Step 7 – Corrosion Guide

Introduction

Corrosion is defined as the degradation of a material or its properties due to a reaction with the environment. Corrosion exists in virtually all materials, but is most often associated with metals. Metallic corrosion is a naturally occurring process whereby the surface of a metallic structure is oxidized or reduced to a corrosion product such as "rust" by chemical or electrochemical reaction with the environment. The surface of metallic structures is attacked through the migration of ions away from the surface, resulting in material loss over time. Given enough time, the material loss can result in significant reduction of area, which in turn leads to a reduction in the structural capacity of a given metallic element. When corrosion eventually destroys a sufficient amount of the structure's strength, a failure will occur.

The corrosion mechanisms involved with buried metallic structures are generally understood, but accurate prediction of metal loss rates in soil is not always easily determined. This section of the design manual provides an introduction to the concepts of underground corrosion and the factors that influence this corrosion in disturbed and undisturbed soils. A few design examples are provided to give the reader a better understanding whether corrosion is a critical factor in a helical screw foundation application. This section is by no means intended as a rigorous design guide, but rather as a "first check" to see if corrosion is a practical concern given the specific project site conditions. A qualified corrosion engineer should be consulted for a site-specific recommendation if helical screw foundations are to be used in a known corrosive soil.

Experience over the past 50 years has shown the vast majority of square shaft and pipe shaft helical screw foundations have a calculated service life well in excess of the design life of the structure (typically 50 to 75 years in the U.S.). In highly corrosive soils and areas of stray currents (e.g., underground transmission pipelines, DC railroads) additional measures must be taken to protect the helical screw foundation. In this case, active protective measures such as sacrificial anodes are employed.

Corrosion Theory

To understand why metallic corrosion occurs, it is necessary to understand how a metal, such as carbon steel, is formed. During the steel making process, natural low energy iron ore is refined into metal. This process adds a great deal of energy to the metal. Once the steel is placed into a corrosive environment, it will, by natural means, return to its low energy state over time. To make the return trip, the steel must give up the energy gained at the mill. This is the essence of the reduction process that we call corrosion.

Mechanical strength, physical size and shape, and chemical composition of the steel are all properties that must be considered when designing helical screw foundations. Mechanical and physical properties are typically well defined and controlled during the manufacturing process. This is also true of the chemical composition – primarily due to the superior process controls put in place by the steel mills. Of the three properties, chemical composition is the primary factor with respect to corrosion.

Corrosion of steel is an electrochemical process. Romanoff [1957] stated:

"For electrochemical corrosion to occur, there must be a potential difference between two points that are electrically connected and immersed in an electrolyte. Whenever

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these conditions are fulfilled, a small current flows from the anode area through the electrolyte to the cathode area and then through the metal to complete the circuit, and the anode area is the one that has the most negative potential, and is the area that becomes corroded through loss of metal ions to the electrolyte. The cathode area, to which the current flows through the electrolyte is protected from corrosion because of the deposition of hydrogen or other ions that carry the current.

"The electrochemical theory of corrosion is simple, i.e., corrosion occurs through the loss of metal ions at anode points or areas. However, correlation of this theory with actual or potential corrosion of metals underground is complicated and difficult because of the many factors that singly or in combination affect the course of the electrochemical reaction. These factors not only determine the amount or rate at which corrosion occurs but also the kind of corrosion."

Depending on the many factors that affect the electrochemical reaction, corrosion can affect a metal in several different ways. Some of these types are listed below:

Table 7.1 - Corrosion Types

Type	Characteristics
Uniform or near uniform	Corrosion takes place at all areas of the metal at the same or similar rate.
Localized	Some areas of the metal corrode at different rates than other areas due to heterogeneities in the metal or environment. This type of attack can approach pitting.
Pitting	Very highly localized attack at specific areas, resulting in small pits that may penetrate to perforation.

Considerations need to be applied as to the types and rates of corrosion anticipated. Current theory does not permit accurate prediction of the extent of expected corrosion unless complete information is available regarding all factors. Therefore, uniform corrosion will be the corrosion type discussed herein.

Romanoff states there are several conditions that must be met before the corrosion mechanism takes place. These are:

1. Electrical Factors
Two points (or areas) on a metallic structure must differ in electrical potential (anode and cathode). The anode is defined as the electrode of an electrochemical cell at which oxidation occurs as the negative terminal of a galvanic cell. The cathode is defined as the electrode of an electrochemical cell at which reduction occurs: the positive terminal of a galvanic cell. An electrical potential can be caused by differences in grain orientation within the steel structure, i.e. difference orientations of the steel grain structure can cause some grains to act as anodes while others act as cathodes, while the rest of the steel material exhibits excellent electrical conductivity. In addition, chemical anisotropy, non-metallic inclusions, strained and unstrained areas, and other imperfections on the surface of a metal can create potential differences – which drives the corrosion process.

2. Metallic Path
The anode and the cathode must be electrically bonded or connected to complete the circuit.

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3. Electrolyte

The principle function of soil moisture is to furnish the electrolyte for carrying current. The ions in the electrolyte may be hydrogen and hydroxyl ions from the water itself and a variety of cations and anions, which depend upon the number and amount of soluble salts dissolved in the water. The presence of these ions determines the electrical conductivity, expressed as resistivity (measured in ohm-cm), of the electrolyte, as well as chemical properties such as acidity or alkalinity, and the development of chemical reactions between the primary products of corrosion and the electrolyte. For example, ferrous material is corroded by electrolytes that contain sulfates or chlorides from the soil because the corrosion products formed at the anode and the cathode are both soluble.

4. Aeration

Aeration affects the access of oxygen and moisture to the metal. Oxygen, either from atmospheric sources or from oxidizing salts or compounds, stimulates corrosion by combining with metal ions to form oxides, hydroxides, or metal salts. If corrosion products are soluble or are otherwise removed from the anodic areas, corrosion proceeds - but if the products accumulate, they may reduce corrosion by providing a barrier that is more noble (cathodic) than the bare metal. The aeration characteristics of a soil are dependent upon physical characteristics such as the particle size, particle size distribution, and unit weight. In volume change soils such as clay, a reduction in moisture content results in cracks that provide effective channels for the oxygen of the air to reach buried metal. Disturbed soils such as fill results in oxygen being more readily available. In some instances, atmospheric oxygen can become trapped in isolated pockets or cells creating the potential for localized anodic regions.

Soil Environments

Soil Type

Soils constitute the most complex environment known to metallic corrosion. Corrosion of metals in soil can vary from relatively rapid material loss to negligible effects. Obviously, some soil types are more corrosive than others. The origin of soils, along with climate, geologic location, plant and animal life, and the effects of man all influence a given soils corrosive potential. Chemical analysis of soils is usually limited to determinations of the constituents that are soluble in water under standardized conditions. The elements that are usually determined are the base-forming elements, such as sodium, potassium, calcium, and magnesium; and the acid-forming elements, such as carbonate, bicarbonate, chloride, nitrate, and sulfate. The nature and amount of soluble salts, together with the moisture content of the soil, largely determine the ability of the soil to conduct an electric current. Therefore, fine-grained soils such as clays and some silts are considered to have a greater corrosion potential because they typically have lower hydraulic conductivity – resulting in the accumulation of acid and base forming materials, which cannot be leached out very quickly. However, granular soils such as sands and gravels are considered to have a reduced corrosion potential because they typically have increased hydraulic conductivity – resulting in the leaching of accumulated salts.

Ground Water

Moisture content in soil will probably have the most profound effect when considering corrosion potential than any other variable. No corrosion will occur in environments that are completely dry. The effect of moisture content on the resistivity of a clay soil is shown in Figure 7.1. When the soil is nearly dry, its resistivity is very high (i.e. no corrosion potential). However, the resistivity decreases rapidly with increases of moisture content

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until the saturation point is reached, after which further additions of moisture have little or no effect on the resistivity. Figure 7.2 shows the effect of temperature on the resistivity of a soil. As the temperature decreases down to the freezing point 32° F (0° C), the resistivity increases gradually. However, at temperatures below the freezing point, the soil resistivity increases very rapidly.
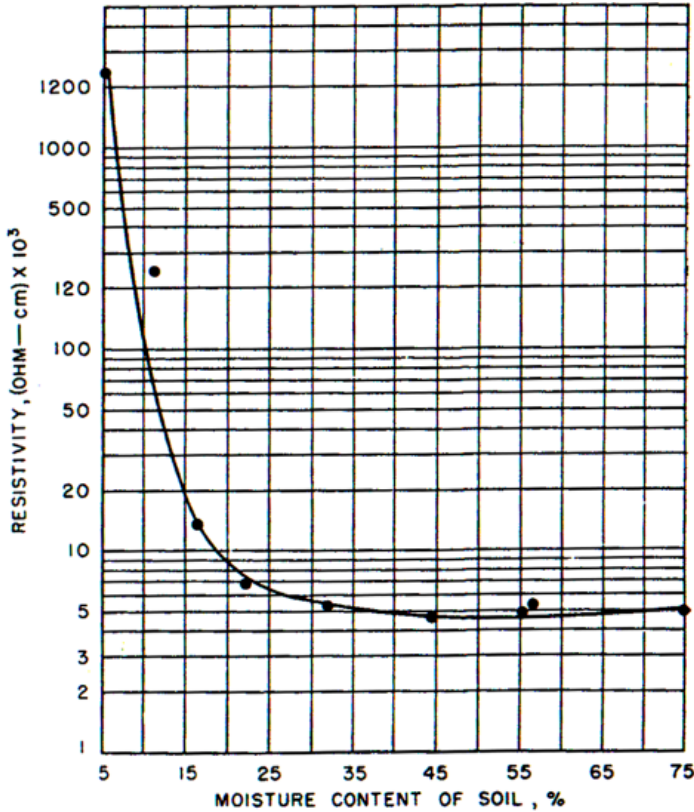

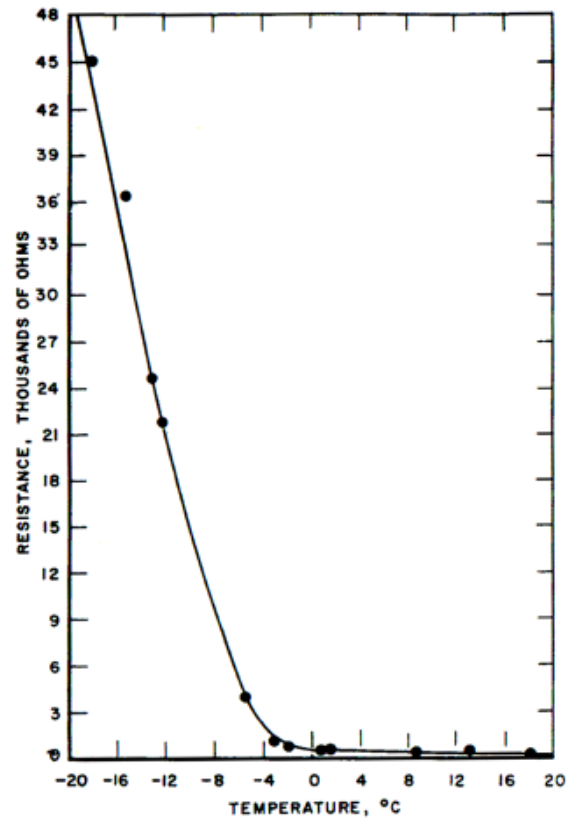**Figure 7.1 - Effect of moisture on soil resistivity (Romanoff, 1957)**

Figure 7.2 - Effect of temperature on earth resistance (Romanoff, 1957)

Soil pH

The pH can be used as an indicator of corrosion loss potential for metals in soil. "pH" is defined as the acidity and alkalinity of a solution that is a number on a scale from 0 to 14 on which a value of 7 represents neutrality and lower numbers indicate increasing acidity and higher numbers increasing alkalinity. Each unit of change represents a ten-fold change in acidity or alkalinity and that is the negative logarithm of the effective hydrogen-ion concentration or hydrogen-ion activity in gram equivalents per liter of the solution. The development of acidity in soils is a result of the natural processes of weathering under humid conditions. Acidic soils are those that have had soluble salts, and other materials removed – usually by moderate to high rainfall. In general, the soils of the Midwest and Eastern United States are acid to a considerable depth, whereas the soils whose development has been retarded by poor drainage or other conditions are alkaline. Most soils fall within a pH range that is strongly acid to mildly alkaline.

Extremely acid soils (below pH 4.5) and very strongly alkaline soils (above pH 9.1) have significantly high corrosion loss rates when compared to other soils. Soil pH is best measured in the field using a pH meter by following the methods per ASTM G 51 – 77.
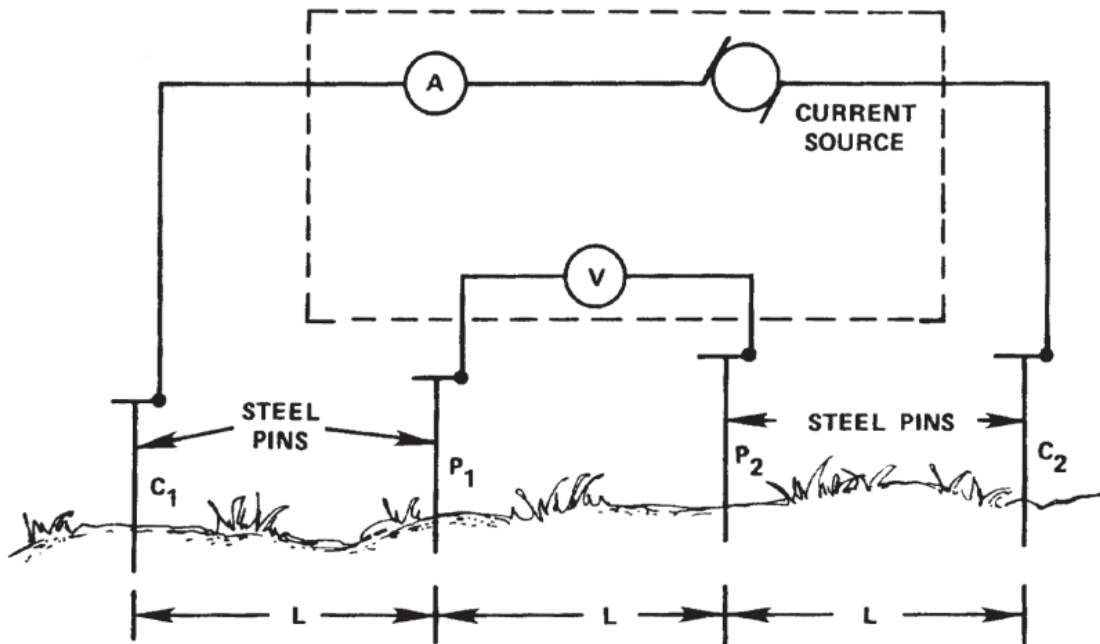
Soil Resistivity

Soil resistivity (reciprocal of conductivity) is the one variable that has the greatest influence on corrosion rate. However, other factors besides resistivity, such as hydrogen-

ion concentration, soluble salts, total acidity are inter-related, and it is difficult to control conditions so that there is only one variable. In general, the lower the resistivity, the higher the corrosion rate. Metals buried in low resistivity soils will generally be anodic, whereas metals buried in adjacent high resistivity soils will generally be cathodic.

As shown in Figure 7.1, moisture content has a profound effect on resistivity. Soil that is completely free of water has extremely high resistivity. For example, sandy soils that easily drain water away are typically noncorrosive; clayey soils that hold water have low resistivity and are typically corrosive. Backfill material will generally be more corrosive than native earth because the backfill soil has a higher moisture content. In addition, backfill material typically never reconsolidates back to the same degree as native soil, allowing more penetration and retention of water.

Soil resistivity is typically measured using one or both of two methods: (1) testing onsite with the Wenner four-pin method, and/or (2) taking a soil sample to a laboratory for a soil box resistivity test. The recommend practice is the onsite Wenner four-pin method per ASTM G57-78 standard specification. The four-pin method is recommended because it measures the average resistivity of a large volume of earth with relative ease. As Figure 7.3 shows, this method is done by placing four pins at equal distances from each other. A current is then sent through the two outer pins. By measuring the voltage across the two inner pins, the soil resistance can be calculated using Ohm's Law (V= IR). Soil resistivity can be determined using Equation 7.1.

Figure 7.3 - Wenner four-pin method for measuring soil resistivity

Resistivity = 191.5 x R x L (ohm-cm)   (Equation 7.1)

Where:
    R = resistance measured with a soil resistivity meter
    L = the pin spacing in feet

The soil box resistivity test is not recommended because it requires a large number of

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samples be taken for an accurate map of soil resistivities in a given area. The soil box test is also much more time-consuming than the four-pin method.

The following table is offered as a guide in predicting the corrosion potential of a soil with respect to resistivity alone:

Table 7.2 - Soil Resistivity/Corrosion Rate Potential

Resistance Classification	Soil Resistivity (ohm-cm)	Corrosion Potential
Low	0 - 2,000	Severe
Medium	2000 - 10,000	Moderate
High	10,000 - 30,000	Mild
Very High	Above 30,000	Unlikely

Prediction of Corrosion Loss Rates

The National Bureau of Standards (NBS) performed extensive studies of underground corrosion between 1910 and 1955. More than 36,500 metal samples were exposed at 128 test locations throughout the United States. In 1957, Romanoff presented the results of these investigations in *Underground Corrosion* [Romanoff (1957)]. The studies showed that most underground corrosion was a complex electrochemical process dependent on the various properties discussed previously. The NBS studies were primarily concerned with buried pipeline corrosion. Since pipes are installed in backfilled trenches, the NBS work was performed on specimens placed in trenches ranging from 18" (0.46 m) to 6 ft (1.8 m) deep. The following conclusions can be drawn from these studies:

1. The metal loss rates reported were from samples placed in backfilled, i.e. disturbed soils.
2. Atmospheric oxygen or oxidizing salts stimulates corrosion by combining with metal ions to form oxides, hydroxides, or metallic salts. This is particularly true in disturbed soils at or near the soil surface.
3. The least corrosive soils had resistivities above 3,000 ohm-cm and low soluble salt concentrations.
4. Metal loss rates in disturbed soils can be determined by assuming they will be similar to the loss rates found at test sites with similar pH and resistivity levels as given in NBS Circular 579 Tables 6, 8 and 13.

A.B. Chance Company Bulletin 01-9204 "Anchor Corrosion Reference & Examples" contains extensive metal loss rate data derived from Romanoff's work. **It is recommended that this information be used to determine the service life of galvanized and un-galvanized steel in disturbed soil.** When hot-dip galvanized steel is used, the service life should be increased by the time it takes the zinc coating to be lost due to corrosion. Hot dip galvanizing is one method of passive control that can be used to provide corrosion protection to the parent carbon steel.

The Federal Highway Administration has proposed uniform corrosion loss rates based on a simple assessment of the electrochemical index properties. Per FHWA-RD-89-198, the ground is considered aggressive if any one of these indicators shows critical values.

**Table 7.3 - Electromechanical Properties of Mildly Corrosive Soils**

Property	Test Designation	Criteria
Resistivity	AASHTO T-288-91	> 3,000 ohm-cm
pH	AASHTO T-289-91	> 5 < 10
Sulfates	AASHTO T-290-91	200 ppm
Chlorides	AASHTO T-291-91	100 ppm
Organic Content	AASHTO T-267-86	1% max.

The design corrosion rates, per FHWA-SA-96-072, suitable for use in mildly corrosive soils having the electrochemical properties limits listed in Table 7.3 are:

For Zinc: 15μm/year [0.385 oz/ft^2/yr.] (first two years)
                4 μm/year [0.103 oz/ft^2/yr.] (thereafter)
For carbon Steel: 12 μm/year [0.308 oz/ft^2/yr.] (thereafter)

Other methods are available to predict corrosion loss rates. Figure 7.4 is a nomograph for estimating the corrosion rate of helical screw foundation shafts. It is a corrosion nomograph adapted from the British Corrosion Journal [King (1977)]. Its appeal is its ease of use. If the resistivity and soil pH is known, an estimate of the service life (defined as $\frac{1}{8}$" material loss) of a helical screw foundation anchor shaft can be obtained for either an acid or alkaline soil.
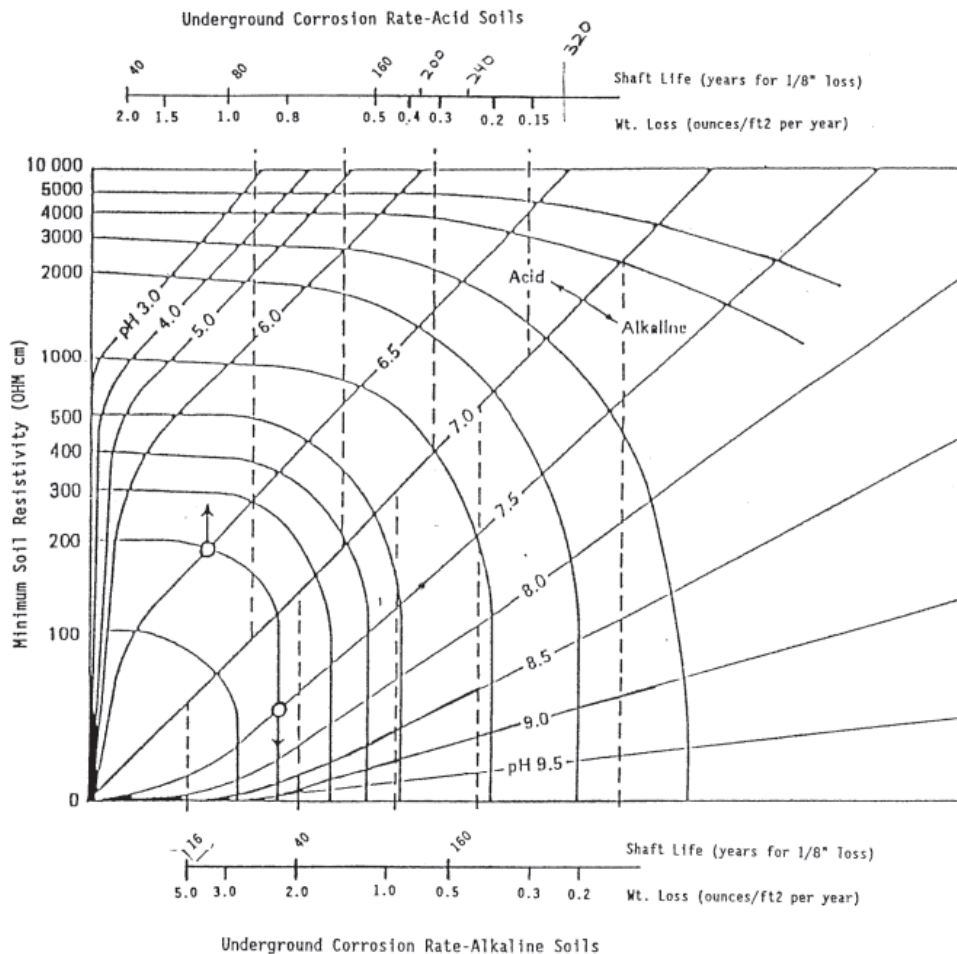
Examples:

For pH 6.5 and Resistivity of 200 ohm-cm: Weight loss is approximately 1.3 oz/ft^2/year and expected life (for $\frac{1}{8}$" shaft loss) is approximately 65 years

For pH 7.5 and Resistivity of 200 ohm-cm: Weight loss is approximately 2.3 oz/ft^2/year and expected life (for $\frac{1}{8}$" shaft loss) is approximately 38 years

**Figure 7.4 - Nomograph for Estimating
the Corrosion Rate of Anchor Shafts**

Corrosion Loss Rates - Special Considerations

Factors other than resistivity and pH can have a strong influence on corrosion loss rates. It is well known that marine environments can be severely corrosive to unprotected steel – particularly in tidal and splash zones. Corrosion loss rates in these environments can be quite high – averaging 6.9 oz./ft.^{2} [Uhlig's Corrosion Handbook (2000)]. Salt spray, sea breezes, topography, and proximity all affect corrosion rate. Studies have shown that corrosion rate for zinc exposed 80 ft. (24.4 m) from shore was three times that for zinc exposed 800 ft. (244 m) from shore.

Seawater immersion is less corrosive than tidal or splash zones. This is because seawater deposits protective scales on zinc and is less corrosive than soft water. Hard water is usually less corrosive than soft water toward zinc because it also deposits protective scales on the metallic surface. Table 7.4 provides corrosion loss rates of zinc in various waters. **In most situations, zinc coatings would not be used alone when applied to steel immersed in seawater, but would form the first layer of a more elaborate protective system – such as active protection using sacrificial anodes.**

Table 7.4 - Corrosion of Zinc in Various Waters*

Water Type	μm/yr	mils/yr	oz./ft^2
Seawater			
Global Oceans, average	15 - 25	0.6 - 1.0	0.385 - 0.642
North Sea	12	0.5	0.308
Baltic Sea and Gulf of Bothnia	10	0.4	0.257
Freshwater			
Hard	2.5 - 5	0.1 - 0.2	0.064 - 0.128
Soft River Water	20	0.8	0.513
Soft Tap Water	5 - 10	0.2 - 0.4	0.128 - 0.257
Distilled Water	50 - 200	2.0 - 8.0	1.284 - 5.13

*Corrosion Handbook, Vol. 13 Corrosion, ASM International

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Corrosion in Undisturbed Soil

In the National Bureau of Standards (NBS) Monograph 127, Underground Corrosion of Steel Piling [Romanoff (1972)], it was reported that driven steel piles did not experience appreciable corrosion when driven into undisturbed soils. These findings were obtained during NBS studies of steel pile corrosion. Romanoff also stated that the NBS corrosion data for steel exposed in disturbed soils was not applicable to steel piles driven in undisturbed soil. He concluded:

> ". . . that soil environments which are severely corrosive to iron and steel buried under disturbed conditions in excavated trenches were not corrosive to steel piling driven in the undisturbed soil. The difference in corrosion is attributed to the differences in oxygen concentration. The data indicates that undisturbed soils are so deficient in oxygen at levels a few feet below the ground line or below the water table zone that steel pilings are not appreciably affected by corrosion, regardless of the soil types or the soil properties. Properties of soils such as type, drainage, resistivity, pH, or chemical composition are of no practical value in determining the corrosiveness of soils toward steel pilings driven underground."

The following conclusions can be drawn from these studies:

1. Oxygen is required at cathodic sites to support underground corrosion of a helical screw foundation.

2. Disturbed soils (fill) contain an adequate supply of oxygen to support underground corrosion, at least at shallow depths. Thus, the top-most extension(s) of the screw foundation's central steel shaft merits corrosion protection – either using passive protection like zinc, epoxy, or Teflon coatings or active protection like sacrificial anodes.

3. The aggressiveness of disturbed soils can be measured, and they can be classified as aggressive and non-aggressive. See Table 7.3 above.

4. Undisturbed soils were deficient in oxygen a few feet below the ground surface, or below the water table. It is recommended to install the helical bearing plates of a helical screw foundation into de-aerated soil.

The role of oxygen in an undisturbed soil overrides the effects of soil resistivity, pH, etc. In those situations where a helical screw foundation is installed into a soil profile where a disturbed soil layer overlies undisturbed soil, the section of the screw foundation in the disturbed soil is cathodic to the rest of the foundation in the undisturbed region as illustrated in Figure 7.5. As a result, the most severe corrosion occurs on the section of the foundation just below the disturbed layer.

**Figure 7.5
Corrosion of Helical Screw Foundation
in a Disturbed Soil**

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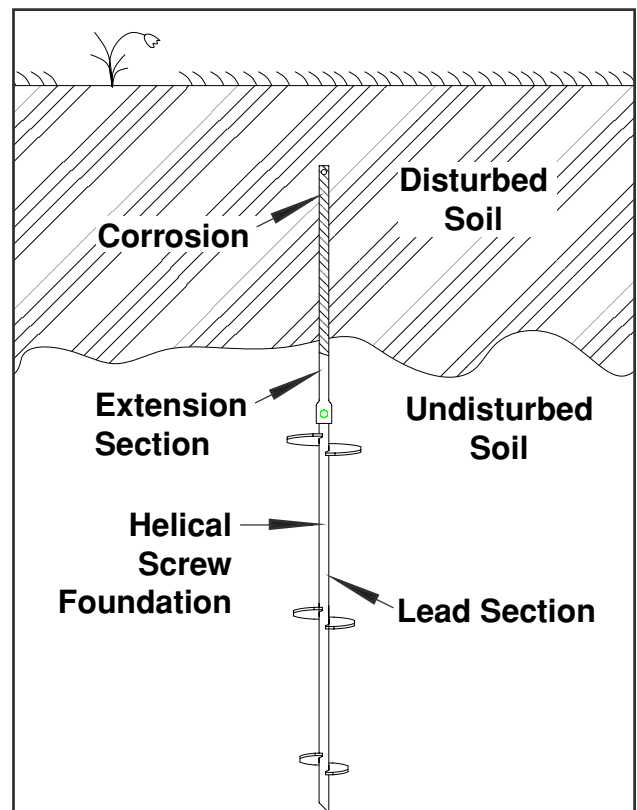
Similarly, a helical screw foundation located in undisturbed soil with a high water table can suffer some corrosion attack at the waterline as illustrated in Figure 7.6. This combination does not result in serious attack, but it is believed that the situation is aggravated by a continuously changing water table, which would draw in oxygen as the waterline dropped. The section of the screw foundation above the waterline acts as a weak cathode to the anode below the waterline.

Figure 7.6
Corrosion of Helical Screw Foundation
at the Waterline
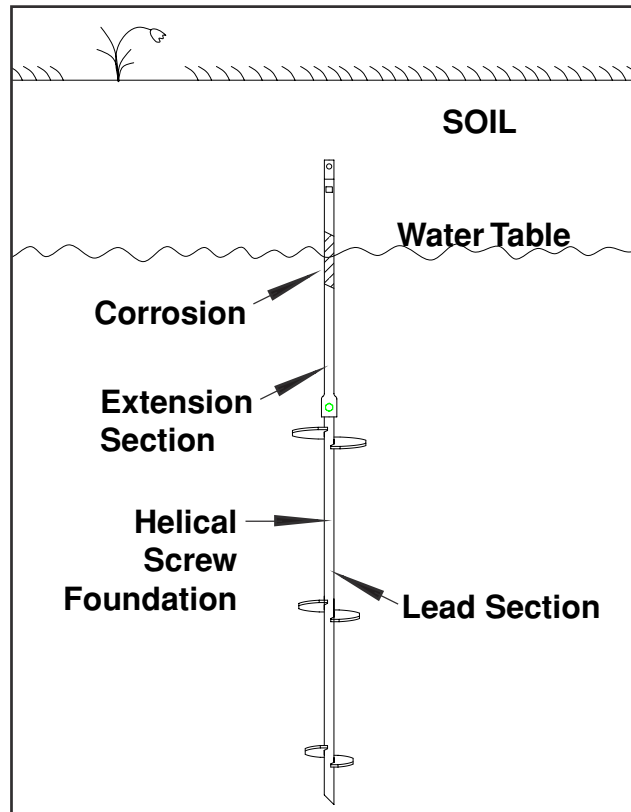
Figure 7.7
Corrosion of Helical Screw Foundation
with a Concrete Cap
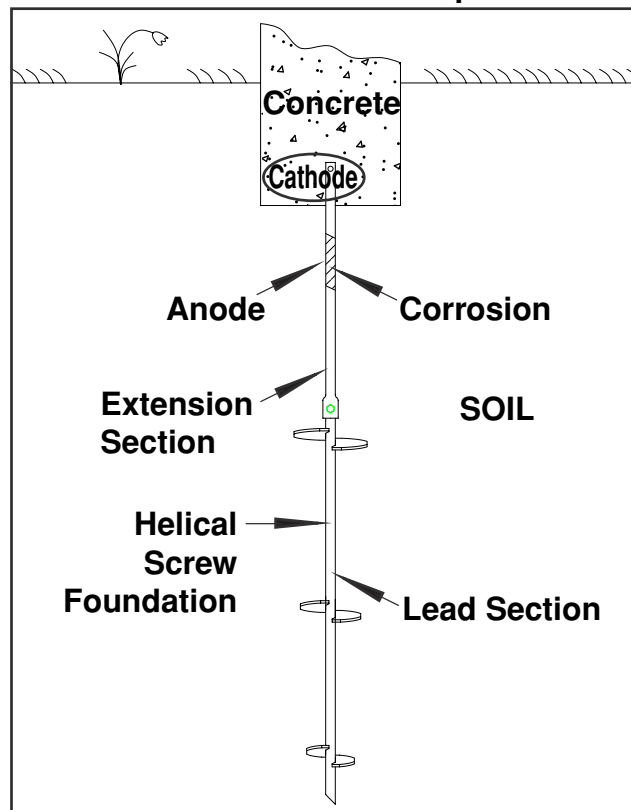
Helical screw foundations are commonly terminated in concrete cap or grade beams. The area of steel in the concrete forms a passive oxide film generated by the action of the highly alkaline environment, and this area is cathodic to the rest of the screw foundation in the soil. However, the high resistivity of the concrete limits the effectiveness of the cathode, thereby limiting the small amount of corrosion attack to the region of the screw foundation immediately outside the concrete as illustrated in Figure 7.7.

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Corrosion Control

The amount and type of corrosion control is a function of structure type, service life, and the overall aggressiveness of the project soils. The following requirements are typical. The specifier should review and edit as appropriate for the project.

Structure Type: Temporary structures generally do not require corrosion protection. A temporary structure is defined within a specified time frame (i.e. months rather than years). In general, permanent structures have a service life greater than 24 months.

Service Life: A typical service life of 50 years should be used unless otherwise specified. If the service life of a temporary helical screw foundation is likely to be extended due to construction delays, it should be considered permanent. For a service life of less than 20 years in non-aggressive soil, corrosion protection is not recommended.

Soil: The soil can be classified as aggressive or non-aggressive. See Table-2 contained in the appendix of the Guide to Model Specification - A. B. Chance® Company Helical Screw Foundations for Structural Support for an example of aggressiveness classification. It is recommended that steel foundation elements installed into soils classified as aggressive be provided with some type of corrosion protection.

Several alternatives are available to protect helical screw foundations against corrosion – and can be roughly categorized in terms of cost. Because of the added cost, the need for corrosion protection must be carefully determined and specified as necessary. Passive protection typically consists of a metal loss allowance (i.e. $\frac{1}{8}$" loss) and/or coatings – such as galvanization or epoxy. Passive protection is relatively inexpensive. Active protection typically consists of cathodic protection via the use of sacrificial anodes. Active protection is relatively expensive and is used in permanent applications where the corrosion potential of the soil is severe.

Passive Protection
Allowable metal loss rate
As mentioned previously, A. B. Chance bulletin 01-9204 "Anchor Corrosion Reference & Examples" contains extensive metal loss rate data derived from Romanoff's work. Design Example-1 demonstrates passive protection calculations that estimate the service life of helical screw foundation shafts in soil using the metal loss rates from Romanoff. The service life is defined as the estimated length of time required for 1/8" of material loss to occur on the helical screw anchor shaft. This amount of loss is strictly arbitrary, but is common for pile evaluation.

Galvanization
Aggressive soils, and the conditions illustrated in Figures 7.5, 7.6, and 7.7 demonstrate the need to coat the section of the helical screw foundation above the waterline in the disturbed soil and, in particular, the area of the screw foundation in the concrete cap or grade beam. Thus, by removing the cathode, the anode/cathode system is disrupted resulting in reduced corrosion. If it were possible to apply a coating capable of guaranteed isolation of the steel surface from the electrolyte (soil), all corrosion concerns would be solved. **However, a coating capable of 100% guaranteed isolation has yet to be developed.** Epoxy coatings provide excellent electrical isolation, but will chip and abrade easily during handling and installation. The same holds true for porcelain, Teflon, and polyurethane coatings. A small chip or crack in the protective coating can cause corrosion activity to be highly localized – possibly leading to severe damage. **The single best coating for helical screw foundations is hot dip galvanizing.**

The first step in the galvanizing process is pickling the steel in dilute acid. This removes any rust, scale, oil or other surface contaminants. The clean steel is then dipped in a vat of molten zinc for time periods ranging up to several minutes for the more massive steel foundations. After the hold period, the zinc-coated steel is withdrawn from the vat at a controlled rate, which allows the coating to quickly cool and harden. The result is a tough, combined zinc and zinc-iron coating which metallurgically bonds to the steel. Other galvanization processes, such as mechanical galvanizing and electroplating, do not form a coating that is metallurgically bonded to the steel.

Hubbell/Chance galvanizes to the latest ASTM standards – either ASTM A153 class B or ASTM A123. ASTM A153 Class B requires an average weight of zinc coating to be 2.0 oz./ft.^{2} (3 mils) and any individual specimen to be no less than 1.8 oz./ft.^{2} (2.8 mils). ASTM A123 can be used to specify thicker zinc coatings – up to 2.3 oz./ft.^{2} (3.9 mils).
Figure 7.8 illustrates how zinc and steel react to form zinc-iron alloy layers. The bottom of the picture shows the base steel, then a series of alloy layers and, on the outside, the relatively pure outer zinc layer. **The underlying zinc-iron alloy layers are actually harder than the base steel.** Therefore, below the relatively soft pure zinc layer, the zinc-alloy layers provide protection in abrasive conditions such as dense sands and gravels.

Figure 7.8 Photomicrograph of Zinc Layer Section
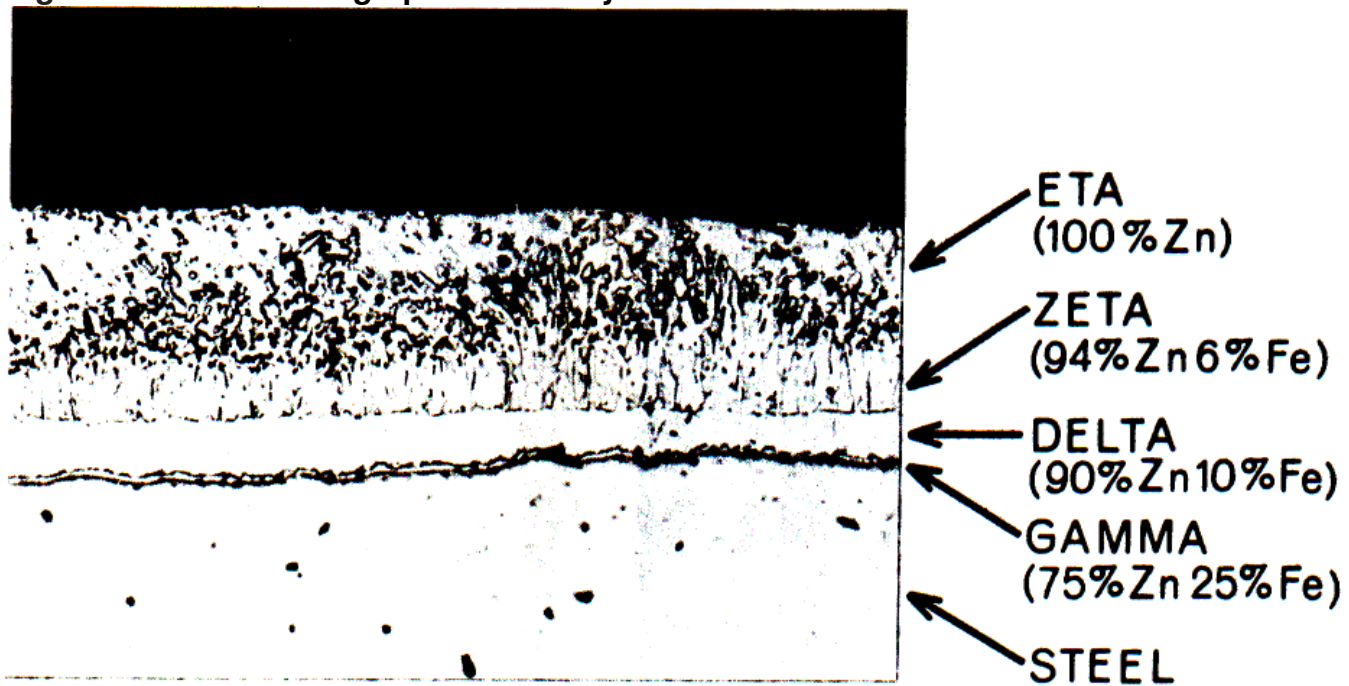
Photomicrograph of a section through a typical hot dip galvanizing coating showing alloy layers. (Courtesy of American Hot Dip Galvanizers Association, Inc.)

Hot dip galvanized coatings protect the carbon steel shaft in two ways. First, the zinc coating provides a protective layer between the helical screw foundation shaft and the environment. Second, if the zinc coating is scratched and the steel surface exposed, the zinc, not the steel, will corrode. This is because zinc is a dissimilar metal in electrical contact with the steel, thus the difference in potential between the two metals and their relative chemical performance (anode or cathode) can be judged by examining a galvanic series as shown in Table 7.5. The materials at the top of the list are most active (anodic) compared to the noble (cathodic) materials at the bottom of the list. Steel is more noble than zinc, thus the more active zinc coating will act as an anode and corrode while the more noble steel will be the cathode and be protected.

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Design Example 2 demonstrates passive protection calculations that estimate the tensile load capacity reduction of a ¾" diameter coupling bolt used with Hubbell/Chance Type SS5/150 helical screw foundations. In this example, the assumed service life is 85 years and design corrosion rates per FHWA-SA-96-072 (as quoted here on pg. 7-7) are used.

Bituminous and Other Coatings

Bituminous or asphaltic coatings or paints only provide physical protection from the environment. They will wear off quickly due to the abrasive action during installation. Extension sections are typically hot-dip galvanized, but other coatings can be specified. Practical application of asphaltic coatings is generally limited to the extension sections located at or near the surface where the coating will provide the greatest benefit. Bituminous and other coatings are best applied in severely corrosive conditions where part of the helical screw foundation is exposed above grade. Examples are steel foundations used in tidal marsh, coastal regions, and contaminated soils.

**Table 7.5 Galvanic Series in Seawater**

ACTIVE	Magnesium
	Zinc
	Beryllium
	Aluminum Alloys
	Cadmium
	Mild Steel, Cast Iron
	300 Series Stainless Steel (Active)
	Aluminum Bronze
	Naval Brass
	Tin
	Copper
	Lead-Tin Solder (50/50)
	90-10 Copper-Nickel
	Lead
	Silver
	300 Series Stainless Steel (Passive)
	Titanium
	Platinum
NOBLE	Graphite

Design Example 1:

Project: Santa Rosa, CA Residence
The purpose of these calculations is to estimate the service life of Type SS Round Cornered Square (RCS) Helical Screw Foundation Shafts on the subject project.

Service life is defined as the estimated length of time required for ⅛" of material loss to occur on the helical screw anchor shaft. This amount of loss is strictly arbitrary, but is common for pile evaluation.

⅛"
Material
Loss

Type SS
or Square Shaft
Helical Screw Foundation
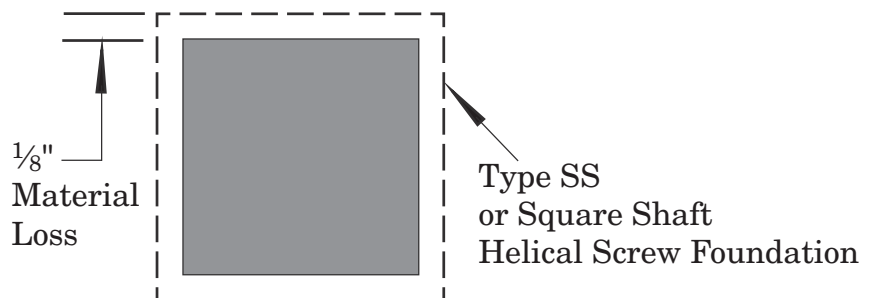
Given:
Screw Foundations Galvanized to ASTM A153 (Minimum Zinc Coating = 1.8 oz/ft.^{2})
Soil Resistivity – minimum resistivity is 760 Ω-cm.
Soil pH - 7.70
Water Soluble Chloride – 11 PPM
Water Soluble Sulfate – 417 PPM

Assumptions:
It is assumed that the material loss rates will be similar to the loss rates found at test sites with similar pH and resistivity levels as given in Melvin Romanoff's Underground

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Corrosion from The National Bureau of Standards (NBS) Circular #579, 1957, Tables 6, 8 and 13.

In Circular #579, site #5 is indicated as having a resistivity of 1,315 Ω-cm and a pH of 7.0. This soil is Dublin Clay Adobe and is located around Oakland, CA. In addition, Site #2 is indicated as having a resistivity of 684 Ω-cm and a pH of 7.3. This soil is Bell Clay and is located around Dallas, TX. The corrosion rates for these two sites will be used to estimate the life of the Type SS helical screw foundation shaft material.

Allowable Steel Loss:
Based on the loss of ⅛" thickness of the helical screw foundation shaft, calculate the steel loss in terms of weight per unit area.

0.125 in. x 0.283 lb/in^3 x 16 oz/lb = 0.566 oz/in^2 x 144 in^2/ft^2 = 81.5 oz/ft^2　(Equation 7.2)

Average Metal Loss per Year:
From Romanoff Site #5: (Dublin Clay Adobe)

Duration of Exposure (years)	Loss in Weight (oz/ft^2)	Loss per year (oz/ft^2)
1.9	1.4	0.737
4.1	2.2	0.585
6.2	4.8	0.774
8.1	5.2	0.642
12.1	5.4	0.446
17.5	8.3	0.474

The average loss per year is 0.61 oz/ft^2. Note that as the duration of exposure increases, the material loss per year generally decreases.

Screw Foundation Shaft Life:
To determine the foundation shaft's service life (SL), the allowable steel loss is divided by the average loss per year.

SL = (81.5 oz/ft^2)/(0.61 oz/ft^2) = **133.6 years**　　　　　(Equation 7.3)

Total Zinc Coat Loss:
A.B. Chance Co. helical screw foundations are provided hot dip galvanized per ASTM A153. The coating thickness for ASTM A153 class B = 1.8 oz/ft^2

From Romanoff NBS Circ. #579, P. 110, Table 65 gives the following average loss rates for Site #5 soils:

Duration of Exposure (years)	Loss in Weight (oz/ft^2)	Loss per year (oz/ft^2)
10.17	2.66	0.262

Estimated Life of Zinc = 1.8 oz/ft^2 / 0.262 oz/ft^2 = **6.9 years**

Total Estimated Service Life of Screw Foundation Shaft = **133.6 + 6.9 = 140.5 years**

From Romanoff Site #2: (BELL CLAY)

Duration of Exposure (years)	Loss in Weight (oz/ft^2)	Loss per year (oz/ft^2)
2.1	2.4	1.143
4.0	3.0	0.750
5.9	3.4	0.576
7.9	3.6	0.456
12.0	5.9	0.492
17.6	8.1	0.460

The average loss per year is 0.65 oz/ft^2. Note that as the duration of exposure increases, the material loss per year generally decreases.

Screw Foundation Shaft Life:
To determine the foundation shaft's service life (SL), the allowable steel loss is divided by the average loss per year.

SL = (81.5 oz/ft^2)/(0.65 oz/ft^2) = **125.4 years**

Total Zinc Coat Loss:
A.B. Chance Co. helical screw foundations are provided hot dip galvanized per ASTM A153. The coating thickness for ASTM A153 class B = 1.8 oz/ft^2

From Romanoff NBS Circ. #579, P. 110, Table 65 gives the following average loss rates for site #2 soils.

Duration of Exposure (years)	Loss in Weight (oz/ft^2)	Loss per year (oz/ft^2)
9.92	0.44	0.044

Estimated Life of Zinc = 1.8 oz/ft^2 / 0.044 oz/ft^2 = **40.9 years**

Total Estimated Service Life of Screw Foundation Shaft = **125.4 + 40.9 = 166.3 years**

Summary:
Total Estimated Service Life of Helical Anchor Shaft in Site #5 Soils = 140.5 years
Total Estimated Service Life of Helical Anchor Shaft in Site #2 Soils = 166.3 years

These calculations are estimated of the service life only ($^1/_8$ inch material loss from shaft) and are based upon loss rates obtained from Romanoff's disturbed soil sites. It is generally accepted that the majority of any corrosion will occur at or near the surface. Hence, it is very likely that helical screw foundation shaft metal loss will control the design.

In the event the estimated service life does not meet the design requirements, one option is to use a larger sized helical screw foundation shaft.

Design Example 2:

Extendable helical screw foundations consist of segmented elements that are coupled together with structural bolts. It is possible for coupling bolts to be located near the surface in disturbed soils. Therefore, it is recommended that the coupling bolt service life be calculated based on corrosion loss rates. This can be accomplished using methods similar to those shown in Design Example 1.

Determine the Diameter Reduction of Type SS5/150 Coupling Bolts Using Corrosion Loss Rates per FHWA-SA-96-072 (as quoted here on pg. 7-7): Type SS5/150 Helical Screw Foundations use ¾" dia. bolts per ASTM A320 Grade L7. Assume a service life of 85 years.

Total Zinc Coat Loss:
A.B. Chance Co. fasteners are provided hot dip galvanized per ASTM A153. The coating thickness for ASTM A153 class B = 1.8 oz/ft^2

Zinc loss the first two years: = 0.385 oz/ft^2/year x 2 years = 0.77 oz/ft^2
Estimated life of zinc coating = [1.8 oz/ft^2 - 0.77 oz/ft^2 = 1.03 oz/ft^2/0.103 oz/ft^2 = 10 years] + 2 years = **12 years**

Total Steel Loss:
Coupling bolt steel loss will occur after the zinc coating is lost. The exposure time to corrosion for the bolt steel is: 85 years – 12 years = 73 years.
Bolt steel loss over 73 years: = 0.308 oz/ft^2/year x 73 years = 22.5 oz/ft^2

22.5 oz/ft^2/144 in^2/ft^2 x 16 oz/lb x 0.283 lb/in^3 = 0.035" (0.9 mm)

Diameter reduction after 85 years is 0.75"– 2 x 0.035" = 0.68" (17.3 mm)

Determine the Tensile Load Capacity Reduction of Type SS5/150 Coupling Bolts:
The minimum ultimate tensile strength for A.B. Chance Co. Type SS5/150 Helical Screw Foundations is 70 kip. The failure mechanism is double shear of the coupling bolt. Assuming a linear relationship between diameter and shear capacity, the bolt diameter reduction from an 85-year exposure per FHWA-SA-96-072 corrosion loss rates suitable for use in mildly corrosive soils will result in a reduced tension load capacity, i.e., 0.68 x 70/ 0.75 = 63.5 kips.

Active Protection
For very aggressive soil environments, cathodic protection, in addition to coatings, is the recommended procedure to minimize or eliminate corrosion. Cathodic protection is a method of eliminating corrosion damage to buried steel structures by the application of DC current. The effect of the DC current is to force the metallic surface to become cathodic (i.e. collecting current). If the current is of sufficient magnitude, all metallic surfaces will become cathodic to the external anode.

Both sacrificial anode and impressed current (rectifier and ground bed) cathodic protection systems are used to provide the required current. If the current source is derived from a sacrificial metal (magnesium and zinc are the two most common galvanic anodes used in soils), the effectiveness will depend on the soil properties in which it is placed. More available current is generated from a sacrificial anode in low resistance soils than high resistance soils. It is also best to place impressed current anode beds in lower resistant soils. However, since the available driving potential is greater (rectifier control), the soil resistivity is less significant.

Current requirements needed to protect a steel structure from corrosion will vary due to physical and environmental factors. These requirements could range from 0.01ma/ft^2 of metal surface for a well-applied, high-dielectric-strength plastic coating to 150 ma/ft^2 for bare steel immersed in a turbulent, high velocity, salt-water environment. In soil, 1 to 3 ma/ft^2 is typically used as the required current to protect carbon steel.

In the case of helical screw foundations, sacrificial anodes are the most common method of cathodic protection used. This is done by electrically connecting the steel to a properly selected anode of a less noble metal such as zinc or magnesium. The dissimilar metals buried in a common electrolyte (soil) form a galvanic cell. The cell works much like the battery in the family car, the less noble anode corrodes or sacrifices itself while the more noble cathode is protected. For steel to be cathodically protected, it is generally recognized that at least one of the following conditions must be met:

**Figure 7.9
Typical Anode Installation**

1. The potential of the steel must be at -0.85 volts or more negative with respect to a saturated copper-copper sulfate half-cell in contact with the electrolyte.
2. A potential shift of -0.3 volts or more negative upon connection of the cathodic protection.

Proper sizing and selection of anodes requires knowledge about the soil profile, resistivity, pH, and location of the water table. Other factors include the area of steel to be protected, plus the required service life. Anodes come in several bag sizes – with anode weights ranging from 5 lb up to 60 lb, depending on the steel area, soil conditions, and required service life. For more specific information on anode selection, refer to A.B. Chance Co. Bulletin 2-8307 "Cathodic Protection of Anchors – A Basic Guide to Anode Selection" and A.B. Chance Co. Bulletin 01-9204 "Anchor Corrosion Reference & Examples."

Typical installation of anode is shown in Figure 7.9. For best operation, the anode should be installed at a depth sufficient to be in permanently moist soil to ensure continuous protection, which means the top of the anode may be several feet below grade. The augered hole should be slightly larger than the packaged anode. When backfilled, the backfill material should be thoroughly tamped around the anode to ensure intimate contact with the soil. Water can be added to expand the packaged anode, which give better long-term performance. The lead of the anode should be installed in a shallow trench deep enough to remain undisturbed. The lead should be coiled or folded at each end to prevent freezing and thawing of the soil from breaking the wire or connection. Electrical connection of the lead to the steel foundation can be accomplished using Cadweld or Therm-O-Weld thermal welds.

Helical Screw Foundation System Design Manual for New Construction

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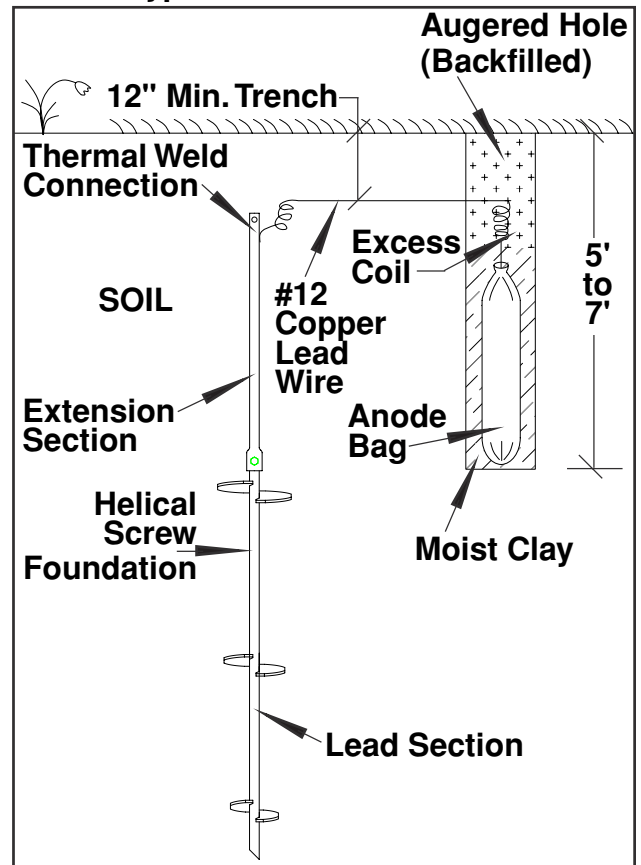
References

1. A.B. Chance Company, "Anchor Corrosion Reference & Examples," Bulletin 01-9204, Copyright 1992 A. B. Chance Company, Centralia, MO
2. A.B. Chance Company, "Chance Anchor Corrosion Report," Bulletin 31-9403, reprinted with permission from Texas Dept. of Transportation, Copyright 1994 A.B. Chance Company, Centralia, MO
3. Escalante, Edward, "Concepts of Underground Corrosion," Effects of Soil Characteristics on Corrosion, ASTM STP 1013, V. Chaker & J. D. Palmer, Eds., American Society for Testing and Materials, Philadelphia, 1989.
4. Federal Highway Administration Publication No. FHWA-SA-96-072, "Corrosion/ Degradation of Soil Reinforcement for Mechanically Stabilized Earth Walls and Reinforced Slopes."
5. King, R. A., Corrosion Nomograph (1977), TRRC Supplementary Report British Corrosion Journal.
6. Metals Handbook, Volume 13 – Corrosion, Ninth Edition, copyright 1987 by ASM International, Metals Park, OH 44073.
7. Rabeler, R. C., "Soil Corrosion Evaluation of Screw Anchors," Effects of Soil Characteristics on Corrosion, ASTM STP 1013, V. Chaker & J. D. Palmer, Eds., American Society for Testing and Materials, Philadelphia, 1989.
8. Romanoff, Melvin, "Corrosion of Steel Pilings in Soil," part of National Bureau of Standards Monograph 127, NBS Papers on Underground Corrosion of Steel Piling 1962-1971. March 1972.
9. Romanoff, Melvin, Underground Corrosion, Published by the National Association of Corrosion Engineers (NACE) Houston, TX, 1989, (Originally Issued by the National Bureau of Standards, Circular 579, 1957).
10. Uhilig's Corrosion Handbook Edited by R. Winston Revie, 2nd Edition, Electrochemical Society Series, 2000.
11. Various Cathodic Protection System Vendors.
12. West, Edward L., "Cathodic Protection of Anchors – A Basic Guide to Anode Selection," Bulletin 2-8307, 1983, A.B. Chance Company, Centralia, MO