

Standard Practice for Assessment of Corrosion of Steel Piling for Non-Marine Applications

AASHTO Designation: PP36-97¹

1. Scope

1.1 This Practice is focused on corrosion of steel piling for non-marine soil applications.

1.2 This 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 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 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 re-use of steel piling in new or rehabilitated structures.

1.3 This 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 the National Cooperative Highway Research Program (NCHRP) 10-46 Final Report.⁽¹⁾

1.5 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems 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:

- T203 Soil Investigation and Sampling by Auger Borings
- T206 Penetration Test and Split Barrel Sampling of Soils
- T207 Thin-Walled Tube Sampling of Soils
- T251 Soil Investigation and Sampling by Hollow-Stem Auger Boring
- T255 Total Moisture Content of Aggregate by Drying

2.2 ASTM Standards:

- D512 Chloride Ion In Water
- D516 Sulfate Ion in Water
- D2487 Standard Classification of Soils for Engineering Purposes (Unified Soils Classification System)
- D2488 Description and Identification of Soils (Visual-Manual Procedure)
- D4220 Preserving and Transporting Soil Samples
- D4972 pH of Soils
 - G51 Measuring pH in Soils for Use in Corrosion Testing
 - G57 Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method

3. Significance and Use - This 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

¹ This provisional standard was approved in November 1997.

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.

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).

Oxidation of Iron	$\text{Fe} \rightarrow \text{Fe}^{++} + 3\text{e}^-$	(1)
Oxygen Reduction	$\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^- \rightarrow 4\text{OH}^-$	(2)
Water Reduction	$2\text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + 2\text{OH}^-$	(3)
Hydrogen Ion Reduction	$2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$	(4)
Formation of Rust	$2\text{Fe}^{++} + 3\text{H}_2\text{O} \rightarrow \text{Fe}_2\text{O}_3 + 6\text{H}^+$	(5)

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 about 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 salt water run-off. 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 Final Report for NCHRP Project 10-46.

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 piles. Stray electrical currents flowing in the ground, from sources such as transit systems, also can contribute to corrosion of structural steels in soils.

PART II

CORROSION CONSIDERATIONS FOR NEW AND EXISTING PILING

5. Summary of Approach

5.1 A preliminary investigation (Phase I Site Assessment) is performed to obtain pertinent available information on the surface and subsurface conditions at the site. Information obtained in this investigation may include the position of the piling or pile cap with respect to the groundwater table, the soil characteristics, and the presence of contaminants in the soil. This information is used to determine whether a further (Phase II) assessment is required. In general, a Phase II site investigation is required unless; (1) the piling or pile cap is or will be below the water table at all times or, (2) the Phase I site assessment provides the necessary information outlined in the Phase II site investigation to establish the corrosivity of the site. In cases where there are multiple sites that require investigation, priority should be given to those sites known to contain corrosive materials such as slag, cinders, ash or other man-made products.

5.2 In the Phase II Site Investigation, continuous soil sampling is performed to a depth of one meter below the minimum water table. The testing protocol outlined in Figure 2 is used for analyzing the soil samples. For homogeneous soils, testing is performed every 60 to 90 cm while testing is performed on each distinct soil

layer for inhomogeneous soils. This testing is limited to resistivity, pH, and particle size.

5.3 The flow chart shown in Figure 3 is used, in conjunction with the results of the soil analyses, to determine the likelihood of significant uniform or macrocell corrosion. As shown in the figure, neither form of corrosion is likely to occur at a significant rate if the saturated soil resistivity is greater than about 2000 ohm-cm. Depending on the homogeneity, particle size, and pH of the soil, one or both forms of corrosion may occur at a significant rate if the saturated soil resistivity is below 2000 ohm-cm.

5.4 The need for corrosion monitoring, corrosion mitigation, or pile repair or replacement is determined using the flow chart shown in Figure 4. No further testing or analysis is required if the results of the soil analyses indicate that there is a low probability of significant uniform or macrocell corrosion. Corrosion monitoring is recommended where one or both forms of corrosion may occur at a significant rate. This corrosion monitoring will establish the rate of corrosion such that a remaining life assessment can be performed. Corrosion mitigation is recommended if the predicted remaining life is less than the design life. Corrosion mitigation is recommended in cases where corrosive soils are present and there is insufficient time for proper corrosion monitoring. Pile repair or replacement is required if there is no predicted remaining life. If the predicted remaining life is much less than the design life, the pile should be excavated and examined to better define the existing condition and the need for repair, replacement, or corrosion mitigation.

6. Phase I (Preliminary Assessment)

6.1 The purpose of the Phase I Site Assessment is to obtain pertinent available information on the surface and subsurface conditions to aid in the assessment of soil corrosivity. Information may be available on (1) the position of the pile or pile cap in relation to the groundwater table, (2) the presence of environmental contaminants, (3) characteristics of the soil and rock at the site, and (4) location, fluctuation, and chemistry of the groundwater.

6.2 Possible sources of relevant information for the Phase I Assessment include (1) local and U.S. Geological Survey; (2) U.S.D.A. Soil Conservation Service and (3) U.S. and State DOT's.

6.3 All data gathered from the Phase I Assessment should be forwarded to the engineer in charge of the project. These data should be used to determine if a