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Standard Guide for Using the Surface Ground Penetrating Radar Method for Subsurface Investigation[1]

This standard is issued under the fixed designation D 6432; 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 subsurface materials using the impulse Ground Penetrating Radar (GPR) Method. GPR is most often employed as a technique that uses high-frequency electromagnetic (EM) waves (from 10 to 3000 MHz) to acquire subsurface information. GPR detects changes in EM properties (dielectric permittivity, conductivity, and magnetic permeability), that in a geologic setting, are a function of soil and rock material, water content, and bulk density. Data are normally acquired using antennas placed on the ground surface or in boreholes. The transmitting antenna radiates EM waves that propagate in the subsurface and reflect from boundaries at which there are EM property contrasts. The receiving GPR antenna records the reflected waves over a selectable time range. The depths to the reflecting interfaces are calculated from the arrival times in the GPR data if the EM propagation velocity in the subsurface can be estimated or measured.

1.1.2 GPR measurements as described in this guide are used in geologic, engineering, hydrologic, and environmental applications. The GPR method is used to map geologic conditions that include depth to bedrock, depth to the water table (Wright et al (**1**)[2]), depth and thickness of soil strata on land and under fresh water bodies (Beres and Haeni (**2**)), and the location of subsurface cavities and fractures in bedrock (Ulriksen (**3**) and Imse and Levine (**4**)). Other applications include the location of objects such as pipes, drums, tanks, cables, and boulders , mapping landfill and trench boundaries (Benson et al (**6**)), mapping contaminants (Cosgrave et al (**7**); Brewster and Annan (**8**); Daniels et al (**9**)), conducting archaeological (Vaughan (**10**)) and forensic investigations (Davenport et al (**11**)), inspection of brick, masonry, and concrete structures, roads and railroad trackbed studies (Ulriksen (**3**)), and highway bridge scour studies (Placzek and Haeni (**12**)). Additional applications and case studies can be found in the various *Proceedings of the International Conferences on Ground Penetrating Radar* (Lucius et al (**13**); Hannien and Autio, (**14**), Redman, (**15**); Sato, (**16**); Plumb (**17**)), various *Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems* (Environmental and Engineering Geophysical Society, 1988–1998), and The Ground Penetrating Radar Workshop (Pilon (**18**)), EPA (**19**), and Daniels (**20**) provide overviews of the GPR method.

1.2 *Limitations*:

1.2.1 This guide provides an overview of the impulse GPR method. It does not address details of the theory, field procedures, or interpretation of the data. References are included for that purpose and are considered an essential part of this guide. It is recommended that the user of the GPR method be familiar with the relevant material within this guide and the references cited in the text and with Guides D 420, D 5730, D 5753, D 6429, and D 6235.

1.2.2 This guide is limited to the commonly used approach to GPR measurements from the ground surface. The method can be adapted for a number of special uses on ice (Haeni et al (**21**); Wright et al (**22**)), within or between boreholes (Lane et al (**23**); Lane et al (**24**)), on water (Haeni (**25**)), and airborne (Arcone et al (**25**)) applications. A discussion of these other adaptations of GPR measurements is not included in this guide.

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

1.2.4 *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 D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.01 on Surface and Subsurface Characterization.

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[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 establish appropriate health and safety practices.*

1.3.2 *If this guide method 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 any regulations prior to use.*

1.3.3 *This guide does not purport to address all of the safety concerns that may be associated with the use of the GPR method. 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.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 420 Guide to Site Characterization for Engineering, Design, and Construction Purposes[3]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[3]

D 5088 Practice for Decontamination of Field Equipment Used at Nonradioactive Waste Sites[3]

D 5608 Practice for Decontamination of Field Equipment Used at Low Level Radioactive Waste Sites[3]

D 5730 Guide for Site Characterization for Environmental Purposes With Emphasis on Soil, Rock, the Vadose Zone and Ground Water[4]

D 5753 Guide for Planning and Conducting Borehole Geophysical Logging[4]

D 6235 Guide for Expedited Site Characterization of Hazardous Waste Contaminated Sites[4]

D 6429 Guide for Selecting Surface Geophysical Methods[4]

3. Terminology

3.1 *Definitions*:

3.1.1 Definitions shall be in accordance with the terms and symbols given in Terminology D 653.

3.1.2 The majority of the technical terms used in this guide are defined in Sheriff **(27)**.

3.1.3 *Additional Definitions*:

3.1.3.1 *antenna*—a transmitting GPR antenna converts an excitation in the form of a voltage pulse or wave train into EM waves. A receiving GPR antenna converts energy contained in EM waves into voltages, which are regarded as GPR data.

3.1.3.2 *attenuation*—(*1*) the loss of EM wave energy due to conduction currents associated with finite conductivity (σ) and the dielectric relaxation (also referred to as polarization loss) associated with the imaginary component of the permittivity (ϵ''), and magnetic relaxation associated with the imaginary component of magnetic permeability.

(*2*) The term "attenuation" is also sometimes used to refer to the loss in EM wave energy from all possible sources, including conduction currents, dielectric relaxation, scattering, and geometrical spreading.

3.1.3.3 *bandwidth*—The operating frequency range of an antenna that conforms to a specified standard (Balanis **(28)**). For GPR antennas, typically the bandwidth is defined by the upper and lower frequencies radiated from a transmitting GPR antenna that possess power that is 3 dB below the peak power radiated from the antenna at its resonant frequency. Sometimes the ratio of the upper and lower 3-dB frequencies is used to describe an antenna's bandwidth. For example, if the upper and lower 3-dB frequencies of an antenna are 600 and 200 MHz, respectively, the bandwidth of the antenna is said to be 3:1. In GPR system design, the ratio of the difference between the upper frequency minus the lower frequency to the center frequency is commonly used. In the preceding case, one would have a ratio of 400:400 or 1:1.

3.1.3.4 *bistatic*—the survey method that utilizes antennas. One antenna radiates the EM waves and the other antenna receives the reflected waves.

3.1.3.5 *conductivity*—the ability of a material to support an electrical current (material property that describes the movement of electrons or ions) due to an applied electrical field. The units of conductivity are Siemens/metre (S/m).

3.1.3.6 *control unit* (C/U)—An electronic instrument that controls GPR data collection. The control unit may also process, display, and store the GPR data.

3.1.3.7 *coupling*—the coupling of a ground penetrating radar antenna to the ground describes the ability of the antenna to get electromagnetic energy into the ground. A poorly coupled antenna is described as being mismatched. A well-coupled antenna has an impedance equal to the impedance of the ground.

3.1.3.8 *depth of penetration*—the maximum depth range a radar signal can penetrate in a given medium, be scattered by an electrical inhomogeneity, propagate back to the surface, be recorded by a receiver GPR antenna, and yield a voltage greater than the noise levels of the GPR unit.

(*1*) In a conductive material (seawater, metallic materials, or mineralogic clay soils), attenuation can be great, and the wave may penetrate only a short distance (less than 1 m). In a resistive material (fresh water, granite, ice, or quartz sand), the depth of penetration can be tens to thousands of metres.

3.1.3.9 *dielectric permittivity*—dielectric permittivity is the property that describes the ability of a material to store electric energy by separating opposite polarity charges in space. It relates ability of a material to be polarized in the electric displacement, D, in response to the application of an electric field, E, through $D = \epsilon E$. The units of dielectric permittivity, ϵ, are farads/metre (F/m). Relative dielectric permittivity (previously called the dielectric constant) is the ratio of the permittivity of a material to that of free space, 8.854×10^{-12} F/m. Whenever the dielectric permittivity is greater than that of free space, it must be complex and lossy, with frequency dependence typically described by the Cole-Cole (Cole and Cole **(28)**) relaxation distribution model. Nearly all dielectric relaxation processes are the result of the presence of water or clay minerals (Olhoeft **(29)**).

[3] *Annual Book of ASTM Standards,* Vol 04.08.

[4] *Annual Book of ASTM Standards,* Vol 04.09.