Cathodic Protection for Galvanized Anchor Rods In Soil

ECB Ashland WI Tower 1998
ECB Fence WI Tower 1991
ECB Bloomington WI Tower 1982

Roger I. Strand, D.E.S

Cathodic Corrosion

Dissimilar metals and alloys have different electrode potentials, and when two or more come into contact in an electrolyte, one metal (that's more reactive) acts as anode and the other (that's less reactive) as cathode. The electropotential difference between the reactions at the two electrodes is the driving force for an accelerated attack on the anode metal, which dissolves into the electrolyte. This leads to the metal at the anode corroding more quickly than it otherwise would and corrosion at the cathode being inhibited. The presence of an electrolyte and an electrical conducting path between the metals is essential for galvanic corrosion to occur. The electrolyte provides a means for ion migration whereby ions move to prevent charge build-up that would otherwise stop the reaction. If the electrolyte contains only metal ions that are not easily reduced (such as Na^+, Ca^{2+}, K^+, Mg^{2+}, or Zn^{2+}), the cathode reaction is the reduction of dissolved H^+ to H_2 or O_2 to OH^-.[1][2][3][4]

In some cases, this type of reaction is intentionally encouraged. For example, low-cost household batteries typically contain carbon-zinc cells. As part of a closed circuit (the electron pathway), the zinc within the cell will corrode preferentially (the ion pathway) as an essential part of the battery producing electricity. Another example is the cathodic protection of buried or submerged structures as well as hot water storage tanks. In this case, sacrificial anodes work as part of a galvanic couple, promoting corrosion of the anode, while protecting the cathode metal.

In other cases, such as mixed metals in piping (for example, copper, cast iron and other cast metals), galvanic corrosion will contribute to accelerated corrosion of parts of the system. Corrosion inhibitors such as sodium nitrite or sodium molybdate can be injected into these systems to reduce the galvanic potential. However, the application of these corrosion inhibitors must be monitored closely. If the application of corrosion inhibitors increases the conductivity of the water within the system, the galvanic corrosion potential can be greatly increased.

Acidity or alkalinity (pH) is also a major consideration with regard to closed loop bimetallic circulating systems. Should the pH and corrosion inhibition doses be incorrect, galvanic corrosion will be accelerated. In most HVAC systems, the use of sacrificial anodes and cathodes is not an option, as they would need to be applied within the plumbing of the system and, over time, would corrode and release particles that could cause potential mechanical damage to circulating pumps, heat exchangers, etc.[5]

1. *Decker, Franco Ian (January 2005). "Volta and the 'Pile'". Electrochemistry Encyclopedia. Case Western Reserve University. Archived from the original on 2012-07-16.*
2. ^ *Turner, Edward (1841). Liebig, Justus; Gregory, William (eds.). Elements of chemistry: including the actual state and prevalent doctrines of the science (7 ed.). London: Taylor and Walton. p. 102. During the action of a simple circle, as of zinc and copper, excited by dilute sulfuric acid, all of the hydrogen developed in the voltaic action is evolved at the surface of the copper.*
3. ^ *Goodisman, Jerry (2001). "Observations on Lemon Cells". Journal of Chemical Education. **78** (4): 516–518. Bibcode:2001JChEd..78..516G. doi:10.1021/ed078p516.* Goodisman notes that many chemistry textbooks use an incorrect model for a cell with zinc and copper electrodes in an acidic electrolyte.
4. ^ *Graham-Cumming, John (2009). "Tempio Voltiano". The Geek Atlas: 128 Places Where Science and Technology Come Alive. O'Reilly Media. p. 97. ISBN 9780596523206.*
5. ^ M. Houser, Corrosion Control Services, Inc., introduction handbook
6. ^ *"Reclothing the First Lady of Metals - Repair Details". Copper Development Association. Retrieved 16 August 2019.*

CHAPTER 2
CATHODIC PROTECTION DESIGN

2-1. Required information.

Before deciding which type, galvanic or impressed current, cathodic protection system will be used and before the system is designed, certain preliminary data must be gathered.

a. Physical dimensions of structure to be protected. One important element in designing a cathodic protection system is the structure's physical dimensions (for example, length, width, height, and diameter). These data are used to calculate the surface area to be protected.

b. Drawing of structure to be protected. The installation drawings must include sizes, shapes, material type, and locations of parts of the structure to be protected.

c. Electrical isolation. If a structure is to be protected by the cathodic system, it must be electrically connected to the anode, as figure 1-2 shows. Sometimes parts of a structure or system are electrically isolated from each other by insulators. For example, in a gas pipeline distribution system, the inlet pipe to each building might contain an electric insulator to isolate inhouse piping from the pipeline. Also, an electrical insulator might be used at a valve along the pipeline to electrically isolate one section of the system from another. Since each electrically isolated part of a structure would need its own cathodic protection, the locations of these insulators must be determined.

d. Short circuits. All short circuits must be eliminated from existing and new cathodic protection systems. A short circuit can occur when one pipe system contacts another, causing interference with the cathodic protection system. When updating existing systems, eliminating short circuits would be a necessary first step.

e. Corrosion history of structures in the area. Studying the corrosion history in the area can prove very helpful when designing a cathodic protection system. The study should reinforce predictions for corrosivity of a given structure and its environment; in addition, it may reveal abnormal conditions not otherwise suspected. Facilities personnel can be a good source of information for corrosion history.

f. Electrolyte resistivity survey. A structure's corrosion rate is proportional to the electrolyte resistivity. Without cathodic protection, as electrolyte resistivity decreases, more current is allowed to flow from the structure into the electrolyte; thus, the structure corrodes more rapidly. As electrolyte resistivity increases, the corrosion rate decreases (table 2-1). Resistivity can be measured either in a laboratory or at the site with the proper instruments. Appendix A explains the methods and equipment needed to complete a soil resistivity survey. The resistivity data will be used to calculate the sizes of anodes and rectifier required in designing the cathodic protection system.

Table 2-1. Corrosivity of soils on steel based on soil resistivity

Soil resistivity range (ohm-cm)	Corrosivity
0 to 2000	Severe
2000 to 10,000	Moderate to severe
10,000 to 30,000	Mild
Above 30,000	Not likely

U.S. Air Force.

g. Electrolyte pH survey. Corrosion is also proportional to electrolyte pH (see glossary for definition of pH and other terms). In general, steel's corrosion rate increases as pH decreases when soil resistivity remains constant.

h. Structure versus electrolyte potential survey. For existing structures, the potential between the structure and the electrolyte will give a direct indication of the corrosivity. According to NACE Standard No. RP-01, the potential requirement for cathodic protection is a negative (cathodic) potential of at least 0.85 volt as measured between the structure and a saturated copper-copper sulfate reference electrode in contact with the electrolyte. A potential which is less negative than -0.85 volt would probably be corrosive, with corrosivity increasing as the negative value decreases (becomes more positive).

i. Current requirement. A critical part of design calculations for cathodic protection systems on existing structures is the amount of current required per square foot (called *current density)* to change the structure's potential to -0.85 volt. The current density required to shift the potential indicates the structure's surface condition. A well coated structure (for example, a pipeline well coated with coal-tar epoxy) will require a very low current density (about 0.05 milliampere per square foot); an uncoated structure would require high current density (about 10 milliamperes per square foot). The average current density required for cathodic protection is 2 milliamperes per square foot of *bare* area. The amount of current required for complete cathodic protection can be determined three ways:

—An actual test on existing structures using a temporary cathodic protection setup.

—A theoretical calculation based on coating efficiency.

—An estimate of current requirements using tables based on field experience.

(1) The second and third methods above can be used on both existing and new structures. Appendix B contains a detailed review of current requirement testing.

(2) Current requirements can be calculated based on coating efficiency and current density (current per square foot) desired. The efficiency of the coating as supplied will have a direct effect on the total current requirement, as equation 2-1 shows:

$$I = (A)(I')(1.0\text{-}CE), \qquad \text{(eq 2-1)}$$

where I is total protective current, A is total structure surface area in square feet, I' is required current density, and CE is coating efficiency. Equation 2-1 may be used when a current requirement test is not possible, as on new structures, or as a check of the current requirement test on existing structures. Coating efficiency is directly affected by the type of coating used and by quality control during coating application. The importance of coating efficiency is evident in the fact that a bare structure may require 100,000 times as much current as would the same structure if it were well coated.

(3) Current requirements also can be estimated from table 2-2. The table gives an estimate of current, in milliamperes per square foot, required for complete cathodic protection. That value, multiplied by the surface area of the structure to be protected (in square feet) gives the total estimated current required. Caution should be used when estimating, however, as under- or overprotection may result.

Table 2-2. Typical current density requirements for cathodic protection of uncoated steel

Environment	Current density (mA/sq ft)	
	AFM 88-9[a]	Gerrard[b]
Neutral soil	0.4 to 1.5	0.4 to 1.5
Well aerated neutral soil	2 to 3	2 to 3
Wetsoil	1 to 6	2.5 to 6
Highly acidic soil	3 to 15	5 to 15
Soil supporting active sulfate-reducing bacteria	6 to 42	Up to 42
Heated soil	3 to 25	5 to 25
Stationary freshwater	1 to 6	5
Moving freshwater containing dissolved oxygen	5 to 15	5 to 15
Seawater	3 to 10	5 to 25

[a] Data are from Air Force Manual AFM 88-9, *Corrosion Control* (U.S. Air Force, August 1962), chap 4, p 203.

[b] Data are from J.S. Gerrard, "Practical Applications of Cathodic Protection," *Corrosion*, Vol 2 (L.L. Shreir, Ed.), Newnes-Butterworths, London, 1976, p 11:65. Used with permission.

j. Coating resistance. A coating's resistance decreases greatly with age and directly affects structure-to-electrolyte resistance for design calculations. The coating manufacturers supply coating resistance values.

k. Protective current required. By knowing the physical dimensions of the structure to be protected, the surface area can be calculated. The product of the surface area multiplied by current density obtained previously in *I* above gives the total current required.

l. The need for cathodic protection. For existing structures, the current requirement survey *(I* above) will verify the need for a cathodic protection system. For new systems, standard practice is to assume a current density of at least 2 milliamperes per square foot of bare area will be needed to protect the structure. (However, local corrosion history may demand a different current density.) In addition, cathodic protection is *mandatory* for underground gas distribution lines (Department of Transportation regulations—Title 49, *Code of Federal Regulations,* Oct 1979) and for water storage tanks with a 250,000-gallon capacity or greater. Cathodic protection also is required for underground piping systems located within 10 feet *a. Sacrificial anode (galvanic) cathodic protection system design.* The following eight steps are required when designing galvanic cathodic protection systems. Appendix C gives examples of galvanic cathodic protection designs.

(1) Review soil resistivity. The site of lowest resistivity will likely be used for anode location to minimize anode-to-electrolyte resistivity. In addition, if resistivity variations are not significant, the average resistivity will be used for design calculations.

(2) Select anode. As indicated in paragraph 1-4, galvanic anodes are usually either magnesium or zinc. Zinc anodes are used in extremely corrosive soil (resistivity below 2000 ohm- centimeters). Data from commercially available anodes must be reviewed. Each anode specification will include anode weight, anode dimensions, and package dimensions (anode plus backfill), as table 2-3 shows for magnesium-alloy anodes. In addition, the anode's driving potential must be considered (para a[3] below). The choice of anode from those available is arbitrary; design calculations will be made for several available anodes, and the most economical one will be chosen.

Table 2-3. Weights and dimensions of selected high-potential magnesium-alloy anodes for use in soil or water

Weight (lb)	Size (in.)	Packaged wt (lb)	Packaged size (in.)
3	3.75 x 3.75 x 5	12	6 x 10
5	3.75 x 3.75 x 7.5	17	6 x 12
9	2.75 x 2.75 x 26	35	6 x 31
9	3.75 x 3.75 x 13.25	27	6 x 17
12	3.75 x 3.75 x 18	36	6 x 23
14	2.75 x 2.75 x 41	50	6 x 46
14	3.75 x 3.75 x 21	42	6.5 x 26
17	2.75 x 2.75 x 50	60	6 x 55
17	3.75 x 3.75 x 26	45	6.5 x 29
20	2.5 x 2.5 x 59.25	70	5 x 66
24	4.5 x 4.5 x 23	60	7 x 30
32	5.5 x 5.5 x 21	74	8 x 28
40	3.75 x 3.75 x 59.25	105	6.5 x 66
48	5.5 x 5.5 x 30	100	8 x 38
48	8 x 16	100	12 x 25
60	4.5 x 4.5 x 60	—	—

Note: Core material is a galvanized 20-gage perforated steel strip. Anodes longer than 24 inches have a 9-gage core. The connecting wire is a 10-foot length of solid No. 12 AWG TW insulated copper wire, silver-soldered to the core with joints sealed against moisture. Special wires or other lengths are available.

U.S. Air Force.

(3) Calculate net driving potential for anodes. The open-circuit potential of standard alloy magnesium anodes is approximately -1.55 volts to a copper-copper sulfate half-cell. The open-circuit potential of high-manganese magnesium anodes is approximately -1.75 volts to a copper-copper sulfate half-cell.

(a) The potential of iron in contact with soil or water usually ranges around -0.55 volt relative to copper-copper sulfate. When cathodic protection is applied using magnesium anodes, the iron potential assumes some value between -0.55 and -1.0 volt, depending on the degree of protection provided. In highly corrosive soils or waters, the natural potential of iron may be as high as -0.82 volt relative to copper-copper sulfate. From this, it is evident that -0.55 volt should not be used to calculate the net driving potential available from magnesium anodes.

(b) A more practical approach is to consider iron polarized to -0.85 volt. On this basis, standard alloy magnesium anodes have a driving potential of 0.70 volt (1.55-0.85 0.70) and high-potential magnesium anodes have a driving potential of 0.90 volt (1.75-0.85 0.90). For cathodic protection design that involves magnesium anodes, these potentials, 0.70 and 0.90 volt, should be used, depending on the alloy selected.

(4) Calculate number of anodes needed to meet groundbed resistance limitations. The total resistance (RT) of the galvanic circuit is given by equation 2-2:

$$R_T = R_a + R_w + R_c, \qquad \text{(eq 2-2)}$$

where R_a is the anode-to-electrolyte resistance, R_w is the anode lead wire resistance, and R_c is the structure-to-electrolyte resistance. The total resistance also can be found by using equation 2-3:

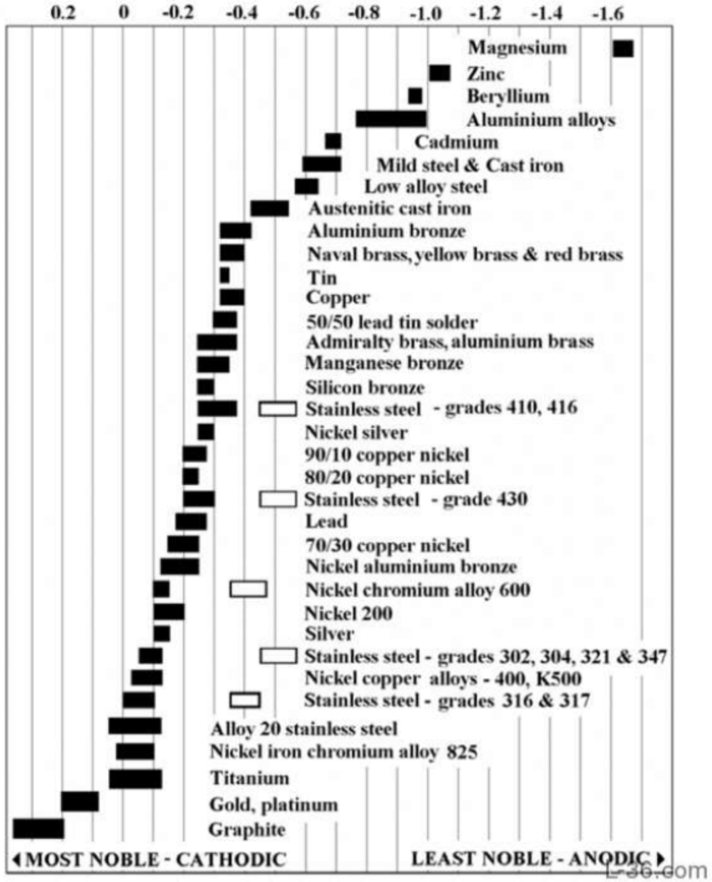
$$R_T = \frac{\Delta E}{I}, \qquad \text{(eq 2-3)}$$

where ΔE is the anode's driving potential discussed in a(3) above and I is the current density required to achieve cathodic protection (para 2-1). R_c in equation 2-2 can be calculated by using equation 2.4:

$$R_c = \frac{R}{A}, \qquad \text{(eq 2-4)}$$

where R is the average coating resistance, in ohms per square feet, at the end of the proposed lifetime for the system (R is specified by the supplier), and A is the structure's surface area in square feet. Assuming R_w in equation 2-2 is negligible, that anode-to-electrolyte resistance can then be calculated from equation 2-5:

water where Stainless Steel become active, while the shaded areas show the potentials of Stainless Steel when is in passive state.



Galvanic Series In Flowing Sea Water

Steady State Electrode Material Potential, Volts referenced to Saturated Calumel Half-Cell

Graphite	+0.25
Platinum	+0.15
Zirconium	0.04
Type 316 Stainless Steel (Passive)	0.05

CHAPTER 1
INTRODUCTION TO CATHODIC PROTECTION

1-1. Purpose.

This manual presents design guidance for cathodic protection systems.

1-2. References.

a. Government publications.

Department of Transportation

Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402

Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards, Subpart 1 - Requirements *Register,* Vol 36, No. 126 (June 30, 1971).

b. Nongovernment publications.

National Association of Corrosion Engineers (NACE), P.O. Box 218340, Houston, TX 77084

Standard RP-01-69 (1972 revision	Control of External Corrosion on Underground or Submerged Metallic Piping Systems
Standard RP-02-72	Direct Calculation of Economic Appraisals of Corrosion Control Measures

1-3. Corrosion.

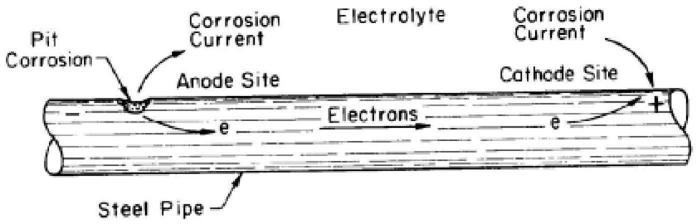
Corrosion is an electrochemical process in which a current leaves a structure at the anode site, passes through an electrolyte, and reenters the structure at the cathode site as figure 1-1 shows. For example, one small section of a pipeline may be anodic because it is in a soil with low resistivity compared to the rest of the line. Current would leave the pipeline at that anode site, pass through the soil, and reenter the pipeline at a cathode site. Current flows because of a potential difference between the anode and cathode. That is, the anode potential is more negative than the cathode potential, and this difference is the driving force for the corrosion current. The total system—anode, cathode, electrolyte, and metallic connection between anode and cathode (the pipeline in fig 1-1)—is termed a *corrosion cell.*

1-4. Cathodic protection.

Cathodic protection is a method to reduce corrosion by minimizing the difference in potential between anode and cathode. This is achieved by applying a current to the structure to be protected (such as a pipeline) from some outside source. When enough current is applied, the whole structure will be at one potential; thus, anode and cathode sites will not exist. Cathodic protection is commonly used on many types of structures, such as pipelines, underground storage tanks, locks, and ship hulls.

1-5. Types of cathodic protection systems.

There are two main types of cathodic protection systems: galvanic and impressed current. Figure 1-2 shows these two types. Note that both types have anodes (from which current flows into the



Reprinted from Cathodic Protection, L.M. Applegate, 1960, with permission of Mc Graw-Hill Book Company

Figure 1-1. Corrosion of a pipeline due to localized anode and cathode sites.

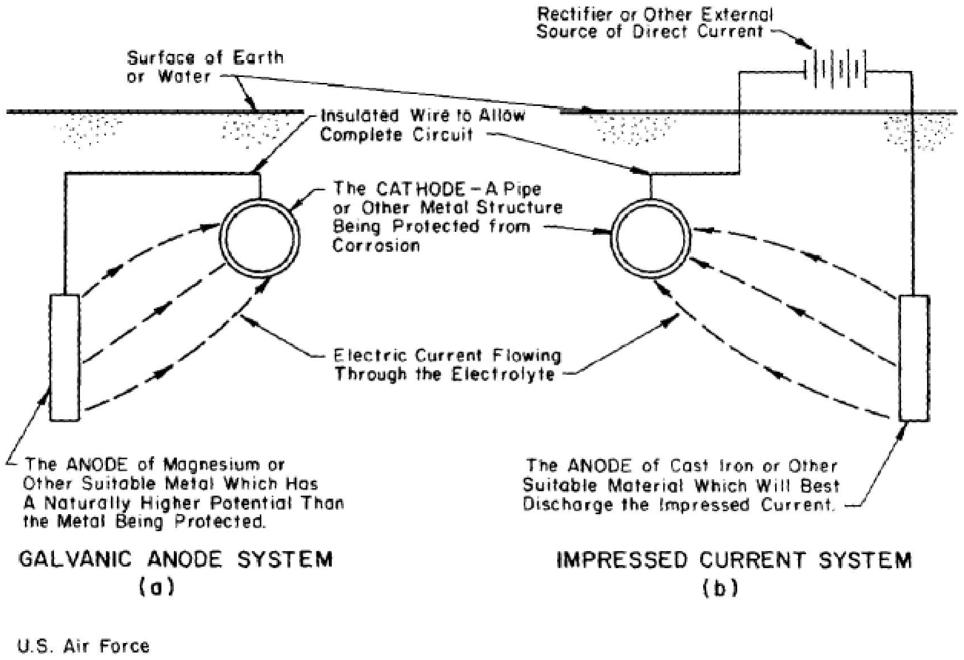
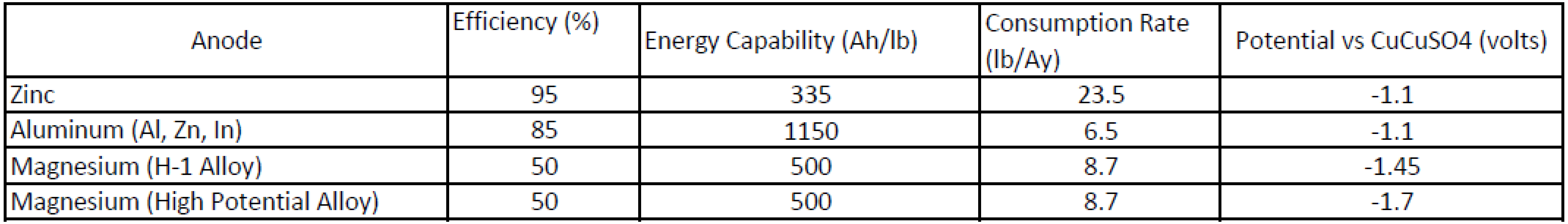


Figure 1-2. (a) Galvanic and (b) impressed current systems for cathodic protection.

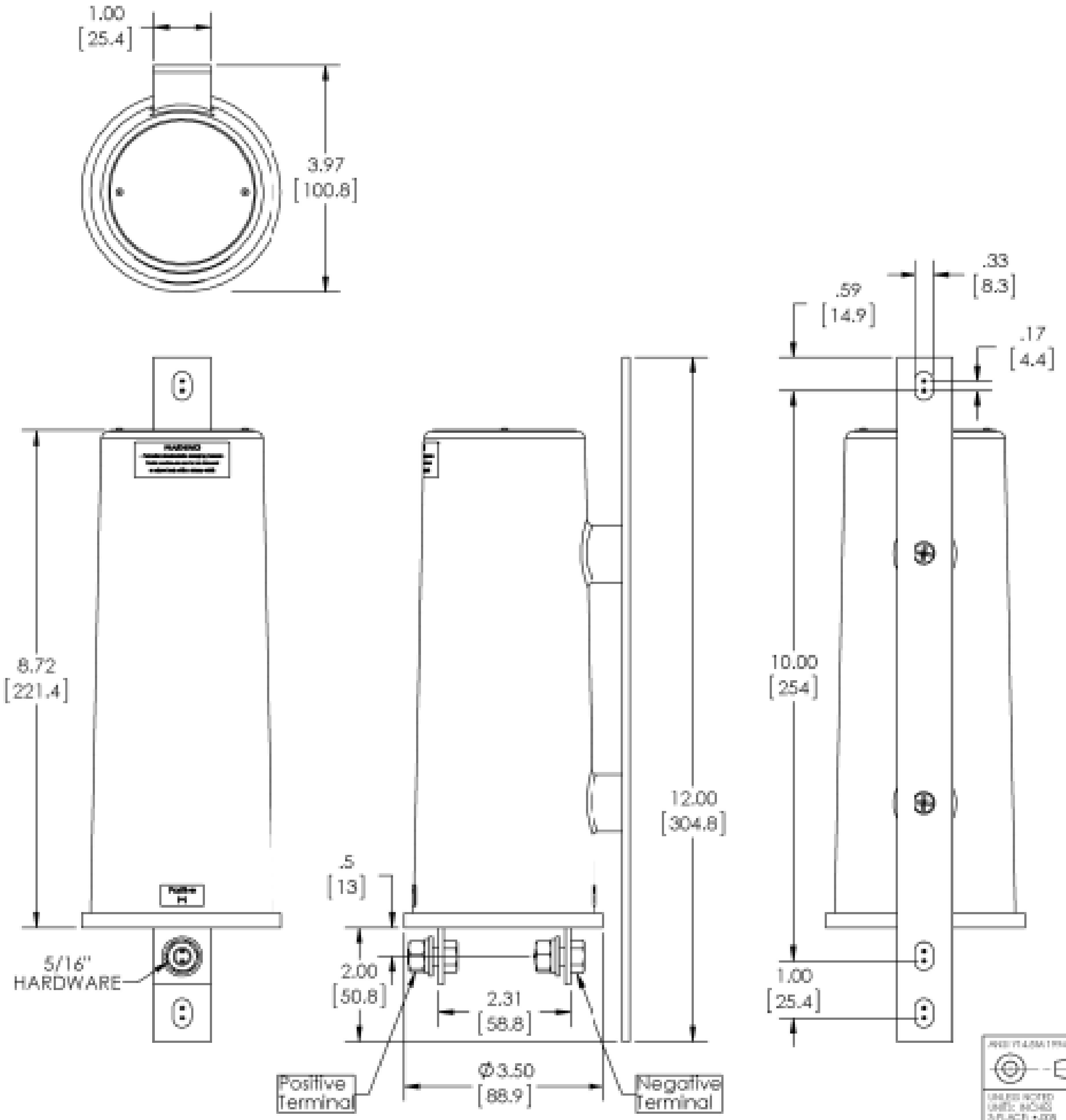
electrolyte), a continuous electrolyte from the anode to the protected structure, and an external metallic connection (wire). These items are essential for all cathodic protection systems.

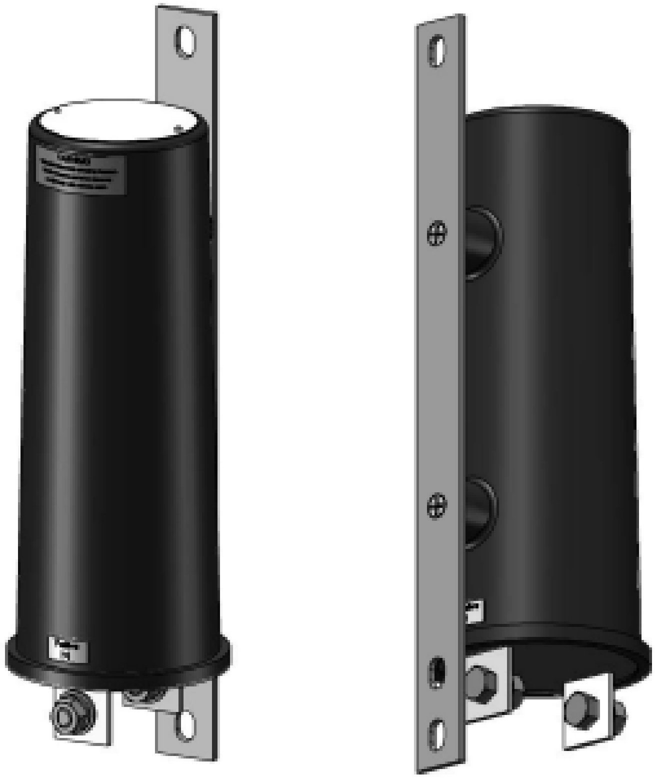
a. Galvanic system. A galvanic cathodic protection system makes use of the corrosive potentials for different metals. Without cathodic protection, one area of the structure exists at a more negative potential than another, and corrosion results. If, however, a much less inert object (that is, with much more negative potential, such as a magnesium anode) is placed adjacent to the structure to be protected, such as a pipeline, and a metallic connection (insulated wire) is installed between the object and the structure, the object will become the anode and the entire structure will become the cathode. That is, the new object corrodes sacrificially to protect the structure as shown in figure 1-2. Thus, the galvanic cathodic protection system is called a *sacrificial anode cathodic protection system* because the anode corrodes sacrificially to protect the structure. Galvanic anodes are usually made of either magnesium or zinc because of these metals' higher potential compared to steel structures.

b. Impressed current systems. Impressed current cathodic protection systems use the same elements as the galvanic protection system, only the structure is protected by applying a current to it from an anode. The anode and the structure are connected by an insulated wire, as for the galvanic system. Current flows from the anode through the electrolyte onto the structure, just as in the galvanic system. The main difference between galvanic and impressed current systems is that the galvanic system relies on the difference in potential between the anode and structure, whereas the impressed current system uses an external power source to drive the current, as figure 1-2b shows. The external power source is usually a rectifier that changes input a.c. power to the proper d.c. power level. The rectifier can be adjusted, so that proper output can be maintained during the system's life. Impressed current cathodic protection system anodes typically are high-silicon cast iron or graphite.



Anode	Efficiency (%)	Energy Capability (Ah/lb)	Consumption Rate (lb/Ay)	Potential vs CuCuSO4 (volts)
Zinc	95	335	23.5	-1.1
Aluminum (Al, Zn, In)	85	1150	6.5	-1.1
Magnesium (H-1 Alloy)	50	500	8.7	-1.45
Magnesium (High Potential Alloy)	50	500	8.7	-1.7





NOTE: Applies to all SSD models with an optional terminal arrangement (non -R model numbers)

ANSI Y14.5M 1994 APPLIES

UNLESS NOTED
UNITS: INCHES
3-PLACE: ±.005
2-PLACE: ±.015
1-PLACE / FRACT: ±.03
ANGULAR: ±1

DAIRYLAND ELECTRICAL INDUSTRIES, INC.
P.O. BOX 187
STOUGHTON, WI 53589
608-877-9900
DAIRYLAND.COM

DESCRIPTION
SSD Outline Drawing - AI Models with Optional Terminals

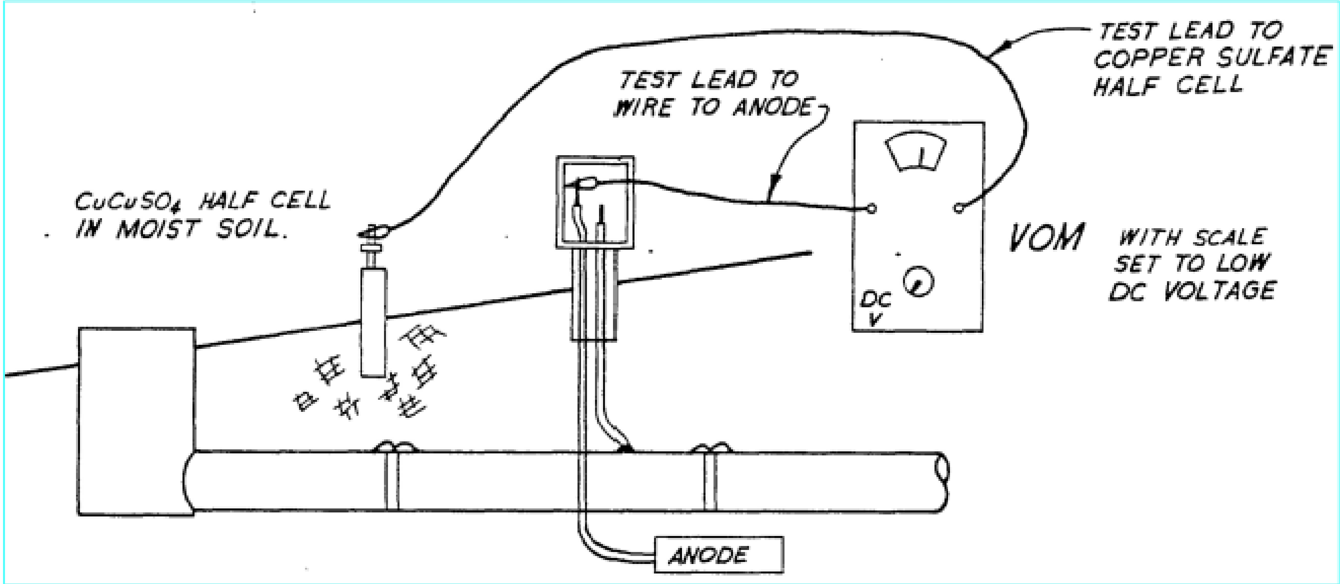
DOCUMENT #	REV	DATE DRAWN	DWG SIZE	DATE APPROVAL
100075	A	2015-04-08	B	2015-04-10

SCALE 1:2 DRAWN: JPW SHEET: 1 OF 1 DWG APPR HNT


DANGER
BEWARE
OF
FALLING ICE
FROM
TOWER

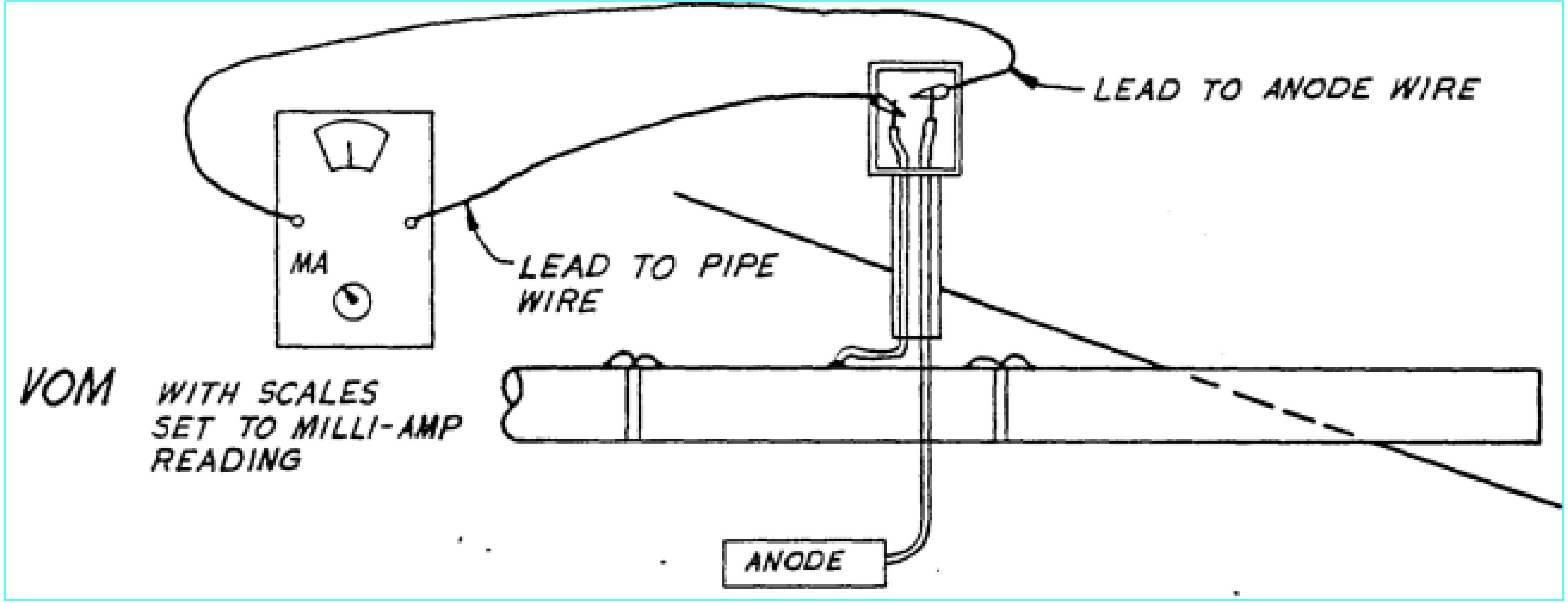
(3) The voltage output of the anode.

This test is a comparative test using the copper sulfate half-cell as in Test 1. The normal anode potential voltage will be in the range of 1.4 to 1.6 volts. A 0 to 0.3 voltage reading 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, back toward the anode, and checking the wire for breaks, since the break often is at the base of the post due to the post having been knocked over. A schematic of the test is:



(4) The measuring of the current flow from the anode(s) to the pipe.

This could vary from 5 ma (0.005 amp) to 300^+ ma (0.3 amp), depending on pipe area, soils resistivity, and soil moisture. A current flow larger than the design current usually means the pipe is protected to a higher level than needed and a waste of the anode, which will result in a reduced anode life. If the current is more than 1.3 times the design needs, a resistance should be added to the circuit to extend the life of the anodes. This is done with a length of special high-resistance wire between the connections in the test box. Schematic follows:


LEAD TO ANODE WIRE
MA
LEAD TO PIPE WIRE
VOM WITH SCALES SET TO MILLI-AMP READING
ANODE

M.C. Miller RE-5 Electrode

Call for pricing

□ ADD TO CART
(HTTP://WWW.AEGION.COM/ABOUT/RESOURCES/CORRPROCATALOG/REFERENCE-ELECTRODES/PORTABLE-REFERENCE-ELECTRODE/RE-5-ELECTRODE#)

M.C. Miller offers a large selection of portable copper/copper sulfate reference electrodes. The RE-5 model is their most standard model with a flat surface ceramic plug. The flat plug allows for good performance in all soil conditions including when the soil is hard packed. The main body is built out of a Lexan tube with a side viewing window to check on the reference cell's condition. Inside the tube, the reference cell comes with a high purity copper core rod an some initial copper/copper sulfate crystals for initial use.

Test Station - Magnesium Anode

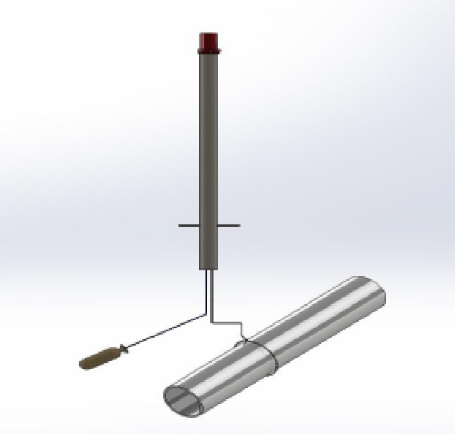
When installing a sacrificial magnesium anode in the ground, an Anode Test Station would be recommended to go along with it. Made using a test station head and industry approved shunt, the anode test station can assist in monitoring the current draw on the anode bed to help show the effectiveness of the anode over its designed lifespan.

Specification

- Built with a test station head and industry standardized test station shunt
- Shunts available in 0.1, 0.01 and 0.001 Ohms
- Comes with a 5-foot mounting post and a 2-foot anchoring post.
- Analog ammeter also available to show anode bed's current output

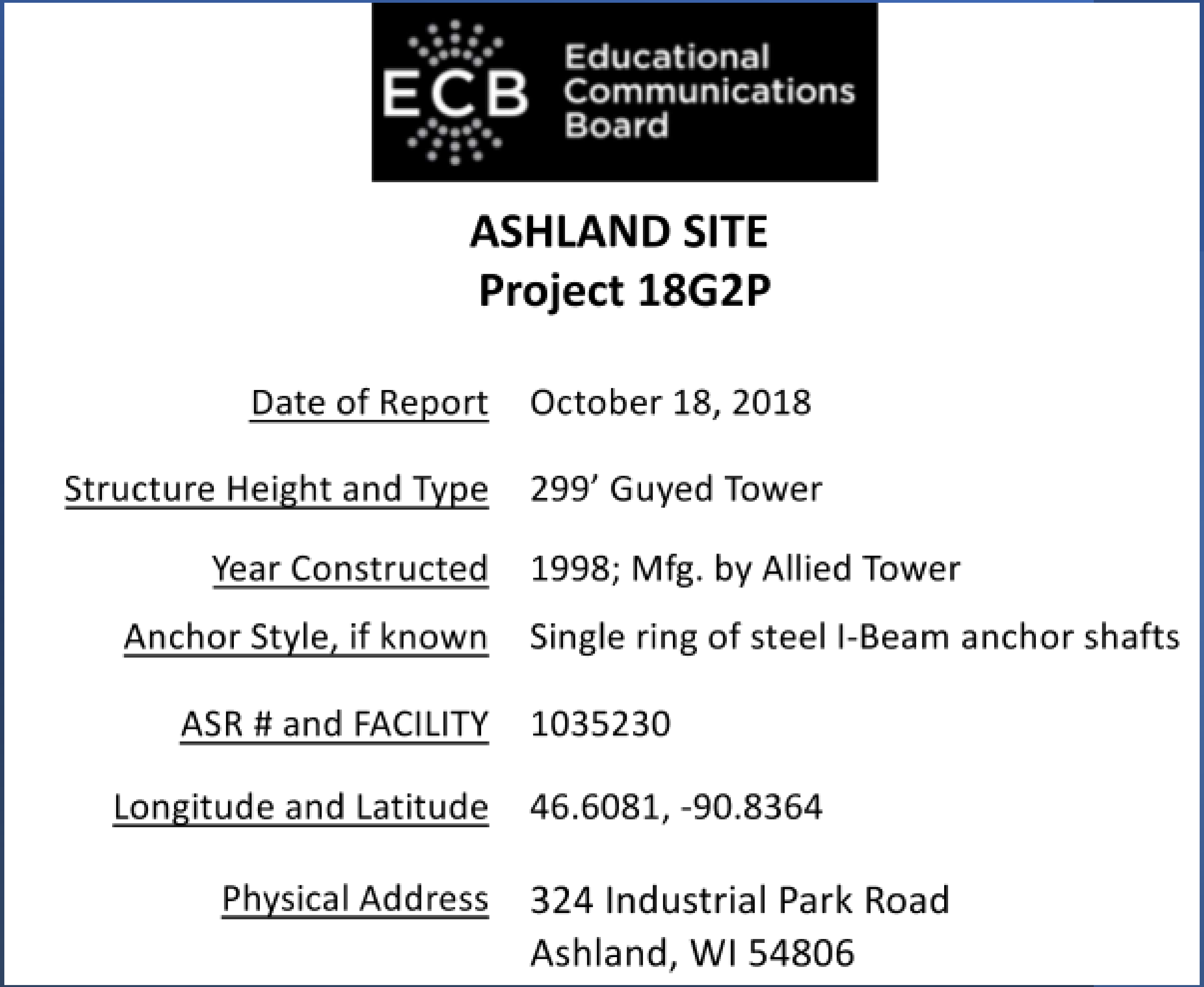
Application

To be installed over top of the anode bed, the Anode Test Station helps monitor the effectiveness of the sacrificial cathodic protection system while also being an effective marker of where the anode bed was installed. A lead wire comes from the anode(s) and is attached to the shunt. From the other terminal of the shunt, a structure connection wire is connected onto the pipe or tank to complete the cathodic protection circuit. Using a True-RMS voltmeter, you can measure the voltage difference across the shunt and calculate the current being drawn from the anode bed.



Ordering Information

When ordering the Anode Test Station, please keep in mind if you also require any sacrificial anodes, lead wire or a connection method to the pipeline or tank



ECB Educational Communications Board

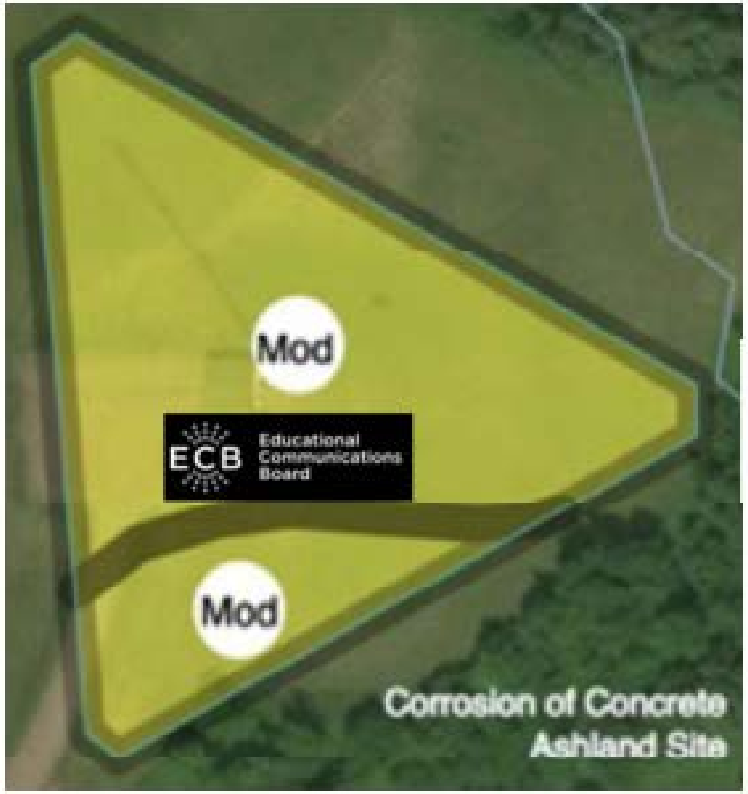
ASHLAND SITE
Project 18G2P

Date of Report	October 18, 2018
Structure Height and Type	299’ Guyed Tower
Year Constructed	1998; Mfg. by Allied Tower
Anchor Style, if known	Single ring of steel I-Beam anchor shafts
ASR # and FACILITY	1035230
Longitude and Latitude	46.6081, -90.8364
Physical Address	324 Industrial Park Road Ashland, WI 54806

CORROSION RISK

🟩 LOW
🟨 MODERATE
🟥 HIGH

Risk for corrosion of steel is HIGH for both soils.



Site-wide, corrosion risk for concrete is MODERATE

pH

pH ranges between very strongly acid to strongly alkaline, with the average pH slightly alkaline.

pH RANGE, BY DEPTH:

- **Soil #1**
  0 to 17 inches: 4.5 to 7.3
  17 to 35 inches: 6.1 to 7.8
  35 to 80 inches: 7.9 to 9.0

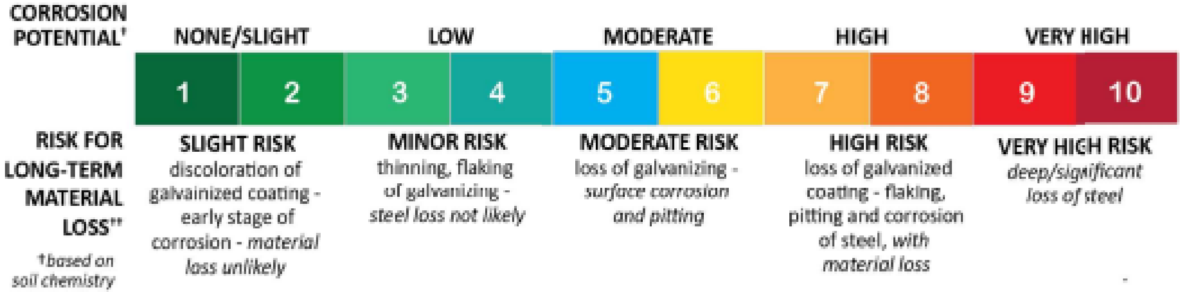
- **Soil #2**
  0 to 12 inches: 4.5 to 7.3
  12 to 30 inches: 5.1 to 7.8
  30 to 80 inches: 7.9 to 9.0

< 3.5	**3.5-4.4**	**4.5-5.0**	**5.1-5.5**	**5.6-6.0**	**6.1-6.5**	**6.6-7.3**	**7.4-7.8**	**7.9-8.4**	**8.5-9.0**	**> 9.1**
■	■	■	■	■	■	■	■	■	■	■
ultra acid	*extremely acid*	*very strongly acid*	*strongly acid*	*moderately acid*	*slightly acid*	*neutral*	*slightly alkaline*	*moderately alkaline*	*strongly alkaline*	*very strongly alkaline*

SUMMARY

The Ashland tower has been in service approximately 20-years.

DUAL RISK INDEX©



CORROSION POTENTIAL†	NONE/SLIGHT	LOW	MODERATE	HIGH	VERY HIGH
	1 🟩 2 🟩	3 🟩 4 🟩	5 🟦 6 🟨	7 🟧 8 🟧	9 🟥 10 🟥
RISK FOR LONG-TERM MATERIAL LOSS††	**SLIGHT RISK** discoloration of galvainized coating - early stage of corrosion - *material loss unlikely*	**MINOR RISK** thinning, flaking of galvanizing - *steel loss not likely*	**MODERATE RISK** loss of galvanizing - *surface corrosion and pitting*	**HIGH RISK** loss of galvanized coating - flaking, pitting and corrosion of steel, *with material loss*	**VERY HIGH RISK** *deep/significant loss of steel*

†based on soil chemistry and site conditions

††considers anchor properties and other influences

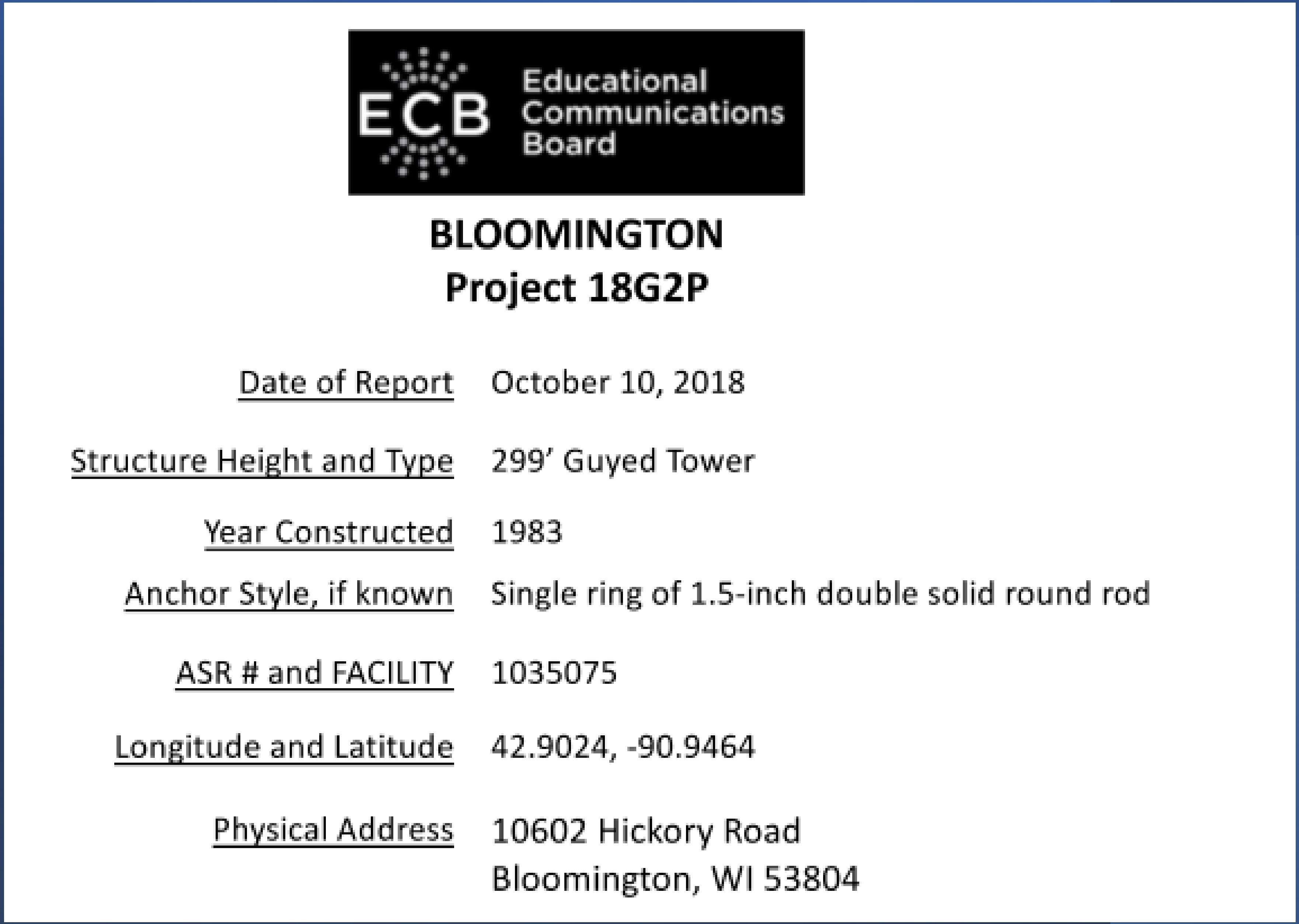
CORROSION POTENTIAL: 8

- CORROSION OF STEEL – *High*
- CORROSION OF CONCRETE – *Moderate*
- Nearby streams and proximity to Lake Superior may have created underground streams, as well as those visible on the surface.
- Soil pH ranges from *very acid to strongly alkaline*, increasing risk potential for both concrete and steel
- Electrical Conductivity is 0.47 to 0.40 dS/meter – *corrosive to steel*
- Entire site is somewhat poorly draining, with ponding likely at C Anchor.
- A welding facility and source of stray current (Mike's Automotive), is located approximately 800-feet from A anchor.

RISK FOR LONG-TERM MATERIAL LOSS: 6

Soil chemistry, high electrical conductivity and high water table all contribute to this potentially corrosive environment for unprotected steel anchor shafts. At present, risk for steel loss is *moderate*. Over time, the risk will continue to increase.

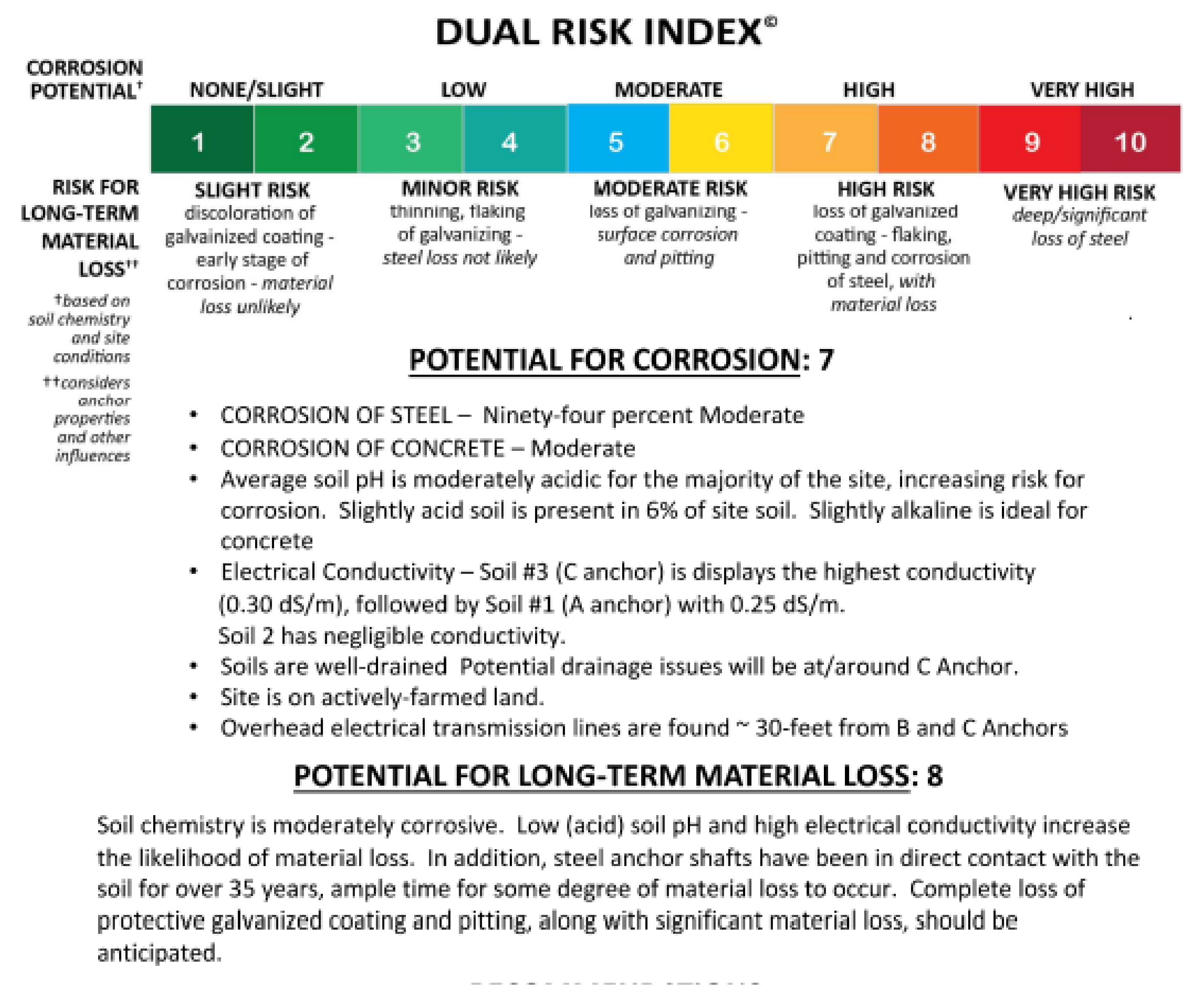
Photo 11_SW Anchor - Worst Area



Educational Communications Board

BLOOMINGTON
Project 18G2P

Date of Report	October 10, 2018
Structure Height and Type	299’ Guyed Tower
Year Constructed	1983
Anchor Style, if known	Single ring of 1.5-inch double solid round rod
ASR # and FACILITY	1035075
Longitude and Latitude	42.9024, -90.9464
Physical Address	10602 Hickory Road Bloomington, WI 53804



DUAL RISK INDEX©

CORROSION POTENTIAL†	NONE/SLIGHT		LOW		MODERATE		HIGH		VERY HIGH	
	1	2	3	4	5	6	7	8	9	10
RISK FOR LONG-TERM MATERIAL LOSS††	**SLIGHT RISK** discoloration of galvainized coating - early stage of corrosion - *material loss unlikely*		**MINOR RISK** thinning, flaking of galvanizing - *steel loss not likely*		**MODERATE RISK** loss of galvanizing - *surface corrosion and pitting*		**HIGH RISK** loss of galvanized coating - flaking, pitting and corrosion of steel, *with material loss*		**VERY HIGH RISK** *deep/significant loss of steel*	

†based on soil chemistry and site conditions

††considers anchor properties and other influences

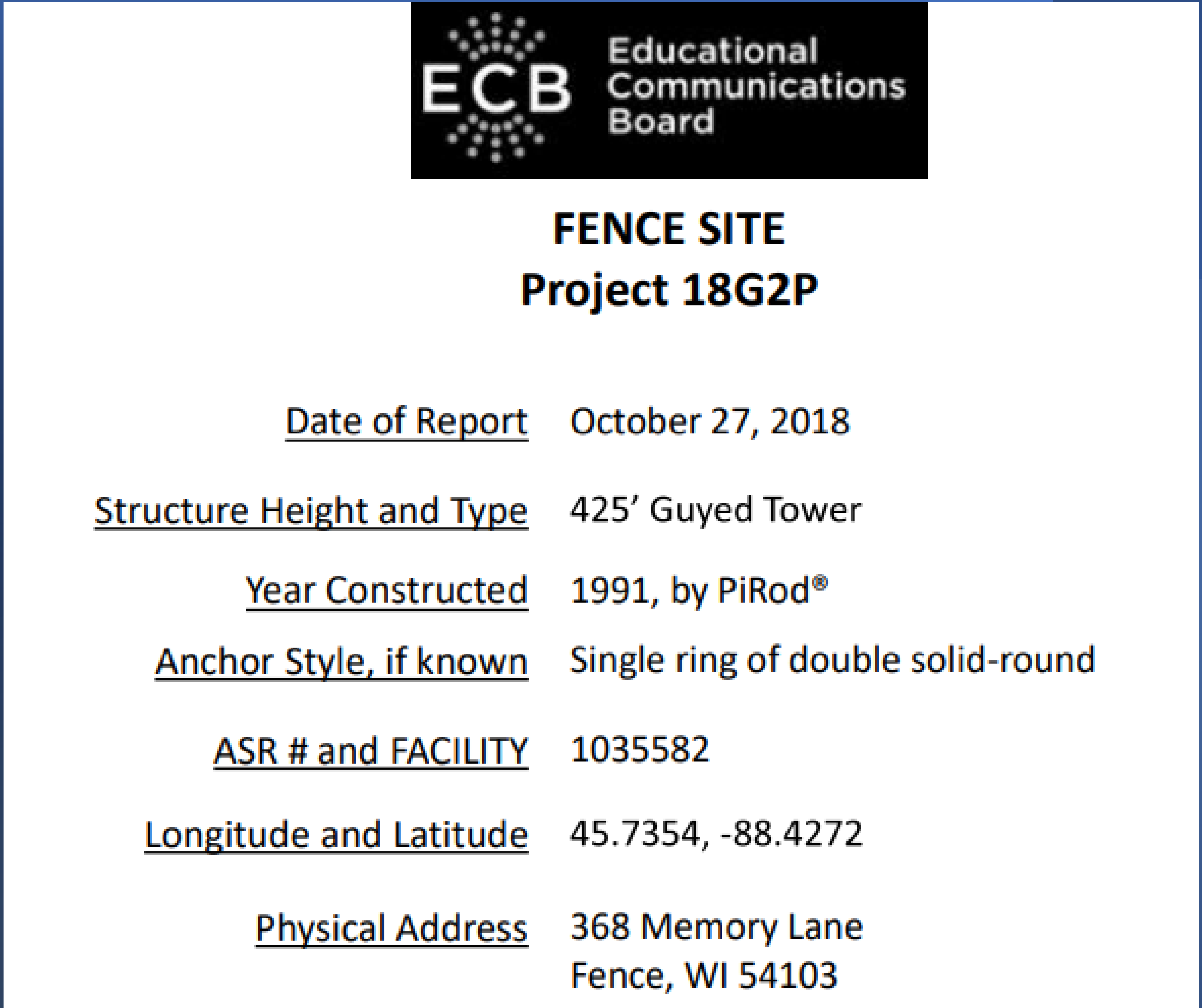
POTENTIAL FOR CORROSION: 7

- CORROSION OF STEEL – Ninety-four percent Moderate
- CORROSION OF CONCRETE – Moderate
- Average soil pH is moderately acidic for the majority of the site, increasing risk for corrosion. Slightly acid soil is present in 6% of site soil. Slightly alkaline is ideal for concrete
- Electrical Conductivity – Soil #3 (C anchor) is displays the highest conductivity (0.30 dS/m), followed by Soil #1 (A anchor) with 0.25 dS/m. Soil 2 has negligible conductivity.
- Soils are well-drained Potential drainage issues will be at/around C Anchor.
- Site is on actively-farmed land.
- Overhead electrical transmission lines are found ~ 30-feet from B and C Anchors

POTENTIAL FOR LONG-TERM MATERIAL LOSS: 8

Soil chemistry is moderately corrosive. Low (acid) soil pH and high electrical conductivity increase the likelihood of material loss. In addition, steel anchor shafts have been in direct contact with the soil for over 35 years, ample time for some degree of material loss to occur. Complete loss of protective galvanized coating and pitting, along with significant material loss, should be anticipated.

Photo 04_North Anchor - Anchor Shaft Below Grade



Educational Communications Board

FENCE SITE
Project 18G2P

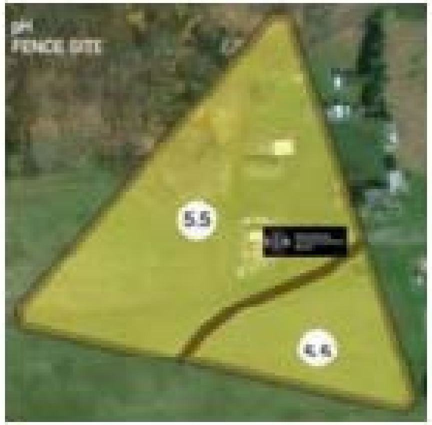
Date of Report	October 27, 2018
Structure Height and Type	425’ Guyed Tower
Year Constructed	1991, by PiRod®
Anchor Style, if known	Single ring of double solid-round
ASR # and FACILITY	1035582
Longitude and Latitude	45.7354, -88.4272
Physical Address	368 Memory Lane Fence, WI 54103

Risk for corrosion of steel is HIGH.

Risk is MODERATE for concrete corrosion.

🟩	🟨	🟥
LOW	MODERATE	HIGH

pH



Average pH is 5.5 and strongly acid. The date, below, illustrates the varying pH readings.

pH RANGE, BY SOIL AND DEPTH:

- **Soil #1**
  0 to 33 inches: 4.5 to 6.0
  33 to 61 inches: 5.1 to 6.5
- **Soil #2**
  0 to 1 inch: 4.5 to 7.3
  1 to 13 inches: 4.5 to 6.0
  13 to 60 inches: 4.5 to 6.5

< 3.5	3.5-4.4	4.5-5.0	5.1-5.5	5.6-6.0	6.1-6.5	6.6-7.3	7.4-7.8	7.9-8.4	8.5-9.0	> 9.1
🟥	🟧	🟧	🟨	🟨	🟩	🟩	🟦	🟦	🟪	🟪
ultra acid	*extremely acid*	*very strongly acid*	*strongly acid*	*moderately acid*	*slightly acid*	*neutral*	*slightly alkaline*	*moderately alkaline*	*strongly alkaline*	*very strongly alkaline*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MISCHLER'S
HARLEY-DAVIDSON

Cathodic Protection-Galvanized Anchor Rods in Soil

Acknowledgements

Hodge Structural Engineers-Dave Davis

Edge Consulting Engineers

Technical Manual No. 5-811-7 Department of the Army, Washington DC. 22 April 1985