

A Methodology, Database, and Maps For Seasonally-Adjusted Soil Resistivity

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ABSTRACT

When assessing corrosion growth rates, the properties of the electrolyte are one of the most critical parameters. For underground pipelines, this electrolyte is the soil. Soil has a variety of corrosion properties such as porosity, composition, and water retention. One of the most critical properties is the soil's resistivity, the electrolyte's ability to conduct electric current. The soil's resistivity is not constant; it is highly seasonal and varies based on weather patterns, local conditions, and contamination.

This work presents a database for collecting soil resistivity measurements and a methodology to assemble high-resolution seasonal maps. In working closely with government agencies that use this data for agriculture, this work demonstrates a process to re-use agricultural conductivity datasets for estimating soil resistivity. This process is validated against field resistivity measurements collected by a North American pipeline operator.

Key words: cathodic protection, geographic information systems, resistivity, soil, soil resistivity

INTRODUCTION

The electrical conductivity of the electrolyte is one of the key parameters in the electromechanics of corrosion. Highly conductive electrolytes will permit more current and increase corrosion rates. Conversely, resistive electrolytes will enable less current to flow until the necessary conditions for corrosion are no longer satisfied or slowed.

Coatings act as a high resistance layer which impedes current flow. In the presence of coating, current may still flow but be restricted to negligible levels. In the presence of a coating holiday, the exposed steel interfaces directly with the soil, and the electrical current is impeded solely by the soil resistivity. Both examples of this are visible in Figure 1, where R represents total resistivity. This work omits any further discussion of coating resistivity, and comprehensive studies and standards have been developed around assessing coating resistivity [1][2][3]. On a local scale, omitting attenuation effects, Figure 1 models the circuit diagram for leakage current and resistivity.

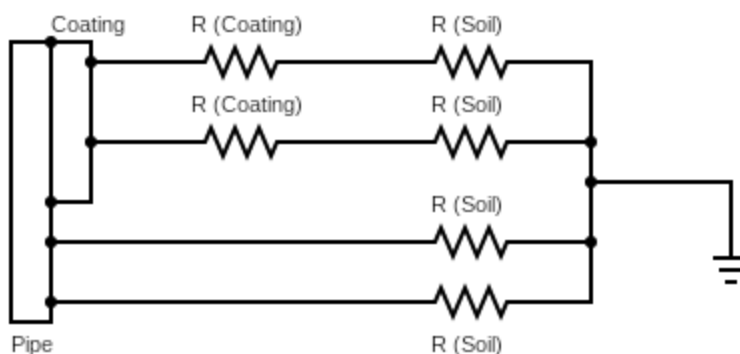


Figure 1: Circuit Diagram of Pipe-to-Soil Pathways

The implications of variations in soil resistivity are significant; applying Ohm's Law and holding voltage constant, the relationship between resistivity and current is inversely related; a 1 unit increase in ohms results in a 1 unit decrease in current (measured in amps). Furthermore, It has been empirically shown that low resistivity soils tend to result in increased pitting, increased depth-wise metal loss, and greater corrosion rates [4]. The general schema for soil resistance to corrosivity mapping is detailed in Table 1.[1]

Table 1
Corrosivity Classifications for Soils

Soil Resistivity (ohm-cm)	Degree of Corrosivity [1]
0-500	Very Corrosive
500-1,000	Corrosive
1,000-2,000	Moderately Corrosive

2,000 - 10,000+	Mildly Corrosive
Above 10,000	Negligible

Resistivity is measured using the SI unit, the ohm-meter (ohm-m). The inverse of resistivity is conductivity, typically measured in the SI unit, siemens.

In the soil science field, this data is collected to assess soil salinity levels or the degree to which it is "salt-affected," so appropriate salt-tolerant crops may be used when salinity levels are high. Practically, this is measured in units of deci-siemens per unit meter of soil (dS/m).

Following convention, this work will measure electrical resistance in ohm-cm. In the soil science field, it is customary to use conductance (in deci-siemens per meter), so in this work these measurements will be converted to ohm-cm. To convert deci-siemens per meter to an ohm-centimeter, divide by ten, invert the result, and multiply by 100. A measurement of 2dS/m is 0.20S/m and the inverse is $1/(0.20)$ or 5 ohm-m or 500 ohm-cm. This work will use this conversion methodology, and a simplified analytical form is included in Equation 1 (*ohm function*) to convert a deci-siemens measurement to ohm-cm.

$$ohm_{cm}(dS/m) = 100\left(\frac{1}{dS/10}\right) = \frac{1000}{dS} \quad (1)$$

Role in Pipelines and Cathodic Protection

Proper modeling of soil resistivity offers an opportunity to improve an indirect assessment program in cases where direct assessment is not available. Soil resistivity information may be paired with additional pieces of information to form a broader view of a given asset. For instance, In the presence of high voltage alternating current (HVAC) inductive loads, a low resistivity soil will result in higher inductive current load.[6][7] In this case, the high voltage lines are forming a transformer circuit with the pipeline and the soil resistivity plays a key role in computing the coupling coefficients. Another option may be to pair soil resistivity data with other known pipeline parameters, such as coating type, pipeline age, or known coating failures to offer a more holistic indirect assessment methodology.

Modeling soil resistivity is essential in the design and maintenance of cathodic protection systems. Consider the case of a long segment of coated and cathodically protected pipeline. As the length of the pipeline increases, the amount of surface area in contact with the soil electrolyte increases. Even assuming no coating holiday, impressed direct current (DC) current is subject to attenuation effects; the resistance of the coating itself is high but not infinite. When paired with high resistivity soils, the attenuation will be low or near zero. Knowledge of soil resistivity offers an opportunity to optimize the tuning and design of impressed current loads. This information is particularly useful in mechanistic modeling and simulations, where soil resistivity plays a key role in optimizing rectifier currents.

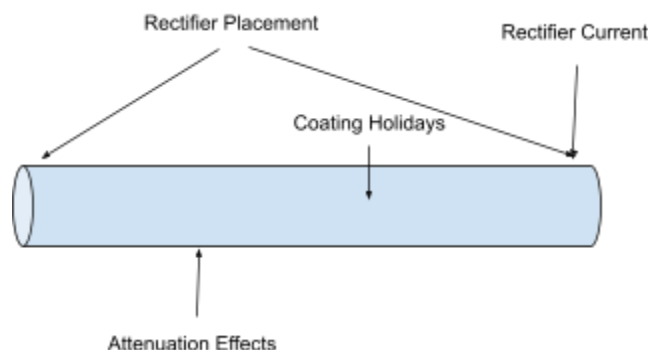


Figure 2: Soil Resistivity Factors Impacting Cathodic Protection System Designs

One key element of the role of soil resistivity and corrosion is the “double-edged sword” nature of the feature. On one hand, low resistivity soils may experience high corrosion growth rates due to the highly conductive nature of the electrolyte. On the other hand, when a system is properly polarized and cathodically protected, low resistivity soils provide an effective electrolyte for current transfer.

Measuring Soil Resistivity

Given the natural heterogeneity of soil, there is no single value of soil resistivity that represents a particular site. Instead, for a given site a range of values are measured at differing depths, also known as “horizons”. These horizons range in value from surface level (0 meters) to pipeline depth (150-200cm) and deeper, depending on the tool used.

There are a few soil resistivity measurement techniques used in the corrosion industry. These include the Wenner Four-Pin Method, Collins Rod, and soil box among the more conventional methods [1]. The Wenner Four-Pin method measures resistivity using four pins, passing through the outer pins, and measuring voltage drop between the inner pins. The single rod measures resistivity, pushing the tip of the rod into the ground and supplying alternating current that is measured using a galvanometer. Finally, the soil box measures resistivity by placing a soil sample into a container, supplying current through, and measuring voltage between two potential electrodes. This measurement is usually taken in-situ at the site of a construction project or dig.

For soil scientists, a completely different method of measuring conductivity is used. The soil is removed from the site to a lab, where it is raised to room temperature and saturated (1:1) forming a soil paste [5]. Then, the conductivity measurements are collected using a calibrated electrical conductivity (EC) meter. This procedure is performed at room temperature and pressure. A comparison of the methods is in Table 2.

Table 2
Soil Resistivity Data Collection Comparison

Method	Location	Reference Temperature	Saturation
Wenner 4-Pin	In Situ	Field Temperature	Field Saturation
Saturated Paste	Laboratory	25 C (77 F)	1:1 Water:Soil