TechData Sheet

Naval Facilities Engineering Service Center
Port Hueneme, California 93043-4328

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CATHODIC PROTECTION SYSTEM DESIGN II -- Electrolyte Resistivity Measurement

Electrolyte resistivity is an important parameter in the design of cathodic protection systems. As cathodic protection systems are essentially direct current electrical circuits, the currents that flow in the circuits depend on the electrical resistance between the circuit elements. For determining the current flow between anodes and the structure to be protected, this resistance value depends on the resistivity of the environment and the geometry of the current flow paths.

Electrolyte resistivity differs from resistance in that resistivity is a characteristic of a material whereas the actual resistance depends on both resistivity of the material and the geometry of the current flow. The commonly used unit of resistivity is the ohm-centimeter (ohm-cm). The unit can be defined as the resistance of a cube of the environment that is one centimeter long on each edge where the resistance is measured across opposite faces as shown in Figure 1. In actuality, the true units of measurement are:

$$\text{Ohms/cm/cm}^2$$

Where:

Ohms = Measurement of resistance
cm = Distance between the faces
cm^2 = Area of the faces

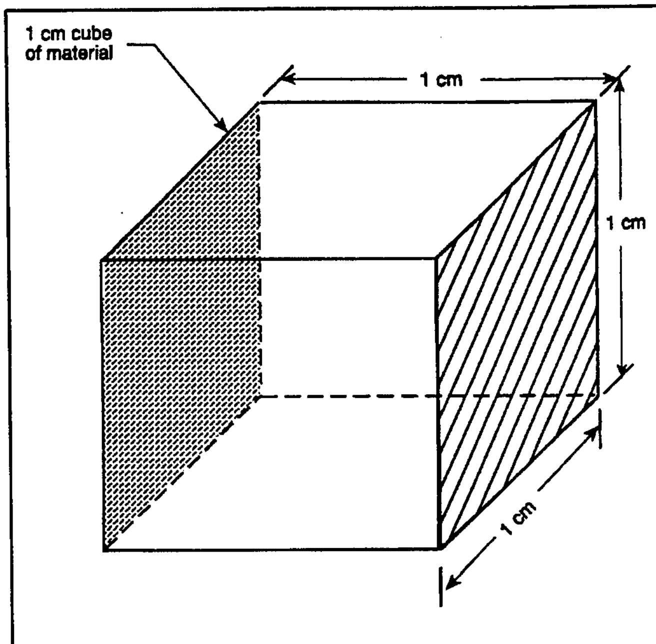
However, this is equivalent to Ohms X cm, thus the unit Ohm-cm.

The closest that people in the corrosion field actually come to measuring material resistivity in this manner is the use of the soil box. A soil box and the resistivity measuring circuit are shown in Figure 2. A measured current (I) is passed through the box between the metallic end plates. The voltage (V) between the pins is then measured. This method eliminates possible errors that might occur due to surface resistance of the end plates. The measured resistance (R) of the material in the soil box is calculated by dividing the measured voltage by the current flow in accordance with ohms law:

Formula 1

$$I = \frac{V}{R} \text{ or } R = \frac{V}{I}$$

The geometry of the soil box, particularly the area of the metallic end plates, the cross sectional area of the box, and



Resistance measured between two opposite faces (crosshatched) gives resistivity of material in ohm-cm.

Figure 1. Concept of resistivity measurement and units.

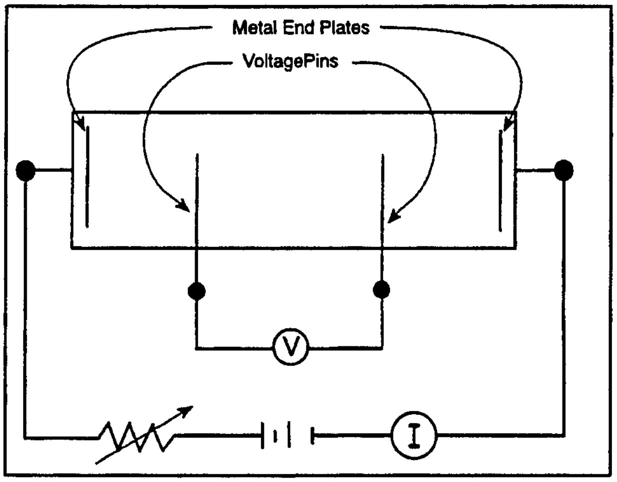


Figure 2. Soil box and resistivity measuring circuit.

the spacing of the voltage pins is designed so that one ohm of measured resistance is equivalent to a resistivity of the material in the box of one ohm-cm.

A combination meter having internal batteries, current control through variable resistors, and dual meters for simultaneous measurement of the current is the most convenient instrument for making the voltage and current measurements in the soil box resistivity measurement, but any accurately measured current source in combination with any high impedance voltmeter can be used.

Using the soil box to measure soil resistivity is not a reliable method. The soil is disturbed during sampling, the moisture content can change from its in-situ moisture content and packing of the soil in the soil box prior to measurement may not reflect actual in-situ compaction.

The primary use of the soil box is to measure the resistivity of water samples. In measuring water resistivity, the problems usually encountered are with getting the box completely full and contamination of the water sample. Filling problems can be handled by careful leveling and filling of the soil box. Water sample contamination can be minimized by thoroughly rinsing the box with demineralized or distilled water, then rinsing the soil box with a portion of the sample before filling the box with the sample water. If two subsequent fillings of the soil box with the sample water then give the same resistance, minimal impact of contamination on the resistivity measurement is indicated.

Soil resistivity is most reliably measured using in-situ measurement techniques. In these measurements, problems with sampling, moisture content variations during handling and shipping and soil compaction are eliminated. The most commonly used and most reliable method of measuring soil resistivity for cathodic protection system design is the Wenner 4-pin method. In this method, as shown in Figure 3, four metal pins are driven into the soil at regular intervals. A measured current is passed through the outer set of pins and the resulting voltage difference between the inner set of pins is measured. The resistivity is computed using the formula:

Formula 2

$$\text{Resistivity (ohm-cm)} = 191.5 \text{ x pin spacing in feet x } \frac{\text{I (amperes)}}{\text{E (volts)}}$$

Some instruments that are specifically designed for measuring soil resistivity using the Wenner 4-pin method read directly in ohms. The formula for calculating resistivity then becomes:

Formula 3

$$\text{Resistivity (ohm-cm)} = 191.5 \text{ x pin spacing in feet x R (ohms)}$$

As electrical currents can flow in the soil independent of the current that is passed between the outer pins, there could be some error in the measurement of the voltage between the inner pins. When using a direct current source, this error can be minimized by measuring the change in voltage when the current is applied between the outer pins. The formula for calculating resistivity then becomes:

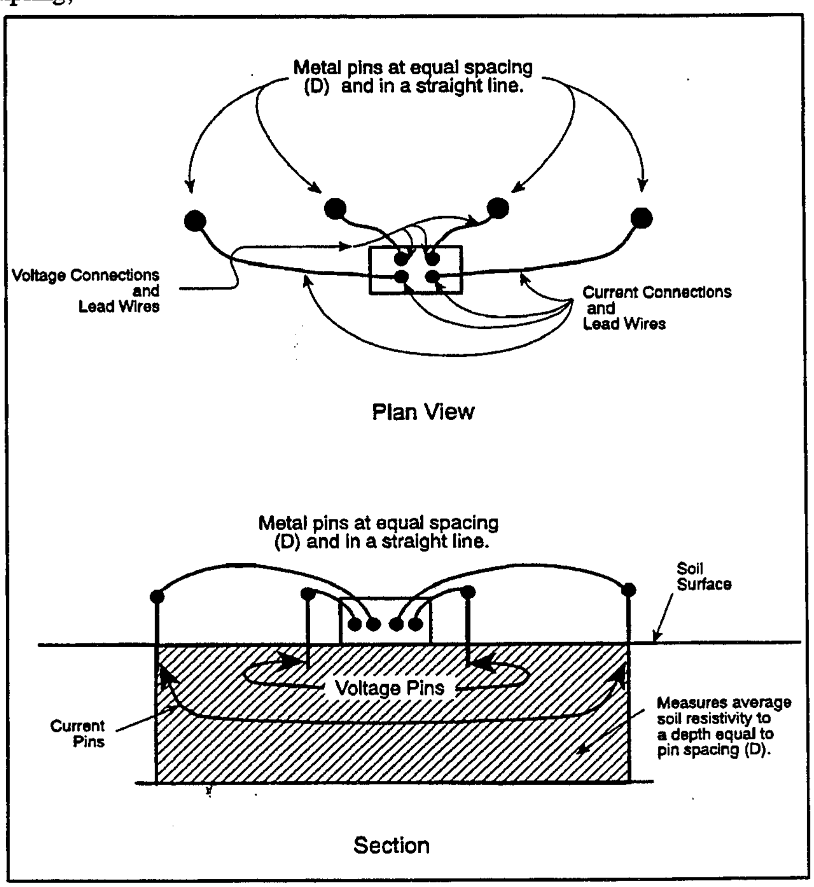


Figure 3. Wenner 4-pin soil resistivity measurement setup.

Formula 4

$$\text{Resistivity (ohm-cm)} = 191.5 \times \text{pin spacing in feet} \times \frac{\text{I (amperes)}}{\Delta \text{E (volts)}}$$

where ΔE = change in voltage that occurs when the current is applied between the outer pins.

When using a direct current source, this error can also be minimized by making two measurements, reversing the current flow between the outer pins between measurements, and averaging the results.

The most convenient method for measuring the current and voltage between the pins is to use a specially built instrument.

These commercially available instruments apply an alternating current to the outer pins (different from the 60 Hertz current that flows in the ground and would cause measurement errors). The voltage between the inner pins at that frequency is measured and an internal circuit converts the current/voltage measurements to a direct reading in ohms. The soil resistivity is then calculated using Formula 3.

In the Wenner 4-pin method, the average resistivity of the soil to a depth equal to the spacing of the pins is measured. As long as good electrical contact with the soil is obtained, the measurement does not depend on the size of the pins or the depth to which they are driven. The resistivity of the soil is different at different depths due primarily to variations in soil composition and moisture content. The resistivity at a depth equal to the burial depth of the structure and at a depth equal to the burial depth of the anodes is important in the design of cathodic protection systems. In practice, the soil resistivity is usually measured using several pin spacings and the variation in resistivity with depth is determined using one of several numerical calculation methods. The Barnes Method is used for determining the variation of soil resistivity with depth based on Wenner 4-pin measurements made with several different pin spacings.

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