Chapter 7

Corrosion Life of Steel Foundation Products

Torque Anchors
Steel Piers

Corrosion Consideration

Corrosion is defined as the deterioration of a metallic structure due to its interaction with the surrounding environment.

Steel Underground - How Long Does It Last? Steel foundation supports are subjected to a range of corrosive forces that are quite different from steel exposed to atmospheric conditions. The performance of steel and galvanized structural steel elements underground are not as well understood as is the life expectancy of steel products in above ground applications.

For corrosion to initiate, steel requires not only oxygen but also the presence of dissolved salts in water. If either of these items is absent, corrosion will not occur.

The causes of corrosion on buried metallic structures are generally understood, but this knowledge base does not always permit an accurate prediction of a design life when placed in a corrosive environment. This chapter is not intended as a rigorous technical text; rather it provides knowledge to help the reader to establishing whether corrosion could be a critical factor in a specific foundation support application.

> A qualified engineer, knowledgeable in design for corrosion environments should be consulted when foundation support products are to be used in a known corrosive environment.

Corrosion occurs by an electrochemical process. In order for corrosion of an underground metallic structure to occur, there must be an electrical potential, an electrolyte (dissolved salts in water) and aeration present.

Difference in Electrical Potential: Corrosion is initiated by a difference in electric potential (electric charge) between two points on a metallic structure. This electrical potential can be caused by strains in the metal or between component parts, or contact with different soil types along the shaft, or non-homogeneities in metal, etc. A difference in electrical potential causes the development of “anodes” and “cathodes” along the surface of the metal. There must be an electrical connection between the anodes and cathodes for corrosion to occur.

Electrolyte: Water or moisture in the soil that surrounds the pile or pier shaft may contain dissolved chemical elements (ions) and serve as the electrical connection between different parts of the structural element. The water containing the dissolved chemical elements is called an electrolyte. The presence (or absence) of these ions, as well as their nature and concentration, determines the electrical conductivity, or resistivity, of the electrolyte.

Aeration: The availability of oxygen (aeration) in the soil surrounding the metal is also essential to the corrosion process. The process of wetting and drying of the soil causes oxygen to be present in the soil. It is also the reason that most corrosion occurs usually near the surface where the wet-dry cycle is more severe.

Under these conditions, metal ions will migrate from the anodic (+) locations on a metallic object and transfer to the cathodic (-) locations. It is this loss in metal at the anodic locations that results in the degradation of the underground metallic structure.

Controlling Factors for Corrosion

Soil Type: Some soil types are more corrosive than others. The physical and mineralogical composition of soils, which is a result of:

- Their origin, decomposition and deposition
- The plant life and its decomposition
- Topography of the land

All of these influence the soil’s corrosivity potential. The soils having greatest concern are those which produce water soluble acid forming chemical elements such as carbonate, bicarbonate, chloride, nitrate and sulfate, or base (alkaline) forming chemical elements such as sodium, potassium, calcium and magnesium. The soils that have the highest corrosive potential, are soils described or classified by geotechnical engineers as silty, loamy, clay, organic (peats, cinders and ashes), and soils which are poorly aerated. Granular soils (sands and gravels) which are highly aerated can drain water away rapidly. In well drained soil the electrolyte is not constantly in contact with the steel and the corrosion process is reduced.

Soil Resistivity: The resistivity of the soil is one of the simplest checks for soil corrosivity. To obtain the soil resistivity, one passes a current through the soil and measures the resistivity of the soil. Generally, when the soil resistivity, measured in ohm-cm, is high; the rate of corrosion and loss of steel is low. Low soil resistivity occurs due to a number of factors, but fine-grained soils (silts, loams, clays, and peats) have low resistivity and the greatest corrosion susceptibility. Table 1 illustrates the average corrosivity for common soil types, and Table 2 provides a measure of the soil corrosivity based upon soil resistivity.

In general it can be said that sandy soils have the higher resistivity values and are generally considered the least corrosive. Clay soils generally have higher corrosivity and when clay soil is situated in an area of saline water, it can be highly corrosive to steel.

Soil resistivity can be measured in the field using a soil resistivity meter or by obtaining a soil sample from the site and testing it in a laboratory using a resistivity meter and a soil box. This equipment is generally available to the geotechnical engineer.

Soil pH: The measure of acidity or alkalinity in a solution is given as pH. Values of pH < 7 are considered acidic and values of pH > 7 to 14 are alkaline. Pure distilled water is neutral and has a pH = 7. pH is a measure of the degree of hydrogen ion concentration in the water. When a sample of soil is mixed with distilled water, the solution can then be tested with a pH meter to arrive at the soil pH number.

While soil corrosivity can exist within a broad range of soil conditions, the amount of acidity (organic reducing soils – pH < 7) or alkalinity of a soil (pH > 7), does influence corrosion susceptibility and rates. Most soils have a pH that falls within the range of pH 3-1/2 to pH 10.

Soils that are highly acidic (pH < 4-1/2) or alkaline (8 < pH < 10-1/2) have significantly higher corrosion rates than soils within the mid-range 4-1/2 < pH < 8.

Table 1. Soil Resistivity Ranges For General Soil Types

Soil Type	Resistivity Range (ohm-cm)	Soil Type	Resistivity Range (ohm-cm)
Gravel	40,000 to 200,000	Fine Silts & Organics	2,000 to 10,000
Sand	10,000 to 100,000	Loams	3,000 to 10,000
Silt	1,000 to 2,000	Humus	1,000 to 4,000
Clay with Silt	3,000 to 5,000	Ashes – Cinders	500 to 5,000
Clay	500 to 2,000	Peat	100 to 2,000
Heavy Plastic Clay	5,000 to 20,000	Marshy Deposit	50 to 300

Notes:
1. High soil moisture content decreases the resistivity making the soil more corrosive.
2. Freezing the soil dramatically raises the resistivity, thus reducing the corrosivity

Table 2. Soil Resistivity and Relative Corrosivity Rating

Resistivity (ohm-cm)	Corrosivity Rating
> 10,000	Non-Corrosive
5,000 to 9,999	Mildly Corrosive
3,000 to 4,999	Moderately Corrosive
1,000 to 2,999	Corrosive
500 to 999	Highly Corrosive
< 500	Extremely Corrosive

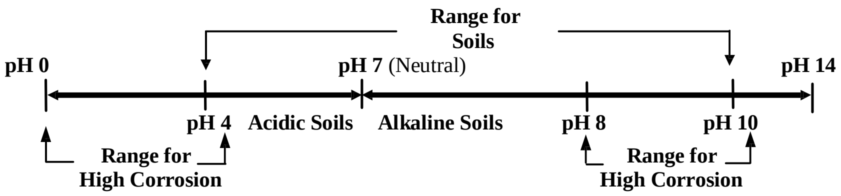


Figure 1. Corrosion of metals within soils can occur over a broad range of pH.

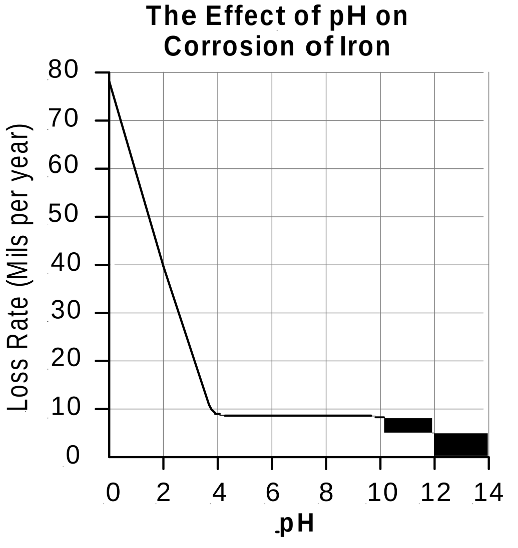
Alkaline soils that have a pH > 10-1/2 will have a significantly decreased corrosion rate due to passivation.

Corrosion Test Results: Doctors Laboratories, a division of the Royal Military College of Canada exposed iron to aerated water at room temperature and determined the corrosion rate as a function of the pH of the water.

As the water became highly acidic (pH < 4), the steel corroded more quickly than the steel did in a highly alkaline environment (pH > 10). It is also interesting to note that zinc used for galvanization provides the best protection to steel subjected to similar environments. Zinc provides the most effective protection through a range of 5.5 < pH < 12.5. In the absence of air, a zinc oxide film does not form on the zinc galvanized surface and corrosion can be more rapid when moisture is present.

The corrosion rate of steel in soil can range from less than 0.79 mils per year (0.0008 in/yr) under favorable conditions to more than 7.87 mils per year (0.0079 in/yr) in very aggressive soils. There are similarities in the corrosion rates of galvanized coatings. Under favorable conditions, the zinc may corrode at less than 0.20 mils per year under mild conditions to more than 0.98 mils in unfavorable soil conditions.

The results of the testing are illustrated in Graph 1. The data suggests that in the range of 4 < pH < 10 the corrosion rate of iron is independent of the acidity or alkalinity (pH) of the environment.

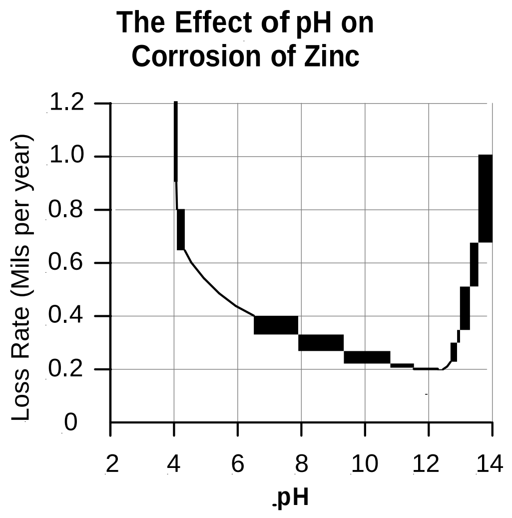


Graph 1.

In acidic conditions (pH < 4) the corrosion rate dramatically increases. The scientists concluded that the acidic conditions dissolve the iron oxide as it forms leaving the iron in direct contact with the water.

Zinc Galvanizing for Corrosion Protection: In Frank Porter's "Corrosion Resistance of Zinc and Zinc Alloys", he determined that dissolved chloride content in water is highly corrosive to zinc. When zinc is subjected to hard (alkaline) water, the insoluble salts in the water form a scale of calcium carbonate and zinc carbonate on the surface of the zinc coating that provides a protective barrier against attack from free chloride anions.

Frank Porter attributes this insoluble scale for the significantly increased corrosion free life of galvanized piles in soils where pH ranges between 5.5 and 12.5. Roathali, Cox and Littreal, the authors of "Metals and Alloys", 1963; presented data showing the corrosion rate of zinc is a function of pH. Excerpts from their data are presented in Graph 2.



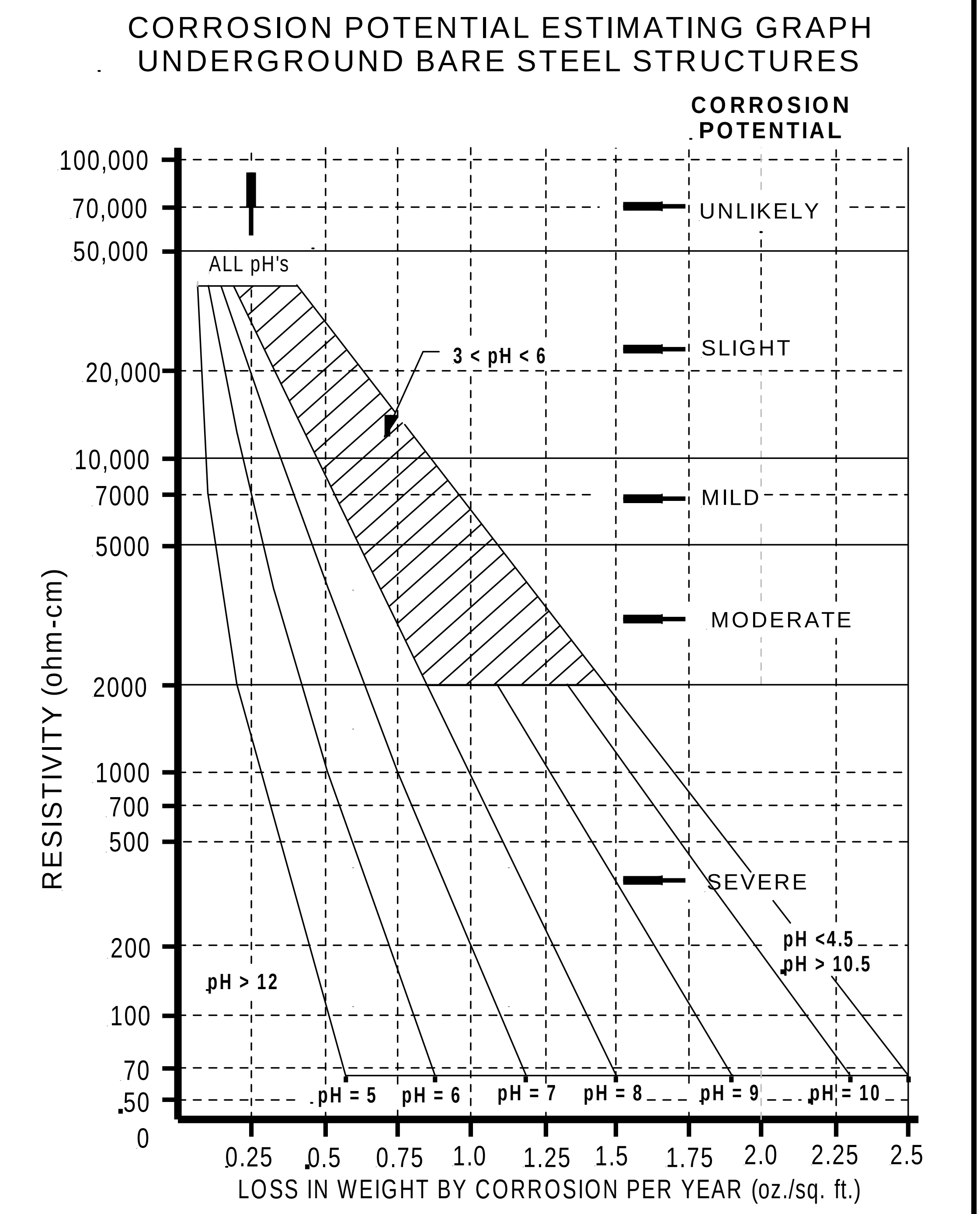
Graph 2.

Oxygen Availability: In addition to soil moisture, free oxygen must be available to complete the corrosion process. Oxygen combines with the metal ions to form oxides, hydroxides and metal salts.

Corrosion rates will drop significantly when the steel structure is below a ground water table (GWT), and the water is relatively stagnant (low to no flow velocity) since available free oxygen is much reduced under these conditions.

Estimating Corrosion Potential

There are a number of variables that influence the corrosion potential for underground metallic structures. Melvin Romanoff has conducted extensive field testing of buried metal structures to evaluate the corrosion levels related to the more significant variables. These results, published by Romanoff in "Underground Corrosion", National Bureau of Standards circular 579, Houston TX, 1989; along with data published in the proceedings of the "Eighth International Ash Utilization Symposium, Vol. 2", American Coal Ash Association, Washington, DC, October, 1987. These data were used to develop Graph 3, which allows during the design process for an empirical calculation to estimate losses due to corrosion.



Graph 3. Prediction of steel loss due to corrosion relative to soil resistivity and pH.

If specific information on a soil is available to the designer (soil type, pH & resistivity), a preliminary estimate for metal corrosion loss of bare steel can be determined. The NBS publication can also be used to find a comparable soil and condition for estimating the rate of corrosion. It should be noted that when hot-dipped galvanizing is used as a form of corrosion protection, the resulting corrosion rate for steel (once the galvanized coating is lost due to corrosion) will be lower than the rates shown in Graph 3 on the previous page. (The estimated reduction rate of corrosion is in the 20% to 100% range).

Special Corrosion Conditions: Soil resistivity and pH are strong influencing factors on corrosion rates; however, there are other special soil conditions such as excessive salt content of water (seawater), velocity of water flow and atmospheric conditions, which may increase the corrosion rate. Uhilig's Corrosion Handbook, Edited by R. Winston Revie, 2nd Edition, provided the following reference material:

1. **Corrosion Rates in Seawater**
   (Pipe Piles, H-Piles, Etc.)
   a. Splash Zone (Average) = 6.9 oz/ft^2 / yr
   b. Tidal Zone (Average) = 2.0 oz/ft^2 / yr
   c. Immersed (Average) = 2.3 oz/ft^2 / yr
   d. Immersed Zone (Range) = 0.5 oz/ft^2/ yr to 9.0 oz/ft^2 / yr
2. **Influence Of Velocity In Fresh Water**

Velocity (m/s)	Corrosion Rate Multiplier
1/2 to 3	4
3 to 15	1.2 to 0.8

3. **Atmospheric Corrosion Rates**
   (Pipe Piles, H-Piles, Etc.)
   Atmospheric = 3.2 oz/ft^2 / yr (Average)
   (< 500 Meters to Seashore)

Soil Corrosion Ratings: In over 90% of foundation underpinning projects corrosion is not a problem, but one needs to recognize the warning signs of problem soils. The American Water Works Association developed a numerical rating to determine the severity of corrosion for cast iron pipes. While ECP products are not constructed from cast iron, a numerical rating system similar to the AWWA system was developed by ECP that provides guidance for steel foundation products in soil. The numerical corrosivity score is designed only as a guide to warn of a possible corrosive environment in which the life of galvanized steel product deterioration may be accelerated due to aggressive corrosion conditions.

Using the information gathered from a specific job site, an indication of the likelihood of corrosion is suggested based upon point values assigned to the three soil parameters linked to increased corrosion rates. Notice in Table 3 that the three elements that influence the rate of corrosion must be known before an assessment of soil corrosivity can be predicted from Table 4.

The sum of these point values gives the numerical corrosivity score for the site. The score suggests the likelihood of slight, moderate or high corrosion potential of the soil. As the score approaches 10, the soil becomes more aggressive. When the numerical corrosivity score equals 10 or higher, it is strongly recommended to seek the advice of an engineer familiar with corrosion to evaluate the project to determine what additional corrosion protective measures in addition to galvanization are required for extended service life.

Table 3. Numerical Corrosivity Score

Soil Parameter	
Soil Resistivity (ohm-cm)	**Points**
< 500	10
500 – 999	8
1,000 – 1,999	5
2,000 – 4,999	2
5,000 – 10,000	1
>10,000	0
pH	**Points**
2 – 4.5	6
5 – 6	0
7 – 9	2
10.5 -- 12	6
Moisture	**Points**
Tidal or Salt Water Exposure	5
Poor Drainage – Always Wet	2
Fair Drainage - Moist	1
Good Drainage – Usually Dry	0

Table 4. Soil Corrosion Potential

Unlikely			Slight		Mild		Moderate		Aggressive					Severe						
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Methods of Corrosion Control

Depending upon the corrosion potential for a given soil environment, several alternatives are available to reduce the corrosion cycle and extend the performance life of the underground steel element. These control measures can be divided into general categories:

- **Passive Control** – for use in soils classified as having mild to moderate corrosion potential
- **Active Control** – for use in soils classified as having moderate to severe corrosion potential

Passive Control

Hot Dip Galvanizing: The products manufactured by Earth Contact Products that are offered with hot dip galvanizing are coated with molten zinc that contains not less than 98% pure zinc metal. The hot dip galvanization process meets or exceeds ASTM A123 Grade 100 which is 2.3 oz/ft^2 of zinc (3.9 mils minimum thickness) for steel plate, structural tubing or bar products..

Quadruple Layer Corrosion Protection: The pier pipe for ECP Steel Piers™ PPB-350 and PPB-300 foundation support systems are supplied with a triple step in-line process of corrosion protection as standard. This corrosion protection process consists of heating the clean steel tubing to 850^0 F and placing it in a bath of molten zinc. This process creates an extremely hard zinc-iron alloy upon which a uniform layer of pure zinc is deposited. Then the zinc is rendered inert against oxidation by a passivation process using a precisely controlled chromate bath. This passivation forms a complex layer of zinc chromate compounds that halts interaction of oxygen and water with the zinc to prevent premature corrosion.

After the chromate bath, in a continuous process, a clear polymer film is applied and cured to complete the corrosion protection system. This three step process provides four layers of corrosion protection:

1. a zinc-iron alloy layer,
2. a pure zinc galvanizing,
3. a layer of zinc chromate compounds,
4. a clear organic polymer film.

The quadruple layer corrosion protection process produces a strong and durable coating on the pier pipe that is smooth and shiny. The interior of the pipe is also coated with zinc-iron alloy, galvanizing and zinc chromate compounds.

Independent laboratory salt spray testing of this tubing from various manufacturers compared with standard galvanized schedule 40 pipe showed the in-line corrosion protection process lasted up to 33% longer.

The laboratory tests were conducted in accordance with ASTM B-117. Standard schedule 40 pipe is normally supplied with hot dip galvanize to ASTM-A123 Grade 75. Because no controlled in-soil corrosion testing is available for the in-line corrosion protected ECP products, a zinc equivalence of 3.0 mils or 1.7 oz/ft^2 (ASTM-A123 Grade 75) appears to be reasonable value to be used for conservatively estimating corrosion life of in-line corrosion protected pier pipe.

Thicker coatings (5 mils) have shown extended life, depending on the corrosion potential of the soil environment. The galvanized coating serves as an anode to provide cathodic protection to the steel. The results of the studies conducted by Romanoff and by Porter indicate that a galvanized (zinc) coating was effective in delaying the onset of corrosion in the buried steel structures. Typical conclusions drawn from this study for the 5 mil (3 oz/ft^2) galvanized coating includes:

- Adequate for more than 10 years corrosion protection for inorganic oxidizing soils.
- Adequate for more than 10 years corrosion protection for inorganic reducing soils.
- Insufficient for corrosion protection in highly reducing organic soils (pH < 4) and inorganic reducing alkaline soils or cinders (8 < pH < 10.5) lasted typically only 3 to 5 years.
- **It was also noted, however, that the use of a galvanized coating significantly reduced the rate of corrosion of the underlying steel structure once the zinc coating was destroyed**. This was observed in Romanoff's study where the rates of corrosion for the previously galvanized coated steel were less than the corrosion rates for never galvanized bare steel.

Active Control

Cathodic Protection: As indicated previously, corrosion is an electrochemical process that involves a flow of direct electrical current from the anodic (corroding) areas of the underground metallic structure into the electrolyte and back onto the metallic structure at the cathodic (non-corroding) areas. In situations where helical piles or steel piers are to be placed in a soil environment classified as severely corrosive, Active Control technique of corrosion control should be used. This Active Control technique is termed *Active Cathodic Protection*.

The basic principle of *Active Cathodic Protection* is to apply an electrical current equal to and opposite to the electrical current generated by the corroding metallic structure, thus effectively eliminating the corrosion process on the foundation element.

Sacrificial Anodes: The sacrificial (galvanic) anode is attached to each underground metallic structure by an electrical conductor (cable) and the anode is placed within the common electrolyte (soil medium) adjacent to the foundation element. The sacrificial anode works best when only a small amount of electrical current is needed for corrosion control and/or when the soil resistivity is low. Anodes are usually installed about three feet below the surface and 3 to 6 feet from the steel subject to corrosion. Magnesium, zinc and aluminum are the most commonly used galvanic sacrificial anodes.

The use of cathodic protection using sacrificial anodes connected to underground metallic structures offers the following advantages:

- no external power supply is required
- low system cost for anode bags and installation
- minimum maintenance costs

The major variables are soil moisture content, resistivity of soil and pH. Each of these items influence the final selection of the cathodic protection system. Typical design life for the cathodic protection is 10 to 20 years, depending upon the size, length and type of the anode canister. After the anode is exhausted, a new anode needs to be installed. Otherwise the underground steel will begin to corrode.

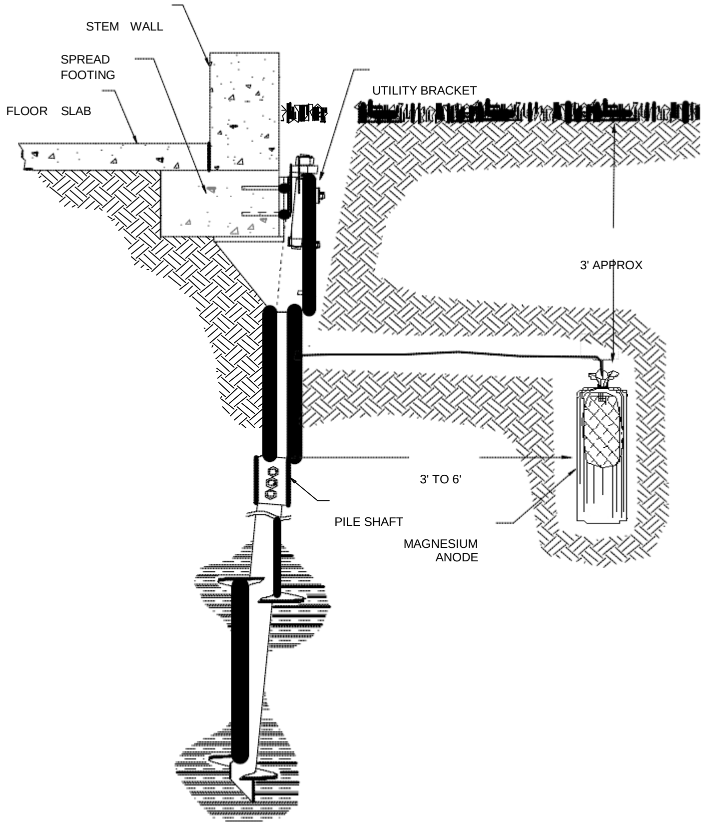


Figure 2. Active corrosion protection with a magnesium anode

Impressed Current: In areas that have the most severe corrosion potential and a large current is required, and in places with high resistance electrolytes; an impressed current system is generally recommended. This system requires a power source, rectifier and a ground bed of impressed current anodes. These systems require a continuous external power source to provide corrosion protection.

The majority of applications where foundation underpinning is installed will not require an active corrosion protection system. In most cases where there is corrosive soil and/or adverse electrolyte conditions, the sacrificial anode protection system will likely be the most economical approach. All corrosion protection systems require technical expertise and training to design and install the products for the specific job site conditions.

As long as the system is properly designed and installed; and the system remains in operation, the underground steel will have unlimited corrosion life.

Corrosion Life Analysis

The estimated corrosion life is based on the following factors:

1. The life of the galvanized coating, (CL_G)
2. The life of a limited amount of steel loss in the pier wall without losing structural integrity of the pile, (CL_P) (The recommended allowance is 10 %.)
3. The life when cathodic protection is present, (Follow the life analysis provided by the sacrificial anode manufacturer.)

There is a high degree of variability in the performance life of steel piers and helical piles in the soil. Including, but not limited to:

- multiple strata soils through the depth of installation,
- soil variations within a given stratum
- variability of the water content of soil both vertically and seasonally
- presence or absence of salt ions in the soil due to leaching, etc.
- non-uniformity of the galvanized coating thickness and areas of stress concentration
- imperfections in the steel
- damage to the steel or galvanized coating
- presence or absence of stray currents

Corrosion Life of Galvanized Coating: The observed rates of corrosion for the galvanized coating were different (less) than that for bare steel in Romanoff's NBS study. Equation 1 can be used to estimate the corrosion (weight loss) rate for galvanized coatings.

Equation 1 - Corrosion Life Zinc:

$$CL_G = G / [0.25 - 0.12 \log_{10} (R/150)]$$

Where:

G = Amount of galvanize coating (oz/ft^2)
R = Soil resistivity (ohm-cm)

Corrosion Life of Steel Pier or Pile: Once the protection offered by the galvanized coating has been exhausted, the steel will begin to corrode and lose thickness. "Safe Use Design" states that a factor of safety of 2.0 or greater shall be used when designing foundation supports. With regard to corrosion loss, experience has shown that the structural integrity of the pier system is not be compromised should there be a corrosion loss of steel not exceeding ten per cent. This is because greater strength is needed for product installation than for support. The formula for estimating average time for ten percent corrosion loss in steel wall thickness (W_S x 0.10) is given in Equation 2, which estimates corrosion loss per year.

Equation 2 - Corrosion Loss Steel Shaft:

$$CL_P = W_{S\text{-}10\%} / K_C$$

Where:

CL_P = Life expectancy of steel tube (years)
$W_{S\text{-}10\%}$ = 10% shaft weight loss – (oz/ft^2)
$K_{C\text{-}1\,yr}$ = Corrosion loss per year - oz/ft^2

- $W_{S\text{-}10\%}$ is the amount of steel loss equal to 10 % of the wall thickness of a pile shaft can be determined by Equation 3.

Equation 3:

$$W_{S\text{-}10\%} = \mathbf{10\%} \text{ x } \mathbf{t} \text{ in x } \mathbf{489.6} \text{ lb/ft}^3 \text{ x } \mathbf{16} \text{ oz/lb}$$

Where: **t** = Wall thickness of the tubular shaft or one-half the thickness of the solid bar - in.

- $K_{C\text{-}1\,yr}$ can be estimated from the data in Graph 3, which estimates of corrosion loss per year based upon the resistivity and pH.

It is important to remember that the corrosion life predicted by these equations provide an average life expectancy for the foundation support product when installed under the given conditions. Furthermore, at the end of the calculated corrosion life, there will be no loss of structural integrity or original design factor of safety.

From the end of the corrosion life predicted here, corrosion to the structural element will begin to reduce the factor of safety built into the design of the product. If left unprotected, corrosion will eventually cause failure sometime in the future.

Caution is required for predictions of performance life beyond 50 years. The equations above provide results that are average corrosion life predictions. The corrosion process is affected by variations in ground water adjacent to the pile or pier shaft. It is also affected by soil strata typically not homogenous, along with other factors such as dissolved minerals, imperfections in the galvanization, imperfections in the steel and/or damage to the products during shipping and installation, etc.

"Quick and Rough" Corrosion Life Estimating

Corrosion Life Tables: The tables that follow were developed from Equations 1 and 2 presented earlier. The values for the pH used in the tables were based upon the values at which corrosion potential generally changes.

Corrosion of the Torque Anchor™ Shafts

The first two columns of Table 5 estimate the corrosion life of an ungalvanized Torque Anchor™ shaft before the pile deterioration affects capacity. This table estimates the time for corrosion to destroy ten percent of the of the pile shaft thickness. Determine the shaft configuration under the heading of the graph. Next, locate the row that most closely matches the soil pH on the job site. Read downward from the shaft configuration and horizontally from the selected pH value until the column and row intersect. This is the "Quick and Rough" estimate of corrosion life of the steel prior to any loss in capacity.

Life of Torque Anchor™ Galvanizing

The vast majority of steel foundation support products are specified with corrosion protection applied. At the far right column of Table 5 estimates the corrosion life of galvanized coating. Simply read horizontally across from the pH that most closely matches the pH at the job site until the estimated life of the galvanization is found at the far right column.

The Torque Anchor™ products are supplied with hot dip galvanizing that meets or exceeds ASTM A123, Grade 100. This puts a minimum of 2.3 oz/ft^2 of zinc, which is 3.9 mils (minimum) thickness.

TABLE 5. Sample ECP Torque Anchor® & Soil Nail Life Expectancy Estimates at Full Load

Soil pH	Plain Steel Life Expectancy at Full Load						Hot Dip Galvanize 2.3 oz/ft^2 - 3.9 Mils (ASTM A123 gr. 100)
	1-1/2" Square Bar	1-3/4" Square Bar	2-1/4" Square Bar	2-7/8" Dia x 0.262" Tube	3-1/2" Dia x 0.300" Tube	4-1/2" Dia x 0.337" Tube	
Soil Resistivity – 500 ohm-cm							
4.5	25 yrs	30 yrs	39 yrs	9 yrs	11 yrs	12 yrs	Add 12 years to life shown at left
5	100+ yrs	100+ yrs	125+ yrs	48 yrs	57 yrs	63 yrs	
8	45 yrs	52 yrs	67 yrs	15 yrs	17 yrs	19 yrs	
10.5	25 yrs	30 yrs	39 yrs	9 yrs	11 yrs	12 yrs	
Soil Resistivity – 1,000 ohm-cm							
4.5	29 yrs	34 yrs	43 yrs	10 yrs	12 yrs	13 yrs	Add 15 years to life shown at left
5	100+ yrs	100+ yrs	125+ yrs	57 yrs	67 yrs	73 yrs	
8	49 yrs	57 yrs	73 yrs	17 yrs	20 yrs	22 yrs	
10.5	29 yrs	34 yrs	43 yrs	11 yrs	12 yrs	13 yrs	
Soil Resistivity – 2,000 ohm-cm							
4.5	34 yrs	39 yrs	51 yrs	12 yrs	14 yrs	15 yrs	Add 20 years to life shown at left
5	125+ yrs	125+ yrs	150+ yrs	85 yrs	100 yrs	100+ yrs	
8	47 yrs	67 yrs	86 yrs	19 yrs	22 yrs	24 yrs	
10.5	34 yrs	39 yrs	51 yrs	12 yrs	14 yrs	15 yrs	
Soil Resistivity – 5,000 ohm-cm							
4.5	45 yrs	52 yrs	67 yrs	16 yrs	18 yrs	20 yrs	Add 34 years to life shown at left
5	150+ yrs	150+ yrs	175+ yrs	100+ yrs	100+ yrs	100+ yrs	
8	82 yrs	95 yrs	100+ yrs	29 yrs	33 yrs	37 yrs	
10.5	45 yrs	52 yrs	67 yrs	16 yrs	18 yrs	20 yrs	

IMPORTANT NOTES:

1. The tables above are designed to suggest to the reader basic life expectancies assuming homogeneous soil and constant soil moisture. These tables are not intended to be used in place of a corrosion analysis and design. This table is not to be considered a substitute for field measurements of pH and resistivity; and a site specific corrosion analysis.

IMPORTANT NOTES CONTINUED NEXT PAGE

2. The life expectancies predicted in Tables 5 & 6 were calculated using recognized engineering principles and are for general information only. While believed to be accurate, this information should not be used or relied upon for any specific application without competent professional examination by a registered professional engineer and verified for accuracy or suitability to the application and site.

3. Reaching the end of the stated life does not indicate that the pile will fail; rather a slow reduction of the factor of safety will occur as the ultimate pile capacity decreases. Failure could occur in months or many years depending upon the soil conditions and the installed product.

4. The tables allow for ten percent of the cross section of the product to corrode away from the solid steel bars and ten per cent of wall thickness from the tubular sections. This extra material was required for torsional strength when installing the helical pile, or for field load testing the steel pier pipe. The helical pile or steel pier should retain the original design capacity with the full factor of safety intact even with this small amount of metal loss.

5. Variations in soil moisture content from season to season and year to year can adversely affect service life. Low field moisture content produces low corrosion rates even if corrosion elements are present. Stray currents from pipe lines, power lines, etc may also affect the life of the pile or pier. Corrosivity, resistivity and pH testing is always recommended in problem soils.

6. Hot Dip Galvanize process is assumed to meet or exceed ASTM A123 – Grade 100. The quadruple layer corrosion protection process found on the ECP Steel Pier pipe is assumed offer protection that is equivalent to ASTM A123 – Grade 75. The 4 inch diameter pier pipe is offered with optional galvanizing to ASTM A123 – GR 100.

7. Once the resistivity becomes higher than 1,000 ohm-cm, the galvanized solid square shaft helical pile product provides an excellent service life exceeding 44 years, when not subjected to soil pH values outside the range of Table 5 or to stray underground currents. Life expectancies exceeding 50 years can be expected for galvanized helical tubular products when the resistivity is above 5,000 ohm-cm.

8. As the predicted life expectancy increases beyond 40 years, the margin for error increases dramatically because the life expectancy estimates are calculated from empirical equations derived from field testing and projected beyond the length of time for the actual corrosion testing.

Corrosion Life of ECP Steel Piers™

Some ECP Steel Pier™ pipe is supplied with quadruple corrosion protection that is similar to ASTM A123, Grade 75. This is equivalent to 1.7 oz/ft^2 of zinc, or 3.0 mils thickness. The PPB-400-EPS pier pipe is supplied with Hot Dip Galvanizing to ASTM A123 – Grade 100. This pipe is also used for PPB-400-EPSB with a mill finish.

Table 6 (next page) is used to estimate corrosion life for the most commonly used ECP Steel Piers™. Because the PPB-300-EPS (2-7/8 inch diameter with 0.165 inch wall pier pipe) and the PPB-350-EPS (3-1/2 inch diameter with 0.165 pier pipe) are supplied with the factory applied quadruple corrosion protection, the values in Table

corrosion life estimates.

To obtain an estimate of the time that it will take for corrosion to destroy the corrosion protection coating on the pier pipe and ten percent of the wall thickness of the steel tube, locate the pier pipe configuration at the top of Table 6. Next, determine the soil pH that most closely matches the pH at the job site. Read downward from the pier pipe that will be used and horizontally from the selected pH value until the column and row intersect. This is the "Quick and Rough" estimate of the corrosion life expectancy of the ECP Steel Pier™ pipe for the particular job site.

The PPB-400-EPSB (4 inch diameter with 0.220 inch wall thickness mill finished pier pipe) and the PPB-400-EPS is the same pier pipe with Hot Dip Galvanization of 2.3 oz/ft^2 of zinc or 3.9 mils thickness to ASTM-A123, Grade 100. The corrosion life for these pier pipes is determined in the same manner as the other steel pier pipes. Locate the 4 inch diameter pier pipe at the top heading of the graph depending upon whether it has HDG or mill finish and read downward until the intersection with the row that represents the closest value of pH found on the job site.

It is important to remember that the corrosion life predicted by these tables provide an average life expectancy for the foundation support product when installed under the given conditions. Furthermore, at the end of the calculated corrosion life, there will be no loss of structural integrity or original design factor of safety for service load.

TABLE 6. Sample ECP Steel Pier® Pipe Life Expectancy Estimates At Full Load				
Soil pH	**PPB-300-EPS** 2-7/8" Dia. Tube Quad-layer-coating (1.7 oz.ft^2 – 3.0 Mils)	**PPB-350-EPS** 3-1/2" Dia. Tube Quad-layer-coating (1.7 oz.ft^2 – 3.0 Mils)	**PPB-400-EPSB** 4" Dia. Tube (Mill Finish)	**PPB-400-EPS** 4" Dia. Tube HDG – (2.3 oz/ft^2 - 3.9 Mils ASTM A123 gr. 100)
Soil Resistivity – 500 ohm-cm				
4.5	15 yrs	15 yrs	7-1/2 yrs	19-1/2 yrs
5	40 yrs	40 yrs	40 yrs	53 yrs
8	19 yrs	19 yrs	13 yrs	25 yrs
10.5	15 yrs	15 yrs	7-1/2 yrs	19-1/2 yrs
Soil Resistivity – 1,000 ohm-cm				
4.5	15-1/2 yrs	15-1/2 yrs	8.5 yrs	24 yrs
5	47 yrs	47 yrs	48 yrs	63 yrs
8	22 yrs	22 yrs	13 yrs	28 yrs
10.5	15-1/2 yrs	15-1/2 yrs	8.5 yrs	24 yrs
Soil Resistivity – 2,000 ohm-cm				
4.5	22 yrs	22 yrs	10 yrs	39 yrs
5	69 yrs	69 yrs	72 yrs	92 yrs
8	27 yrs	27 yrs	17 yrs	37 yrs
10.5	22 yrs	22 yrs	10 yrs	39 yrs
Soil Resistivity – 5,000 ohm-cm				
4.5	35 yrs	35 yrs	13 yrs	47 yrs
5	97 yrs	97 yrs	95 yrs	100 yrs
8	43 yrs	43 yrs	25 yrs	59 yrs
10.5	35 yrs	35 yrs	13 yrs	47 yrs

Please see "Important Notes" on the two previous pages

Results of Field Tested Galvanized Coating Life

The National Bureau of Standard conducted testing of corrosion of metals in soils. As early as 1924, research on corrosion of galvanized pipe was in progress. In 1937 a zinc corrosion study began using 1-1/2 inch diameter galvanized steel pipe with a 5.3 mil (0.0053") zinc coating. The results from the testing are shown in Table 7. The test also found that the galvanization prevented pitting of the steel even after the zinc coating was completely consumed. The bare steel that was formally under the galvanization corroded at a much slower rate than comparable bare steel under identical conditions.

* Test of buried 1-1/2" diameter steel pipe with 5.3 mils of zinc galvanizing -- National Bureau of Standards – 1937.

** Life expectancy is only for galvanize coating and not any loss of steel.

Table 7. Corrosion of Galvanized* Steel Pipe* in Contact with Various Soils		
Inorganic Soils	**Zinc Loss /yr** (mil per year)	**Life of Zinc**** (years)
Acid Soils – Oxidizing		
Cecil Clay Loam	0.08	66
Hagerstown Loam	0.08	66
Susquehanna Clay	0.11	48
Acid Soils – Reducing		
Sharkey Clay	0.15	35
Acadia Clay	0.91	6
Alkaline Soils – Oxidizing		
Chino Silt Loam	0.15	35
Mohave Fine Gravelly Loam	0.15	35
Alkaline Soils – Reducing		
Docas Clay	0.22	24
Merced Silt Loam	0.10	53
Organic Acid Soil - Reducing		
Carlisle Muck	0.44	12
Tidal Mush	0.38	14
Muck	1.42	4
Rifle Peat	2.64	2
Cinders	1.64	3

Manufacturer's Warranty

Earth Contact Products strives to provide quality foundation support products at competitive prices. We are proud that [illegible] e providing long term foundation support to structures across the nation. We are so confident in our products that we offer [illegible] s limited 25 year warranty against defects in materials and workmanship. The text of our warranty is shown below:

> *"Earth Contact Products, L.L.C. offers a 25 year warranty from the date of installation against any defects in manufacturing and workmanship on ECP Steel Piers™ and ECP Torque Anchors™ when installed by an authorized ECP installer in normal soil conditions*. Earth Contact Products, L.L.C. will furnish new product replacement, if any ECP Steel Pier™ or ECP Torque Anchor™ should fail to function due to defects in its quality of manufacturing material or workmanship. All replacement materials will be furnished F.O.B. from the point of manufacture. This is a product warranty provided by the manufacturer and does not include installation or service of the product. Installation and service shall be furnished by the selling contractor as a service warranty on his installation workmanship.*
>
> *This warranty covers only the quality of the manufactured product."*

Research shows that our products will meet or exceed this life expectancy in the vast majority of applications and soil environments. Because our products are sometimes exposed to extremely corrosive environments, we defined what we consider "normal" soil conditions below:

> **Normal Soil Condition is defined as soil having a resistivity greater than 2,000 ohm-cm and between pH 5 and pH 8. Excessive corrosion due to aggressive soil or corrosive environment is NOT considered a manufacturing defect. In corrosive environments, additional corrosion protection may be required for extended service life.*

If you suspect that the environment on a site would be corrosive to steel underpinning products, or if you require a service life exceeding 25 years, we strongly recommend that you request a site specific soil resistivity test at intervals to 20 feet below grade and soil pH values from a geotechnical engineer or soil testing laboratory.

Upon request, ECP offers complementary corrosion life analysis to determine the estimated service life for ECP products specified for a specific site when the request includes the required soil corrosivity data indicated above.