Designation: G57 − 20

Standard Test Method for Measurement of Soil Resistivity Using the Wenner Four-Electrode Method[1]

This standard is issued under the fixed designation G57; 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 test method covers the equipment and procedures for the measurement of soil resistivity, both in situ and for samples removed from the ground, for use in assessment and control of corrosion of buried structures.

1.2 The values stated in SI units are to be regarded as standard. The values given in parentheses after SI units are provided for information only and are not considered standard. Soil resistivity values are reported in ohm-centimeter.

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]
D1193 Specification for Reagent Water
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
G187 Test Method for Measurement of Soil Resistivity Using the Two-Electrode Soil Box Method
G193 Terminology and Acronyms Relating to Corrosion

2.2 *UNS Standards:*[3]
UNS Designation S30400 and S30403
UNS Designation S31600 and S31603

3. Terminology

3.1 *Definitions:*

3.1.1 *four-electrode soil box, n*—a non-conductive container of known internal dimensions with four electrodes for measuring a substance's resistivity.

3.1.2 *saturated soil, n*—soil whose entire soil porosity is filled with water.

3.1.3 *soil resistance meter, n*—an instrument capable of measuring soil resistance.

3.1.4 *soil resistivity, n*—the electrical resistance between opposite faces of a unit cube of material, typically expressed in ohm-meter, ohm-cm, or similar units; the reciprocal of conductivity

3.2 The terminology used herein, if not specifically defined otherwise, shall be in accordance with Terminology G193. Definitions provided herein and not given in Terminology G193 are limited only to this test method.

3.3 *Discussion*—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.

4. Summary of Test Method

4.1 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

[1] This test 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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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] *Metals and Alloys in the Unified Numbering System (UNS)*, 13th Edition, developed jointly by ASTM International, West Conshohocken, PA, and SAE International, Warrendale, PA, 2017.

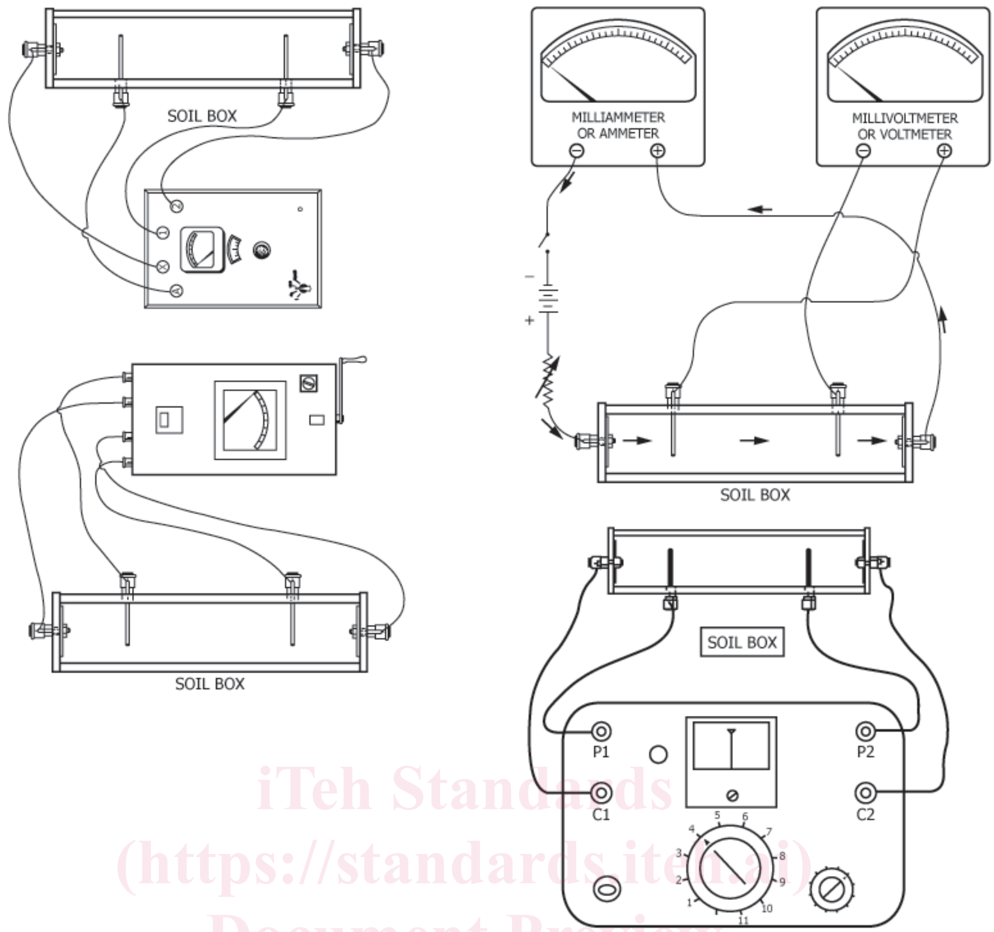

FIG. 1 Typical Connections for Use of Soil Box with Various Types of Instruments

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.

4.2 A voltage is impressed between the outer electrodes, causing current to flow, and the voltage drop between the inner electrodes is measured using a voltmeter. Alternatively, the resistance can be measured directly using a soil resistance meter. The resistivity, ρ, is then:

$$\rho,\ \Omega\cdot\text{cm} = 2\pi\, aR\ (a \text{ in cm}) \tag{1}$$

$$= 191.5\, aR\ (a \text{ in ft})$$

where:

a = electrode separation, and
R = resistance, Ω.

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

4.3 If the current-carrying (outside) electrodes are not spaced at the same interval as the potential-measuring (inside) electrodes, the resistivity, ρ, is:

$$\rho,\ \Omega\cdot\text{cm} = 95.76\, bR(1 + b/a) \tag{2}$$

where:

b = outer electrode spacing, ft,
a = inner electrode spacing, ft, and
R = resistance, Ω.

or:

$$\rho,\ \Omega\cdot\text{cm} = \pi\, bR(1 + b/a) \tag{3}$$

where:

b = outer electrode spacing, cm,
a = inner electrode spacing, cm, and
R = resistance, Ω.

4.4 For soil contained in a soil box similar to the one shown in Fig. 1, the resistivity, ρ, is:

$$\rho,\ \Omega\cdot\text{cm} = R\, A/a \tag{4}$$

where:

R = resistance, Ω,
A = cross sectional area of the container perpendicular to the current flow, 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.

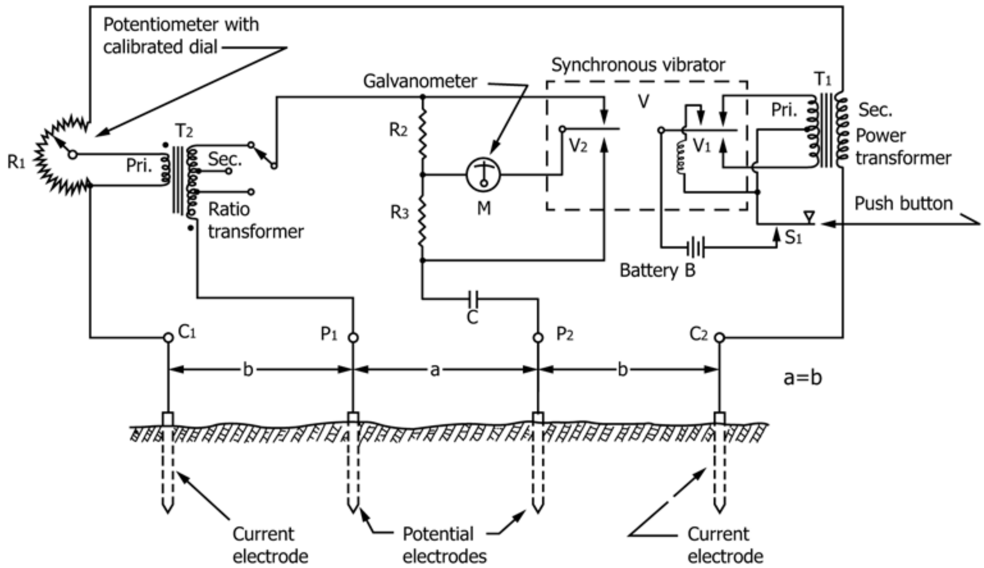

FIG. 2 Wiring Diagram for Typical dc Vibrator-Current Source

5. Significance and Use

5.1 Measurement of soil resistivity is used for assessment and control of corrosion of buried structures. Soil resistivity is used both for the estimation of expected corrosion rates and for the design of cathodic protection systems. As an essential design parameter for cathodic protection systems, it is important to take as many measurements as necessary so as to get a sufficiently representative characterization of the soil environment to which the entire buried structure will be exposed.

6. Apparatus

6.1 *At-Grade Measurements in situ:*

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

6.1.2 *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, which is internal to many soil resistance meters. 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.

6.1.3 *Four Terminal Soil Resistance Meter*—Commercially available, four terminal soil resistance meters are commonly used for measuring soil resistivity. They offer convenience, ease of use, and repeatability. Soil resistance meters yield direct readings in ohms. Some meters allow readings to be taken at multiple depths using electrodes spaced at predetermined intervals. These meters allow switching between electrode sets without having to rearrange electrodes and can calculate resistivity from the entered geometry and measured current and voltages. Other models have the capability of providing one or two dimensional analysis of soil resistivity at different depths. The meter utilized may limit the upper range of resistivity, which can be measured. In such cases, the resistivity should be reported as greater than the meter's upper limit.

6.1.4 *Voltmeter*—The voltmeter shall not draw appreciable current from the circuit to avoid influencing the results. 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.

6.1.5 *Electrodes* fabricated from mild steel or martensitic stainless steel 0.475 cm to 0.635 cm (3⁄16 in. to 1⁄4 in.) in diameter and 30 cm to 60 cm (1 ft 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 soils, or soils containing rocks or gravel. The electrodes should be formed with a handle and a terminal for wire attachment.

6.1.6 *Wiring,* 18 gauge to 22 gauge 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.

6.2 *Soil Sample Measurement* (that is, soil box)*:*

6.2.1 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 mounted electrodes (see Fig. 1).

6.2.2 Four-electrode soil boxes can be constructed in various sizes provided the inside dimensions are known. Design and construction shall incorporate materials that are durable and machinable. The two end plate electrodes shall be constructed of a clean, polished, corrosion-resistant metal or alloy (that is, UNS Designation type S30400/S30403 or UNS S31600/S31603 stainless steel) that will not form a heavy oxide film or otherwise add significant resistance. The body of the box shall be constructed of a material that is nonconductive and able to maintain its desired dimensions (polycarbonate plastics). The box shall be readily cleanable to avoid contamination by previous samples. Some soil box designs incorporate removable pins (that is, electrodes) to facilitate cleaning. Other soil box designs incorporate two electrodes in lieu of four electrodes (see Test Method G187).

6.2.3 If the current-carrying (outside) electrodes are not spaced at the same interval as the potential-measuring (inside) electrodes, the resistivity, ρ, is determined using Eq 2, where the spacing is given in feet, and Eq 3, where the electrode spacing is given in centimeters.

6.2.4 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.

7. Reagents and Materials

7.1 Distilled or deionized water (Type IV grade as referenced in Specification D1193) to saturate samples.

7.2 Commercially available solutions in the range of 1000 ohm-cm, 5000 ohm-cm, and 10 000 ohm-cm are recommended for the purpose of calibration.

8. Standardization

8.1 Periodically check the accuracy of resistance meters using manufacturer's recommendations. 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 Ω·cm, 5000 Ω·cm, and 10 000 Ω·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).[4]

9. Field Procedures

9.1 *At-Grade Measurements:*

9.1.1 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, and so forth, which are not representative of the soil of interest, in the electrode span. Conductive structures such as pipes and cables should not be within ½ *a* of the electrode span unless they are at right angles to the span.

9.1.2 Select electrode spacings with regard to the structure of interest. Since most pipelines are installed at depths of from 1.5 m to 4.5 m (5 ft to 15 ft), electrode spacings of 1.5 m, 3.0 m, and 4.5 m (5 ft, 10 ft, 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 m, 3.16 m, and 4.75 m (5.2 ft, 10.4 ft, 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.

9.1.3 Impress a voltage to create a current 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.

NOTE 2—Some newer models of soil resistivity meters allow resistivity measurements to be collected in such a way as to automatically analyze soil resistivity at different depths. A number of pins are driven at equal spacing and the instrument switches between different combinations of four pins. The information can then be processed using software to give either one or two dimensional profiles

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

9.2 *Soil Sample Measurement* (that is, soil box measurements)*:*

9.2.1 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 mixed 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 (9.1.3). 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 Ω·cm, and so forth.

9.2.2 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 ASTM Specification D1193 reagent water. If the soil resistivity is expected to be below 10 000 Ω·cm, local tap water can be used without introducing serious error.

NOTE 3—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.

9.2.3 *Temperature*—Soils shall not be frozen at the time of measurement. 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.

[4] *Handbook of Chemistry and Physics*, 41st ed., The Chemical Rubber Co., p. 2606.