Designation: D6431 – 99 (Reapproved 2010)

Standard Guide for Using the Direct Current Resistivity Method for Subsurface Investigation[1]

This standard is issued under the fixed designation D6431; 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 *Purpose and Application:*

1.1.1 This guide summarizes the equipment, field procedures, and interpretation methods for the assessment of the electrical properties of subsurface materials and their pore fluids, using the direct current (DC) resistivity method. Measurements of the electrical properties of subsurface materials are made from the land surface and yield an apparent resistivity. These data can then be interpreted to yield an estimate of the depth, thickness, and resistivity of subsurface layer(s).

1.1.2 Resistivity measurements as described in this guide are applied in geological, geotechnical, environmental, and hydrologic investigations. The resistivity method is used to map geologic features such as lithology, structure, fractures, and stratigraphy; hydrologic features such as depth to water table, depth to aquitard, and groundwater salinity; and to delineate groundwater contaminants. General references are, Keller and Frischknecht (**1**),[2] Zohdy et al (**2**), Koefoed (**3**), EPA(**4**), Ward (**5**), Griffiths and King (**6**), and Telford et al (**7**).

1.2 *Limitations:*

1.2.1 This guide provides an overview of the Direct Current Resistivity Method. It does not address in detail the theory, field procedures, or interpretation of the data. Numerous references are included for that purpose and are considered an essential part of this guide. It is recommended that the user of the resistivity method be familiar with the references cited in the text and with the Guide D420, Practice D5088, Practice D5608, Guide D5730, Test Method G57, D6429, and D6235.

1.2.2 This guide is limited to the commonly used approach for resistivity measurements using sounding and profiling techniques with the Schlumberger, Wenner, or dipole-dipole arrays and modifications to those arrays. It does not cover the use of a wide range of specialized arrays. It also does not include the use of spontaneous potential (SP) measurements, induced polarization (IP) measurements, or complex resistivity methods.

1.2.3 The resistivity method has been adapted for a number of special uses, on land, within a borehole, or on water. Discussions of these adaptations of resistivity measurements are not included in this guide.

1.2.4 The approaches suggested in this guide for the resistivity method are the most commonly used, widely accepted and proven; however, other approaches or modifications to the resistivity method that are technically sound may be substituted if technically justified and documented.

1.2.5 *This guide offers an organized collection of information or a series of options and does not recommend a specific course of action. This document cannot replace education or experience and should be used in conjunction with professional judgements. Not all aspects of this guide may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.*

---

[1] This guide is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.01 on Surface and Subsurface Characterization.

Current edition approved May 1, 2010. Published September 2010. Originally approved in 1999. Last previous edition approved in 2005 as D6431–99(2005). DOI: 10.1520/D6431-99R10.

[2] The boldface numbers in parentheses refer to the list of references at the end of this standard.

1.3 *Precautions:*

1.3.1 *It is the responsibility of the user of this guide to follow any precautions in the equipment manufacturer's recommendations and to consider the safety implications when high voltages and currents are used.*

1.3.2 *If this guide is used at sites with hazardous materials, operations, or equipment, it is the responsibility of the user of this guide to establish appropriate safety and health practices and to determine the applicability of regulations prior to use.*

1.4 *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. Referenced Documents

2.1 *ASTM Standards:*[3]

D420 Guide to Site Characterization for Engineering Design and Construction Purposes (Withdrawn 2011)[4]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D5088 Practice for Decontamination of Field Equipment Used at Waste Sites

D5608 Practices for Decontamination of Field Equipment Used at Low Level Radioactive Waste Sites

D5730 Guide for Site Characterization for Environmental Purposes With Emphasis on Soil, Rock, the Vadose Zone and Groundwater (Withdrawn 2013)[4]

D5753 Guide for Planning and Conducting Borehole Geophysical Logging

D6235 Practice for Expedited Site Characterization of Vadose Zone and Groundwater Contamination at Hazardous Waste Contaminated Sites

D6429 Guide for Selecting Surface Geophysical Methods

G57 Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method

3. Terminology

3.1 *Definitions:*

3.1.1 Definitions shall be in accordance with the terms and symbols given in Terminology D653.

3.1.2 The majority of the technical terms used in this document are defined in Sheriff (1991).

3.1.3 *Additional Definitions:*

3.1.3.1 *apparent resistivity*—the resistivity of homogeneous, isotropic ground that would give the same voltage-current relationship as measured.

3.1.3.2 *conductivity*—The ability of a material to conduct an electrical current. In isotropic material, it is the reciprocal of resistivity. The units of conductivity are siemens per metre.

3.1.3.3 *resistance*—opposition to the flow of direct current. The unit of resistance is ohms.

3.1.3.4 *resistivity*—the property of a material that resists the flow of electrical current. The units of resistivity are ohmmetres or ohm-feet (1 Ωm = 3.28 Ω-ft).

4. Summary of Guide

4.1 *Summary*—The measurement of electrical resistivity requires that four electrodes be placed in contact with the surface materials (Fig. 1). The geometry and separation of the electrode array are selected on the basis of the application and required depth of investigation.

4.1.1 In an electrical resistivity survey, a direct current or a very low frequency alternating current is passed into the ground through a pair of current electrodes, and the resulting potential drop is measured across a pair of potential electrodes (Fig. 1). The resistance is then derived as the ratio of the voltage measured across the potential electrodes and the current electrodes. The apparent resistivity of subsurface materials is derived as the resistance multiplied by a geometric factor that is determined by the geometry and spacing of the electrode array.

4.1.2 The calculated apparent resistivity measurement represents a bulk average resistivity of the volume of earth determined by the geometry of the array and the resistivity of the subsurface material. This apparent resistivity is different from true resistivity unless the subsurface materials are electrically uniform. Representative resistivity values of layers are interpreted from apparent resistivity values obtained from a series of measurements made with variable electrode spacing. Increasing electrode spacing may permit distinction among layers that vary in electrical properties with depth.

4.1.3 Most resistivity surveys for geologic, engineering, hydrologic, and environmental applications are carried out to determine depths of specific layers or lateral changes in geologic conditions at depths of less than a hundred metres. However, with sufficient power and instrument sensitivity, resistivity measurements are made to depths of several hundred metres.

4.2 *Complementary Data*—Other complementary surface geophysical methods (D6429) or borehole geophysical methods (Guide D5753) and non-geophysical methods may be necessary to properly interpret subsurface conditions.

5. Significance and Use

5.1 *Concepts*—The resistivity technique is used to measure the resistivity of subsurface materials. Although the resistivity of materials can be a good indicator of the type of subsurface material present, it is not a unique indicator. While the resistivity method is used to measure the resistivity of earth materials, it is the interpreter who, based on knowledge of local geologic conditions and other data, must interpret resistivity data and arrive at a reasonable geologic and hydrologic interpretation.

5.2 *Parameter Being Measured and Representative Values:*

5.2.1 Table 1 shows some general trends for resistivity values. Fig. 2 shows ranges in resistivity values for subsurface materials.

5.2.2 Materials with either a low effective porosity or that lack conductive pore fluids have a relatively high resistivity

[3] 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.

[4] The last approved version of this historical standard is referenced on www.astm.org.

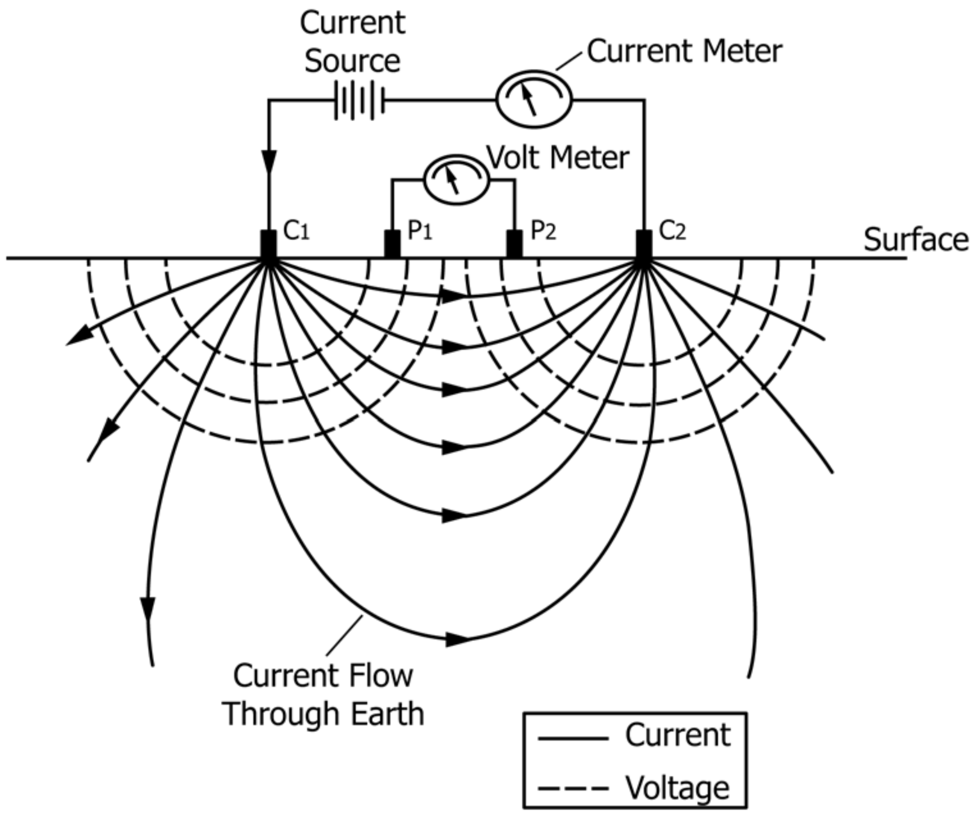

FIG. 1 Diagram Showing Basic Concept of Resistivity Measurement (from Benson et al, (8))

TABLE 1 Representative Resistivity Values for Soil, Water, and Rock (Mooney (4))

Regional Soil Resistivity	Ωm
- wet regions	50–200
- dry regions	100–500
- arid regions	200–1000 (sometimes as low as 50 if the soil is saline)
Waters	Ωm
- soil water	1 to 100
- rain water	30 to 1000
- sea water	order of 0.2
- ice	105 to 108
Rock Types	Ωm
- igneous and metamorphic	100 to 10,000
- consolidated sediments	10 to 100
- unconsolidated sediments	1 to 100

(>1000 Ωm). These materials include massive limestones, most unfractured igneous rocks, unsaturated unconsolidated materials, and ice.

5.2.3 Materials that have high porosity with conductive pore fluids or that consist of or contain clays usually have low resistivity. These include clay soil and weathered rock.

5.2.4 Materials whose pore water has low salinity have moderately high resistivity.

5.2.5 The dependence of resistivity on water saturation is not linear. Resistivity increases relatively little as saturation decreases from 100 % to 40-60 % and then increases much more as saturation continues to decrease. An empirical relationship known as Archie's Law describes the relationship between pore fluid resistivity, porosity, and bulk resistivity (McNeill (**10**)).

5.3 *Equipment*—Geophysical apparatus used for surface resistivity measurement includes a source of power, a means to measure the current, a high impedance voltmeter, electrodes to make contact with the ground, and the necessary cables to connect the electrodes to the power sources and the volt meter (Fig. 1).

5.3.1 While resistivity measurements can be made using common electronic instruments, it is recommended that commercial resistivity instruments specifically designed for the purpose be used for resistivity measurements in the field.

5.3.2 Commonly used equipment includes the following elements:

5.3.2.1 A source of current consisting of batteries or a generator,

5.3.2.2 A high-impedance voltmeter or resistivity unit,

5.3.2.3 Metal stakes for the current and potential electrodes, and

5.3.2.4 Insulated wire to connect together all of the preceding components.

5.3.3 Care must be taken to ensure good electrical contact of the electrodes with the ground. Electrodes should be driven into the ground until they are in firm contact. If connections between electrodes and the insulated wire are not waterproof, care must be taken to ensure that they will not be shorted out by moisture. Special waterproof cables and connectors are required for wet areas.

5.3.4 A large variety of resistivity systems are available from different manufacturers. Relatively inexpensive battery-powered units are available for shallow surveys. The current