

Introduction to Corrosion and Galvanizing of Helix Foundations

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Abstract

A basic review of helix foundation corrosion and galvanizing is presented. The review includes an introduction to the electrochemical process of corrosion, various forms of corrosion, soil and pore water effects on corrosion rates, and soil classification based on conductivity. The phenomena of passivity and galvanic corrosion are briefly discussed. Different types of galvanizing processes are summarized. Minimum and average helix foundation life-expectancy are estimated for different soil types.

Introduction

In order that helix foundations provide support for the design life of a structure, it is important that they be protected from corrosion. Galvanizing is the most often incorporated method of corrosion protection used by helix foundation manufacturing companies. A fundamental review of corrosion and galvanizing is presented. The review is intended to aid foundation engineers in approximately judging the expected lifespan of a helix foundation and in understanding the importance of galvanization.

Corrosion

Corrosion is the exothermic chemical transformation of a metal or metal alloy to a non-reactive covalent compound such as an oxide or silicate that is often similar or even identical to the mineral from which the metals were extracted. Thus, corrosion has been called "extractive metallurgy in reverse" (Payer, et al., 1980).

"Rust" is a general term often used for the covalent compounds formed during the corrosion of iron and steel. The composition of rust depends on the abundance and species

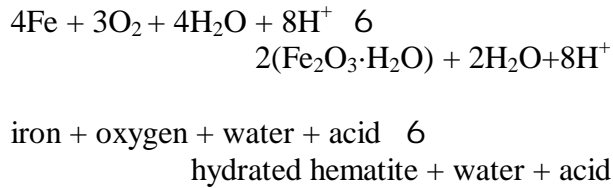
of other chemicals available during corrosion. Metallic corrosion occurs most prevalently in aqueous solutions, which conduct electric charge through ions. The electrochemical composition of the aqueous solution almost always governs the rate of corrosion and the composition of rust.

With regard to helix foundations and other underground metallic structures, corrosion rate is generally governed by the flow of electricity in soil and is a function of moisture content, presence of dissolved salts, acidity, soil density, soil type, and permeability. A measure of the rate of flow of electrical current is conductivity. Ground water by itself does not have very high conductivity. However, all ground water contains some soluble salts. Higher salt content increases conductivity.

The acidity of a ground water is a measure of the concentration of hydrogen ions. Recall that the concentration of hydrogen ions is typically represented by the pH (negative of the logarithm base 10 of the concentration of H^+ ions). High acidity (low pH) indicates more hydrogen ions. Hydrogen ions remove electrons from iron making it more chemically reactive. The rate of

corrosion is also a function of the quantity of dissolved and free oxygen and the diffusion rate of oxygen.

Of many possible reactions, one example of the net chemical reaction for the corrosion of iron and steel in the presence of acidic water with ample dissolved oxygen is given below. Note that hydrated hematite is the reddish-brown mineral most often associated with the term rust.



Although all hydrogen ions and some water are conserved on both sides of the net reaction given above, these chemicals are important facilitators of the corrosion reaction for the reasons stated above.

The opposite of electrical conductivity is resistivity. Either term is often used to describe the corrosivity of soil. A guide to characterizing the corrosivity of soil based on resistivity is provided in Table 1 (Modified from Miller, Foss, and Wolf, 1981).

Table 1. Soil Corrosivity Classification

Corrosivity	Resistivity (S cm)
Very Low	>10,000
Low	5,000 to 10,000
Moderate	2,000 to 5,000
High	1,000 to 2,000
Very High	<1,000

Long-term soil-testing programs conducted by the National Bureau of Standards between 1910 and 1955 comprise much of the data on soil corrosivity in the

United States (Romanoff, 1989). These data are shown graphically in Fig. 1 and represent the rate of corrosion as a function of soil resistivity for over 300 buried iron and steel samples from 54 locations across the United States. It can be seen in the figure that low resistivity (high electrical conductivity) is generally associated with high rates of corrosion. In general, soils with high moisture content, ample supply of dissolved oxygen, considerable salt content, and high acidity are most corrosive.

Different types of iron, steel, and zinc have been found to corrode at essentially the same rate in most soil types (Uhlig and Revie, 1985). This finding caused some engineers, including the author at one time, to incorrectly believe that zinc coating of underground metallic structures was unimportant. Better understanding of the function of zinc coating and corrosion related failure mechanisms leads to the conclusion that the zinc coating of helix foundations is not only important but also necessary.

There are various forms of corrosion including uniform, galvanic, crevice, pitting, intergranular, cracking, erosion, dealloying, and hydrogen damage (Jones, 1996). Uniform corrosion accounts for the greatest amount of metal transformation, however crevice and pitting forms of corrosion are more insidious. Zinc coating protects iron and steel from these types of corrosion by two important aspects, passivity and galvanization.

Passivity

Passivity is the formation of a thin, non-conductive, oxide surface film that hinders the flow of electrical current and reduces the rate of corrosion. Zinc forms such a layer in the presence of carbon dioxide, which is almost always found in soil pore air and dissolved in ground water.

Galvanic Corrosion

The galvanizing process is the

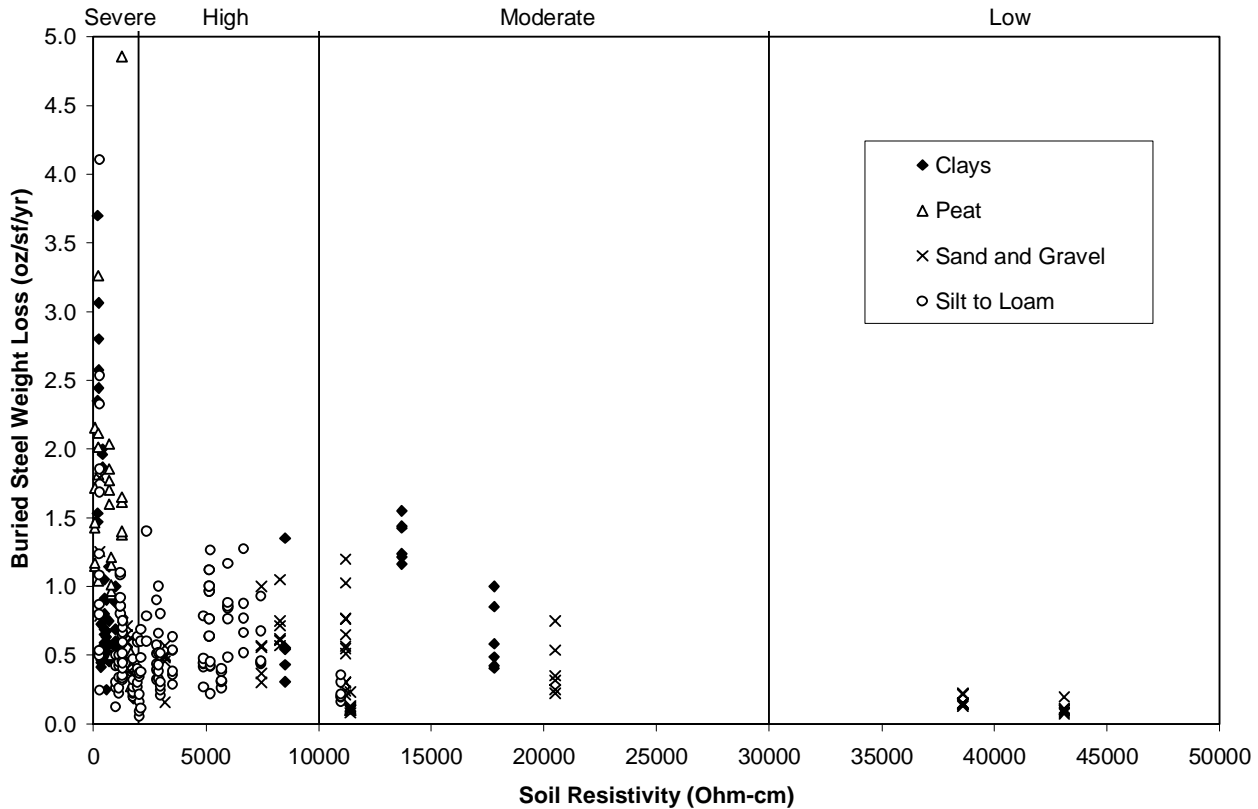


Fig. 1 Corrosion Rates

fortunate result of understanding the science behind galvanic corrosion of metals. Galvanic corrosion occurs when two dissimilar metals are placed in contact. The metal or metal alloy with higher electric potential will corrode before the metal with lower electric potential. Zinc has a high electric potential and will sacrifice itself to protect iron and steel to which it is electrically coupled.

As helix foundations are installed into the ground, pits and scratches may occur through the zinc coating. The process of galvanic corrosion protects bare iron and steel exposed in pits and scratches. In fact, zinc will prevent corrosion of exposed areas of iron and steel up to 1/8 inch wide (Industrial Galvanizers America, Inc., 1999).

A graph showing the corrosion rates for pairs of bare and galvanized iron and steel pipe samples from 20 locations across the United States is shown in Fig. 2 (constructed

from the data in Uhlig and Revie, 1985). The figure indicates that a zinc coating can reduce uniform corrosion rates by a factor of 50 to 98%.

Galvanized Coatings

There are several methods of coating metal with zinc including spraying, electroplating, continuous, and the hot-dip process. Hot-dip galvanized coatings are typically 80 to 100 microns thick, moderately flexible, and result in a zinc iron alloy that is harder than steel. Other types of zinc coatings are typically 12-25 microns thick, very flexible, and softer than steel. (Industrial Galvanizers America, Inc., 1999)

Hot-dip zinc galvanizing is preferred in the construction of helix foundations for several reasons. It protects iron and steel pipe surfaces inside and out. The coating is harder than any paint. The coating is chemically

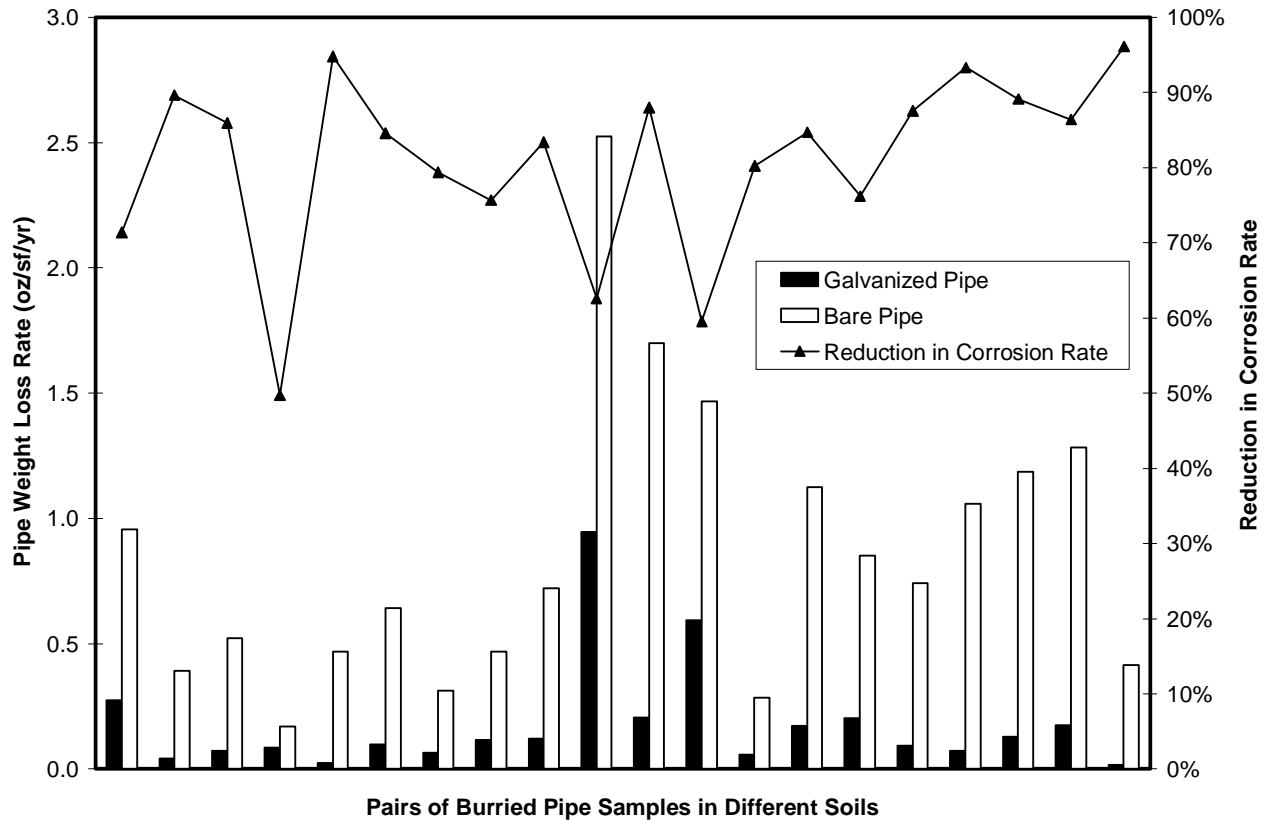


Fig. 2 Effect of Galvanization

bonded and normally never flakes or peels, and the coating is immune to ultraviolet radiation damage. After a hot-dip galvanized helix foundation is installed and then removed from the ground, it appears shiny and smooth and it gives the false impression that the zinc has been rubbed off by the soil. However, what is being observed is one of the zinc iron alloys formed in the hot-dip process. These alloys have significant passive corrosion resistance properties. Other types of zinc coating processes do not produce these alloys. For these reasons, engineers should specify hot-dip galvanization as opposed to other types of zinc coatings.

Life Expectancy

The helix foundation manufacturer A.B. Chance Company (1992) used steel and zinc loss in weight over time given by Ramanoff (1989) to provide a sample

calculation of helix foundation life as a function of soil resistivity. Their results are shown in Fig. 3. Expected helix foundation life was defined as the point in time when the entire zinc coating and 1/8-inch of steel helical blade thickness is lost to corrosion. Their calculations are subjective in that they only allow for a 3 to 9.5 year benefit from the zinc galvanization, and they only considered three data points.

The data of Ramanoff (1989), shown in Fig. 1, and that of Uhlig and Revie (1985), shown in Fig. 2, were statistically analyzed to obtain a more comprehensive estimate of helix foundation life expectancy for different soil types. The calculations consisted of determining the amount of time that would be required to transform 1/3 of the helical blade thickness and 1/2 the central shaft thickness of a helix foundation into rust by uniform corrosion. Galvanization was considered to

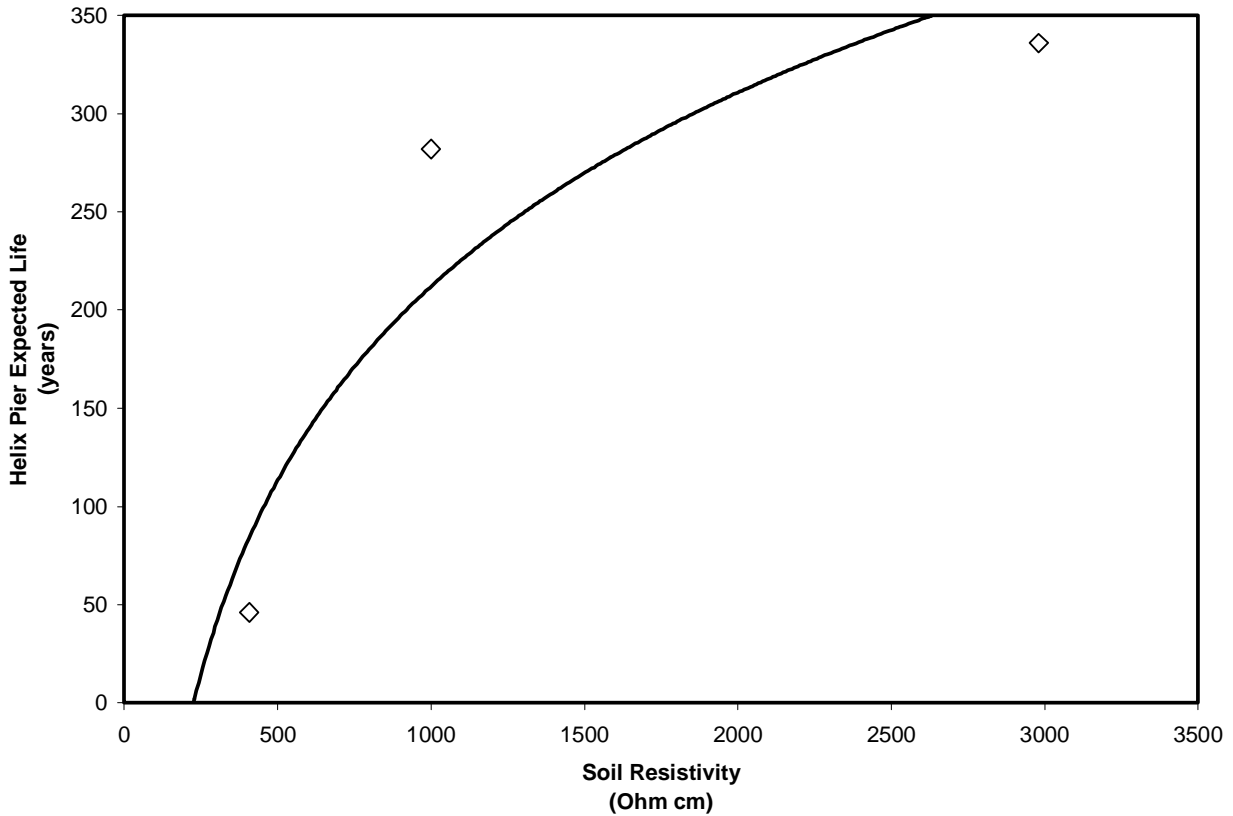


Fig. 3 Sample Calculation for Expected Helix Life (A.B. Chance, Co., 1992)

reduce corrosion rates by 50%, which is the most conservative and least effect shown in Fig. 2.

A helix foundation with 3/8 inch thick blade and Schedule 80 pipe shaft was used as the model in the analysis. This configuration is representative of round-shaft helix foundations manufactured by Magnum Piering, Inc. (standard and heavy duty series), Atlas Foundations, Inc., Precision Pier USA, Inc., and the A.B. Chance Company, among others. The computations are considered valid approximations for square shaft helix foundations with nominal dimensions of at least 1.5x1.5 inches, however the computed life expectancies should be divided by 2 for thinner wall pipe shaft helix foundations such as the Magnum Piering, Inc. light duty series.

Results of the analysis are shown in Table 2. Different soil types were categorized according to electrical resistivity. Some

examples of soil types comprising each category are given in the table. Estimated life expectancy is shown for bare metal and galvanized helix foundations. The minimum life expectancy, which represents the most rapid rate of corrosion measured in each category of soil corrosivity, is given by the top number in each row. The mean life expectancy for each category is the lowest number in each row. Life expectancy with approximately 95% probability, the point located two standard deviations from the mean, is given by the bold-font middle number in each row. The results indicate that a galvanized helix foundation of the configuration described above has an approximately 95% probability of a lifespan between 75 and 800 years depending on soil type.

There are many different soil types that are listed in more than one category in

Table 2. In order to determine the corrosivity of soil at a particular job site, it is necessary to obtain soil resistivity measurements. One frequently used method of field resistivity testing consists of placing several copper rods into the soil and directly measuring the flow of electrical current between them. Municipal water districts often maintain a data base of soil resistivity measurements for their area. These records are used as a guide for determining the degree of corrosion protection required for buried water pipes. These data often can be obtained by contacting local municipal water districts. Where there is a risk of severely corrosive soils and where accurate determination of the life expectancy of a helix foundation or anchor supported structure is required, site specific field resistivity testing should be performed.

foundation failure may be the corrosion induced fracture of the shaft near the ground surface where there is increased oxidation. This effect may be diminished by proper site drainage and encapsulation of the helix foundation shaft in concrete at the ground surface.

Soil resistivity does not provide a measure of the permeability, diffusivity, and therefore the residence time of water on buried surfaces. There is no single easily measured soil parameter that can be used to determine soil corrosivity. Rather, low soil resistivity values indicate areas of potentially high corrosivity that warrant further study. (Jones, 1996)

Electrically coupling the helix foundation to ungalvanized steel reinforcing or structural steel in a building, bridge or other types of construction may change the galvanic corrosion rate of the zinc coatings on helix foundations and may alter the electric

General Discussion

A more realistic mode of helix

Table 2. Estimated Helix Foundation Lifespan

Soil Resistivity (Ohm-cm)	Corrosivity Category	Example Soils	(Minimum) 95% Probability (Average) Helix Foundation Life Expectancy	
			Bare Metal	Galvanized
0-2,000	SEVERE	soil in marine environments; organic soils and peat; soft, wet silts and clays; wet shales	(15) 30 (80)	(40) 75 (200)
2,000-10,000	HIGH	stiff, moist clays; medium dense silts and loams; wet clayey to silty sand; wet sandstone	(55) 70 (135)	(140) 170 (340)
10,000-30,000	MODERATE	dry to slightly moist clays; dry silts and loams; sand and gravel; limestone	(50) 55 (140)	(125) 140 (350)
> 30,000	LOW	dry shales; dry sandstone; clean and dry sand and gravel; slate and granite	(345) 325 (555)	(865) 810 (1385)

potential of the helix foundation with respect to the soil pore-water aqueous solution. Whenever possible, the helix foundation should be electrically isolated from the rest of the structure.

A corrosion engineer should be consulted when very high corrosive soils are encountered. It may be appropriate to provide additional corrosion protection to extend the life of the helix foundation system. A potential solution is cathodic protection. Cathodic protection reduces the corrosion rate by providing an excess supply of electrons to a corroding metal surface. The excess electrons slow the rate of metallic ionization. The level of cathodic protection must be carefully controlled.

References

- A.B. Chance, Co. (1992). “Anchor Corrosion Reference & Examples.” National Association of Corrosion Engineers, Houston, TX.
- Industrial Galvanizers America, Inc. (1999). “Product Galvanizing Brochure”, International Business Publishers, Atlanta, GA.
- Jones, D.A. (1986). *Principles and Prevention of Corrosion*, 2nd Ed., Prentice-Hall, Inc., London.
- Miller, F.E., Foss, J.E., and Wolf, D.C. (1981). ASTM STP 741, American Society for Testing and Materials, p. 19.
- Prayer, J.H., et al. (1980). *Material Performance*, May-Nov.
- Romanoff, M. (1989). *Underground Corrosion*, National Bureau of Standards No. 579, 1957, Reprinted by NACE, Houston.
- Uhlig, H.H. and Revie, R.W. (1985). *Corrosion and Corrosion Control*, 3rd Ed., John Wiley and Sons, New York.