



# Standard Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method<sup>1</sup>

This standard is issued under the fixed designation G 57; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This method covers the equipment and procedures for the field measurement of soil resistivity, both *in situ* and for samples removed from the ground, for use in the control of corrosion of buried structures.

1.2 To convert cm (metric unit) to metre (SI unit), divide by 100.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Terminology

### 2.1 Definition:

2.1.1 *resistivity*—the electrical resistance between opposite faces of a unit cube of material; the reciprocal of conductivity. Resistivity is used in preference to conductivity as an expression of the electrical character of soils (and waters) since it is expressed in whole numbers.

2.1.2 Resistivity measurements indicate the relative ability of a medium to carry electrical currents. When a metallic structure is immersed in a conductive medium, the ability of the medium to carry current will influence the magnitude of galvanic currents and cathodic protection currents. The degree of electrode polarization will also affect the size of such currents.

## 3. Summary of Test Method

3.1 The Wenner four-electrode method requires that four metal electrodes be placed with equal separation in a straight line in the surface of the soil to a depth not exceeding 5 % of the minimum separation of the electrodes. The electrode separation should be selected with consideration of the soil strata of interest. The resulting resistivity measurement represents the average resistivity of a hemisphere of soil of a radius equal to the electrode separation.

3.2 A voltage is impressed between the outer electrodes,

causing current to flow, and the voltage drop between the inner electrodes is measured using a sensitive voltmeter. Alternatively, the resistance can be measured directly. The resistivity,  $\rho$ , is then:

$$\begin{aligned} \rho, \Omega \cdot \text{cm} &= 2\pi aR \quad (a \text{ in cm}) \\ &= 191.5 aR \quad (a \text{ in ft}) \end{aligned}$$

where:

$a$  = electrode separation, and  
 $R$  = resistance,  $\Omega$ .

Using dimensional analysis, the correct unit for resistivity is ohm-centimetre.

3.3 If the current-carrying (outside) electrodes are not spaced at the same interval as the potential-measuring (inside) electrodes, the resistivity,  $\rho$  is:

$$\rho, \Omega \cdot \text{cm} = 95.76 b R \left( 1 - \frac{b}{b+a} \right)$$

where:

$b$  = outer electrode spacing, ft,  
 $a$  = inner electrode spacing, ft, and  
 $R$  = resistance,  $\Omega$ .

or:

$$\rho, \Omega \cdot \text{cm} = \pi b R \left( 1 - \frac{b}{b+a} \right)$$

where:

$b$  = outer electrode spacing, cm,  
 $a$  = inner electrode spacing, cm, and  
 $R$  = resistance,  $\Omega$ .

3.4 For soil contained in a soil box similar to the one shown in Fig. 1, the resistivity,  $\rho$ , is:

$$\rho, \Omega \cdot \text{cm} = RA/a$$

where:

$R$  = resistance,  $\Omega$ ,  
 $A$  = cross sectional area of the container perpendicular to the current flow,  $\text{cm}^2$ , and  
 $a$  = inner electrode spacing, cm.

NOTE 1—The spacing between the inner electrodes should be measured from the inner edges of the electrode pins, and not from the center of the electrodes.

<sup>1</sup> This method is under the jurisdiction of ASTM Committee G01 on Corrosion of Metals, and is the direct responsibility of Subcommittee G01.10 on Corrosion in Soils.

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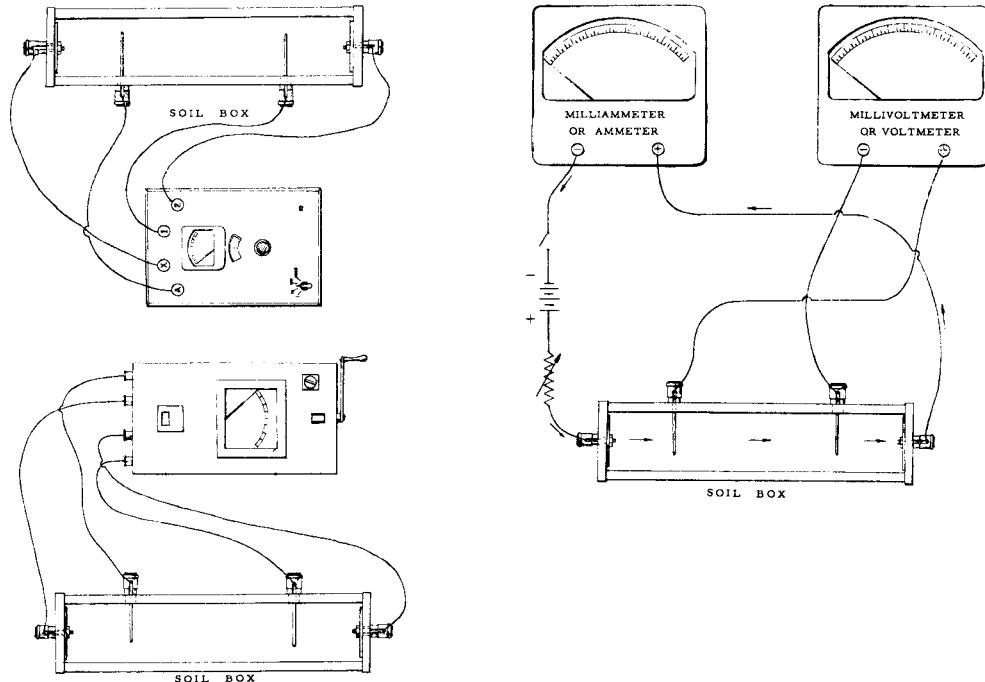


FIG. 1 Typical Connections for Use of Soil Box with Various Types of Instruments

#### 4. Apparatus

##### 4.1 At-Grade Measurements in situ:

4.1.1 The equipment required for field resistivity measurements to be taken at grade consists of a current source, a suitable voltmeter, ammeter, or galvanometer, four metal electrodes, and the necessary wiring to make the connections shown in Fig. 2.

4.1.2 *Current Source*—An ac source, usually 97 Hz, is preferred since the use of dc will cause polarization of most metal electrodes, resulting in error. The current can be provided by either a cranked ac generator or a vibrator-equipped dc source. An unaltered dc source can be used if the electrodes are abraded to bright metal before immersion, polarity is regularly

reversed during measurement, and measurements are averaged for each polarity.

4.1.3 *Voltmeter*—The voltmeter shall not draw appreciable current from the circuit to avoid polarization effects. A galvanometer type of movement is preferred but an electronic type instrument will yield satisfactory results if the meter input impedance is at least 10 megaohm.

4.1.4 *Electrodes* fabricated from mild steel or martensitic stainless steel 0.475 to 0.635 cm ( $\frac{3}{16}$  to  $\frac{1}{4}$  in.) in diameter and 30 to 60 cm (1 to 2 ft) in length are satisfactory for most field measurements. Both materials may require heat treatment so that they are sufficiently rigid to be inserted in dry or gravel soils. The electrodes should be formed with a handle and a

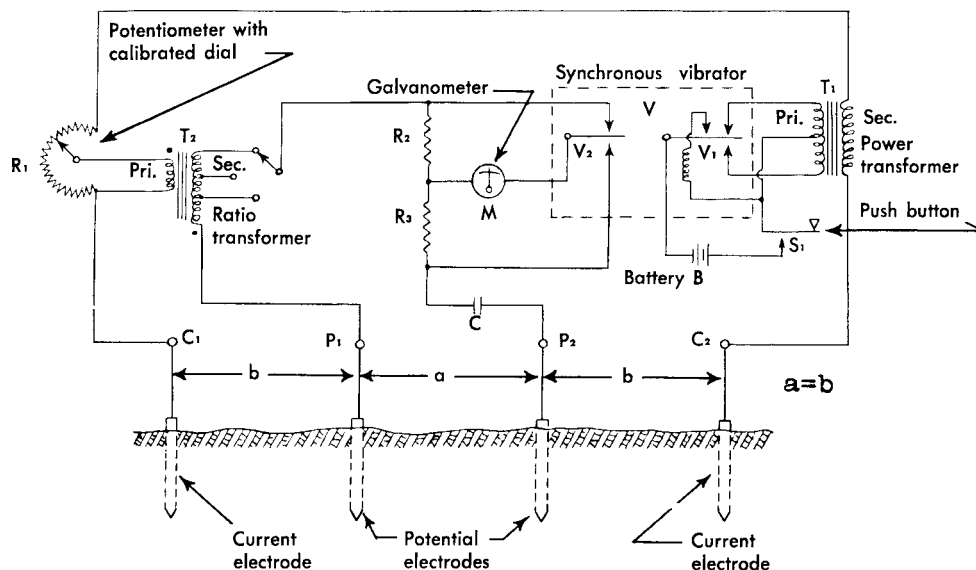


FIG. 2 Wiring Diagram for Typical dc Vibrator-Current Source

terminal for wire attachment.

4.1.5 *Wiring*, 18 to 22-gage insulated stranded copper wire. Terminals should be of good quality to ensure that low-resistance contact is made at the electrodes and at the meter. Where regular surveys are to be made at fixed electrode spacing, a shielded multiconductor cable can be fabricated with terminals permanently located at the required intervals.

#### 4.2 *Soil Sample Measurement:*

4.2.1 The equipment required for the measurement of the resistivity of soil samples, either in the field or in the laboratory, is identical to that needed for at-grade measurements except that the electrodes are replaced with an inert container containing four permanently mounted electrodes (see Fig. 1).

4.2.2 If the current-carrying (outside) electrodes are not spaced at the same interval as the potential-measuring (inside) electrodes, the resistivity,  $\rho$ , is:

$$\rho, \Omega\text{-cm} = 95.76 b R / \left( 1 - \frac{b}{b+a} \right)$$

where:

- $b$  = outer electrode spacing, ft,
- $a$  = inner electrode spacing, ft, and
- $R$  = resistance,  $\Omega$ .

or:

$$\rho, \Omega\text{-cm} = \pi b R / \left( 1 - \frac{b}{b+a} \right)$$

where:

- $b$  = outer electrode spacing, cm
- $a$  = inner electrode spacing, cm, and
- $R$  = resistance,  $\Omega$ .

4.2.3 The dimensions of the box can be established so that resistivity is read directly from the voltmeter without further calculation. The box should be readily cleanable to avoid contamination by previous samples.

## 5. Standardization

5.1 Periodically check the accuracy of resistance meters using a commercial resistance decade box. Meter error should not exceed 5 % over the range of the instrument. If error exceeds this limit, prepare a calibration curve and correct all measurements accordingly. A soil box can be calibrated using solutions of known resistivity. Solutions of sodium chloride and distilled water with resistivities of 1000, 5000, and 10 000  $\Omega\text{-cm}$  are recommended for this purpose. These solutions should be prepared under laboratory conditions using a commercial conductivity meter, itself calibrated to standard solutions at 20°C (68°F).<sup>2</sup>

## 6. Field Procedures

### 6.1 *At-Grade Measurements:*

6.1.1 Select the alignment of the measurement to include uniform topography over the limits of the electrode span. Do not include large nonconductive bodies such as frozen soil, boulders, concrete foundations, etc., which are not representa-

tive of the soil of interest, in the electrode span. Conductive structures such as pipes and cables should not be within  $\frac{1}{2} a$  of the electrode span unless they are at right angles to the span.

6.1.2 Select electrode spacings with regard to the structure of interest. Since most pipelines are installed at depths of from 1.5 to 4.5 m (5 to 15 ft), electrode spacings of 1.5, 3.0, and 4.5 m (5, 10, and 15 ft) are commonly used. The  $a$  spacing should equal the maximum depth of interest. To facilitate field calculation of resistivities, spacings of 1.58, 3.16, and 4.75 m (5.2, 10.4, and 15.6 ft), which result in multiplication factors of 1000, 2000, and 3000, can be used when a d-c vibrator-galvanometer instrument is used.

6.1.3 Impress a voltage across the outer electrodes. Measure the voltage drop across the inner electrodes and record both the current and voltage drop if a separate ammeter and voltmeter are used. Where a resistivity meter is used, read the resistance directly and record.

6.1.4 Make a record of electrode spacing, resistance or amperes and volts, date, time, air temperature, topography, drainage, and indications of contamination to facilitate subsequent interpretation.

### 6.2 *Soil Sample Measurement:*

6.2.1 Soil samples should be representative of the area of interest where the stratum of interest contains a variety of soil types. It is desirable to sample each type separately. It will also be necessary to prepare a mixed sample. The sample should be reasonably large and thoroughly mixed so that it will be representative. The soil should be well-compacted in layers in the soil box, with air spaces eliminated as far as practicable. Fill the box flush to the top and take measurements as previously detailed (6.1.3). The meter used may limit the upper range of resistivity, which can be measured. In such cases, the resistivity should be recorded as <10 000  $\Omega\text{-cm}$ , etc.

6.2.2 The measured resistivity will be dependent on the degree of compaction, moisture content, constituent solubility, and temperature. The effect of variations in compaction and moisture content can be reduced by fully saturating the sample before placing it in the box. This can be done by preparing a stiff slurry of the sample, adding only sufficient water to produce a slight amount of surface water, which should be allowed to evaporate before the slurry is remixed and placed in the box. Where available, use ground water from the sample excavation for saturation. Otherwise, use distilled water. If the soil resistivity is expected to be below 10 000  $\Omega\text{-cm}$ , local tap water can be used without introducing serious error. Some soils absorb moisture slowly and contain constituents that dissolve slowly, and the resistivity may not stabilize for as much as 24 h after saturation. The saturated measurement will provide an approaching minimum resistivity, and can be usefully compared with "as-received" resistivity measurements. Surplus water should not be poured off as this will remove soluble constituents.

6.2.3 Temperature correction will not be required if measurement is made in-the-ditch or immediately after the sample is taken. If samples are retained for subsequent measurement, correct the resistivity if the measurement temperature is substantially different from the ground temperature. Correction

<sup>2</sup> *Handbook of Chemistry and Physics*, 41st ed., The Chemical Rubber Co., p. 2606.

to 15.5°C (60°F) is recommended if the sample temperature exceeds 21°C (70°F).

$$R_{15.5} = R_T \left( \frac{24.5 + T}{40} \right)$$

where:

$T$  = soil temperature, °C, and

$R_T$  = resistivity at  $T$  °C.

A nomograph for this correction is shown in Fig. 3.<sup>3</sup>

## 7. Planning and Interpretation

### 7.1 Planning:

7.1.1 Surveys may be conducted at regular or random intervals. The former method is suited to graphical presentation and plotting resistivity versus distance, and will identify gradients and abrupt changes in soil condition. The latter method permits precise mathematical treatment, such as cumulative probability analysis. This method permits the determination of the probability of the presence of a soil with a resistivity equal to or greater than a particular value.<sup>4</sup> Where

random resistivities are measured over a plant site, these can best be displayed on a plot plan or similar layout. In either case, use pedological surveys in the planning and interpretation of any extensive survey. Measurements could be made in each soil classification under a variety of drainage conditions to simplify survey planning.

7.1.2 If resistivity information is required to assess the requirement for corrosion control measures, it is recommended that the tests be made on a true random basis. Since the number of soil sections that could be inspected is essentially unlimited, infinite population characteristics can be used to simplify statistical treatment. Risk and error must be arbitrarily selected to allow determination of the number of measurements. A risk of 5 % of an error greater than 100 Ω·cm should be suitable for most situations. The error limit should be about 10 % of the anticipated mean resistivity. Where mean or median values cannot be estimated with reasonable accuracy, sequential sampling techniques can be employed.

7.2 Interpretation—Interpretation of the results of resistivity surveys will largely depend on the experience of the persons concerned. The mean and median resistivity values will indicate the general corrosivity of the soil. Sharp changes in resistivity with distance and appreciable variations in moisture content and drainage are indicative of local severe conditions.

<sup>3</sup> National Institute of Standards and Technology *Circular No. 579*, p. 157.

<sup>4</sup> Scott, G. N., "Corrosion," *National Association of Corrosion Engineers*, Vol 14, No. 8, August 1958.

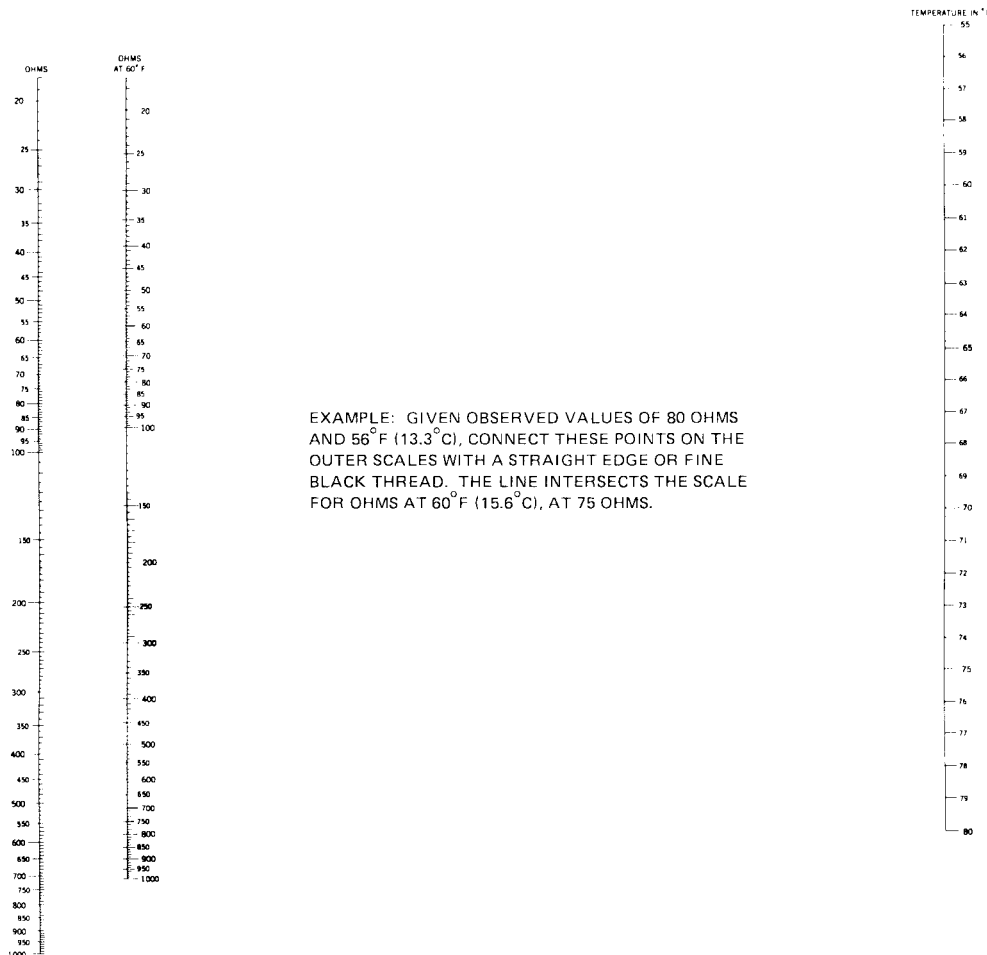


FIG. 3 Nomogram or Conversion Chart for Reducing Soil Paste Resistance in ohms at a Particular Temperature as Measured in the Bureau of Soils Cup, to Resistance at 15.6°C (60°F)

Cumulative probability plots will indicate the homogeneity of the soil over the area or route and will indicate the probability of severe, moderate, and minimal corrosion of the various construction materials. Available pedological data should be used to facilitate interpretation.

## 8. General

8.1 It should be recognized that subsurface conditions can vary greatly in a short distance, particularly where other buried structures have been installed. Surface contamination tends to concentrate in existing ditches with surface run-off, appreciably lowering the resistivity below the natural level. Since a pipeline ditch cannot be included in the span of at-grade measurements, soil box samples should be obtained where the opportunity exists. To evaluate contamination effects when a new route is being evaluated, soil samples can be obtained at crossings of existing pipelines, cables, etc, or by intentional sampling using soil augers.

8.2 Other field resistivity measurement techniques and equipment are available. These commonly use two electrodes mounted on a prod that is inserted in the soil-at-grade in an excavation or a driven or bored hole. The two-electrode technique is inherently less accurate than the four-electrode method because of polarization effects, but useful information can be obtained concerning the characteristics of particular strata. More precise procedures may be employed in laboratory investigations and these should be defined in reporting the results. Where resistivity information is included in published information, the measurement techniques used should be defined.

## 9. Precision and Bias

9.1 *Precision*—The precision of this test method was determined by a statistical evaluation of a multi-participant evaluation with each participant using a different meter. The data from this evaluation are available from ASTM in a research report. A summary of these data is given in Table 1.

**TABLE 1 Statistics from Multi-participant Evaluation of Wenner Four Electrode Soil Resistivity Measurement<sup>A</sup>**

	Site No. 1	Site No. 3
Electrode spacing, m	6.1	1.5
Average measured resistance	10.9	62.6
Average resistivity, $\Omega$ - cm	41 700	59 900
Repeatability standard deviation, $\Omega$ - cm	2 300	4 700
Repeatability coefficient variation, Cv, %	5.5	7.8
Reproducibility standard deviation, S, $\Omega$ - cm	6 900	10 000
Reproducibility coefficient of variation, Cv, %	16.5	16.6

<sup>A</sup> Evaluation in Chester, New Jersey on May 28, 1993. Triplicate soil resistivity measurements by seven participants each using different meters.

9.1.1 *Repeatability*—Repeatability refers to the variation in results obtained by the same operator with the same equipment and same operating conditions in successive runs. In the case of soil resistivity measurements, the repeatability may be characterized by a coefficient of variation, Cv, representing the repeatability standard deviation divided by the average result and expressed in percent. The multi-participant test program results indicate a repeatability Cv of 6.7 %. The 95 % confidence interval is 2.8 Cv or 18.8 %.

9.1.2 *Reproducibility*—Reproducibility refers to the variation in results that occurs when different operators measure the same soil. In the case of soil resistivity measurements reproducibility may be characterized by a coefficient of variation, Cv, representing the reproducibility standard deviation divided by the average result and expressed in percent. The multi-participant test program results indicate a reproducibility Cv of 16.6 %. The 95 % confidence interval is 2.8 Cv or 46.5 %.

9.2 *Bias*—The procedure in Test Method G 57 for measuring soil resistivity by the Wenner Four Pin Method has no bias because the value of Wenner Four Pin soil resistivity is defined only in terms of this test method.

## 10. Keywords

10.1 four electrodes method; soil resistivity

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