
Standard Practice for

Assessment of Corrosion of Steel Piling for Non-Marine Applications

AASHTO Designation: R 27-01 (2023)

Technically Revised: 2001

Reviewed but Not Updated: 2023

Technical Subcommittee: 1a, Soil and Unbound Recycled Materials



American Association of State Highway and Transportation Officials
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1. SCOPE

- 1.1. This standard practice is focused on corrosion of steel piling for non-marine soil applications.
- 1.2. This standard practice is divided into two parts: Part I—Environmental Conditions Causing Corrosion of Steel Piling, and Part II—Corrosion Considerations for New and Existing Piling.
 - 1.2.1. Part I of the standard practice describes the current knowledge of the mechanism of underground corrosion to aid the reader in better understanding the controlling factors and identifies the known factors that cause corrosion of piling in non-marine applications.
 - 1.2.2. Part II of the standard practice describes procedures that should be followed to assess the soil corrosivity at a specific site and offers guidance in the selection of corrosion mitigation procedures for new piling installations. Methods are described to evaluate the present condition of existing steel piling. Guidance is provided in the continued use of existing steel piling or reuse of steel piling in new or rehabilitated structures.
- 1.3. This standard practice does not preclude testing and test methods used to assess design parameters for the placement or continued use of piling.
- 1.4. Test methods not currently available as AASHTO or ASTM Methods are included in the Appendices of NCHRP Report 408 (Beavers and Durr, 1997).
- 1.5. *This standard practice may involve hazardous materials, operations, and equipment. This standard practice does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

- 2.1. *AASHTO Standards:*
 - < T 206, Penetration Test and Split-Barrel Sampling of Soils
 - < T 207, Thin-Walled Tube Sampling of Soils
 - < T 255, Total Evaporable Moisture Content of Aggregate by Drying
 - < T 291, Determining Water-Soluble Chloride Ion Content in Soil
- 2.2. *ASTM Standards:*
 - < D512, Standard Test Methods for Chloride Ion in Water

- < D516, Standard Test Method for Sulfate Ion in Water
- < D1452/D1452M, Standard Practice for Soil Exploration and Sampling by Auger Borings
- < D2487, Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
- < D2488, Standard Practice for Description and Identification of Soils (Visual-Manual Procedures)
- < D4220/D4220M, Standard Practices for Preserving and Transporting Soil Samples
- < D4972, Standard Test Method for pH of Soils
- < G51, Standard Test Method for Measuring pH of Soil for Use in Corrosion Testing
- < G57, Standard Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method

2.3. *NCHRP Report:*

- < Beavers, J. A., and C. L. Durr. *National Cooperative Highway Research Report 408: Corrosion of Steel Piling in Non-Marine Applications*. CC Technologies, Columbus, OH, for the National Cooperative Highway Research Program Project 10-46, TRB, National Research Council, Washington, DC, May 1997.

3. SIGNIFICANCE AND USE

- 3.1. This standard practice identifies the factors that cause corrosion of steel piles subjected to subsurface, non-marine environment in underground conditions. It provides procedures to assess the corrosion potential of the piles and offers recommendations on the ways to mitigate the corrosion. By determining the existing condition, the remaining life of the piles can be predicted.

PART I—ENVIRONMENTAL CONDITIONS CAUSING CORROSION OF STEEL PILING

4. MECHANISM OF UNDERGROUND CORROSION

- 4.1. Corrosion of structural steel in soils is electrochemical in nature. When steel corrodes, the iron atoms in the steel undergo oxidation and lose electrons (Equation 1). Other components in the soil are reduced and gain the lost electrons (some combination of Equations 2, 3, and 4). The electrochemical reaction associated with oxidation is the anodic reaction and the electrochemical reaction associated with reduction is the cathodic reaction. The sites where the anodic and cathodic reactions take place are termed the anode and cathode, respectively. The combination of the anode and the cathode, coupled with current flow between the two, is called a corrosion cell.
- 4.2. Figure 1 is a schematic of a corrosion cell. As shown in Figure 1, the electrons produced by the oxidation reaction flow from the anode to the cathode in the steel where they are consumed by the reduction reaction. Note that the direction of current flow is opposite to the direction of electron flow since, by definition, current is the flow of positive charge. In the soil, current must flow from the anode to the cathode to maintain charge neutrality. Current flow in the soil is carried by ions, moving through the water in pore spaces between the soil particles.

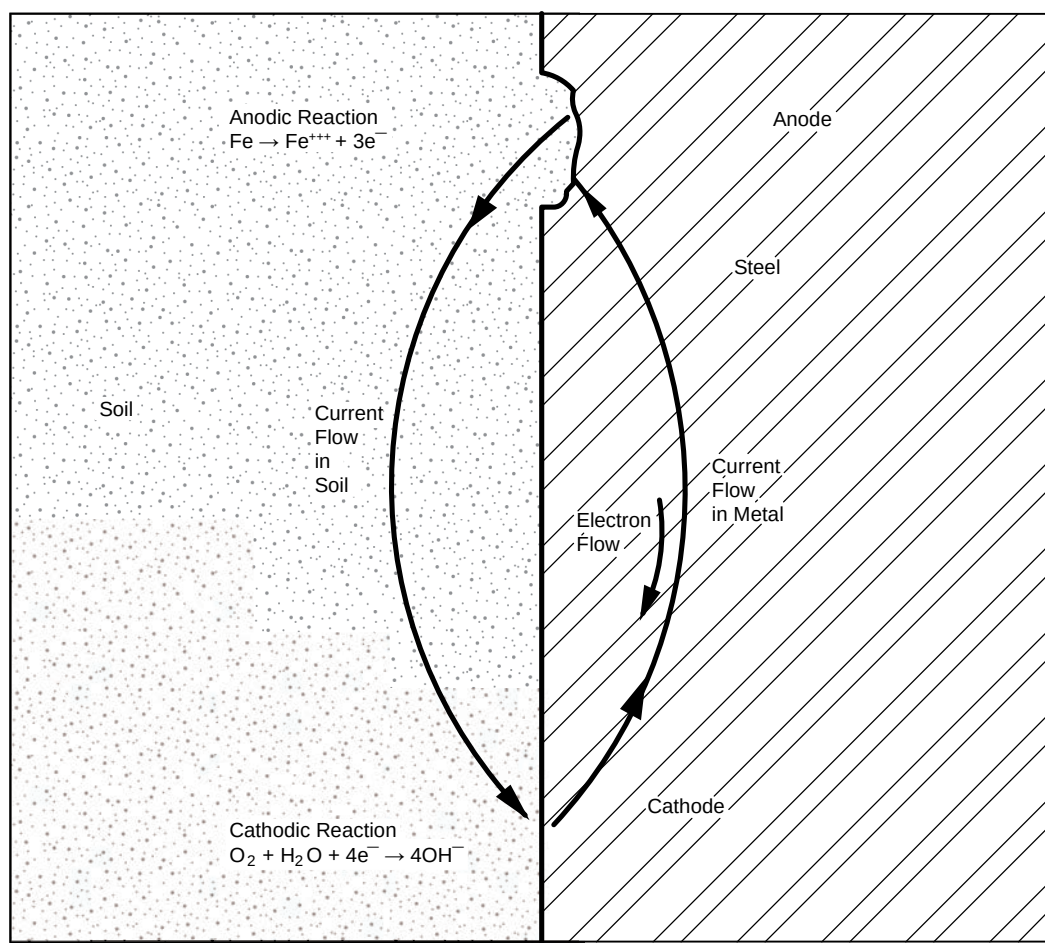


Figure 1—Schematic of a Corrosion Cell

4.3. Oxygen reduction (Equation 2) usually controls the rate of corrosion of steel in soils. This reaction is, in turn, controlled by the rate of movement of oxygen through the soil and water to the steel surface. In the absence of oxygen, reduction of water (Equation 3) can occur. However, this is normally slow enough to cause no significant corrosion damage to steel. Hydrogen ion reduction (Equation 4) occurs when the soil is very acidic and can significantly contribute to the rate of corrosion of steel in such soils. The iron ions produced by oxidation of the steel can eventually react with components in the soil to form corrosion products. For example, Equation 5 shows the iron ions reacting with water to produce rust. Other corrosion-related products are formed on the surface of the metal by the reduction reactions. These products include hydroxide ions (Equations 2 and 3) and hydrogen gas (Equations 3 and 4).

4.3.1. *Oxidation of Iron:*



4.3.2. *Oxygen Reduction:*



4.3.3. *Water Reduction:*



4.3.4. *Hydrogen Ion Reduction:*



4.3.5. *Formation of Rust:*



4.4. If the anodes and cathodes are very close to each other and evenly distributed on the steel surface, uniform corrosion of the steel occurs. On most underground steel structures, rates of uniform corrosion are low and rarely cause service failures. The most notable exception is where the soil pH is below 4.

4.5. Where the anode and cathode sites are well separated on a steel surface, a “macrocell” is formed. Severe corrosion and resulting service failures can occur when the anode in a macrocell is confined to a relatively small area of the steel. In this instance, the form of corrosion is frequently referred to as pitting. Once macrocells are started on a steel surface, the products of the electrochemical reactions generally cause the macrocell to continue. For example, the reduction reactions cause an increase in the pH at the cathode. Steels form protective films in elevated pH environments, reducing the rate of corrosion. On the other hand, the reactions at the anode reduce the pH. The acidic environment created at the anode causes protective oxide films on the steel to break down, increasing the corrosion rate. As the pH at the anode decreases, the reduction of hydrogen ions may occur locally, further increasing the rate of attack.

4.6. One of the common macrocells on piling in soils is caused by variation in oxygen concentration over the steel surface. Oxygen macrocells frequently develop in stratified soils. Anodes are formed where the oxygen concentration is low, such as in clay soils, and cathodes are formed where the oxygen concentration is high, such as in sandy soils. The water table is another area where oxygen macrocells usually develop. A macrocell also may develop where there is variation in the chloride content of the soil, such as along roads with saltwater runoff. In this macrocell, anodes form in regions of high chloride concentration.

4.7. Other factors that affect the rate of oxygen macrocell corrosion include the relative surface area of the anode and the cathode, soil resistivity, and microbiological activity. Where the cathode is large and the anode is small, a large current is concentrated at the anode, leading to high rates of corrosion at the anode. Soil corrosivity generally increases with decreasing soil resistivity. Where the soil resistance is high, a high current flow between the anode and cathode cannot occur due to the high voltage (IR) drop in the high resistance soil path. Microbiological activity, or the presence of welds or inclusions in the steel, can also aggravate macrocell corrosion by aiding in the creation of the anodic sites. Further discussion of the effects of resistivity and other parameters on corrosion is given in the NCHRP Report 408.

4.8. Piling and other underground structures also can undergo accelerated corrosion as a result of stray current flow in the soil. Sources of stray current include cathodic protection systems for other structures, direct current (DC) electric transit systems, mining activity, and high voltage DC electric power lines. DC electric current, flowing parallel to a structure, will jump onto that structure if that structure has a lower resistance in the direction of the current flow than the soil. The structure is cathodically protected where the current jumps onto the structure and corrosion is accelerated where the current leaves the structure. Stray current corrosion is most commonly observed on structures that have large dimensions in one horizontal direction, such as pipelines. Sheet piling and other piling that are electrically continuous also can experience stray current corrosion.

4.9. To summarize, corrosion of structural steel in soils is electrochemical in nature and is caused by the presence of oxygen and moisture in the soil. Corrosion is most likely to occur at or above the water table in disturbed stratified soils having low resistivity. For example, fill soils containing man-made materials such as cinders, slag, or ash are known to cause significant corrosion of steel