22. CATHODIC PROTECTION

DESCRIPTION AND PURPOSE

The purpose of cathodic protection is to protect metal pipe from rapid deterioration by electrolytic corrosion due to contact with corrosive soils. Cathodic protection may be used with welded steel pipe (WSP) and zinc-coated corrugated metal pipe (CMP).

NRCS Technical Release 60, Earth Dams and Reservoirs, requires cathodic protection for corrugated steel pipe and welded steel pipe in soil whose resistivity in a saturated condition is less than 4,000 ohm-cm or whose pH is lower than 5.0. Cathodic protection is commonly provided using sacrificial anodes, usually zinc or magnesium alloy, connected to the pipe. The theory of underground corrosion and the mechanics of cathodic protection are discussed in Design Note 12, Control of Underground Corrosion.

Information in this amendment does not specifically apply to aluminum or aluminized CMP. Aluminum tends to resist corrosion due to the formation of a natural oxide layer following exposure to the air. Certain conditions, however, such as highly alkaline or dense, stiff clay backfill soils, may promote corrosion of aluminum. For this reason, aluminized CMP principal spillway pipe joints should be electrically bridged to allow addition of anodes at a later date in the event corrosion is noted. Magnesium anodes may be used to protect an aluminum or aluminized pipe or structure.

In Iowa the resistivity of the soil (ohm-cm) is the best indicator of the potential for corrosion of a metal pipe installed in moist to saturated conditions. The relative effect of soil resistivity can be defined by ranges of resistivity as:

1. Over 4,000 ohm-cm soil has little or no adverse effect on zinc-coated CMP, with life expectancy of over 30 years.

2. In 4,000 ohm-cm to 2,500 ohm-cm soils, zinc-coated CMP normally will last 25 years or longer. The zinc coating on CMP, in addition to protecting the steel from direct contact with surrounding soil, acts as a sacrificial anode to protect the steel.

   Addition of a polymer coating over zinc coated CMP may extend the life an additional 10 years or more; however, corrosion tends to concentrate at any minor imperfection or damaged area of the polymer coating. Cathodic protection is strongly recommended whenever polymer-coated CMP is used in soils below 4,000 ohm-cm. Use of polymer-coated CMP will decrease the number of anodes required, compared to cathodic protection for plain galvanized CMP.

3. In 2,500 ohm-cm to 1,500 ohm-cm soils, CMP requires a polymer coating in addition to the zinc coating for a 20 to 25 year life expectancy. Cathodic protection should be installed at the time of construction to extend life beyond 20 to 25 years.

4. Soils below 1,500 ohm-cm resistivity are quite corrosive; therefore, both polymer coating and anodes are necessary to assure a life beyond 5 or 10 years for zinc-coated CMP.

5. It is recommended that cathodic protection be considered for welded steel pipe (WSP) in soils below 4,000 ohm-cm resistivity.

Cathodic protection is designed to protect only the outside surface of pipes which are in direct contact with the soil. It will not protect the pipe from corrosion from the inside to the pipe exterior. In areas where there is a history of low pH water or acid drainage which has caused corroded pipes, consideration should be given to using some type of fully coated pipe.

DESIGNING A CATHODIC PROTECTION SYSTEM

A cathodic protection system for a metal pipe is a closed electrical circuit consisting of the pipe, the anodes, and the soil surrounding these elements. The design involves obtaining field measurements of the resistivity of the site soils and selecting anodes based on those measurements and the surface area of metal that is in contact with the soil.

FIELD MEASUREMENTS

Determine the resistivity of the soils which are most likely to surround the metal pipe and the soils in the location of the anode bed. The equipment needed for the soil resistivity test is a 4-pin direct current soil resistivity measurement kit. The depth to the soil where resistivity is measured is equal to the spacing between the pins. Soil resistivity, Re, is measured in ohm-cm.

1. Measure the soil resistivity in the proposed borrow areas and/or along the proposed location of the principal spillway. If the pipe is already installed, measurements are to be taken of materials surrounding the pipe. Measurement shall begin at the ground surface and continue until the nominal pin spacing is greater than the borrow depth or pipe depth, whichever applies (see Soil Resistivity Measurements, Form IA-ENG-38).

2. Measure soil resistivity in the proposed anode bed location. Typically the anodes for a metal principal spillway pipe are located just downstream of the structure embankment, either on the right or left side of the downstream channel. Anodes should be located in natural ground where the soil will be moist but not saturated. They should not be placed in compacted earthfill. Typical depth to the anode bed is around 3 to 4 ft. Use a pin spacing that is equal to the assumed depth of the anode bed. If there is more than one possible anode bed location, measure Re in both and select the one with the lowest resistivity measurement. This will maximize current flow from the anode.

DESIGN PROCEDURE

A spreadsheet, *IaCathodicProtection.xls*, is available on the NRCS-IA website to facilitate selecting the appropriate type, size and number of anodes. The following steps describe the design process, whether using the spreadsheet or designing by hand.

1. Estimate the actual surface area of pipe which will be in contact with the soil. Include any metal riser pipe, drawdown pipe, and anti-seep collars (see Table 1).

2. Estimate total protective current required.

   a) For coated pipe (e.g. polymer coated CMP):

$$I_t = C \frac{(A)}{Re_b}$$

Where: I_t = total current required, in milliamps (mA)
C = pipe coating constant (see Table 2)
A = surface area of pipe in contact with soil, in sq. ft.
Re_b = resistivity of backfill material around pipe, in ohm-cm.

b) For bare pipe (e.g. WSP or plain galvanized CMP):

$I_t = I_k (A)$

Where: I_k = cathode current requirement, in mA/square foot. For galvanized pipe use I_k = 0.2 to 0.3; for steel pipe use I_k = 0.5 to 1.0 for design. Use higher end of range where Re_b is low (Re_b should be measured in the field even though it is not part of the formula for required current). Check with field measurements after construction.

3. Select anode material, size, shape, and potential. This may be a trial-and-error process to determine the most efficient anodes for the site. Zinc anodes are recommended where anode bed resistivity is less than 2,000 ohm-cm, or where design life is greater than 25 years. Magnesium is recommended where anode bed resistivity is greater than 3,000 ohm-cm. Between 2,000 and 3,000 ohm-cm, either may be used.

   See Table 3 for a list of some commercially available prepackaged anodes.

   Form IA-ENG-37, Cathodic Protection Data, may be used to record design and maintenance information and data.

4. Calculate current output for selected anode.

   $I_m = k / Re_a$

   Where: I_m = current output for one anode, in mA
   k = anode constant (see Table 3)
   Re_a = soil resistivity in anode bed location

5. Calculate the number of anodes required.

   $N = I_t / I_m$

6. Determine expected life of anodes selected.

   a) Magnesium anodes: $L_{mag} = \frac{47(W)}{I_m}$ < 25 years

   Where L_{mag} = expected life of magnesium anodes, in years
   W = weight of single bare anode, in pounds

If expected life is inadequate, select a different size, shape or potential of anode 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 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 alloy. 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 significantly longer than necessary or much greater than 25 years, select an anode with a higher ratio of k/W (see Table 3).

For a typical 35 to 50 year design life, use of magnesium anodes means the owner or sponsor may need to replace the anodes during the design life of the structure. If this is not feasible, zinc anodes may be a more appropriate choice.

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

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

If expected life is inadequate, add more anodes, or try another size with lower ratio of k/W. If life is too long, select size with higher k/W ratio.

7. Check completed cathodic protection system after installation to ensure that current and potential are in the proper range to provide adequate protection to the pipe (See MAINTENANCE section below).

TABLE 1

SURFACE AREA OF METAL PIPE

Material	Pipe Diameter (inches)	Pipe Surface Area* (Sq Ft/Ft)	Rectangular Anti-Seep Collar Nominal Dimensions	Anti-Seep Collar Surface Area** (Sq Ft)	Square Anti-Seep Collar Nominal Dimensions			
					5'x5'	6'x6'	7'x7'	8'x8'
					Anti-Seep Collar Surface Area** (Sq Ft)			
WSP	6	1.73			50			
WSP	8	2.26			49			
WSP	10	2.81			49			
WSP	12	3.34			48			
CMP 1/2" Corr.	12	3.57	6' x 5'	66	54	78	107	
CMP 1/2" Corr.	15	4.42	8' x 6'	104	53	77	106	
CMP 1/2" Corr.	18	5.27	8' x 6'	103	52	76	105	
CMP 1/2" Corr.	21	6.12	8' x 6'	101	50	75	103	
CMP 1/2" Corr.	24	6.97	8' x 6'	100	49	73	102	135
CMP 1/2" Corr.	30	8.69	8' x 7'	113	45	69	98	131
CMP 1/2" Corr.	36	10.41	10' x 7'	140	40	64	93	126
CMP 1/2" Corr.	42	12.11	10' x 7'	134		59	87	121
CMP 1/2" Corr.	48	13.82	10' x 7'	127		52	81	114
CMP 1/2" Corr.	54	15.52	12' x 8'	178			73	107
CMP 1/2" Corr.	60	17.22	12' x 8'	170			65	98
CMP 1" Corr.	66	21.75						
CMP 1" Corr.	72	23.70						
CMP 1" Corr.	78	25.65						
CMP 1" Corr.	84	27.59						

* All pipe, including drawdown, riser, and principal spillway.

** Both faces of anti-seep collar after deducting the area of principal spillway pipe.

TABLE 2

PIPE COATING CONSTANT, C

DESCRIPTION	C VALUE
Fiber-bonded asphalt coated galvanized CMP	120
Polymer coated galvanized CMP	120
Class A coated steel pipe	32
Class B coated steel pipe	60
Tape-wrapped steel pipe	5

TABLE 3
PREPACKAGED ANODES

ZINC ANODES: (EMF = -1.1 V)

Anode Type	Bare Anode Weight (lb.)	Package Dimensions Diam. X Length (in.)	k Value, STEEL Pipe	k/W	k Value, GALV. Pipe	k/W
S5	5	6 X 16	19,850	3,970	12,400	2,480
S12	12	6 X 30	28,500	2,380	17,900	1,490
S15	15	6 X 36	32,000	2,140	20,000	1,340
S15A	15	6 X 21	23,000	1,530	14,400	960
S18	18	6 X 42	35,500	1,970	22,200	1230
S30	30	6 X 66	48,500	1620	30,300	1010
S30A	30	6 X 36	32,000	1070	20,000	670
S45	45	6 X 51	40,500	900	25,300	560
S60	60	6 X 66	48,500	810	30,300	510

STANDARD POTENTIAL MAGNESIUM ANODES: (EMF = -1.55 V)

Anode Type	Bare Anode Weight (lb.)	Package Dimensions Diam. X Length (in.)	k Value, STEEL Pipe	k/W	k Value, GALV. Pipe	k/W
1 lb	1	3.5 x 10	39,000	39,000	24,010	24,010
3 lb	3	5.25 x 8	44,300	14,760	27,250	9,080
5 lb	5	5.25 x 11.25	50,700	10,150	31,230	6,250
9 lb	9	5.25 x 20	68,700	7,640	42,300	4,700
17 lb	17	7.5 x 24	88,900	5,230	54,710	3,220
32 lb	32	8.5 x 28	102,400	3,200	63,010	1,970
50 lb	50	10 x 24	102,000	2,040	62,760	1,260

HIGH POTENTIAL MAGNESIUM ANODES: (EMF = -1.7 V)

Anode Type	Bare Anode Weight (lb.)	Package Dimensions Diam. X Length (in.)	k Value, STEEL Pipe	k/W	k Value, GALV. Pipe	k/W
1R8	1	3.25 X 9	43,860	43,860	30,150	30,150
3D3	3	6 X 10	64,290	21,430	44,200	14,730
5D3	5	6 X 12	69,210	13,840	47,580	9,520
9D2	9	6 X 31	116,450	12,940	80,060	8,900

9D3	9	6 X 17	81,950	9,110	56,340	6,260
17D2	17	6 X 55	170,650	10,040	117,320	6,900
17D3	17	6.5 X 29	115,140	6,770	79,160	4,660
20D2	20	5 X 66	184,380	9,220	126,760	6,340
32D3	32	6.5 X 53	170,510	5,330	117,220	3,660
32D5	32	8 X 28	122,740	3,840	84,390	2,640
40D3	40	6.5 X 66	198,620	4,970	136,550	3,410
48D5	48	8 X 38	147,290	3,070	101,260	2,110
60S4	60	7 X 64	198,730	3,310	136,630	2,280

Anode sizes listed are those available from Mesa Technologies as of November 2015. The k values were calculated assuming a polarized pipe potential of -0.9 V for steel pipe, -0.975 V for galvanized pipe with zinc anodes, and -1.15 V for galvanized pipe with magnesium anodes. Values of k for other anodes may be easily calculated using procedures in Design Note 12.

FIELD LAYOUT

Figures 1 and 2 show typical NRCS anode installations for cathodic protection of buried pipes.

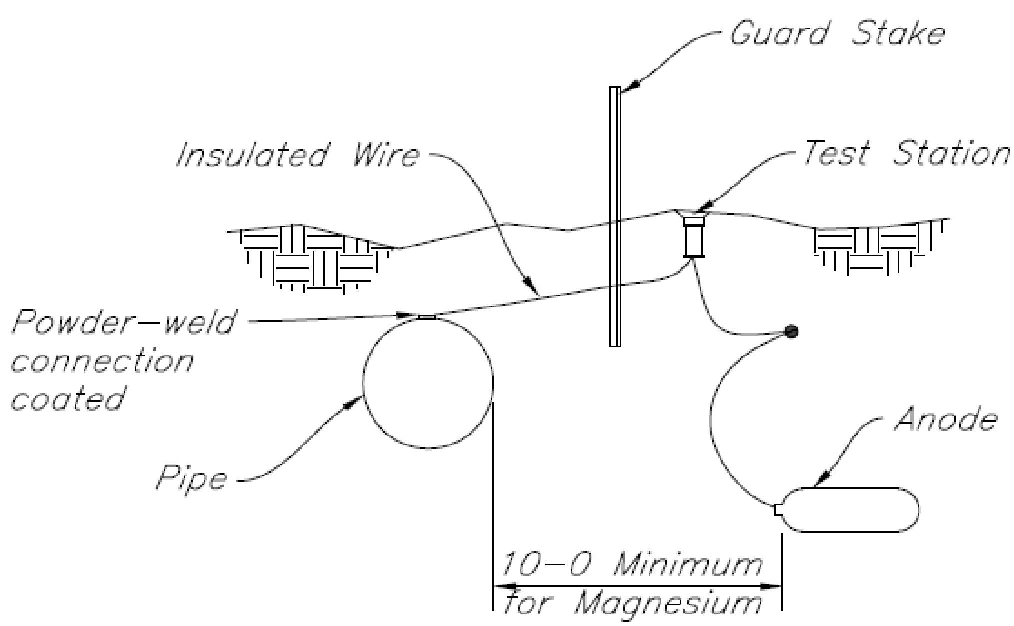

Figure 1. Typical Installation of a Single Anode

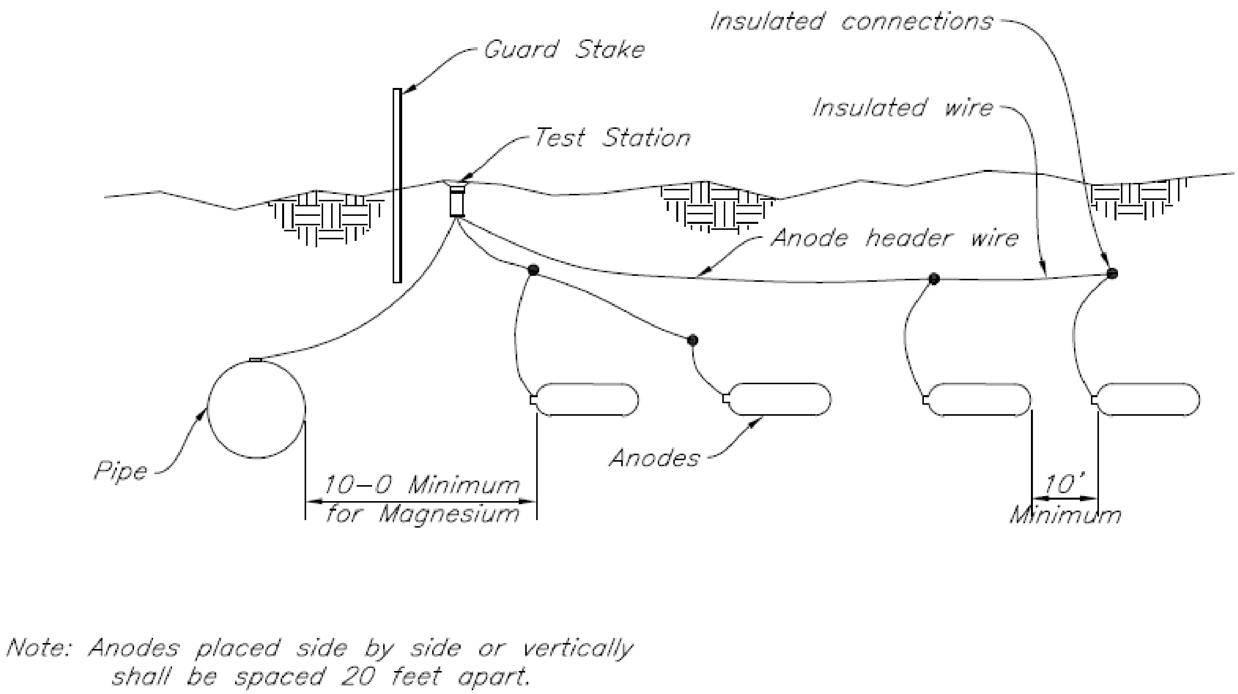

Figure 2. Typical Installation of Multiple Anodes

When anodes are placed in a trench with tight native clay soil, some provision must be made to insure continued irrigation of the anode. This can be accomplished with a sandy gravel "French drain". To install the drain, backfill the trench at one end with sandy gravel from anode depth to the surface of the ground. The trench length should extend away from the anode 2 to 3 times the depth of the anode. The gravel drain should not be placed in contact with the anode as the gravel would reduce the current output 30 to 50 percent. Provide at least one square foot of gravel drain area to the soil surface.

It is recommended that not more than three anodes be connected to each header wire. For installations with more than 3 anodes, two or more header wires are recommended. This allows some anodes to be disconnected if voltage output is found to be too high.

EXAMPLE:

Given:	Structure Design Life	- 50 years
	Barrel length	- 154.33 ft. of 24" galvanized C.M. Pipe, polymer coated
	Riser length	- 11.0 ft. of 36" galvanized C.M. Pipe, polymer coated
	Anti-Seep collars	- 4 ea. (7' x 7'), polymer coated
	Re_b = 2,200 ohm-cm	Re_a = 2,000 ohm-cm

Barrel Area	=	(6.97)(135.82)*	=	947 sq. ft.
Riser Area	=	(10.41)(11.0)	=	115 sq. ft.
Anti-seep Collar Area	=	(4)(102)	=	408 sq. ft.
		Area	=	1,470 sq. ft.

*Excludes length of pipe not covered by fill material.

Trial 1

Current Required: $I_t = \frac{C(A)}{Re_b} = \frac{120(1,470)}{2,200} = 80.2$ mA

Try 32 pound standard potential magnesium anodes

k = 63,010 k/W = 1,970 (Table 3)

Current Output: $I_m = \frac{k}{Re_a} = \frac{63,010}{2,000} = 31.5$ mA

Number of Anodes Required: $N = I_t / I_m = 80.2 / 31.5 = 2.5$ SAY 3 EACH

Expected Life: $L_{mag} = \frac{47(W)}{I_m} = \frac{47(32)}{31.5} = 48$ years

Note: This exceeds the 25 year expected life of magnesium. Try an anode with a higher k/W ratio. (See the discussion about magnesium anode life under Design Procedure above).

Trial 2

Try 32 pound high potential magnesium anodes, Type32D3

k = 117,220 k/W = 3660 (Table 3)

Current Output: $I_m = \frac{k}{Re_a} = \frac{117,220}{2,000} = 59$ mA

Number of Anodes Required: $N = I_t / I_m = 80.2 / 59 = 1.4$ SAY 2 EACH

Expected Life: $L_{mag} = \frac{47(W)}{I_m} = \frac{47(32)}{59} = 25$ years

USE 2 Each 32 pound high potential magnesium anodes, Type 32D3

MAINTENANCE

Cathodic protection systems need to be checked during installation and once every 2 to 4 years thereafter to make sure they are functioning properly. Testing of the system is straightforward but special equipment is needed. Each cathodic protection system has a test box installed to facilitate testing.

The anodes make a very low voltage-current flow system with voltage and current flow less than that of a 2-cell flashlight. As the anodes corrode to supply the small current, they are being “sacrificed” to keep the pipe from corroding. Eventually, the anodes are used up to the point where, like a battery, they cease to function and should be replaced. Other than anode depletion, the most likely problems in a system are a broken wire, broken connection, or broken weld. A schematic drawing of a system is shown in Figure 3.

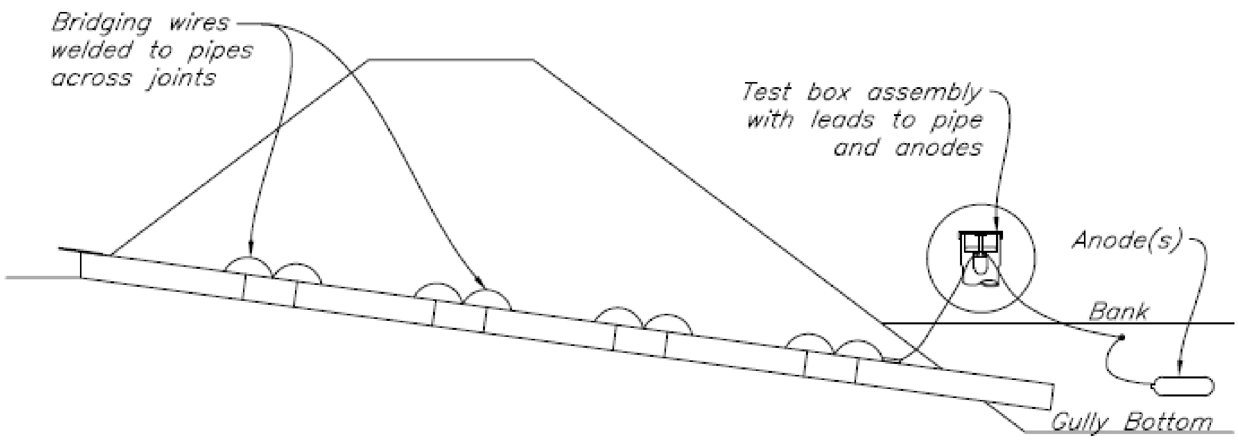

Figure 3. Schematic of a Cathodic Protection Installation

Basic equipment needed to perform the test is as follows:

a. 250 to 300 feet of rubber-coated, stranded #18 wire with reel.

b. A volt-ohm-milliamp (VOM) meter with DC volt ranges of 0 to 2.5 or 3 volts, milliamp ranges of 0 to 500 with two lower maximum deflection ranges, and ohm ranges with expanded scale in the 1 to 5+ ohm range.

c. A copper-copper sulfate half-cell with porous plug.

d. Two or three 4 ft. to 8 ft. leads of #18 wire with small alligator clips.

The FIVE tests normally used for checking the system are:

1. <u>PIPE TO SOIL POTENTIAL (Closed Circuit, See Figure 4)</u>

This test should always be done first before any circuits are disconnected. One reading at the inlet and one at the outlet are recommended. The half-cell should be at least five feet from the pipe. This test is performed first since, upon disconnection, the system tends to depolarize and the voltage begins to drop.

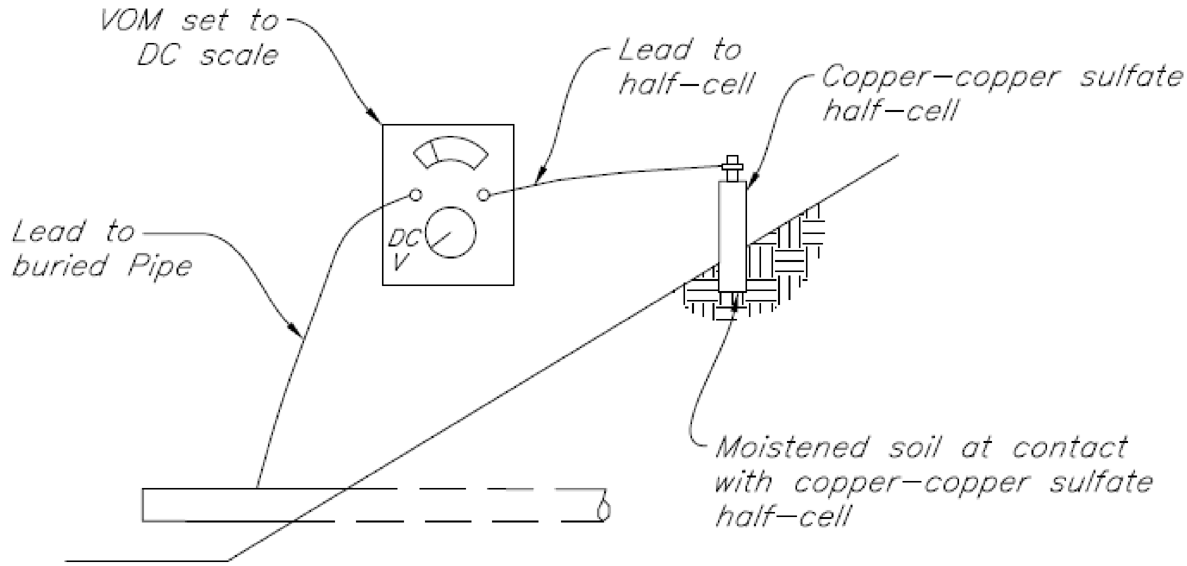

Figure 4. Schematic of Using Copper-Copper Sulfate Half-Cell Pipe to Soil Potential

The copper-copper sulfate half-cell is a specialized half of a battery cell. When it is placed in contact with moistened soil and connected through the VOM (volts DC mode) to a metal in contact with the soil it will produce a comparative voltage for the metal to soil. The comparative voltage for a corrugated iron or steel pipe that is protected should be between 0.85 volts and 1.20 volts (negative potentials). Less than 0.80 volt means the pipe is probably corroding and additional anodes should be added. Voltages more negative than -1.3 may cause the zinc coating to separate from the steel pipe due to the formation of hydrogen gas bubbles under the surface. Some anodes may need to be temporarily disconnected from the system, reducing the driving voltage.

2. <u>MEASURE THE CURRENT FLOW (From the Anodes to the Pipe, See Figure 5)</u>

Because of the depolarizing process mentioned above, the current flow should be checked next. Connect the VOM (milliampere 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 observed 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 wastes the anode and will result in reduced anode life. If the current is more than 1.3 times the design needs, a resistance should be added to the circuit. This is done with a length of special high-resistance wire connected to the circuit in the test box. Another method involves disconnecting an anode(s) from the system.

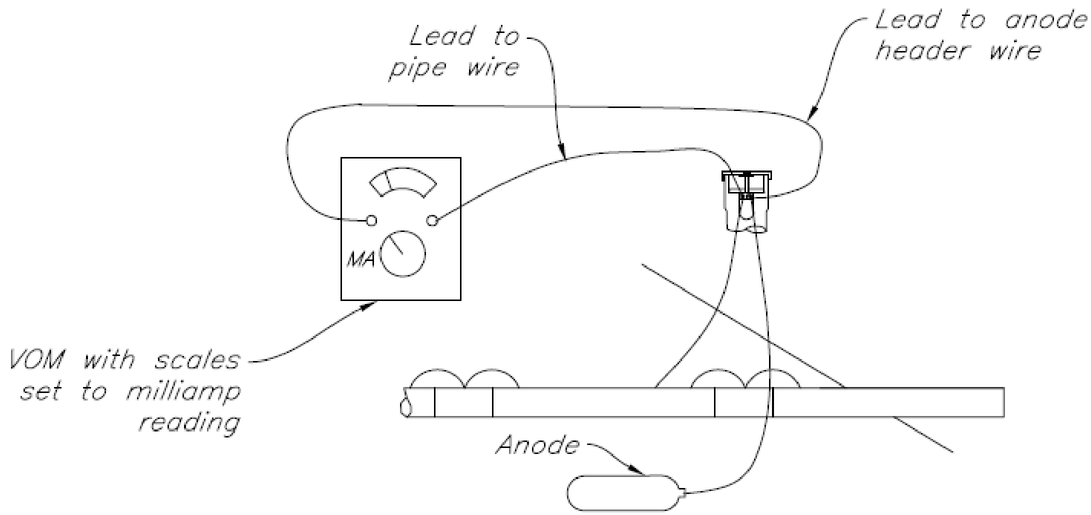

Figure 5. Schematic of Anode to Pipe Current Flow

3. PIPE TO SOIL POTENTIAL (Open Circuit)

Test No. 1 should be repeated with the circuit open (anodes disconnected).

4. ANODE TO SOIL POTENTIAL (Open Circuit, Voltage Output of the Anode, See Figure 6)

This test is a comparative test using the copper-copper sulfate half-cell connected through the VOM (volts DC mode) to the lead wire from the anode. The normal anode voltage will be in the range of 1.4 to 1.8 volts for magnesium anodes, and around 0.85 to 1.2 volts for zinc anodes. A reading of 0 to 0.3 volts means the wire or a connection is broken between the test box and the anode. Sometimes this can be corrected by digging to the base of the post or the test box assembly (as applicable) and back toward the anode and checking the wire for breaks. The break is often at the base of the post because of the post having been knocked over.

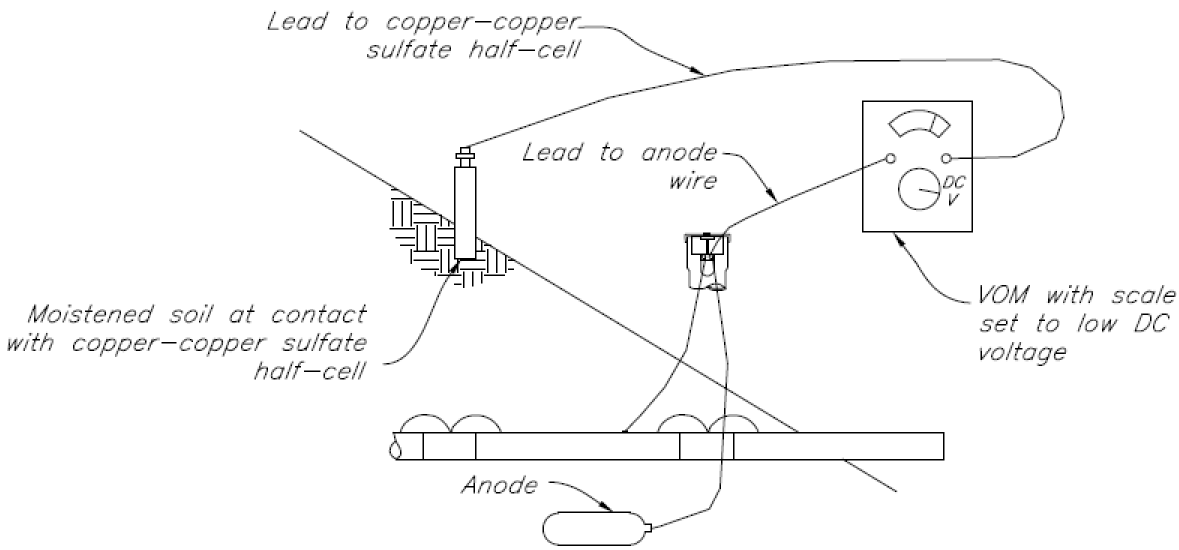

Figure 6. Schematic of Voltage Potential of Anode to Copper-Copper Sulfate Half-Cell

5. CIRCUIT THROUGH PIPE (See Figures 7A and 7B)

The pipe should act like one large wire from the inlet to the last fully buried joint so that current added from the anodes will flow through and protect the total length of the pipe. Since a poor weld under the earth fill is nearly impossible to correct, the pipe must be thoroughly checked before backfill is completed. This can be done by two different methods. These tests should be made during construction and each time that the system is tested thereafter.

Method A: Connect the pipe inlet and outlet in a circuit through a VOM. If the circuit is complete, the voltage should be zero, since the pipe itself has no driving voltage. See Figure 7A.

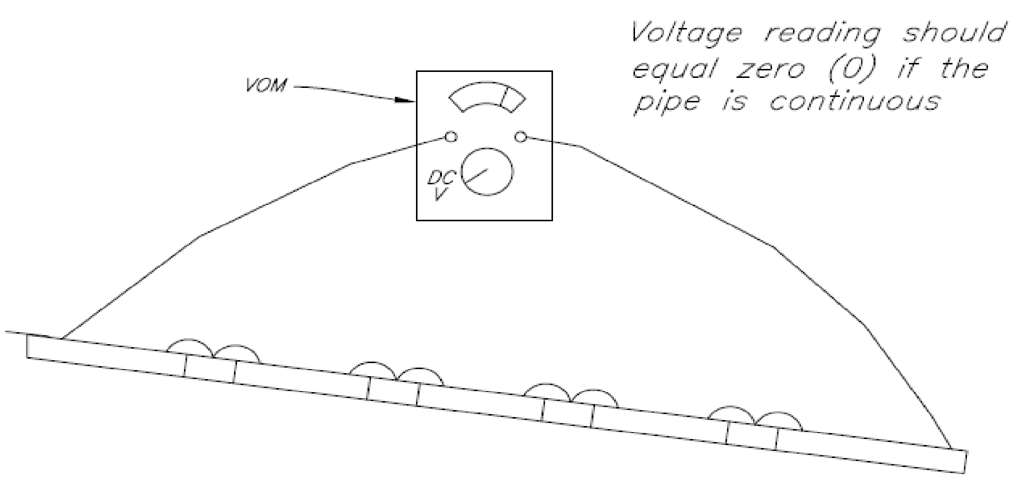

Figure 7A. Schematic of Test for Pipe Continuity

Method B: A similar test is shown in Figure 7B. This test involves measuring the pipe to soil potential at both the inlet and the outlet with leads that are connected successively to the inlet and the outlet. The voltages measured at each location should be equal since the reference cell stays in the same position. The voltages may vary slightly from inlet to outlet because of different soil conditions.

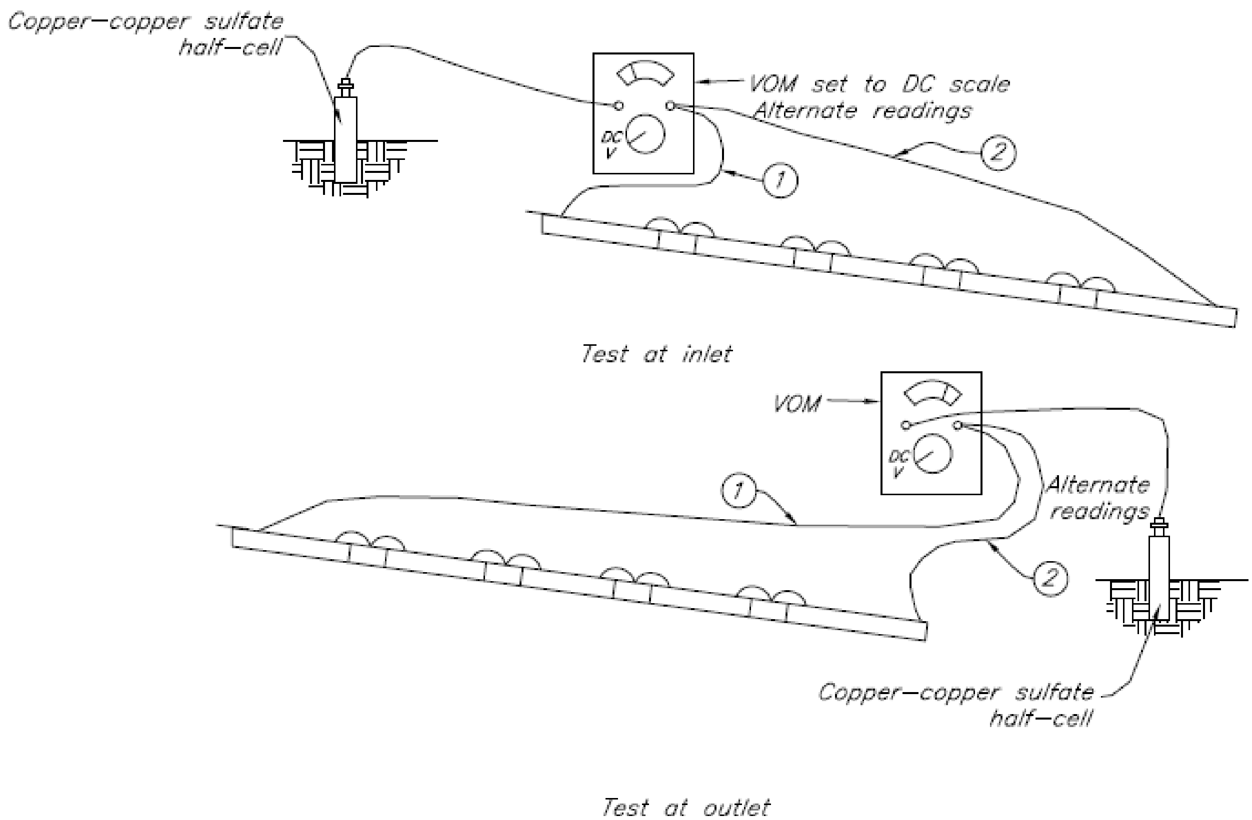

Figure 7B. Schematic of Tests for Pipe Continuity

Typical Continuity Check Readings

Using Method B (Figure 7B)

	Wire Connected To Pipe At	Reference Cell at Inlet	Reference Cell at Outlet
1	Inlet	741 mv	708 mv
2	Outlet	741 mv	708mv

Readings are equivalent, therefore the pipe is continuous.