

**Standard Protocol to
Evaluate the Performance of Corrosion Mitigation Technologies
in Concrete Repairs**

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Introduction

The protocol for measuring the performance of corrosion mitigation technologies for concrete reinforcing steel was first suggested by a group of industry recognized experts and strategic planners in support of goals outlined in Vision 2020: “A Vision for the Concrete Repair, Protection and Strengthening Industry”. Vision 2020 is an industry created strategic plan and roadmap; documents were developed over a several year period which began in 2003. Information about these documents is available at the American Concrete Institute (ACI) Foundation’s [Strategic Development Council \(SDC\)](#) website.

One goal of the Vision 2020 group was to develop a test protocol which could be used to evaluate the effectiveness of steel reinforcement corrosion mitigation techniques for existing structures. As a first step toward achieving that goal, a panel of industry experts met to discuss a proposed protocol during the summer of 2008. The panel reviewed and discussed currently available test methods, concrete repair industry needs, and current research programs. The panel stressed the importance of having a flexible test program that would properly evaluate the performance of current corrosion mitigation options while allowing for future innovations. The panel recommended a pilot program be conducted prior to final adoption of a testing protocol or initiation of any full scale testing program to validate the repeatability and reproducibility of the protocol.

This protocol is the outcome of the pilot program which was conducted by the Bureau of Reclamation under a cooperative agreement with the SDC through contract awarded to Tourney Consulting Group (TCG). The contract was funded by Reclamation using funds from the ACI Foundation.

Special thanks go to the panel of experts that devoted countless hours to developing, editing and revising the protocol and to the review committee that reviewed the plans for the pilot program and suggested changes to the protocol based on test results. None of this would have been possible without their talent, hard work and expertise.

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M-82 - Standard Protocol to Evaluate the Performance of Corrosion Mitigation Technologies in Concrete Repairs

PART 1 GENERAL

1.01 SCOPE

- A. This test method covers two procedures for measuring and differentiating the performance of reinforcing steel corrosion mitigating technologies for concrete repairs caused by damage due to chloride ingress.
- B. The values stated in inch-pound units are to be regarded as standard. The SI values given in parentheses are for information only.
- C. This standard does not address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

1.02 REFERENCE STANDARDS

- A. Unless otherwise indicated, use most recent version.
- B. American Concrete Institute (ACI)
 - 1. ACI 440.6 Specification for Carbon and Glass Fiber-Reinforced Polymer (FRP) Bar Materials for Concrete Reinforcement
- C. ASTM International (ASTM)
 - 1. ASTM A 615/A 615 M Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
 - 2. ASTM A 706/A 706 M Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement
 - 3. ASTM A 1064/A 1064 M Carbon-Steel Wire and Welded Wire Reinforcement, Plain and Deformed, for Concrete
 - 4. ASTM C 31/C 31 M Making and Curing Concrete Test Specimens in the Field
 - 5. ASTM C 33/C 33 M Concrete Aggregates
 - 6. ASTM C 39/C 39 M Compressive Strength of Cylindrical Concrete Specimens
 - 7. ASTM C 94/C 94 M Ready-Mixed Concrete
 - 8. ASTM C 143/C 143 M Slump of Hydraulic-Cement Concrete
 - 9. ASTM C 150 Portland Cement
 - 10. ASTM C 171 Sheet Materials for Curing Concrete

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| 11. | ASTM C 231 | Air Content of Freshly Mixed Concrete by the Pressure Method |
| 12. | ASTM C 260 | Air-Entraining Admixtures for Concrete |
| 13. | ASTM C 403/C 403 M | Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance |
| 14. | ASTM C 494/C 494 M | Chemical Admixtures for Concrete |
| 15. | ASTM C 881/C 881 M | Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete |
| 16. | ASTM C 876 | Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete |
| 17. | ASTM C 1017/C 1017 M | Chemical Admixtures for Use in Producing Flowing Concrete |
| 18. | ASTM C 1152/C 1152 M e1 | Acid-Soluble Chloride Content Determination in Concrete |
| 19. | ASTM C 1202 | Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration |
| 20. | ASTM C 1602/C 1602 M | Mixing Water Used in the Production of Hydraulic Cement Concrete |
| 21. | ASTM C 1760 | Standard Test Method for Bulk Electrical Conductivity of Hardened Concrete |
| 22. | ASTM D 632 | Standard Specification for Sodium Chloride |
| 23. | ASTM F 2170 | Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using in situ Probes |
| 24. | ASTM G 57-06 | Standard Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method |
| 25. | ASTM G 187 | Standard Test Method for Measurement of Soil Resistivity Using the Two-Electrode Soil Box Method1 |
| D. National Association of Corrosion Engineers (NACE) | | |
| 1. | NACE/ASTM G 193-12d | Standard Terminology and Acronyms Relating to Corrosion |
| E. National Electrical Manufacturer's Association (NEMA) | | |
| 1. | NEMA 250 | Enclosures for Electrical Equipment (1000 Volts Maximum) |

- F. The Society for Protective Coatings (SSPC)
 - 1. SSPC-SP 3 Power Tool Cleaning
 - 2. SSPC-SP 8 Pickling

1.03 SUMMARY

- A. The protocol involves the production of 40-inch long by 40-inch wide x 5.5-inch thick (all dimensions +/- 0.5 inch) concrete slabs with discrete steel reinforcing bars near the top of the slab and welded-wire reinforcing (WWR) near the bottom of the slab.
- B. The steel bars are connected to the WWR through 1 ohm (Ω) resistors through switches in a junction box attached to the side of the slab.
- C. The concrete slabs are cyclically ponded with a 5% by mass sodium chloride (NaCl) solution for two weeks and then the solution is removed for two weeks.
- D. The macrocell current between each bar and the WWR is determined by measuring the voltage drop across the resistor. The positive macrocell currents (reinforcing steel bar is corroding) are integrated over time to have total macrocell corrosion for each bar. The total for all of the bars is also determined.
- E. The switches in the junction box are set so that all the bars and the WWR can be electrically connected through the resistors. For potential mapping the bars are connected.
- F. There are two configurations for the slabs:
 - 1. Configuration A slabs are used when the repair treatment is to be surface applied only (topical treatment).
 - a. Topical treatment slabs have 6 steel reinforcing bars in the top layer that are equally spaced apart, but are offset from one side to provide a section of the slab in which cores and resistivity measurements can be performed without affecting concrete near the bars.
 - 2. Configuration B slabs are used when concrete around corroding steel is removed as part of the repair method (topical or integral treatment). The slabs can also be made with a defect that can be removed after a specified corrosion level is reached.
 - a. Configuration B slabs for integral repair have a section called a hotspot that can be removed during the repair process.
 - b. Two steel reinforcing bars are located inside the hotspot. These bars are half-length bars supported by fiberglass bars to maintain their position.
 - 3. Repair technologies are applied according to manufacturer's instructions once a specified level of corrosion is reached.
 - 4. Measurements include:
 - a. Half-cell potential
 - b. Macrocell corrosion currents

- c. Concrete resistivity - Determined by the Wenner Four-Electrode method.
- d. Mat to mat resistance - Determined by disconnecting the WWR from the steel reinforcing bars, but leaving the bars electrically connected.

1.04 SIGNIFICANCE AND USE

- A. This protocol provides a reliable means for:
 - 1. Predicting the mitigation of preexisting corrosion activity by a surface applied or integral repair treatment.
 - 2. Comparing different mitigation technologies compared to control specimens receiving no treatment.
 - 3. Development of studies of concrete repair systems for corrosion mitigation.
 - 4. This test method can be used to determine the corrosion threshold value for chloride induced corrosion for black steel under the specified test conditions.

1.05 DEFINITIONS

- 1. Corrosion initiation is defined as when the first bar has a potential more negative than -300 millivolt (mV) vs. copper/copper sulfate (Cu/CuSO₄) reference electrode (CSE) and the macrocell current is greater than 0.03 milliamp (mA), or the macrocell current is greater than 0.03 mA for two cycles.

PART 2 PRODUCTS

2.01 ACCESSORIES

- A. Portable voltmeter (Minimum input impedance of 10 megohms and capable of measuring DC voltages between plus or minus 0.01 millivolt to plus or minus 100 volts).
- B. Meter for measuring Wenner four-electrode resistivity and electrodes, as described in ASTM G 57.
 - 1. Electrodes to be type 304 stainless steel, 1/8-inch diameter by 4-inches long.
- C. Portable Cu/CuSO₄ reference electrode, as described in ASTM C 876.
- D. Equipment for measuring relative humidity (RH) and temperature in slabs according to ASTM F 2170.
- E. Electroplaters tape.
- F. Polyolefin shrink tubing - 3M FP-301 Flexible Polyolefin meeting UL, CSA and MIL-DTL-23053/5 or equal.
- G. Liquid Electrical Tape.
- H. Epoxy - Meeting the requirements of ASTM C 881, Type IV, Grade 3 Class E with viscosity suitable for injection into tubing.

- I. Epoxy sealer - Meeting the requirements of ASTM C 881, Type III, Grade 1 Class C for sealing concrete slab sides.
- J. Extruded polystyrene or polyurethane closed cell insulation – For ponding dams, 2-inches thick.
- K. Neoprene Tubing, with 3-mm wall thickness and 0.5-inch inner diameter.
- L. Neutral cure silicone adhesive for bonding rigid foam insulation to concrete slabs.
- M. Type 304 Stainless steel screws, ¼-inch diameter x 1.5 inch long – 20 thread, one per bar.
- N. Type 304 Stainless Steel Nuts, two per bar to fit stainless steel screws.
- O. Non-conductive supports for reinforcing.
- P. Wood pallets with minimum 30% openings between top slats for supporting and moving slabs.
- Q. Copper wiring, 16-gauge multi-strand, insulated.
- R. One Ω , 1% tolerance, 1 watt shunt resistors.
 - 1. Use 7 for Configuration A slabs.
 - 2. Use 10 for Configuration B slabs
- S. NEMA 250, Type 4X Junction Box.
- T. Switches to open and close circuits, compatible with wiring and resistors.
 - 1. One switch is needed per resistor.
- U. Single-wire (one conductor) banana plugs, female, to access the junction box, for outlet connections to the voltage meter.
 - 1. One banana plug is needed for each resistor.
- V. PVC pipe and fittings, or similar, for draining slabs.
- W. Sulfuric Acid, 10% by mass.
- X. Salt solution, prepared by dissolving 5 parts sodium chloride, complying with ASTM D 632, in 95 parts potable water, by mass
- Y. Tools for finishing concrete – float, darby, broom finish, hand held bristle brush.

2.02 REINFORCING

- A. Reinforcing Bars:
 - 1. ASTM A 615, Grade 60.
 - 2. Deformed steel bar.

3. Size number 4, all from the same lot.
- B. Reinforcing Fabric: ASTM A 1064, electrically-welded wire fabric.
1. W4/W4 6 x 6-inch
- C. Non-conductive Glass Fiber Reinforced Polymer - ACI 440.6-08
1. Size number 3 to 5

2.03 CEMENTITIOUS MATERIALS

- A. Portland cement:
1. ASTM C 150, Type II.
 2. Meet equivalent alkali's requirements of ASTM C 150 - Table 2.
 3. Meet false-set requirements of ASTM C 150 - Table 4.

2.04 WATER

- A. ASTM C 1602, including optional requirements of Table 2.

2.05 AGGREGATE MATERIALS

- A. Fine aggregate: ASTM C 33, including requirements of Table 2, and paragraph 7.3.
- B. Coarse aggregate: ASTM C 33, Size No. 7.

2.06 ADMIXTURES

- A. Air-entraining admixture:
1. ASTM C 260.
- B. Chemical admixtures:
1. Allowable chemical admixtures:
 - a. ASTM C 494, Type A, D, F, G, or S.
 - b. ASTM C 1017, Type I or II.
 2. Do not use chemical admixtures which contain more than 0.1 percent chloride, by weight.

2.07 CURING MATERIALS

- A. Water: ASTM C 1602, including optional requirements of Table 2.
- B. Polyethylene film: ASTM C 171, clear.
1. Free from cuts or tears.

2.08 CONCRETE MIXTURE

- A. Cement: 517 to 611 lbs/cubic yard
- B. Net water-cementitious materials ratio: 0.48 to 0.52, by weight.
- C. Slump: 3 to 5 inches, in accordance with ASTM C 143.
- D. Air entrainment: 4 to 6 percent air by volume of concrete as discharged at placement, in accordance with ASTM C 231.

2.09 BATCHING, MIXING, AND TRANSPORTING

- A. Manufacture and deliver in accordance with ASTM C 94.
- B. Prevent appreciable segregation of ingredients, or slump loss exceeding 2 inches in concrete delivered to work.

2.10 CONCRETE TEMPERATURE

- A. Concrete temperature at placing: 50 to 90 degrees F (10 to 32 degrees C).

2.11 CONCRETE TESTING

- A. Testing:

Table A - Materials Testing Requirements and Frequency				
PROCEDURE	TEST STANDARD	STANDARD TITLE	STANDARD REQUIREMENT	MINIMUM FREQUENCY OF TESTING
Fresh Concrete	ASTM C 31	Making and Curing Concrete Test Specimens in the Field	As specified	1 test per each batch of placement or each mixture.
	ASTM C 143	Slump of Hydraulic-Cement Concrete		
	ASTM C 138	Unit Weight, Yield, and Air Content (Gravimetric) of Concrete		
	ASTM C 231	Air Content of Freshly Mixed Concrete by the Pressure Method (alternative to ASTM C 138 gravimetric method)		

Table A - Materials Testing Requirements and Frequency				
PROCEDURE	TEST STANDARD	STANDARD TITLE	STANDARD REQUIREMENT	MINIMUM FREQUENCY OF TESTING
	ASTM C 403	Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance		
	ASTM C 1064	Temperature of Freshly Mixed Concrete		
Compressive Strength, Cylinders	ASTM C 39	Compressive Strength of Cylindrical Concrete Specimens	90 percent exceed specified compressive strength at 28 days.	1 test per each batch of placement of each class. Make sufficient 4-inch diameter x 8-inch tall cylinders to perform 3 compressive strength tests each at ages of 3, 7, 28, 56, and 90 days.
Chloride Content	ASTM C 1152	Acid-Soluble Chloride Content Determination in Concrete		1 test per each batch of placement of each class. Test 3 cylinders at age of 28 days.
Chloride Ion Resistance	ASTM C 1202 or ASTM C 1760	Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration		1 test per each batch of placement of each class. Make sufficient 4-inch diameter x 8-inch tall cylinder to test 3 cylinders each at ages of 28, 90, 180, and 365 days.

PART 3 EXECUTION

3.01 PREPARATION

- A. Cast, cure, store, and perform all tests in a facility with temperature controlled environment between 65 to 85 deg. F.
- B. Make a minimum of five molds to produce 40-inch long by 40-inch wide x 5.5-inch thick control slabs and sufficient molds of the same size to make five slabs for each repair material to be tested. Prepare molds to hold reinforcing steel in place and allow for reinforcing steel to protrude through the mold.
- C. Clean reinforcing steel bars in accordance with SSPC SP3. Power tool clean all loose mill scale, loose rust, and other loose detrimental foreign matter. It is not intended that well adhered material be removed by this process and is considered well adhered if it cannot be lifted with a dull putty knife.

- D. Cut WWR to 30-inches x 36-inches +/-1/4 inch. Clean an area in accordance with SSPC SP3 for copper wire connection. Braze the wire connection to the WWR and encapsulate the connection in epoxy. See Figure 1 for example of wire attachment and placement of the WWR in the concrete mold.
- E. Install ports or other access points onto sides of molds or drill holes after curing and before ponding for instruments to read and record relative humidity (RH) and temperature according to ASTM F 2170.

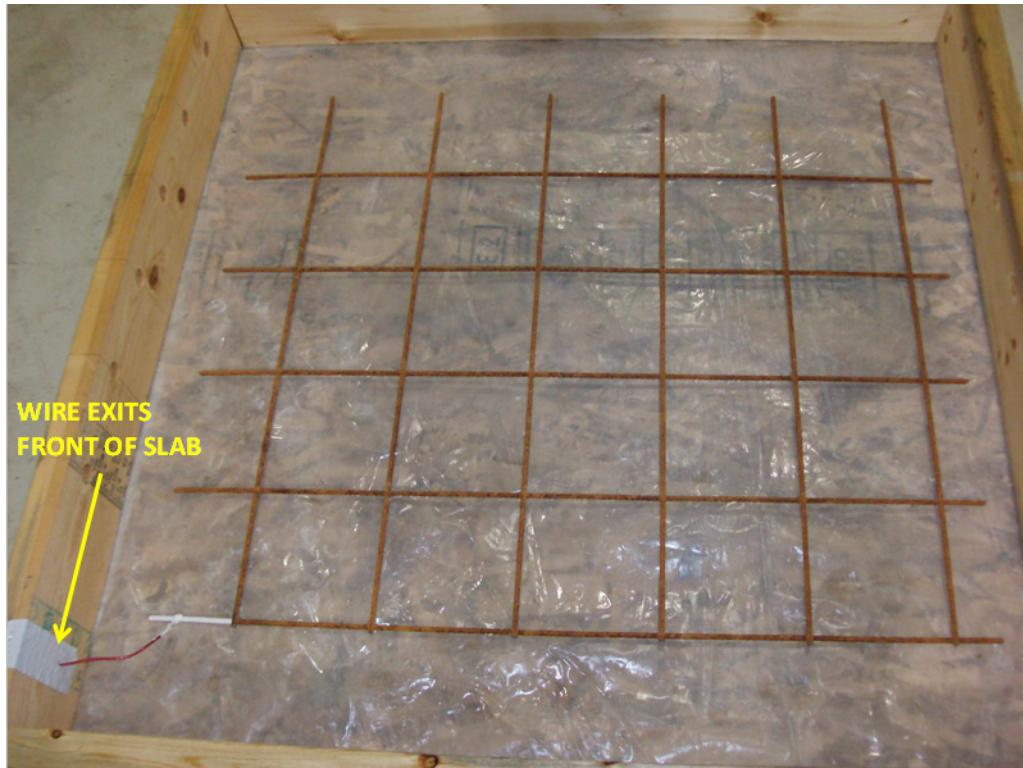


Figure 1 – WWR with copper wire attached and supported by non-conductive supports in concrete mold.

- F. Preparation - Configuration A slabs
1. Use six steel reinforcing bars 44-inches +/- 1/4 long.
 2. Drill and tap one end of the each bar to attach the stainless screw and nuts.
 3. Pickle 4 +/- 1/4 inches of each bar end in sulfuric acid solution in accordance with SSPC SP8 for 10-15 minutes, rinse with tap water, and clean pickled area with wire wheel.
 4. Attach screw with two nuts to the end of the steel reinforcing bar. Cover part of the screw with the same epoxy used to fill the neoprene tubing such that sufficient threads are exposed so that the nuts can be tightened to the connection wires.
 5. Cover cleaned end of steel reinforcing bars with rubber tubing, and inject epoxy in cavity between rubber tubing and reinforcement bar completely filling the space.

G. Preparation - Configuration B slabs

1. Use four steel reinforcing bars 44 +/- 1/4 inches-long and six steel bars 21 +/- 1/4 – inch long.
 - a. Two-21-inch long bars will be used for repairs.
2. Prepare the 44-inch long bars according to the preparation steps for Configuration A slabs
3. For 21-inch long steel reinforcing bars, prepare only one end according to the preparation steps for Configuration A slabs.

H. Position of steel reinforcement: Configuration A slabs

1. Place WWR on non-metallic bar supports to provide 1-inch +/- 1/8-inch of clear cover from the bottom of the concrete slab.
 - a. Supports can be small pieces of concrete, plastic chairs or similar.
2. Place steel reinforcing bars in the molds so that they will have a clear cover of 1 inch +/- 1/8 inch below the top surface of the concrete.
3. Place bars parallel to each other starting 11 inches from the edge to rebar reinforcing steel center, and 5 inches center to center, for a total of 6 steel reinforcing bars, as shown in Figure 2.

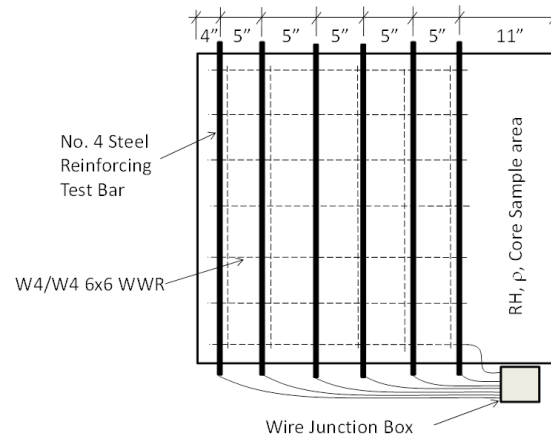


Figure 2 – Topical Treatment Test Specimen Photograph (Left) and Configuration A (Right)

I. Position of steel reinforcement: Configuration B slabs

1. Place WWR on non-metallic bar supports to provide 1-inch +/- 1/8 inch of clear cover from the bottom of the concrete slab.
 - a. Supports can be small pieces of concrete, plastic chairs or similar.
2. Place steel reinforcing bars as in Configuration A, except substitute four - 21-inch long bars for middle two – 44 inch bars, as shown in Figure 3.
3. Place FRP bars perpendicular to steel reinforcing bars to support the 21-inch long steel reinforcing bars at the same height of 44-inch long steel reinforcing bars.
 - a. Secure the 21-inch bars to the FRP bars.
4. For integral repairs slabs using Configuration B:
 - a. Create a hotspot by reducing concrete cover over the 21-inch long bars to 0.75 inches.
 - b. Reduce cover by placing an 8-inch wide by 14-inch long by 1/4-inch thick block 4 inches inside the mold with the 8-inch dimension perpendicular to the steel reinforcing direction and centered above the front two 21-inch long steel reinforcing bars.
 - 1) Block to be similar to form work material.
 - c. Attach block to mold to prevent block movement while concrete is placed in mold and finished, as shown in Figure 4.

- d. Remove block during finishing after most of water sheen has disappeared.

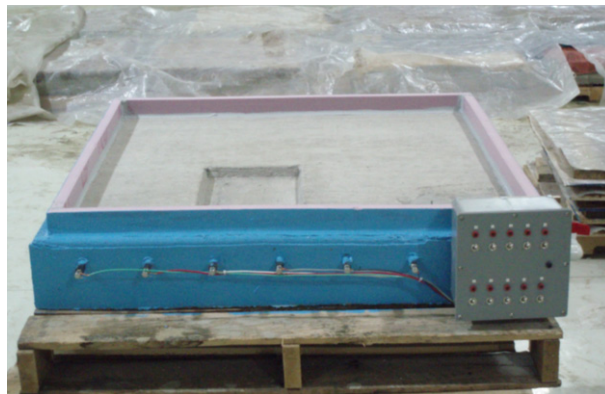
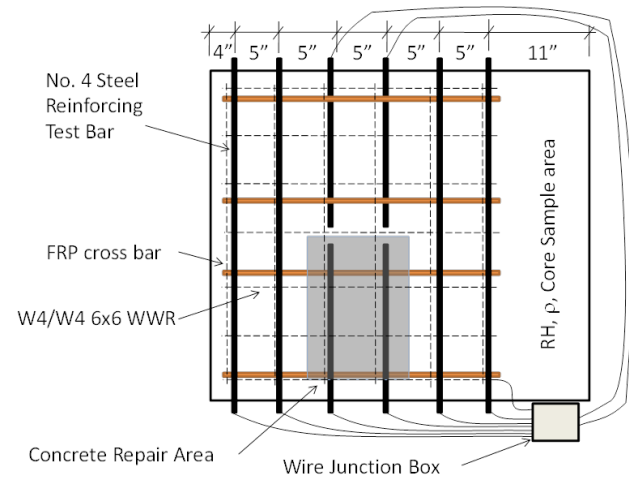


Figure 3 - Repair Test Specimen Photograph (Left) and Configuration B (Right)



Figure 4 – Block attached to mold to create area of reduced concrete cover. The area of reduced cover makes a hotspot.

J. Concrete placing

1. Cast control and test slabs randomly to ensure that variability within a batch or truck does not result in bias.
2. Do not retemper concrete.
3. Do not use concrete which has become so stiff that concrete cannot be properly placed.
4. Place formed concrete in continuous, approximately horizontal layers.
5. Vibrate concrete until concrete has been consolidated to maximum practical density, is free from pockets of coarse aggregate, and closes snugly against surfaces of forms and embedded materials.
 - a. Do not disturb steel reinforcing bars or WWR.

K. Finishing

1. Unformed surfaces:
 - a. Finish
 - 1) Begin floating using a magnesium float as soon as screeded surface has sufficiently stiffened and before bleed water forms.
 - 2) Finish surface with minimum floating necessary to produce a surface that is free of screed marks and is uniform in texture.
 - b. Broomed finish:

- 1) Finish surface with a wood float or darby to a smooth and uniformly fine granular or sandy texture of waves, irregularities, or tool marks when most of the water sheen has disappeared, and just before the concrete hardens so the surface will not be torn or unduly roughened by the operation.
- 2) Produce a scored surface by brooming with a fiber-bristle brush with adjacent strokes slightly overlapping, followed by edging.
 - a) For slabs with a hotspot, use hand held bristle brush in hotspot to match broom finish surface.
- 3) Tool top edges of slabs to a radius of 1/4 inch
- 4) Finished surface shall have a uniform appearance and shall be free of abrupt corrugation exceeding 1/8 inch in depth.
- 5) Broom to eliminate the flat surface left by the surface face of the edger.

L. Resistivity electrodes

1. Apply electroplaters tape or polyolefin shrink tubing between 1/2 and 3 inches from the bottom of the electrode such that one end of the electrode has 1/2-inch bare and one end has 1-inch bare. See Figure 5.
2. Install electrodes for resistivity measurements after finishing of the concrete and before final set. Install electrodes with 1/2-inch bare end in concrete.
3. Place electrodes 2 inches apart in a line that is perpendicular to the longitudinal direction of the steel and 1 1/2-inches deep.
4. Install the electrodes so that the top of the tape extends 1-inch above the concrete surface, and the bottom 1/2 inch is in bare and in intimate contact with the concrete.

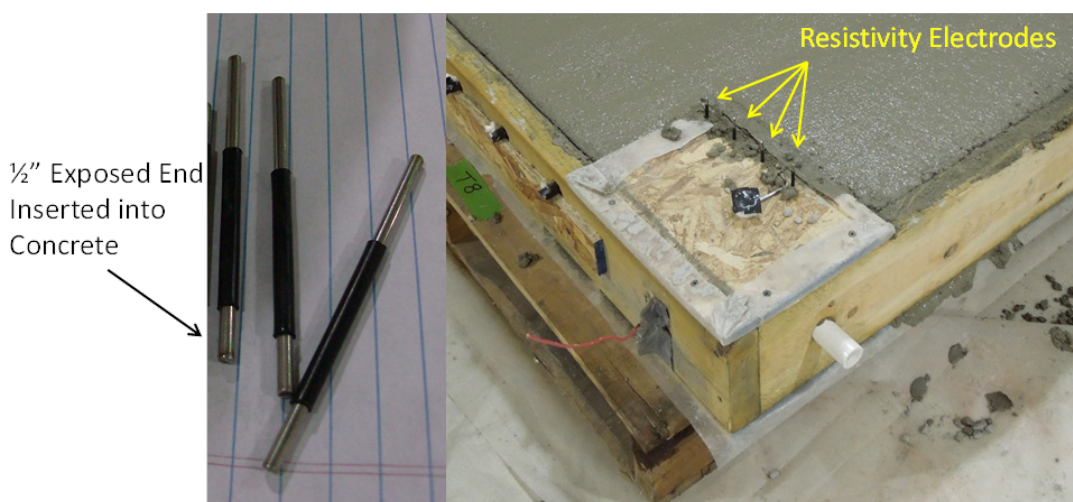


Figure 5 – Resistivity electrodes with electroplaters tape (left) and placed in fresh concrete (right).

M. Curing

1. Polyethylene film curing:
 - a. Thoroughly moisten concrete surface by lightly spraying with water as soon as concrete has hardened sufficiently to prevent damage.
 - b. Completely cover concrete surface with polyethylene film to provide an airtight, water-retaining film over entire surface.
 - c. Lap edges of polyethylene sheets to seal adjacent sheets.
 - d. Place tightly against concrete surface at extreme edge of curing area.
 - e. Secure film to prevent circulation of air inside curing film.
 - f. Keep surface wet for 7 days, minimum.
2. Air drying:
 - a. After moist curing, allow slabs to air dry for 21 days, minimum.
 - 1) Temperature: 65 to 85 degrees Fahrenheit
 - 2) Relative humidity: below 70%.
 - a) Record relative humidity daily.

N. Slab preparation

1. Completely remove slab from mold.
2. Support each slab such that there is open space for air to flow below the specimen.
 - a. A typical wooden pallet made with slats is suitable for support.
3. Coat sides of slabs with epoxy sealer after 14 days of air drying (7 days before start of ponding).
4. Use silicone sealant to attach about 2-inch high strips of rigid insulation around perimeter of slabs, about 4-inches in from the front and back edges (areas where reinforcing steel bars protrude from the slab) and about 2-inches in from the side edges to form a watertight dam. See Figure 6.
5. Attach copper wire to each steel reinforcing bar by clamping the wire between the two nuts on the stainless steel screw and to WWR. Apply coating to electrical connections with liquid electrical tape.

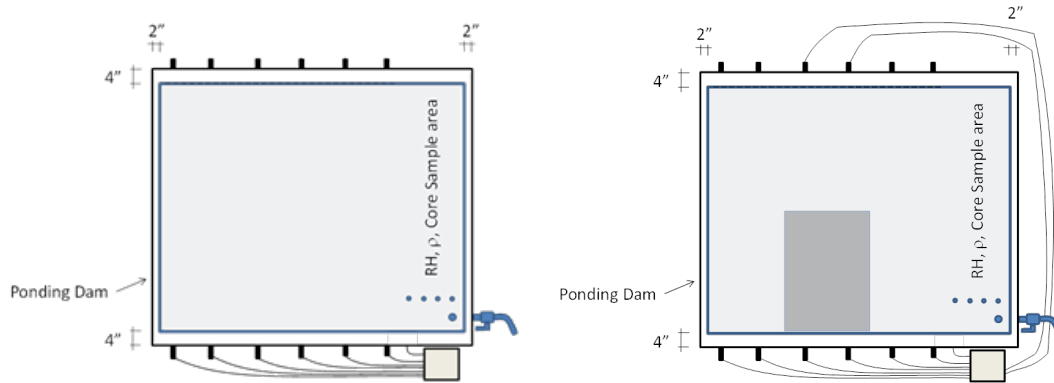


Figure 6. – Layout of Ponding dams for Configuration A and B slabs. Valve on lower right of slabs is one option for draining NaCl solution.

6. Run wire to the screw terminals in the junction box. Wire system to be configured such that the individual steel reinforcing bars and WWR are connected across a resistor.
 - a. In addition, locate a single pole, single throw switch in the system so that each component can be disconnected from the circuit. See Figure 7 for example of wiring inside the junction box.

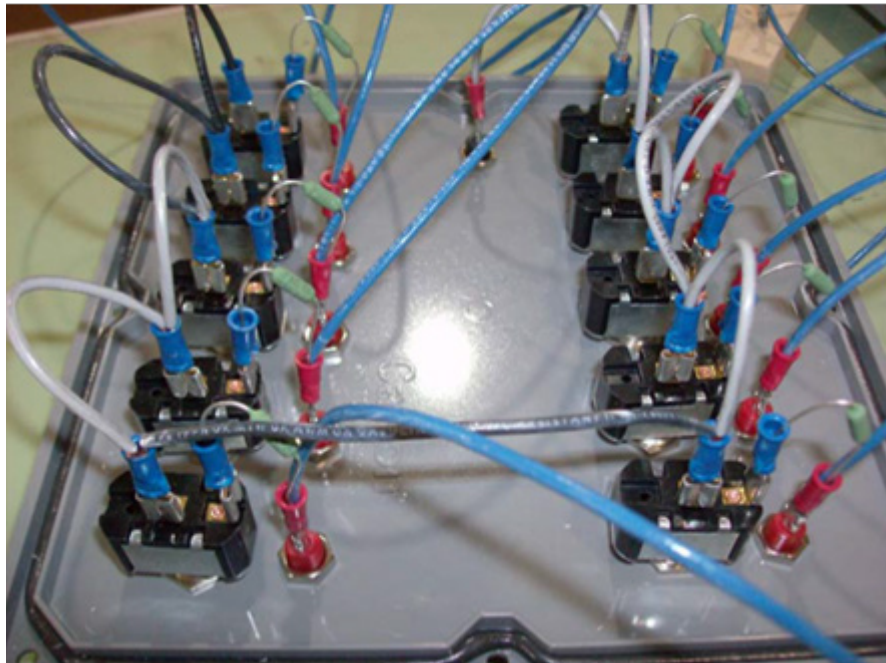


Figure 7 – Wiring in NEMA 4X Box for a ten circuit system for Configuration B test slab.

7. See Figure 8 for a wiring diagram for a Configuration A slab and Figure 9 for a Configuration B slab. See Figure 10 for examples of slabs ready to tests.

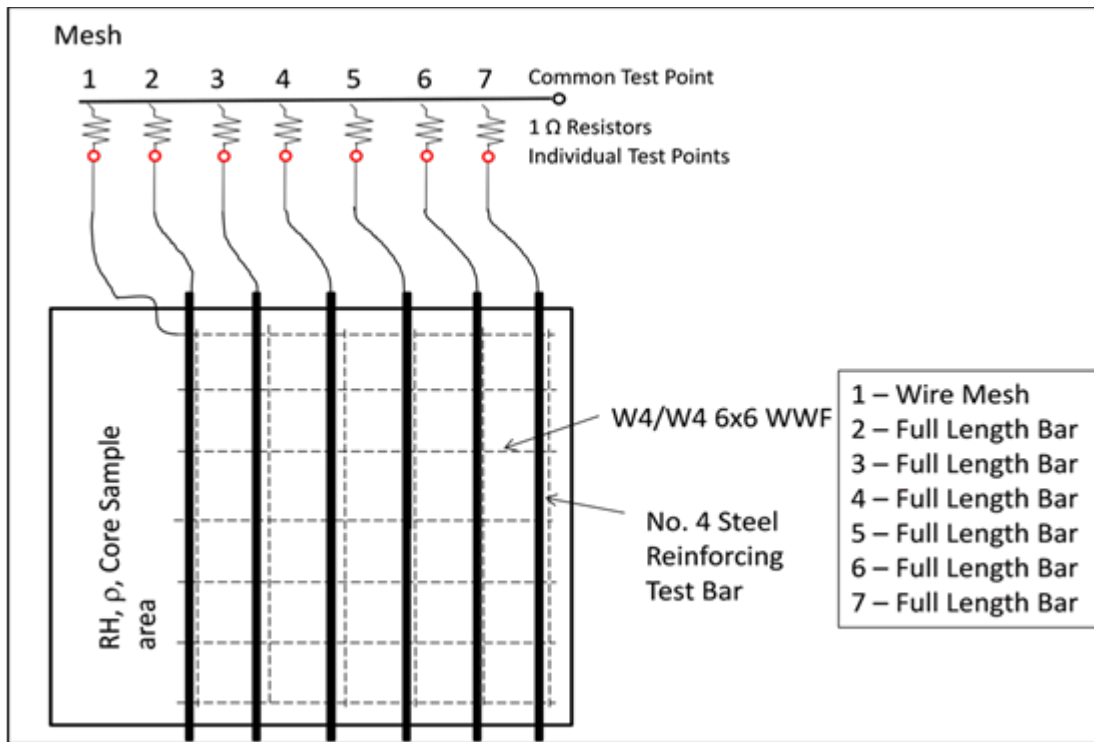


Figure 8 – Wiring diagram for a Configuration A slab.

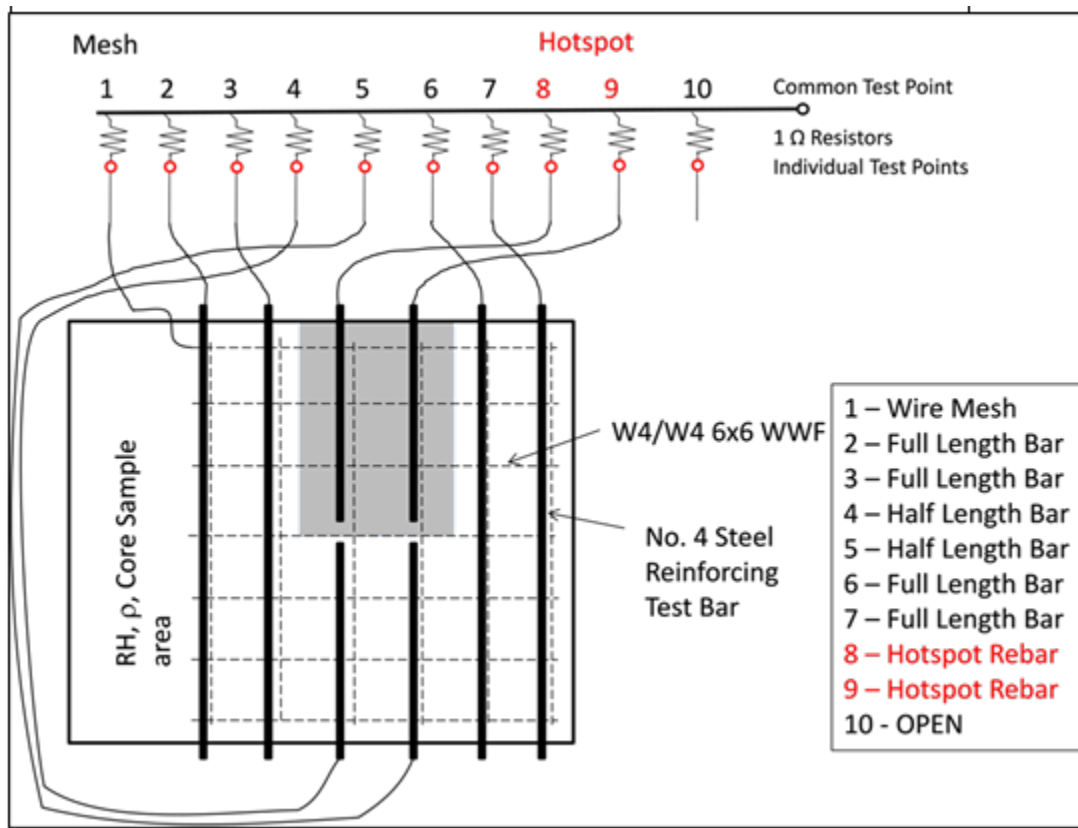


Figure 9. - Wiring diagram for a Configuration B slab.



Figure 10 – Example of a Configuration A slab (left) and Configuration B slab (right) ready for use.

3.02 PROCEDURE

- A. Start ponding after 21 days of air drying (28 days after casting) by placing salt solution on slabs 0.75 to 1.5-inch deep (approximately 5 gallons/specimen).
 1. Keep solution on slabs for 14 days at 65 – 85 deg. F.
 2. Cover with a plastic sheet during the ponding cycle to minimize evaporation.
 3. After 14 days, remove the plastic sheet, drain salt solution, and allow specimens to dry for 14 days.
 4. One complete cycle is 28 days.
 5. Record ambient relative humidity (RH) and temperature daily or with an automatic device

- B. Unless directed otherwise, when measurements are made after a ponding cycle, they should be made when the solution has been removed and while the concrete surface is damp within 24 hours after the end of a ponding cycle.

- C. Relative humidity and temperature of the slabs
 1. According to ASTM F 2170
 2. At the end of each drying period and at the end of the ponding cycle for each cycle.

- D. Measure Macrocell Corrosion Current
 1. Measure the current as the voltage drop across the resistor between each individual reinforcing bar and the WWR
 2. Measure within 1 hour of connection of reinforcing bars and the WWR.
 3. Measure within 24 hours of initial ponding.
 4. Perform subsequent measurements at the end of each ponding cycle immediately prior to removal of the ponding solution.
 5. See Figure 11 for an example of measuring the macrocell corrosion current.

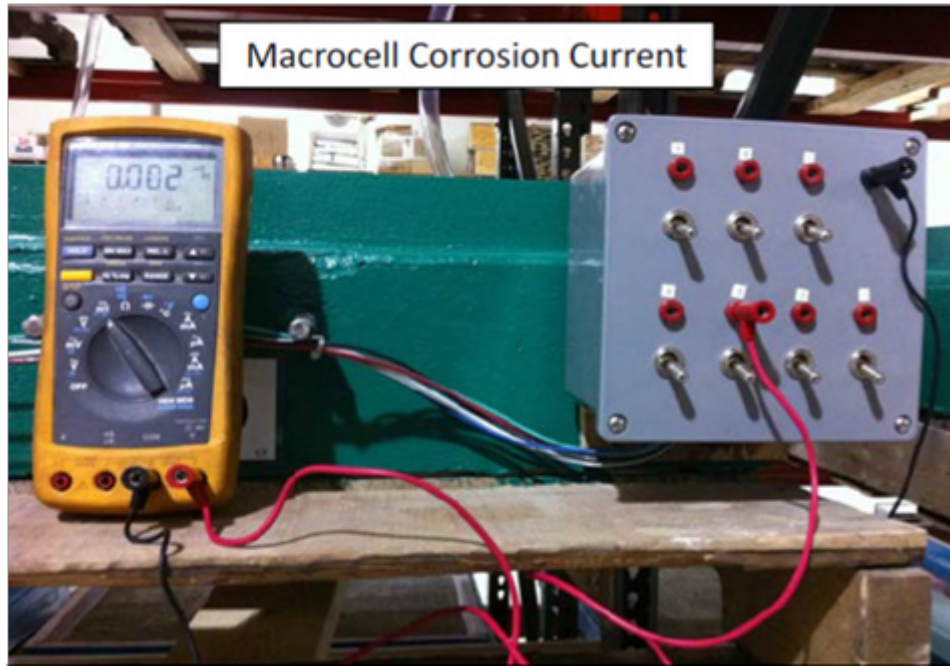


Figure 11 – Macrocell corrosion current reading for a Configuration A slab.

- E. Measure corrosion potential according to ASTM C 876.
1. Measure corrosion potential for each bar at 6-inch intervals along the bars (30 measurements) with the bars connected to the WWR and repeat future measurements at the same point at the end of every ponding cycle. See Figure 12
 - a. Permanently mark the points of measurement so that for each cycle the measurements occur at the same point. A small mark made from a waterproof marker can be used

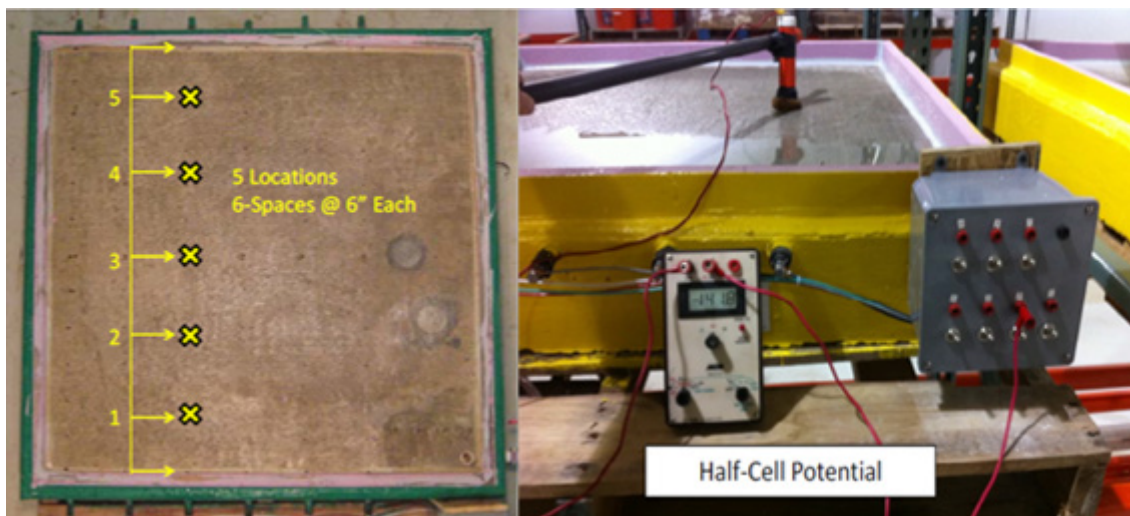


Figure 12 – Example of layout of measuring points and measurement for half-cell potential.

- F. Measure mat-to-mat resistance between all the connected top reinforcing bars and the bottom WWR (electrically discontinuous from the top mat) using soil resistance equipment according to ASTM G187. See Figure 13.
1. Make measurements after the 1st, 6th, 12th, 18th, and 24th ponding cycle.
 2. Make subsequent measurements when repair criteria are met, after repairs are made, every third cycle after repairs, and at end of testing

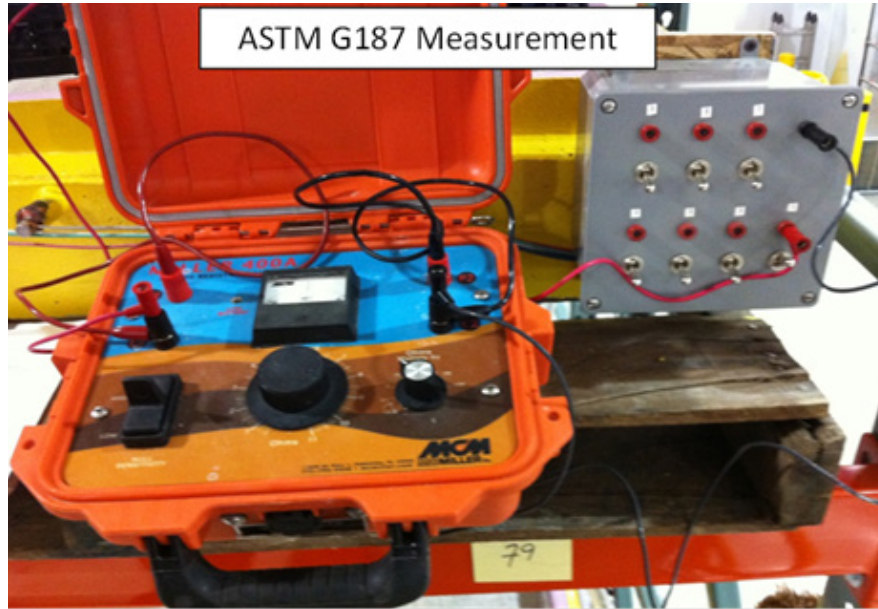


Figure 13 – Example for measuring mat-to-mat resistance.

- G. Measure electrical resistivity according to ASTM G57 using the 4 resistivity electrodes.
1. Make measurements at the end of the first ponding cycle, and then at the end of the ponding cycle when repair criteria are met, after repairs are installed, at the end of every third ponding cycle after repairs, and at end of testing. See Figure 14.



Figure 14 – Example for measuring electrical resistivity according to ASTM G 57 using the resistivity electrodes.

- H. Measure chloride profiles when corrosion initiates on a slab.
1. Corrosion initiation is defined as when the first bar has a potential more negative than -300 mV vs. CSE and the macrocell current is greater than 0.03 mA, or the macrocell current is greater than 0.03 mA for two cycles.
 2. Obtain samples for chloride content from cores obtained from the area outside the steel reinforcing bars.
 3. Cores to be about 1.75- +/- 1/4 –inch diameter and at least 2-inches deep.
 4. Cut core into about ½-inch thick slices.
 5. Determine chloride content for each slice according to ASTM C 1152.

3.03 Making Repairs

- A. Configuration A slab repairs
1. Before applying the repairs or designating a slab as a control, determine the chloride profile and chloride content at the steel reinforcing bar level as described in 3.02 H.
 2. Perform repairs after 5,000 Coulombs of combined macrocell corrosion current for all bars is reached and the chloride levels are above 1000 parts per million (ppm) by mass of concrete in the core piece nearest the depth of the reinforcing steel.
 - a. If chloride levels are below 1000 ppm continue ponding for another cycle and measure chloride content as described in 3.02 H. Repeat until the chloride content is 1000 ppm by mass chloride content value is met.

- b. As an alternative, repairs may be applied after 10,000 Coulombs is reached if the surface applied repair does not depend upon the amount of chloride present at the reinforcing bars, or protection at a higher initial chloride content level is to be demonstrated.
 - c. Apply all repairs before 20,000 Coulombs are reached.
- 3. Perform half-cell potential mapping as described in 3.02 E., with the reinforcing steel bars and the WWR connected.
 - a. Perform these measurements just prior to repairs, just after repairs, every third ponding cycle after repairs, and at the end of testing.
 - b. For slab repairs that involve a membrane treatment, refer to Appendix 1 for steps to make half-cell potential reading areas.
- 4. Follow the manufacturer's procedure for applying the repair material(s).
- 5. Slabs may not meet the requirements for application of repair material(s) at the same time. Select control slabs and test slabs according to the following:
 - a. For one repair material
 - 1) Repair the first slab to meet the repair criteria. Use the next 2 slabs meeting the repair criteria for control slabs that will receive no treatment.
 - 2) Use the 4th and 5th slabs to reach the repair criteria as repair slabs.
 - 3) Use the 6th and 7th slabs to meet the repair criteria as control slabs.
 - 4) Use the 8th and 9th slabs to reach the repair criteria as repair slabs.
 - 5) Use the 10th slab to meet repair criteria as a control slab.
 - 6) Repeat this pattern if more than 5 specimens slabs for repair material testing are produced.
 - b. For more than one repair material:
 - 1) Use the first slab to reach the repair criteria as a control.
 - 2) Use the next slab to reach the repair criteria as a repair slab for material 1.
 - 3) Use the next slab to reach the repair criteria as a repair slab for material 2.
 - 4) Repeat until all repair materials are used.
 - 5) Reverse the repair material order for the next series of slabs.
 - 6) See the appendix 2 for an example.

B. Configuration B slabs for integral repairs

- 1. Electrically disconnect the steel reinforcing bars in the hotspot from those outside of the hotspot when the steel reinforcing bars in the hotspot reach a minimum of 10,000 Coulombs of corrosion or the bars outside the hotspot have over 2500 Coulombs of corrosion.

2. Continue ponding cycles until there are 2500 Coulombs of corrosion on the bars outside of the hotspot.
3. Measure half-cell potentials as described in 3.02 E.
4. Before applying the repairs or designating a specimen as a control, determine the chloride profile and chloride content at the reinforcing bar level as described in 3.02H.
5. Apply and use repair material(s) according to manufacturer's instructions.
 - a. Do not use curing compound.
 - b. For moist curing, confine moisture to repair material only
 - c. If hotspot concrete and 21-inch long steel reinforcing bars are removed as part of the repair procedure, replace 21-inch long steel reinforcing bars in the hot spot with steel reinforcing bars from the same lot as the bars in the slab that have been prepared identically using the process in Section 3.01 above.
6. Repair for the control slab:
 - a. Remove damaged concrete in the hotspot,
 - b. Remove and replace the 21-inch long steel reinforcing bars in the repair area.
 - c. Replace removed concrete with the same concrete mixture used for the original concrete. Cure for 7 days according to 3.01 K.
 - d. Concrete cover over the new reinforcing bars shall be the same as the reinforcing bar cover over the bars outside of the repair area.
7. Galvanic anode repairs:
 - a. If a galvanic anode is part of the repair, then connect the anode as shown in Figure 15.

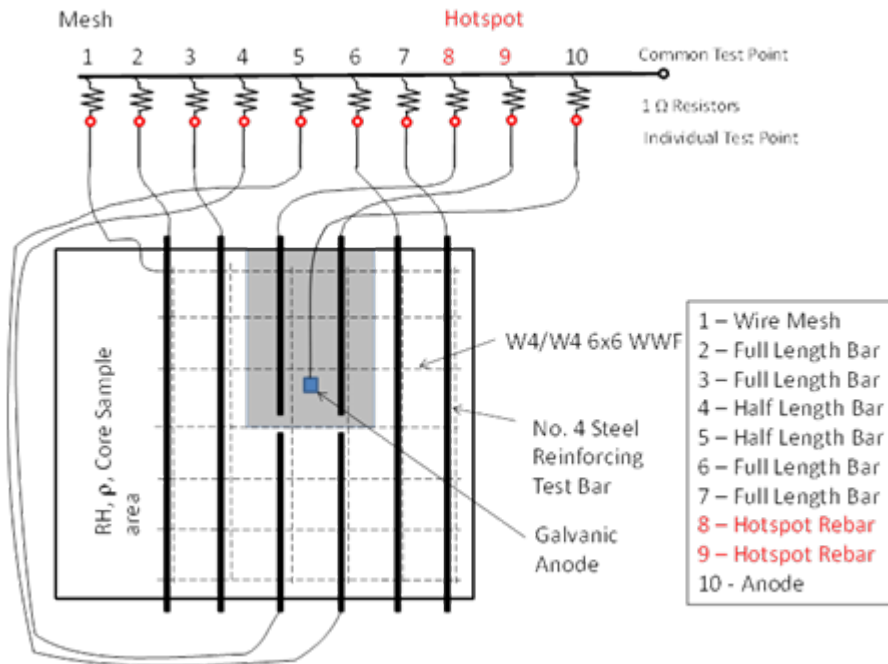


Figure 15 – Wiring diagram when a galvanic anode is used in the repair.

8. Follow the steps in 3.03 A. 5. to select control slabs and repair slabs.

3.04 Measurements after repairs

- A. Start ponding cycles 6 weeks after repair material application. Continue ponding and drying cycles and corrosion measurements described in 3.02.
- B. Testing is complete two cycles after 80% of the control slabs have corrosion induced cracking over the reinforcing bars.
- C. Compare the average macrocell corrosion after repairs and note when the average of the repair slabs is less than that of the control slabs and when the 95% confidence limits (C.L.) do not overlap.

1. $C.L._{95\%} = t_{95\%} \times S.D. \div \sqrt{n}$, where
 $t_{95\%}$ is from the double sided t distribution for n-1 degrees of freedom
 $S.D.$ is the standard deviation
 n is the number of slabs¹

- D. At completion of testing:

1. Produce a potential map according to 3.02 E.
2. Photograph slab and cracks
3. Measure crack length over each bar to nearest 0.05 inch (1 mm).

¹ <http://www.itl.nist.gov/div898/handbook/eda/section3/eda352.htm>

4. Measure crack width at 6-inch intervals to nearest 0.003 inch (0.1mm).

E. Destructive testing

1. Remove the top layer of concrete above steel reinforcing bars by saw cutting groves in the slabs and removing concrete with a chipping hammer to observe the reinforcing bars. Do not damage the bars.
2. Remove bars and photograph the bars on both sides so that the full length can be seen in 10-inch long sections.
3. Describe surface corrosion level for each 6-inch section using the classification in Table B.

Table B. – Classification of corrosion levels	
Rating	Description
0	No visual corrosion
1	< 1% Area corroded
2	< 5% Area corroded
3	< 15% Area corroded
4	<40% Area corroded
5	>40% Area corroded

4. Describe the degree of corrosion of each 10-inch section using the classification in Table C.

Table C. – Rating for estimating degree of corrosion	
Rating	Description
L	Light
M	Moderate
H	Heavy
P	Pitting

3.05 REPORT

A. Report the following concrete:

1. Mix Design: For each concrete mix.
 - a. Mixture proportions.
 - b. Material sources.
 - 1) Name and manufacturer of each cementitious material.

- 2) Name of aggregate source(s).
 - 3) Product name and manufacturer of admixtures to be used in mix.
 - c. Certifications and test reports:
 - 1) Cementitious materials manufacturer's certifications and test reports:
 - a) Certification and test reports for each lot from which shipments are drawn.
 - i. Certify materials were tested during production or transfer in accordance with specified reference standards.
 - 2) Aggregate producer's certifications and test reports, less than 6 months old:
 - a) ASTM C33 physical properties
 - b) ASR testing reports for each aggregate source.
 2. Furnish batch ticket with each batch of concrete in accordance with ASTM C94
 3. Concrete properties
 - a. All fresh and hardened properties tested in Table A.
 - b. Mat-to-Mat resistance.
 - c. Electrical resistivity.
 4. Relative humidity and temperature of the slabs
- B. Report the following corrosion related data:
1. Heat or lot number of reinforcing bars, grade and ASTM designation.
 2. Time to corrosion in ponding cycles for:
 - a. Individual slabs, average values for slabs, and standard deviation.
 3. Total Coulombs for each slab at each cycle noting cycle at which repairs were performed or the cycle where a slab was designated a control.
 4. Time to repair in ponding cycles for:
 - a. Individual slabs, average values for slabs, and standard deviations.
 5. Chloride profiles at time to corrosion, time to repair, and at end of test
 6. Average time to cracking.
 - a. Use time of test completion for specimens that did not crack.
 7. Plot the potential map data for each data set, at last cycle before repair, one cycle after repair, and at test completion.
 8. Total crack length and average width for each slab
 9. Provide photographs as described in 3.04 E. 2.
 10. Description of corrosion according to 3.04 E. 3 and 4.

11. Average coulombs and 95% C.L. at end of testing for controls and repair systems.
- C. Report the following for the repair systems evaluated:
1. Coulombs reached just prior to repairs
 2. Manufacturer and product name or names
 - a. Include technical data sheets
 3. Generic description of repair materials
 4. Procedure for applying repairs
 - a. Include method to calculate coverage rate and number of applications for topical treatments
 - b. Include amount of material applied.
 - c. Admixtures and mixture proportions in repair concrete for integral repairs and curing conditions
 - d. If galvanic anodes are used note their dimensions, mass, location, and number installed

3.06 PRECISION AND BIAS

- A. Precision
1. The precision of this test method is being determined. The repeatability, standard deviation, and reproducibility of this test method have not been determined.
 2. Bias: No information can be presented on the bias of this procedure because the repair performance is determined by this test, and an accepted reference material is not available.

Appendix 1

Additional Slab Preparation Steps for Configuration A slabs for Use with a Membrane Repair System

PART 1 ACCESSORIES

- A. PVC pipe, 1.50 inch inside diameter, cut into 2.5 to 3.0-inch long pieces, and cap to seal one end.
- B. Cement, ASTM C 150 type I or II
- C. Tap water

PART 2 PROCEDURE

2.01 Perform additional steps just before application of the repair system.

- A. Prepare surface by washing to remove surface chlorides and loose debris.
- B. Drill 2-inch diameter core holes approximately 0.75-inch deep in top surface at locations shown in Figure 1-1.
- C. Chip out concrete to steel reinforcing bar depth.
 - 1. Do not damage steel reinforcing bar.
- D. Create potential measurement well in core hole.
 - 1. Fill hole with neat cement grout proportioned at 1:1 water to cement by weight
 - 2. Immediately push PVC pipe section about 2.5 to 3.0-inches long into grouted hole.
 - 3. Ensure that pipe is at least $\frac{3}{4}$ full of grout.
 - 4. Allow grout to cure a minimum 24 hours before preparing the slab for repair system installation.
- E. Prepare surface of slab according to repair system manufacturer's instructions.
 - 1. Protect potential well.
- F. Apply repair system according to manufacturer's instructions.
- G. Connect steel reinforcing bars and WWR 48 hours prior to start of ponding cycle.

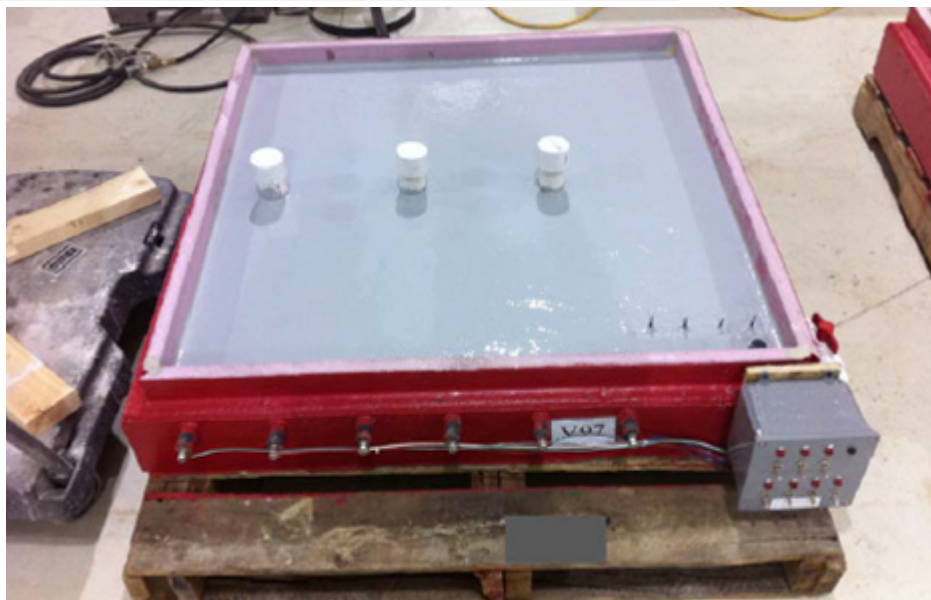
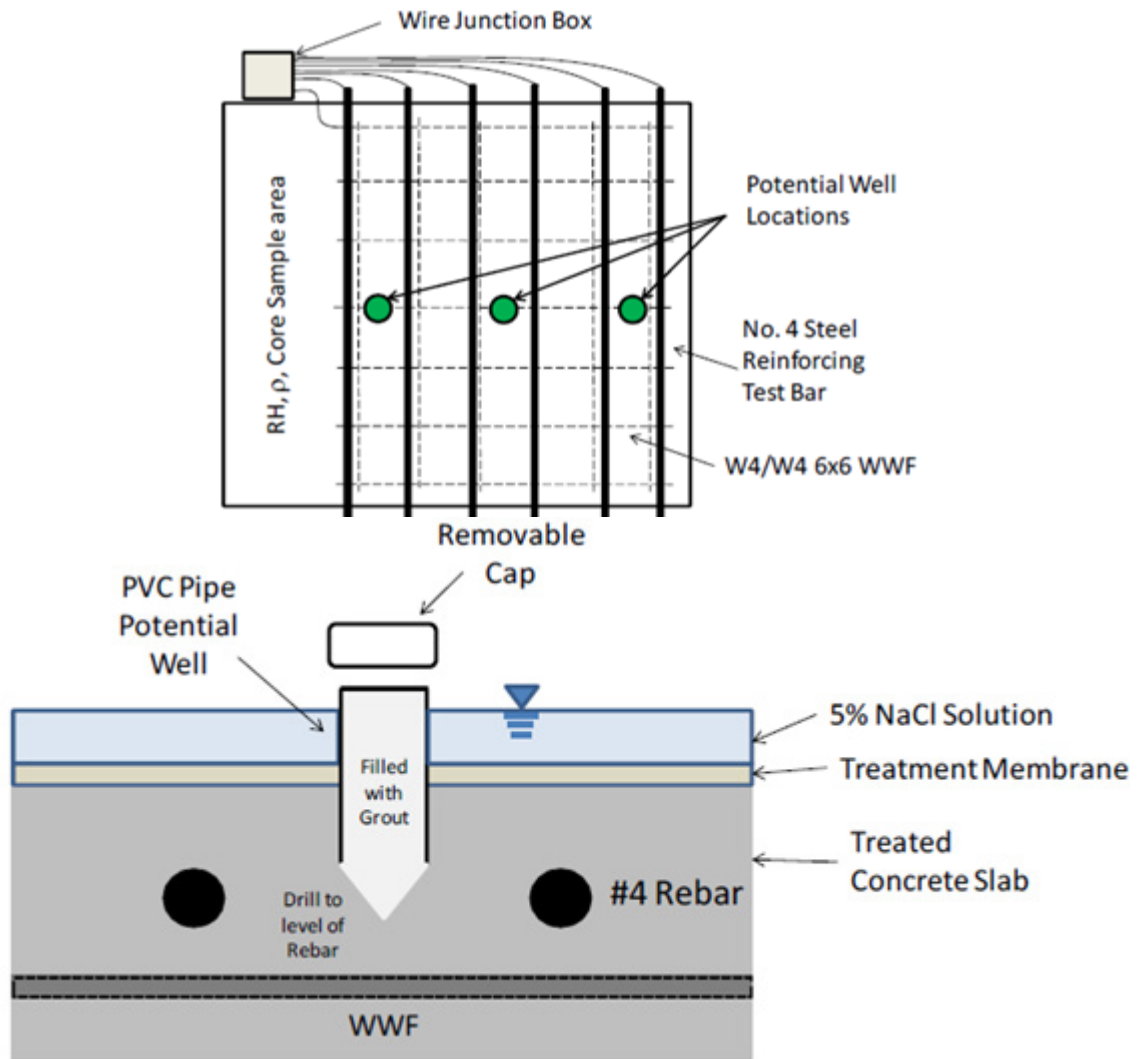


Figure 1-1. – Location and layout of potential well locations.

Appendix 2

Table 1-A - Repair Sequence Table for Single and Multiple Technologies

Order of Test Specimen Meeting Criteria	Application Sequence for One Technology	Application Sequence for Two Technologies	Application Sequence for Three Technologies
1	Product 1	Control	Control
2	Control	Product 1	Product 1
3	Control	Product 2	Product 2
4	Product 1	Product 2	Product 3
5	Product 1	Product 1	Product 3
6	Control	Control	Product 2
7	Control	Control	Product 1
8	Product 1	Product 1	Control
9	Product 1	Product 2	Control
10	Control	Product 2	Product 1
11		Product 1	Product 2
12		Control	Product 3
13		Control	Product 3
14		Product 1	Product 2
15		Product 2	Product 1
16			Control
17			Control
18			Product 1
19			Product 2
20			Product 3