



Standard Recommended Practice

The Use of Coupons for Cathodic Protection Monitoring Applications

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NACE International
1440 South Creek Drive
Houston, Texas 77084-4906
+1 (281) 228-6200

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Foreword

Coupons are used to determine the level of corrosion protection provided by a cathodic protection (CP) system to a variety of structures, such as buried or submerged pipelines, underground storage tanks (USTs), aboveground (on-grade) storage tank bottoms, and steel in reinforced concrete structures. Structure-to-electrolyte potential measurements have long been used as the basis for assessing CP levels and compliance with CP criteria. It is well known that a voltage (IR) drop exists in the soil and across the coating, and that this IR drop produces an error in the structure-to-electrolyte potential measurement. This IR drop can be a function of reference electrode placement, soil resistivity, burial depth of the structure, coating condition, stray currents, local or long-line corrosion cells, and the amount of CP current applied.

CP coupons have been used since the 1930s by several pioneers of the corrosion-control industry, both in North America and in Europe. CP coupons have been shown to be a practical tool for determining the level of polarization of a structure and to confirm the IR drop in a potential measurement. Research sponsored by the pipeline industry has explored the use of CP coupons and has helped validate the use of this technology. The purpose of this standard recommended practice is to provide a method for evaluating the effectiveness of a CP system using coupons. It is intended for use by people who design and maintain CP systems for buried or submerged pipelines, USTs, on-grade storage tank bottoms, reinforcing steel in concrete, water storage tanks, and various other structures in buried or aqueous environments.

The body of the standard primarily addresses applications for coupons attached to buried pipelines. Appendices cover the use of coupons for other applications, including USTs, aboveground storage tanks (ASTs), internal surfaces of water tanks, and reinforced concrete structures.

This standard was prepared by Task Group (TG) 210 on Coupon Technology for Cathodic Protection Applications. TG 210 is administered by Specific Technology Group (STG) 35 on Pipelines, Tanks, and Well Casings and is sponsored by STG 05 on Cathodic/Anodic Protection. This standard is issued by NACE under the auspices of STG 35.

In NACE standards, the terms *shall*, *must*, *should*, and *may* are used in accordance with the definitions of these terms in the NACE Publications Style Manual, 4th ed., Paragraph 7.4.1.9. *Shall* and *must* are used to state mandatory requirements. The term *should* is used to state something good and is recommended but is not mandatory. The term *may* is used to state something considered optional.

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The Use of Coupons for Cathodic Protection Monitoring Applications

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Section 1: General

1.1 A CP coupon may be used to determine the level of CP of a buried or submerged metallic structure. CP coupons are installed in the electrolyte near the structure and are then connected to it through a test station. This allows the CP coupon to be connected to the CP system on the structure, thus simulating a similar-sized bare area of the structure's surface, such as at a holiday in the coating. The CP coupon may be disconnected from the circuit during periodic testing, and its instant-disconnect potential measured. The potential of the CP coupon may then continue to be monitored and the depolarization calculated. These measurements represent the polarized and depolarized potentials of the structure in the vicinity of the CP coupon. They also allow the IR drop in the electrolyte to be calculated for use in conventional potential measurements made from grade level. A second, freely corroding (native) coupon may be installed at the same location as the CP coupon to measure the free-corrosion potential of the structure in open-circuit conditions.

1.2 NACE Standard RP0169¹ includes criteria for determining the CP status of a buried or submerged structure. For voltage measurements that are made when CP current is applied, IR drops other than those across the structure-to-electrolyte boundary must be considered. NACE Standard RP0169 includes a number of ways this may be done and NACE Standard TM0497² includes a number of test methods used for these criteria. CP coupons may also be used to evaluate compliance with CP criteria, including considering the IR drop. The practices described in this standard must be followed with careful evaluation of the specific situation in which the coupons are to be used.

1.3 CP coupons have several advantages. Structure-to-electrolyte potentials that have the IR drop considerably

reduced or eliminated may be obtained without interrupting multiple CP sources. CP coupons may also be used on buried structures with direct-connected galvanic anodes, which must not be interrupted. Using CP coupons, depolarization testing may be performed in most cases without de-energizing the CP system. An additional advantage is the ability to record accurate structure-to-electrolyte potentials on structures affected by stray currents.

1.4 When CP coupons are used, there may be differences between polarized potentials of the CP coupon and the structure. This is because the polarized structure-to-electrolyte potential measured at grade is usually the combined potential of the structure over a rather large area, including holidays in the coating and locations where the electrolyte or other conditions that affect the potential of a structure may vary. Errors caused by these variations are included in a potential measured at any given point along a structure and may be significant. These errors generally do not occur with coupons because of their small size and uniform conditions. Coupons located in areas where these variables are different can provide a good representation of the CP effectiveness on a structure.

1.5 A typical problem in measuring a structure-to-electrolyte potential is the effect of IR drops from uninterruptible current sources. By design, CP coupons may be disconnected from the structure and CP system, thereby eliminating the IR drop attributable to these current sources. Even when all current sources have been interrupted, long-line currents can still affect the structure-to-electrolyte potential readings measured at grade on a pipeline. Because the effective reference point of a CP coupon is very close to the CP coupon surface, IR drops caused by long-line currents are minimized.

Section 2: Definitions

Automated Coupon Reader: A portable electronic instrument capable of taking several types of measurements at multiple coupon test stations and storing these values to be later uploaded to a computer.

Buried Stationary Reference Electrode: A reference electrode, usually copper-copper sulfate (Cu/CuSO₄ or CSE), designed to last for many years permanently installed in a buried position.

Cathodic Protection (CP) Coupon: A coupon that is connected to the external surface of, and immersed in the electrolyte adjacent to, the structure being protected by cathodic protection.

Concentric CP Coupon and Reference Electrode: A device containing a CP coupon and a reference electrode that have the same geometric center point.

Corrosion Potential (E_{corr}): The potential of a corroding surface in an electrolyte relative to a reference electrode under open-circuit conditions. (Also known as *rest potential*, *open-circuit potential*, or *freely corroding potential*).

Coupon: A metal specimen made of similar material as the structure under investigation.

Coupon-to-Electrolyte Potential: The potential difference between the surface of a buried or submerged coupon and

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the electrolyte that is measured with reference to an electrode in contact with the electrolyte.

Coupon Instant-Disconnect On-Potential: The instant-disconnect potential of the coupon measured while current to the structure is applied.

Coupon Instant-Disconnect Off-Potential: The instant-disconnect potential of the coupon measured while current to the structure is interrupted.

Depolarized Potential: The steady-state potential that the CP coupon reaches some time after disconnecting from the structure.

Depolarizing Wave Form: A recorded plot of potential versus time, from just prior to disconnecting the CP coupon from the structure, to some time thereafter. This plot is often done until the potential reaches a stable value and is often used to determine instant-disconnect, instant-off, and depolarized potentials.

Electrical Isolation: The condition of being electrically separated from other metallic structures or the environment.

Electrometer: An ultrahigh-impedance, low-current volt meter. The input resistances are typically many mega ohms. These instruments can be used to measure low currents, voltages from high-resistance sources, charges, or high resistances.

Foreign Structure: Any metallic structure that is not intended as a part of a system under cathodic protection.

Free-Corrosion Coupon: A coupon that is immersed in the electrolyte adjacent to the structure but is not connected to the structure. Also known as a *native coupon*.

Free-Corrosion Potential: See *Corrosion Potential*.

Galvanic Anode: A metal that provides sacrificial protection to another metal that is more noble when electrically coupled in an electrolyte. This type of anode is the electron source in one type of cathodic protection.

Holiday: A discontinuity in a protective coating that exposes unprotected surface to the environment.

Impressed Current: An electric current supplied by a device employing a power source that is external to the electrode system. (An example is direct current for cathodic protection.)

Instant-Disconnect Potential: The coupon-to-electrolyte potential made without perceptible delay after disconnecting the coupon from the structure.

Instant-Off Potential: The polarized half-cell potential of an electrode taken immediately after the cathodic protection current is stopped, which closely approximates the potential without IR drop (i.e., the polarized potential) when the current was on.

Interrupted Wave Form: A recorded plot of potential versus time from just prior to disconnecting the CP coupon from the structure, to some time thereafter, typically a few seconds. This wave-print may be used to record or determine the instant-off and instant-disconnect potentials.

IR Drop: The voltage across a resistance in accordance with Ohm's law.

Native Coupon: See *Free-Corrosion Coupon*.

Native Potential: See *Corrosion Potential*.

Open-Circuit Potential: The potential of an electrode measured with respect to a reference electrode or another electrode in the absence of current.

Polarization: The change from the open-circuit potential as a result of current across the electrode/electrolyte interface.

Polarized Potential: The potential across the structure/electrolyte interface that is the sum of the corrosion potential and the cathodic polarization.

Reference Electrode: An electrode whose open-circuit potential is constant under similar conditions of measurement, which is used for measuring the relative potentials of other electrodes.

Reference Tube: See *Soil-Access Tube*.

Reference Tube Structure-to-Electrolyte Potential: A structure-to-electrolyte potential measurement performed with the reference electrode located within a reference tube that extends down to near the structure surface.

Soil-Access Tube: A tube that is nonconductive and impermeable to moisture (polyvinyl chloride [PVC], polyethylene, polycarbonate) that can be used in conjunction with a coupon and can be filled with electrolyte. (Also known as a *Reference Tube*.)

Structure-to-Electrolyte Potential: The potential difference between the surface of a buried or submerged metallic structure and the electrolyte that is measured with reference to an electrode in contact with the electrolyte.

Telluric Current: The current in the earth resulting from geomagnetic fluctuations.

Section 3: Applications

3.1 Coupons may be used for potential measurements on pipelines and many other structures. When properly installed and maintained, coupons may be used, either by themselves or in conjunction with other measurement techniques, for evaluating compliance with CP criteria. It has long been realized that an IR drop that produces an error in the structure-to-electrolyte potential exists in the electrolyte and across the coating. This IR-drop error varies from pipeline to pipeline and along the length of a given pipe because of variations in soil resistivity, depth of burial, coating condition, stray current, local and long-line corrosion cells, and the magnitude of CP current. This IR drop may be determined by measuring the difference between the on potential and the instant-off potential of a structure immediately after interrupting the CP current. The instant-off potential measured without perceptible delay after interruption is an accepted method of determining the polarized potential of the pipe.

3.2 The CP coupon methodology may be used as an alternative to the conventional instant-off potential measurement for evaluating the effectiveness of a CP system. By disconnecting the coupon from the pipe (and therefore, from the CP system as well) and measuring the potential of the coupon surface with a reference electrode located very close to the coupon or in a soil-access tube, the instant-off potential errors for the coupon are either eliminated or minimized.

3.3 The CP coupon polarized (off) potential is not identical to the conventional structure-to-electrolyte off potential measured from the surface of the ground. The structure-to-electrolyte off potential is affected by many factors, including:

- the number and distribution of holidays along and around the structure surface both near to and far from the coupon,
- variations in the specific conductance of the coating along and around the structure surface both near to and far from the coupon,
- possibly large surface areas exposed to the electrolyte (especially for bare pipe),
- different electrolyte conditions (soil type, moisture content, chemistry, resistivity, temperature, and amount of oxygen) along the length and depth of the pipe,
- different current densities along and around the surface of the pipe, resulting in different levels of polarization,
- long-line currents and local currents established between areas with different levels of polarization,
- interference effects from foreign CP systems, telluric currents, and other alternating current (AC) and direct current (DC) stray current sources, and
- bimetallic structure connections that may be inadvertently or deliberately in contact with the cathodically protected structure.

3.4 Because of these differences, when a structure-to-electrolyte potential is measured, each measurement is actually a weighted average of all the areas exposed to the electrolyte. It has been demonstrated that the polarized potential of exposed steel at small holidays on large-diameter pipelines can vary significantly over small distances because of the factors listed in Paragraph 3.3. The significance of these differences on an individual structure-to-electrolyte measurement is usually difficult to determine. In contrast, the polarized potential of the coupon represents the polarized potential of a single, small area of either an uncoated structure or a coating defect (holiday) on a coated structure.

3.5 When a coupon is installed close to the structure and the electrolyte around each is the same, the coupon essentially receives the same level of CP current and attains the same level of polarization as an adjacent equal area of the structure that has the same resistance-to-earth. This allows CP measurements to be made on the coupon from which the CP status of the structure in that area may be determined. The coupon method evaluates the effectiveness of a CP system based on an accurate polarized potential measurement of a coupon (representing an equivalent surface on the structure) rather than a structure-to-electrolyte off-potential measurement that may contain errors. This is especially true when error sources are known to be near the measurement area. Coupons may be used to obtain significant information on the level of protection supplied by a CP system to a structure. The instant-disconnect potential, depolarization behavior, and the current picked up by the CP coupon can be easily measured.

3.6 Coupons may be used in a wide variety of applications. The most common usage is for buried or submerged pipelines. They are also used for USTs, on-grade storage tank bottoms, reinforcing steel in concrete, internal surfaces of elevated or on-grade water storage tanks, and various other structures in aqueous environments. Information on these applications can be found in Appendices A, B, and C. Pipelines that can use coupons include transmission, distribution, gathering, utility, and in-plant piping. Coupons may also be used for cable-carrying piping or conduit that is buried or submerged and protected from external corrosion with CP.

3.7 Coupons may be used when any of the following conditions occur:

- (a) current from multiple rectifiers must be interrupted synchronously (or a nonsynchronous interruption method, like the wave-form analyzer or stepwise reduction method, must be used);
- (b) foreign CP systems are present in the area, for which either the locations are unknown or the rectifiers cannot be

interrupted, resulting in IR-drop errors in the off-potential measurement;

(c) the presence of directly connected sacrificial anodes that cannot be interrupted, resulting in IR-drop errors in the off-potential measurement;

(d) long-line or telluric currents that result in IR-drop errors that interruption cannot eliminate;

(e) stray current that causes significant IR-drop errors in the off-potential measurement;

(f) structures utilizing polarization or depolarization criterion;

(g) locally corrosive areas in an otherwise noncorrosive environment;

(h) rapid IR transients (spikes) immediately following interruption that cause errors in the off-potential measurement;

(i) simple averaging over a length of pipe based on structure-to-electrolyte measurements made at grade that cause local potential fluctuations to be underestimated;

(j) multiple pipelines in the same right-of-way that produce interference with one another, thus preventing an accurate measure of any individual line;

(k) the structure may be under the influence of alternating current; and

(l) no known CP problem exists, but additional information is desired.

3.8 In areas where multiple impressed-current sources influence the structure-to-electrolyte potential, interruption of all current sources is not always practical. A coupon may be disconnected from the structure and its instant-disconnect potential measured to evaluate the protection level with respect to the relevant polarized potential criterion. Additionally, a coupon may be allowed to

depolarize, permitting evaluation with respect to the relevant polarization criterion without the need to turn off CP systems for extended periods.

3.9 Coupons may be used to assess the level of protection on structures affected by stray currents. Stray current sources include DC traction systems, foreign rectifiers, telluric earth currents, and high-voltage direct-current (HVDC) electrodes.

3.10 In some cases, galvanic anodes are directly connected to the structure and cannot be interrupted to reduce the measurement error caused by the IR drop. In such cases, coupons may be used because their potential may be measured after they are disconnected from the structure.

3.11 In complex piping environments, such as industrial plants in which mixed metals can be electrically continuous with the affected structure, application of polarized potential or polarization criteria has not always been technically correct or practical. The measured potential is a result of a combination of the potentials of the metals involved. In a similar way, during current interruption, secondary IR drops from circulating galvanic current can cause errors in potential or polarization measurements on structures with widely varying potentials. When coupons are used, potential and polarization measurements should be made by locally disconnecting the CP coupon from the affected structure, thus avoiding the problem.

3.12 When several structures are bonded together, the structure-to-electrolyte potential measured at grade above one structure is actually a mixed potential of all the structures. The use of coupons is a means for determining a more local potential because each pipeline or structure can have its own coupon.

3.13 A CP coupon or a free-corrosion coupon as described in this standard, installed adjacent to a location with a disbonded, high-dielectric coating that shields CP current from reaching the structure surface, may not represent the CP protection status of the structure under the disbonded coating.

Section 4: Design of CP Coupons

4.1 Depending on the specific circumstances, various types of coupon designs may be used. Some common types of coupons are listed below. Other types of coupons may be manufactured for specific circumstances.

- Two-wire with various shapes. A cylindrical type is shown in Figure 1a.

- Coupons with a built-in, integral, reference electrode. As an option, the coupon assembly may include a flexible conduit extending to grade for irrigation in dry conditions. See Figure 1b.
- Coupons with a stationary electrode permanently buried near the coupon.
- Dual coupons of identical geometry and surface area for use in monitoring both CP and native potentials.

4.2 Depending on the specific application, a determination must be made as to which features are required for the

particular system under investigation. The proper coupon design for the CP monitoring program must then be selected.

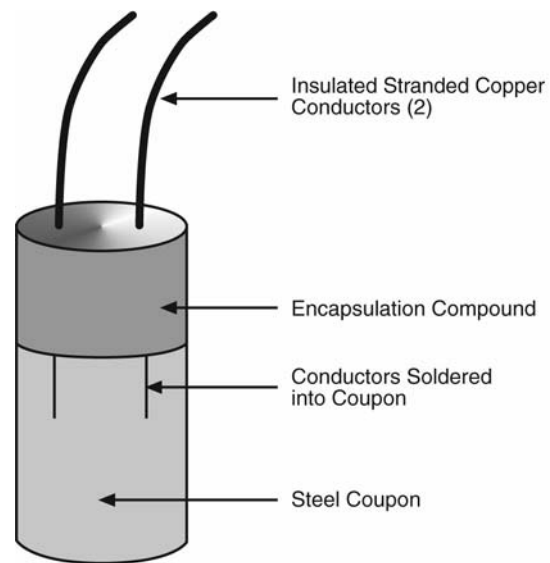


FIGURE 1a: Coupon with Cable Connections

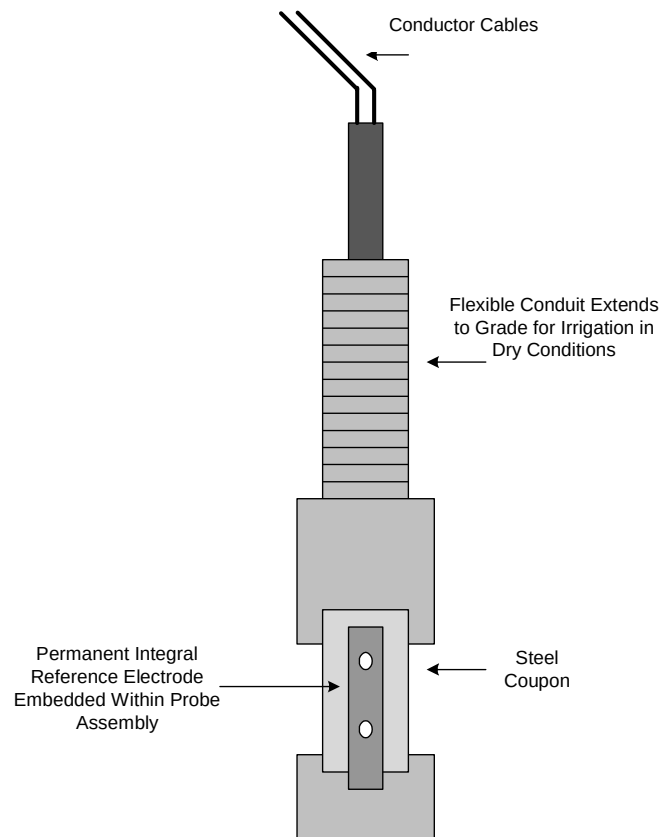


FIGURE 1b: Coupon with Built-In Reference Electrode

4.3 When a CP coupon system is designed, the magnitude of the voltage gradient (IR drop) in the electrolyte between the reference electrode and the coupon during the expected measurement steps, soil conditions, and current in the electrolyte should be considered. In cases in which the current density and/or electrolyte resistivity values are low, and especially when the distance between the coupon and reference electrode is small, the IR drops may be insignificant. In cases in which the magnitude of the IR drop is either not known, considered to be significant, or may change significantly (e.g., with changing soil resistivity or current density or in dynamic stray current conditions), the coupon should be designed such that the reference electrode can effectively be located very close to the coupon. In such cases, a design using either a close-coupled CP coupon and reference electrode, a concentric CP coupon and reference electrode (such as shown in Figure 1b), or a soil-access tube (as described in Section 6) should be used.

4.4 Some important features of CP coupons include:

- (a) the associated fittings and soil-access tubes (if used) should be made of nonmetallic materials;
- (b) the diameter of the soil-access tube should be large enough to allow entry of an external reference electrode;
- (c) use of an accessible test station for lead-wire access; and
- (d) use of a disconnect switch or similar feature to allow rapid disconnection of the coupon from the structure.

4.5 The coupon material should be similar to the material of the structure under investigation. Coupons may be in ring, cylindrical, circular-plate, and rectangular-plate shapes. Coupons may have access slots or ports through the plate for inserting a reference electrode to create a concentric CP coupon and reference electrode.

4.6 The size of the CP coupon should simulate the largest anticipated coating holiday size on the structure in the area under investigation. Commercially available CP coupons range in size from 650 to 10,000 mm² (1.0 to 16 in.²), but any size may be used. When the size of a coupon is determined, the measurement errors described in Section 3 should be considered. A coupon that is too large may also be subject to these same sources of measurement error as the structure. For bare or poorly coated structures, consideration should be given to using larger coupons than might be used on a well-coated structure on which only small holidays are expected.

4.7 Different sizes and shapes of coupons have different resistance-to-earth and therefore can polarize to different levels for the same bare surface area. The location and orientation of the coupon with respect to the structure may also have an effect on the current it receives and on its polarization.

4.8 Coupon connections to the lead wires must be securely attached to the coupon such that low-resistance electrical continuity is maintained throughout the design life. This may be done using silver solder, exothermic welding, mechanical connections, or any other appropriate technique. The lead wire connections should be encapsulated with a protective coating suitable for the service conditions to isolate the connection from the electrolyte. Figure 1a illustrates soldered connections to a cylindrical coupon. Figure 1b illustrates a coupon with a built-in reference electrode.

4.9 When a CP coupon system is designed, the method to be used for measuring the potential-to-electrolyte of the coupon(s) should be considered. When stationary reference electrodes are to be used in close proximity to the coupon, consideration should be given to the potential for leakage of electrolyte or chemicals from the reference cell assembly that could contaminate the coupon surface and the electrolyte around it. This would introduce errors in the comparison between the potentials of the structure and coupon that may be difficult to determine.

Section 5: Selection of CP Coupon Locations

5.1 The placement of a coupon should be dictated by the need to gain information about the polarization of a structure. The information about current density, direction of current flow (to or from the structure), the specific IR drop associated with the coupon location, and the corrosiveness of the environment can provide additional information about the level of corrosion protection that ordinarily cannot be provided by other methods.

5.2 Coupons must be installed in close proximity to and in the same type of electrolyte as the protected structure. The coupon must be electrically connected to the protected structure if the coupon is intended to replicate the corrosion control conditions of the structure. To facilitate the testing

described in this standard, the coupon must be connected to the structure through a test station or other accessible device. Coupons should be installed at any location where instant-off potential measurements, degree of polarization, or current-density measurements are desired. Typical locations where a coupon may be installed are listed in Paragraph 3.7. Care must be taken in accurately selecting the location and placement of a coupon so that it is representative of the cathodic conditions at the point of interest, i.e., not receiving preferential or diminished protection compared to the structure.

5.3 Coupons may be used to sample the protection level at multiple locations of a broadly reaching impressed-current

system. Locations that may have different soil resistivity, soil chemistry, moisture content, current density, coating condition, and temperature should be considered for coupons. Examples of such locations are (1) the top of a dry, rocky hill, (2) low-lying wet valley, (3) mid-span between CP current sources, and (4) suction and discharge of compressor stations. Coupons should be placed in each environment to help identify the effectiveness of the impressed current system in that specific environment.

5.4 The details of each specific situation must be considered when the number and location of coupons for use on coated, bare, or poorly coated structures are determined. In similar conditions, a poorly coated or bare pipeline may be more affected than a well-coated pipeline by the factors that cause measurement errors to the structure-to-electrolyte potential described in Section 3. More coupons should be installed on a bare or poorly coated pipeline than on a well-coated pipeline. Coupons should be considered for locations where the effects are greatest or of significant interest.

5.5 Coupons may be placed on the opposite side of the distributed anode system on a protected structure. This may shield the coupons from the CP current and cause readings that are more positive than the average polarization value of the structure when the structure-to-electrolyte potentials are measured at the surface. This may also indicate that the structure surface adjacent to the coupon is shielded.

5.6 The type and location of anodes should be factored into the placement of the coupon. For example, a distributed galvanic anode system may produce uneven polarization on the protected structure. Conversely, a remote impressed-current system may produce a more even distribution of current, resulting in more uniform polarization. Coupons may be placed in various locations near a structure to determine the effect of anode type and location, uniformity of current distribution, and level of polarization.

Section 6: Installation

6.1 Good electrical contact must be maintained between the coupon surface and the surrounding environment.

6.1.1 During the installation process, the soil around the coupon shall be compacted to prevent settlement and air voids forming around the coupon. These voids could result in loss of full contact between the coupon surface and the surrounding soil.

6.1.2 The possible loss of contact because of soil movement caused by freezing or subsidence of the backfill material around the coupon shall be considered and minimized during installation.

6.2 CP coupons may be installed by a number of different methods, including:

- Excavation activities during structure investigation,
- Auguring,
- Vacuum excavation,
- Hand digging, and
- Installation of the coupon during construction of the structure under investigation.

6.3 The installation method selected depends on site access, the type of soil to be excavated, the cost involved, and the availability of an electrical connection to the structure. A typical coupon installation for a buried pipeline is illustrated in Figures 2a and 2b. Other configurations or installation methods may also be used.

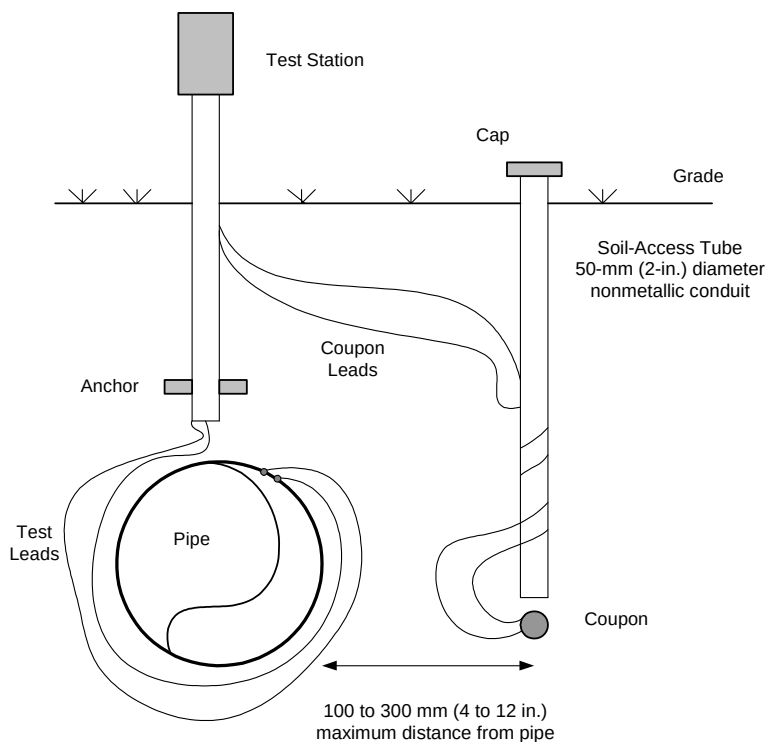


FIGURE 2a: CP Coupon Test Station—End View

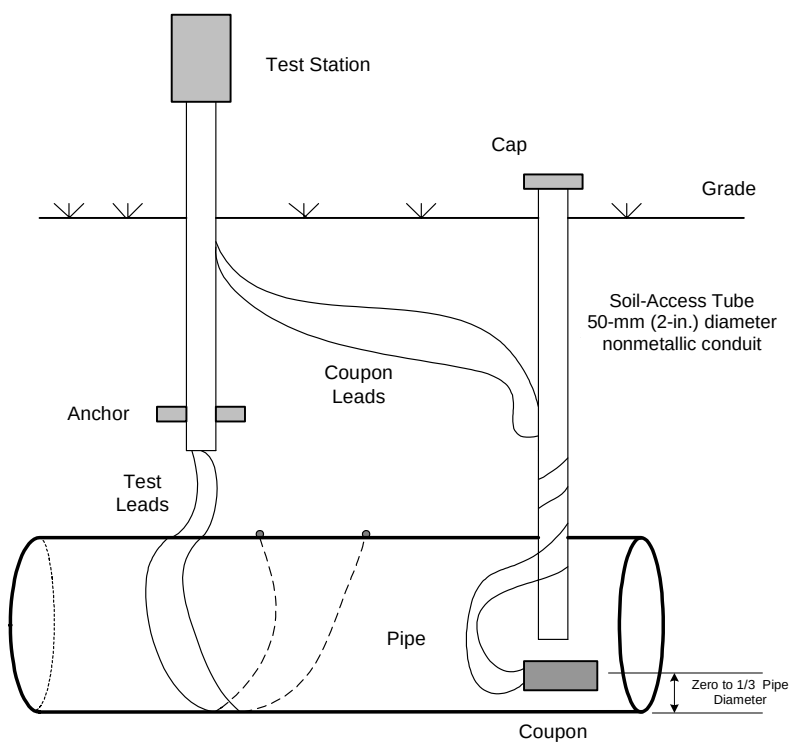


FIGURE 2b: CP Coupon Test Station—Elevation

6.4 Coupons should be installed:

6.4.1 In the same backfill as the protected structure and in conditions that closely resemble the conditions of the structure under investigation.

6.4.2 In the case of a cylindrical structure, adjacent to the lower half of the structure, i.e., below the 3 to 9 o'clock position.

6.4.3 Within 100 to 300 mm (4 to 12 in.) from the outer surface of the structure, as illustrated in Figure 2a.

6.4.4 With wiring to the structure through a test station or other accessible device, as illustrated in Figure 2b.

6.5 On large-diameter pipelines, coupons may be useful at other locations around the pipe because of the increased possibility of local differences in soil and coating conditions from one area to another around the circumference that can cause local differences in CP effectiveness.

6.6 A CP coupon should be installed such that it receives the same current density as the structure in that area and does not shield cathodic current from the structure. For a flat coupon with one coated surface, the bare surface should face away from the structure. Flat coupons with two bare sides should be installed perpendicular to the structure. Small cylindrical coupons may be installed either parallel or perpendicular to the structure. Large cylindrical (pipe-type) coupons should generally be installed parallel to the pipe axis. When large coupons and/or other shapes or configurations are used, consideration must be given to the shape and size of the coupon and its distance from the structure to avoid the possibility that the coupon could shield CP current from the structure, and to make sure it stays within the same electrolyte conditions as the structure. Care should be taken to make sure that the coupon does not come into direct physical contact with the structure.

6.7 When the design of a CP coupon system includes a soil-access tube, it should be installed with:

6.7.1 A nonmetallic conduit soil-access tube with a minimum diameter of 50 mm (2 in.).

6.7.2 The top of the soil-access tube at least 300 mm (12 in.) above grade. To prevent damage or obstruction, the soil-access tube may terminate in a flush-mounted box or other appropriate location if required.

6.7.3 A cap to prevent the ingress of debris, contaminants, or other foreign matter.

6.8 The pipe diameter can affect the practical alternatives for the safe placement of coupons on an existing pipeline. For example, on an existing 1,060-mm (42.0-in.) diameter pipeline with concrete overcoat, the coupon may be located in the 3 to 4 o'clock or 8 to 9 o'clock position. This is necessary in order to stay within the recommended distance allowed from the pipe. For a 100-mm (4-in.) diameter pipe, the distance at the bottom or 6 o'clock position may be easily achieved. The location of the coupon should be selected to meet the objectives stated in Section 5.

6.9 In locations with soil resistivity greater than 10,000 Ω -cm, the resistance of the soil column in the soil-access tube must be considered because it can be sufficiently high to result in erroneous (more positive) potentials when standard 10-M Ω impedance voltmeters are used. (See additional information in Section 8.)

6.9.1 Imported low-resistivity material, such as bentonite, may be used to form a mixture with local soil or calcium sulfate to lower the total soil column resistance. Leaching of this material must not contaminate the environment of the coupon and make it dissimilar to the electrolyte around the structure. The soil in contact with the coupon shall be the same soil as that in contact with the structure and shall not be mixed with foreign material.

6.9.2 Sufficient soil shall be filled over the coupon to prevent a differential aeration effect between the coupon and the structure. This fill should be brought up to grade level.

6.9.3 Soil-access tubes that are designed to be filled with soil can freeze in winter and result in high-resistance measuring circuit problems.

6.10 Below-grade cable penetrations in the soil-access tube must be avoided or sealed such that IR drops in the soil are not measured through the entry hole. When coupon test stations are installed close to foreign structures, structures connected to galvanic anodes, or AC voltage mitigation grounding systems, considerable errors can result when the soil-access tube contains test lead entry holes or holes for stabilization bars. For additional information, see Section 8.

Section 7: Construction Precautions

7.1 To prevent the formation of voids in a soil-access tube, the soil should be screened and compacted during installation. Small quantities of water may be used in the soil-access tube to wet and compact the soil. Care should

be taken to prevent the migration of water to the coupons themselves. This can decrease the soil resistivity around the coupon and result in different current densities and potentials than a bare area on the pipe would have.

7.2 When a soil-access tube is not filled to grade with soil, it can be difficult to obtain good contact between the soil in it and the porous plug on the reference electrode. This problem can also occur when nonconductive debris is

allowed to collect in the soil-access tube. A cover should be used to prevent the entry of foreign debris into the soil-access tube.

Section 8: Monitoring and Interpretation

8.1 Monitoring coupon test stations provides an effective means of determining the CP status of a structure. For proper interpretation of data collected from coupons and the accuracy of the data in representing the CP status of the structure, one must understand the design and installation of the coupon and protected structure and the similarity of the electrolytes to which they are exposed. Measurements should be made in accordance with NACE Standard TM0497.²

8.2 Depending on the design of the coupon, location of the reference electrode with respect to the structure and coupon, soil resistivity, and current density, it is possible that IR-drop errors may be introduced in the measured coupon-to-electrolyte potentials. These errors may be caused by the presence of uninterrupted CP currents or other currents in the soil in the vicinity of the coupon and reference electrode. This effect is greatest when the coupon is close to an anode or a coating flaw (holiday), or when the coupon is near the structure and there is a high IR drop in the soil because of current going to either the structure or the coupon. If these conditions do not exist, this IR drop may be insignificant. These sources of errors should be considered. A process for doing this is described in Paragraph 8.3.

8.2.1 When the surface of the coupon (either a CP coupon or a free-corrosion coupon) and the porous surface of the reference electrode have the same geometric center point (as in Figure 1b), IR drops in the earth generally have minimal effect on the measured potential of the coupon.

8.2.2 When the surface of the coupon and the porous surface of the reference electrode do not have the same geometric center point, a IR-drop error may occur between the reference electrode and the CP coupon. The IR-drop error may occur whether or not the coupon is connected to the structure. The magnitude of the IR-drop error depends on coupon and reference-electrode geometry, distance between the coupon and reference electrode, magnitude of the CP current, and soil resistivity.

8.2.2.1 When the coupon is connected to the structure, current is applied to both the coupon and the structure. There are IR drops between the reference electrode and the structure and between the reference electrode and the coupon. The IR drops are similar in nature to IR drop in the electrolyte in measurement circuits for any cathodically protected structure. Their magnitude

may be significant and must be considered and understood for each specific situation.

8.2.2.2 When the coupon is disconnected from the structure, CP current still flows to the structure. Because of this current, there may be an IR drop in the earth between the reference electrode and coupon. This IR drop is included in the coupon-to-electrolyte potential measurement as long as there is current going to the structure. The magnitude of this IR drop must be considered. In some applications it may be negligible and may be ignored.

8.2.2.3 When a free-corrosion coupon is placed in a large-IR drop between an external anode and the protected structure, the current going to the structure or another coupon may cause stray-current corrosion of the free-corrosion coupon. This can result in distinct anodic and cathodic regions on opposite sides of the free-corrosion coupon because of the flow of current both onto the coupon and discharging from it. This causes the actual potential of the free-corrosion coupon to change from its native state. The amount of this effect must be accounted for if considered significant.

8.2.2.4 When a free-corrosion coupon is used for corrosion rate measurement, the effect of possible stray current corrosion of the free-corrosion coupon should be considered.

8.3 The magnitude of IR-drop error in the measured coupon-to-electrolyte potential may be determined by performing a test whereby the current to the protected structure is cycled on and off while the coupon is also connected and disconnected from the protected structure. The following test procedure may be used to determine the magnitude of this IR-drop error. The indicated potential measurements may be taken using either a stationary or portable reference electrode next to the coupon or with a portable reference electrode at the soil surface.

8.3.1 The on and instant-off potentials of the coupon shall be measured and recorded while it is connected to the structure by interrupting the influencing current sources.

8.3.2 The instant-disconnect potential of the coupon shall be measured and recorded while current is

continuously applied to the structure by briefly disconnecting the coupon from the structure.

8.3.3 When the coupon on, instant-off, and instant-disconnect potentials are all similar, the IR drop in the electrolyte is small for each measurement. Either the coupon on or instant-disconnect potential may be used as long as the current density, soil resistivity, and other operating conditions do not change substantially and the reference electrode placement is the same as in the test condition.

8.3.4 When the coupon instant-off and instant-disconnect potentials are similar, but the on potential is substantially different, the IR drop is significant for the on-potential measurements, but not for the others. In this case, only the instant-disconnect potential may be used as long as the current density, soil resistivity, and other operating conditions do not change substantially and the reference electrode placement is the same as in the test condition.

8.3.5 When the coupon instant-off, instant-disconnect, and on potential are not similar there may be a significant IR drop incorporated in the measurements. Additional testing should be done to determine the amount of the IR drop in each case using the procedure in Appendix D. When this additional testing proves unsuccessful, there may be something wrong with the test station, such as incorrect arrangement or geometry of the coupon and reference electrodes. The test station should not be used until the problem is identified and corrected.

8.4 The IR-drop free value of the CP coupon-to-electrolyte instant-disconnect potential represents the polarized potential of an area on the structure near the coupon that is in the same electrolyte conditions and has the same resistance-to-earth as the coupon.

8.5 A variety of instruments are used to monitor CP coupons. Some of the equipment used to monitor CP coupons is commonly used for other CP readings, while other equipment is more specialized. There are advantages, disadvantages, and varying degrees of accuracy for the different options. Table 1 lists the equipment used for the seven most common measurements. An appropriate instrument must be selected for the intended measurement and the operator of the selected test equipment must be experienced in its proper use. When properly used, each of these alternatives can obtain satisfactory data. The operator must use experience and judgment when selecting the appropriate equipment for the circumstances in order to acquire the data accurately.

8.5.1 The limitations of these instruments in the accurate measurement of each parameter must be recognized. For example, a digital voltmeter may be satisfactory for measuring on-potential readings, but may require special procedures for determining instant-off and instant-disconnect potentials because the refresh rate of the meter may not allow it to display the precise value repeatedly.

Table 1: Equipment Commonly Used to Measure Coupons

Measurement	Equipment Used
On potential	- High-impedance voltmeter and reference electrode^(A) - Automated CP coupon reader and reference electrode^(A) - Data logger and/or chart recorder and reference electrode^(A)
Instant-off and instant-disconnect potentials	- High-impedance voltmeter and reference electrode^(A) - Automated CP coupon reader and reference electrode^(A) - Oscilloscope/chart recorder or wave-form-capable high-impedance voltmeter and reference electrode^(A) - Data logger and/or chart recorder and reference electrode^(A)
Depolarized potential	- High-impedance voltmeter and reference electrode^(A) - Automated CP coupon reader and reference electrode^(A) - Data logger and/or chart recorder and reference electrode^(A)
Free-corrosion potential	- High-impedance voltmeter and reference electrode^(A) - Automated CP coupon reader and reference electrode^(A) - Data logger and/or chart recorder and reference electrode^(A)
CP coupon current	- Zero-resistance ammeter - Multimeter with in-line current-measuring capability in the μA range - Automated CP coupon reader - High-impedance voltmeter and shunt
Current direction	- Zero-resistance ammeter - Multimeter with in-line current-measuring capability in the μA range - Automated CP coupon reader - High-impedance, high-resolution voltmeter and shunt
Corrosion rate	- Electrochemical impedance spectroscopy (EIS) equipment - Linear polarization-resistance (LPR) equipment - Electrical-resistance (ER) equipment

^(A) Reference electrode is either a stationary reference electrode or a portable reference electrode.

8.6 Minimizing the IR drop in a coupon-to-electrolyte potential depends on the placement of the reference electrode when CP current sources are operating. The reference electrode may be placed in different locations to confirm the accuracy of the measurements in order to reduce the error to acceptable levels. Reference electrode placement varies depending on specific site conditions. As shown in Figure 3, an on-potential reading with the reference electrode in the soil-access tube reduces IR-drop error. Typical reference electrode placements are:

- Portable reference electrode inside a soil-access tube (Location A),
- Portable reference electrode at grade next to the soil-access tube (Location B),
- Stationary reference electrode buried near the CP coupon (Location C),
- Stationary reference electrode buried inside the soil-access tube (Location D).

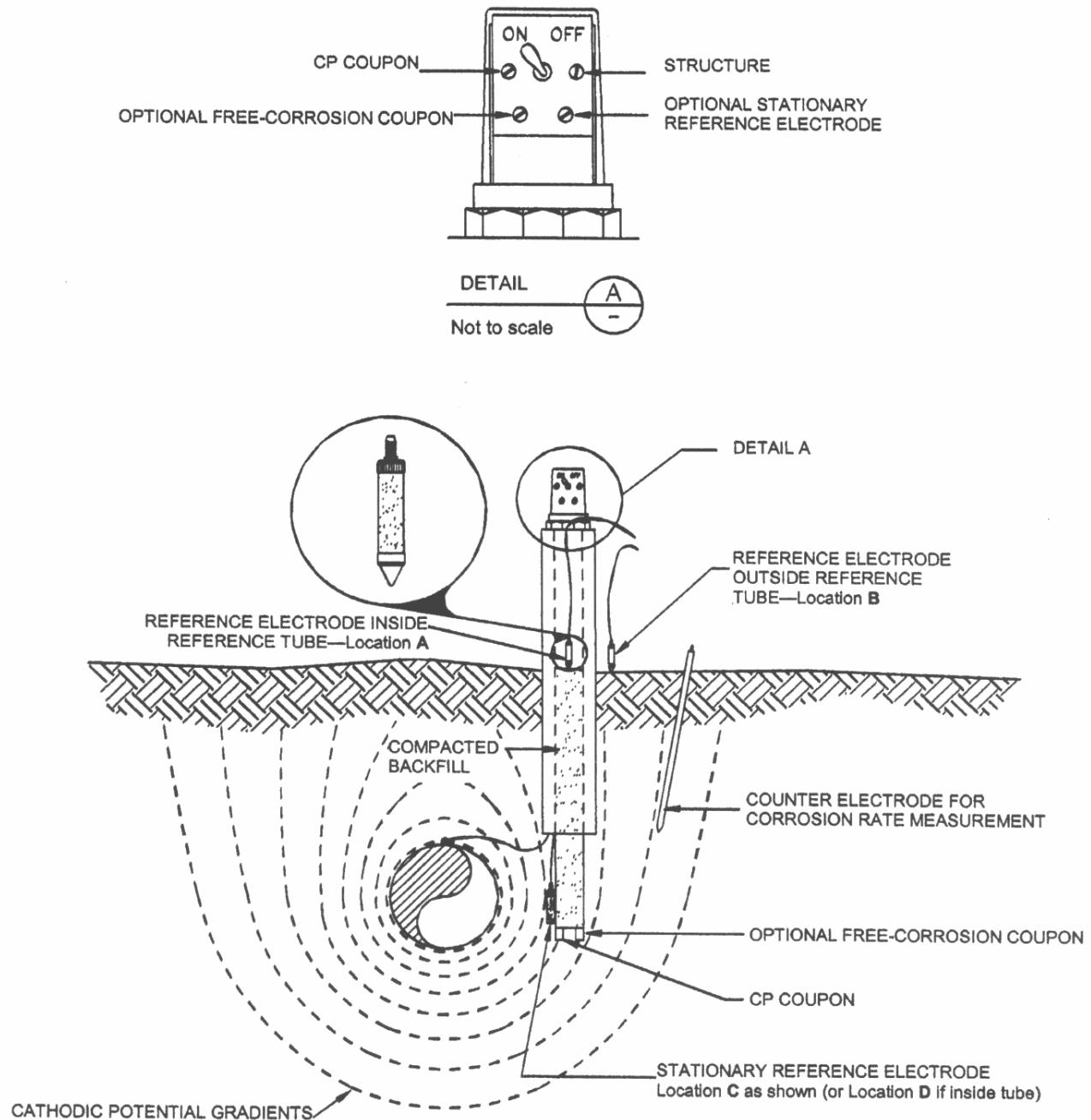


FIGURE 3: Possible Reference Electrode Placements

8.6.1 When two coupons are installed (as with a soil-access tube in Figure 3), both coupons should be installed parallel to the surface of the structure (or axis of the pipe). The orientation of the soil-access tube and coupons in Figure 3 is rotated 90° for clarity. When coupons are installed as actually shown in Figure 3, with the reference electrode located closer to the pipe than the coupons (Location C), and current is

applied to the structure, an IR drop in the electrolyte may occur between the coupon and the reference electrode. Depending on the magnitude of the IR drop, the measured value of the free-corrosion and instant-disconnect potentials of the coupon may be noticeably more positive than they actually are. As mentioned in Paragraph 8.2, this IR drop may be insignificant in many cases.

8.6.2 In soil-access tubes with high-resistivity backfill or in locations at which voids have formed and reliable readings cannot be obtained with the reference electrode placed inside the soil-access tube, the reference electrode should be placed outside the tube. CP coupon potential readings made outside the soil-access tube may contain an IR-drop error in the on potential, instant-disconnect potential, depolarized potential, and free-corrosion coupon potential caused by current through the electrolyte to the structure. When the CP system is interrupted during these measurements, IR drops may be reduced to insignificant levels, unless stray currents from other sources are present.

8.6.3 In locations where the resistivity of the soil in the access tube may be greater than 10,000 Ω -cm, or may become excessively dry, consideration shall be given to the resistance of the soil column inside the soil-access tube. The resistance of the soil column in the soil-access tube can be sufficiently high to result in erroneous (more positive) potentials when standard 10-M Ω impedance voltmeters are used. When watering is used to reduce the contact resistance of the reference electrode, the water should not be allowed to permeate to the coupon. This alters the electrochemical properties of the electrolyte and affects the potential of the coupon.

8.7 When the CP system is energized, and the CP coupon is initially connected to the structure, the coupon should show a net current pick-up, with the magnitude dependent on the surface area and free-corrosion potential of the coupon and polarized potential of the structure. When uncorroded steel is used as the material for a CP coupon for an existing structure, in some cases the initial free-corrosion potential of the CP coupon may be more negative than the polarized potential of the structure. In this situation, the CP coupon may discharge current to the

structure (act as an anode) when connected, even with CP current applied. In this case, the coupon should remain disconnected until the coupon-to-electrolyte free-corrosion potential has become more positive than the structure polarized potential. The length of time the coupon should remain disconnected varies with environmental conditions. A period of up to 12 months may be required in extreme cases. When a CP coupon is installed at the same time as the structure, this delay may not be necessary because of the similarity of the initial conditions of the coupon and bare surfaces of the structure.

8.7.1 Each wire in the test station should be properly identified and attached to the appropriate terminal. There must be no electrical interconnection between the coupon and the structure for this testing. A typical schematic for a two-coupon installation is shown in Figure 4. References to Terminals A through F throughout the remainder of Section 8 refer to Figure 4.

8.7.2 The potential between each wire in the test station and a reference electrode shall be measured and recorded. Depending on the type of test station, the following wires may be present:

- (a) Two wires attached to the CP coupon (marked "CP COUPON") (Terminals A and E)
- (b) Two wires attached to the pipeline (marked "PIPE") (Terminals B and F)
- (c) One wire attached to a second coupon that may remain isolated (marked "FREE-CORROSION COUPON") (Terminal C)
- (d) One wire attached to a stationary reference electrode (typically marked "REFERENCE") (Terminal D)

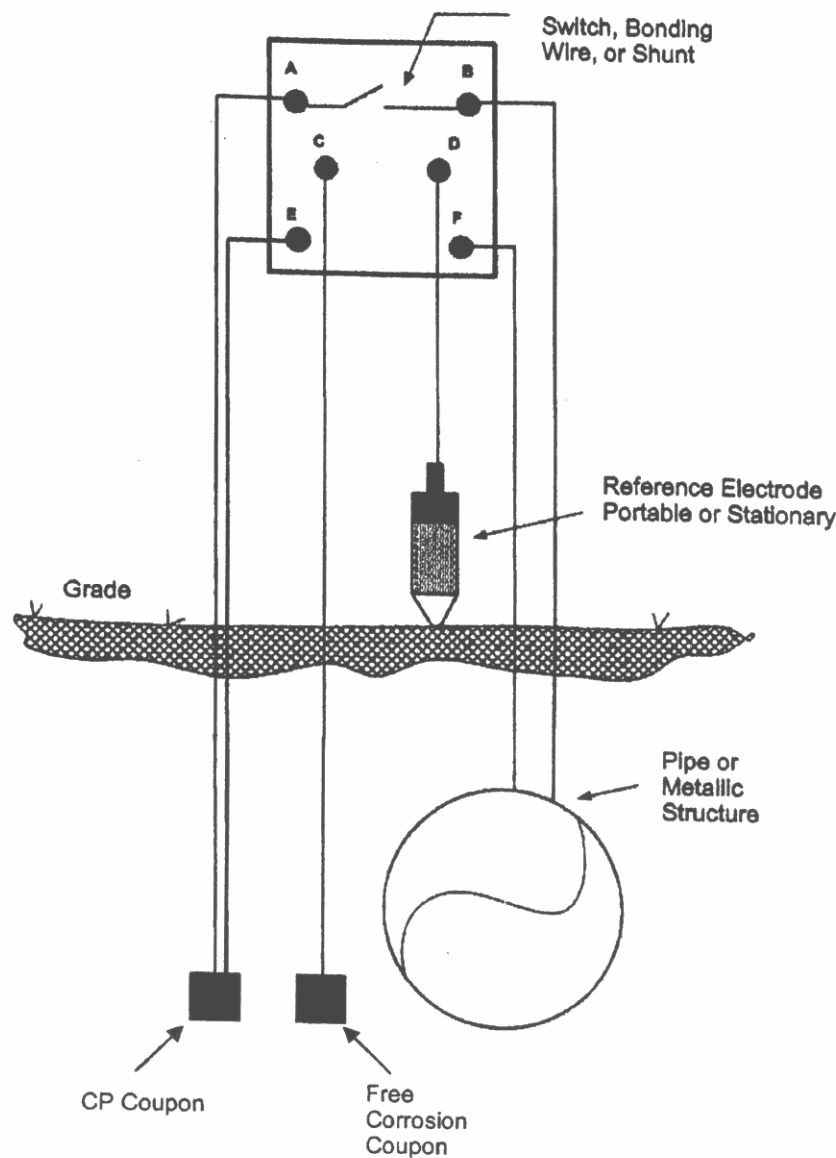


FIGURE 4: Typical Coupon Test Lead Measuring Schematic
(Coupons rotated 90° for clarity)

8.7.3 The coupon and/or structure-to-electrolyte potentials of primary interest should be measured with respect to a stationary reference electrode near the coupon or to a portable reference placed in contact with compacted soil inside the soil-access tube. Depending on the application, these potentials may also be measured with respect to a portable reference electrode placed at grade over the pipeline. This would allow the soil IR drop in potentials measured at grade to be calculated.

8.7.4 One of the wires attached to the pipeline shall be connected to one of the wires attached to the CP coupon. When a shunt is to be used to measure current, it should be installed in the circuit between the CP coupon and the structure. A switch or other technique by which the coupon circuit can be rapidly disconnected should also be installed.

8.8 Sufficient time shall be given for the coupon to polarize before final measurements are collected. In high-resistivity soils it may be necessary to wait for longer periods for a stable potential to be reached. Each of the following

potential measurements should be made with the reference electrode either in the reference tube or adjacent to the coupon, when practical. Measuring structure-to-electrolyte potentials with reference electrodes close to the structure or in a soil-access tube, may reduce, but not necessarily eliminate, the factors affecting structure-to-electrolyte potentials mentioned in Paragraph 3.3.

8.8.1 The on potential of the coupon and the pipe should be measured by connecting a voltmeter or automated CP coupon reader between the reference electrode (Terminal D) and the terminals for the coupon(s) and the pipe (Terminals E, C, and F, in turn). This on potential shall be recorded. This potential measurement is made with the CP current flowing and the CP coupon connected to the pipe.

8.8.1.1 The coupon-to-electrolyte on-potential measurement shall be taken with the CP system energized (on). The coupon-to-electrolyte on potential measures a mixed potential of both the coupon and the pipe local to the reference tube. This measurement can have IR-drop voltage errors from several sources: (1) primary impressed current CP (ICCP) system, (2) galvanic anodes, (3) long-line current, (4) stray current (either dynamic or static), (5) telluric current, and (6) foreign impressed current CP systems. The magnitude of these errors should be minimized by having the reference electrode positioned close (within 13 mm [0.50 in.] of the coupon.)

8.8.1.2 Two sets of potentials should be measured: one set with respect to the stationary reference electrode or to a portable reference electrode placed in contact with compacted soil inside the soil-access tube, and one set with respect to a portable reference electrode placed at grade over the pipeline. These two measurements may be used to calculate and consider the IR drop in the electrolyte to evaluate the potential criteria with the CP current applied.

8.8.1.3 When a current shunt is present, the current returning to the pipeline from the coupon shall be calculated from the IR drop measured across the shunt. When only a very small current exists, an electrometer may be necessary for this measurement.

8.8.2 The instant-disconnect potential of the coupon and the pipe should be measured and recorded using one of the following methods.

8.8.2.1 High-Impedance Digital Voltmeter/Data Logger: The high-impedance voltmeter shall be connected between the CP coupon (Terminal E or A) and the reference electrode (Terminal D). The CP coupon shall then be disconnected from the structure. The value displayed by the meter

quickly changes from the initial value displayed as the on potential.

8.8.2.1.1 Several measurements at a test point may be used to determine whether this method of determining instant-off or instant-disconnect potentials is valid at that point. Often, the first different potential to register on the meter display varies considerably, but the second one repeats to a suitable level of accuracy. As a rule-of-thumb, the instant-off or instant-disconnect potential is considered to be the second different potential to register visibly on the digital display after CP coupon interruption. The measured coupon-to-electrolyte potential using this technique may be conservative (more positive than actual) because of some amount of depolarization that may have occurred during this process. Site-specific testing using an alternate test method such as one that takes faster consecutive readings should be conducted to verify that this rule-of-thumb technique gives acceptable results.

8.8.2.2 Automated CP Coupon Reader: When an automated CP coupon reader is used, it should be installed and operated in accordance with the manufacturer's recommendations. The automated CP coupon reader shall be connected to the appropriate terminal lugs on the CP coupon test station test head. The instant-disconnect potential shall be measured with the appropriate time delay for the instrument.

8.8.2.3 Oscilloscope/Chart Recorder or Wave-Print-Capable High-Impedance Voltmeter: The oscilloscope or wave-print-capable high-impedance voltmeter shall be connected between the CP coupon (Terminal E or A) and the reference electrode (Terminal D). The CP coupon shall be disconnected from the structure while the resulting waveform is recorded. The instant-disconnect potential shall be established from the waveform as the potential from which the waveform deviates from linearity.

8.8.2.4 Nonprogrammable digital voltmeters and excessively damped analog voltmeters may have difficulty accurately capturing the instant-off or instant-disconnect potential value.

8.8.3 When the instant-disconnect potential of the coupon is at least as negative as the polarized potential criterion, that criterion for CP is satisfied.

8.8.3.1 The coupon-to-electrolyte instant-disconnect potential measurement should be made with the coupon interrupted from the pipe but with the CP system energized. The coupon should be disconnected from the pipe to isolate it

from all IR-drop voltage errors associated with current pick-up or discharge on the coupon surface. The current pick-up and discharge comes from the following sources: (1) primary CP system, (2) hot-spot anodes, (3) long-line current, (4) stray current (either dynamic or static), (5) telluric current, and (6) foreign CP systems. Current from these sources is not interrupted. To reduce these errors there should be a short distance between the reference tube and the coupon, and the coupon size should be relatively small. The coupon-to-electrolyte instant-disconnect potential is an accepted method for determining the coupon polarized potential when the IR-drop errors are small.

8.9 In order to evaluate the polarization or depolarization CP criterion in accordance with NACE Standard RP0169,¹ the CP coupon must remain disconnected from the structure following measurement of the instant-disconnect potential. The time the CP coupon remains disconnected may range from a few minutes to a few days or weeks, depending on the conditions surrounding the CP coupon. The depolarizing CP coupon potential versus time should be plotted, either continuously or at frequent intervals, to assess that the change in potential is a result of polarization decay rather than changes in environmental conditions.

8.9.1 When the CP coupon depolarizes at least as much as the specified polarization criterion, this CP criterion is satisfied. Application of the polarization decay criterion in accordance with NACE Standard RP0169¹ may be determined without observing a completely depolarized potential. The polarization criterion may also be satisfied by the formation of polarization during the commissioning process.

8.9.2 The surface condition of the free-corrosion coupon may or may not be similar to that of the structure. With time, the corrosion potential of the free-corrosion coupon may change as a result of the formation of corrosion films on its surface, while products of cathodic reactions may develop on the surface of the protected structure. Therefore, the difference between the instant-disconnect potential of the CP coupon and the potential of the free-corrosion coupon should not be used as the basis for assessing compliance with a polarization criterion unless it can be demonstrated that the potential of the free-corrosion coupon is similar to the depolarized potential of the structure.

8.10 The magnitude and direction of the CP coupon current should be measured using one of the following methods:

8.10.1 Galvanometer, Zero-Resistance Ammeter, or Multimeter: The zero-resistance ammeter, galvanometer, or multimeter (using the current measurement setting) shall be connected between the CP coupon (Terminal A) and the structure (Terminal B).

The switch, bonding wire, or shunt shall be opened, causing the current to flow through the meter.

8.10.2 Automated Coupon Reader: The automated coupon reader shall be connected to the appropriate terminals and operated in accordance with the manufacturer's instructions. The magnitude and direction of current should be measured and recorded. The proper operation and results of an automated coupon reader must be verified prior to use.

8.10.3 High-Impedance Digital Voltmeter and Shunt: With a shunt of known resistance (generally less than 10% of the overall circuit resistance) installed in series between the CP coupon (Terminal A) and the structure (Terminal B), the high-impedance digital voltmeter shall be connected across the terminals on the shunt. The IR drop shall then be measured. The IR drop shall then be converted to current, using Ohm's Law, by dividing the measured IR drop by the shunt resistance. The circuit shall be allowed to reach equilibrium in order to increase the accuracy of the measured value. A shunt resistance that allows voltages to be measured within the range of the meter shall be used.

8.10.4 Direction of CP Coupon Current: The CP coupon current direction shall be recorded as the electrolytic or positive ionic current flow, which is opposite to electron flow. The direction of current flow shall be determined from the polarity of the instrument's connection to the terminals for the CP coupon and structure (Terminals A and B respectively) and the polarity of the resulting measured value. Current direction shall be considered to be from the positive (+) terminal to the negative (-) terminal of the instrument. For example, a positive IR drop across a shunt with the positive meter voltage terminal connected to the CP coupon wire indicates current pick-up on the CP coupon. A negative IR drop with the same connection indicates current discharge from the CP coupon. This test method is shown in NACE Standard TM0497.²

8.11 CP coupons sample the effectiveness of a CP system at a particular location and are not actually measuring the structure itself. Other factors, including the following, must be considered for proper interpretation of CP coupon data:

- Types of CP sources present;
- Changes in the CP system along the length of the structure;
- Type and location of directly connected galvanic anodes;
- Location of the CP coupon relative to the CP source and the structure; and
- Stray currents, either static or dynamic, near the structure.

8.12 In dry soil conditions, the resistance of the soil column in the soil-access tube can be sufficiently high to result in erroneous (more positive) potentials when standard 10-MΩ impedance voltmeters are used. In such cases, potential

measurements taken with variable-input impedance voltmeters or similar techniques should be used to determine whether the resistance in the soil-access tube column has a significant effect on the structure- or coupon-to-electrolyte potentials. Significant effects shall be considered when the true potential of the structure or coupon is determined.

8.13 When coupons are used to monitor CP in stray current areas, disconnecting the coupon from the structure also disconnects it from the stray current. Instant-disconnect coupon-to-electrolyte potentials for a coupon connected to a structure under the influence of stray current may not be the same as the dynamic coupon- or structure-to-electrolyte potential caused by the stray current. In many cases the magnitude and direction of current to or from the coupon while connected to the structure is a more reliable indication of the effect of stray current on the structure.

8.14 Corrosion rates of a coupon may be measured using one of the following techniques:

8.14.1 Electrochemical Impedance Spectroscopy (EIS)

8.14.1.1 EIS is an accurate method to measure the instantaneous general corrosion rate of a coupon. Commercially available field equipment is portable, but considerable operator training is involved in its use. A small AC potential ($\sim \pm 10$ mV) shall be impressed over a range of frequencies from a simple, temporary counter electrode (anode) onto the native coupon, the potential of which shall be monitored with a portable or stationary reference electrode. The instrument software analyzes the coupon response and, when combined with physical coupon parameters entered into the equipment, can determine the coupon free-corrosion potential, general corrosion rate, polarization resistance, and other data selected by the operator.

8.14.1.2 Additionally, the instrument can measure the polarized potential of the CP coupon, hold the CP coupon potential at its polarized potential, and then measure the instantaneous corrosion rate of the CP coupon at its particular polarized potential.

8.14.2 Linear Polarization Resistance (LPR)

8.14.2.1 LPR is another method of measuring the instantaneous general corrosion rate of a native coupon. Portable and self-contained field equipment is commercially available for this type of measurement. A small range of DC potentials ($\sim \pm 10$ mV) shall be impressed from a simple, temporary counter electrode (anode) onto the native coupon, the potential of which shall be monitored with a portable or stationary reference electrode. The instrument software analyzes the DC potential and current and, when combined with physical coupon parameters, can determine the coupon native potential, general corrosion rate, and polarization resistance.

8.14.3 Electrical Resistance (ER)

8.14.3.1 ER is a method to measure the cumulative metal loss from a coupon. Portable and self-contained field equipment is commercially available to take this type of measurement. Because of the very low electrical resistance involved, very sensitive monitoring circuits, also known as ER probes, shall be used to measure the change in specially designed coupons. The instrument measures the change of the resistance of the coupon exposed to the environment compared to the resistance of a protected (coated) reference element. Software or manual calculations shall be used to calculate the average corrosion rate between measurements.

Section 9: Maintenance and Record Keeping

9.1 Introduction

9.1.1 This section describes maintenance and corrosion-control records relating to the installation, operation, maintenance, and monitoring of CP coupons.

9.2 Maintenance

9.2.1 Each conductor should be clearly labeled in a permanent manner. Markings should be inspected periodically to ensure that the labels are clear.

9.2.2 Electrolyte conditions in the soil-access tube and around coupons should be kept as similar as possible

to the environment surrounding the structure. Soil-access tube covers should remain in place and should not allow water or debris to contaminate the soil-access tube.

9.2.3 The continuity of the structure connection to the CP coupon, as well as the low resistance of the connection to the coupon, should be maintained. A high-resistance connection from the structure to the coupon reduces the CP current protecting the coupon, and the coupon exhibits a lower level of protection than actually being afforded the structure.

9.2.4 The accuracy of any permanently buried stationary reference electrode should be verified

periodically. Contamination of the electrolyte at the surface of the coupon, as a result of leakage from the stationary reference electrode, can result in inaccurate readings. Contamination of the electrolyte in a stationary reference electrode may also cause measurement errors.

9.2.5 Free-corroding coupons may require replacement periodically when conditions on or near the surface of the coupon, such as severe pitting and formation of layers of corrosion products, do not represent those of the structure.

9.2.6 Coupons used for weight-loss (gravimetric) data must be installed and removed with care. Once removed, the coupons should not be reused without proper preparation.

9.3 Record keeping

9.3.1 In accordance with NACE Standard RP0169,¹ records of surveys, inspections, and tests should be maintained to demonstrate that applicable criteria for corrosion control and CP have been satisfied.

9.3.2 Records sufficient to demonstrate the evaluation of the need for, and the effectiveness of, external corrosion-control measures should be maintained as long as the facility involved remains in service. Other related external corrosion-control records should be retained for such a period as satisfies individual company needs.

9.3.3 Records of the installation, removal, and any maintenance of the coupons should be maintained. Detailed drawings of the coupon location relative to the structure, connections, conductors, and soil-access tubes should be maintained. The structure to which the coupon is attached should be identified.

9.3.4 The coupon may be identified with a serial number. In addition, other information about the

coupon, including the coupon material, the coupon surface area, and the initial weight of the coupon (for gravimetric analysis), may be recorded prior to installation. When the coupon is installed, the installation date should be recorded.

9.3.5 Information about the structure, including the type of pipe, and year of installation, if known, the type of surface preparation and coating (if any) on the pipe, the general condition of the coating and size of any observed coating anomalies, general soil type, and relative moisture level (dry, saturated, etc.) should be recorded.

9.3.6 Several types of potential readings, including on potentials, instant-disconnect potentials, depolarized potentials, and native potentials may be measured and recorded. The type of potential reading should be recorded, along with the magnitude and polarity of the reading, the date and time of the reading, the type and location of the reference electrode, and the type and location of CP coupon. The person who took the reading and the equipment used should be identified.

9.3.7 The magnitude and direction of the CP current in the conductor between the structure and the coupon should be recorded. The person who took the reading and the equipment used should be identified.

9.3.8 When installations allow, the instantaneous corrosion rate should be recorded. The person who took the reading and the equipment used should be identified.

9.3.9 In addition, other information such as the procedure used to take each reading and comments (e.g., operating conditions, weather conditions, changes to CP settings), structure potentials, CP source outputs, and environmental data such as pH, resistivity, and soil/water analysis may be recorded.

References

1. NACE Standard RP0169 (latest revision), "Control of External Corrosion on Underground or Submerged Metallic Piping Systems" (Houston, TX: NACE).
2. NACE Standard TM0497 (latest revision), "Measurement Techniques Related to Criteria for CP on Underground or Submerged Metallic Piping Systems" (Houston, TX: NACE).
3. NACE Standard RP0285 (latest revision), "Corrosion Control of Underground Storage Tanks by Cathodic Protection" (Houston, TX: NACE).
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⁽²⁾ American Gas Association (AGA), 400 N Capitol Street NW, Washington, DC 20001

⁽³⁾ Gas Technology Institute (GTI) (formerly the Gas Research Institute [GRI]), 1700 South Mount Prospect Road, Des Plaines, IL 60018-1804.

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⁽⁶⁾ National Institute of Standards Technology (NIST) (formerly National Bureau of Standards [NBS]), 100 Bureau Drive, Stop 3460, Gaithersburg, MD 20899-3460.

⁽⁷⁾ Society of Petroleum Engineers (SPE), 222 Palisades Creek Dr., Richardson, TX 75080.

⁽⁸⁾ European Gas Research Group (GERG), Avenue Palmerston 4 - 1000 Brussels, Belgium.

⁽⁹⁾ 3R International, Sorterargatan 1, 162 50 Vällingby, Sweden.

⁽¹⁰⁾ CEOCOR, c/o CIBE, rue aux laines, 70, B-1000 Brussels, Belgium.

Appendix A: Underground Storage Tanks (USTs)

General

The use of coupons on USTs requires some special considerations. The previous sections of this standard apply, but with the following exceptions and additions.

NACE Standard TM0497² includes some of the methods used to satisfy NACE Standard RP0285.³

Types of Measurements

Grade Tank-to-Electrolyte Potential

A tank-to-electrolyte potential measurement performed with the reference electrode (typically CSE) located at grade level and ideally located centered over the tank. The measurement is either an on potential or an instant-off potential measurement.

Reference Tube Tank-to-Electrolyte Potential

A tank-to-electrolyte potential measurement performed with the reference electrode (typically CSE) located within a reference tube that extends down toward the tank surface. For the coupon test sites, the coupon reference tube is used. The measurement is either an on potential or an instant-off potential. The closer the tube extends to the top of the tank, the closer this reading represents the local potential of the tank directly below the reference electrode placement.

Installation for USTs

CP coupons may be installed by a number of different methods. One method is to install the coupon during construction of the UST. Coupons may be installed on an existing structure by excavation, auguring, vacuum

excavation, or by digging a hole to the intended depth. When an electrical connection to the existing tank is not available, excavation must be done to the top of the tank to make an electrical connection.

The backfill should be excavated to the top of the tank and an electrical wire shall be connected to one of the lifting lugs or other appropriate connection point on the tank using thermite welding or other types of low-resistance connections. The electrical wire should be brought up to a test station at grade through a nonmetallic conduit. Another hole should be augured or excavated next to the tank and the coupon placed near the bottom of the tank. The coupon lead wires shall also be brought up to the at-grade test station. A stationary reference electrode may also be installed with the coupon.

Selection of CP Coupon Locations for USTs

On tanks with a high-quality coating with low conductivity, only one coupon system may be necessary. In cases in which the coating is of lesser quality or has higher conductance, additional coupons should be used to represent the additional holidays anticipated in the coating.

Many times, coupons are installed in the “worst-case” position to determine whether the tank is protected. When the anodes are connected to the tank heads, the coupon should be installed near the longitudinal center of the tank, near the bottom of the excavation. Coupons installed closer to the anodes have higher CP current density than the majority of the UST. Variations in CP current density, electrolyte and coating condition, type and location of anodes, potential stray currents, and the proximity of other underground metallic structures must be considered when the number of coupons and where they should be placed are determined.

Appendix B: Aboveground Storage Tanks (ASTs)

General

The use of coupons on an AST requires some special considerations. The previous sections of this standard apply, but with the following exceptions and additions.

The environment beneath ASTs can vary considerably. It is not uncommon for tank pads to have a high resistivity, especially in relatively dry climates. In some cases, anodes are installed close to the tank bottom. These situations can create high levels of IR drop in the electrolyte, which may be difficult to measure or consider with typical under-tank or tank rim potential measurement techniques. This is especially true when tanks are not electrically isolated from

other structures, such as neighboring tanks, buried piping, and electrical grounding systems, and/or when numerous CP systems make interrupting current sources impractical. CP coupon systems may be used in such cases to determine the IR drop in the electrolyte and the tank-to-electrolyte polarized potential. As an alternative to CP coupons, ER probes may be used to measure corrosion rates of tank bottoms in high-resistivity tank pads and/or nonaqueous corrosion (oxidation) under heated tanks or in other conditions in which tank-to-electrolyte potential measurements or the use of CP coupons may not be appropriate.

Location

The locations of CP coupons should be carefully selected if they are to provide meaningful data. They are most conveniently installed when a new floor is being placed in a tank, or during the construction of a new tank. Typically, the most effective use of coupons is achieved when they are installed in the tank pad material close to the tank floor so that the local environment around the coupon is similar to that of the tank bottom. For tanks on ringwall foundations with distributed or deepwell CP systems, at least two CP coupons should be used, one located near the center of the tank and one just inside the ringwall. On large-diameter tanks with or without ringwalls, additional coupons may be located at mid-radius locations and/or 1 to 3 m (3 to 10 ft) in from the rim. For tanks with under-tank anodes, IR drop is at a minimum at a point midway between anodes. One or more CP coupons should be installed in these locations. For tanks in which temperature, moisture, oxygen content, or the chemistry of the tank pad may vary either seasonally or at different locations under the tank, these variations should be considered when the number and location of coupons that should be used are determined.

The size, location, and orientation of a CP coupon should be designed such that it receives the same current density as the tank bottom in that area and does not shield cathodic current from the tank bottom. Coupons with an approximate area of 1,000 mm² (1.5 in.²) may be located as close as 50 mm (2 in.) below a new tank floor. Care should be taken to make sure the coupon does not come into direct physical contact with the tank bottom.

Coupons may be installed under existing ASTs by directional drilling or other techniques. This may result in coupons being located in a different electrolyte (e.g., wetter,

different soil chemistry and oxygen content, native soil or structural fill rather than sand, etc.) and at a greater distance from the tank bottom than those installed close to a new tank bottom. This generally results in different current densities and levels of polarization than the tank bottom itself. These data may still be beneficial in determining the effectiveness of CP on the tank bottom, but requires additional interpretation of the data. For further information see "Using Coupons to Monitor the Effectiveness of Tank Bottom Cathodic Protection."⁴

All coupons should be individually bonded to the structure at a test station (by means of a shunt, if desired) so they may be disconnected when measurements are being made. Coupons should be placed in close proximity to a reference electrode, preferably within 25 mm (1.0 in.), to minimize IR-drop error when measuring coupon-to-electrolyte potential. Available reference-electrode coupon configurations suitable for AST applications include:

- (1) The coupon and reference electrode are separate stand-alone devices;
- (2) The coupon is attached to the reference electrode by a short lead wire; and
- (3) The coupon is attached directly to the body of the reference electrode.

ER probes and other devices may be used to monitor corrosion rates instead of using coupons to monitor CP status. In such cases, consideration must be given to variations in electrolyte conditions between the probe location and the tank bottom. ER probes should generally be installed in similar locations as described above for CP coupons. Corrosion-rate measurements may be made without disconnecting the probe from the structure.

Appendix C: Reinforced Concrete Structures

Coupon Usage in Reinforced Concrete

Coupons used in reinforced-concrete applications are commonly termed "rebar probes." As is the case for underground applications, these rebar probes are used to obtain more accurate potential measurements, predict current demand, or measure the corrosion rate by LPR. A typical rebar probe is a 50-mm (2-in.) length of #4 rebar with one or two wires attached. When installed, the probe

should be positioned in the center of a square formed by the rebar mesh. In order to obtain meaningful data, probes must be placed the same distance below the surface (depth of cover) as the outermost rebar mesh. A stationary reference electrode should be placed directly above or below the probe and separated from it by a distance of about 25 mm (1.0 in.). Refer to Figure C1 for additional details.

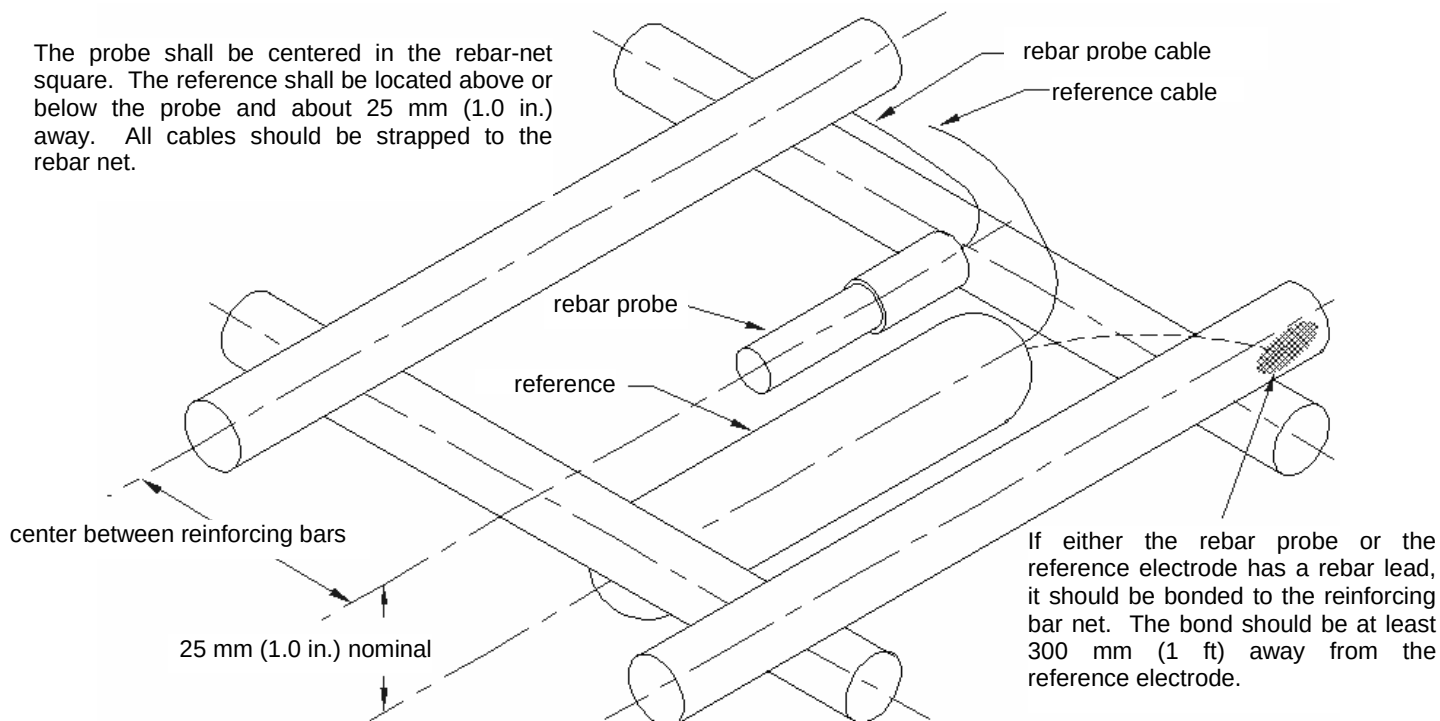


FIGURE C1: Rebar Probe Installation

When rebar probes are retrofitted to an existing structure, the corrosion potential, corrosion rate, and current demand of the probes are partly determined by the patching cement used for installation. This material is not necessarily the same as that in contact with the reinforcing bars embedded in the balance of the structure. This factor shall be considered when data from these probes are interpreted. Note: Patching cements with high electrical resistance, such as polymer-based grouts, must not be used for installing rebar probes.

Potential Measurements.

When a probe is being used to make accurate potential measurements, the probe's lead wire must be bonded to a lead wire coming from a rebar with the same depth of cover as the probe. The bonding must be done at an accessible test station and the lead wire from the reference electrode must also come to the same test station. The rebar lead is usually joined to the rebar by brazing and this joint should be located at least 300 mm (1 ft) away from the probe location so as not to affect the potential measurements (see Figure C1).

Potential measurements in concrete must be made with a high-impedance voltmeter in order to minimize measurement circuit IR-drop errors. An input impedance of 100 MΩ is considered the minimum for concrete measurements with 200 MΩ being preferred.

Reinforced concrete structures can have an IR-drop field pattern created by macro cells. Therefore, it is advisable to take some instant-off potential measurements, using techniques described throughout this standard, in order to determine whether IR-drop error is significant at the probe location. Significant IR-drop errors must be considered when potential measurements made at the location of the error are interpreted.

Corrosion-Rate Measurements

By using rebar probes periodically to monitor the corrosion rate by LPR measurements, it is possible to determine when the corrosiveness of the concrete at the depth of the rebar probe has increased. Possible causes of an increase in corrosiveness of concrete include ingress of chlorides, failure of surface sealant, or loss of efficacy of inhibitive additives. When a rebar probe is used to measure corrosion rate, it must not be connected to the rebar net. This is to ensure that the corrosion rate is determined solely by the surrounding concrete environment and is not influenced by macro cells. During LPR measurements, the rebar probe is the working electrode and the rebar net is the counter electrode. The reference electrode is positioned as shown in Figure C1.

Corrosion rates measured by this technique may not be numerically accurate because of uncertainty in the value of the polarization constant used for data reduction. Because the purpose of these measurements is to detect a change in corrosion rate over an extended time interval, the change is

apparent as long as the same values are used for the constants during all measurements.

Current-Demand Measurements

Rebar probes may be used to estimate the amount of current required to protect a reinforced concrete structure cathodically. In this application, the same relative placement of rebar probe, reference electrode, and rebar net used in potential measurements is used (Figure C1). When a rebar probe is retrofitted to an existing structure, it

should be located in the most anodic site as determined by surface potential mapping. Provision must be made to measure the current flowing through one of the probe lead wires. The other probe wire is used to measure the potential between the probe and the reference electrode.

Current is applied to the probe to shift its potential to the desired protected potential and the current required to do so is measured. This measured current is converted to current density on the probe, which may then be used to calculate the amount of current required for the entire structure.

Appendix D: Coupon IR-Drop Calculation Procedure

The following test procedure may be used to determine the specific amount of IR-drop in a coupon instant-disconnect potential reading. This is useful in cases in which the coupon instant-off and instant-disconnect potentials are not similar or for determining the IR-drop value that should be considered in future coupon instant-disconnect potential-to-electrolyte measurements.

The following potential-to-earth measurements should be taken in the soil near the coupon⁽¹¹⁾:

1. Structure-to- electrolyte with current applied and coupon connected (V_{S-a-c})
2. Structure-to-electrolyte with current applied and coupon disconnected (V_{S-a-d})
3. Structure-to-electrolyte with current interrupted and coupon connected (V_{S-i-c})
4. Structure-to-electrolyte with current interrupted and coupon disconnected (V_{S-i-d})
5. Coupon-to-electrolyte with current applied and coupon connected (V_{C-a-c})
6. Coupon-to-electrolyte with current applied and coupon disconnected (V_{C-a-d})

7. Coupon-to-electrolyte with current interrupted and coupon connected (V_{C-i-c})

8. Coupon-to-electrolyte with current interrupted and coupon disconnected (V_{C-i-d})

V_{S-i-d} represents the instant-off potential of the protected structure. V_{C-i-d} represents the coupon-to-electrolyte potential that simulates V_{S-i-d} (it is not always convenient to interrupt the current to the structure). The measurement that is most convenient is V_{C-a-d} . The difference between V_{C-a-d} and V_{C-i-d} is the IR drop in the coupon-to-electrolyte potential when current is applied to the structure. This is called the "coupon IR drop" (V_{C-IR}).

The coupon IR-drop (V_{C-IR}) is added to the coupon-to-electrolyte potential with current applied and coupon disconnected (V_{C-a-d}) to determine the IR-drop-free value of the coupon-to-electrolyte potential ($V_{C-IR \text{ FREE}}$). V_{C-IR} should remain stable as long as soil conditions and current remain stable and may be used for future measurements until conditions change. Such changes could be the result of changes in seasons, rainfall, current from known or unknown sources, adjustments by potential-controlled rectifiers, etc.

⁽¹¹⁾ The subscripts used in Steps 1 through 8 represent, in order:

1. structure or coupon
2. applied or interrupted
3. connected or disconnected

