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TECHNICAL NOTE

ENGINEERING - DESIGN SD-2003-3

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CATHODIC PROTECTION

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INTRODUCTION

This Technical Note replaces Design SD-2003-2, dated July 7, 2003. Voltage Polarity was added under the Maintenance section of this Technical Note.

The purpose of this Technical Note is to provide design and maintenance information for sacrificial anode cathodic protection systems. Biological corrosion, stray current corrosion, and the use of impressed electrical current are beyond the scope of this Technical Note. The purpose of cathodic protection is to protect metal (pipes, etc.) from rapid deterioration by galvanic corrosion (rusting, etc.) due to contact with low electrical resistance soil and water. For additional information, refer to Peabody's Control of Pipeline Corrosion, A. W. Peabody, 2nd Edition, 2001.

GENERAL DISCUSSION

Corrosion of metals at near-ambient (normal) temperatures occurs in water containing environments and is an electrochemical process involving a complete electrical circuit. Within the circuit, one metal (or location on the metal) corrodes (anode) and protects the other (cathode) metal (or location on the metal). This process involves four essential elements to create the corrosion cell or battery:

1. There must be corroding metal (anode). The anode produces the electrical negative (-) pole of the battery.
2. There must be protected metal (cathode). The cathode produces the electrical positive (+) pole of the battery.
3. There must be a metallic path electrically connecting the anode and cathode. This could be through the object itself, or (as in a cathodic protection system) an electrical wire may be installed to connect the anode to the metal object being protected (cathode).
4. The anode and cathode must be immersed in an electrically conductive electrolyte such as acid, ground water, or moist soil.

In a similar way, the negative (-) pole (anode) of a car battery is metalically connected through the car electrical wiring system to the battery plus (+) pole (cathode), and both poles are immersed in the battery acid (electrolyte) within the battery. The anode corrodes inside the battery and electrical current flows when the circuit is complete.

The kind of metal chosen for the anode causes it to become the anode and corrode slowly while protecting the pipe or other metal object. The differing vigor with which different metals tend to dissolve in electrolytes provides the electrical driving force for galvanic corrosion and gives rise to the **galvanic series**. The galvanic series is a listing of metals in decreasing order of their corrosion when any two (or more) of them are the electrodes involved in galvanic corrosion. A metal higher on the list will be the anode to be corroded and thereby protect a metal lower on the list. Longer anode life is achieved by selecting anode metals only slightly above the metal to be protected. Aluminum, cadmium, or zinc are normally used to protect (coating or anodes) iron or steel, and magnesium is used to protect zinc coated (galvanized) iron or steel. In the latter situation, the magnesium will corrode and protect the zinc which also protects the iron or steel. Commercially available metals are rated in a galvanic series in **Table 1**.

Table 1 – Galvanic series of metals and alloys (Note – metals grouped together show little tendency to corrode galvanically when connected)

Corroded end of Table 1 (anode or “least noble”)	Typical millivolts in neutral soil and water vs. Cu/CuSO ₄
Magnesium (High Potential Alloy)	-1750 to -1770
Magnesium alloys (H-1) (6% Al, 3% Zn, 0.2% Mn)	-1500 to -1600
Zinc	-1100
Aluminum 2S (5% Zinc)	-1050
Cadmium	-800 (estimate)
Aluminum 17ST (commercially pure aluminum)	-800
Mild Steel	(rusty or in concrete) -200 to -800 (clean)
Cast Iron (not graphitized)	-500
Chromium-iron (active)	
Ni-Resist	
18-8 Chromium-nickel-iron (active)	
18-8-3 Chromium-nickel-molybdenum-iron (active)	
Lead-tin solders	
Lead	-500
Tin	
Nickel (active)	
Inconel (active)	
Hastelloy C (active)	
Brass	-200
Copper	-200
Bronzes	-200
Copper-nickel alloys	
Monel	
High Silicon Cast Iron, Mill Scale on Steel	-200
Silver solder	-200 (estimate)
Nickel (passive)	
Inconel (passive)	
Chromium-iron (passive)	
18-8 Chromium-nickel-iron	
18-8-3 Chromium-nickel-molybdenum-iron (passive)	0 to -100 (est.)
Hastelloy C (passive)	
Silver	
Platinum	0 to -100
Carbon, Graphite, Coke	+300
Gold	

Protected end of Table 1 (cathode or “most noble”)

Note that metals are presented in groups in Table 1. Metals grouped together have low voltage when connected together and have little tendency for galvanic corrosion. Therefore, in general, they can be used in direct contact with each other without damaging effects. When electrically connected, metals from different groupings create a significant voltage, and the amount of voltage increases as indicated by increased separation between the metals listed in Table 1. In Table 1, metals that are most likely to corrode and act as an anode are listed above metals that are more likely to be protected and act as a cathode. Table 1 is only a guide; results may be affected by other factors such as how clean (amount of surface films, etc.) or rusted the metals are compared to other metals or areas of the same metal.

Protection of Aluminum. Cathodic protection of aluminum pipe, etc. is a special problem. Aluminum is sensitive to alkali (high pH). If too much cathodic protection current is applied, alkalinity at the aluminum surface may break down normal passive protection films on the aluminum surface and promote rather than prevent corrosion. This effect, sometimes called “cathodic corrosion,” does not occur on iron and steel. Precise upper limits for cathodic protection of aluminum have not been established. Experience has shown low-level cathodic protection of aluminum can be beneficial. Guidelines suggest maintaining cathodic protection voltages for protecting aluminum at approximately -1000 to -1100 millivolt (mV) (note: **1,000 mV = 1 volt**). Because of this limitation, cathodic protection of aluminum must be done with more care than with most other metals (see Maintenance below and Peabody’s Control of Pipeline Corrosion, second edition, 2001, Chapter 4).

Soil Electrical Resistivity. Prime factors that affect soil electrical resistivity and the severity and acceleration of corrosion of metals in soil are **moisture content, salts (particularly sulfide and chloride) content, acid content, and aeration**. Each factor has an effect on soil electrical resistivity. Soil resistivity is especially indicative of soil corrosivity in alkaline soils and is useful as a guide in acid soils. Most South Dakota soils are neutral to alkaline. Slightly acid South Dakota soils may be found in fertilized surface soils or in some types of shale.

Higher soil resistivity results in lower corrosion rates. The commonly used unit of measure of soil and water resistivity is the ohm-centimeter (**ohm-cm**), which is the resistance in ohms of a one centimeter cube of the material in question measured between two opposite, parallel faces.

Soil moisture content (and resistivity) may change radically with seasons. Moisture variation, for example, can cause soil resistivity variation from 2,500 when wet to 10,000 ohm-cm when extremely dry. The effect of the soil-water mixture on the corrosion rate is also dependent on the temperature, the dissolved oxygen concentration, and the nature and concentration of the various dissolved salts which may or may not tend to make the water scale forming. The interrelationship of these factors with respect to corrosion is not fully understood. Therefore, firm and specific criteria for evaluating the corrosion property of water on the basis of its chemical characteristics is not available. Best practices generally involve the use of electrical resistance measurements as discussed below.

Polarization. When corrosion occurs, many chemical reactions occur at the electrodes. These reactions may “plate” other reaction products on the electrodes; for example, hydrogen ions may be converted to uncharged hydrogen or calcium ions which ultimately may be converted to calcium carbonate scale on the cathode (metal being protected). Such deposits often act to increase the electrical resistance in the electrical circuit, with the result that the flow of electrical current and corrosion rate are reduced. Another effect of this “plating” in an unprotected pipeline is that if a new section of matching metal pipe is added to the old pipeline (but not electrically isolated from the old pipe), future corrosion will often be concentrated in the new pipe because resistance is lower there. Scrapes and scuffs during repairs of old pipe will also concentrate corrosion at those locations.

Opposing chemical reactions also occur and tend to depolarize the system. For instance, oxygen in the electrolyte may react with hydrogen to form water. This reverse reaction tends to negate the beneficial “plating” effects of polarization. The effects of these processes must be managed by careful maintenance (see below).

Design Guidance to Minimize Galvanic Corrosion. Galvanic corrosion can be minimized in design as follows:

- a) Where metals will be in electrical contact, choose metals from groups as close together as possible in the galvanic series (Table 1).
- b) Electrically insulate from each other metals from different groups (Table 1). If complete insulation cannot be achieved, paint or plastic coating the contact area will reduce the corrosion problem.
- c) If dissimilar metals well apart in the series (Table 1) must be in contact, avoid joining them using threaded connections because the threads are likely to deteriorate excessively. In this situation, brazed or thermal joints are preferred, using a brazing alloy located lower (more cathodic) in Table 1, then at least one of the metals to be joined. (This principle is used to join copper wires to steel pipe in cathodic protection systems.)
- d) For structures, avoid using metal combinations where the surface area of the more anodic (higher in Table 1) metal is relatively small compared with the area of the more cathodic (lower in Table 1) metal.
- e) Where dissimilar metals are in electrical contact, avoid painting the more anodic (higher in Table 1) metal without also painting the more cathodic metal; otherwise, greatly accelerated attack may be concentrated at paint imperfections in coatings on the anodic metal. Keep such coatings in good repair. Resist the temptation to paint only the metal that is rusting.
- f) Impressed or stray electrical currents flowing into metal objects that have extensive ground contact will generally not be eroded at the many locations the current leaves the metal object. However, if electrical currents leave the metal object at a concentrated location, significant loss of metal will occur. These areas of concentrated metal loss will likely appear as a clean, sharp, pocked (pitted) surface.
- g) Exposed portions of metal (especially iron or steel) partially embedded in concrete may corrode because the exposed portion is serving as the anode protecting the embedded portion of the metal. The concrete creates a different electrolytic environment than is experienced by the exposed metal.
- h) Coat the metal (cathode) to be protected. Consider including a cathodic protection system in the design.

Soil Resistivity vs. corrosion. Measured soil resistivity may be correlated with expected corrosion as follows:

- a) Resistivity values of 1,000 ohm-cm or lower indicate very corrosive conditions.
- b) Values from 1,000 to 5,000 ohm-cm usually indicate moderately corrosive conditions.
- c) Values from 5,000 to 10,000 ohm-cm indicate mildly corrosive conditions.
- d) Values above 10,000 ohm-cm indicate slightly corrosive conditions.

Areas of sudden change in soil resistivity may indicate the location of corrosion concentration. For example, if a series of resistivity readings are running 10,000 ohm-cm and in a short distance readings drop to 2,000 ohm-cm, concentrated corrosion is likely to occur in the 2,000 ohm-cm contact or near contact area. These areas of low resistance are referred to as "hot spots." Also, sharp changes in high soil resistivity (for example, a change from 10,000 to 100,000 ohm-cm) can sometimes concentrate corrosion in one area of the structure.

Soil Resistivity Effects on Buried Metal Pipe. In South Dakota, soil resistivity is generally the best indicator of the potential for corrosion of metal pipe installed in moist to saturated soil conditions. The expected effect of soil resistivity on zinc coated corrugated steel pipe (CSP) is as follows:

- a) For soils below 1,500 ohm-cm, CSP must have both additional coating (preferably polymer) and anodes (complete cathodic protection system) in order to assure a functional life beyond 5 to 10 years.
- b) For 1,500 to 2,500 ohm-cm soils, CSP must have an additional coating (asphalt or polymer) to achieve 20 to 25 year functional life expectancy. Cathodic protection should be installed at the time of construction to further extend functional life expectancy.
- c) For 2,500 to 4,000 ohm-cm soils, zinc coated CSP is expected to last 25 years or longer. Asphalt or polymer coated should extend the functional life an additional 10 years. Cathodic protection should be considered for useful life beyond 35 years.
- d) For soils consistently over 4,000 ohm-cm, little or no corrosion effect is expected on zinc coated corrugated steel pipe (CSP).

In addition to protecting the steel from direct contact with the surrounding soil, zinc coating on CSP acts as a sacrificial anode protecting the steel. Asphalt or polymer coatings (or a loose "plastic tube" insulator) provide further separation of pipe and soil along with some electrical insulation. The electrical insulation serves to resist corrosion causing electrical currents.

In most situations, cathodic protection systems in soil are designed to protect only the outside of the buried pipe. Corrosion of the interior of the pipe is dependent on the interior environmental conditions, including the pH and electrical resistivity of whatever fluids or gasses exist in the pipe. Pipe interior corrosion is generally controlled (where needed) by pipe coatings rather than by anodes located in the fluids or gasses in the pipe. An example of an exception is that water heaters are sometimes protected by magnesium anodes projecting into the water within the water heater. For buried metal pipes carrying acid mine runoff or other low pH water, heavy duty pipe interior coatings are likely to be required to control pipe interior corrosion.

It is generally recommended that both coatings and cathodic protection be considered for buried welded steel pipe.

Electrical Grounding. It is generally appropriate to use anodes (usually zinc) for the dual purposes of cathodic protection and grounding of electrical systems (at pumping plants, etc.).

Typical NRCS Cathodic Protection System. Most cathodic protection systems in NRCS work have been used to protect buried metal pipes. Most South Dakota installations involve magnesium anodes designed to lengthen the functional life of zinc coated corrugated steel pipe. Figure 1 describes typical NRCS designs.

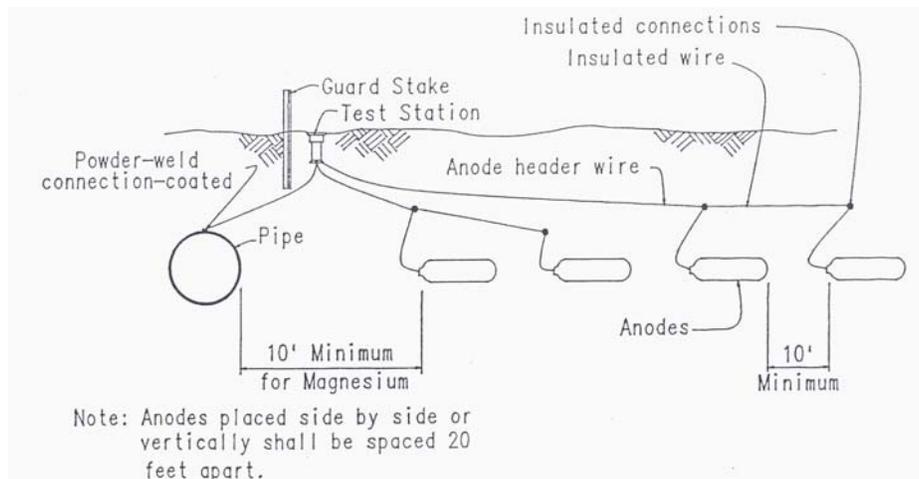


Figure 1 – Typical Multiple Anode Cathodic Protection System Installation

DESIGN PROCEDURE - Cathodic Protection Systems for Buried Iron and Steel Structures

- 1) Make several resistivity measurements of the soils (trench soils, backfill, borrow etc.,) located or to be located adjacent to or near the buried metal pipe or other structure. Select the value of soil resistivity to be used for design based on the best estimate of soil conditions around the buried pipe or other metal object.
- 2) Measure soil resistivity in the proposed anode bed location.
- 3) Estimate the actual surface area of the pipe or other metal in contact with the soil.
- 4) Estimate the total protective current required.

- a) For coated metal to be protected (e.g. polymer coated pipe, etc.,)

$$I_t = (C)(A) / Re_b$$

Where: I_t = total current required, in milliamps (mA)

C = pipe coating constant (Table 3)

A = surface area of metal (pipe etc.,) in contact with soil, in square feet (sq. ft.)

Re_b = resistivity of soil around the pipe and/or other buried metal, in ohm-centimeters (ohm-cm)

- b) For bare metal contact with soil (e.g. uncoated steel or plain galvanized steel, etc.,)

$$I_t = I_k (A)$$

Where: I_k = cathode current requirement in mA per square foot of metal to be protected. For galvanized steel use $I_k = 0.2$ to 0.3 ; bare steel use $I_k = 0.5$ to 1.0 for design. Use the higher end of the range where Re_b is below 4,000 ohm-cm. Check with field measurements after construction.

A = surface area of metal (pipe etc.,) in contact with soil, in square feet

- 5) Select anode material, size, shape, and potential. This may be a trial-and-error process to determine the most efficient anodes for the site. Either zinc or magnesium may be used over a wide range of soil resistivities. For economic reasons, zinc anodes are recommended where anode bed resistivity is less than 1,500 ohm-cm. Magnesium may be the most economical where anode bed resistivity is greater than 3,000 ohm-cm. Between 1,500 and 3,000 ohm-cm either may be economical. Zinc anodes in soils of any resistivity are more likely to be self-regulating and continue to provide sufficient current for adequate protection without excessive current waste. Aluminum anodes have a theoretical energy content (ampere-hours per pound of metal) exceeding that of magnesium and zinc. However aluminum has not proven practical (so far) for earth buried anodes because of problems keeping it electrically active and operating efficiently. Aluminum anodes are primarily used for marine applications.

- 6) Calculate current output estimate for selected anodes.

- a) $I_m = k / Re_a$

Where: I_m = current output estimate for anode, in mA

k = anode constant (Table 4)

Re_a = soil resistivity in anode bed location

- 7) Calculate number of anodes required.

$$\text{Number of anodes} = N = I_t / I_m$$

- 8) Determine expected life of anodes selected.

- a) Magnesium anodes: $L_{mag} = (47)(W) / I_m$

Where: L_{mag} = expected life of magnesium anodes, in years

W = weight of single bare anode, in pounds

If selected life is inadequate, select a different anode size, shape, or potential and repeat steps 5) through 8).

To get longer life, select an anode with a smaller k value and/or greater weight (lower ratio of k / W).

Note that the maximum life of a magnesium anode is about 25 years regardless of current requirement or other factors, due to the relatively low efficiency of the magnesium. A calculated life much higher than 25 years may simply indicate that some of the magnesium will be wasted from internal corrosion mechanisms. If calculated life is much greater than 25 years, select a higher ratio of k / W (Table 4).

For design life significantly longer than 25 years, use of magnesium anodes means the system will need to be tested and upgraded at intervals in the future. Alternatively zinc anodes may be used.

- b) Zinc anodes: $L_{zn} = (31)(W) / I_m = (31)(W)(N) / I_t$

Where: L_{zn} = expected life of zinc anodes, in years

If expected life is inadequate, add more anodes, try another size with lower k / W or plan for future maintenance, repair and upgrade. If calculated life is too long, select a size with higher k / W .

- 9) Actual conditions vary. Check completed cathodic protection system after installation to ensure that current and potential (voltage) are in the proper range to provide adequate protection to the pipe or other protected metal (see Maintenance section below).

Cathodic Protection System Design Example for a Dam Principal Spillway Pipe with Riser Pipe:

Given: Structural Design Life -----50 years

Pipe -----154.33 feet of 24" diameter polymer coated corrugated steel pipe

Buried Riser Pipe -----10.12 feet of 36" diameter polymer coated corrugated steel pipe

Anti-Seep Collars -----4 each, (12.12 x 7.5 feet), polymer coated corrugated steel

Re_b = 2,200 ohm-cm, Re_a = 2,000 ohm-cm

Exterior Surface Area of Buried Portion of Pipe = (6.97)(135.82) = 947 square feet

Buried Riser Exterior Surface Area = (10.41)(10.12) = 105 square feet

Anti-Seep Collar Soil Contact Area = (4)(189) = 756 square feet

Total area to be protected of steel surface in contact with soil, A = 1808 square feet

Design Trial 1:

Current Required: $I_t = (C)(A) / Re_b = (120)(1808) / 2,200 = 98.6 \text{ mA}$

Try 32 pound, standard potential magnesium anodes (Table 4), $k = 61,000$, $k / W = 1906$

Current Output: $I_m = k / Re_a = (61,000) / (2,000) = 30.5 \text{ mA}$

Number of Anodes Required: $N = I_t / I_m = 98.6 / 30.5 = 3.2$ Choose 4 each

Expected Life: $L_{mag} = (47)(W) / (I_m) = (47)(32) / 30.5 = 49 \text{ years}$

Note: Exceeds 25 year reliable functional life of magnesium. Try an anode with higher (k / W) ratio. See the above discussion about magnesium life under Design Procedure.

Design Trial 2:

Try 32 pound, high potential magnesium anodes (Table 4), $k = 88,000$, $k / W = 2,750$

Current Output: $I_m = k / (Re_a) = 88,000 / 2,000 = 44 \text{ mA}$

Number of Anodes Required: $N = I_t / I_m = 98.6 / 44 = 2.2$ Choose 3 each

Expected Life: $L_{mag} = (47)(W) / (I_m) = (47)(32) / (44) = 34 \text{ years}$

Use 3 each, 32 pound high potential magnesium anodes and recognize in the maintenance agreement that anodes will likely need to be added after 25 years.

Many other solutions are also possible.

Table 2 – Surface Area of Steel Pipe

Material	Nominal Pipe Diameter, inches	Pipe Exterior Surface Area, square feet per foot of pipe length
Welded Steel Pipe	6	1.73
	8	2.26
	10	2.81
	12	3.34
Corrugated Steel Pipe, ½ inch corrugation	12	3.57
	15	4.42
	18	5.27
	21	6.12
	24	6.97
	30	8.69
	36	10.41
	42	12.11
	48	13.82
	54	15.52
Corrugated Steel Pipe, 1 inch corrugation	66	21.75
	72	23.70
	78	25.65
	84	27.59

Table 3 – Pipe Coating Constant “C”

Coating Description	C Value
Fiber-bonded asphalt coated galvanized corrugated steel	120
Polymer coated galvanized corrugated steel	120
Class A coated steel	32
Class B coated steel	60
Tape-wrapped steel	5

Table 4 – Values of “k” for some Prepackaged Anodes

Zinc Anodes: (EMF = -1.1 Volts)

Bare Anode Weight, pounds	Package Diameter X Length, inch	k Value Steel Pipe	k / W	k Value Galvanized Steel	k / W
5	5 x 15	18,000	3,600	11,000	2,200
12	5 x 30	27,000	2,250	17,000	1,417
18	5 x 42	33,000	1,833	21,000	1,167
30	5 x 66	46,000	1,533	29,000	967
30	5 x 36	30,000	1,000	19,000	633
45	5 x 51	38,000	844	24,000	533
60	5 x 66	46,000	767	29,000	483

High Potential Magnesium Anodes: (EMF = -1.7 Volts)

Bare Anode Weight, pounds	Package Diameter X Length, inch	k Value Steel Pipe	k / W	k Value Galvanized Steel	k / W
3	6 x 9	62,000	20,667	43,000	14,333
5	6 x 11	67,000	13,400	46,000	9,200
9	6 x 17	82,000	9,111	56,000	6,222
17	6 x 30	114,000	6,706	78,000	4,588
20	5 x 62.5	177,000	8,850	122,000	6,100
32	8 x 30	128,000	4,000	88,000	2,750
48	8 x 34	138,000	2,875	95,000	1,979

Standard Potential Magnesium Anodes: (EMF = -1.5 Volts)

Bare Anode Weight, pounds	Package Diameter X Length, inch	k Value Steel Pipe	k / W	k Value Galvanized Steel	k / W
1	6 x 6	46,000	46,000	28,000	28,000
3	6 x 9	50,000	16,667	31,000	10,333
5	6 x 11	54,000	10,800	33,000	6,600
9	6 x 17	67,000	7,444	41,000	4,556
17	6.5 x 19	73,000	4,294	45,000	2,647
32	8 x 30	104,000	3,250	61,000	1,906
50	10 x 18	90,000	1,800	55,000	1,100

Anode sizes listed in Table 4 are examples available from Harco Technologies (www.corrpro.com). The k values were calculated assuming polarized pipe potential of -900 mV for steel pipe, -975 mV for galvanized pipe with zinc anodes, -1150 mV for galvanized pipe with magnesium anodes. Values of k for other anodes may be calculated using procedures in Design Note No. 12.

INSTALLATION – Sacrificial Anode Cathodic Protection Systems

- 1) For lowest resistance to earth, anodes in a multiple anode bed should be placed in a straight line. The line of anodes should be placed in a horizontal position either parallel or perpendicular to the metal being protected. Place anodes in undisturbed soils at a location that is normally moist. Magnesium anodes must be located at least 10 feet (preferably 15 feet or more) from the metal being protected. For optimum performance, zinc anodes should also be at least 10 feet from the protected metal, but may be closer as needed when protecting coated pipe. Horizontal position avoids effects of fertilizer in surface soils.
- 2) Excavate and prepare bedding for the anodes consisting of well tamped, moist clayey silt, clay loam, silt, or silt loam. In sandy and gravelly areas, fine soil must be imported for bedding and for covering the anode packages to a depth of six inches.
- 3) Place the anode package in the prepared bed making sure the anode is centered in the package. Use extreme caution to not get the anode package wet before it is in final position. Never lift the anode by the lead wire.
- 4) After placement, irrigate the anode package to insure moistening of the anode packaged backfill. To insure the chemical backfill is irrigated, the anode package may be punctured with a pitchfork or similar device. Next, complete backfilling around the anodes to a six-inch depth above the anode package.
- 5) Often anodes placed in tight native clays must be irrigated by some method. This can often be accomplished by incorporating a clean sand/gravel “French drain” to trap water around the anodes. The sand/gravel must be at least 6 inches from the anode packages to prevent 30 to 50 percent reduction of anode current output.
- 6) Connect the lead wires from anodes to header wires using a minimum five wrap joint and tin-lead (or other appropriate) solder. Waterproof the wire connection using materials and procedures recommended by the anode manufacturer. No more than three anodes should be connected to the same header wire. Separate connection of anodes adds reliability and allows some anodes to be disconnected if voltage output is too high. Header wires should be passed through test boxes to permit periodic measurement of output current and calculation of probable remaining functional life. From the test box, attach the header wires to the pipe or other metal being protected using a powder weld process designed for the purpose. Repair disturbed pipe coatings.
- 7) Test boxes should be installed following manufacturers recommendations. Because of the low electrical voltages involved, oxidation of wire connections is a concern. Wire-to-wire connections should be soldered.
- 8) Complete trench backfill using native soils. Leave a six-inch deep surface depression for irrigation of the anode bed.
- 9) Carefully join all steel objects to be protected using a commercial powder weld process designed for the purpose. Carefully test to assure electrical continuity.
- 10) Test the Cathodic protection system (see Maintenance below) to assure correct voltage and current are being provided.

MAINTENANCE OF CATHODIC PROTECTION SYSTEMS

Voltage Polarity. This technical release is written following the polarity (+ or -) conventions used in Peabody’s Control of Pipeline Corrosion (note: reverse conventions are also used in the corrosion industry.) However for most NRCS work polarity will not be an issue. Iron, steel, zinc, magnesium and most other metals (gold is an exception) generate the same polarity voltage (see Table 1). Cathodic protection is provided to a metal by inducing a voltage (same polarity) higher than the protected (cathode) metal will generate by itself corroding.

For the following maintenance measurements, polarity readings as discussed in this technical release will be obtained by connecting the volt meter minus (-) pole to the anode or reference electrode and the plus (+) pole to the pipe or other metal to be protected (cathode).

Maintenance Criteria for Steel and Cast iron. One or more of the following alternative criteria may be appropriate for checking cathodic protection of underground or submerged steel or cast iron piping (1 volt = 1000 millivolt (mV)):

- A. The most widely used criteria for well coated structures is to achieve -850 mV (or more negative) pipe to saturated copper-copper sulfate reference electrode with cathodic protection applied (anodes connected). For this alternative criteria, locate the copper-copper sulfate electrode in soil directly above the pipe.
- B. A polarized potential of -850 mV (or more negative) pipe to saturated copper-copper sulfate reference electrode. Polarized potential (“instant-off” voltage) is measured immediately after interruption of all current sources (anodes etc.).

- C. At least 100 mV of polarization decay after disconnecting the anodes (instant-off voltage compared to off voltage measured, if necessary, several days or weeks after disconnection of anodes (or before anodes were connected)). The corrosion rate of a structure decreases by a factor of 10 for every 100 mV extra (more negative) voltage applied by the anodes compared to stabilized voltage without anodes. Corrosion reduction by a factor of 10 is typically more than adequate cathodic protection. This criteria is most commonly used for poorly coated or bare pipe where either of the above -850 mV criteria are difficult or costly to attain. It is also used to minimize cathodic protection upgrade costs. This criteria is not applicable to situations of stray currents or dissimilar structure metals.
- D. For bare or poorly coated pipes where long term corrosion activity is the primary concern, criteria may be based on the net protective current needed. This criteria should be used only as a last resort.

Maintenance Criteria for Aluminum. The 100 mV polarization decay criteria (C) listed for steel and cast iron above may also be used to protect aluminum. Cathodic protection voltages should not be more negative than -1200 mV for aluminum in order to prevent “cathodic corrosion.”

Maintenance Criteria for Copper. The 100 mV polarization decay criteria (C) listed for steel and cast iron above may also be used for copper.

Maintenance Criteria for Buried Structures Containing Dissimilar Metals. Maintain a negative voltage between all structure soil contact surfaces and a stable copper-copper sulfate reference electrode in contact with the soil equal to that required for the most anodic structure metal (listed upper most in Table 1). Metals that corrode in both acid and alkaline environments (such as aluminum, titanium, zirconium,) should be electrically isolated and separately protected with cathodic protection.

This criteria applies most commonly where carbon steel or cast iron is in contact with a more cathodic (listed lower in Table 1) metal such as copper. In this situation either of the -850 mV criteria A or B (under steel and cast iron above) would apply. Other criteria (C and D) are not applicable to this situation.

Maintenance Tests. Check functioning of cathodic protection systems at the completion of construction and at intervals of not more than five years. Testing of the system is not difficult, but special (very accurate) equipment designed for the purpose is required. The most likely problems with cathodic protection systems are broken wires, electrically broken connections or broken welds.

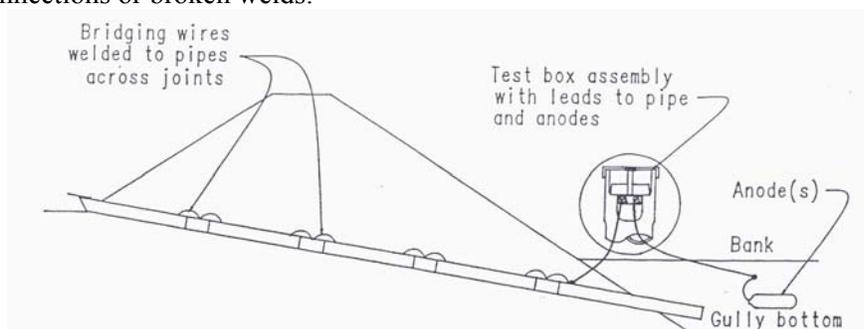


Figure 3 – Schematic Drawing of a Typical Cathodic Protection System for a Dam Principal Spillway Pipe

Basic equipment needed to test a dam principal spillway pipe cathodic protection system is as follows:

- 1) Insulated electrical wire, 250 to 300 feet long, #18 or heavier gage. Two or more 4 foot minimum length leads of #18 insulated copper electrical wires with alligator clips.
- 2) A volt-ohm-milliamp (VOM) meter designed for the purpose. It should have mV ranges of 0 to 2500 (or 3000), milliamp ranges of 0 to 500 with lower maximum deflection ranges, and ohm ranges with expanded scale in the 1 to 5+ ohm range.
- 3) A copper-copper sulfate half-cell with porous plug designed for the purpose.

Measurement of Pipe to Soil Voltage with Anodes Connected, (Figure 4) – data for criteria A

This test will produce voltage data for criteria A described above under Maintenance Criteria for Steel and Cast Iron. This test should always be done first before any circuits are disconnected because, upon disconnection, the systems tend to depolarize and the voltage begins to drop. One reading at the inlet and one at the outlet are recommended. Preferred location of the half-cell is directly above the pipe, at a point with at least five feet of soil cover over the pipe.

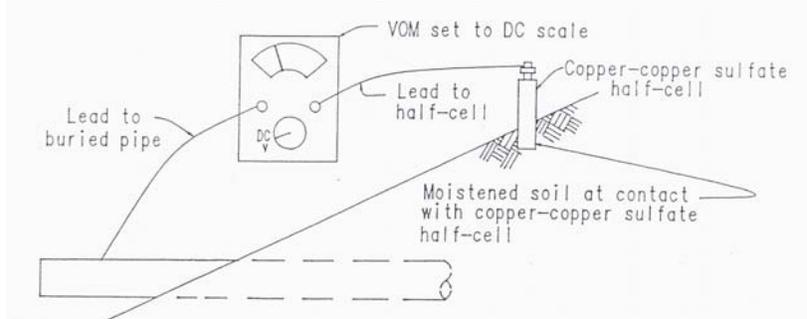


Figure 4 – Test setup for pipe-to-soil potential test

The copper half-cell is a specialized half of a battery cell that provides standardized measurements. When the half-cell is placed in contact with moistened soil and connected through the VOM (set for mV DC mode) to a metal in contact with the soil, it will produce a comparative voltage for the metal to the soil. This comparative voltage for a corrugated iron or steel pipe that is protected by a cathodic protection system should be between -850 and -1200 mV. Measurements less negative than -850 mV indicates the pipe may be corroding and additional anodes should be added. Voltages more negative than -1300 mV may cause zinc coating to separate from the galvanized steel pipe due to the formation of hydrogen gas bubbles under the zinc surface. Magnesium anodes are more likely to cause this condition than are zinc anodes. In this condition, some anodes may need to be temporarily disconnected from the system, thereby reducing the driving negative voltage.

Measurement of Pipe to Soil Voltage Instantly After Disconnecting Anodes – data for criteria B and C

Data for criteria B and C is also collected using the Figure 4 test setup. Anode instant-off voltage measurement should be read before proceeding to the following test procedures. After the reading is made, the anodes can be reconnected until the following tests are completed. Later, after other tests are completed, anodes can be left disconnected as needed to record the longer term anode off voltage measurement for criteria C.

Measurement of the Current Flow (from the anodes to the pipe) – data for criteria D

Because of the depolarizing process discussed above, the current flow should be measured next. Connect the VOM (set to milliamper mode) to the lead wire from the pipe and the header wire from the anodes. During this test you will notice the current decrease as the pipe and anodes are disconnected. Record the maximum reading as the current flow. The current flow could vary from 5 ma (0.005 amp) to 300+ ma (0.3+ amp), depending on pipe area, soil resistivity, and soil moisture. A current flow larger than the design current usually means the pipe is protected to a higher level than needed. This larger current wastes the anode and will reduce the anode functional life. If the current is more than 1.3 times design need, a resistance should be added to the circuit. This is done with a length of special high-resistance wire connected in the circuit (usually in the test box). Another method involves temporarily disconnecting an anode from the system. Figure 5 shows the wiring for this test.

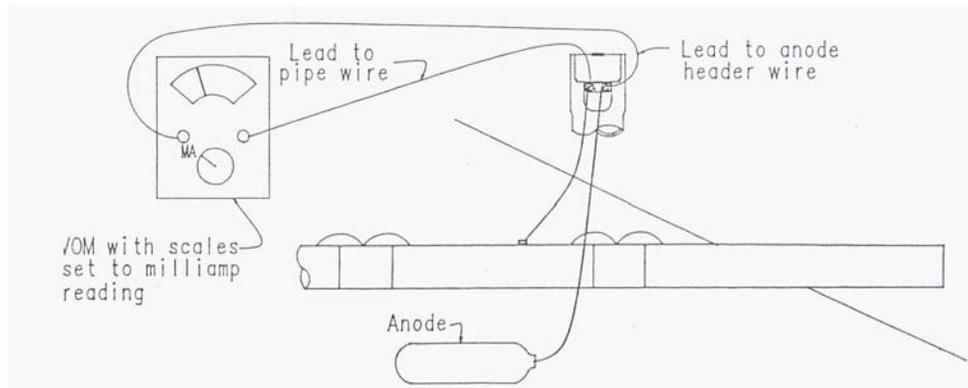


Figure 5 – Schematic for Anode to Pipe Current Flow Test

Measurement of Anode to Soil Potential (open circuit, voltage output of the anode bed, Figure 6)

This test is a comparative test using the copper-copper sulfate half-cell connected through the VOM (set on DC voltage) to the lead wire from the anode. The normal anode voltage will be in the range of 1400 to 1800 mV for magnesium anodes, and 850 to 1200 mV for zinc anodes. A reading of 0 to 300 mV probably means the wire or a connection is broken between the VOM and the anode. Sometimes this can be corrected by digging along the wire toward the anode to find the electrical fault (break). If the problem involves a test station located on a post, the wiring break may be at the base of the post because of past disturbance of the post. Figure 6 shows the wiring for this test.

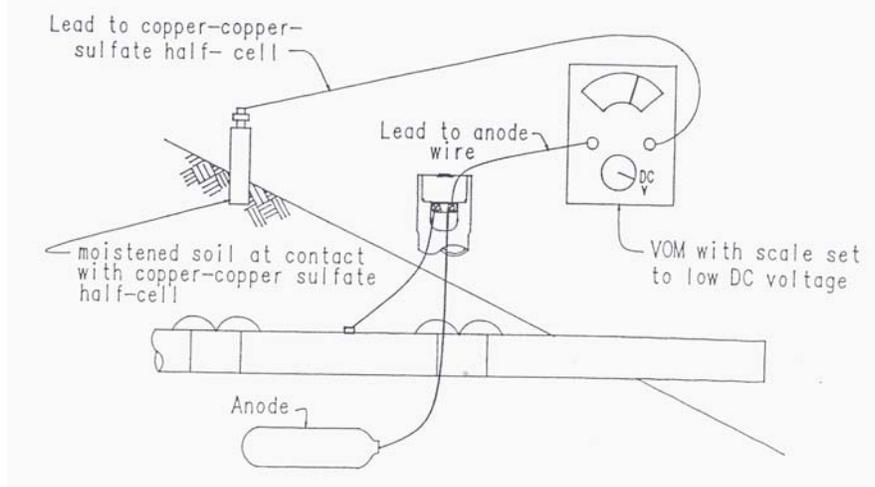


Figure 6 – Schematic of Anode to Copper-Copper Sulfate Half-Cell Test

Measurement of Voltage Through The Pipe (Figure 7A or 7B)

Assuming dissimilar metals are not included in the structure, the buried pipe should be electrically connected and act like one large wire from inlet to outlet so current added from the anodes will flow through and protect the total buried length of the pipe. These tests should be made during construction and each time the system is tested thereafter. This test can be by either of the following methods.

Test Method 1. – Connect the pipe inlet and outlet in a circuit through a VOM. The circuit should show low (ohm) resistance (circuit complete), and zero voltage, since noncorroding pipe itself has no driving voltage. If the circuit is not complete or if a voltage is indicated, the pipe may be corroding as various pieces may be serving as anodes and cathodes to each other. Wiring for this test method is shown in Figure 7A.

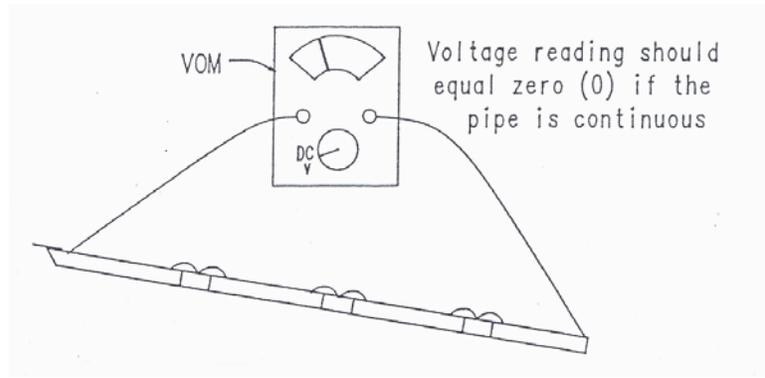


Figure 7A – Schematic for Pipe Continuity Test, Method 1.

Test Method 2 – This method involves measuring the pipe to soil potential (voltage) at both the inlet and outlet with leads that are connected successively to the inlet and outlet (inlet voltage and outlet voltage). The voltages measured at each location should be equal since the half-cell stays in the same position for each measurement. The voltages may vary slightly due to different soil conditions in the two circuits.

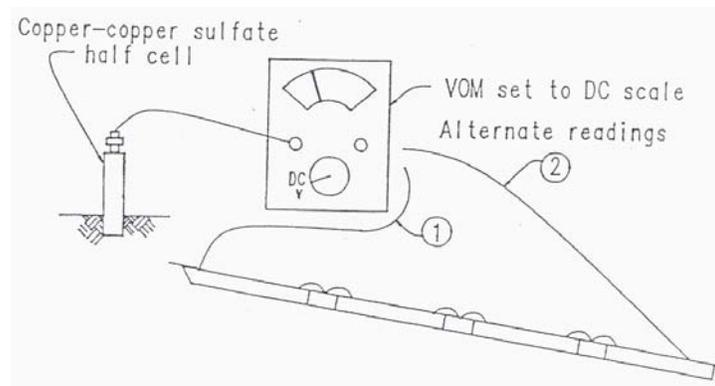


Figure 7B - Schematic for Pipe Continuity Test, Method 2.