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## Standard Test Method for Half-Cell Corrosion Potentials of Uncoated Reinforcing Steel in Concrete<sup>1</sup>

This standard is issued under the fixed designation C 876; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

### 1. Scope

~~1.1 This test method covers the estimation of the electrical half-cell potential of uncoated reinforcing steel in field and laboratory concrete, for the purpose of determining the corrosion activity of the reinforcing steel.~~

~~1.2 This test method is limited by electrical circuitry. A concrete surface that has dried to the extent that it is a dielectric and surfaces that are coated with a dielectric material will not provide an acceptable electrical circuit. The basic configuration of the electrical circuit is shown in~~

~~1.1 This test method covers the estimation of the electrical corrosion potential of uncoated reinforcing steel in field and laboratory concrete, for the purpose of determining the corrosion activity of the reinforcing steel.~~

~~1.2 This test method is limited by electrical circuitry. Concrete surface in building interiors and desert environments lose sufficient moisture so that the concrete resistivity becomes so high that special testing techniques not covered in this test method may be required (see 5.1.4.1). Concrete surfaces that are coated or treated with sealers may not provide an acceptable electrical circuit. The basic configuration of the electrical circuit is shown in Fig. 1.~~

~~1.3 The values stated in inch-pound units are to be regarded as the standard.~~

~~1.3 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.~~

~~1.4 This standard does not purport to 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.~~

### 2. Referenced Documents

2.1 *ASTM Standards:*<sup>2</sup>

~~G 3 Practice for Conventions Applicable to Electrochemical Measurements in Corrosion Testing~~ Practice for Conventions Applicable to Electrochemical Measurements in Corrosion Testing

~~G 15 Terminology Relating to Corrosion and Corrosion Testing~~ 3666-4f96-a9fb-7323bacdc9bc/astm-c876-09

~~G 16 Guide for Applying Statistics to Analysis of Corrosion Data~~

### 3. Significance and Use

~~3.1 This test method is suitable for in-service evaluation and for use in research and development work.~~

~~3.2 This test method is applicable to members regardless of their size or the depth of concrete cover over the reinforcing steel.~~

~~3.3 This test method may be used at any time during the life of a concrete member.~~

~~3.4 The results obtained by the use of this test method shall not be considered as a means for estimating the structural properties of the steel or of the reinforced concrete member.~~

~~3.5 The potential measurements should be interpreted by engineers or technical specialists experienced in the fields of concrete materials and corrosion testing. It is often necessary to use other data such as chloride contents, depth of carbonation, delamination survey findings, rate of corrosion results, and environmental exposure conditions, in addition to half-cell potential measurements;~~

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee G01 on Corrosion of Metals and is the direct responsibility of Subcommittee G01.11 on Electrochemical Measurements in Corrosion Testing.

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<sup>2</sup> Annual Book of ASTM Standards, Vol 03.02.

<sup>2</sup> For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For Annual Book of ASTM Standards volume information, refer to the standard's Document Summary page on the ASTM website.

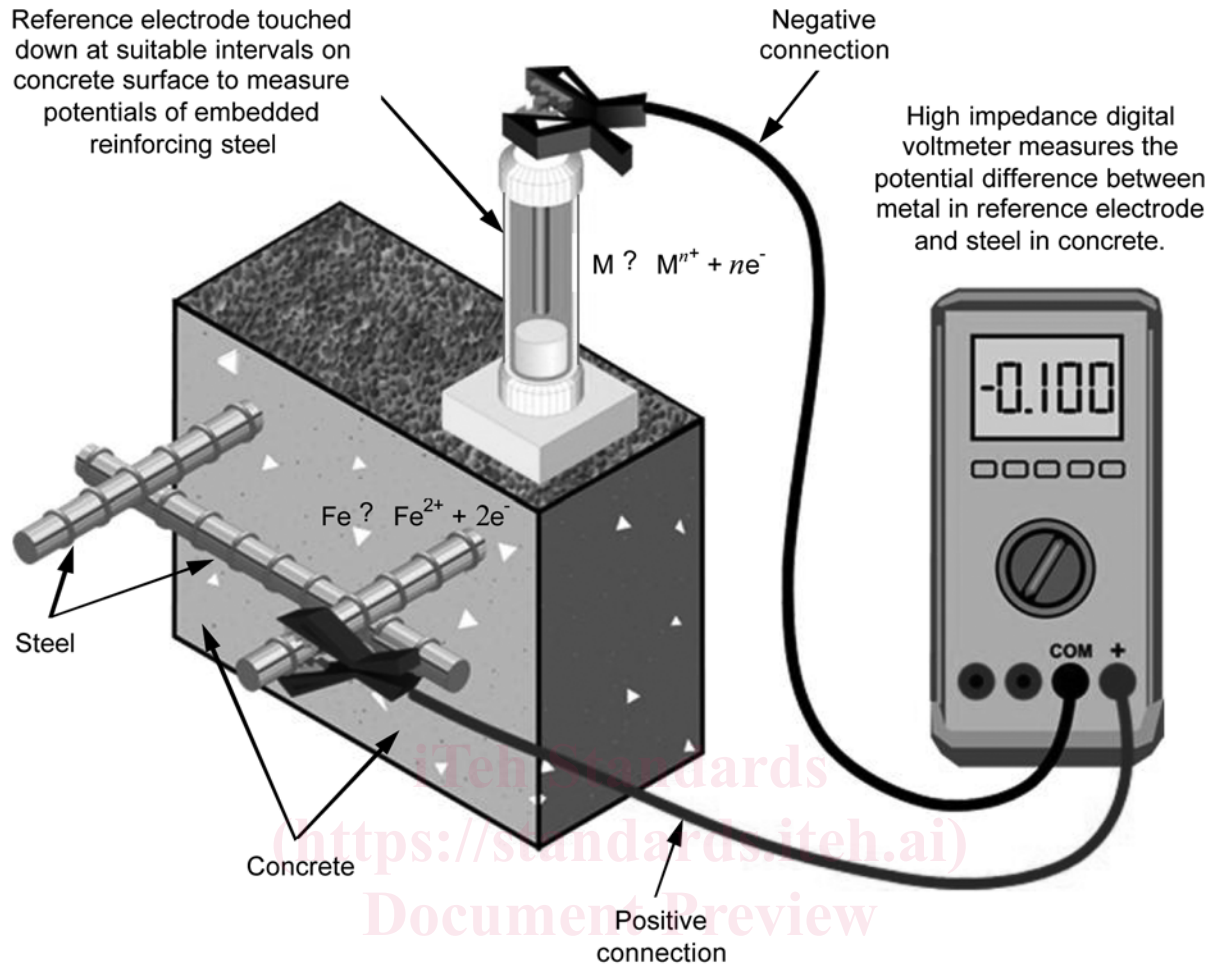


FIG. 1 Reference Electrode Circuitry

to formulate conclusions concerning corrosion activity of embedded steel and its probable effect on the service life of a structure.

Terminology

3.1 For definitions of terms used in this test method, refer to Terminology G 15.

**4. Significance and Use**

4.1 This test method is suitable for in-service evaluation and for use in research and development work.

4.2 This test method is applicable to members regardless of their size or the depth of concrete cover over the reinforcing steel. Concrete cover in excess of 3 in. (75 mm) can result in an averaging of adjacent reinforcement corrosion potentials that can result in a loss of the ability to discriminate variation in relative corrosion activity.

4.3 This test method may be used at any time during the life of a concrete member.

4.4 The results obtained by the use of this test method shall not be considered as a means for estimating the structural properties of the steel or of the reinforced concrete member.

4.5 The potential measurements should be interpreted by engineers or technical specialists experienced in the fields of concrete materials and corrosion testing. It is often necessary to use other data such as chloride contents, depth of carbonation, delamination survey findings, rate of corrosion results, and environmental exposure conditions, in addition to corrosion potential measurements, to formulate conclusions concerning corrosion activity of embedded steel and its probable effect on the service life of a structure.

**5. Apparatus**

4.1 The testing apparatus consists of the following:

4.1.1 *Half Cell*

5.1 The testing apparatus consists of the following:

5.1.1 *Reference Electrode:*

4.1.1.1 A copper-copper sulfate half cell (Note 1) is shown in Fig. 2

5.1.1.1 The reference electrode selected shall provide a stable and reproducible potential for the measurement of the corrosion potential of reinforcing steel embedded in concrete over the temperature range from 32 to 120°F (0 to 49°C).

5.1.1.2 For the purposes of this standard, corrosion potentials shall be based upon the half-cell reaction  $\text{Cu} \rightarrow \text{Cu}^{++} + 2\text{e}^-$  corresponding to the potential of the saturated copper-copper sulfate reference electrode as referenced to the hydrogen electrode being  $-0.30 \text{ V}$  at  $72^\circ\text{F}$  ( $22.2^\circ\text{C}$ ).<sup>3</sup> The copper-copper sulfate reference electrode has a temperature coefficient of approximately  $0.0005 \text{ V}$  more negative per  $^\circ\text{F}$  for the temperature range from  $32$  to  $120^\circ\text{F}$  ( $0$  to  $49^\circ\text{C}$ ). It consists of a rigid tube or container composed of a dielectric material that is nonreactive with copper or copper sulfate, a porous wooden or plastic plug that remains wet by capillary action, and a copper rod that is immersed within the tube in a saturated solution of copper sulfate. The solution shall be prepared with reagent grade copper sulfate crystals dissolved in distilled or deionized water. The solution may be considered saturated when an excess of crystals (undissolved) lies at the bottom of the solution.

4.1.1.2 The rigid tube or container shall have an inside diameter of not less than  $1 \text{ in.}$  ( $25 \text{ mm}$ ); the diameter of the porous plug shall not be less than  $\frac{1}{2} \text{ in.}$  ( $13 \text{ mm}$ ); the diameter of the immersed copper rod shall not be less than  $\frac{1}{4} \text{ in.}$  ( $6 \text{ mm}$ ), and the length shall not be less than  $2 \text{ in.}$  ( $50 \text{ mm}$ ).

4.1.1.3 Present criteria based upon the half-cell reaction of  $\text{Cu} \rightarrow \text{Cu}^{++} + 2\text{e}^-$  indicate that the potential of the saturated copper-copper sulfate half cell as referenced to the hydrogen electrode is  $-0.316 \text{ V}$  at  $72^\circ\text{F}$  ( $22.2^\circ\text{C}$ ). The cell has a temperature coefficient of about  $0.0005 \text{ V}$  more negative per  $^\circ\text{F}$  for the temperature range from  $32$  to  $120^\circ\text{F}$  ( $0$  to  $49^\circ\text{C}$ ).

Note 1—While this test method specifies only one type of half cell, that is, the copper-copper sulfate half cell, others having similar measurement range, accuracy, and precision characteristics may also be used. In addition to copper-copper sulfate cells, calomel cells have been used in laboratory studies. Potentials measured by other than copper-copper sulfate half cells should be converted to the copper-copper sulfate equivalent potential. The conversion technique can be found in Practice G3 and it is also described in most physical chemistry or half-cell technology text books.

4.1.2

5.1.1.3 Other reference electrodes having similar measurement range, accuracy, and precision characteristics to the copper-copper sulfate electrode may also be used. Calomel reference electrodes have been used in laboratory studies. For concrete submerged in seawater, using silver-silver chloride reference electrodes avoids chloride contamination problems that may occur with copper-copper sulfate electrodes. Silver/silver chloride/potassium chloride reference electrodes are also applied to atmospherically exposed concrete. Potentials measured by reference electrodes other than saturated copper-copper sulfate should be converted to the copper-copper sulfate equivalent potential. The conversion technique can be found in Practice G 3 and "Reference Electrodes, Theory and Practice" by Ives and Janz.<sup>4</sup>

5.1.2 *Electrical Junction Device*—An electrical junction device shall be used to provide a low electrical resistance liquid bridge between the surface of the concrete and the half cell. It shall consist of a sponge or several sponges pre-wetted with a low electrical

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<sup>3</sup> The boldface numbers in parentheses refer to the list of references at the end of this standard.

<sup>3</sup> Hampel, C. A., *The Encyclopedia of Electrochemistry*, Reinhold Publishing Co., New York, 1964, p. 433.

<sup>4</sup> Ives, D. J. G., and Janz, G. J., *Reference Electrodes Theory and Practice*, Academy Press, NY, 1961.

<https://standards.iteh.ai/catalog/standards/sist/e8d4f60c-3666-4f96-a9fb-7323bacdc9bc/astm-c876-09>

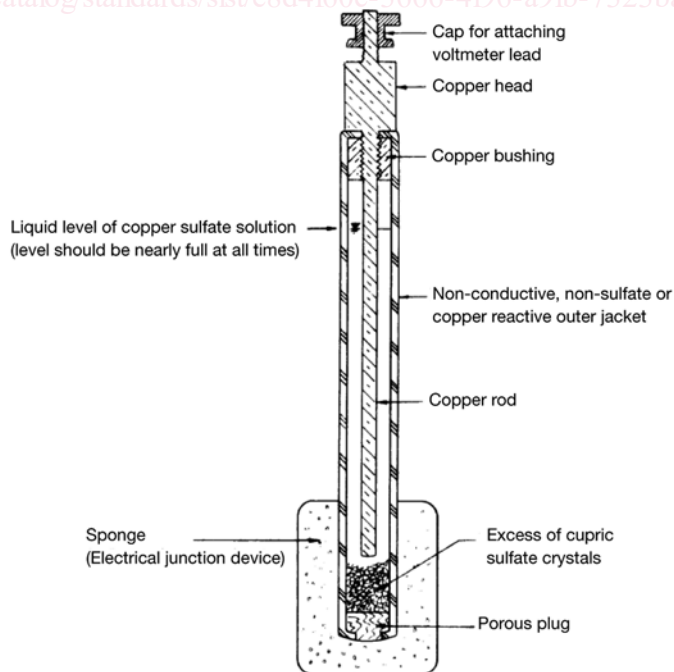


FIG. 2 Sectional View of a Copper-Copper Sulfate Reference Electrode

resistance contact solution. The sponge may be folded around and attached to the tip of the half cell so that it provides electrical continuity between the porous plug and the concrete member.

4.1.3—An electrical junction device shall be used to provide a low electrical resistance liquid bridge between the surface of the concrete and the reference electrode. It shall consist of a sponge or several sponges pre-wetted with a low electrical resistance contact solution. The sponge may be folded around and attached to the tip of the reference electrode so that it provides electrical continuity between the porous plug and the concrete member. The minimum contact area of the electrochemical junction device shall be the area equivalent of a circle with  $3\times$  the nominal diameter of the concrete coarse aggregate to a maximum of  $16\text{ in.}^2$  ( $0.01\text{ m}^2$ ).

5.1.3 Electrical Contact Solution—In order to standardize the potential drop through the concrete portion of the circuit, an electrical contact solution shall be used to wet the electrical junction device. One such solution is composed of a mixture of 95 mL of wetting agent (commercially available wetting agent) or a liquid household detergent thoroughly mixed with 5 gal (19 L) of potable water. Under working temperatures of less than about 50°F (10°C), approximately 15 % by volume of either isopropyl or denatured alcohol must be added to prevent clouding of the electrical contact solution, since clouding may inhibit penetration of water into the concrete to be tested. Conductive gels may be employed to reduce drift in the measured corrosion potential that can derive from dynamic liquid junction potentials. On large horizontal reinforced concrete, such as bridges, preliminary cleaning of the concrete surface with “street sweepers” has proven successful.

4.1.45.1.4 Voltmeter—The voltmeter shall have the capacity of being battery operated and have  $\pm 3\%$  end-of-scale accuracy at the voltage ranges in use. The input impedance shall be no less than 10 M $\Omega$  when operated at a full scale of 100 mV. The divisions on the scale used shall be such that a potential difference of 0.02 V or less can be read without interpolation.

4.1.5—The voltmeter shall allow dc voltage readings, have the capacity to be battery operated, and provide adequate input impedance and ac rejection capability for the environment where this test method is applied.

5.1.4.1 Prior to commencing testing, a digital voltmeter with a variable input impedance ranging from 10 to 200 M $\Omega$  may be used to determine the input impedance required to obtain precision readings. The use of a meter with variable input impedance avoids meter loading errors from high concrete resistivity. An initial reading is taken in the 10 M $\Omega$  position and then switching to successively higher impedances while watching the meter display until the reading remains constant through two successive increases. Then decrease the impedance on setting to reduce noise and provide the most precise readings. If the voltmeter does not display a constant reading through 200 M $\Omega$ , then the use of galvanometer with input impedance of 1 or 2 G $\Omega$  should be considered. Logging voltmeters may also be used.

5.1.4.2 Electromagnetic interference or induction resulting from nearby ac power lines or radio frequency transmitters can produce error. When in the proximity of such interference sources, the readings may fluctuate. An oscilloscope can be used to define the extent of the problem and be coupled with the dc voltmeter manufacturer’s specification for ac rejection capability to determine resolution of induced ac interference with successful application of this test method.

5.1.5 Electrical Lead Wires—The electrical lead wire shall be of such dimension that its electrical resistance for the length used will not disturb the electrical circuit by more than 0.0001 V. This has been accomplished by using no more than a total of 500 linear ft (150 m) of at least AWG No. 24 wire. The wire shall be suitably coated with direct burial type of insulation.

## **5. Calibration and Standardization**

5.1 Care of the Half Cell—The porous plug shall be covered when not in use for long periods to ensure that it does not become dried to the point that it becomes a dielectric (upon drying, pores may become occluded with crystalline copper sulfate). If cells do not produce the reproducibility or agreement between cells described in Section 11, cleaning the copper rod in the half cell may rectify the problem. The rod may be cleaned by wiping it with a dilute solution of hydrochloric acid. The copper sulfate solution shall be renewed either monthly or before each use, whichever is the longer period. At no time shall steel wool or any other contaminant be used to clean the copper rod or half-cell tube. The electrical lead wire shall be of such dimension that its electrical resistance for the length used will not disturb the electrical circuit by more than 0.0001 V. This has been accomplished by using no more than a total of 500 linear ft (150 m) of at least AWG No. 24 wire. The wire shall be coated with a suitable insulation such as direct burial type of insulation.

5.1.6 In addition to single reference electrodes connected to a voltmeter, multiple electrode arrays, reference electrodes with a wheel junction device and logging voltmeters that record distance and potential may also be used.

## **6. Calibration and Standardization**

6.1 Care of the Reference Electrode—Follow the manufacturer’s instructions for storage, calibration, and maintenance. Electrodes should not be allowed to dry out or become contaminated. The porous plug (salt bridge) shall be covered when not in use for long periods to ensure that it does not become dried to the point that it becomes a dielectric (upon drying, pores may become occluded with crystalline filling solution).

6.2 Calibration of the Reference Electrode—Reference electrodes shall be calibrated against an approved standard traceable to a national standard at regular intervals. If cells do not produce the reproducibility or agreement between cells described in Section 12, cleaning may rectify the problem. If reproducible and stable readings are not achieved the reference electrode should be replaced.



6.3 Calibration of the Voltmeter—The voltmeter shall be calibrated against an approved standard traceable to a national standard at regular intervals.

## **7. Procedure**

### **6.1**

7.1 Spacing Between Measurements—While there is no pre-defined minimum spacing between measurements on the surface of the concrete member, it is of little value to take two measurements from virtually the same point. Conversely, measurements taken with very wide spacing may neither detect corrosion activity that is present nor result in the appropriate accumulation of data for evaluation. The spacing shall therefore be consistent with the member being investigated and the intended end use of the measurements (Note 2<sub>1</sub>).

NOTE 2—A spacing of 4 ft (1.2 m) has been found satisfactory for evaluation of bridge decks. Generally, larger spacings increase the probability that localized corrosion areas will not be detected. Measurements may be taken in either a grid or a random pattern. Spacing between measurements should generally be reduced where adjacent readings exhibit algebraic reading differences exceeding 150 mV (areas of high corrosion activity). Minimum spacing generally should provide at least a 100-mV difference between readings.

6.2 1—A spacing of 4 ft (1.2 m) has been found satisfactory for rapid evaluation of structures with large horizontal surfaces like bridge decks. Generally, larger spacings increase the probability that localized corrosion areas will not be detected. Measurements may be taken in either a grid or a random pattern. Spacing between measurements should generally be reduced where adjacent readings exhibit reading differences exceeding 50 mV (areas of high corrosion activity). Cracks, cold joints, and areas with dynamic structural activity can produce areas of localized corrosion activity where the corrosion potential can change several hundred millivolts in less than 1 ft (300 mm) and care must be given that relatively large spacing between readings does not miss areas of localized corrosion activity. For small, lightly reinforced members, it may be advantageous to map the reinforcement locations with a cover meter and place the reference electrode over the bars on a suitable grid.

### 7.2 Electrical Connection to the Steel:

6.2.1 Make a direct electrical connection to the reinforcing steel by means of a compression-type ground clamp, or by brazing or welding a protruding rod. To ensure a low electrical resistance connection, scrape the bar or brush the wire before connecting to the reinforcing steel. In certain cases, this technique may require removal of some concrete to expose the reinforcing steel. Electrically connect the reinforcing steel to the positive terminal of the voltmeter.

6.2.2 Attachment must be made directly to the reinforcing steel except in cases where it can be documented that an exposed steel member is directly attached to the reinforcing steel. Certain members, such as expansion dams, date plates, lift works, and parapet rails may not be attached directly to the reinforcing steel and, therefore, may yield invalid readings. Electrical continuity of steel components with the reinforcing steel can be established by measuring the resistance between widely separated steel components on the deck. Where duplicate test measurements are continued over a long period of time, identical connection points should be used each time for a given measurement.

6.3 Electrical Connection to the Half Cell—Electrically connect one end of the lead wire to the half cell and the other end of this same lead wire to the negative (ground) terminal of the voltmeter.

### **6.4**

7.2.1 The type of connection used will depend on whether a temporary or permanent connection is required. Make a direct electrical connection to the reinforcing steel by means of a compression-type ground clamp, by brazing or welding a protruding rod, or by using a self tapping screw in a hole drilled in the bar. To ensure a low electrical resistance connection, scrape the bar or brush the wire before connecting to the reinforcing steel to ensure a bright metal to bright metal contact. In certain cases, this technique may require removal of some concrete to expose the reinforcing steel. Electrically connect the reinforcing steel to the positive terminal of the voltmeter. Special care should be exercised with prestressing steels to avoid serious injury and only mechanical connections should be made. Where welding is employed to make connections to conventional reinforcing steel, preheating will be necessary to avoid forming a brittle area in the rebar adjacent to the weld and such welding should be performed by certified welders.

7.2.2 Attachment must be made directly to the reinforcing steel except in cases where it can be documented that an exposed steel member is directly attached to the reinforcing steel. Certain members, such as expansion dams, date plates, lift works, scuppers, drains, and parapet rails may not be attached directly to the reinforcing steel and, therefore, may yield invalid readings. Electrical continuity of steel components with the reinforcing steel can be established by measuring the resistance between widely separated steel components on the deck. Where duplicate test measurements are continued over a long period of time, identical connection points should be used each time for a given measurement.

7.2.3 Care should be taken that the whole area of reinforcing mat being measured is electrically continuous by checking electrical continuity between diagonally opposite ends of the area surveyed.

7.3 Electrical Connection to the Reference Electrode —Electrically connect one end of the lead wire to the reference electrode and the other end of this same lead wire to the negative (ground) terminal of the voltmeter.

### 7.4 Pre-Wetting of the Concrete Surface:

6.4.1 Under certain 7.4.1 Under most conditions, the concrete surface or an overlaying material, or both, must be pre-wetted by either of the two methods described in 6.4.37.4.3 or 6.4.47.4.4 with the solution described in 4.1.35.1.3 to decrease the electrical resistance of the circuit.

~~6.4.2A~~7.4.2 A test to determine the need for pre-wetting ~~may~~shall be made as follows:

~~67.4.2.1~~ Place the half-cell reference electrode on the concrete surface and do not move.

~~6.4.2.2~~7.4.2.2 Observe the voltmeter for one of the following conditions:

~~(a)The~~(1) The measured value of the half-cell corrosion potential does not change or fluctuate with time.

~~(b)The~~(2) The measured value of the half-cell corrosion potential changes or fluctuates with time.

~~67.4.2.3~~ If condition ~~(a(1))~~ is observed, pre-wetting the concrete surface is not necessary. However, if condition ~~(b(2))~~ is observed, pre-wetting is required for an amount of time such that the voltage reading is stable ( $\pm 0.02$  V) when observed for at least 5 min. If pre-wetting cannot obtain condition ~~(a(1))~~, either the electrical resistance of the circuit is too great to obtain valid half-cell corrosion potential measurements of the steel, or stray current from a nearby direct current traction system or other fluctuating direct-current, such as arc welding, is affecting the readings. In either case, the half-cell reference electrode method should not be used.

~~6.4.3~~7.4.3 *Method A for Pre-Wetting Concrete Surfaces*—Use Method A for those conditions where a minimal amount of pre-wetting is required to obtain condition ~~(a(1))~~ as described in ~~6.4.2.2~~7.4.2.2. Accomplish this by spraying or otherwise wetting either the entire concrete surface or only the points of measurement as described in ~~6.17.1~~ with the solution described in ~~4.1.35.1.3~~. No free surface water should remain between grid points when potential measurements are initiated.

~~6.4.4~~

~~7.4.4~~ *Method B for Pre-Wetting Concrete Surfaces*—In this method, saturate sponges with the solution described in ~~4.1.35.1.3~~ and place on the concrete surface at locations described in ~~6.17.1~~. Leave the sponges in place for the period of time necessary to obtain condition ~~(a(1))~~ described in ~~6.4.2.2~~7.4.2.2. Do not remove the sponges from the concrete surface until after the half-cell reference electrode potential reading is made. In making the half-cell corrosion potential measurements, place the electrical junction device described in ~~4.1.25.1.2~~ firmly on top of the pre-wetting sponges for the duration of the measurement.

~~6.5~~

~~7.5~~ *Underwater, Horizontal, and Vertical Measurements:*

~~6.5.1~~ Potential measurements detect corrosion activity, but not necessarily the location of corrosion activity. The precise location of corrosion activity requires knowledge of the electrical resistance of the material between the half cell and the corroding steel. While underwater measurements are possible, results regarding the location of corrosion must be interpreted very carefully. Often it is not possible to precisely locate points of underwater corrosion activity in salt water environments because potential readings along the member appear uniform. However, the magnitude of readings does serve to indicate whether or not active corrosion is occurring. Take care during all underwater measurements that the half cell does not become contaminated and that no part other than the porous tip of the copper-copper sulfate electrode half cell comes in contact with water.

~~6.5.2~~ Perform horizontal and vertically upward measurements exactly as vertically downward measurements. However, additionally ensure that the copper-copper sulfate solution in the half cell makes simultaneous electrical contact with the porous plug and the copper rod at all times.

## 7. Recording Half-Cell Potential Values

~~7.1~~ Record the electrical half-cell potentials to the nearest 0.01 V. Report all half-cell potential values in volts and correct for temperature if the half-cell temperature is outside the range of  $72 \pm 10^\circ\text{F}$  ( $22.2 \pm 5.5^\circ\text{C}$ ). The temperature coefficient for the correction is given in ~~4.1.1.3~~.

~~7.5.1~~ Potential measurements detect corrosion activity, but not necessarily the location of corrosion activity. The precise location of corrosion activity requires knowledge of the electrical resistance of the material between the reference electrode and the corroding steel. While underwater measurements are possible, results regarding the location of corrosion must be interpreted very carefully. Underwater, or other situations where the concrete is saturated with water such as tunnels, often have very low oxygen concentrations at the surface of the reinforcement. Reduction of oxygen availability will shift the rebar corrosion potential significantly in the electronegative direction. Often it is not possible to precisely locate points of underwater corrosion activity in salt water environments because potential readings along the member appear uniform. Take care during all underwater measurements that the reference electrode does not become contaminated with salt water and that no electrically conductive part other than the porous tip of the copper-copper sulfate electrode reference electrode comes in contact with water including use of cable connectors specifically designed for use with submerged reference electrodes.

~~7.5.2~~ Perform horizontal and vertically upward measurements exactly as vertically downward measurements. However, additionally ensure that when using a copper/copper sulfate electrode that the solution in the reference electrode makes simultaneous electrical contact with the porous plug and the copper rod at all times.

## 8. Recording Corrosion Potential Values

~~8.1~~ Record the electrical corrosion potentials to the nearest 0.01 V. Report all corrosion potential values in volts and correct for temperature if the reference electrode temperature is outside the range of  $72 \pm 10^\circ\text{F}$  ( $22.2 \pm 5.5^\circ\text{C}$ ). The temperature coefficient for the correction is given in ~~5.1.1.3~~.

## 9. Data Presentation

~~8.1~~Test9.1 Test measurements may be presented by one or both of two methods. The first, an equipotential contour map,