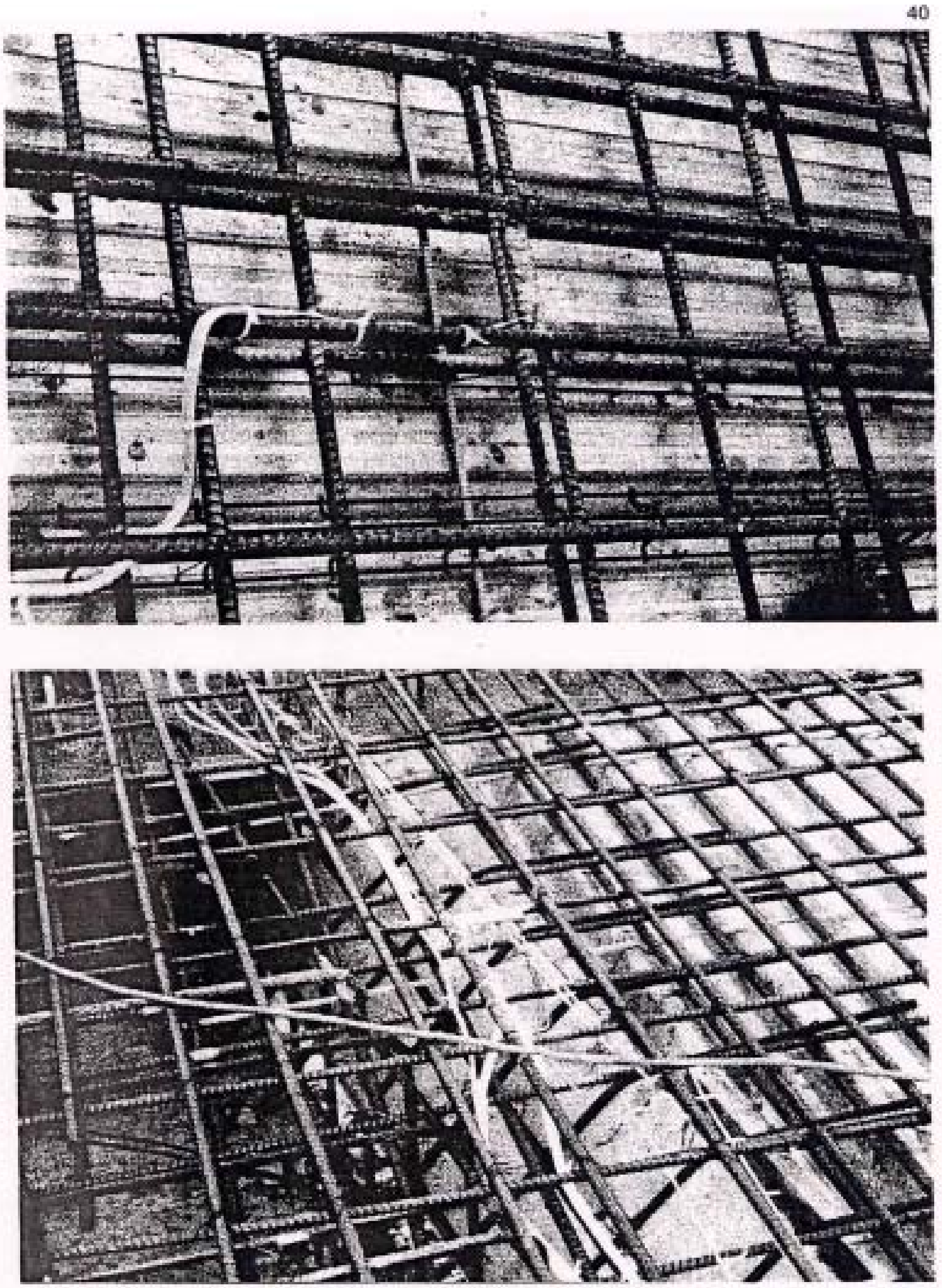

Fig.E.1: Connection to North Main Street Westbound

(The white wires connects the black steel to junction box, located at the abutments)

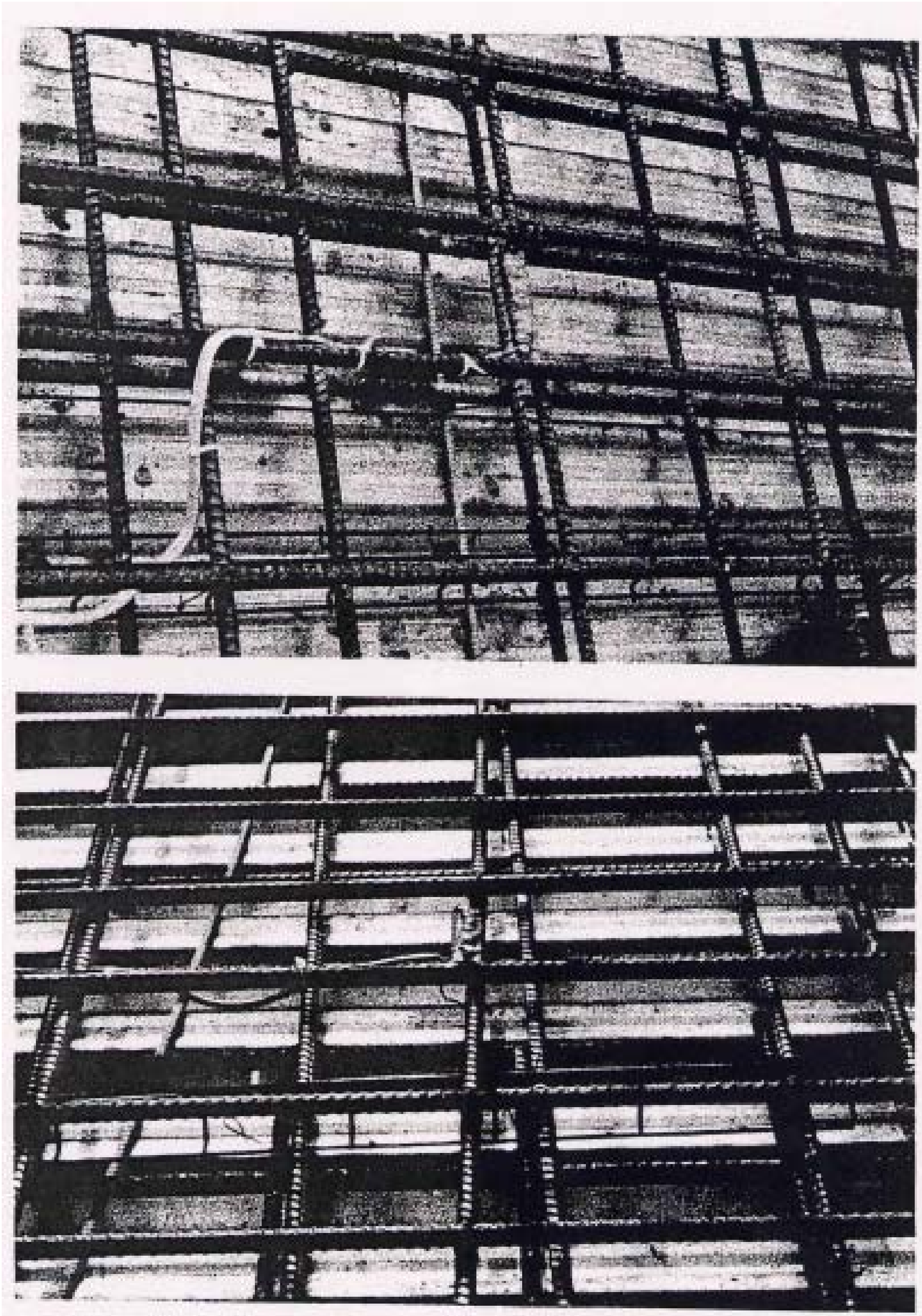

Fig.E.2: Connection to North Main Street Eastbound

(The white wires connects the black steel to junction box, located at the abutments)

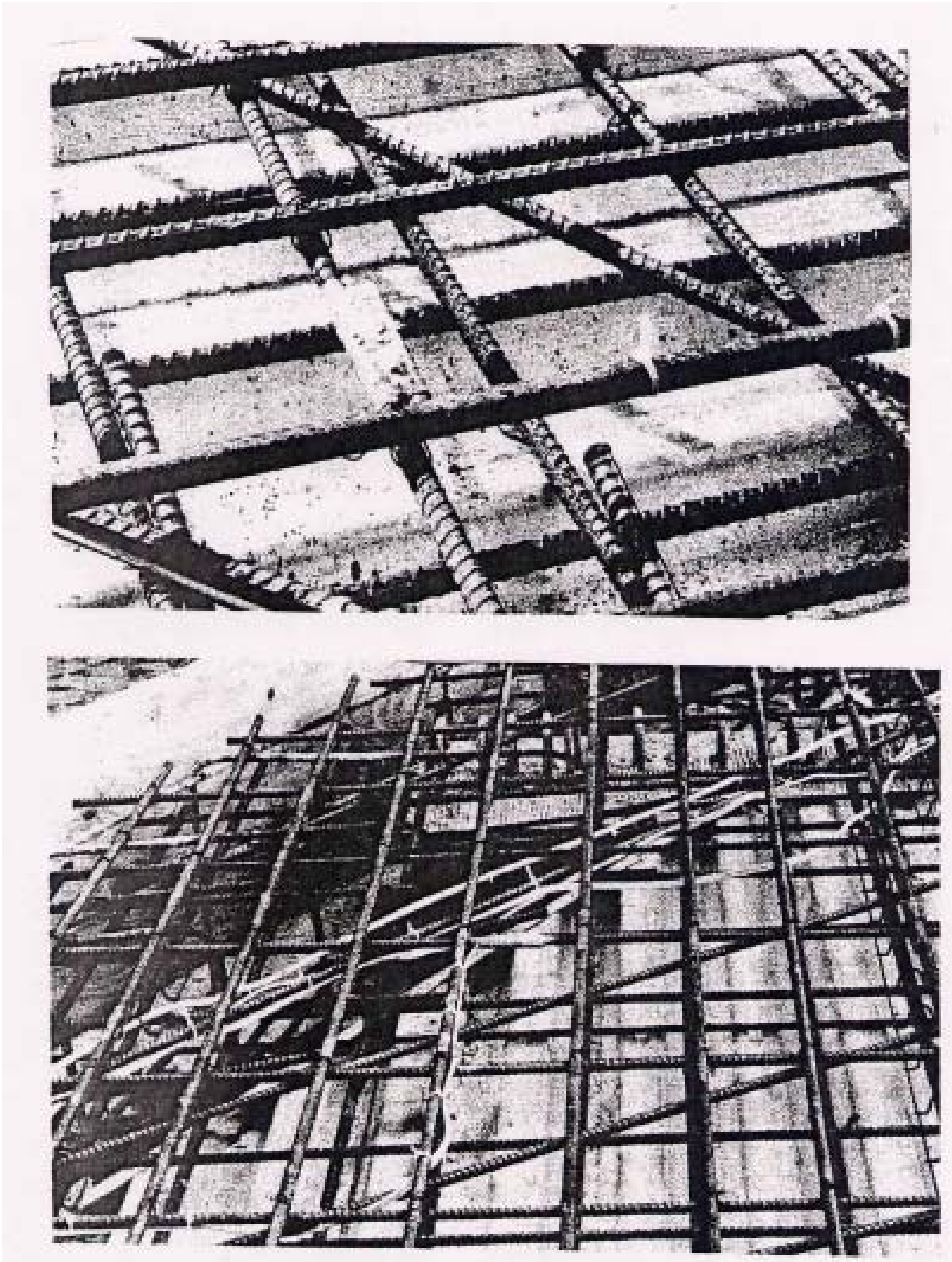

Fig.E.3: Connection to Wyckoff Road Westbound

(The white wires connects the black steel to junction box, located at the abutments)

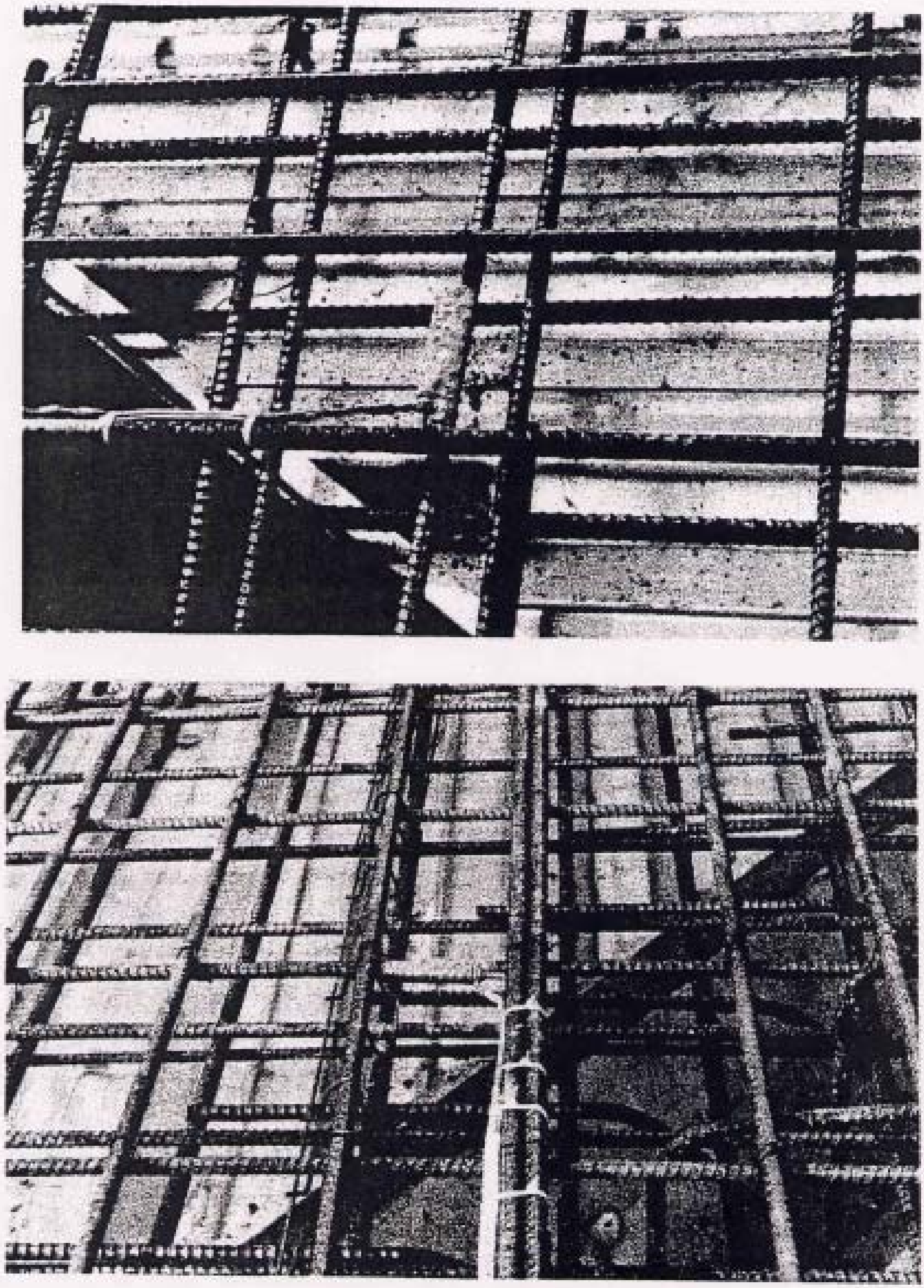

Fig.E.4: Connection to Wyckoff Road Eastbound

(The white wires connects the black steel to junction box, located at the abutments)

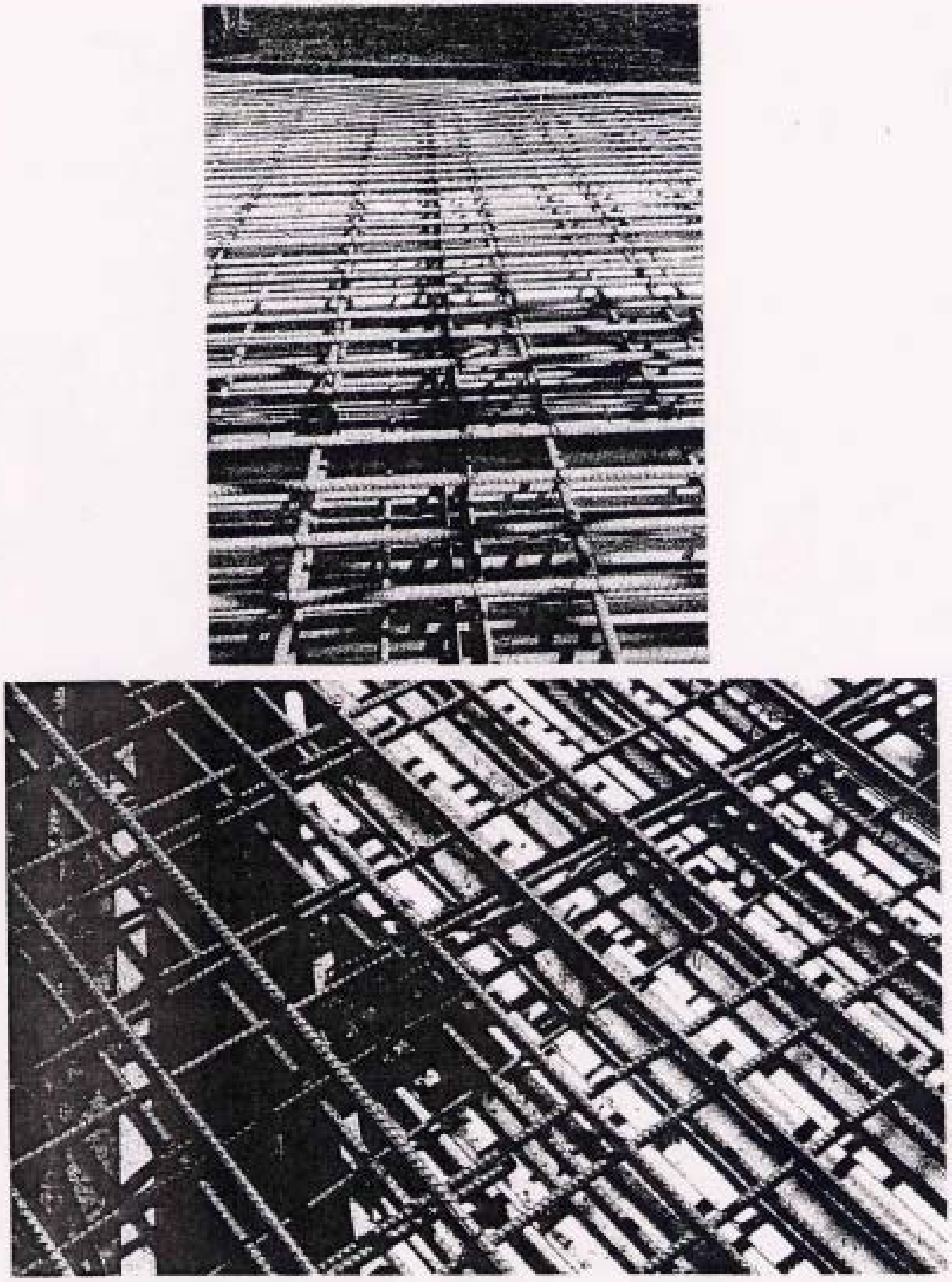

Fig.E.5: Connection to Route 130 Westbound

(The white wires connects the black steel to junction box, located at the abutments)

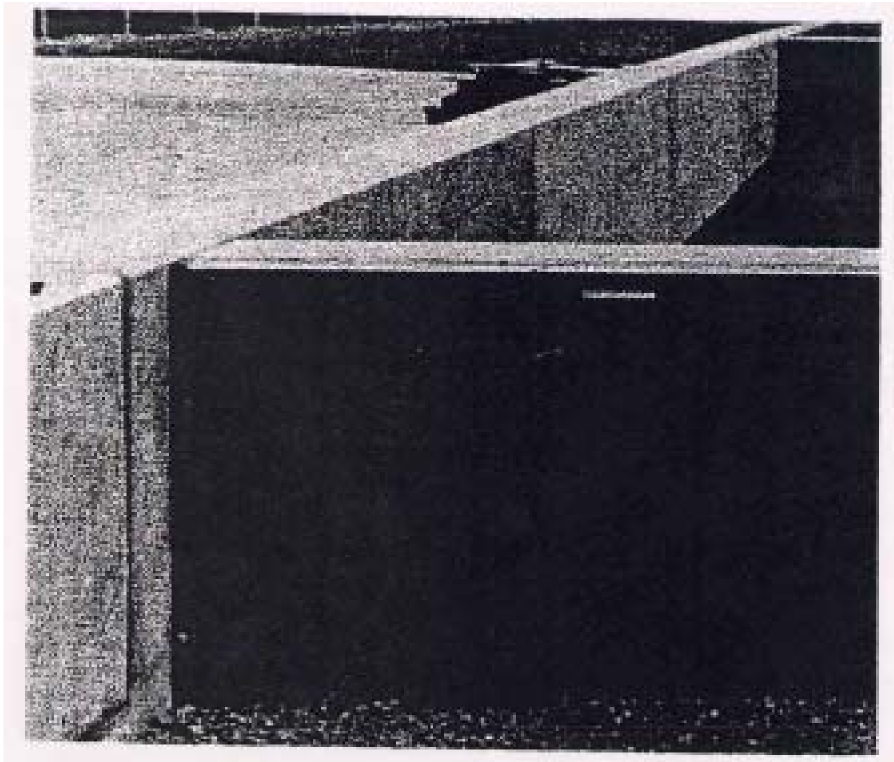

Fig.E.6: Conduits and Enclosure – North Main Street Westbound

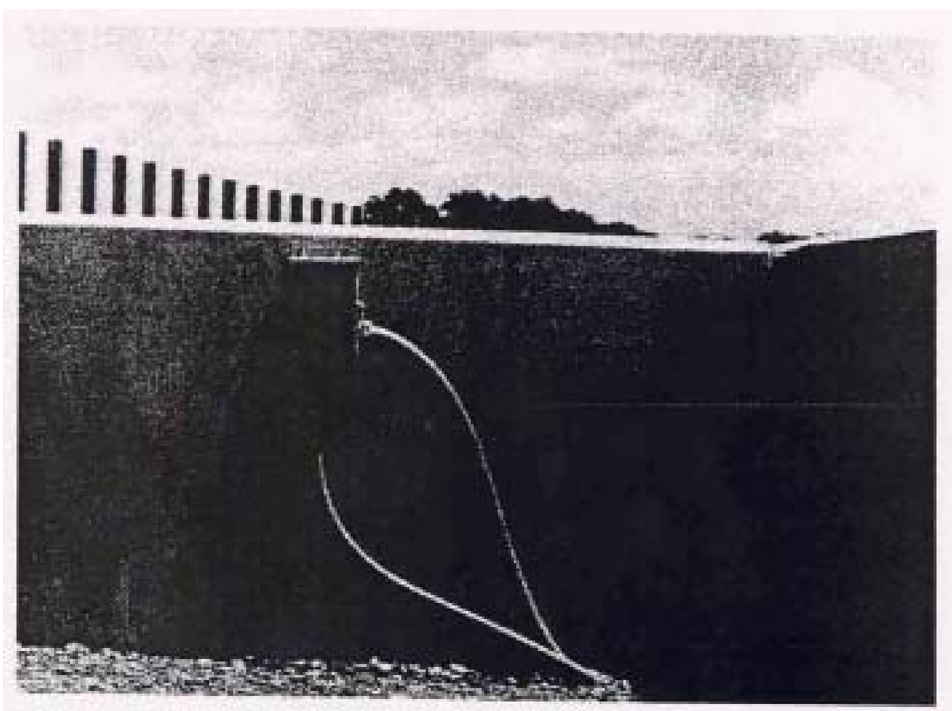

Fig.E.7: Conduits and Enclosure – North Main Street Eastbound

(Junction box attached to the abutment)

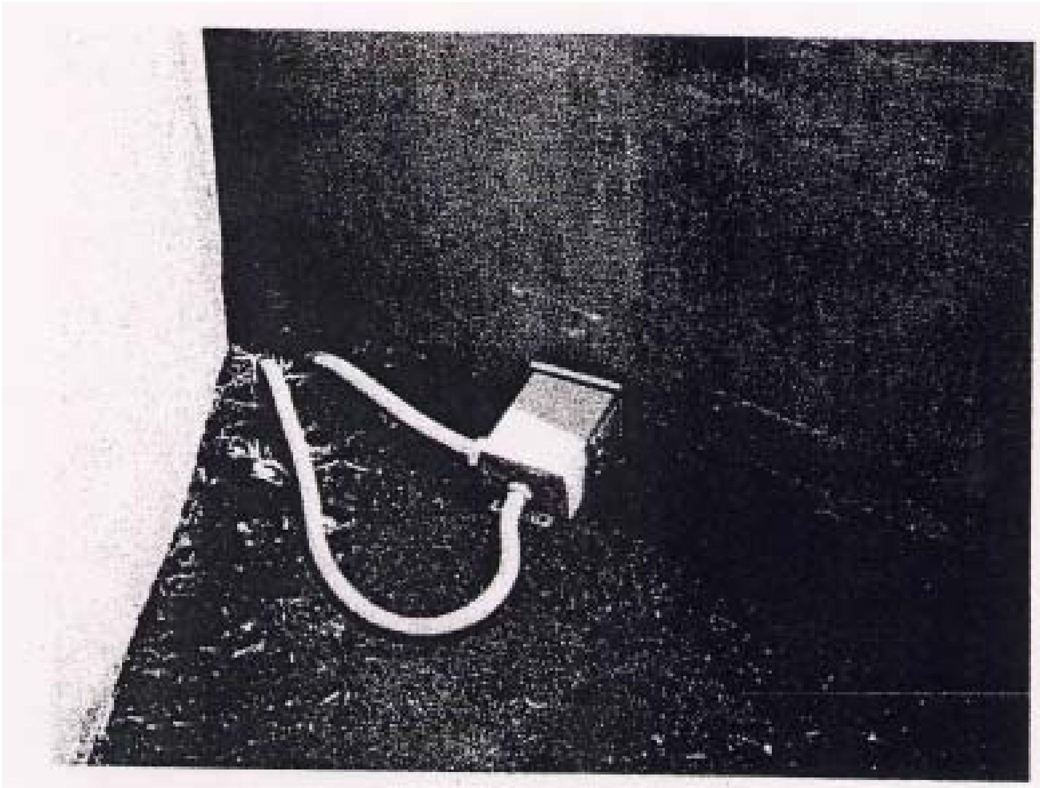

Fig.E.8: Conduits and Enclosure – Wyckoff Road Westbound

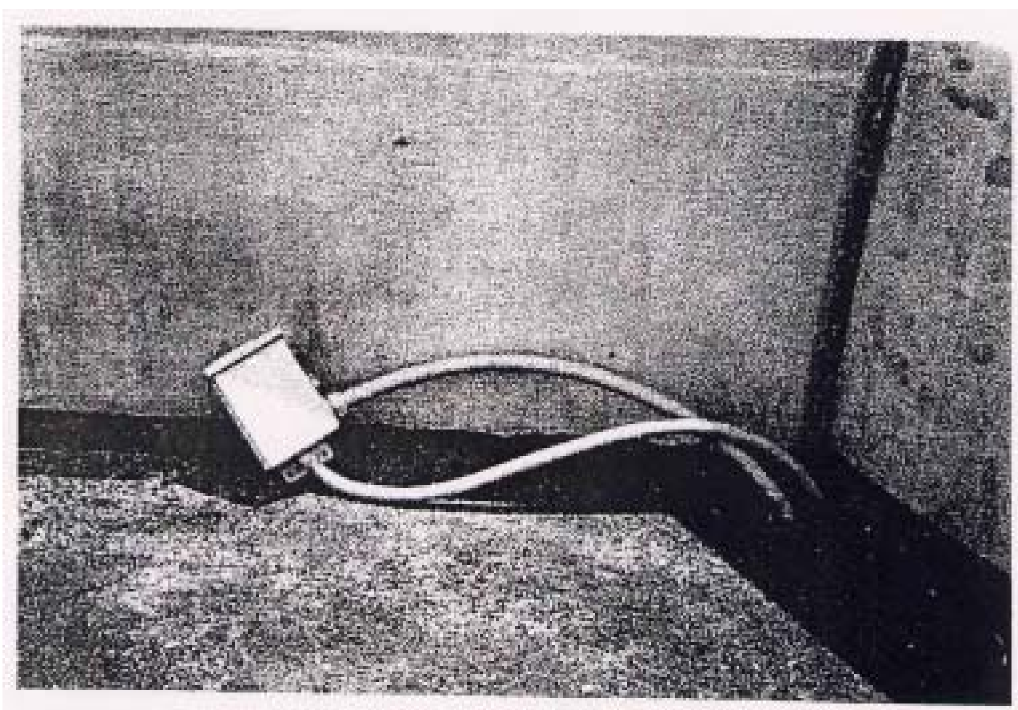

Fig.E.9: Conduits and Enclosure – Wyckoff Road Eastbound

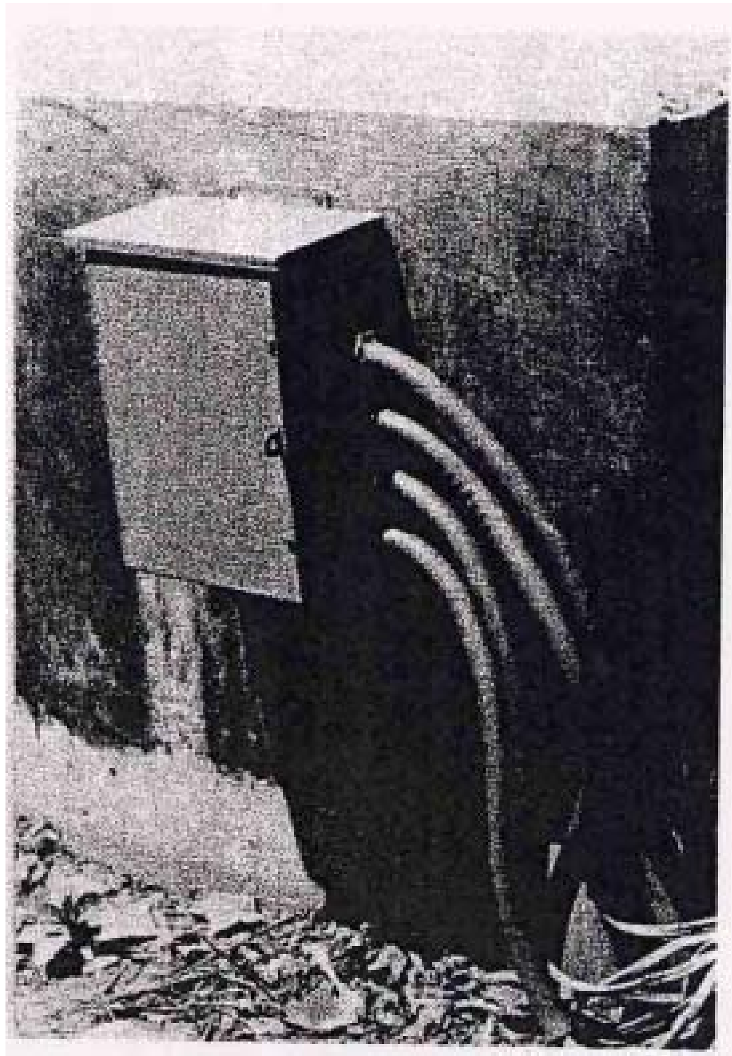

Fig.E.10: Conduits and Enclosure – Route 130 Westbound
(Junction box attached to the abutment)

Fig.E.11: Vibrating of Fresh Concrete at North Main Street Eastbound

Fig.E.12: Placement of Fresh Concrete at North Main Street Westbound
(Connections withstood the construction process)

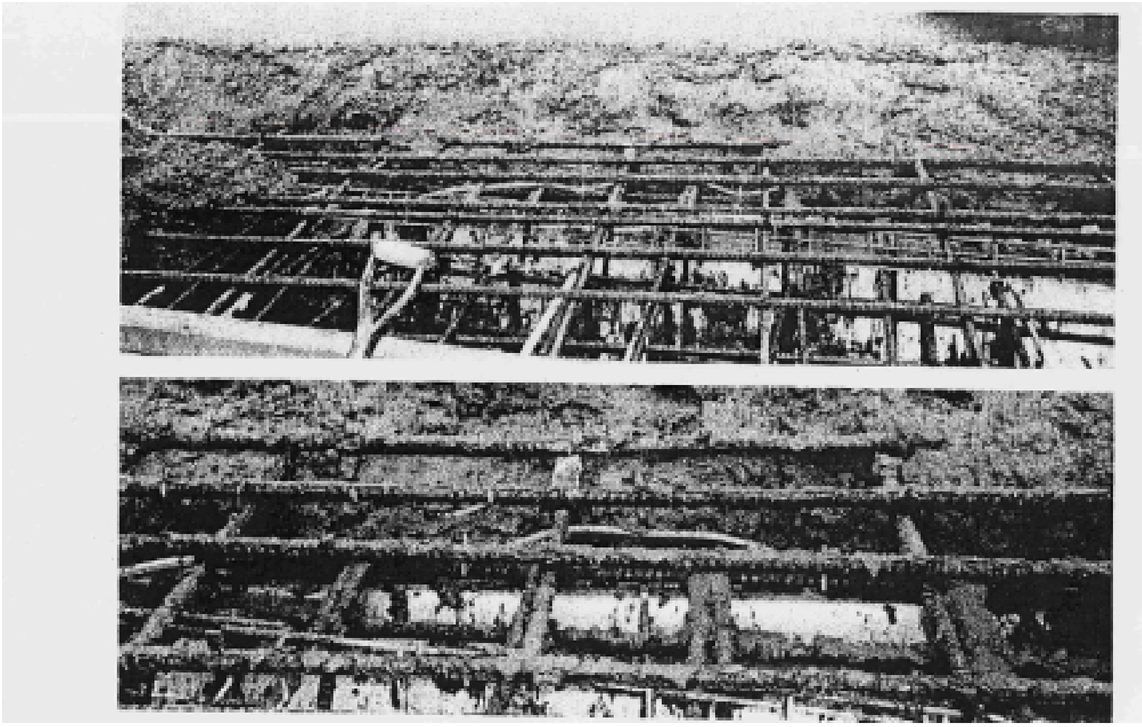

Fig.E.13: View of Connections at North Main Street Westbound during Concrete Placement

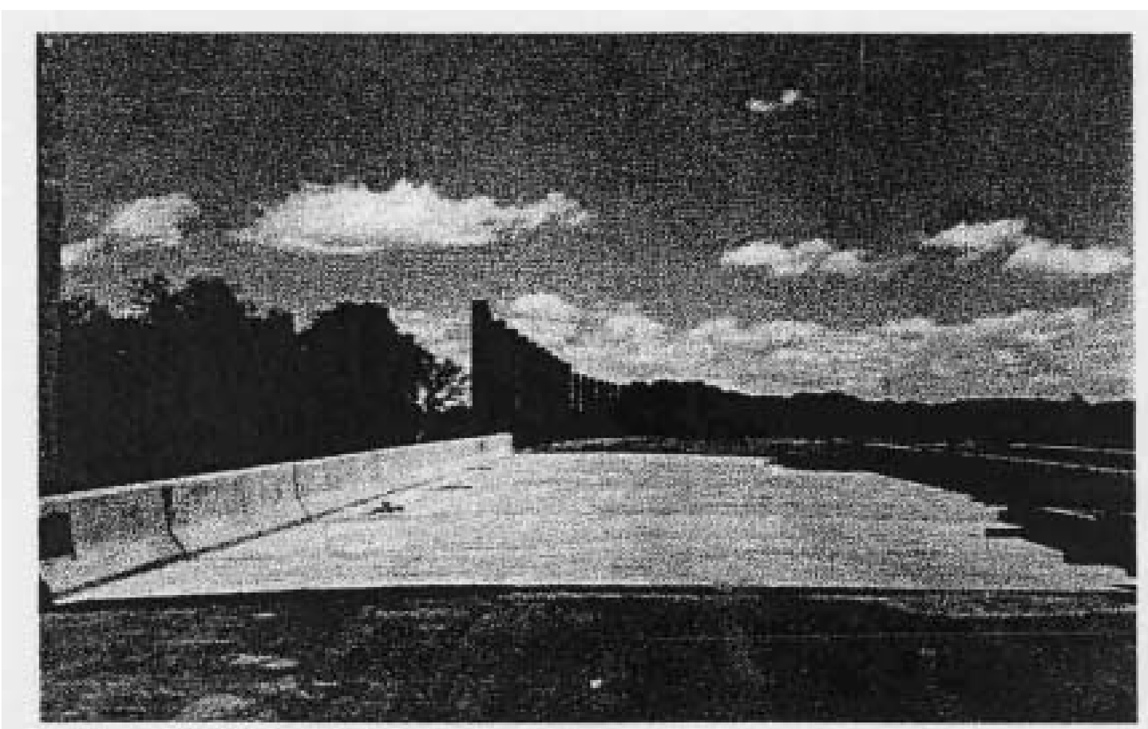

Fig.E.14: Bridge Deck over North Main Street Westbound near Completion

Fig.E.15: Bridge Deck over North Main Street Eastbound near Completion

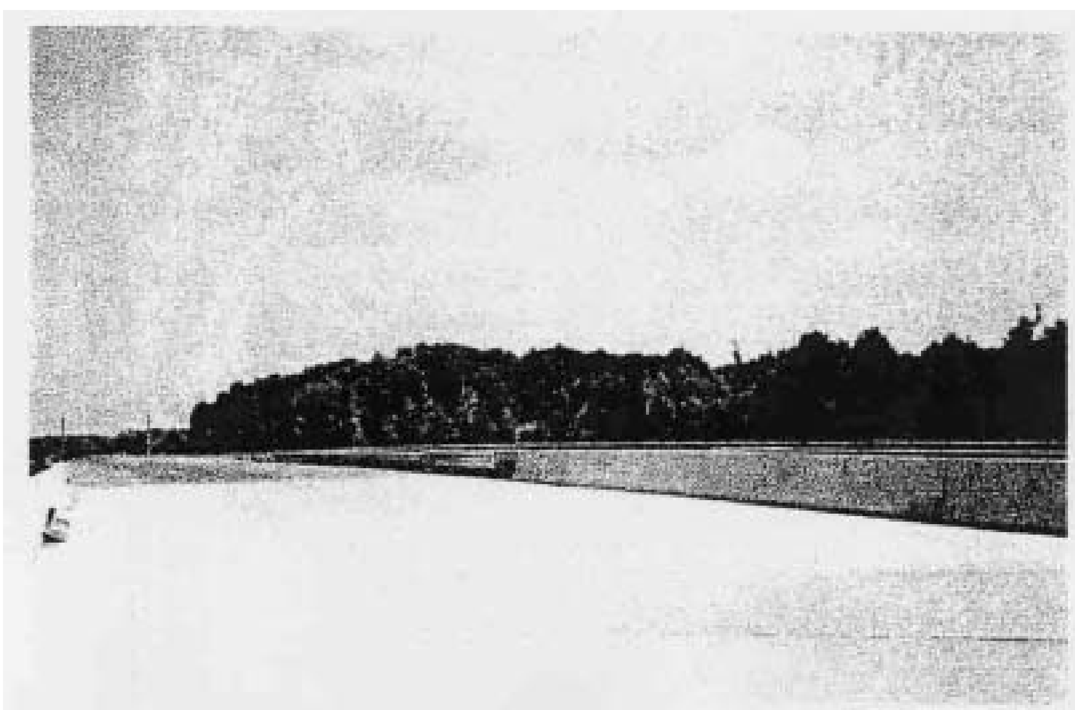

Fig.E.16: Bridge Deck over Wyckoff Road Westbound near Completion

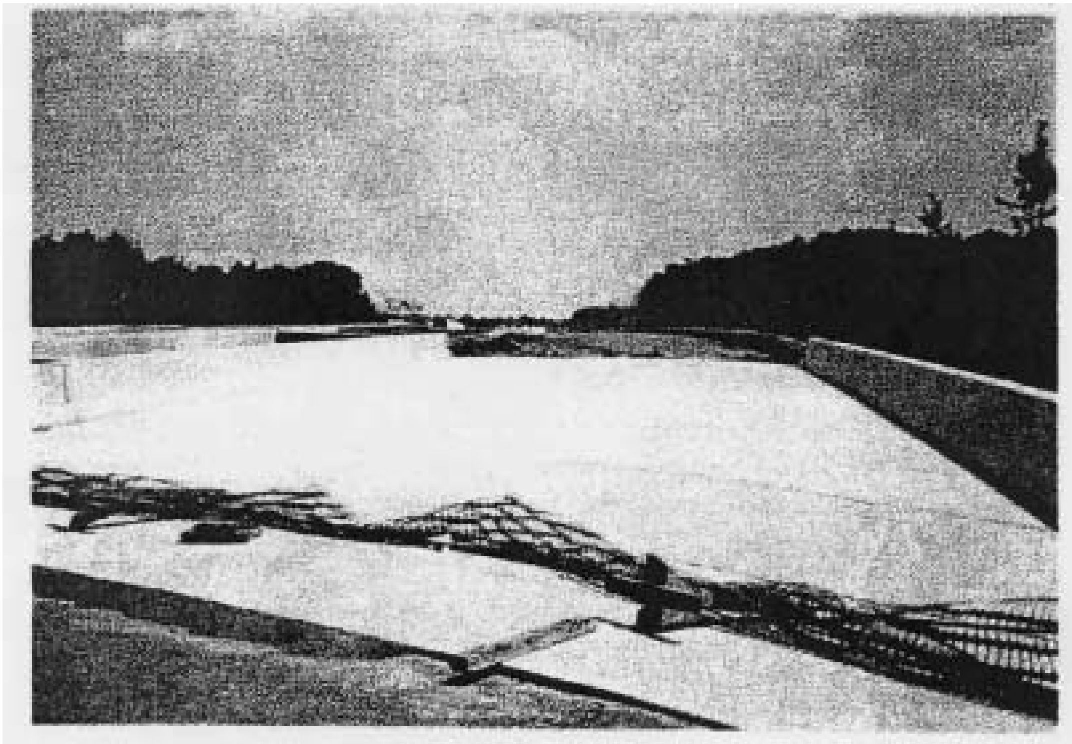

Fig.E.17: Bridge Deck over Wyckoff Road Eastbound near Completion

Fig.E.18: Bridge Deck over Rout 130 Westbound near Completion

Appendix F

Electrical Resistance and Air Permeability

Table F.1: North Main Street Westbound GECOR 6 Electrical Resistance (KΩ)

Connection #	Reading No.	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
B1	1	1.57	1.42	2.86	1.04
	2	1.22	1.60	1.46	1.05
	3	1.17	1.48	1.53	1.20
	4	1.20	1.44	1.39	0.97
	5	1.06	1.46	1.12	0.83
B2	1	1.18	1.11	1.60	1.30
	2	1.23	1.20	1.27	1.11
	3	1.20	1.24	1.29	1.08
	4	1.16	1.24	1.37	1.06
	5	1.24	1.23	1.28	0.97
B3	1	1.21	1.24	1.45	1.14
	2	1.28	1.55	1.60	1.14
	3	1.26	1.30	1.16	0.97
	4	1.32	1.38	1.14	0.93
	5	1.26	1.34	1.17	1.04
B4	1	1.51	1.52	1.12	1.02
	2	1.20	1.40	1.52	1.12
	3	1.75	1.46	1.82	1.61
	4	1.33	1.44	1.26	1.14
	5	1.27	1.38	1.54	1.14
	Average	1.28	1.37	1.45	1.09

Table F.2: North Main Street Westbound Air Permeability Vacuum (mm Hg), SCCM (ml/min)

Reading No.	1st Quarter		2nd Quarter		3rd Quarter		4th Quarter	
	Vacuum	SCCM	Vacuum	SCCM	Vacuum	SCCM	Vacuum	SCCM
1	783.70	34.75	776.90	53.10	774.80	58.43	776.70	29.02
2	782.20	52.22	796.90	48.09	770.00	57.30	771.80	46.28
3	785.60	24.45	791.60	54.32	708.50	31.27	683.50	32.76
4	786.10	16.66	787.20	55.93	779.10	57.09	678.20	50.49
5	783.70	30.75	795.40	43.18	774.40	57.39	676.90	32.57
6	784.90	24.42	792.30	54.87	780.20	50.07	770.00	32.60
7	779.10	56.79	748.80	45.19	776.30	44.59	679.00	32.55
8	786.30	15.63	790.50	33.31	781.10	39.03	680.40	32.66
9	784.20	34.34	783.90	55.72	779.30	53.01	775.60	23.42
Average	783.98	32.22	784.83	49.30	769.30	49.80	721.34	34.71

Table F.3: North Main Street Westbound Electrical Resistance Sealer Test (kΩ)

Quarter	Reading No.	DC End to End (Ω) Strip 1	DC End to End (Ω) Strip 2	DC Side to Side (MΩ)	AC (KΩ)	Avg. AC (KΩ)
1	1	9.2	14.5	6.0	150.0	
	2	17.8	8.1	5.0	22.0	74.0
	3	6.0	5.2	10.0	50.0	
2	1	4.7	8.8	27.3	210.0	
	2	4.8	6.4	26.5	57.0	118.3
	3	2.8	2.4	6.7	88.0	
3	1	6.2	2.4	22.0	200.0	
	2	8.6	6.4	36.0	54.0	124.7
	3	2.9	2.2	7.8	120.0	
4	1	4.6	9.1	32.6	36.0	
	2	6.5	6.8	8.5	120.0	87.3
	3	2.6	2.5	23.5	106.0	

Table F.4: North Main Street Eastbound GECOR 6 Electrical Resistance (KΩ)

Connection #	Reading No.	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
B1	1	2.75	2.69	1.23	1.36
	2	1.70	1.71	1.55	1.40
	3	1.51	1.29	1.20	1.27
	4	1.61	1.15	2.77	1.34
	5	1.69	1.34	1.31	1.22
B2	1	1.47	0.99	1.53	1.00
	2	1.70	1.01	1.48	1.02
	3	1.52	0.73	1.02	1.02
	4	1.47	1.20	1.46	1.28
	5	1.53	1.08	1.60	1.26
B3	1	1.43	0.87	1.30	1.14
	2	1.56	0.82	1.18	1.18
	3	1.45	1.01	1.47	1.21
	4	1.55	1.30	1.31	1.27
	5	1.41	0.99	1.12	1.02
B4	1	1.27	0.99	3.21	3.73
	2	1.69	0.89	0.78	1.20
	3	1.54	1.05	1.16	1.10
	4	1.71	1.05	1.42	1.16
	5	1.36	1.12	0.90	0.94
	Average	1.60	1.16	1.45	1.31

Table F.5: North Main Street Eastbound Air Permeability Vacuum (mm Hg), SCCM (ml/min)

Reading No.	1st Quarter		2nd Quarter		3rd Quarter		4th Quarter	
	Vacuum	SCCM	Vacuum	SCCM	Vacuum	SCCM	Vacuum	SCCM
1	784.00	33.50	713.70	27.18	778.40	58.19	690.60	32.39
2	785.50	19.80	792.50	51.18	781.50	32.72	688.00	32.21
3	783.70	26.79	744.20	39.60	781.30	54.76	685.90	32.32
4	784.80	21.72	736.30	35.25	780.00	43.27	684.00	32.42
5	785.50	15.55	785.30	55.75	780.70	46.36	681.90	32.31
6	783.50	20.72	759.60	48.72	777.10	55.34	773.60	45.85
7	780.20	35.04	748.20	40.64	770.90	58.03	681.60	32.48
8	782.20	26.70	797.20	35.74	781.80	21.95	769.90	56.67
9	774.80	55.23	761.80	50.72	777.90	44.31	682.30	32.84
Average	782.69	28.34	759.87	42.75	778.84	46.10	704.20	37.15

Table F.6: North Main Street Eastbound Electrical Resistance Sealer Test (KΩ)

Quarter	Reading No.	DC End to End (Ω) Strip 1	DC End to End (Ω) Strip 2	DC Side to Side (MΩ)	AC (KΩ)	Avg. AC (KΩ)
1	1	6.8	9.4	5.3	15.0	
	2	1.7	2.2	4.6	32.0	19.7
	3	2.4	3.2	8.3	12.0	
2	1	4.5	6.3	16.3	37.0	
	2	2.5	2.2	22.3	39.0	34.0
	3	1.8	2.3	19.8	26.0	
3	1	5.0	6.5	8.0	25.0	
	2	7.6	5.2	2.3	22.0	21.0
	3	1.7	2.4	5.8	16.0	
4	1	27.1	14.2	20.9	24.0	
	2	25.3	24.4	19.5	34.0	28.3
	3	24.5	7.7	20.8	27.0	

Table F.7: Wyckoff Road Westbound GECOR 6 Electrical Resistance (KΩ)

Connection #	Reading No.	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
B1	1	4.47	1.96	3.43	2.05
	2	4.83	1.57	3.02	2.46
	3	3.43	1.11	2.98	1.44
	4	2.47	2.21	2.87	1.63
	5	3.00	1.58	3.07	1.19
B2	1	3.77	1.45	3.22	1.34
	2	3.67	1.32	2.53	1.37
	3	2.90	1.24	2.91	1.06
	4	2.80	1.15	2.22	1.22
	5	2.54	1.30	3.30	1.13
B3	1	2.67	1.36	1.54	1.37
	2	2.72	1.49	2.64	1.34
	3	3.25	1.40	1.93	1.25
	4	2.28	1.09	2.51	1.20
	5	2.72	1.46	3.23	0.89
B4	1	3.20	1.86	4.15	0.98
	2	2.99	1.56	2.92	0.96
	3	3.33	1.86	2.52	0.97
	4	3.05	1.75	2.42	0.99
	5	2.89	1.87	2.66	0.87
	Average	3.15	1.53	2.80	1.29

Table F.8: Wyckoff Road Westbound Air Permeability Vacuum (mm Hg), SCCM (ml/min)

Reading No.	1st Quarter		2nd Quarter		3rd Quarter		4th Quarter	
	Vacuum	SCCM	Vacuum	SCCM	Vacuum	SCCM	Vacuum	SCCM
1	767.80	15.71	784.80	53.20	782.90	29.68	770.70	58.96
2	769.70	16.55	796.20	34.31	784.00	13.77	688.10	31.41
3	766.30	36.41	793.50	40.39	780.90	45.06	689.50	31.25
4	766.50	57.78	707.50	27.18	781.60	47.23	770.00	57.04
5	775.70	17.08	797.90	34.84	776.40	58.21	694.10	31.57
6	774.30	22.94	793.60	53.07	774.70	59.08	690.80	31.19
7	773.80	28.53	791.50	54.90	778.60	34.94	768.50	56.29
8	775.10	19.15	793.10	52.09	780.10	28.33	695.90	32.23
9	775.50	17.00	792.80	52.40	780.50	43.66	766.20	44.83
Average	771.63	25.68	783.43	44.71	779.97	40.00	725.98	41.64

Table F.9: Wyckoff Road Westbound Electrical Resistance Sealer Test (KΩ)

Quarter	Reading No.	DC End to End (Ω) Strip 1	DC End to End (Ω) Strip 2	DC Side to Side (MΩ)	AC (KΩ)	Avg. AC (KΩ)
1	1	3.0	2.7	36.0	25.0	
	2	2.1	2.4	16.0	35.0	25.3
	3	1.9	2.2	7.8	16.0	
2	1	2.1	3.1	23.0	170.0	
	2	4.7	24.2	31.0	68.0	88.3
	3	1.5	1.8	17.4	27.0	
3	1	1.7	1.4	7.4	32.0	
	2	4.3	5.2	7.8	18.0	26.3
	3	1.0	1.4	12.9	29.0	
4	1	6.5	3.8	7.2	60.0	
	2	1.0	3.2	15.0	84.0	73.0
	3	1.0	1.3	8.1	75.0	

Table F.10: Wyckoff Road Eastbound GECOR 6 Electrical Resistance (KΩ)

Connection #	Reading No.	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
B1	1	3.54	1.72	2.09	1.89
	2	4.17	1.91	1.55	2.31
	3	3.14	1.72	1.44	2.36
	4	1.20	1.11	1.45	2.05
	5	1.75	0.85	1.37	2.11
B2	1	1.67	0.72	1.42	2.05
	2	2.04	0.73	1.45	2.04
	3	1.59	1.01	1.40	2.18
	4	1.72	1.11	1.38	1.55
	5	1.74	1.07	1.46	2.16
B3	1	1.84	0.87	1.61	1.45
	2	1.48	0.95	1.70	1.83
	3	1.60	0.69	1.62	1.28
	4	1.94	0.71	1.65	1.89
	5	1.83	0.85	1.34	2.37
B4	1	5.16	1.16	1.32	1.81
	2	3.97	0.90	1.48	2.02
	3	2.05	0.73	0.97	2.22
	4	2.02	1.03	1.53	1.85
	5	1.67	0.85	1.46	2.20
	Average	2.31	1.05	1.48	1.99

Table F.11: Wyckoff Road Eastbound Air Permeability Vacuum (mm Hg), SCCM (ml/min)

Reading No.	1st Quarter		2nd Quarter		3rd Quarter		4th Quarter	
	Vacuum	SCCM	Vacuum	SCCM	Vacuum	SCCM	Vacuum	SCCM
1	767.80	15.71	784.80	53.20	782.90	29.68	770.70	58.96
2	769.70	16.55	796.20	34.31	784.00	13.77	688.10	31.41
3	766.30	36.41	793.50	40.39	780.90	45.06	689.50	31.25
4	766.50	57.78	707.50	27.18	781.60	47.23	770.00	57.04
5	775.70	17.08	797.90	34.84	776.40	58.21	694.10	31.57
6	774.30	22.94	793.60	53.07	774.70	59.08	690.80	31.19
7	773.80	28.53	791.50	54.90	778.60	34.94	768.50	56.29
8	775.10	19.15	793.10	52.09	780.10	28.33	695.90	32.23
9	775.50	17.00	792.80	52.40	780.50	43.66	766.20	44.83
Average	771.63	25.68	783.43	44.71	779.97	40.00	725.98	41.64

Table F.12: Wyckoff Road Eastbound Electrical Resistance Sealer Test (KΩ)

Quarter	Reading No.	DC End to End (Ω) Strip 1	DC End to End (Ω) Strip 2	DC Side to Side (MΩ)	AC (KΩ)	Avg. AC (KΩ)
1	1	3.0	2.7	36.0	25.0	
	2	2.1	2.4	16.0	35.0	25.3
	3	1.9	2.2	7.8	16.0	
2	1	2.1	3.1	23.0	170.0	
	2	4.7	24.2	31.0	68.0	88.3
	3	1.5	1.8	17.4	27.0	
3	1	1.7	1.4	7.4	32.0	
	2	4.3	5.2	7.8	18.0	26.3
	3	1.0	1.4	12.9	29.0	
4	1	6.5	3.8	7.2	60.0	
	2	1.0	3.2	15.0	84.0	73.0
	3	1.0	1.3	8.1	75.0	

Table F.13: Route 130 Westbound GECOR Electrical Resistance (KΩ)

Connection #	Reading No.	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
B1	1	1.78	1.59	1.41	1.48
	2	1.79	1.80	1.24	1.27
	3	1.51	1.65	1.49	1.33
	4	2.54	2.20	1.54	1.34
	5	2.23	2.15	1.40	1.28
B2	1	1.85	2.07	1.68	1.07
	2	1.50	1.63	1.10	1.11
	3	1.47	1.64	1.01	1.10
	4	1.53	1.69	0.97	0.99
	5	1.71	1.87	1.24	1.22
B3	1	1.81	2.05	1.02	1.19
	2	2.08	1.89	0.97	1.08
	3	1.51	1.48	1.11	1.14
	4	1.37	1.67	1.30	1.32
	5	1.41	1.67	1.33	1.30
B4	1	1.97	1.97	1.37	1.18
	2	1.80	1.75	1.07	1.26
	3	1.70	1.66	1.18	1.42
	4	1.67	1.63	1.28	1.06
	5	1.43	1.56	1.09	1.03
B5	1	2.11	2.52	1.73	1.28
	2	1.73	1.58	1.71	1.24
	3	1.72	2.22	1.28	1.00
	4	1.87	2.39	1.84	1.20
	5	1.76	2.11	0.85	1.22
	Average	1.70	1.85	1.26	1.17

Table F.14: Route 130 Westbound Air Permeability Vacuum (mm Hg), SCCM (ml/min)

Reading No.	1st Quarter		2nd Quarter		3rd Quarter		4th Quarter	
	Vacuum	SCCM	Vacuum	SCCM	Vacuum	SCCM	Vacuum	SCCM
1	787.10	14.60	793.40	41.32	780.50	22.69	770.00	46.13
2	784.40	30.59	791.90	33.74	780.40	38.76	771.70	50.38
3	784.30	33.99	786.30	36.71	779.40	52.22	773.10	48.80
4	784.00	24.70	754.90	48.30	764.30	57.09	770.00	56.45
5	782.60	52.15	783.20	56.57	779.90	47.57	773.50	46.30
6	780.30	56.52	792.10	46.45	780.80	40.45	774.90	38.78
7	784.50	45.54	787.60	52.38	779.40	52.13	769.90	58.79
8	786.30	37.45	785.00	45.44	776.20	58.48	776.00	43.58
9	786.60	28.42	784.80	54.20	782.50	42.71	774.00	45.66
Average	784.46	36.00	784.36	46.12	778.16	45.79	772.57	48.32

Table F.15: Route 130 Westbound Electrical Resistance Sealer Test (KΩ)

Quarter	Reading No.	DC End to End (Ω) Strip 1	DC End to End (Ω) Strip 2	DC Side to Side (MΩ)	AC (KΩ)	Avg. AC (KΩ)
1	1	16.3	19.0	7.5	48.0	
	2	11.1	10.1	8.0	11.0	30.3
	3	32.6	17.5	7.0	32.0	
2	1	3.5	11.1	6.0	57.0	
	2	4.9	4.9	11.4	49.0	88.7
	3	7.1	8.9	10.3	160.0	
3	1	2.8	2.5	8.5	51.0	
	2	5.7	4.8	17.5	46.0	75.7
	3	9.2	9.9	12.6	130.0	
4	1	2.3	2.3	23.8	79.0	
	2	8.5	2.5	17.9	30.0	69.0
	3	2.6	6.1	17.6	98.0	

Appendix G

Corrosion Measurements

Table G.1: Minideck A – ASTM G 109 Corrosion Rate (μA/cm^2)

Specimen	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10	Cycle 11
A1	0.60	0.90	0.60	0.90	1.00	0.90	0.90	1.00	0.15	0.08	0.18
A2	0.30	0.60	0.70	0.80	1.00	0.80	1.00	0.90	0.18	0.08	0.25
A3	0.20	1.00	0.60	1.10	1.00	1.10	1.50	1.50	0.73	0.73	0.90
A4	1.00	0.50	0.30	0.70	0.80	0.70	0.80	0.80	0.03	0.08	0.08
A5	0.30	0.10	0.10	0.00	0.40	0.10	0.10	0.20	0.03	0.15	0.03
A6	0.10	0.30	0.30	0.50	0.40	0.30	0.40	0.40	0.10	0.15	0.15
Average	0.42	0.57	0.43	0.67	0.77	0.65	0.78	0.80	0.20	0.21	0.26

Specimen	Cycle 12	Cycle 13	Cycle 14	Cycle 15	Cycle 16	Cycle 17	Cycle 18	Cycle 19	Cycle 20	Cycle 21	Cycle 22
A1	0.03	0.11	0.09	0.59	0.20	0.40	10.10	1.10	12.80	7.50	9.60
A2	0.04	0.14	0.13	0.00	0.30	0.04	0.00	0.30	7.80	2.30	2.00
A3	0.04	0.60	0.57	0.00	0.30	0.03	1.60	0.70	1.00	2.20	4.60
A4	0.08	0.06	0.07	0.17	0.80	0.98	0.30	0.10	0.10	0.10	0.20
A5	0.00	0.05	0.06	0.00	3.40	3.80	0.50	0.27	8.20	1.40	2.30
A6	0.01	0.10	0.10	0.07	0.10	0.20	0.40	0.30	0.10	0.10	0.20
Average	0.03	0.18	0.17	0.14	0.85	0.91	2.15	0.46	5.00	2.27	3.15

Table G.2: Minideck A – ASTM G 109 Corrosion Potential (mV)

Specimen	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10	Cycle 11
A1	N/A	N/A	-11.67	-12.12	-15.29	-13.88	-23.07	-12.54	-14.00	-6.92	-6.46
A2	N/A	N/A	-2.19	-1.48	-4.97	-3.06	-11.80	-1.09	0.01	-0.24	-0.15
A3	N/A	N/A	-0.75	-6.80	-5.39	-3.27	-10.46	-0.86	-23.51	-17.07	-14.38
A4	N/A	N/A	-2.07	-2.68	-7.36	-6.44	-16.03	-6.16	-15.69	-9.92	-7.67
A5	N/A	N/A	-5.60	-5.92	-10.28	-9.53	-18.69	-8.99	-23.76	-18.28	-15.48
A6	N/A	N/A	-13.58	-13.91	-18.46	-17.71	-27.64	-20.50	-33.82	-27.73	-25.14
Average	N/A	N/A	-5.98	-7.15	-10.29	-8.98	-17.95	-8.36	-18.46	-13.36	-11.54

Specimen	Cycle 12	Cycle 13	Cycle 14	Cycle 15	Cycle 16	Cycle 17	Cycle 18	Cycle 19	Cycle 20	Cycle 21	Cycle 22
A1	-4.81	-10.06	-4.90	-5.90	0.03	12.30	-259.7	111.45	2.72	21.39	2.58
A2	-0.12	-0.01	0.00	0.01	3.75	4.60	25.50	-6.25	1.23	9.20	1.24
A3	-11.22	-17.74	-11.64	-12.24	7.86	8.36	14.98	4.65	1.81	35.40	1.17
A4	-5.70	-10.91	-5.30	-4.51	13.30	13.65	20.00	0.98	1.94	4.90	0.89
A5	-13.43	-18.29	-12.53	-12.16	12.84	15.36	66.47	0.81	6.30	13.11	0.87
A6	-22.75	-28.77	-21.80	-21.53	4.01	5.01	-8.70	0.82	8.10	4.51	0.88
Average	-9.67	-14.29	-9.36	-9.39	6.97	9.88	-23.58	18.74	3.68	14.75	1.27

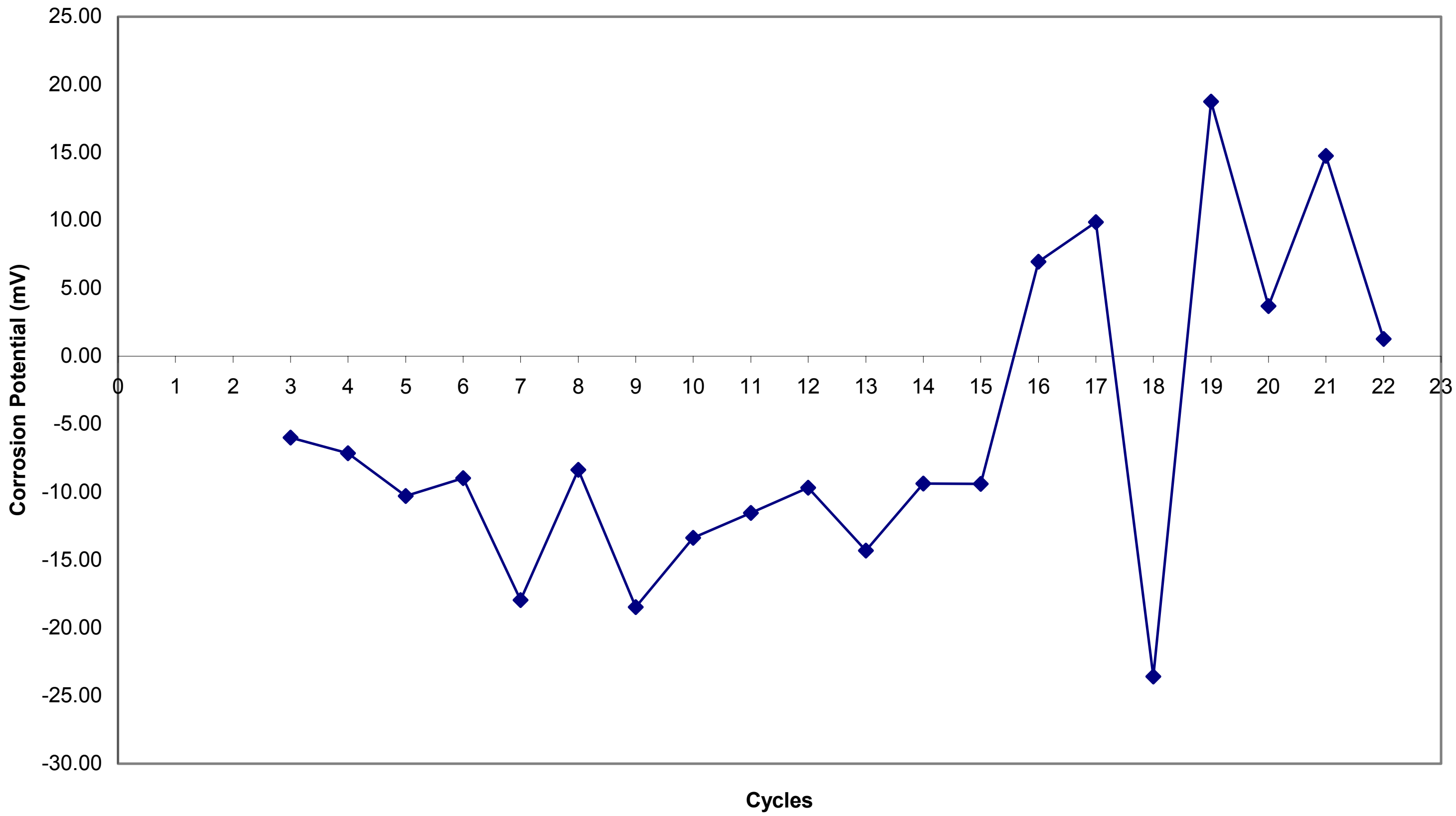

Fig G.1: Minideck A – Average Corrosion Potential (mV)

Table G.3: North Main Street Westbound GECOR 6 Corrosion Rate ($\mu A/cm^2$)

Connection #	Reading #	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8
B1	1	0.181	0.145	0.063	0.197	0.131	0.072	0.232	0.311
	2	0.280	0.157	0.096	0.135	0.177	0.345	0.034	0.206
	3	0.265	0.084	0.121	0.201	0.055	0.210	0.127	0.175
	4	0.216	0.127	0.171	0.181	0.192	0.272	0.179	0.321
	5	0.250	0.110	0.129	0.001	0.234	0.310	0.091	0.142
B2	1	0.295	0.231	0.109	0.119	0.112	0.212	0.234	0.310
	2	0.264	0.140	0.089	0.094	0.072	0.121	0.232	0.045
	3	0.244	0.203	0.136	0.137	0.214	0.134	0.079	0.310
	4	0.262	0.116	0.154	0.136	0.092	0.129	0.132	0.272
	5	0.211	0.150	0.131	0.131	0.217	0.312	0.121	0.042
B3	1	0.222	0.162	0.156	0.208	0.037	0.107	0.302	0.233
	2	0.205	0.175	0.147	0.127	0.112	0.179	0.290	0.157
	3	0.259	0.178	0.138	0.119	0.311	0.202	0.191	0.161
	4	0.206	0.136	0.155	0.139	0.091	0.072	0.055	0.199
	5	0.263	0.211	0.159	0.156	0.192	0.011	0.197	0.209
B4	1	0.191	0.196	0.155	0.362	0.272	0.111	0.290	0.218
	2	0.216	0.169	0.151	0.130	0.047	0.075	0.147	0.139
	3	0.274	0.413	0.132	0.162	0.312	0.275	0.310	0.194
	4	0.183	0.227	0.128	0.150	0.149	0.263	0.311	0.279
	5	0.196	0.154	0.133	0.156	0.172	0.229	0.099	0.078
	Average	0.234	0.174	0.133	0.152	0.160	0.182	0.183	0.200

Table G.4: Main Street Westbound GECOR 6 Corrosion Potential (mV)

Connection #	**Reading #**	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**	**Cycle 5**	**Cycle 6**	**Cycle 7**	**Cycle 8**
B1	1	-88.8	-127.4	-220.7	-234.9	-249.1	-252.3	-190.4	-170.9
	2	-56.2	-128.1	-168.6	-154.2	-94.4	-197.1	-270.3	-141.2
	3	-63.5	-124.5	-190.3	-202.5	-97.2	-242.4	-179.1	-157.6
	4	-75.9	-140.9	-183.2	-194.3	-170.2	-73.2	-84.6	-121.4
	5	-83.0	-133.4	-187.8	-192.7	-201.9	-214.3	-197.2	-212.4
B2	1	-78.2	-126.4	-214.7	-219.7	-181.1	-99.3	-147.4	-212.4
	2	-84.1	-87.8	-211.8	-218.7	-178.6	-109.5	-88.2	-153.2
	3	-73.5	-123.6	-218.8	-227.1	-91.7	-205.4	-167.6	-221.3
	4	-76.4	-120.8	-227.5	-233.2	-192.4	-146.0	-81.7	-159.3
	5	-73.6	-126.3	-221.1	-235.8	-78.7	-200.3	-100.4	-166.6
B3	1	-86.4	-108.6	-233.3	-253.5	-89.4	-104.6	-111.8	-191.4
	2	-95.5	-116.7	-240.4	-249.7	-107.5	-92.4	-207.9	-129.3
	3	-99.8	-116.1	-266.2	-267.4	-192.4	-187.4	-201.2	-148.5
	4	-89.9	-126.5	-213.3	-220.5	-148.5	-84.9	-97.3	-94.7
	5	-95.7	-142.3	-216.6	-226.3	-204.4	-79.8	-87.2	-148.5
B4	1	-91.2	-142.9	-203.3	-239.2	-141.4	-114.3	-186.7	-202.4
	2	-98.5	-131.5	-222.4	-245.3	-187.2	-172.5	-155.5	-191.6
	3	-83.1	-153.3	-203.8	-227.6	-121.4	-76.4	-89.2	-104.8
	4	-83.2	-141.5	-169.7	-181.7	-200.4	-22.3	-270.5	-91.0
	5	-91.7	-142.3	-191.1	-201.9	-158.5	-167.5	-176.5	-214.9
	Average	-83.4	-128.0	-210.2	-221.3	-154.3	-142.1	-154.5	-219.6

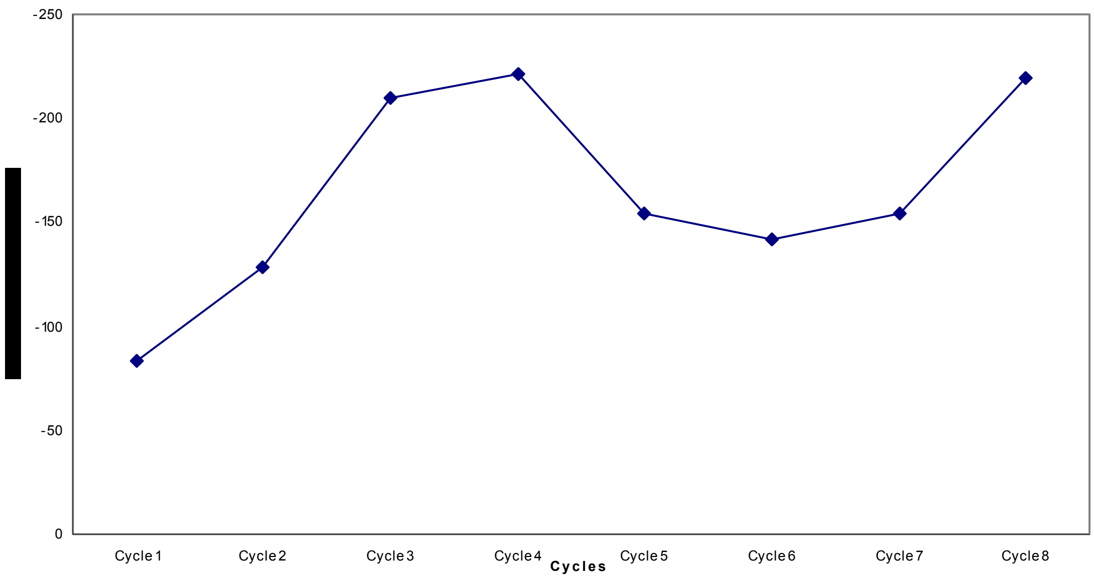

Fig G.2: North Main Street Westbound GECOR 6 Average Corrosion Potential (mV)

Table G.5: Minideck B – ASTM G 109 Corrosion Rate (μA/cm^2)

Specimen	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10	Cycle 11
B1	0.00	0.20	0.20	0.30	0.30	0.30	0.50	0.40	0.03	0.02	0.28
B2	0.10	0.00	0.00	0.10	0.20	0.10	0.30	0.20	0.05	0.08	1.08
B3	0.00	0.10	0.10	0.10	0.30	0.20	0.20	0.20	0.04	0.01	0.23
B4	0.10	0.20	0.10	0.00	0.00	0.10	0.10	0.10	0.10	0.08	1.00
B5	0.10	0.30	0.40	0.20	0.40	0.50	0.50	0.50	0.12	0.08	0.58
B6	0.30	0.30	0.50	0.30	0.50	0.20	0.40	0.40	0.01	0.01	0.50
Average	0.10	0.18	0.22	0.17	0.28	0.23	0.33	0.30	0.06	0.05	0.61

Specimen	Cycle 12	Cycle 13	Cycle 14	Cycle 15	Cycle 16	Cycle 17	Cycle 18	Cycle 19	Cycle 20	Cycle 21	Cycle 22
B1	3.00	0.23	0.10	1.60	0.20	0.40	8.90	8.10	10.70	9.50	1.74
B2	9.00	0.85	0.93	4.37	0.10	0.14	3.10	2.30	1.50	0.10	0.40
B3	3.50	0.03	0.15	0.20	0.20	0.30	9.10	6.85	0.20	0.10	0.40
B4	1.08	1.08	1.18	0.00	0.20	0.20	0.60	0.10	0.10	0.30	0.20
B5	1.35	0.95	1.38	1.07	0.10	0.10	14.60	1.64	21.80	11.40	1.65
B6	1.75	0.10	0.00	0.00	0.30	0.35	3.10	3.80	0.80	1.90	0.50
Average	3.28	0.54	0.62	1.21	0.18	0.25	6.57	3.80	5.85	3.88	0.82

Table G.6: Minideck B – ASTM G 109 Corrosion Potential (mV)

Specimen	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10	Cycle 11
B1	N/A	N/A	-21.52	-21.55	-24.51	-21.98	-31.16	-20.19	-26.17	-20.37	-17.64
B2	N/A	N/A	-18.61	-17.65	-20.35	-18.32	-27.87	-15.69	-22.09	-16.20	-13.09
B3	N/A	N/A	-20.51	-23.42	-30.03	-31.47	-45.88	-37.66	-79.59	-46.00	-42.09
B4	N/A	N/A	-19.45	-19.27	-21.94	-19.32	-28.53	-17.60	-38.37	-31.75	-29.60
B5	N/A	N/A	-17.75	-17.26	-20.33	-17.48	-25.77	-14.35	-22.72	-17.36	-15.29
B6	N/A	N/A	-6033	-18.64	-22.87	-23.64	-35.04	-27.19	-11.72	-5.68	-2.41
Average	N/A	N/A	-19.03	-19.63	-23.34	-22.04	-32.38	-22.11	-33.44	-22.89	-20.02

Specimen	Cycle 12	Cycle 13	Cycle 14	Cycle 15	Cycle 16	Cycle 17	Cycle 18	Cycle 19	Cycle 20	Cycle 21	Cycle 22
B1	-15.98	-20.55	-16.22	-16.55	8.88	9.32	288.94	74.22	8.32	16.55	1.05
B2	-11.38	-17.32	-11.41	-11.15	16.37	16.39	3.50	2.52	7.05	3.96	0.93
B3	-42.84	-62.92	-40.95	-41.25	18.45	20.15	12.58	6.19	10.18	4.60	1.45
B4	-29.39	-33.95	-29.19	-28.82	9.16	10.23	7.45	5.15	3.26	2.95	1.60
B5	-6.87	-18.99	-13.32	-13.14	17.98	19.56	262.68	4.57	5.68	10.99	1.95
B6	-0.67	-6.12	-0.39	-0.43	18.05	20.58	8.78	5.95	4.04	3.18	2.55
Average	-17.85	-26.64	-18.58	-18.55	14.82	16.04	97.32	16.43	6.42	7.04	1.59

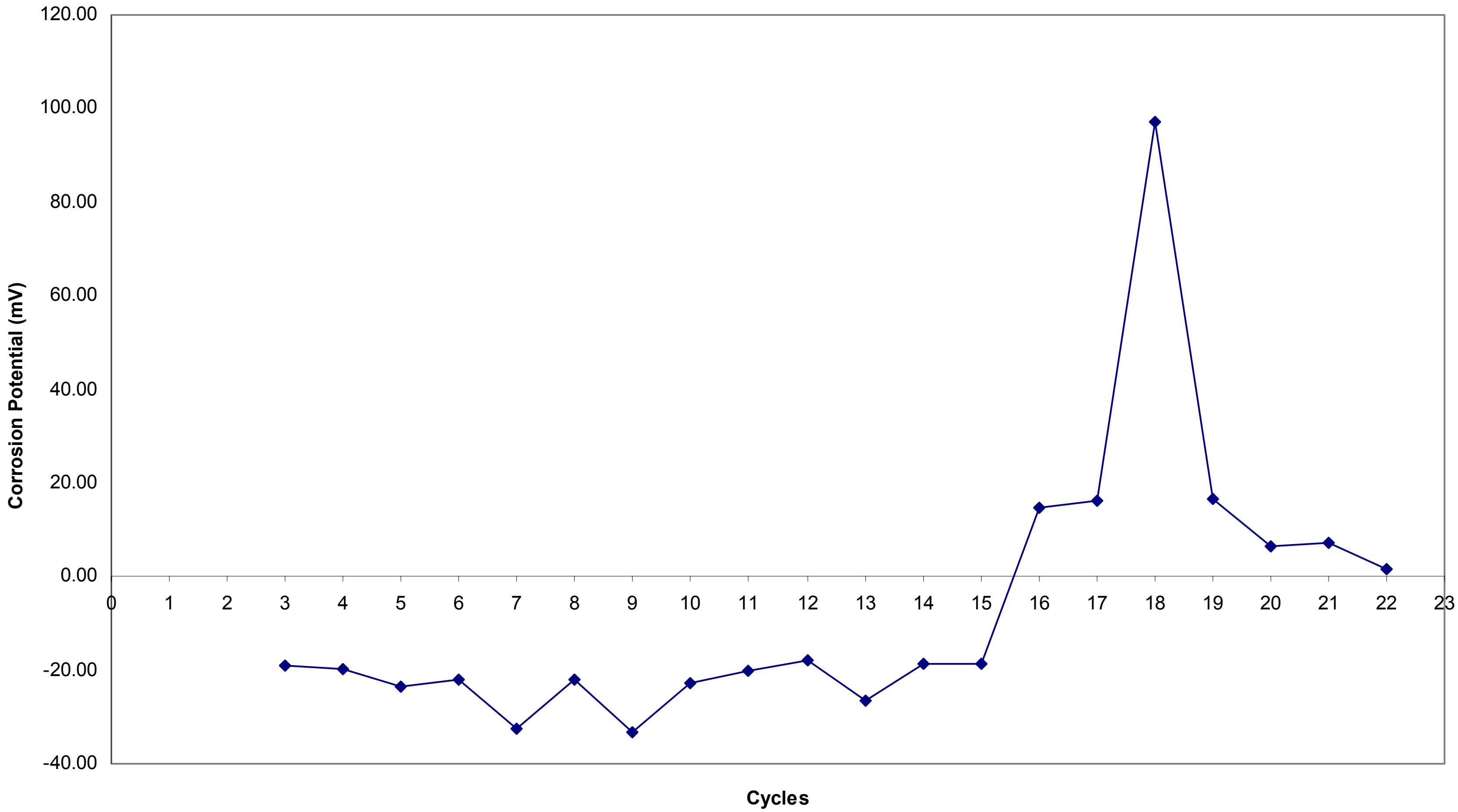

Fig. G.3: Minideck B – Average Corrosion Potential (mV)

Table G.7: North Main Street Eastbound GECOR 6 Corrosion Rate ($\mu A/cm^2$)

Connection #	Reading #	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8
B1	1	0.050	0.156	0.294	0.259	0.261	0.293	0.311	0.272
	2	0.093	0.231	0.382	0.209	0.291	0.202	0.312	0.372
	3	0.090	0.068	0.138	0.455	0.379	0.209	0.427	0.482
	4	0.091	0.179	0.276	0.200	0.147	0.197	0.277	0.304
	5	0.050	0.120	0.264	0.398	0.407	0.442	0.472	0.279
B2	1	0.098	0.115	0.215	0.743	0.229	0.374	0.497	0.507
	2	0.140	0.139	0.409	0.654	0.577	0.612	0.405	0.779
	3	0.080	0.909	0.242	0.252	0.123	0.272	0.297	0.372
	4	0.081	0.084	0.307	0.328	0.299	0.372	0.272	0.407
	5	0.077	0.140	0.269	0.253	0.277	0.197	0.372	0.394
B3	1	0.087	0.134	0.478	0.884	0.701	0.645	0.644	0.601
	2	0.100	0.287	0.432	0.296	0.227	0.312	0.407	0.327
	3	0.069	0.083	0.323	0.539	0.417	0.392	0.207	0.499
	4	0.056	0.130	0.354	0.342	0.397	0.472	0.312	0.409
	5	0.097	0.101	0.288	0.666	0.578	0.720	0.609	0.578
B4	1	0.088	0.067	0.110	0.088	0.107	0.097	0.172	0.119
	2	0.152	0.087	0.507	0.438	0.279	0.478	0.511	0.427
	3	0.091	0.105	0.241	0.361	0.352	0.317	0.411	0.397
	4	0.089	0.085	0.324	0.539	0.572	0.642	0.391	0.694
	5	0.100	0.069	0.424	0.593	0.384	0.578	0.412	0.578
	Average	0.089	0.164	0.314	0.425	0.350	0.391	0.386	0.440

Table G.8: North Main Street Eastbound GECOR 6 Corrosion Potential (mV)

Connection #	Reading #	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8
B1	1	-54.9	-98.0	-143.5	-139.6	-172.0	-98.4	-82.4	-104.2
	2	-16.8	-67.8	-87.3	-89.6	-41.4	-56.7	-92.4	-76.2
	3	-16.7	-24.8	-92.2	-125.8	-82.7	-74.4	-57.2	-38.9
	4	-19.8	-35.5	-88.6	-103.4	-54.8	-17.2	-53.7	-41.4
	5	-5.8	-57.1	-66.6	-91.2	-58.9	-67.3	-75.5	-23.4
B2	1	-63.1	-82.2	-130.2	-177.9	-152.1	-121.4	-94.3	-31.2
	2	-57.4	-51.3	-118.6	-135.6	-172.4	-120.9	-167.2	-112.4
	3	-20.3	-106.9	-154.6	-155.4	-145.4	-71.4	-31.2	-107.4
	4	-8.1	-15.2	-107.7	-129.1	-121.4	-148.4	-159.6	-71.4
	5	-33.1	-34.5	-100.3	-118.0	-97.6	-82.4	-72.3	-48.9
B3	1	-71.5	-148.9	-162.1	-176.6	-170.4	-76.7	-112.9	-138.9
	2	-5.6	-69.0	-109.6	-104.9	-18.9	-19.7	-27.3	-96.4
	3	-6.9	-26.7	-100.9	-123.6	-132.1	-111.7	-92.3	-76.6
	4	-66.9	-92.0	-137.0	-151.6	-42.4	-66.7	-79.8	-31.2
	5	-32.9	-32.0	-117.0	-139.2	-112.4	-97.4	-82.3	-51.7
B4	1	-73.6	-68.4	-112.5	-125.5	-79.3	-61.4	-22.4	-47.8
	2	-51.3	-17.6	-123.4	-114.1	-112.4	-179.3	-92.8	-79.8
	3	-24.2	-39.5	-96.4	-113.3	-87.9	-92.4	-14.8	-55.6
	4	-3.6	-36.8	-108.4	-126.7	-100.2	-79.3	-172.4	-49.8
	5	-3.1	-15.0	-104.7	-131.3	-79.3	-100.4	-187.3	-100.9
	Average	-31.8	-56.0	-113.1	-128.6	-101.7	-87.2	-88.5	-69.2

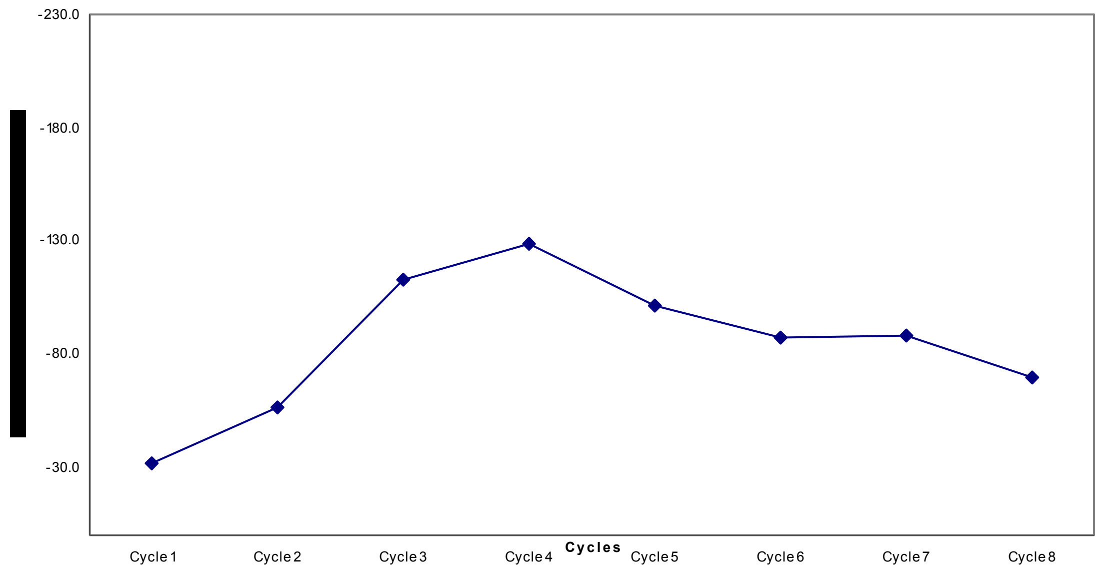

Fig. G.4: North Main Street Eastbound GEOCOR 6 Average Corrosion Potential

Table G.9: Minideck C –ASTM G 109 Corrosion Rate (μA/cm^2)

Specimen	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10	Cycle 11
C1	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.08	0.08	0.08
C2	0.10	0.20	0.40	0.40	0.40	0.30	0.40	0.40	0.25	0.05	0.10
C3	0.60	0.60	1.20	1.00	1.30	1.20	1.30	1.40	0.08	0.15	0.08
C4	0.40	0.70	0.60	0.70	0.60	0.40	0.80	0.60	0.13	0.13	0.18
C5	0.20	0.30	0.50	0.40	0.50	0.40	0.60	0.50	0.15	0.18	0.05
C6	0.00	0.10	0.20	0.20	0.10	0.20	0.30	0.30	0.13	0.13	0.03
Average	0.23	0.32	0.48	0.45	0.48	0.42	0.58	0.55	0.13	0.12	0.08

Specimen	Cycle 12	Cycle 13	Cycle 14	Cycle 15	Cycle 16	Cycle 17	Cycle 18	Cycle 19	Cycle 20	Cycle 21	Cycle 22
C1	0.08	0.05	0.10	0.00	0.10	0.20	0.10	0.00	0.10	0.00	0.10
C2	0.30	0.15	0.13	0.10	0.10	0.30	0.20	0.00	0.10	0.10	0.10
C3	0.08	0.10	0.00	0.17	0.10	0.40	0.10	2.30	1.40	0.40	0.20
C4	0.35	0.05	0.60	0.00	0.00	0.36	0.50	0.50	0.30	0.20	0.20
C5	0.10	0.25	0.28	0.67	0.30	0.01	0.20	6.40	3.80	1.10	0.70
C6	0.10	0.03	0.05	0.13	0.50	0.54	0.30	0.20	0.20	0.40	4.60
Average	0.17	0.10	0.19	0.18	0.18	0.30	0.23	1.57	0.98	0.37	0.98

Table G.10: Minideck C – ASTM G 109 Corrosion Potential (mV)

Specimen	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10	Cycle 11
C1	N/A	N/A	-14.31	-13.82	-17.82	-14.80	-25.45	-12.50	-20.66	-13.29	-9.80
C2	N/A	N/A	-6.39	-6.22	-10.01	-6.85	-17.94	-7.23	-28.25	-20.42	-17.09
C3	N/A	N/A	-32.81	-31.44	-36.36	-33.52	-44.23	-30.50	-44.44	-35.74	-32.29
C4	N/A	N/A	-35.54	-34.81	-38.87	-35.27	-46.52	-33.90	-25.49	-17.90	-14.56
C5	N/A	N/A	-14.24	-13.47	-18.28	-16.65	-27.81	-16.43	-37.27	-29.33	-25.47
C6	N/A	N/A	-21.82	-21.75	-25.78	-23.66	-35.38	-23.36	1.01	12.72	16.38
Average	N/A	N/A	-20.85	-20.25	-24.52	-21.79	-32.89	-20.65	-25.85	-17.33	-13.80

Specimen	Cycle 12	Cycle 13	Cycle 14	Cycle 15	Cycle 16	Cycle 17	Cycle 18	Cycle 19	Cycle 20	Cycle 21	Cycle 22
C1	-7.66	-15.28	-8.76	-9.09	17.42	18.02	11.52	11.52	5.66	2.02	3.56
C2	-15.19	-23.37	-15.52	-12.15	17.72	18.36	20.15	0.95	2.98	3.54	1.48
C3	-29.96	-39.37	-30.18	-22.11	17.66	20.25	3.58	0.96	5.44	10.55	1.40
C4	-12.53	-20.60	-12.33	-20.98	3.53	4.00	-2.25	15.39	3.09	2.06	2.66
C5	-23.60	-32.43	-22.48	-29.12	3.26	4.36	15.43	263.60	3.99	179.64	1.05
C6	18.86	7.64	20.99	12.00	16.25	19.36	12.42	-1.37	4.10	51.40	0.95
Average	-11.68	-20.57	-11.38	-13.57	12.64	14.06	10.14	48.51	4.21	41.54	1.85

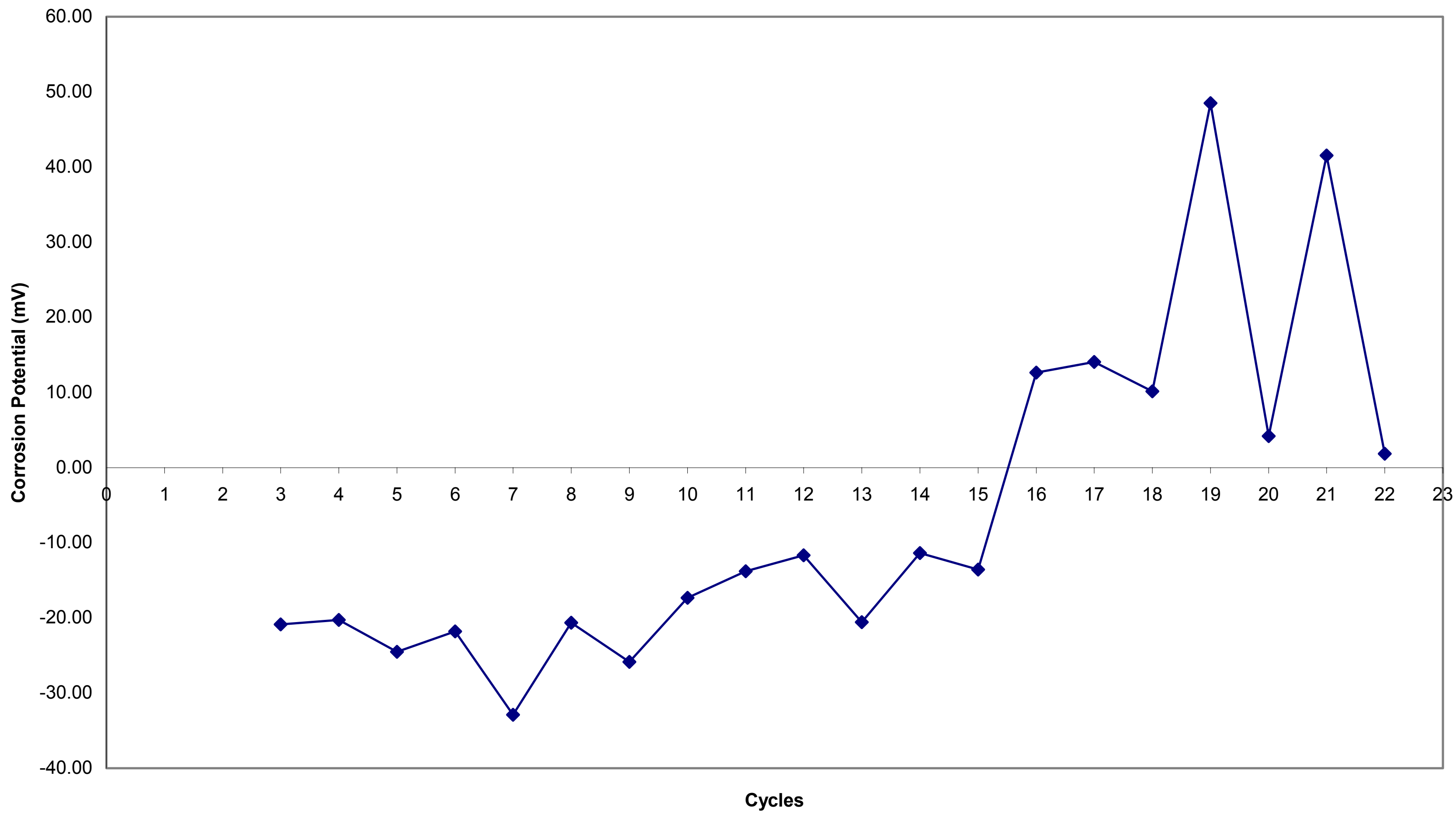

Fig G.5: Minideck C – Average Corrosion Potential (mV)

Table G.11: Wyckoff Road Westbound GECOR 6 Corrosion Rate ($\mu A/cm^2$)

Connection #	Reading #	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8
B1	1	0.061	0.150	0.069	0.381	0.217	0.229	0.394	0.462
	2	0.040	0.095	0.057	0.315	0.085	0.197	0.402	0.472
	3	0.063	0.098	0.066	0.434	0.279	0.127	0.397	0.272
	4	0.082	0.155	0.065	0.119	0.372	0.402	0.287	0.197
	5	0.064	0.110	0.031	0.567	0.599	0.379	0.234	0.099
B2	1	0.069	0.188	0.037	0.233	0.112	0.087	0.217	0.307
	2	0.059	0.114	0.049	0.233	0.297	0.187	0.398	0.402
	3	0.083	0.104	0.044	0.336	0.205	0.112	0.077	0.325
	4	0.067	0.144	0.046	0.312	0.372	0.424	0.278	0.221
	5	0.089	0.176	0.059	0.558	0.599	0.473	0.372	0.617
B3	1	0.100	0.121	0.276	0.223	0.227	0.079	0.114	0.472
	2	0.116	0.248	0.051	0.303	0.409	0.198	0.224	0.395
	3	0.059	0.204	0.096	0.324	0.221	0.188	0.272	0.155
	4	0.064	0.117	0.048	0.263	0.255	0.097	0.072	0.137
	5	0.072	0.150	0.030	0.468	0.572	0.432	0.397	0.482
B4	1	0.075	0.181	0.021	0.492	0.572	0.302	0.272	0.599
	2	0.126	0.209	0.032	0.441	0.277	0.124	0.343	0.407
	3	0.068	0.079	0.043	0.277	0.317	0.297	0.397	0.317
	4	0.107	0.191	0.044	0.309	0.402	0.198	0.272	0.612
	5	0.066	0.136	0.042	0.347	0.192	0.355	0.473	0.578
	Average	0.077	0.149	0.060	0.347	0.329	0.244	0.295	0.376

Table G.12: Wyckoff Road Westbound GECOR 6 Corrosion Potential (mV)

Connection #	Reading #	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8
B1	1	-23.6	-111.2	-52.4	-118.2	-59.3	-67.4	-41.4	-105.3
	2	-30.4	-82.3	-49.4	-110.2	-114.3	-92.4	-87.3	-56.2
	3	-14.6	-72.2	-91.5	-118.8	-82.4	-121.4	-67.3	-71.4
	4	9.6	-92.9	-58.7	-118.8	-48.9	-61.9	-92.4	-82.7
	5	-15.1	-98.1	-77.5	-145.1	-131.4	-92.4	-72.4	-50.9
B2	1	-40.2	-127.8	-67.4	-202.1	-185.4	-221.4	-179.2	-65.4
	2	-51.2	-95.8	-57.8	-127.9	-62.4	-48.4	-112.9	-79.9
	3	-20.9	-104.5	-66.9	-117.2	-100.4	-141.4	-67.2	-112.4
	4	7.9	-97.6	-76.9	-115.0	-72.4	-121.3	-55.3	-36.7
	5	-7.8	-83.8	-98.6	-134.9	-121.2	-92.3	-72.1	-67.8
B3	1	-216.7	-139.0	-109.4	-163.6	-141.4	-96.6	-78.3	-58.3
	2	-30.9	-120.8	-65.9	-140.6	-129.3	-99.7	-142.3	-107.3
	3	-4.7	-118.6	-90.3	-109.5	-114.3	-127.3	-62.1	-39.3
	4	29.4	-77.0	-69.7	-108.7	-47.3	-113.4	-87.8	-41.7
	5	9.1	-94.6	-131.2	-137.5	-91.9	-192.4	-48.4	-131.3
B4	1	-20.5	-111.2	-153.7	-162.3	-152.3	-100.4	-78.4	-41.3
	2	-23.3	-101.7	-60.3	-141.1	-92.7	-114.8	-98.4	-107.4
	3	-24.0	-117.4	-101.8	-143.5	-67.3	-121.3	-77.9	-27.2
	4	-65.8	-134.8	-66.4	-142.9	-122.4	-87.3	-131.9	-137.9
	5	-4.3	-84.1	-129.4	-155.8	-78.4	-111.4	-121.8	-137.9
	Average	-26.9	-103.3	-83.8	-135.7	-100.8	-111.2	-88.7	-77.9

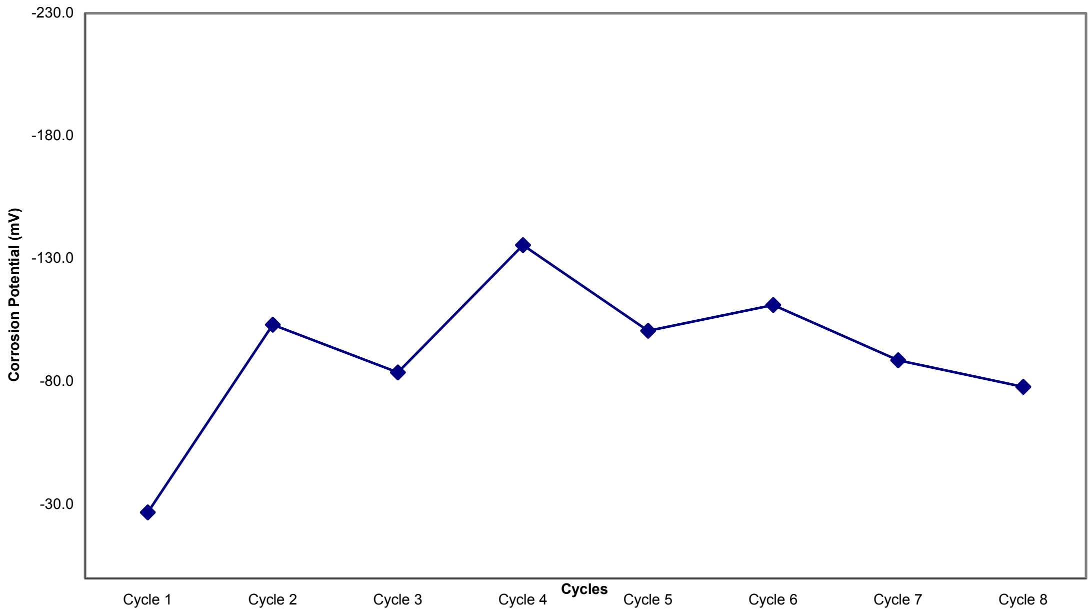

Fig G.6: Wyckoff Road Westbound GECOR 6 Average Corrosion Potential (mV)

Table G.13: Minideck D – ASTM G 109 Corrosion Rate (μA/cm²)

Specimen	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10	Cycle 11
D1	0.70	1.00	1.40	0.80	1.10	0.70	1.00	1.00	0.43	0.33	0.63
D2	0.80	0.80	0.90	1.10	1.20	1.20	1.30	1.20	0.25	0.08	0.08
D3	0.40	0.80	0.80	0.80	0.80	0.80	0.80	0.90	0.83	0.95	1.53
D4	0.20	0.50	0.40	1.10	0.40	0.30	0.40	0.40	0.28	0.20	0.20
D5	0.70	0.80	1.20	1.30	1.30	0.80	1.20	1.10	0.70	0.73	0.75
D6	0.70	0.80	1.20	1.30	1.40	1.20	1.40	1.40	1.03	0.80	1.20
Average	0.58	0.78	0.98	1.07	1.03	0.83	1.02	1.00	0.58	0.51	0.73

Specimen	Cycle 12	Cycle 13	Cycle 14	Cycle 15	Cycle 16	Cycle 17	Cycle 18	Cycle 19	Cycle 20	Cycle 21	Cycle 22
D1	0.53	.5	0.40	0.00	0.10	0.12	0.10	0.10	0.10	0.10	0.20
D2	0.08	0.08	0.00	0.07	0.10	0.12	3.30	1.00	3.10	2.30	1.40
D3	0.80	1.53	0.63	0.00	0.10	0.23	0.20	0.10	3.10	0.30	0.50
D4	0.28	0.08	0.03	0.00	0.20	0.20	4.50	2.30	0.10	2.00	1.30
D5	0.83	2.25	1.00	0.00	0.10	0.15	0.20	0.00	0.10	0.50	0.10
D6	0.95	0.89	0.85	0.00	0.40	0.50	2.90	1.80	2.50	1.70	1.50
Average	0.58	0.96	0.48	0.01	0.17	0.22	1.87	0.88	1.50	1.15	0.83

Table G.14: Minideck D – ASTM G 109 Corrosion Potential (mV)

Specimen	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10	Cycle 11
D1	N/A	N/A	-20.97	-16.84	-20.13	-15.07	-22.00	-8.25	-42.62	-33.94	-29.90
D2	N/A	N/A	-17.64	-14.79	-17.93	-13.59	-19.78	-5.63	-5.19	4.67	8.16
D3	N/A	N/A	-20.80	-18.51	-21.74	-17.93	-23.80	-13.50	-1.27	25.97	29.46
D4	N/A	N/A	-6.80	-5.35	-8.82	-3.96	-8.14	-4.73	3.76	13.89	17.72
D5	N/A	N/A	-18.30	-16.55	-20.00	-15.17	-22.06	-9.65	2.46	22.66	26.20
D6	N/A	N/A	-18.38	-16.55	-19.83	-15.23	-20.22	-6.77	-15.08	-11.87	-8.06
Average	N/A	N/A	-17.15	-14.77	-18.08	-13.49	-19.33	-8.09	-9.66	3.56	7.26

Specimen	Cycle 12	Cycle 13	Cycle 14	Cycle 15	Cycle 16	Cycle 17	Cycle 18	Cycle 19	Cycle 20	Cycle 21	Cycle 22
D1	-30.26	-34.66	-31.22	-30.76	23.40	26.36	41.67	-20.58	1.12	1.88	1.43
D2	10.44	1.09	11.68	12.21	22.98	25.56	25.59	-12.88	1.86	2.08	1.50
D3	30.95	21.93	30.48	31.40	18.54	20.36	22.73	-5.66	5.05	8.37	2.13
D4	19.57	10.10	18.81	18.62	11.22	11.63	26.71	-10.58	1.91	3.17	1.50
D5	27.46	14.55	28.05	29.06	2.65	2.36	25.22	-5.73	2.07	4.50	1.20
D6	-5.82	-4.22	-5.36	-5.32	3.50	3.80	20.60	-9.44	1.19	37.82	1.72
Average	8.72	1.46	8.74	9.20	13.72	15.01	27.09	-10.81	2.20	9.64	1.58

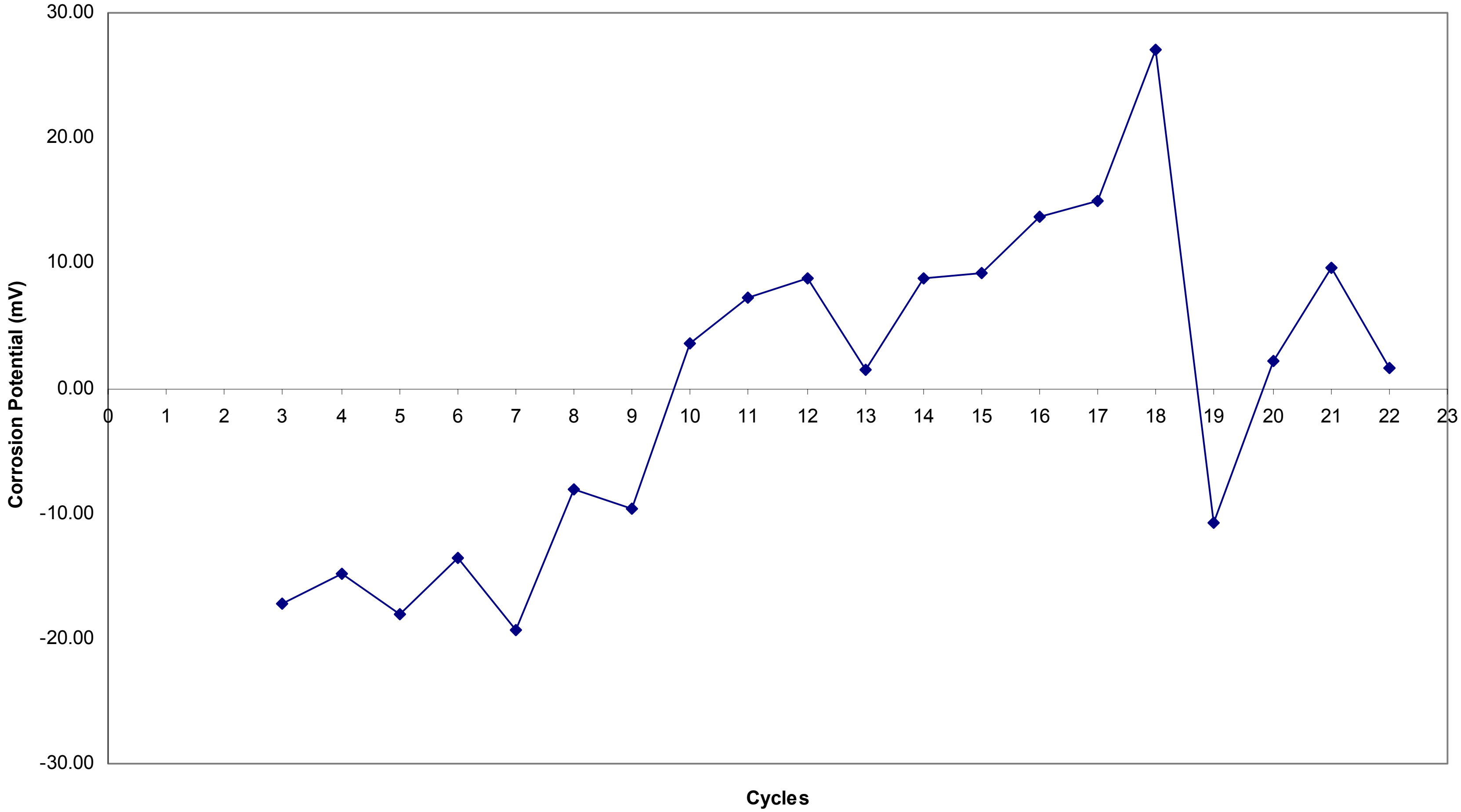

Fig. G.7: Minideck D – Average Corrosion Potential (mV)

Table G.15: Wyckoff Road Eastbound GECOR 6 Corrosion Rate (μA/cm^2)

Connection #	Reading #	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8
B1	1	0.038	0.146	0.257	0.071	0.052	0.212	0.317	0.297
	2	0.048	0.118	0.249	0.092	0.192	0.077	0.272	0.121
	3	0.033	0.089	0.214	0.210	0.272	0.178	0.199	0.244
	4	0.168	0.125	0.168	0.150	0.422	0.134	0.222	0.307
	5	0.153	0.198	0.283	0.092	0.042	0.079	0.212	0.199
B2	1	0.190	0.578	0.229	0.078	0.092	0.117	0.232	0.322
	2	0.134	0.593	0.379	0.078	0.177	0.224	0.334	0.209
	3	0.094	0.105	0.285	0.112	0.077	0.124	0.272	0.319
	4	0.176	0.142	0.274	0.105	0.179	0.212	0.312	0.099
	5	0.162	0.146	0.320	0.130	0.272	0.144	0.211	0.275
B3	1	0.135	0.106	0.314	0.142	0.155	0.167	0.044	0.272
	2	0.096	0.120	0.356	0.066	0.212	0.052	0.313	0.212
	3	0.110	0.083	0.198	0.134	0.137	0.144	0.232	0.372
	4	0.126	0.132	0.234	0.062	0.071	0.123	0.054	0.109
	5	0.200	0.179	0.195	0.043	0.121	0.321	0.091	0.262
B4	1	0.036	0.223	0.210	0.153	0.155	0.167	0.272	0.148
	2	0.028	0.180	0.321	0.112	0.073	0.148	0.198	0.278
	3	0.084	0.140	0.708	0.085	0.312	0.243	0.297	0.311
	4	0.169	0.210	0.369	0.088	0.278	0.312	0.066	0.124
	5	0.108	0.138	0.623	0.115	0.194	0.244	0.233	0.092
	Average	0.114	0.188	0.309	0.106	0.174	0.171	0.219	0.229

Table G.16: Wyckoff Road Eastbound GECOR 6 Corrosion Potential (mV)

Connection #	Reading #	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8
B1	1	-29.0	-85.3	-101.1	-89.2	-78.6	-100.3	-44.3	-56.7
	2	10.5	-25.0	-97.7	-98.4	-99.3	-72.4	-52.3	-40.9
	3	9.7	-38.3	-94.0	-151.5	-1221.3	-181.3	-92.4	-67.8
	4	-1.3	-56.7	-99.6	-124.1	-131.4	-96.4	-89.3	-45.6
	5	-13.3	-82.9	-110.4	-125.9	-91.8	-89.3	-61.4	-32.3
B2	1	-59.2	-162.3	-172.0	-89.2	-94.7	-104.3	-88.7	-100.4
	2	-27.3	-78.2	-107.3	-77.6	-58.9	-63.7	-42.8	-31.9
	3	17.1	-1.0	-82.8	-93.4	-107.4	-112.4	-82.3	-48.9
	4	-1.3	-17.7	-81.9	-117.6	-37.3	-49.4	-56.7	-39.4
	5	-4.2	-18.5	-100.3	-136.6	-107.4	-112.4	-132.4	-114.3
B3	1	-81.0	-82.7	-143.2	-104.6	-93.8	-99.8	-172.3	-101.8
	2	-27.5	-33.2	-110.2	-82.0	-48.4	-27.3	-94.3	-49.2
	3	-1.2	-14.9	-77.4	-131.4	-114.3	-121.4	-100.7	-27.3
	4	-0.7	-16.9	-69.8	-94.1	-62.3	-79.3	-82.3	-119.3
	5	-2.2	-41.7	-86.5	-155.6	-89.5	-107.3	-48.9	-121.3
B4	1	-28.1	-82.1	-134.2	-146.2	-108.7	-88.7	-79.3	-29.4
	2	-7.6	-52.7	-114.2	-115.1	-79.8	-87.3	-99.3	-102.8
	3	-1.7	-60.2	-118.9	-94.8	-111.4	-89.4	-93.4	-111.3
	4	-3.8	-67.5	-89.0	-99.7	-123.4	-76.4	-78.4	-48.9
	5	-7.2	-41.9	-114.7	-124.8	-58.8	-63.2	-59.8	-53.4
	Average	-13.0	-53.0	-105.3	-112.6	-145.9	-91.1	-82.6	-67.1

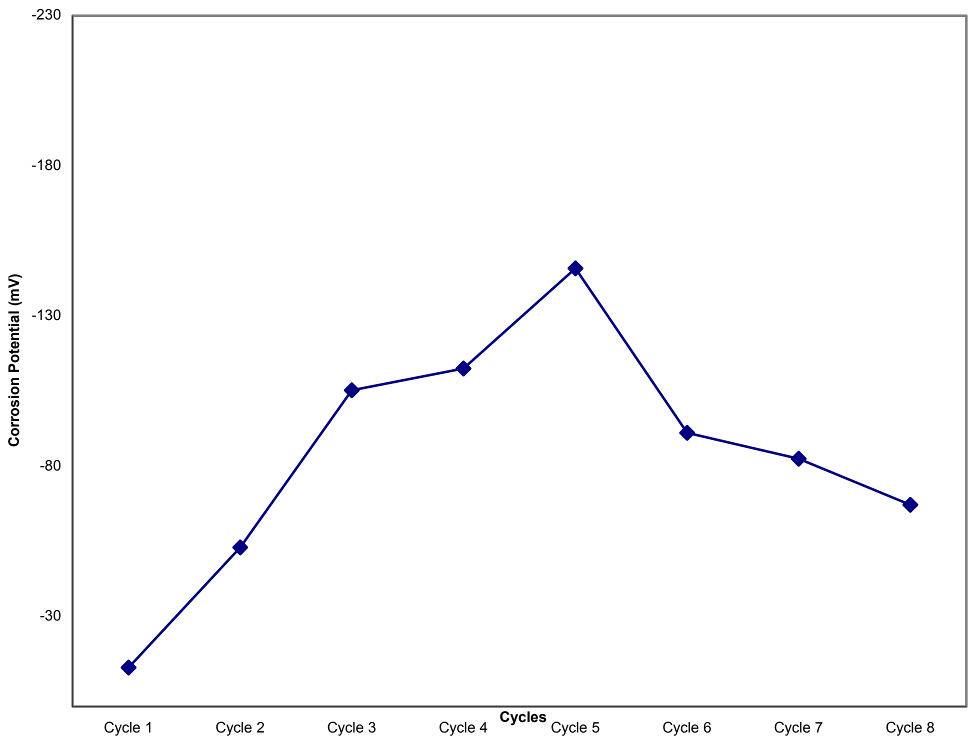

Fig G.8: Wyckoff Road Eastbound GECOR 6 Average Corrosion Potential (mV)

Table G.17: Minideck E – ASTM G 109 Corrosion Rate (μA/cm^2)

Specimen	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10	Cycle 11
E1	0.80	1.40	1.40	1.20	1.90	1.80	N/A	N/A	0.25	0.20	0.01
E2	3.00	1.80	1.40	0.80	0.50	0.50	N/A	N/A	0.08	0.03	0.08
E3	2.00	1.40	1.30	0.80	0.70	0.00	N/A	N/A	1.03	0.80	1.13
E4	0.90	1.10	0.90	0.40	0.80	0.80	N/A	N/A	0.05	0.05	0.03
E5	0.90	0.90	0.60	0.30	0.70	0.60	N/A	N/A	0.08	0.05	0.08
E6	7.00	3.10	2.00	0.90	0.50	0.40	N/A	N/A	0.00	0.00	0.00
Average	2.43	1.62	1.27	0.73	0.85	0.68	N/A	N/A	0.25	0.19	0.22

Specimen	Cycle 12	Cycle 13	Cycle 14	Cycle 15	Cycle 16	Cycle 17	Cycle 18	Cycle 19	Cycle 20	Cycle 21	Cycle 22
E1	0.20	5.95	0.10	2.55	15.20	12.60	2.70	2.40	2.30	1.70	1.30
E2	0.10	1.38	0.03	0.00	0.20	0.36	0.20	0.50	0.40	0.30	0.10
E3	0.90	0.75	0.75	0.10	0.70	0.77	0.10	0.20	0.40	0.10	0.10
E4	0.05	0.03	0.03	0.07	1.20	1.36	0.70	0.50	0.40	0.20	0.20
E5	0.05	0.10	0.00	0.07	0.90	1.23	0.10	0.20	0.30	0.20	0.20
E6	0.00	0.00	0.00	0.10	0.40	0.06	0.20	0.30	0.00	0.30	0.10
Average	0.22	1.37	0.15	0.48	3.10	2.73	0.67	0.68	0.63	0.47	0.33

Table G.18: Minideck E – ASTM G 109 Corrosion Potential (mV)

Specimen	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10	Cycle 11
E1	-94.32	-73.40	-66.60	-55.86	-62.34	-38.95	N/A	N/A	8.78	12.61	16.22
E2	-7.97	-64.68	-53.10	-39.54	-45.07	-18.83	N/A	N/A	-12.15	-3.34	0.67
E3	-62.93	-46.52	-42.77	-33.97	-40.54	-22.73	N/A	N/A	-21.28	-13.70	-10.08
E4	-73.88	-53.66	-48.76	-41.68	-50.61	-32.22	N/A	N/A	-14.53	-6.00	-1.14
E5	-79.75	-56.92	-51.90	-43.13	-50.35	-30.42	N/A	N/A	-17.51	-13.95	-10.30
E6	-110.5	-77.53	-70.85	-52.01	-55.15	-33.19	N/A	N/A	-1.72	-10.8	0.15
Average	-84.90	-62.12	-55.66	-44.37	-50.68	-29.39	N/A	N/A	-9.74	-5.86	-0.75

Specimen	Cycle 12	Cycle 13	Cycle 14	Cycle 15	Cycle 16	Cycle 17	Cycle 18	Cycle 19	Cycle 20	Cycle 21	Cycle 22
E1	17.84	11.73	20.35	22.85	3.32	3.36	13.28	3.44	1.21	50.64	2.28
E2	2.49	-0.48	2.95	2.10	3.25	3.45	22.90	-9.72	1.65	9.81	3.55
E3	-8.10	-16.21	-8.09	-8.18	18.00	20.00	16.62	-1.71	1.46	6.88	3.92
E4	0.84	-8.68	1.74	2.08	2.42	3.60	10.75	4.36	2.18	7.50	0.92
E5	-8.24	-12.45	-8.72	-8.37	13.18	14.58	14.12	-0.06	1.90	18.38	0.89
E6	5.67	-0.01	-0.91	-5.32	18.25	19.36	11.45	2.92	0.98	7.33	1.44
Average	1.75	-4.35	1.22	0.86	9.74	10.73	14.85	-0.13	1.56	16.76	2.17

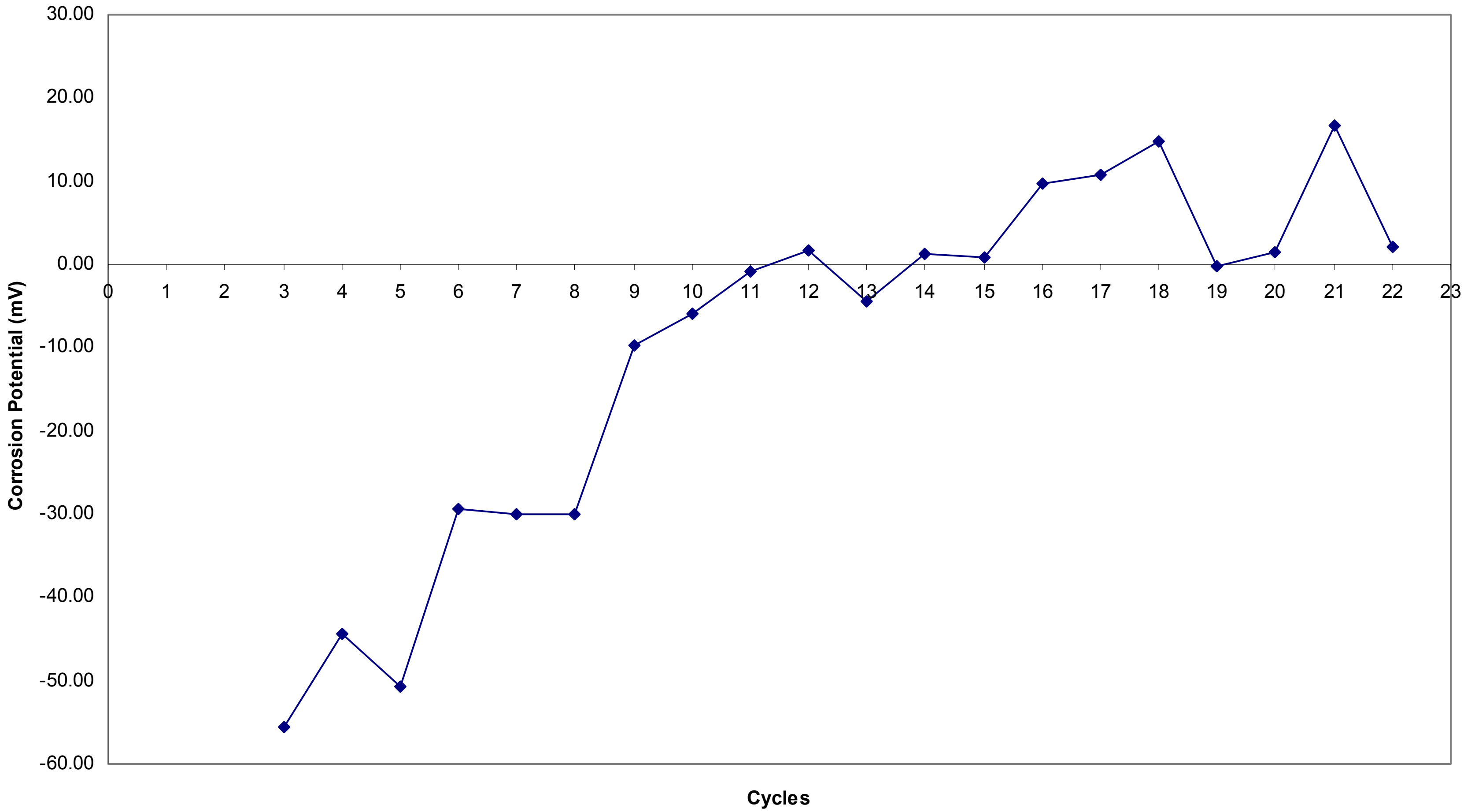

Fig. G.9: Minideck E – Average Corrosion Potential (mV)

Table G.19: Route 130 Westbound GECOR 6 Corrosion Rate (μA/cm^2)

Connection #	Reading #	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8
B1	1	0.096	0.276	0.100	0.093	0.072	0.052	0.052	0.124
	2	0.185	0.142	0.262	0.050	0.123	0.077	0.077	0.112
	3	0.203	0.190	0.129	0.073	0.052	0.085	0.085	0.091
	4	0.138	0.109	0.101	0.092	0.172	0.142	0.142	0.123
	5	0.132	0.096	0.115	0.103	0.124	0.172	0.172	0.131
B2	1	0.235	0.096	0.104	0.077	0.142	0.117	0.117	0.107
	2	0.202	0.145	0.054	0.066	0.097	0.094	0.094	0.042
	3	0.172	0.169	0.098	0.091	0.087	0.132	0.132	0.092
	4	0.174	0.189	0.107	0.414	0.137	0.127	0.127	0.077
	5	0.161	0.223	0.130	0.099	0.124	0.192	0.192	0.051
B3	1	0.152	0.132	0.258	0.058	0.092	0.272	0.272	0.129
	2	0.088	0.223	0.074	0.075	0.123	0.255	0.255	0.141
	3	0.210	0.198	0.064	0.078	0.137	0.234	0.234	0.172
	4	0.209	0.173	0.080	0.095	0.148	0.313	0.313	0.142
	5	0.209	0.261	0.088	0.091	0.078	0.149	0.149	0.154
B4	1	0.139	0.267	0.096	0.056	0.048	0.237	0.237	0.091
	2	0.222	0.231	0.058	0.075	0.114	0.199	0.199	0.052
	3	0.277	0.209	0.073	0.071	0.271	0.144	0.144	0.212
	4	0.313	0.317	0.061	0.074	0.314	0.152	0.152	0.324
	5	0.271	0.343	0.524	0.073	0.421	0.212	0.212	0.177
B5	1	0.266	0.107	0.053	0.055	0.094	0.172	0.172	0.097
	2	0.212	0.151	0.087	0.099	0.073	0.054	0.054	0.121
	3	0.177	0.119	0.064	0.067	0.312	0.232	0.232	0.342
	4	0.220	0.250	0.072	0.079	0.272	0.198	0.198	0.482
	5	0.250	0.198	0.788	0.091	0.432	0.272	0.272	0.511
	Average	0.197	0.193	0.146	0.092	0.162	0.171	0.171	0.164

Table G.20: Route 130 Westbound GECOR 6 Corrosion Potential (mV)

Connection #	Reading #	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8
B1	1	123.2	26.8	21.5	28.7	31.7	42.4	27.2	53.2
	2	86.1	52.5	-23.9	54.0	57.2	31.2	73.2	87.2
	3	65.1	107.0	-5.3	-3.2	12.3	14.1	27.2	91.3
	4	-6.0	55.4	-13.9	-30.6	-7.9	-10.3	-21.3	1.7
	5	-42.4	20.9	-8.2	-22.2	-31.3	-9.2	-12.3	-8.9
B2	1	76.2	82.8	6.7	15.9	18.4	92.4	67.3	55.6
	2	45.1	34.6	52.4	30.7	42.3	10.7	91.4	63.3
	3	27.9	34.1	-3.2	-16.0	-15.3	-10.9	21.4	13.5
	4	7.6	53.1	0.4	-66.4	-55.3	-17.8	-21.4	-1.9
	5	-6.8	57.2	-7.1	-7.7	-2.3	-12.4	-19.5	-11.9
B3	1	74.1	70.9	-37.5	21.0	14.4	21.4	17.7	27.9
	2	1.0	-12.5	33.6	9.6	12.3	8.9	31.4	48.9
	3	33.2	70.8	49.1	17.5	71.7	82.3	97.2	78.7
	4	33.6	61.7	43.8	10.1	14.8	19.8	27.3	33.4
	5	-8.3	45.7	56.1	19.4	27.2	33.4	47.5	58.8
B4	1	52.3	16.9	37.1	37.1	49.3	57.4	62.3	38.7
	2	18.6	30.4	109.3	31.0	42.2	55.6	33.4	19.8
	3	21.8	40.0	53.1	13.5	55.7	66.7	78.9	81.9
	4	23.1	76.3	109.2	40.5	67.3	77.4	88.4	91.7
	5	13.7	47.7	-8.1	10.6	81.9	89.5	75.6	66.4
B5	1	89.3	98.2	68.6	15.7	12.4	67.8	71.7	52.4
	2	67.5	78.7	42.1	3.5	21.3	77.8	89.9	15.5
	3	23.0	52.8	47.9	11.0	31.4	84.4	81.2	17.7
	4	18.7	37.3	46.0	11.3	42.4	96.4	21.2	19.8
	5	2.3	22.8	-64.5	18.8	55.6	21.9	31.4	21.4
	Average	33.6	50.5	24.2	10.2	26.0	39.6	43.5	40.6

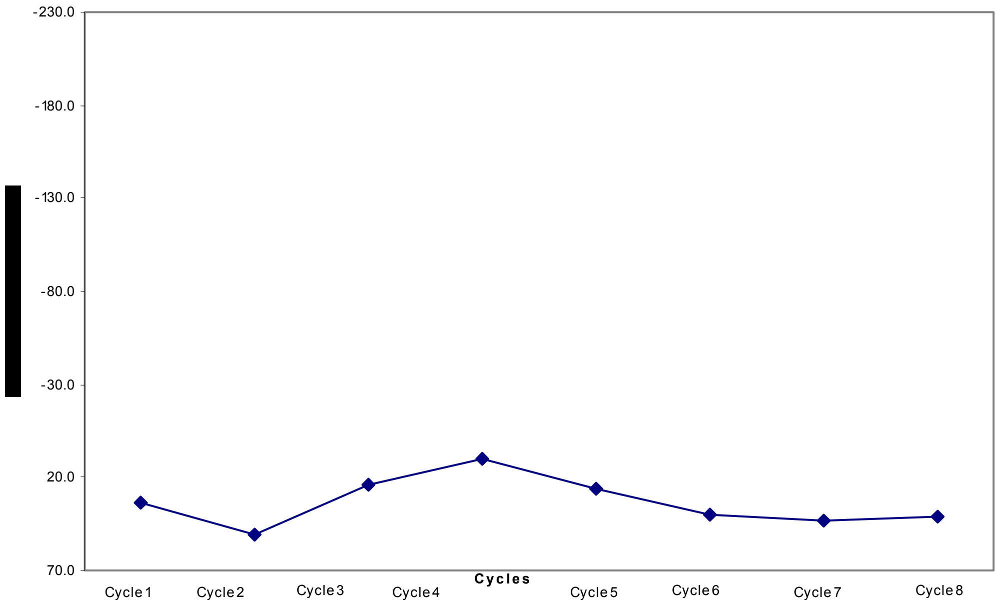

Fig G.10: Route 130 Westbound GECOR 6 Average Corrosion Potential (mV)